

**The Hologram and its Antecedents 1891-1965:
The Illusory History of a Three-Dimensional
Illusion**

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This dissertation is submitted for the degree of Doctor of Philosophy
University of Cambridge, 2004

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ACKNOWLEDGEMENTS

The research for my thesis would not have been possible without an award from the Arts and Humanities Research Board, England. Nor could it have been achieved without the patience and good humour of my supervisor Simon Schaffer. For his generous insights and criticisms I owe a special debt of thanks.

I would like to thank many individuals who have helped me complete this project: Emmett Leith, for inviting me to Michigan University, and for making available his private papers and granting copyright permission. Adam Kozma and Juris Upatnieks for permitting me to interview them. Professor Emeritus John Anderson for recollecting his time, as a junior colleague with Dennis Gabor, at Imperial College, London. Mary Brück for her discussions on C.P. Smyth. Jean-Marc Fournier for sharing his research on Lippmann-photographs. Rosemary Jackson for copyright permission. I am also indebted to many archivists, as well as curators for setting-up viewers and photographs and assisting with their reproduction. In particular I wish to thank: Anne Barratt, Imperial College; Jim Bennett, Museum for the History of Science, Oxford; Shona McEachern and Karen Moran, the Royal Observatory, Edingburgh; Christophe Blaser, Musée de l'Elysée, Lausanne, Switzerland; Shannon Thomas Perich, Photographic History Collection, the Smithsonian Museum of American History, Washington; David Wooters, George Eastman House, Rochester, NY, and the staff of the MIT Museum, Cambridge, Mass, and the Geneva Photographic Library, Switzerland.

I wish to thank those who have commented, and advised on this work in progress: Jon Agar, Charlotte Bigg, Soraya de Chadaverian, Liba Taub, Jennifer Tucker, Andy Warwick; my fellow students in the History Workshop, the History and Philosophy of Science Department, Cambridge University; the participants of the Fin de Siècle, Seminar Series, Oxford University, and the Spectroscopy Workshop held at the Deutches Museum, Munich, 2002. I also wish to thank Tamara Hug in the HPS department for her help.

Finally, I thank Arthur and Iris Gamble for their support, Sheila Wenyon for tolerating my unsociability, and Michael Wenyon for enduring all the tedium with me.

Preface

In this thesis I explore a history of the hologram that has been gaining popularity since the mid-1960s amongst a community of optical physicists. Their collective history is one that defines the hologram, as an invention by Dennis Gabor (1900-1978), primarily as a new form of photography with a nineteenth-century antecedent. It is a narrative that addresses the hologram in its most spectacular manifestation—as a popular three-dimensional image. It was this form of hologram—a laser-illuminated image—that attracted the attention of the press following the first public demonstration in 1964.

When I began this research in 1998, there was no independent book-length history of the hologram by an academic or professional historian. Recent historical surveys on three-dimensional imagery, for example, the publications: *Devices of Wonder: From the World in a Box to Images on a Screen*, by Barbara Maria Stafford and Frances Terpak,¹ and Walter Grau's *Virtual Art: from Illusion to Immersion*,² have overlooked the hologram. The lack of standard history might contribute in part to that omission, but it might also be perceived, by these authors, that the now apparently obsolete hologram offers no insight into the recent digital three-dimensional image, the origin of which these surveys seek to address.

One is more likely to read of the hologram anecdotally. Umberto Eco, writing in the 1980s, described holography's mythic qualities:³

Holography, the latest technical miracle of laser rays, was invented back in the '50s by Dennis Gabor; it achieves a full-colour photographic representation that is more than three-dimensional. You look into a magic box and a miniature train or horse appears; as you shift your gaze you can see those parts of the object that you were prevented from glimpsing by the laws of perspective. If the box is circular you can see the object from all sides.

Because there are no book-length histories of the hologram, I have selected the optical physicists' existing narrative for a fuller exploration. In reviewing this narrative I attempt to lay out, in far more human and archival detail, a history that is typically written in less than 3,000 words. I wish to stress that this is not *my* history. In choosing this narrative, I wish to make it clear that I do not feel that this is by any means the *true*

¹ Barbara Maria Stafford and Frances Terpak, *Devices of Wonder: From the World in a Box to Images on a Screen* (Los Angeles: Getty Research Institute, 2001).

² Walter Grau, *Virtual Art: From Illusion to Immersion* (Cambridge, Mass: MIT Press, 2003).

or only history; rather, it is one of several valid narratives on this technology, any one of which might justify a thesis. Nor do I suggest that this is an ‘alternative’ history to the one Dennis Gabor presented in his 1971 Nobel Lecture on winning the Nobel Prize for Physics. That ‘Nobel’ history—on publication—gained an authority associated with this prize. The popular, or physicists’ history that I will explore was invented in 1962, nine years before Gabor received the Nobel Prize. Gabor acknowledged the existence of this popular history in his Nobel Lecture, although he never contributed to its origination. Given that there is no existing standard history of the hologram,⁴ this history is the one that appears to be gaining some currency of use—outside of its initial discipline—and is, for example, cited in a few books and journals on cultural and photographic history. It is beginning to perform as a potential candidate for a ‘public history’, one that cultural historian Ludmilla Jordanova describes as a history effective with a wide audience and one that can also be a tool of the establishment.⁵

I first came across this particular history as a practitioner of holography myself. However, unlike those who have forged this narrative, from 1980 onwards I worked with holography as an artist—not a scientist. I worked in an independent facility housed by Goldsmiths’ College, University of London, dedicated to promoting holography as a medium for artists. I never enlarged upon any history other than the line: “Dennis Gabor invented the hologram in 1948 for which he eventually won the Nobel Prize for Physics in 1971”. That brief description still functions for those wishing to progress quickly onto a discussion of art holography or imagery.⁶ Many discussions of art holography require no definition of an invention; an art medium is defined by the artist’s intent and not merely as a technology.⁷ At Goldsmiths’ Holography Workshop we assumed that we could run a facility for artists modelled on a printmaker’s atelier, the oldest model of an open-access workshop. In pursuit of that objective we experienced two events that were to indicate that holography was unlike other art media—including video, which was also

³ Umberto Eco, “Travels in Hyperreality”, in *Faith in Fakes* (London: Secker & Warburg, 1986).

⁴ Ludmilla Jordanova, *History in Practice* (London, New York: Arnold & Oxford University Press Inc., 2000), 19. Jordanova defines a ‘standard’ as a history that is both widely accepted and proven to be popular, as an example, she cites the books by historian Eric Hobsbawm: *The Age of Revolution* (1962), *The Age of Capital* (1975), *The Age of Empire* (1987) and *The Age of Extremes* (1994).

⁵ *Ibid*, 141.

⁶ Sarah Radley Maline, *Art Holography 1968-1993: A Theatre of the Absurd*, University of Texas, PhD thesis 1995. This PhD on the art history of the hologram moves on very quickly from this definition of invention.

⁷ Martin Kemp, ed., *The Oxford History of Western Art* (Oxford, New York: Oxford University Press, 2000), 444. This entry, which defines artists using holography, requires no explanation of an inventor.

considered in 1980 to be a new medium—in that it was not as easily available to the artist as we had assumed. As the potential for commercial holography expanded in the 1980s, issues of ownership were raised. For example, the now defunct Atari Inc. had written in the early 1980s to Goldsmiths' College (and to all holographic artists) demanding that holographers were now obliged to purchase a licence and pay royalties to Atari. This was on account of Atari's claim to have purchased a portfolio of 'original holographic patents' for applications in computer or video games.⁸ However, as this thesis will reveal, Gabor's original patent was intended solely as an application within an electron microscope. The second occasion was on witnessing a new holographic display—intended for use in dental surgeries—created by a small London 'Start-up Company'. Shortly after viewing the prototype, I was requested by letter to sign the British Official Secrets Act and to not disclose or describe the display. This start-up company was essentially brought to a closure. Restrictions were also put into place in the United States on published verbal descriptions of simple techniques used by artists and holographic image-makers; these restrictions were lifted in the early 1990s at the end of the Cold War. Such restrictions, and their subsequent removal, were circulated through American academic optical and holographic societies. Unlike other twentieth-century image-making technologies—video and digital imagery—holography was not licensed or packaged for public use through corporate agents.

The military use of holography in the twentieth-century formed a pervasive background to this invention. Decisions regarding what information was, or was not, exoteric to military requirements, determined both the nature and timing of the original publication of 'the hologram' in 1940s war-time Britain; and the medium's subsequent Cold War development, at Michigan University, into a popular three-dimensional image. The decision, on the part of optical physicists, either to acknowledge the military applications and interventions where possible, or alternatively, elect to present the hologram as existing independently of any twentieth-century military input, is for them a disciplinary issue. A scientist must present a background account to any new theory or proposal, if only to define the scientific discipline they perceive themselves to address or be part of. In this way, as this thesis will explore, scientists are frequently inventors of both new artefacts and their histories, where a 'history' is generated through an accumulated citation of papers.

⁸ These patents might have been purchased from Dennis Gabor or Emmett Leith and Juris Upatnieks.

Introduction

The link between a nineteenth-century photograph and the twentieth-century hologram

There is a common story, often told by optical physicists, which claims the ‘interference colour photograph’, invented by Gabriel Lippmann (1845-1921) in 1891, as the antecedent of the ‘hologram’ invented by Dennis Gabor in 1948. It is a history that suggests the hologram is primarily a photographic form of image, one that is premised on Lippmann’s 1891 invention. When employed by physicists, the history addresses the three-dimensional hologram with an emphasis on the revival of Lippmann’s technique. Lippmann’s solution for achieving colour in photography was based upon principles, familiar to physicists, of wave theory and interference. Throughout this thesis I will refer to this popular account as the ‘Lippmann-to-Gabor’ history. With this emphasis, the Lippmann-to-Gabor history will often overlook, with a cursory mention, much of the twentieth-century development of the laser hologram by two radar communication engineers, Emmett Leith (1927–) and Juris Upatnieks (1936–). Leith and Upatnieks were employees at the University of Michigan’s military research laboratory in the 1960s. However, one linking fact that might have connected Lippmann with Leith and Upatnieks in this narrative was the type of photographic emulsion that they used to record their three-dimensional laser hologram. Lippmann’s name defined a type of photographic emulsion—a *Lippmann-emulsion*—that was still in production; although it was sold as a numbered commercial product. This use of Lippmann’s invention gave the three-dimensional hologram an apparent link to an earlier photographic form. However the Lippmann-to-Gabor history does not stress the revival made by Leith and Upatnieks of this nineteenth-century process. Rather, the historical link to Lippmann provides an opportunity to omit the laser-hologram’s Cold War research environment at Michigan University. The popular history is one that can ignore the existence of American military interest and pacify the invention’s implications by co-opting an historical antecedent.

This Lippmann-to-Gabor account may be found in professional journals encompassing the fields of optics and holography. Most of these journals are intended for a group of corporate or academic research scientists as opposed to the general reader. These papers are typically contemporary reviews by optical physicists of the

Lippmann photograph, holographic emulsions, or celebratory historical accounts.¹ Many of these optical physicists are also producers of holograms. Some are actively researching Lippmann photography in conjunction with contemporary photopolymer materials.² These are new photographic films that contain no conventional silver salts and, therefore, can record a *Lippmann photograph* or a hologram, because such techniques are recorded physically not chemically. This new application of a nineteenth-century technique has arisen because Lippmann photography could not be printed onto paper and was, therefore, unsuited to mass-production. Studio photographers and writers in the late nineteenth century perceived the fact that Lippmann photographs could not be printed on paper as a significant disadvantage in a colour photograph. Now, in the era of accessible colour reproduction with a computer and inkjet-printer, Lippmann photography is a possible candidate—as the hologram has already been—for security images on credit cards, banknotes, and passports. In the twenty-first century it is perceived as advantageous for a colour photograph to remain an ‘original’.

Sociologist of science Michael Mulkey has pointed out, with regard to such typically brief accounts by scientists of their own histories, that they will present the narrative as one of, “...a steady undeviating advance...they note the major discoveries which occurred early on and then skip quickly through to the current framework of knowledge—as if all that happened in between was part of an inevitable progression”.³ This is even true even of those scientists purporting to present a more historical

¹ N.J. Phillips, H. Heyworth, and T. Hare, “On Lippmann’s Photography”, *Journal of Photographic Science*, 32, no.5 (1984), 158-169. Phillips, N.J. “Links between Photography and Holography: The Legacy of Gabriel Lippmann”. *Proceedings of SPIE*, 523 (1985) 313-318. P. Connes, “Silver Salts and Standing Waves”, *Journal of Optics (Paris)* 18, no.4 (1987), 147-166. H. Nareid, “A Review of the Lippmann Color Process”, *Journal of Photographic Science*, 36, no.4 (1988), 140-147. Jean-Marc Fournier, “Interference Color Photography: One Hundred Years Later”, *Journal of Optics, Paris*, 22, no.6 (1991), 259-256. Jean-Marc Fournier, “An Investigation on Lippmann Photographs: Materials, Processes, and Color Rendition”, *Proceedings of SPIE*, 2176, Practical Holography VIII (1994), 144. J-M. Fournier and P.L. Burnett, “Color Rendition and Archival Properties of Lippmann Photographs”, *Journal des Optics (Paris)*, 38, no.6 (1994), 507. C.C. Rich, L. Dickerson and C.A. Pedro, “Lippmann Photographic Process Put to Practice with Available Materials”, *Proceedings of SPIE*, 2688, Holographic Materials II (1996), 85-95. H.I. Bjelkhagen, T.J. Jeong and R.J. Ro, “Old and Modern Lippmann Photography”, *Proceedings of SPIE*, 3358, Sixth International Symposium on Display Holography (1998), 72-83. W.R. Alschuler, “On the Physical and Visual State of 100 Year Old Lippmann Color Photographs”, *Proceedings of SPIE*, 3358, Sixth International Symposium on Display Holography (1998), 84-94. J-M Fournier, B.R. Alexander, P.L. Burnett and S.E. Stamper, “Recent Developments in Lippmann Photography”, *Proceedings of SPIE*, 3358, Sixth International Symposium on Display Holography (1998), 95-103.

² Hans I. Bjelkhagen, “Lippmann Photographs Recorded in Dupont Color Photopolymer Material”, *Proceedings of SPIE*, 3011 Practical Holography XI and Holographic Materials III (1997), 358-356.

narrative than a sole focus on contemporary research. Their narrative will always conclude with, and be directed towards, the current practice.⁴

Where and how did the ‘Lippmann-to-Gabor’ history originate?

This narrative appears to have been initiated by a former Soviet scientist, Yuri Denisyuk (1927–), now living and working in Russia. In 1962, Denisyuk linked Gabor’s proposal for the hologram with Gabriel Lippmann’s 1891 photograph in a paper proposing a three-dimensional ‘wave photograph’ to be viewed in sunlight, *Photographic Reconstruction of the Optical Properties of an Object in its own Scattered Radiation*.⁵ The only references in the paper were to Gabor and Lippmann. This paper suggested a hypothetical method for optical reconstruction and, with the availability of the lasers after 1964, Denisyuk’s proposition was realised. However it did suggest that a “complete illusion of reality” was possible. This paper was available to American scientists, during the Cold War, because the American Institute of Physics published some English translations of the Proceedings of the USSR Academy of Science. Denisyuk’s paper was published before the University of Michigan announced, in a 1963 press release, what it first described as ‘lensless-photography’. With a press release, as opposed to an academic paper, it is the immediacy of the event and the location that is communicated to the wider community. This press release did cite Gabor as the original inventor, but it lacked the authority of a refereed paper. Later, publishing in a scientific journal, Leith and Upatnieks were to cite the papers both of Denisyuk and of Lippmann, initiating a process in which historical material began to be circulated. This citation formed an important precedent for subsequent story-tellers.

What is interesting here is that this ‘Lippmann-to-Gabor’ history is based upon theories which were not realised in their practical form at the time of publication. Gabor’s theory of the hologram is one such publication: Gabor never realised his hologram as originally envisaged for the electron microscope. Denisyuk’s 1962 paper is another. Lippmann’s 1908 paper for a lenticular three-dimensional screen, which I

³ M.J. Mulkey, “Methodology in the Sociology of Science: Some Reflections on the Study of Radio Astronomy”, *Perspectives on the Emergence of Scientific Disciplines*, ed. Gerard Lemaine, et al. (The Hague, Paris, Chicago: Maison des Sciences de l’Homme, Paris Publications, 1976), 207-220, on 212.

⁴ Hans I. Bjelkhagen, “Lippmann Photography: Reviving an Early Colour Process”, *History of Photography*, 23, (1999), 274-280. This review of historical practice concludes with contemporary applications.

review in Chapter Two, was also an unrealised proposal.⁶ Such a history, based on references to Gabor and Lippmann in journals since 1962, continues to assert the authority of the theory, as opposed to the more mundane but actual applications realised by others. This resembles the process which Mulkay has described as the “groping development”. The stress on theory suggests a more cerebral and intellectual origin for the process than do references to technological applications or patents. This perhaps, offers a more pliable history for the contemporary scientist. The flexibility of ‘theory’ permits these authors to redefine the original problem and, according to Mulkay, such redefinitions will occur as the science develops.⁷

What advantages are gained in citing the Lippmann-to-Gabor narrative?

Both Lippmann and Gabor won Nobel Prizes in Physics: Lippmann in 1908, and Gabor in 1971. A narrative that links these two celebrated theories asserts the importance of image invention within the traditional discipline of optical physics. With this aim the narrative attempts to embed holography into a wider academic context and not belittle it as a mere subdivision of a field. The assertion that a new invention is not merely a new application is one aspect of discipline formation that is vital to establishing an academic arena of interest. This particular move suited the position of advocates, many non-American, who made statements from the mid 1960s onwards. For example, in writing on the history of Soviet holography, Yuri Denisyuk, suggested an even earlier precedent: “Those studies [of Young and Fresnel], as a matter of fact, just laid the theoretical foundations of holography, and holography apparently, might have been discovered by both Young and Fresnel”.⁸ This claim stresses a more rarefied and European background to holography. Also, it suggests an independence from a legacy of American (or Soviet) Cold War military funding and any subsequent restrictions on publications that might impinge upon classified military applications.

For the French in particular, the narrative maintains a strong historical position of photographic and optical achievement. Some of these histories fit the definition given

⁵ Yuri Denisyuk, “Photographic Reconstruction of the Optical Properties of an Object in Its Own Scattered Radiation Field”, *Soviet Physics—Doklady*, 7, no. 6 (1962), 543-545, on 545. Translated from: *Doklady. Akademii. Nauk. S.S.S.R* 144, no. 6 (1962), 1275-1278.

⁶ It was this particular 1908 paper by Lippmann—as opposed to the 1891 paper cited by Denisyuk—that Gabor chose in reviewing his own intellectual position on his invention in 1971.

⁷ M.J. Mulkay, “Methodology in the Sociology of Science: Some Reflections on the Study of Radio Astronomy”, 212.

by the historian of science Paul Forman in his 1969 paper *The Discovery of the Diffraction of X-rays by Crystals; A Critique of Myths*, who described accounts put forward to celebrate anniversaries. The celebrations in 1989, of 150 years of photography, produced new memoirs and a conference to celebrate Lippmann. These provided opportunities to assert this history and its relevance to modern technology, alongside the celebrated 1839 invention of Louis Jacques Mandé Daguerre (1789-1851). Forman describes such stories as the tribal ‘myth of origins’ account, whereby history is subordinated to the needs of the present. This history can even be used to antedate Gabor’s contribution. It removes twentieth-century corporate interest from the story by effacing the significance of the electron microscope. In this way it performs in the manner Forman describes, a history which “...only survives to such extent, and in such form, as serves present needs”.⁹

Did Gabor cite Lippmann’s work?

A historian might expect to find antecedents of the hologram to be cited within Gabor’s ‘original’ paper of 1949. However, Gabor cited his contemporaries: those with whom he perceived himself to have a discipline in common. In 1949, this discipline was the field of electron microscopy and diffractive imaging techniques, as exemplified by the X-ray microscope. Gabor described his own investigations as being both suggested by, and extending those of Sir William Lawrence Bragg’s ‘X-ray microscope’.¹⁰ Gabor defined the problem in his paper: Gabor’s holography shared a dependence on the principle of interference with X-ray microscopy. Gabor, for example, did not cite Lippmann’s 1891 interference photography because, presumably, he did not perceive his theory to pertain to the discipline of photography. The academic discipline Gabor taught at Imperial College from 1949 was described as electrical engineering and later as electron engineering. As I have already mentioned, Gabor never realised the application of holography to the electron microscope. My thesis will also reveal that Gabor was never actively involved in the production of three-dimensional laser holograms—the type with which his invention was later associated—when the interest of the science community

⁸ Yuri Denisyuk and V. Gurkov, “Advancement of Holography: Investigations by Soviet Scientists”, *History and Technology*, 8, no. 2 (1992), 127-131, on 227.

⁹ Paul Forman, “The Discovery of the Diffraction of X-Rays by Crystals; a Critique of Myths”, *Archive for the History of Exact Sciences*, 6 (1969), 38-71, on 68. “...the scientist... places no value upon historical fact; history... only survives to such extent, and in such form, as serves present needs”.

¹⁰ Dennis Gabor, “Microscopy by Reconstructed Wave-Fronts”, *Proceedings of the Royal Society*, 197 July (1949), 458-487 on 455.

peaked in 1965. Perhaps more importantly for the historian of science, Gabor's contributions to the discipline of 'holography', as it emerged from the mid-1960s, are also overlooked in the Lippmann-to-Gabor narrative. I believe it is perhaps this lack of an inventor as a strong discipline builder, one who pushes the invention along a continuous linear path, that begins to fragment the history of the hologram into many competing narratives.

Had Gabor achieved his original proposal for the electron-microscope, then Gabor could have modelled his disciplinary activities on that of the two Braggs: William Lawrence Bragg (1890-1971), who with his father William Henry Bragg (1862-1942) had jointly won a Nobel Prize in 1915. Lawrence Bragg was a personal supporter and advisor to Gabor. For example, it was Bragg who read Gabor's original paper in front of the 1949 Royal Society meeting. The Braggs' promotion of X-ray diffraction has already been the subject of disciplinary discussion by historians of science. That holography might have been modelled upon, or absorbed within it in 1949, is an interesting point of consideration.

Historians of science have identified key points in the success of the Braggs in promoting their practice. Paul Forman explained the pursuits of the Braggs and others that were necessary to define this discipline as one of:

...an ever-expanding field of crystal structure analysis by X-rays—a field lying between, and shared by, physics, chemistry, crystallography, geology, and now biology. The leaders of X-ray Crystallography have striven to maintain a separate identity and resisted degradation of their field to the status of a mere technique common to these various sciences.

The Braggs achieved this with the International Union of Crystallography formed to “sponsor meetings and publications...trying to define... ‘A Crystallographer’ and what he ought to know...”¹¹ Forman describes how during the first fifty years a large number of brief retrospective accounts of the origins and immediate sequels of the discovery were produced. These accounts are what Forman labels as the “myth of origins”.¹² And this constant repetitive use of such accounts, within groups, determines a community of professionals with a shared ‘history’.¹³

¹¹ Forman, “The Discovery of the Diffraction of X-Rays by Crystals; a Critique of Myths”, 38-71, on 40.

¹² Ibid.

¹³ Jordanova, *History in Practice*, 14. See also Jordanova discussing historians' own use of history and behaviour: “Professional bodies, in other words, help historians develop an ownership of their subject, to debate issues, to promote a general sense of the value of history, and to forge their identities in the

Contemporary sociologist John Law has also commented on the Braggs' successful establishment of their field into a mainstream one. This, Law suggests, was assisted by the Braggs' positions in two academic establishments (in London and Manchester) as well as their developing important master-pupil relationships. Academic teaching led to the Braggs having trained nearly all the subsequent British exponents of X-ray crystallography. Law states that this traditional model was a significant social tool in advancing a science before World War II.¹⁴ In comparison to holography, Gabor was never involved with the development of holography to this extent, even after 1963 and the apparent popular success of his invention. Gabor could never support a school of disciples, since as an electrical engineer he never taught optical or laser holography, the discipline with which his invention was later associated. Furthermore, he retired from Imperial College in 1965, just as the laser hologram gained media exposure. This moment might have been the time when academic structure and position would have mattered most to sustaining an emerging discipline.

The 1949 'hologram' and the personality of the inventor were discovered retrospectively, from 1963 onwards. However there was no clear definition of a practicing 'holographer' or of holography's applications. The laser hologram that Leith and Upatnieks presented to the press was not associated with a well-defined application. Indeed, possibly its most successful application at that time was to remain hidden by military secrecy until after 1968. This invisibility of this application was not in fact a problem for the popular press. Rather, readers were to be engaged with the notion that the hologram's most important consequences would lie in the future.

On winning the Nobel Prize in 1971, Gabor's role was that of a 'figure-head' inventor. In his Nobel Lecture, Gabor presented a history that revised his own 1949 'discovery' but redefined the context to take account of its new post-laser success. Gabor restated his proposal for the electron microscope, and played down the role of

process. We can see these working in presidential addresses and inaugural lectures, when distinguished members of the field have a chance to address their fellows and lay out key issues. Many members will strongly identify with those figures and use their words to affirm or adjust their own sense of themselves as historians, just as many may digress and will clarify their identity by contrast. All these processes and characteristic of the ways in which professional middle classes establish and maintain their positions.... New fields and scholars who fear they may be marginal are especially reliant on groups of like-minded people running conferences, perhaps publishing proceedings, and generally publishing their activities in order to achieve respectability and legitimation".

¹⁴ John Law, "The Development of Specialities in Science: The Case of X-Ray Protein Crystallography", *Perspectives on the Emergence of Scientific Disciplines*, ed. Gerard Lemaine, et al. (Maison des Sciences de l'Homme, Paris Publications, 1976), 132-152, on 127.

Leith and Upatnieks in creating the first pictorial laser image. In this lecture, Gabor even claimed the popular three-dimensional image to have been one of his own “...favourite brainchildren”.¹⁵ In referring to the emerging popular history that cited Lippmann’s ‘interference photography’ of 1891, Gabor trumped this reference with another, Lippmann’s 1908 paper for a three-dimensional ‘lenticular’ image. In this Nobel Lecture Gabor presented himself as a protagonist in all of holography’s emerging narratives. This was aided by Gabor’s celebrated position, which permitted him to assume many of the mythic notions that the press projected onto him. The public assumed that he ‘invented’ the three-dimensional image; that this laser imagery was the same as his original concept; that following this invention he produced holograms; and that he was the field’s disciplinary leader. Gabor essentially presents to this audience, at the Nobel Foundation, the narrative they wish to hear in response to the occasion. Historian of science Steve Woolgar has identified this type of account as a “discovery account”, a presentation that no longer needs to persuade or argue for the invention’s validity.¹⁶ It is in part a historical anecdote, which Forman has suggested undermines history but may play a role and “...perhaps even legitimate functions in contemporary science, especially as devices for expressing the mores of the scientific community without exposing the scientist to the mores of self-consciousness”.¹⁷

Did Leith and Upatnieks invent the three-dimensional laser hologram?

Leith and Upatnieks undertook the optical and promotional work required to present the laser hologram to the general public. This they undertook as staff of the Willow Run Research Laboratories, a University of Michigan managed military research-facility. Historian Rebecca Lowen in her book *Creating the Cold War University* explains that by the early 1960s one billion dollars of federal defence money went to such university affiliated centres, with just six of those receiving over half the budget. “These universities in turn, depended on federal patronage for over fifty per cent of their

¹⁵ Dennis Gabor, “Holography, 1948-1971” (paper presented at the Prize Lecture, Stockholm, 11 December 1971), 168-200, on 197, in *Dennis Gabor Papers*, Imperial College Archives (London). Also in *Science*, 177 (1972), 200-313; and online at: www.nobelprize.org/physics/laureates/1971/gabor-lecture.html

¹⁶ Steve Woolgar, “Writing an Intellectual History of Scientific Development: The Use of Discovery Accounts”, *Social Studies of Science*, 6 (1976), 395-422, on 417.

¹⁷ Forman, “The Discovery of the Diffraction of X-Rays by Crystals; a Critique of Myths”. In footnote 6.

operating costs”.¹⁸ Amongst those six were MIT, Michigan and Stanford, all of which had large electrical engineering departments and generated both federal and industrial sponsored off-campus laboratories employing academic researchers.¹⁹ This type of funding was for applied research and not basic undergraduate training.²⁰ By the mid-1960s the university-managed government research laboratory was perceived by some critics as “not relating contract research to the academic program”,²¹ or failing academic scholarship by “...defining research according...to its patrons”.²² These patrons were state defence departments and allied industrial corporations. Many liberal scientists hoped that the National Science Foundation could provide the alternative to military funding but as historian of technology, Jessica Wang pointed out, that remained “a distant dream”.²³

Leith was part of a generation whose military service in World War II (Leith was a naval radar engineer) offered access through the G.I. Bill to higher education. Historian of science David Kaiser describes American academic physics departments from the 1950s onwards as being a training ground for potential military personnel. Both the Army and the Navy aimed to stimulate universities at the outset of the Cold War by funding proposals, which afforded young men training possibilities.²⁴ After World War II trained scientists were required to develop new technological weapons, “ballistic missiles, guidance systems, hydrogen bombs, and radar”.²⁵ Defence money provided the instruments and equipment on an unprecedented scale, which gave rise to a large increase in PhD students who were perceived simultaneously as both cheap labour

¹⁸ Rebecca S. Lowen, *Creating the Cold War University: The Transformation of Stanford* (Berkeley, Los Angeles, London: University of California Press, 1997), 2. Citing Clark Kerr, *The Uses of the University* (Cambridge, MA.: Harvard University Press), 1963, 53-55.

¹⁹ *Ibid*, 4.

²⁰ *Ibid*, 115.

²¹ *Ibid*, 103.

²² *Ibid*, 222.

²³ Jessica Wang, *American Science in an Age of Anxiety: Scientists, Anticommunism, and the Cold War* (Chapel Hill, London: University of North Carolina Press, 1999), 262.

²⁴ David Kaiser, “Cold War Requisitions, Scientific Manpower, and the Production of American Physicists after WWII”, *Historical Studies in the Physical and Biological Sciences*, 33, no. 1 (2002), 131-159, on 139. Two thirds of Harvard physics students in 1948 served in WWII prompted by the aid the G.I Bill provided. The plan to afford physicists military research experience was approved by General Leslie Groves in order to recover the lost generations of trained naval men in WWII.

²⁵ Lowen, *Creating the Cold War University: The Transformation of Stanford*, 2.

and the next generation of scientists.²⁶ Leith, a mature student, had not yet gained his PhD during the development of the laser hologram. Kaiser states that:²⁷

Most American physicists did not spend the bulk of their time working on weapons during the 1950s. Yet they received money from defense-related bureaus to create an 'elite reserve labor force' of potential weapon-makers in the ranks. For more than two decades after World War II most physicists, government officials, and nationally syndicated journalists equated the nation's security with the production of physicists.

The emergence of the popular three-dimensional hologram from a site of military research is complex. This is because it was never made clear to the public at the time (and therefore is still not transparent to the historian), which actual elements of the laser hologram were undertaken as part of a military program. Since it was first declassified in 1968, it has been known that Leith participated in a larger research program which developed Gabor's theory as an imaging application for military radar surveillance. Yet, since the three-dimensional hologram was presented to the public from 1963, five years earlier, and described as independent of any military application, the origins of the laser hologram have been obscured by military secrecy. In a recent interview, Leith described working on this project at the Willow Run Laboratories as the result of their having been casually experimenting in between contracts.²⁸ However, it is not easy to evaluate what degree of freedom existed here within the larger technological system of the laboratory,²⁹ as military researchers required permission to perform as civilian researchers,³⁰ and civilian researchers were also subject to background security clearances that became a permanent feature of Cold War science.³¹

Kaiser questions such military-funded university research: "...did physicists make over-rated claims for work essentially seen only in military terms by their patrons... or can military work find a significance independent of its original funding application?"³² The three-dimensional laser hologram succeeded in attracting attention and in gaining

²⁶ Ibid, 115.

²⁷ Kaiser, "Cold War Requisitions, Scientific Manpower, and the Production of American Physicists after WWII", 131-159, on 133.

²⁸ Susan Gamble, *Taped Interview with Emmett Leith* (12 December 2000).

²⁹ Thomas P. Hughes, "The Evolution of Large Technological Systems", in *The Social Construction of Technological Systems*, ed. W.E. Bijker, T.P. Hughes and T.J. Pinch (Cambridge, Mass: MIT Press, 1994), 51-82, on 54. Hughes writes, people "...are components of but not artifacts in the system", they have a degree of freedom.

³⁰ Michael Aaron Dennis, "'Our First Line of Defense': Two American Universities in the Post-war American State", *ISIS*, 85 (1994), 427-455, on 454.

³¹ Wang, *American Science in an Age of Anxiety: Scientists, Anticommunism, and the Cold War*, 2.

³² Kaiser, "Cold War Requisitions, Scientific Manpower, and the Production of American Physicists after WWII", 131-159, on 153.

some commercial applications, but its public perception and significance was bound and fixed to press reports at the time. This public reception is perhaps almost unchangeable by any subsequent reviews or histories, including those written by Leith following the 1968 declassification of the original radar application. This is because such revisions will no longer occupy the same large public arena and will prove less effective. As this thesis will reveal, the hologram as a mid-twentieth-century invention, was defined more by popular press accounts than by academic papers or conference addresses. Therefore, it is unlikely that academic history can revise, within living memory, the general reader's perception of a popular account.

What effect did military secrecy have on the development of the discipline's history?

Dennis Gabor only discovered the military use of his invention after it was de-classified. He commented on this in his Nobel Lecture drawing attention to the military provisions, the laser, the time, and the team, behind the three-dimensional laser hologram.³³

... their [Leith and Upatnieks'] success was due not only to the laser, but the long theoretical preparation of Emmett Leith, which started in 1955. This was unknown to me and to the world, because Leith and his collaborators, Cutrona, Palermo, Procello and Vivian applied his ideas first to the problem of 'side-looking radar', which at the time was classified.

There was no communication between Gabor and Leith from 1955 on the development of the hologram from Gabor's original theory towards its military surveillance application—and its eventual emergence as a three-dimensional image. Military secrecy, imposed upon Leith, prevented communication between these key protagonists. There was no shared information, educational background, equipment or even geographical site. Typically such shared social elements act within a discipline to contribute towards what John Law has identified as the community's "...mechanical solidarity from shared method". An absence of strong social forms of normative practice, plus a lack of accepted labelling—normally generated by a strong actor—could, Law suggests, weaken the communal ground and, therefore, give rise to deviant disciplines.³⁴ Hence, there was no agreed upon foundation for an emerging narrative of holography's history.

³³ Gabor, "Holography, 1948-1971", 168-200, on 177.

³⁴ John Law, "Theories and Methods in the Sociology of Science: An Interpretive Approach", in *Perspectives on the Emergence of Scientific Disciplines*, ed. Gerard Lemaine, et al. (The Hague, Paris, Chicago: Maison des Sciences de l'Homme, Paris Publications, 1976), 221-231, on 224-225.

Here we can begin to see how the discipline of holography was fragmented. The laser hologram, which Gabor first read of in the press, was not presented with the actual antecedent of its recent development. Therefore, the citing of the *Lippmann photograph*, by the Soviet scientist Yuri Denisyuk, provided a useful historical structure to those physicists wishing to consider the hologram as pertaining to an optical discipline. After declassification, when Leith could openly discuss and review the use of holography in military radar surveillance, the history Leith embellished, and the discipline he addressed, was one of signal information, or “communication theory”. This did not produce any significant revision to the perception of the ‘hologram’ and the narratives that had originally accompanied it in the popular press.

The role of the Lippmann-to-Gabor history within the discipline of holography

Like radio astronomy, holography was a post-World War II science that was to combine two disciplines; these were optics and electrical engineering. Radio astronomy also gave rise, initially, to divisions between the more traditional astronomical community and the emerging new discipline.³⁵ Like Leith, many radio astronomers were former military radar operators who sought civilian applications for their training. They had ease of access to radar and military equipment, and they were physicists. It was an *optical* laser hologram that attracted press attention from the mid-1960s but, in the background, hidden from public scrutiny, was a military-radar hologram. The Lippmann-to-Gabor history is one that addresses the need to establish a discipline for those practitioners, who sought to develop the pictorial hologram, recorded onto a photographic medium, as it was presented in the popular press from 1964 onwards.

In this thesis, I bring together, perhaps for the first time, differing accounts of the hologram. In this sense, the history of the hologram is (by default rather than theoretical intention) a post-modern one; there is no clear linear development formed on one site, by one individual, and there is no requirement to reduce the history further.³⁶ There is no orthodoxy; the practitioners’ history is a fragmentation of contributions offering varied standpoints from opposing sites, American, European and Soviet, in the Cold

³⁵ G. Nigel Gilbert, “The Development of Science and Scientific Knowledge: The Case of Radar Meteor Research”, *Perspectives on the Emergence of Scientific Disciplines*, ed. G. Lemaine, et al. (Maison des Sciences de l’Homme, Paris Publications, 1976), 187-204, on 188-189.

³⁶ Umberto Eco, “Openness, Information, Communication”, in *The Open Work* (London: Hutchinson Radius, 1989), 44. Eco on post-modern artistic structures: “... instead of relying on a univocal, necessary sequence of events, [they] prefer to disclose a field of possibilities, to create “ambiguous” situations open to all sorts of operative choices and interpretations”.

War era.³⁷ This is a brief summary of these historical narratives available to physicists, all based on specific inventions:

1. The history Gabor outlined in his 1949 paper.³⁸
2. The Lippmann antecedent as suggested by the Soviet researcher Yuri Denisjuk in 1962.
3. Gabor's 1971 Nobel Lecture: a revision of his original position.³⁹
4. The independent 'discovery' by Leith and Upatnieks of the laser hologram as presented in the popular press circa 1963-65.⁴⁰
5. The emergence of the declassified radar surveillance application as the antecedent to the laser hologram.
6. The notion that the Michelson Interferometer (1891) is the antecedent to Leith and Upatnieks' laser hologram.

Narratives 4 and 6 are what Jordanova would describe as a popular histories: that is they are narratives which contribute to what the general public think, rather than professional academics; these narratives exist in museums, magazines and on television.⁴¹ Item 6 for example, proposes that the American Albert Michelson's (1852-1931) interferometer precedes the laser set-up used in Leith and Upatniek's laser hologram. This historical conclusion was presented as a visual display in the Deutsches Museum, Munich, in 1991. In this museum, a historical exhibition defining the history of the spectroscope, through a collection of instruments and reconstructions of laboratories, introduced a laser hologram asserting its relationship to the Michelson Interferometer. This is an interesting comparison because laser 'holographic-interferometry' did become an established industrial and laboratory diagnostic technique. Within the museum narratives it can be constructed 'visually' around demonstrations and objects, rather

³⁷ Edward Yoxen, "Seeing with Sound: A Study of the Development of Medical Images", in *The Social Construction of Technological Systems*, ed. W.E. Bijker, T.P. Hughes, and T.J. Pinch (Cambridge, Mass: MIT Press, 1994), 281-303, on 301. Yoxen describes the development of ultrasound as "overlapping and multilinear" with "inputs from applied science and not just at the origin. It was, ...mediated through all kinds of different applications". A typical ultrasound technician had familiarity with electronics, the propagation of a signal, plus ideas of reflection and image composition.

³⁸ This history is mentioned in R.G.W. Brown and E.R. Pike, "A History of Optical and Optoelectronic Physics in the Twentieth Century", in *Twentieth Century Physics*, ed. Laurie. M. Brown, A. Pais, and Sir B. Pippard (Bristol & Philadelphia, New York: Institute of Physics Publishing, American Institute of Physics Press, 1995), 1414. It states that holography's "foundation can be traced to back to X-ray crystallography ...as early as 1920". Citing Wolfe, 1920, and Bragg, 1939 and 1942. No overview or opinion is given as to how these papers form the 'foundation' as such; this mention offers no additional insight to Gabor's paper of 1949.

³⁹ Gabor died 7 years later, others did not repeat the account and it is not referred to in Gabor's obituaries.

⁴⁰ D.J. Lovell, *Optical Anecdotes* (Bellingham, Washington: SPIE-The International Society of Optical Engineering, 1981; reprint, 1983), 38-71, on 41. American publications such as this one will often tend to stress Leith, rather than Gabor, as the source of the hologram: "Fortunately wave-front reconstruction was independently discovered by Emmett Leith while investigating optical processing techniques to store and display radar signals".

⁴¹ Jordanova, *History in Practice*, 142-3.

than from texts. Employing this visual emphasis the museum's cases of spectroscopes were then followed with a display of popular holographic images aimed at children.

The Lippmann-to-Gabor history, as a public history, is a narrative which is being read by both a professional elite and general readership. This history can be found very briefly in books on other fields such as art history or cultural studies. Recent examples include the photographic exhibition and edited catalogue *Beauty of Another Order*. Paul McElhone discussing Lippmann photographs in an essay, remarks that, "Interference photography is closely connected with the production of reflection holograms..." he does not cite Gabor, but cites Denisjuk.⁴² Brian Winston in the book *Media Technology and Society: A History: from the Telegraph to the Internet* refers to the development of the hologram from Lippmann onwards, he includes Leith and Upatnieks' laser hologram but Winston asks: "What use is holography?" Winston does not include holography's military or industrial applications. He then asks, "...whether or not holography will acquire movement and thereby emerge as an entertainment medium".⁴³ The assumption here, which was also assumed by the popular press, is that the medium will succeed if it can attain wide popular use by developing the attributes of film, colour, and movement.

In addition to the various narratives listed, further divisions occur between popular and elite accounts, although, as we see the most successful candidate for a public history must function across these two boundaries. Differing stories are told for differing audiences and the pictorial visual hologram was an artefact aimed at the wider public. In researching this thesis I emailed Yuri Denisjuk through a translator. I asked him about his original 1958 investigations in illusionistic display devices, as cited in one Soviet academic publication, which stated "he followed Gabor's pattern of thinking".⁴⁴ He replied, not wishing to elaborate on the 1958 display applications: "The problem of answering to your questions would be greatly facilitated if you read my very popular (easy to understand) paper in the journal *Leonardo*".⁴⁵ This paper, published in an MIT journal for art and science, did not mention the earlier research on the display devices. Rather, it suggested that the author had found inspiration for holography through

⁴² John P. McElhone, "The Signature of Light: Photo-Sensitive Materials in the Nineteenth Century", in *Beauty of Another Order*, ed. Ann Thomas (New Haven, London, Ottawa: Yale University Press, National Gallery of Canada, 1997), 60-75, on 75.

⁴³ Brian Winston, *Media Technology and Society: A History: From the Telegraph to the Internet*, 2nd ed. (London, New York: Routledge, 1998), 337-342, on 339.

⁴⁴ Yuri Denisjuk, *Fundamentals of Holography: Lectures* (Leningrad: State Optical, S.I. Vavilov Institute, 1978), 58.

⁴⁵ Yuri Denisjuk, "My Way in Holography", *Leonardo*, 25, no. 5 (1992), 125-130.

reading science fiction, which is a less revealing account for the historian seeking a technology's development. In 1971, after winning the Nobel Prize, Gabor was also to present his invention as one stemming from creative inspiration.⁴⁶ These authors are responding to the interests of a general audience with a popular 'discovery account'. Historians of technology Trevor Pinch and Wiebe Bijker have explored the ways in which such inventions might offer variant meaning to different groups. They show, too, how these variations are very consequential for artefacts' careers.⁴⁷

It is clear that for both the *Lippmann photograph* and the hologram, public recognition was perceived as a prerequisite for the discipline's advance. Many of the visual inventions from 1891 to 1965 raise the issue of an individual protagonist in search of a popular arena. This is a unifying theme I explore in this thesis. In seeking popularity, there is perhaps always myth-making, an elaboration of narrative into something more heroic or hagiographic. This is a topic Forman suggested was worthy of study, for it might reveal historical circumstances that were not all "fanciful invention".⁴⁸ In adhering to the Lippmann-Gabor story I aim to explore such historical circumstances, for these might demonstrate, as Forman suggests, the process of mythicisation, and in doing so reveal the more mundane and overlooked aspects of a technology's performance in a public arena. With this Lippmann-Gabor narrative, history is an intellectual product that has emerged alongside the technology.

The role of the image in scientific and popular displays

It was only as spectacular images that the hologram and the *Lippmann photograph* gained popular success. That this accumulated social prestige could influence the perception of these inventions attests to the value placed upon visual material within science, by both the scientific elite and the general public. The transformation of a theory into a new visual medium requires display and an audience, a site, and a means of dissemination. The emphasis on display, in the form of the journal illustration, the lectern demonstration, or the conference tradeshow, presents constant challenges to the

⁴⁶ Ernst Kris and Otto Kurz, *Legend, Myth and Magic in the Image of the Artist*, trans. Alistair Laing, 1979 ed. (New Haven, London: Yale University Press, 1934), 49. 'Inner vision' is perceived as divine, pertaining both to saints and modern genius.

⁴⁷ T.J. Pinch and W.E. Bijker, "The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other", *Social Studies of Science*, 14 (1984) 399-441.

⁴⁸ Forman, "The Discovery of the Diffraction of X-Rays by Crystals; a Critique of Myths", 38-71, on 69.

actors within this history. Such a demand was irrespective of the actor's social status or historical period.

But how do other scientists and the general public assess images produced within scientific domains? With what conceptual tools do historians access these images? Can art history be applied to these images? The historian Ludmilla Jordanova has expressed caution on the use of traditional art history in examining scientific imagery as if it were art. As an alternative, she has pointed out that many historians now follow the lead of art historians, Michael Baxandall and Svetlana Alpers, in using the term 'visual culture'. This is because, as Jordanova suggests, art is already 'owned' by a separate discipline that requires specialist knowledge:

...if we think in terms of 'visual culture' or material culture instead of 'Art'...the situation looks rather different... and the way is open for a more flexible blending of disciplines... Visual culture, like material culture, is a more historical category than 'Art'.

She asserts that this is more important when, "...looking at the history of popular culture, for example, there is possibly more visual material than anything else. ... Visual culture is inclusive, for example, by including items accessible to the non-literate. So we are not talking of 'Art' here".⁴⁹

In giving the many images here careful examination, I agree with Jordanova's suggestion that such interpretation should not be based on "connoisseurial attribution" in the traditional sense of art practice, but on what she describes as an integrative approach. For me, this broadens the field of discussion away from the disciplines of art history and aesthetics. An integrative approach shifts the responsibility of successful image-making from a unique author, the traditional creative source, and situates it rather more within the viewer's reception and the context provided by the site of display. That is to say, that an image will only succeed if there is an existing audience capable of responding to it. This is especially important in this thesis, because there are no 'artists', and even though I discuss photographic inventions, there are no 'photographers'. This is not to suggest these actors are lacking in visual skills, but rather, that no protagonist has pursued a career solely trading in imagery. In examining both the nineteenth-century photographs in Chapters One and Two, and the twentieth-century magazine photographs in Chapter Four, I stress the fact that these images are produced to promote an invention, although some of them are similar to images created for the fine-art market.

⁴⁹ Jordanova, *History in Practice*, 89.

For example, even the American inventor Frederic Ives (1856-1937), who produced his own *Kromograms*, only did so to provide imagery with his own invention, the *Kromskop*, which he sold as a package. Ives described and promoted himself as an inventor not as a photographer, and his patents covered numerous devices in the printing and theatrical industries. The Lumière Brothers, one of Europe's largest photographic-plate manufacturers, produced *Lippmann photographs* solely to promote the potential of colour emulsions. These images were not for sale and their photographic skills were not for hire. These industrialists used their image-making talents in order to develop and promote their products to potential purchasers, industry, institutions, and commercial studio photographers. In doing so they created excellent imagery.

Even though one might be tempted to 'see' these images as having the aesthetic attributes we now associate with 'art', for me, this would be to assign them with a value they never attained in their own period. As historian of photography, Ariane Isler-de Jongh has suggested, colour photographic developments of this period were disparagingly called 'chromo', and any aesthetic photographic development came about as a reaction to this pursuit of commercialism.⁵⁰ Most of the photographs illustrated in this thesis, for example those taken by Lippmann and Frederic Ives, are in museums because the inventor's heirs deposited them there, or the inventors themselves donated them: rather, than the images having been independently collected as 'art' or the experimental residue of important science. In examining this imagery, I am seeking to understand how, and why, these technologies succeeded and failed. As some historians of technology have stated: "The success of an artefact is precisely what needs to be explained".⁵¹ And all of these images went out into a public arena, whether a nineteenth-century bourgeois *conversazione*, or a 1960s newspaper, to successfully represent a new technology. Therefore, I see these visual artefacts as strategic promotional agents. One new historical insight gained from this research, is that photographs currently attributed to Lippmann may have been part of a collection donated to him by others for presentation at his Nobel Lecture in 1908. This fact

⁵⁰ Ariane Isler-de Jongh, "The Origins of Colour Photography: Scientific, Technical and Artistic Interactions", *History of Photography*, 18, no. 2 (1994), 111-119, 113. "It was against this more commercialised trend that a renewal of interest for original prints, some by, or in close collaboration with artists would happen".

⁵¹ T.J. Pinch and W.E. Bijker, "The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other", in *The Social Construction of Technological Systems*, ed. W.E. Bijker, T.P. Hughes and T.J. Pinch (Cambridge, Mass: MIT Press, 1994), 17-50, on 24.

undermines any assumption that Lippmann might have been both a prolific and creative image-maker as well as a *savant* physicist.

Clearly, more general issues of taste and style are at work here, and I have tried to depict the consensus of prevailing taste within which any image might be contained and seen. This is speculative, because any extant visual or material object does not come with a written account by its author of the image's intended effect upon a viewer. But historian of technology, Thomas P. Hughes feels that fellow historians can use the concept of style to their advantage because again they are not burdened by rigid art historical definitions of style, and:⁵²

Furthermore the concept of style accords with that of social construction of technology. There is no best way to paint the Virgin: nor is there one best way to build a dynamo.

This variation in depiction permits the historian to perceive regional differences of how a technology might gain international appeal. For Hughes, “The concept of style applied to technology counters the false notion that technology is simply applied science and economics”. And, within discussions of technology, Hughes argues, “The concept of style also facilitates the writing of comparative history”.⁵³

To gain an overview of prevailing period ‘style’, the historian will often be referred back to the art of the period. As historian Raphael Samuel has pointed out “Aesthetics rather than histories are responsible for constituting our notions of ‘period’”.⁵⁴ On this premise I engage in a discussion of period to define a style. For example, in Chapter One I compare Lippmann’s interference spectrum to another presentation of spectral data on display. Here, I take as my definition of style a description by art historian Irene J. Winter and applicable to scientific imagery:⁵⁵

...style is a function of a period, place, workshop, or hand; it is inherent in the work, and it is thus what is apparent to the perceiver. Stylistic analysis then introduces the conscious observation, selection, and articulation of manifest properties to the act of perception.

I also examine the subject matter of the visual artefacts. This traditional art historical process of analysis—iconography—is employed to determine the meaning of the image.

⁵² Hughes, “The Evolution of Large Technological Systems”, 68.

⁵³ *Ibid.*, 69.

⁵⁴ Raphael Samuel, *Theatres of Memory* (London: Verso, 1996), 21.

⁵⁵ Irene J. Winter, “The Affective Properties of Styles: An Inquiry into Analytical Process and the Inscription of Meaning in Art History”, in *Picturing Science Producing Art*, ed. Peter Galison and Caroline A. Jones (New York, London: Routledge, 1998), 55–77, on 56.

In Chapter One I examine the ‘rainbow’ iconography of *Lippmann’s spectrum*. In Chapter Four, I discuss the military iconography of masculine imagery appearing within Leith and Upatnieks’ holograms that depict ‘John Bull’ trains and chess sets. As the late twentieth-century iconographer Erwin Panofsky has argued in discussing film, popular images become fixed in their iconographic meaning and operate within popular culture through wide recognition.⁵⁶ Such visual imagery develops into a language recognised by its target audience. There is no reason why scientific objects, produced for public display, should not be considered to be partial to the style, or symptoms of the pervasive visual culture.

Whereas the reader might detect an aesthetic or artistic appearance in the nineteenth-century photographs reproduced here, a style suited to their original display at soirées, such an association of ‘high art’ would never occur in the case of the twentieth-century holograms under review. These objects are more likely to be judged today as vulgar and commercial, because they are often encountered in mass produced and available novel forms: credit cards or ‘stickers’, for example. It has been observed by sociologist Pierre Bourdieu, that within mid-twentieth-century culture, popularity, even for items of ‘classical’ music or painting such as a Beethoven Sonata or a Renoir, is perceived to cheapen the cultural product for the modern elite.⁵⁷ Did this cultural paradox have any bearing upon actors in this history or on the existence of the Lippmann-to-Gabor history itself? I suggest, from examining the success of Leith and Upatnieks in promoting the hologram, and Gabor’s eventual rejection of popular imagery in his Nobel Lecture, that it might have done. Unlike Bourdieu who conducted social surveys of French taste to support his thesis, a historian cannot access this method retrospectively. Historical assessments can only be produced from archival sources. In assessing the role of the image, I have sought to resolve how public opinion shapes the reception, and possible rejection, of these visual technologies, all of which went into a

⁵⁶ Erwin Panofsky, “Style and Medium in the Motion Pictures”, in *Three Essays on Style*, ed. Irving Lavin (Cambridge, Mass: MIT Press, 1995), 112. Iconographic Images offer a movie audience representations or characters that are, “...identifiable by standardized appearance, behavior and attributes, the well-remembered types of the Vamp and the Straight Girl...” or the “...checked tablecloth meant, once for all, a “poor but honest milieu”.

⁵⁷ Pierre Bourdieu, *Distinction: A Social Critique of the Judgement of Taste*, 7th English ed. (London: Routledge & Kegan Paul, 2003). Bourdieu explores through social surveys the concept of twentieth-century French consumer taste, revealing how popularisation devalues classical musical works; works such as the Blue Danube are redefined as ‘middle-brow’ or as ‘light music’. The more educational capital required to appreciate a work or art or music the more legitimate this work appears to the higher social classes.

public arena as promotional materials ahead of the intellectual property they represented.

The structure and contents of this thesis

I review the Lippmann-to-Gabor history by exploring three key categories of research: the social, the technical, and the visual. I examine patents and inventions—cited within the Lippmann-to-Gabor narrative, dating from 1891 to 1965. I also review their subsequent reception which, in this case, extends—with the hologram—into the early 1980s. With each chapter I form a historical ‘vignette’ around a particular publication: a journal paper, a lecture, or a promotional event significant to the Lippmann-to-Gabor history. I have used archival material, to draw upon the personal backgrounds of inventors’ lives, in order to depict the broader social context of their practice. Much of this research forms a unique contribution to the existing texts, because it is exactly this type of social history that is omitted by scientists who refer solely to scientific cultural objects such as papers, patents or prizes. I draw upon secondary material, from the history of science, photography, art and sociology, to locate my analysis within the context of current historical knowledge on subjects ranging from French nineteenth-century laboratories to the American university-laboratory in the Cold War. With each chapter I evaluate the circumstances and components to this ‘publication’ in order to determine which elements (a prize-winning paper, a label) are retained within historical memory and thus carried forward with the Lippmann-to-Gabor thesis, and which are lost.

This thesis is original in reviewing the emergence of the hologram. For example, Chapter Five is the only chapter in which I am able to engage with a historian of science who has described, in a published paper, the same event and actors. Also, little has been written on the *Lippmann photograph* that places it in a context of historical ‘visual and technical culture’. Despite a Nobel Prize, Lippmann is not remembered as a significant actor within the history of French Third Republic Science. Rather, he is more often recalled by historians of science as the teacher of Madame Curie,⁵⁸ or as a former student of Gustav Kirchoff,⁵⁹ whose reputations proved more historically enduring. I

⁵⁸ Mary Jo Nye, *Before Big Science: The Pursuit of Modern Chemistry and Physics 1800-1940* (New York: Twayne Publishers, 1996), 16. “Marie Curie (nee Manya Slodowska 1867-1934)... came to Paris from Poland to study mathematical and experimental physics under Gabriel Lippmann...”

⁵⁹ Robert Fox and Anna Guagnini, *Laboratories, Workshops, and Sites: Concepts and Practices of Research in Industrial Europe, 1800-1914* (Berkeley: University of California, 1999), 45. Fox

attempt to extend the Lippmann-to-Gabor narrative with a fuller exploration of what might now be perceived as the early stages of a discipline now described as optoelectronics—the twentieth-century merger of the optical and electrical. This field encompasses devices from photocopiers to liquid-crystal displays.

Because this Lippmann-to-Gabor narrative is one premised on a relationship between two Nobel-winning theories, I begin, in Chapter One, with a review of Lippmann’s 1891 paper for a colour photograph. I chose to begin here because of those promoters of this narrative who identify ‘interference’ as the linking physical concept between this photograph and Gabor’s hologram. This group often assumes that the present conditions for ‘the hologram’ existed within the chosen historical antecedent—Lippmann’s 1891 paper. This is a literary construct that many scientists, as authors, employ to define previous origins of current technology. Here, for example, the optical-physicist Yuri Denisyuk assesses Lippmann’s previous work in this manner:⁶⁰

The irony of the fate is that having approached holography, G. Lippmann had suggested to produce such photographs by means of a completely different method...

For Denisyuk, the chosen antecedent is judged from a standpoint premised on the perceived and predicted success of the current technology, i.e. Lippmann *might* have made a hologram. Some historians of science describe this type of assertion as “presentism”.⁶¹ For those authors constructing a ‘whiggish’ or progressive history of a new technology, it is far more advantageous to assert noted and successful attempts—to produce new image techniques—over failed and forgotten ones. In Chapter One, to explore and assess their claim, I study Lippmann’s paper for its theoretical proposal, as well as for its initial social and visual presentations. Like the hologram the *Lippmann photograph* had to prove its validity within a popular arena, as well as to the theoretical elite. I argue that Lippmann achieved this with his *Lippmann spectrum*, a successful display-object produced with his new photography.

In Chapter Two I review the wider reception to Lippmann’s 1891 invention in this period of its publication. I assess the value of pictorial imagery as additional

describes Gustav Kirchoff’s appointment as Professor of Physics, at Heidelberg University in 1854, “as a landmark” in research. Other foreign physicists who studied at Heidelberg, in addition to Lippmann, are Kammerlingh Onnes (Holland), Ludwig Boltzmann (Austria) and Arthur Schuster (GB) Robert Bunsen had the chair in chemistry.

⁶⁰ Yuri Denisyuk, “The Development of Initial Ideas”, *Journal of Optics*, 22, 6 (1991), 275-280 on 277.

promotional material to Lippmann's formal publications. Two individuals whose pursuits are revealed here are the American father and son, Frederic E. Ives and Herbert Ives (1882-1953). Although they worked individually, Frederic as an independent inventor and Herbert in Bell Laboratories, their joint archive in the Library of Congress Washington, reveals a life-long informal partnership that spans photographic technology from the late nineteenth century through to the mid-twentieth century. If Lippmann and Gabor are perceived as having provided the key theoretical papers to this historical narrative, then the uncelebrated labours and concerns of Frederic and Herbert Ives provide an insight into its more overlooked elements. Herbert Ives, for example, wrote the first English language review of Lippmann's 1891 paper, which is constantly cited by contemporary physicists referring to the Lippmann-to-Gabor narrative. Ives' paper published in 1908, has perhaps, been more widely read than Lippmann's original French publication. In this chapter I analyse the role of his paper in this narrative. My research reveals that this paper was the outcome of Herbert's PhD on the Lippmann photographic process and his father Frederic was one of Lippmann's keenest critics. By examining these more social aspects (the labours of a student and the critic's reviews) I seek to reveal how Lippmann's technology was challenged at the time, rather than accept its applauded Nobel Prize status that is presented within the Lippmann-to-Gabor construct.

Rather than pursue an analysis dependent on what current thinking these technologies have provoked, I study the reception of these artefacts within their original period of publication and the efforts of inventors to gain public attention. This approach provides new comparisons. One can examine, for example, the assistance provided by the French photographic plate-manufacturers the Lumière Brothers, Auguste (1862-1954) and Louis (1864-1948), to Lippmann in producing his first pictorial colour photographs. This work the Lumière Brothers undertook prior to their own invention of a photographic colour process and their subsequent invention of the *Cinematograph*. I examine the role of the Lumière Brothers' aid to Lippmann and compare that relationship to the promotion of Gabor's invention by Leith and Upatnieks. These collaborators and image-makers are all overlooked in the Lippmann-to-Gabor account.

In Chapter Three, I review Gabor's original paper of 1949 and the circumstances of its production and publication. In analysing this text I aim to discern which elements

⁶¹ Stephen G. Brush, "Scientists as Historians", *Osiris* vol. 10 (1995), 217. Brush describes how scientists see the past in terms of the present 'presentism' in contrast to historicism to see history in its

of linguistic terminology and description, within the paper, have endured and remain pertinent to the Lippmann-to-Gabor narrative. I reveal how Gabor's desire to produce both imagery and a visual explanation for this publication, essentially defined the 'hologram'. I also review the work of other experimenters who attempted to prove Gabor's hypothesis in the 1950s. Their contribution, often cited solely in the form of a journal reference within the Lippmann-to-Gabor history, is never elaborated upon or celebrated. These publications reviewed and made some progress upon this holographic 'process' without the 1960s invention of the laser.

In Chapter Four, I address the 'discovery' and announcement of the three-dimensional laser hologram presented by the University of Michigan in the 1960s. I identify how the reference to Lippmann emerged and was cited. I analyse the type of journal papers, press releases, and publications used to disseminate this information to the public. I also review the imagery selected and produced by Leith and Upatnieks to accompany articles, and stimulate interest in the three-dimensional hologram. By using archival sources, press articles, and recent reviews by Emmett Leith of his time working at Willow Run, I depict some elements of the hidden and classified military pursuit of Gabor's 'wave-front reconstruction'.

In Chapter Five I study the disputes that emerged at the University of Michigan, between two competing teams of holographic researchers, one led by Leith and the other by George Stroke (b.1924), as public interest in the hologram peaked in 1965. I explore Gabor's attempt to re-establish himself within the new field of 'three-dimensional holography', as well as claim the position of the discipline's leader. Given that the military uses of Gabor's invention were still classified in 1965, I try to assess what impact classification would have had on a developing historical account of the hologram. Finally, I review the content and context of Gabor's Nobel Prize Lecture, examining the new 'discovery' account of his 'hologram' that Gabor presented to the public in 1971 and I reveal how the fragmentation of the discipline, through disputes, might have influenced the Lippmann-to-Gabor story.

With this thesis I aim to achieve an insight into the invention and role of popular history as a promotional tool for an emerging new technology. Whereas the Lippmann-to-Gabor history was structured on theories and Nobel Prizes, this thesis will also

analyse these technologies as visual artefacts promoted to both elite and popular audiences. A review based on visual artefacts allows a differing historical account to be formed, one that is now premised on the artefacts' operation within popular culture. The chapters follow the layout of the Lippmann-to-Gabor narrative. However, in writing and researching this thesis, I have wanted to address some overlooked themes which fall in between the celebrated *Lippmann photograph* and hologram. In doing so, my conclusion considers some of the obscured or neglected three-dimensional inventions with which the protagonists of this thesis engaged.

Lippmann's *La photographie des couleurs*

Here I examine Lippmann's paper and the circumstances surrounding its publication in 1891. I review the differing presentations Lippmann offered to both elite and popular audiences through exhibition and demonstration, in order to access the reception of this photographic invention in the nineteenth century. To achieve this, I draw upon press accounts in nineteenth-century scientific journals and newspapers and accounts by nineteenth-century historians in order to comprehend the aesthetic appeal of this photograph.¹

The Paris Académie des Sciences was the first institution to formally accept the principle of light interference, awarding a prize to Fresnel for his published mathematical theory in 1816 and, from 1819, undulationist explanations were introduced into physics textbooks for university courses.² Such explanations often depicted images of interference fringes: patterns of visible dark and light stripes as an explanatory cipher to Newton's experiments with rings (fig.1.1), or Young's experiments with slits; these optical experiments were now revised by Fresnel's theory.



Fig.1.1. Newton's Rings
reproduced from the 1979 Dover edition of *Opticks*.

The Royal Society of London went on to offer provisional endorsement of wave theory when in 1827 it awarded Fresnel the Rumford medal for the undulatory theory of

¹ This chapter was published as: "An Appealing Case of Spectra: Photographs on Display at the Royal Society, 1891", *NUNCIUS* (December 2002), 635-651.

² Nahum Kipnis, *History of the Principle of Interference of Light*, vol. 5, *Science Networks Historical Studies* (Basel, Boston, Berlin: Birkhäuser Verlag, 1991), 230.

polarization. Wave optics and the imagery of interference soon became a dominant concern of nineteenth-century physics. By 1889 further developments in the use of interference, specific to the new demands of interferometry and spectroscopy, were promoted by a group including Lord Rayleigh in Britain and Albert Michelson in the United States.³ It was against this background of a wide acceptance of interference and the emerging uses for spectrosopes as important imaging devices, that Gabriel Lippmann presented his 1891 paper on *La photographie des couleurs* to the Paris Académie des Sciences.

Lippmann, Professor of Mathematical Physics at the Sorbonne, from 1883, and member of the Bureau of Longitude, married the daughter of the French naturalist writer Victor Cherbuliez, and according to Lippmann's colleague Daniel Berthelot, was to move in a "milieu de haute culture et de haut savoir" including men of literature as well as scientists "les plus fameux: Ernest Renan, Hippolyte Taine, Paul Dubois, Gaston Paris... mon père [Marcellin Berthelot]".⁴ Lippmann was primarily an instrument physicist; he invented the coeleostat, an astronomical tracking instrument attached to a telescope, still in modern use, and the uranograph (installed in the Paris observatory by J. Mascart and W. Ebert) and a capillary electrometer, a device to measure voltage. Since a student in Heidelberg working with spectroscopists Kühne and Kirchoff, and later in 1874-5 working in Berlin under the physicist and physiologist Helmholtz, Lippmann had investigated the effects of electrical charges on mercury and their converse—the generation of electricity through mechanically deforming mercury. Mercury and its physical application to photographic recording, in the role of a mirror, was to be a crucial element in Lippmann's colour photographic invention. From observing the effects of an electrical current moving through mercury, one can speculate, that Lippmann may have projected this model (of energy moving through a medium) theoretically onto another part of the energy spectrum: to light and its physical movement through a photographic emulsion.

Solving the problem of colour photography was a desirable goal sought by a number of differing professional and non-professional groups, and it was *Interferential Photographie* that positioned Lippmann on an immediate trajectory towards acclaimed success in the realms of both physics and popular culture as the inventor of an

³ Ibid, 239.

instantaneous colour image. His photographic process, as an imaging tool, was soon rendered obsolete and Lippmann is now often only recalled as the teacher of Madame Curie, whose fame and science proved more historically enduring.⁵

Lippmann's theory of 1891

Lippmann's successful but brief presentation to the Paris Académie des Sciences was solely dependent on a demonstration of a colour photographic solar spectrum accompanying his short *Note* (fig.1.2). For this audience, familiar with optical wave theory and spectroscopy, the spectrum was ample evidence of the Lippmann photographic process to respond to *all* the visible wavelengths of sunlight in one exposure. It demonstrated the full potential of a *natural colour* photography, a recording process that was without the artifice of pigments or the intervention of colour separations, with a photographic image of one instrumentally isolated object, the sun via a spectroscope. Like a daguerreotype, the *Lippmann photograph* had to be held in the light at an angle for the image of the spectrum to be seen. Then sunlight reflecting from its surface would reconstruct, and project onto a screen, what appeared to the audience to be an aesthetically satisfying simulacrum of nature's 'rainbow'. This photographic spectrum could also record the characteristic Fraunhofer black lines, familiar to astronomers. Lippmann's spectrum was a physicist's solution to hopes for photography that had not yet come to fruition in the 50 years since the technology's emergence.

⁴ Daniel Berthelot, *Funeral of Gabriel Lippmann* (Paris: Institute de France Académie de Sciences, 1921), 2.

⁵ Mary Jo Nye, *Before Big Science: The Pursuit of Modern Chemistry and Physics 1800-1940* (New York: Twayne Publishers, 1996), 16.



Fig.1.2. Lippmann Solar Spectrum, circa. 1891

size approximately 60mm x 40mm, attributed to Gabriel Lippmann. Silver-halide emulsion on glass.
Reproduced with permission from the Musée de l'Elysée Lausanne, Switzerland.

The *Lippmann spectrum*, like *Newton's Rings*, performed a dual function, providing evidence of the physical nature of wave theory in addition to being an image of the sun. It was a recorded phenomenon presented as a cipher to comprehending the invisible nature and process of interference.

When Lippmann presented this photograph, his first claim for this invention within his paper—as if this was the fundamentally new proposal—was the provision of a photographic image that would last indefinitely, it would not fade or decay under light:⁶

Je me suis proposé d'obtenir sur une plaque photographique l'image du spectre avec ses couleurs, de telle façon que cette image demeurât désormais *fixée* et pût rester exposée indéfiniment au grand jour sans s'altérer.

This was possible because the photograph contained no dyes or light-sensitive remnants of organic chemistry; interference was a physical not a chemical phenomenon. The new photographic process has to physically affect or 'shape' the gelatine emulsion to generate an image, rather than provide a tonal graduation of silver-salts, in relationship to intensities of light.

⁶ G. Lippmann, "La Photographie Des Couleurs", *Comptes Rendus à l'Academie des Science*, 112, no. Feb (1891), 274.

Known for his exceedingly brief papers,⁷ Lippmann concisely outlines in less than 500 words the two new physical conditions required for *Interferential Photographie*: the presence of a reflective surface behind the emulsion in the camera; and an emulsion receptive to recording interference. This invention, presented initially without any mathematics or reference to the work of others had, by the time it won the Nobel Prize in 1908, accumulated a reputation amongst scientists of being both ‘elegant’ and ‘simple’.⁸

To satisfy the first condition, Lippmann proposed a device new to photography: a ‘mirror’ behind the emulsion-coated glass-plate, within the camera, formed using liquid mercury which enabled the mirror to be in optical contact with the emulsion. This, according to Lippmann, permitted a light wave, travelling through the camera lens, to pass through the transparent emulsion, hit the mercury mirror and return, thus interfering with itself along the same continuous path within the emulsion. This addition of a mirror to the camera satisfies one of the principles of interference according to the Helmholtz-Young theory (of light interfering with itself along the same continuous path) even though it was to render the function of loading a plate into a camera a clumsy one.

To fulfil the second condition, Lippmann defined a variation on the standard photographic emulsion that would render the emulsion more receptive to the physical formation of interference: this emulsion should be as transparent as possible with very fine and evenly distributed grains of silver salts. With these two conditions satisfied, ‘interference’ could occur with ease: “La théorie de l’expérience est très simple”. But the event was invisible to the eye during the exposure and the development process:⁹

La lumière incidente, qui forme l’image dans la chambre noire, interfère avec la lumière réfléchiée par le mercure. Il se forme, par suite, dans l’intérieure de la couche sensible, un système de franges, c’est-à-dire de maxima lumineux et de minima obscurs. Les maxima seuls impressionnent la plaque; à la suite des opérations photographiques, ces maxima demeurent marqués par des dépôts d’argent qui occupent leur place. La couche sensible se trouve partegée par ces dépôts en une série de lames minces qui ont pour épaisseur l’intervalle qui sépareit deux maxima, c’est-à-dire une demi-longueur d’onde

⁷ A.S., “Obituary Notices of Fellows Deceased”, *Proceedings of the Royal Society of London, Series A*, 101 (1922), ii.

⁸ Professor Hasselberg K.B., President of the Royal Swedish Academy of Science, *The Nobel Prize in Physics 1908* (Nobel e-Museum, The Nobel Foundation, 6 June 2000, 1908 [cited 2001]); available online: www.nobel.se/physics/laureates/1908/press.html. “Professor Lippmann has created this elegant method of obtaining images which combine stability with colorific splendour”.

⁹ G. Lippmann, “La Photographie Des Couleurs”, *Comptes Rendus à l’Académie des Science*, 112, Feb (1891), 275.

de la lumière incidente. Ces lames minces ont donc précisément l'épaisseur nécessaire pour reproduire par réflexion la couleur incidente.

Here within the emulsion, silver grains would physically react and through further chemical development they would form “thin films” of which Lippmann stated 200 could exist in an emulsion one-twentieth of a millimetre thick. The purity of the colours was dependent on the existence of these “miroirs élémentaires” but the visual effect and unifying theory was that “Les couleurs visibles sur le cliché sont ainsi de même nature que celles de bulles de savon”. It was here portrayed as a seemingly natural occurrence appealing to a popular notion of photography commonly held, that the medium was: “a natural phenomena discovered and revealed by experimenters, not a process invented by humans”.¹⁰

Originally, at the Paris Académie des Sciences the formal response to Lippmann's *Note* came from Edmond Becquerel, Professor of Physics at the Paris Conservatoire National des Arts et Métiers, whose own photographic demonstration in 1848 of a colour solar spectrum—recorded onto a reflective silver-electroplated copper-plate with a surface layer of light-sensitive silver chloride—Lippmann now had apparently merely improved upon.

Becquerel's photographs were known to fade when viewed under light, and Lippmann had ‘fixed’ that ‘theoretically’, as he cites no empirical experimentation with chemistry. In his response to Lippmann, Becquerel pointed out the differences between the two processes: he perceived his own process as being only and totally chemical; Lippmann was now proposing an entirely physical action. In defending the stability of his image, Becquerel stressed his own findings: “Ces images sont absolument inaltérables dans l'obscurité et je possède encore les reproductions du spectre solaire faites il y a plus de quarante ans...” Becquerel reveals here how far his own process is from providing a solution to the practical demands of colour reproduction. He also indicates the difficulty that exists in comprehending what actual physical contribution the emulsion plays in his own process, as opposed to the chemical action of the silver salts in producing the effects of colour. He pointed out to Lippmann that in 1865, “M. Poitevin a fait usage pour obtenir, sur papier, les images colorées que je produisais sur plaques métallique...” material evidence to Becquerel that questions Lippmann's

¹⁰ Mary Warner Marien, *Photography and Its Critics, 1839-1900* (Cambridge University Press, 1997), 3.

necessity for a ‘mirrored’ surface to produce this image and thus questions the conditions for interference to occur.¹¹

This issue raised a debate over the process: how can one ascertain whether interference alone or a photochemical effect or even an additional “courant électrochimique”, as Becquerel goes on to speculate, form the colours in a Becquerel plate? How could the results be analysed if the process was invisible to the eye?

That interference could have played a part in Becquerel’s process had been suggested before by a German, Wilhelm Zenker, in his own publication of 1868; but Zenker had no experimental results to show, nor had Becquerel responded to this suggestion.¹² These two processes, the chemical and the physical, were subject to further spectral scrutiny after Lippmann’s publication. The German experimentalist Otto Wiener subjected both types of spectra to examination through a prism placed on top of the photographic plates. Wiener argued in 1895 that pigment or chemical colours should appear to the eye to remain fixed in their location but interference colours will change their location, as light will be bent by the prism.¹³

In his final publication on the subject for the Royal Society in London 1896, Lippmann elaborated further in ‘modelling’ this invisible event for his British audience. He compared the colours to those occurring in ‘Newton’s rings’ and the process and resulting photograph to a mechanically made diffraction grating: “This system impresses its periodic structure on the film. The photographic deposit, therefore, takes the form of a grating, a continuous grating”. He also reiterated the simplicity of the process less metaphorically for the British: “In a word the technics of ordinary photograph remain unchanged”. But additionally Lippmann also volunteered that:

This theory can be subjected to experimental proof. If we examine a photograph of the spectrum, or any other object by white light, we observe the following facts. (1) Colours are seen in the direction of specular reflection, and are invisible in every other direction. (2) The colours change with the incidence; the red changing successively to green, blue, and violet, when the incidence grows more oblique, the whole image of the spectrum is displaced, and gradually passes into the infra-red region.

¹¹ Edmond Becquerel, “Photographie. Observations De M. Edm Becquerel Sur La Communication De M. Lippmann Au Sujet De La Reproduction Photographique Des Couleurs”, *Comptes rendus à l’Academie des Science* 112 (1891), 276.

¹² Wilhelm Zenker, *Lehrbuch der Photochromie* (Berlin: the author, 1868; reprint, Friederich Vieweg und Sohn, Braunschweig, 1900).

¹³ Otto Wiener, “Über Farbenphotographie Durch Köperfarben, Und Mechanische Farbenanpassung in Der Natur”, *Wiedemann’s Annalen*, 1 (1895).

Lippmann then produced a visual demonstration of the physical changes by wetting the spectrum plate, so that “the colour changes in the opposite direction, from violet to red...” appealing to his audience to consider the evidence:¹⁴

...[that this] phenomena is due to the swelling up of the gelatine or albumen, causing the intervals between the elements of the grating to become larger. The smaller intervals, corresponding to violet and blue light, gradually swell up to the values proper to red and infra-red waves. A photograph immersed in water loses all its colours, these appearing again during the process of drying.

Following this presentation, one correspondent to *Nature* wrote pointing out Wiener’s claim that both interference and pigment colours existed in Becquerel’s process,¹⁵ but another wrote it was “unanswerable speculation”.¹⁶ Even to experimenters looking below the surface with a microscope, the archaeology of the photographic event—in the form of physical or chemical remains left within the photographic emulsion—was inaccessible. Later, on winning the Nobel Prize, Lippmann formally acknowledged the work of Becquerel, Wiener and Zenker. In doing so he defined this debate as one between mere experimental artefact on Wiener’s part and strategic objectives on his, stating in his Nobel Lecture that “...Otto Wiener fixed by photography a shot of interference fringes that are found in the neighbourhood of a silver mirror. That physicist did not, however, envisage obtaining colours by an interference method”.¹⁷

Lippmann, both in fixing *his* solar spectrum to prevent further oxidisation of the silver, and in defining a theory, completed this process and presented it to a scientific audience as a usable product. However, the spectrum was the only photograph he could demonstrate. For this audience, the spectrum perhaps recalled the earlier daguerreotype of 1839, and of the ambitions of Francois Arago, Director of the Paris Observatory and Secretary to the Paris Academy, for the daguerreotype to succeed as an objective medium for photometry and astronomy.¹⁸

¹⁴ G. Lippmann, “On Colour Photography by the Interferential Method”, *Proceedings of the Royal Society of London*, 60 (1896), 11.

¹⁵ C.H. Bothamley, “Letter To”, *Nature*, 54, 1385 (1896).

¹⁶ R. Meldola, “Letter”, *Nature*, 54, 1385 (1896).

¹⁷ Gabriel Lippmann, *Colour Photography, Nobel Lecture*, 14 December 1908.(Nobel e-Museum, The Nobel Foundation, 6 June 2000, 1908 [cited 2001]); available online: www.nobel.se/physics/laureates/1908/press.html

¹⁸ Marien, *Photography and Its Critics 1839-1900*, 6. Arago wanted the daguerreotype to be an “artificial retina” for science.

As an early biographer of Lippmann reminded his reader, Lippmann photography—announced more than 50 years after but in the same place as the daguerreotype—could claim a fundamental break from the older daguerrian era of artisan experiments:¹⁹

Whereas, it was chance and trial and error that presided over all the discoveries of photography. M. Lippmann substituted these for rational scientific method.

Lippmann omitted mentioning any experimental trials with his theoretical minimal and verbal simplicity. As a theory Lippmann photography could appear to stand upon a French national scientific legacy of wave theory: the optical work of Fresnel, as well as the mathematics of Fourier. As a photograph rather than theory, it distinguished itself as French for not being either an elaboration of Fox Talbot's British paper talbotype, or of Maxwell's three-colour projection experiment. It also seemed that the medium's apparent direct instantaneous recording of colour, cleanly differentiated it from the many rival synthetic colour inventions by French artisans such as Louis Ducos Du Huron, and Charles Cros, the poet and collaborator with Impressionist painter Manet. Ariane Isler-de Jongh, a contemporary historian of photography, has suggested that Becquerel, in opposing the publications of these authors at the Paris Académie des Sciences acted "as if he had a monopoly on the whole field of colour reproduction", in "meanly" rejecting these inventors who were eventually to publish through a lesser organ: the *Société française de photographie*.²⁰ Du Huron, Cros and the American Frederic Ives, keenly fought for a priority in authorship of 'colour photography' at this time by publishing patents for methods and instruments to synthesise a 'natural' colour from three separations. This group sought pragmatic mechanical solutions to image reproduction as suited the emerging needs of the late nineteenth-century fine art publishing market. Science, it seemed, demanded a more theoretical solution.

An interviewer reported of Lippmann, who had begun to occupy the pages of the popular press with his new invention for colour photography:²¹

He thinks that he will be able to reproduce composite hues, such as are found in the human complexion, or a landscape, but said he had never tried, and therefore can assert

¹⁹ Emile D'Haurt, "Extract from a Paper on Colour Photography..." in *Gabriel Lippmann, Biographie*, ed. Ernst Lebon (Paris: Gauthier-Villars, 1911), 40.

²⁰ Ariane Isler-de Jongh, "The Origins of Colour Photography: Scientific, Technical and Artistic Interactions", *History of Photography*, 18, no. 2 (1994).

²¹ Paris correspondent of the Daily News, "Photography in Colours", *The British Journal of Photography*, 20 February (1891), 121.

nothing. Scientists, however, despaired of getting the bright rather than the subdued colours, the former of which he has been able to catch and fix.

Brilliant, well-defined, separate wavelengths satisfied the scientists. As the contemporary anthropologist Barbara Saunders has noted: “Colour was not for nothing a pre-eminent topic across disciplines in 19th century science”.²² Colour was seen to be divisible between physiological or psychological concepts on the one hand, versus the empirical notion of mathematically defined optical phenomena on the other. Aware of this demand for an objective and quantifiable replication of colour as seen in nature, Lippmann appealed further in 1896 to a professional scientific elite at the Royal Society, London, by advocating the unique ability of his colour process to provide an image able to resist artistic manipulation:²³

...in the case of the spectrum, the colours are visible only in the direction of specular reflection. If I had tried to touch up these photographs by means of watercolours or other pigments, these would be made apparent by slightly turning the photograph. Thus the touching up or falsifying by hand of a colour photograph is happily made impossible.

By representing the process with a spectrum, Lippmann could present the photograph as an imaging device strategic to many scientific fields. In this form Lippmann photography claimed to avoid any artful skill-based handiwork or compromise with the demands of an artistic and commercial market to improve and falsify reality.

Lippmann’s spectra on display in London

Four months after their initial appearance at the Paris Académie des Sciences, the objects described by the London *Telegraph* of 7 May 1891, as Lippmann’s “now world-famous-spectrum-negatives, the first distinct step towards photography in colours”, were on display in The Royal Society, London.²⁴ Thomas Bolas the photographic historian and inventor of ‘the detective camera’, commented on this fame and exposure in 1900, making this comparison with Lippmann’s earnest rival:²⁵

...the patient labours of Mr Frederic E. Ives not only in explaining the theory of three colour photography but also in bringing about its practical realisation are well known;

²² Barbara Saunders, “The Spectre of Colour: A Sociobiological Paradigm”, *Science as Culture*, 8, no. 4 (1999), 483.

²³ Lippmann, “On Colour Photography by the Interferential Method”, 13.

²⁴ Press Cuttings in the Archives of the Royal Society, London

²⁵ Thomas Bolas, “History and Development of Heliography”, in *Handbook of Photography in Colours*, ed. Thomas Bolas (London: Marion & CO, 1900), 9.

while Professor Lippmann's name is known even to the newspaper reader in connection with heliochromy...

The *Conversazione*, held annually in June, had become a London *Society* event, part of a culture of display and promenade once intended for the aristocracy but, since 1880, accommodating an ever-expanding new peerage of industrialists. Not an exhibit in the modern sense, that presumes science should pertain to a didactic role, in this case science was to offer a socially useful context of apparent accessibility—providing the arena for an elite social ritual. For the Royal Society this was a more public reinvention²⁶ of the President's private *Soiree*, a change brought about in 1871 to facilitate the appointment as President of Sir George Airy, Astronomer Royal. Unlike his predecessors, Airy was not an aristocratic 'gentleman scientist' but a government employee without the private means to personally entertain the Fellows, so the *Conversazione* became the responsibility of the institution.²⁷ Having relocated in 1873, The Royal Society found itself at Burlington House on the doorstep of the Royal Academy of Arts, an institution dedicated to educating the public in matters of taste, and already drawing 315,000 visitors to its first public Summer Exhibition of painting in 1869.²⁸ Both institutions had for some years courted the new mobile and professional classes with events such as exhibitions and lavish openings that could also guarantee further mediation by the press.

The Conversazione, like all *Society* events, was dependent on the presence of escorted women for its status. Without women, the exhibit, first hung in May for the Fellows' annual dinner, was lacking both social glamour and press attention. *The Globe*, of June 17, 1891, describes the two Royal Society events:²⁹

Of the two annual soirees which are held in the rooms of the Royal Society, the second, or 'ladies night' ...is by far the more interesting to the layman. The first is more serious and scientific. ... The apparatus exhibited are usually the latest conquests of science, and the talk is more or less of a purely scientific character. On this occasion we have the scientific bow but half-bent. On the 'ladies night' it is completely unstrung; a result which is partly due to the presence of the fair sex...

²⁶ Eric Hobsbawm and Terence Ranger, eds, *The Invention of Tradition* (Cambridge University Press, 1983). I refer here to the example of nineteenth-century 'reinvention' that the authors discuss throughout this book.

²⁷ Marie Boas Hall, *All Scientists Now: The Royal Society in the Nineteenth Century* (Cambridge University Press, 1984), 108.

²⁸ John Barrell, *The Political Theory of Painting from Reynolds to Hazlitt* (New Haven and London: Yale University Press, 1986), 70.

²⁹ Press Cuttings in the Archives of the Royal Society, London

The presence of women, if only for one night, altered the nature of science and of the institution itself, which fittingly appeared more fragrant with a profusion of greenery and flowers. The Royal Society as a venue represented the typical private institutional environment that these selected objects and their exhibitors would have been privileged to on the European circuit of exhibitions. But how did women of this period see spectra? For such an urbane audience science would have been assessed with the aesthetics pervasively applied to all objects of culture of this period: material quality would have been uppermost. For these viewers, Lippmann's brilliant spectral strip of colour, embedded in its glass plate, would have appeared, as one Parisian reporter commented, with a specular luminosity "...comparable to the prismatic hues of a well-cut Golconda diamond".³⁰ This female audience could make this value judgement themselves in assessing both the exhibits and their own social rank: tiaras were mandatory dress for women at all *Society* evening events, even though items of jewellery were specifically rejected by the Fellows for display.³¹ This aesthetic jewel-like quality remained a prominent characteristic of Lippmann spectra even to a twentieth-century physicist who, in seeking the physical archaeology within the nineteenth-century photographic emulsion under an electron microscope, compared it to the "resonate optical structure" of an artificial opal.³²

An explanatory catalogue was provided at the *Conversazione* for those guests that the *Globe* portrayed as being "...attracted thither by the glamour of fashion rather than a love of science..." guests who were not Fellows but "Lord Mayors and men of wealth, famous soldiers, eminent lawyers, distinguished travellers, fashionable physicians, popular actors, successful engineers..." For this new plutocracy the catalogue described Lippmann's two spectra thus:³³

The colours seen on these plates are produced by the direct action of the light; they are not due to any pigments, the substance of the films remaining colourless, but are of the same kind as the colours of soap bubbles, and mother-of-pearl, viz: interference

³⁰ Paris correspondent of the Daily News, "Photography in Colours", 121.

³¹ Royal Society, "House Committee Soiree Minutes" (13 April 1874). "An application from W. Streeter for leave to exhibit jewellery at the *Conversazione* was declined".

³² Jean-Marc Fournier, "An Investigation on Lippmann Photographs: Materials, Processes, and Colour Rendition", *Proceedings of the SPIE*, 2176, Practical Holography VIII (1994), 144-152, 147. "Some birds, insects, moths and butterflies generate spectra corresponding to interferential colours... opals constitute another typical example of resonate optical structures, as it has been demonstrated through electron micrography... artificial opals diffract 'green light' each layer made of close packed 20 nanometer diameter polystyrene spheres."

³³ Catalogue, *Conversazione* (Burlington House, London: Royal Society, 1891, May 6), Archives of the Royal Society, London

phenomena; they are due to the structure imparted to the film by the stationary waves of incident light during exposure in the camera. These colours are perfectly permanent.

Lippmann's apparent rendering of colour with light itself provided a visually appealing and a 'realist' solution to the problems of depiction that are inherent in graphic pictorial representations. Lippmann's interference spectra presented colour objectively rendered, without chemistry. It was a "scientifically-perfect process" to Alfred Russel Wallace, whereby:³⁴

The principle is the same for the light-waves as that of the telephone for sound waves.... An even more striking and, perhaps, closer analogy is that of the phonograph, where vibrations of the diaphragm are permanently registered in a wax cylinder, which, at any time, can be made to set up the vibrations of the air, and thus produce the same sounds...

Wallace remarked "the only fault being that the colours are more brilliant than in nature".³⁵ The bright immaterial colour of these spectra was described in 1908 for Lippmann's presentation of a Nobel Prize for Physics as "virtual colours".³⁶ They were virtual in the optical sense of their apparent reconstruction within 'space'; the colours seemingly not residing in a fixed location but requiring illumination before a viewer. In this form, the Lippmann spectrum seemed to achieve that superior technical rendition of the physical 'retinal' experience of seeing colour, which French painters from the Impressionists to Seurat sought in pigment. Such an emphasis on the pleasurable physical sensation of viewing versus literal depiction was, for the French art critic Hippolyte Taine, to distinguish French painting from creations by the puritanical British, which Taine found too factual.³⁷ Such sensory experiences counted for this social class of audience at the Royal Society, schooled in the prevailing 'aesthetic attitude', who relied empirically on their senses in engaging with what were, to them, non-propositional objects, aesthetic items without narrative or function: stones or prisms.

³⁴ Alfred Russel Wallace, *The Wonderful Century*, 2nd ed. (London: Swan, Sonnenschein & Co, Limited, 1903), 117.

³⁵ Ibid, 118.

³⁶ Hasselberg K.B., *The Nobel Prize in Physics 1908*.

³⁷ Hippolyte Taine, *Notes on England*, trans. Edward Hyams, 1957 English ed. with Introduction (London: Thames & Hudson, 1860–1870), 265-266. Taine finds English painters to be "literal copyists" and it is not sufficient for the English critic Ruskin that a painter can "provoke sensory pleasure".

The *Conversazione*, 1891, spectra by Charles Piazzi Smyth

By contrast, also on display in the same exhibit, were photographs of the solar spectrum by Charles Piazzi Smyth, former Astronomer Royal for Scotland. Smyth presented a series of black and white graphic notations in a complex framework. Seen together as exhibit 22, in the same room with Lippmann's coloured spectra, these two sets of spectra establish individual extremes of conceptualisation and design, demanding comparative interpretation and competing for recognition. For this general audience of 1891, exploring such visual and national differences would certainly have been one engagement with modern science.

Smyth, a close friend of Henry Fox Talbot, was well known for both his photography and spectroscopy, much of which he financed himself and invested with his visual skills and experience. A former Fellow of the Royal Society, Smyth had resigned when the Society rejected his paper—resulting from his own survey of The Great Pyramid—claiming a British revision of this monument to favour the British inch, as a standard metrology instead of the French metre. In fact for Smyth both "...ancient profane Egyptian or modern aesthetical French models..." were to be equally damned.³⁸ However, exhibitors need not be Fellows and Smyth, like Lippmann, was present at the *Conversazione*.

Smyth's spectra on display came from an ongoing photographic project funded from 1890 by the British Association for the Advancement of Science.³⁹ This project was perhaps addressing an attempt to resolve a photographic form of presentation for spectroscopy, which had not yet settled on an international standard. Smyth printed his own photographs, unlike other spectroscopists in this arena such as Norman Lockyer FRS, who on exhibiting photographic solar spectra at the Royal Society, *Conversazione*, 1874, had them enlarged by the best London photographic publishers, Negretti & Zambra.

Spectroscopy was germane to photography's early development and the medium's ultimate pursuit amongst 'gentlemen' astronomers and physicists, especially those in Fox Talbot's circle, such as John Herschel, David Brewster and Smyth. Even as early as 1839, Brewster wrote to Fox Talbot thanking him for sending on the results of his first

³⁸ C.P. Smyth, *The Great Pyramid, Our Inheritance In*, Steinerbooks 1977 ed. (London: Daldy, Isbister & Co., 1877), 530.

³⁹ H.A. Brück and M.T Brück, *The Peripatetic Astronomer* (Bristol: Adam Hilger, 1988), 249-250.

experiments. Of these “photogenic specimens” Brewster remarked that “the lace one is especially interesting” but he then asks if Talbot has made “a map of the solar lines on his prepared paper” as if this were the more pertinent image to their mutual concerns.⁴⁰

To spectroscopists spectra were both images and information to be seen and read simultaneously, and as images they required an aesthetic appeal that concisely depicted the field of data under consideration. Spectra were iconographic images for a scientific milieu enabling Lippmann’s spectrum to represent his invention with a direct visual immediacy. But spectra were difficult for the general viewer to interpret, they appeared to offer complex information, and thus could remain in closer rein to the esoteric institutional group. In this sense spectra could always pose on public display for aesthetic appreciation and remain safely ‘scientific’, whereas mid-Victorian astronomical images often fell into a pictorial genre of popular culture. In the context of a public exhibition these spectra could occupy a boundary position between a popular and a scientific reading.

Smyth’s spectra were paper Talbot-types then considered the normative photographic practice.⁴¹ Black and white photographic representations depended on graphic notations to indicate wavelength positions. By contrast, Lippmann’s spectrum was itself ‘a mathematical object’: in its making and reconstruction it was without any subjective intervention or notational symbolism.

⁴⁰ David Brewster, to Henry Fox Talbot, 12 February 1839, in *Selected Correspondence of W.H. Fox Talbot 1823-1874*, ed. L. Schaaf (London: Science Museum and the National Museum of Film and Photography, 1994), 18.

⁴¹ Fox Talbot’s Talbot-type or calotype employed a paper ‘negative’ from which further copies could easily be produced.

the authority of the inscription with its ‘lapidary’ succinctness and its sense of decorum”.⁴³

In doing so Smyth gives *The Great H and K* all the decorum of an institution in order to be recognised by this audience. Architecture in the nineteenth century was considered to be above sculpture and painting in a hierarchy that would have placed photography well below watercolour as the lowest art form. Smyth elevates his medium as well as his message here.

Smyth was a committed architectural aesthete, joining the Edinburgh *Aesthetic Club* in 1852, a gathering around David Ramsey Hay, the appointed ‘Limner to the Queen’, an interior decorator and aesthetic theorist.⁴⁴ Hay proposed one unifying theory for taste in both art and science:⁴⁵

Aesthetical taste...depends on certain, scientific and irrefutable principles...it may...be cultivated and improved and from its intimate connections with optics, acoustics, and geometry it ought to be studied in connection with these sciences.

A friend of both Brewster and Maxwell, it was Hay who produced the coloured paper discs Maxwell used in his colour wheel experiment.⁴⁶ Socially absorbing a scientific standpoint, Hay would later reconstruct it in interior design, for example, promoting the use of white in interior decor because white was proved by Brewster to be the sum of other colours.⁴⁷ From a showroom and gallery opposite the Royal Institution, Edinburgh, Hay sold books such as his own *The Orthographic Beauty of the Parthenon*, which illustrated (fig.1.4) the means by which the eye is guided over this monument through “angular proportion” and “harmonic ratios”.⁴⁸ Such were the exchanges within the club. Evidence of architectural contemplation occupying Smyth is perhaps found in his notebook drawing of the Edinburgh Royal Observatory’s Tuscan columns. This sketch of the Astronomer Royal’s own institution appears on a page between notes on instrument loans and administrative matters, the Visitor’s meeting (fig.1.5).

⁴³ E.H. Gombrich, *The Sense of Order* (London: Phaidon, 1979), 238.

⁴⁴ MSS, “The Aesthetic Club, Edinburgh” (Edinburgh University, DC.2.58).

⁴⁵ D.R. Hay, house painter and decorator to the Queen, Edinburgh, *The Laws of Harmonious Colouring Adapted to Interior Decorations, &C to Which Is Now Added an Attempt to Define Aesthetical Taste*, 5th ed. (Edinburgh and London: Fraser and Co, W.S. Orr and Co, 1844), 98.

⁴⁶ Paul D Sherman, *Colour and Vision in the Nineteenth Century: The Young-Helmholz-Maxwell Theory* (Bristol: Adam Hilger Ltd, 1981), 158.

⁴⁷ D.R. Hay, house painter and decorator to the Queen, Edinburgh, *The Laws of Harmonious Colouring Adapted to Interior Decorations, &C to Which Is Now Added an Attempt to Define Aesthetical Taste*, 5th ed. (Edinburgh and London: Fraser and Co, W.S. Orr and Co, 1844), 11.

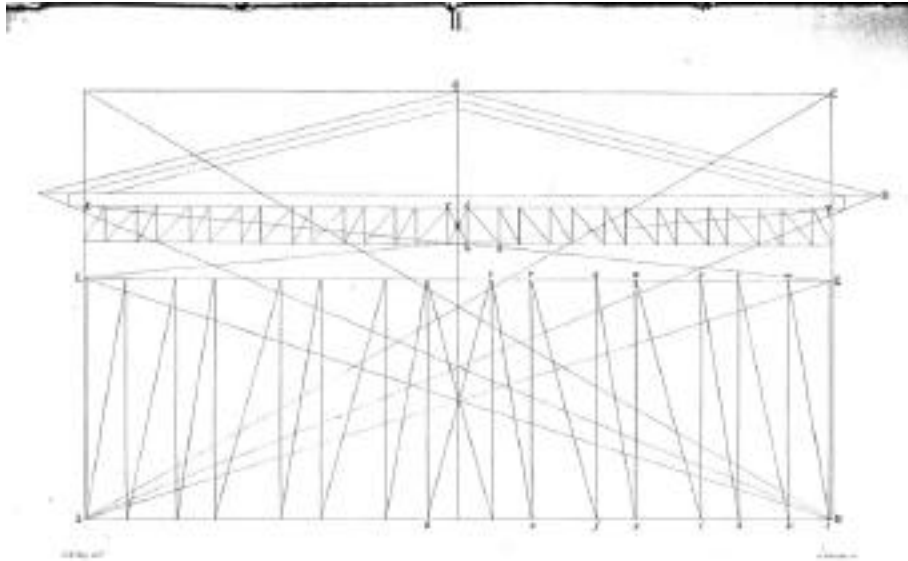


Fig.1.4. Illustration from *The Orthographic Beauty of the Parthenon*.

From the drilled masculine and military proportions of the Tuscan column Smyth has extracted the elemental visual blocks, the “column-and-superstructure” with which the Observatory’s portico addresses the viewer. Such a familiar portico Smyth later rebuilds in his solar spectrum. Data of such visual grandeur could take up its position on mahogany lecterns and communicate in a standard visual language. Form in light could become analogous to form in architecture and in doing so gain a framework by which a viewer could feel comfortable with the placing of varying numerical scales and other abstractions from nature. Light need not lose its aesthetic appeal through a graphic transformation; it would merely obtain a different, more familiar one.

⁴⁸ D.R. Hay, *The Orthographic Beauty of the Parthenon* (Edinburgh & London: William Blackwood and Sons, 1853), 18-19.

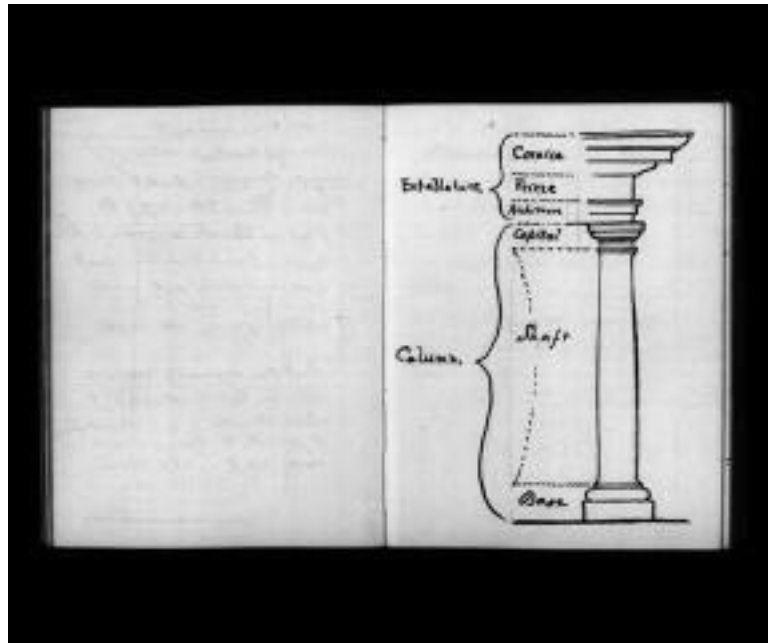


Fig.1.5. Sketch by Charles Piazzi Smyth in a notebook, February-November 1874.
 Reproduced with permission from the Royal Observatory, Edinburgh

Aesthetic values were important in the production of spectra. Objects were selected for exhibit on this visual premise, a vital point of dissemination to the press, public and the scientific elite in the nineteenth-century. Both these spectra were successful display objects. As images they were aesthetically appealing, they could communicate both to the lay-audience and the informed, as an image or information, or simultaneously both. The spectra draw on 'local' visual and cultural references, architectural notational elements in Smyth's image, and the aesthetics and materiality of the jewel in Lippmann's spectrum. With these aesthetic properties common to the same cultural group, the spectra could provide an entertaining conversational focus between the genders, and strangers within an elite *Society* gathering. For Lippmann, this object alone was seminal in promoting his theory. For spectroscopists at the end of the nineteenth century, the possibilities of representational variations within spectra (by differing authors), offered a broad platform for individual expression, and the opportunity to find a general audience for their science.

The assistance of the Lumière Brothers

The Lippmann spectrum was replicated and distributed for Lippmann by the Lumière Brothers, already France's largest photographic-plate manufacturers. Profits from the Lumière's plate-making industry later funded experiments with the *Cinematograph*.

Lippmann himself contacted the Lumières, six months after his original publication, on hearing of their attempts to reproduce his technique. In appealing to the Lumières, Lippmann confessed to such organic chemical experiments and failures as ‘fogging’, to gain their assistance for his project on pictorial imagery. Writing to them he requested some photographic plates for his process.⁴⁹

I have made too few experiments to call them conclusive, but I have to say that so far I have only managed to produce residual traces of colour in that manner. Now it’s the holidays and I have to interrupt my work.

If, in the autumn, you have produced colour plates, I could certainly try them out.

In perfecting photographic plates for Lippmann’s process, the Lumières produced solar spectra repeating Lippmann’s process by imaging the sun through a spectroscope onto what became known as a *Lippmann photographic emulsion*. For the Lumières, recording solar spectra in this manner provided an excellent test of an emulsion’s range of sensitivity to daylight, a prerequisite experiment demanded of a colour photographic process intended for use in *natural light*. As Lippmann intended, the invention was an applied tool. A solar spectrum was an excellent diagnostic device for the analysis of an emulsion’s response to wavelength, revealing directly the differing bands of prismatically split sunlight. What knowledge the Lumières gained here they would no doubt later apply, as a trade secret, to the production of their own colour emulsion, the *Autochrome*. Consequently, the Lumières generated a number of these solar-spectra tests, which they then offered to institutions. These tests had the academic virtue of being replicas of Lippmann’s authentic demonstration, as well as that aesthetically pleasing luminescent rainbow of colour.

One receiving organisation was the Conservatoire National des Arts et Métiers, Paris. The Director, Aimé Laussédats, wrote to Messieurs Lumière on 9 March 1892, regarding:⁵⁰

...your kind offer of a donation [of] the solar spectrum which one of you has obtained by Monsieur G. Lippmann’s process.

I am most grateful to you for the gift of this remarkable object which we are currently having framed in order that it may be placed, together with the appropriate description of its nature and origin, in the gallery which we have specially arranged for the display of objects pertaining to the history and applications of photography.

⁴⁹ Auguste and Louis Lumière, *Letters*, ed. Jacques and Yvelise Dentzer Rittuad-Hutinet, trans. Pierre Hodgson (London Boston: Faber and Faber, 1995), 4.

⁵⁰ *Ibid*, 6.

In this manner *Lippmann spectra* found a permanent place in the newly emerging history and museology of photography. Such spectra by the Lumières were even considered by exhibitors such as the Grenoble Photographic Society to be "...so much more successful and more exemplary than Monsieur Lippmann's".⁵¹ For display purposes, appearance was valued higher than authorship.

For Bolas, the Lippmann photographic process and its ability to image the visible spectrum affirmed the use of the spectroscope as an investigative tool for colour photography, which could equal the camera:⁵²

Hence it will not matter whether it is the colour of a flower, the blue of a sky, the iridescence of mother-of-pearl...It cannot be too distinctly emphasised that there is no difference between colours as seen in nature and those produced by a spectroscope. It is for this reason that we are correct in employing the spectroscope as a source of pure colour in experimental work.

These pursuers of colour photography or heliochromy employed the Lippmann process with the spectroscope merely for the aesthetic colour effect and improvement in the emulsion. In contrast, astrophysicists sought to obtain further information with regard to a subject. Such photographers possibly considered themselves more professional in the sense that they brought to photography a formal university education often in the sciences and sought to employ photography as an applied tool, as opposed to the typical artisan-apprentice or self-taught studio portrait photographer of the mid-nineteenth century. Of the few that took up the Lippmann process, many were chemists, or emerging photo-experimentalists, both equally likely to employ a spectroscope as they were to use a camera. Such individuals included Eduard Valenta, Professor of Photochemistry at the *Versuchsanstalt für Photographie und Reproduktionsverfahren* in Vienna, a unique institution, founded by practitioner and historian Josef Maria Eder, author of the *History of Photography*, first published in German in 1892.⁵³ This school was dedicated to combining the arts and sciences in image-reproduction and to professionalising the field itself. Valenta wrote a short handbook on making Lippmann spectra: *Die Photographie in natürlichen Farben 1894*.⁵⁴ Edgar Senior wrote a section on producing Lippmann photographs including spectra, in Bolas' book. These

⁵¹ Ibid, 10.

⁵² Bolas, *Handbook of Photography in Colours*, 1900,153.

⁵³ Josef M. Eder, *History of Photography*, trans. E. Epstein, 4th ed. (New York: Columbia University, 1945).

⁵⁴ E. Valenta, *Die Photographie in Natürlichen Farben* (Halle: Wilhelm Knapp, 1894).

practitioners and educators, writing at the end of the nineteenth century, considered the spectroscope a tool pertinent to photography.

Even when Lippmann projected ‘popular’ pictorial photographic images to accompany his 1896 paper at the Royal Society, London, a report of the event in *Nature* that year, informs us that it was not ‘flowers’ that excited this elite audience. Rather they, “discussed the potential of [combining] Lippmann’s technique with the new Röntgen X-light...” Lord Rayleigh suggested that Lippmann’s process and “X-rays be [recorded] at nearly grazing incidences on metallic mirrors-or no metallic mirrors...” Rayleigh speculated that in recording X-rays at extreme angles of incidence on a *Lippmann emulsion* and then in reconstructing the image back at a less extreme angle, “such a photograph would show tints from green to violet when viewed normally...” He proposed that one artefact in the Lippmann process, later perceived as a problem—that the colours changed with the angle of reconstruction—could provide a solution to bring X-rays into the visible part of the spectrum. Lord Kelvin was reported in the same issue as suggesting the use of a violet source near, perhaps head-on to the photographic plate to produce interference and therefore ‘concentric rings’ in the violet, a colour or wavelength difficult to emulate in pigments.⁵⁵ Violet as light was considered a pure or spectral colour, whereas it required the mixing of two colours, blue and red, to create violet in pigment. In principle, the Lippmann photograph could claim to record a violet that would be reconstructed as an isolated wavelength. Kelvin and Rayleigh could immediately consider the Lippmann process as improving imaging problems crucial to science; demonstrating here that what were to be considered negative attributes to commercial studio-photographers, could in fact be an advantage to the scientist.

Conclusion

A Lippmann spectrum was a successful visual tool in the dissemination of Lippmann’s theory. It aided public history through museum collection and public display and it also provided evidence in support of Lippmann’s theory to a scientific elite. A *Lippmann emulsion* became a name given to generic photographic emulsion highly sensitive to the entire visible spectrum, probably in limited use for high-resolution scientific imaging: spectroscopy and astronomy. In 1933 this was still in use at the Institute du Radium, Paris, and historian of science Peter Galison cited Marietta Blau, an ‘emulsion

physicist', as remarking that: "...Lippmann plates, for example, often failed to register a single hit by an alpha".⁵⁶ But the name *Lippmann* was eventually dropped from these plates in favour of manufacturers' trade names or numbers after World War II. It was this type of *Lippmann emulsion* packaged as a Kodak spectroscopic-plate that was used to record the first laser viewable holograms. The Kodak product provided physicists Leith and Upatnieks with the means to record the interference pattern of a hologram without having to develop a new emulsion. Optical holography took as its carrier this essentially nineteenth-century photographic substrate. However, it was the Soviet scientist Yuri Denisyuk who, in 1962, provided a revival of Lippmann's paper and identified a historical photographic premises for the hologram. As historian of science Derek J. De Solla Price pointed out in 1963 that "In fields tending to honour their pioneers by eponymic fame—name laws, name constants, name species—one may find that good papers actually improve with age, and their chance of citation increases".⁵⁷

⁵⁵ Staff reporter, "Professor Lippmann's Presentation at the Royal Society, April 23", *Nature* 154, no. 1384 (1896).

⁵⁶ Peter Galison, *Image and Logic: A Material Culture of Microphysics* (Chicago and London: University of Chicago Press, 1997), 151. See also Peter L. Galison, "Marietta Blau: Between Nazis and Nuclei", *Physics Today* 50, no. 11 (1997).

⁵⁷ Derek J. De Solla Price, *Little Science, Big Science* (New York and London: Columbia University Press, 1963), 81.

Popular pictorial Lippmann photographs: the producers, the critics, the Nobel Prize, and the three-dimensional image

This chapter looks at Lippmann's need to provide pictorial *Lippmann photographs* to a wider public and at his further technical collaboration with the Lumière Brothers. In analysing the reception of these images, I introduce the American inventor Frederic Ives, a published critic of Lippmann and independent photographic manufacturer. It was his son, Herbert Ives, who wrote the first English-language review of Lippmann's 1891 paper. Published in 1908, this review was intended for a readership of twentieth-century astrophysicists and is frequently cited by optical physicists in the current revival of Lippmann's work. But the scepticism of the late-nineteenth-century photographic community and the social circumstances, from which both father and son sought to address the Lippmann process, is omitted from a historical memory that exists as a citation list. In this chapter I explore some of the differing responses to the *Lippmann photograph* from artisan and professional groups. I also introduce Lippmann's invention of a device for a three-dimensional image, published the same year he received the Nobel Prize, which was also reviewed by Herbert Ives. Both, the proposal by Lippmann and its subsequent review by Ives, were known to Gabor who referred to this project in his own Nobel Lecture of 1972. I also seek to identify why some inventions succeed and are retained within historical memory and can be retrieved, whereas others are lost. Three of the *Lippmann photographs* illustrated here are from a collection (of 150) in Lippmann's possession at his death and donated to the Musée de l'Elysée Lausanne, Switzerland, in 1993. Subsequently all images (except one that was labelled) are currently attributed to him. In this text I suggest that some of these photographs may have been presented to Lippmann by other practitioners, to provide projected images for Lippmann's 1908 Nobel Lecture. However, I retain the museum's current attribution on the captions.

It was not the solar spectrum recorded by interference which was to generate a wider public response to Lippmann's invention but the demonstration of colour-

photographs of familiar genres: landscapes, still-lives and, by 1893, portraits. The lay-public did not perceive the solar spectrum as a representational photograph. Again Lippmann achieved this with technical assistance from the Lumière Brothers. Lippmann did not have the facilities to produce reliable batches of the emulsion-coated plates needed for pictorial experiments. His laboratory prior to 1894 was considered “rudimentary” according to his biographer: it was a former glass-works situated behind a wine-merchant.¹ Historians of science Robert Fox and Anna Guagnini also support this view, citing the comments of Octave Gréard, an eminent French educational administrator on the squalor of “dilapidated attics and hangars of the court Saint-Jacques where Lippmann had produced his first steps in colour photography”.²

By contrast what was required for producing photographic emulsion was a clean dairy-like facility. The factory owned by the Lumière Brothers would have been both a light and temperature-controlled environment, with emulsion-churning tubs and plate-coating machinery. In 1894 this was operated by their staff of 200 skilled and mostly female handlers.³ The Lumière Brothers had a commercial interest in acquiring another product—a colour photographic process in addition to the successful ‘Blue Label’ plates—that would use the production plant already in place. This they achieved, but not with *Lippmann photography*. They were to develop their own product based on patents purchased from the French inventor, and friend of their father Louis Ducos du Hauron.⁴ This relationship between savant and commerce was one motivated by technical requirements on Lippmann’s behalf and by the Lumière Brothers’ desire to align themselves with an increasingly professional scientific elite; all of which served both parties desires to develop French imaging technology.

In April 1892, less than a year after the publication of his original theory and using photographic plates supplied by the Lumières, Lippmann presented pictorial colour photographs to the Académie des Sciences, Paris.⁵ The resources provided by the

¹ Ernest Lebon, *Gabriel Lippmann, Biographie* (Paris: Gauthier-Villars, 1911), 4-5.

² Octave Gréard, “Introduction”, in *Mongraphie De Nouvelle Sorbonne*, ed. H.-P. Nénot (Paris: 1903), 19-20. Cited in Robert Fox and Anna Guagnini, *Laboratories, Workshops, and Sites. Concepts and Practices of Research in Industrial Europe, 1800-1914* (Berkeley: University of California, 1999), 57.

³ Auguste and Louis Lumière, *Letters*, ed. Jacques and Yvelise Dentzer Rittuad-Hutinet, trans. Pierre Hodgson (London, Boston: Faber and Faber, 1995), 14.

⁴ Louis Ducos du Hauron translated by Philip Hypler, “Colours in Photography the Problem Resolved (Original Publication: Les Coleurs En Photographie: Solution Du Problème, Paris: A. Marion 1869)”, *History of Photography*, 23 (1999), 282-293. Patented in 1868.

⁵ Auguste and Louis Lumière, *Letters*, 305. “...thanks to the Lumière Brothers he [Lippmann] was able show ...some photographs”.

Lumières in producing the emulsion, which is possibly one of the most difficult and mysterious aspects of the Lippmann process to the studio photographer, created a false impression of the ease with which Lippmann was able to produce his own pictorial photographs. If the Lumières had also produced a pictorial image on a *Lippmann plate* they did not publish it before Lippmann himself. According to historical witness Eduard Valenta, then Professor of Photochemistry at the Versuchsanstalt für Photographie und Reproduktionsverfahren, Vienna, that same year the Lumières announced a chemical formula for making a silver bromide *Lippmann emulsion* at the Société des Sciences Industrielles, in Lyon; but they only demonstrated a *Lippmann spectrum*.⁶ The historian and photochemist Josef Eder commented that this publication by the Lumières was not widely transmitted within the photographic community at the time and it contained no detailed description on preparing the plates with this formula.^{7 8}

The Lumières also invented a *Megascope* to enlarge and project the small *Lippmann photographs* to an audience.⁹ This was not a projection through the image—as with nineteenth-century lanternslides on glass—but by light reflected off the front surface of the photograph. Light illuminating the *Lippmann photograph* was bounced-back off the physical surface of the emulsion in the corresponding wavelengths; the image was then magnified as it was thrown onto a screen so an audience in a darkened room could see the photograph. The Lumières also produced a metallic-surfaced screen that reflected the projected image more efficiently, so the images could be seen at their most luminescent. These two inventions, the *Megascope* and the metallic-screen, enabled both Lippmann and the Lumières to present picture-shows and for Lippmann these accompanied repeat presentations of his papers.

The first images

Lippmann's first images on the Lumière-produced plates were a stained-glass window, a bowl of oranges against a red cloth and a parrot, all images that would be rendered exceptionally well in bright contrasting spectral colours.¹⁰ These photographs depicted

⁶ Eduard Valenta, *Die Photographie in Natürlichen Farben* (Wilhelm Knapp, 1894), 47.

⁷ Josef M. Eder, *History of Photography*, trans. E. Epstein, 4th ed. (New York: Columbia University, 1945), 670.

⁸ Valenta, *Die Photographie in Natürlichen Farben*, 47. Valenta wrote up the formula in the journal *Photographischen Correspondenz*, 1892. no. 432, and then himself went on to produce and demonstrate what he described as “a brilliant” projected spectrum to a large audience in Vienna.

⁹ Thomas Bolas, “History and Development of Heliography”, in *Handbook of Photography in Colours*, ed. Thomas Bolas (London: Marion & Co, 1900), 51.

¹⁰ Lebon, *Gabriel Lippmann, Biographie*, 12.

simple genres, still-lives or single subjects that were pertinent to zoologists, chemists and the general public alike. Of these images, the parrot was to become the iconographic *Lippmann photograph* in projection displays. The subject was familiar in both nineteenth-century popular and 'high' art; for example the Realist French artist and academician Courbet featured the bird in his acclaimed painting *Woman and a Parrot*, 1866.

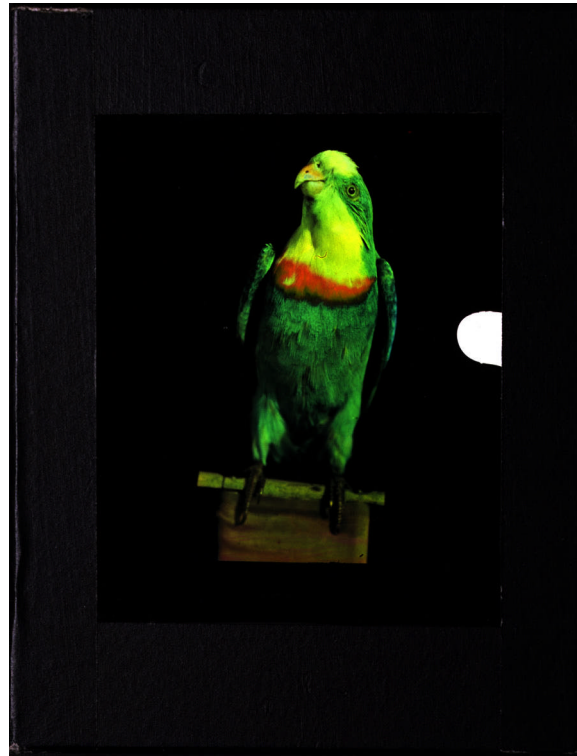


Fig.2.1. Lippmann photograph attributed to the German chemist R. Neuhauss, made 'after Lippmann' and in the possession of Lippmann at his death. Reproduced with permission of the Musée de l'Elysée Lausanne, Switzerland.

This image was probably copied by differing experimenters, in a similar way that the holograms of trains and chess pieces—that later appeared in the pages of mid-twentieth-century magazines—were repeated after Leith and Upatnieks. In selecting a parrot (fig.2.1) we can understand how Lippmann, and others, exploited a limited photographic range of colour—an emulsion that responded to bright spectral colours more easily than muted browns or whites—and selected a uniquely brightly hued subject. This image created the illusion of the medium's ability to replicate the natural world because it implied that other types of bird might also record equally well. This was not only the illusion of the *Lippmann photograph's* ability to record completely all *natural* colour, but also an illusion of the emulsion's speed: the photograph's ability to freeze the

movement of living subjects. The original parrot Lippmann photographed, in 1892, would have been stuffed because the exposure time, in hours, was too long for anything other than a static object. Only after Lippmann's initial demonstration, and prior to publicly presenting their own pictorial photographs, did Louis Lumière, according to photographic historian and witness, Thomas Bolas, succeed in reducing the exposure, first "to half an hour and then to four minutes". This he achieved by working on the process back in his factory, to increase the sensitivity or 'speed' of the emulsion.¹¹

As a projected image, the parrot is intended to appear life-size, to be sitting in space. This we can discern because the image 'bleeds-out' to black at the edges, a device often considered contemporary to twentieth-century graphic design but also employed in nineteenth-century portraiture, which would also isolate an individual in a dark field. The *Lippmann photograph* of the parrot was projected onto a small metallic screen so that the parrot would appear to 'be there' on its perch (on the screen) next to the lectern. The dark background of the photograph would register as an absence of light on the screen. The viewer, unable to distinguish the presence of the screen by its edges, would see only the bright spectre of a parrot coming to the foreground of the darkened room. As cultural historian Wolfgang Schivelbusch states of projections within popular culture:¹²

Common to all these media from the dioramas to the cinemascope screen, is a darkened auditorium and a brightly illuminated image. These have remained constant despite all the technical changes of the last 150 years. In light-based media, light does not simply illuminate existing scenes; it creates them.

For some of the elite audience at the Académie des Sciences, this accurate depiction of a parrot offered diagnostic potential: identifying the hue of bird's feathers locates it within a species. As a work of photographic realism, the medium would have appealed generally to the scientific audience with its capacity to document in colour an apparently living subject. Objective reality combined with rationally defined colour—by wavelength not by pigment—was demonstrated as fulfilling the needs of scientific imaging.¹³ But the same image of the parrot for the lay-public would have been illusion

¹¹ Auguste and Louis Lumière, *Letters*, 5.

¹² Wolfgang Schivelbusch, *Disenchanted Night: The Industrialization of Light in the Nineteenth Century*, trans. Angela Davis, English ed. (Berkeley, Los Angeles, London: University of California Press, 1988), 220.

¹³ Peter Galison, "Judgement against Objectivity", in *Picturing Science Producing Art*, ed. Caroline A. Jones and Peter Galison (New York, London: Routledge, 1998), 327-359, 327, "...objectivity is

and spectacle, a theatrical mimicry of reality offering no further interpretation. As an illusion, the isolated subject—the parrot—is similar to the later treatment of subject matter in a hologram.

These first pictorial *Lippmann photographs*, understood to be of Lippmann's authorship, went on display with work by other French artisan inventors in the Champ de Mars, Paris, although some contemporary historians have doubted Lippmann's authorship of these early pieces.¹⁴ On this occasion Lippmann was given honorary membership of the Paris Photo-Club, a group keen to promote French photography as an acceptable 'art'. This further stimulated the benefits of the relationship between savant and commerce, as Robert Fox has stressed regarding the social function of academies and societies to confer "status and authority" in nineteenth-century France.¹⁵ Lippmann's membership would advantage the Paris Photo-Club, whose artisan members (and now Lippmann's co-exhibitors) were excluded from professional societies, but might now profit, by association, from Lippmann's inclusion.

The occasion of this presentation to Lippmann, in May 1893, was accompanied at the Photo-Club by a display, by the Lumières, of *Lippmann photographs* (fig.2.2).¹⁶ This was a projection display of flower arrangements. Flowers as projected images were an artful arrangement of media as floristry itself was already a bourgeois art suggestive of subjective expression. Images by the Lumières possibly fell into the category that the Photo-Club frequently described in its *Bulletins* of 1892-93 as *art moderne*. These photographs privileged sensuality over objectivity, and perhaps, sought to evoke in the viewer the "personal experience of a peculiar emotion", a response that was considered an essential acknowledgement of an image being *art*.¹⁷ The imagery received greater critical acclaim from this community than Lippmann's own photographs. The Lumière Brothers' skills as image-makers and commercial promoters, demonstrated Lippmann's

deeply, ineradicably, a nineteenth-century category, one bound up with the process of depicting objects".

¹⁴ Auguste and Louis Lumière, *Letters*, 305. The editors of these manuscripts suggest that others also assisted Lippmann: "...thanks to the Lumière Brothers he was able to show ...some photographs his associates had taken".

¹⁵ Robert Fox, *The Culture of Science in France, 1770-1900* (Aldershot, UK and Vermont, USA: VARIORUM, Ashgate Publishing Ltd, 1992), 556.

¹⁶ Auguste and Louis Lumière, *Letters*, 305.

¹⁷ Clive Bell, "The Aesthetic Hypothesis: Significant Form and Aesthetic Emotion", in *The Philosophy of the Visual Arts*, ed. Philip Alperson (New York, Oxford: Oxford University Press, 1992), 119-126, on 120.

invention as a technology capable of successfully appealing to an urbane, cultivated, and bourgeois group.



Fig.2.2. Lippmann photograph attributed to Gabriel Lippmann.

Reproduced with permission of the Musée de l'Elysée Lausanne, Switzerland. This image also matches published descriptions of photographs by the Lumière Brothers.

With this subject matter the Lumières removed some of the stark one-to-one objective replication that Lippmann employed to address a scientific audience. The images were intended to elevate the medium so that it might be appreciated in the realm of French society where it was necessary to maintain a highly aesthetic state of appeal; a condition which pertained among Lippmann's "milieu de haute culture et de haut savoir".¹⁸ Differing groups of images served the division that existed between the intellectual and the sensitive, observed within fin-de-siècle masculinity.¹⁹ The Lumière Brothers produced a display set of *Lippmann photographs*, which they toured and hired out; these accompanied their own presentations and probably those of Lippmann after 1892. However, the Lumières abandoned the Lippmann process in 1894 in order to research a colour process of their own: the *Autochrome*, based on Ducos du Hauron's patents. With

¹⁸ Daniel Berthelot, *Funeral of Gabriel Lippmann* (Paris: Institute de France Academie de Sciences, 1921), 2.

¹⁹ Anthea Callen, "Doubles and Desire: Anatomies of Masculinity in the Later Nineteenth Century", *Art History* 26, no. 5 (2003), 669-699, on 669. Callen also cites, Annelise Mauge, *L'identité Masculine En Crise Au Tourant Du Siècle* (Paris: 1987), 28-38.

their new invention the *Cinematograph* in production for its launch the following year they were unwilling to supply further exhibition venues with *Lippmann photographs*.²⁰

The American Frederic Ives and his three-dimensional colour invention

In 1892 the year of Lippmann's pictorial photographic debut, Frederick Ives, the American inventor of colour photography and subsequent critic of Lippmann's process, arrived in London. Ives came to exhibit his *Heliochromoscope* at The Royal Institution, invited by Cameron Swan, son of Sir Joseph Wilson Swan, inventor of a light bulb and a photographic dry plate. Ives also sought to promote and market his colour photographic process, which he called *composite heliochromy*.²¹ In 1894, intent on manufacturing this tabletop instrument and its subsequent stereo update *The Kromskop*, in Europe, Ives took up residence in London. He brought with him his wife Mary, and son Herbert, whom Ives sent to Harrow public school, plus a young assistant, Bill Jennings. It was Jennings whose defining remark on *The Kromskop*, "That name killed it",²² summed up their investment of time and struggle with this particular product. For promoters of invention like Ives, as well as potential buyers, London was "by the 1880s...no longer the place for the native English gentry. It had become the capital of capital; a social summit open to talent, [and] accessible to worldwide ambition".²³

Britain had the most permissive commercial regulations in Europe and British sterling was the international currency. Opportunities existed within this society, which supplied Ives with a platform and a market that did not exist at home in the United States. Indeed despite his own claim to an American 'first' with colour photography, the only publication of his early invention was the Philadelphia Novelties Exhibition in 1885. This event lacked credibility for professionals in the field and, subsequently,

²⁰ Auguste and Louis Lumière, *Letters*, 45. "We abandoned colour photography by the Lippmann method some months ago. A number of the prints we had managed to make were lost by a railway company while on their way home after being lent out. As we consider the remaining prints of be of historical interest, and are attached to them, we have decided not to allow them to travel before new ones are made if we ever decide to take up that method again".

²¹ Frederic E. Ives, *The Autobiography of an Amateur Inventor* (Philadelphia: Privately Printed by Innes & Sons, 1928), 39.

²² W.N. Jennings (Coast-to-Coast Photo-Service) to Friend Fred, 25 November 1930, Collection of F. & H. Ives, Manuscript Division of the Library of Congress. Jennings recalls the events and clients of London 1894: "...Herr K----- The morning all Germany blew in the shop—Fur lined coat to his feet—Dress suit underneath. Looks long and earnestly in to Kromskop (that name killed it)—Peers furtively around to see object of which this is a reflection?"

²³ J. Mordant Crook, *The Rise of the Nouveaux Riches: Style and Status in Victorian and Edwardian Architecture* (John Murray, Abermarle St, London, 1999), 155.

historians disputed his contribution.²⁴ In this respect Frederic Ives' use of the popular display arena for publication, as opposed to the academic journal paper, has some similarity with the use of the popular press in the 1960s by Leith and Upatnieks. Both, Ives and Leith, experienced difficulties in asserting their authorship outside of their immediate American community. Also, as historian of photography Ariane Isler-de Jongh has pointed out, individual inventors, such as Ives, pioneering colour photographic techniques, were hampered by a lack of communication and foreign language skills.²⁵ Whereas educated professionals could rely on the conduits of communication established for their disciplines.

Ives was not a man driven by theory: he relied on demonstration for putting his inventions across, and for skilful hand-drawn patents for their definition. For Ives, the culture of display for the arts and sciences provided excellent opportunities to exhibit in London, and these platforms were identical to those sought by Lippmann, and the Lumière Brothers, in seeking wider public recognition. In addition to the Royal Institution, *The Heliachromoscope* appeared at the Royal Society *Conversazione*, the Society of the Arts, and the Royal Photographic Society. The acme of its display was the instrument's appearance at St. James Palace in 1896.²⁶ These exhibitions offered possibilities for sales as well as social opportunities for what Ives' assistant Jennings described as "gormandising and inflating".²⁷ Ives also exhibited and sold both his instruments and sets of his own accompanying photographs through the London private gallery system.²⁸ Intermingling in this fashionable and mobile high society, Ives and Jennings were forever instinctively on the lookout for being ripped-off by those

²⁴ Louis Walton Siple, *A Half Century of Colour* (New York: The Macmillan Company, 1951), 13. "There has been some question among historians as to whether Ives did really exhibit such a color process". Siple reproduces the catalogue of the Philadelphia Novelties Exhibition in 1885, and Ives listing within it on page 5. The photo-caption states " [this catalogue] was the proof the late Edward Epstean insisted on finding before he would accept Ives' statement".

²⁵ Ariane Isler-de Jongh, "The Origins of Colour Photography: Scientific, Technical and Artistic Interactions", *History of Photography* 18, no. 2 (1994), 111-119, 115.

²⁶ Mary Olmstead Ives, diary entry for 16 January 1896, from the Collection of F. & H. Ives, Manuscript Division of the Library of Congress. There, according to Mary Ives, "Fred was introduced to the Duchess of York..." and of his invention, "She was intelligently appreciative".

²⁷ Jennings, "O Boy!!! Such a lunch. I can see Hicks, like Kings Balloon. Slowly gormandising and inflating..."

²⁸ Mary Olmstead Ives, to (an unidentified) Dear Friend, January 22 1897, copy of a letter, from the Collection of F. & H. Ives, Manuscript Division of the Library of Congress. "Mr Ives invention has been on exhibition at the St Georges Gallery the past month, and has received a great deal of attention. The first order came from N [W?] H. Kendall the actor..."

Europeans whom Jennings described as: “Too smiley” and “Too velvety-voiced” those intent on duplicating their inventions without first buying a patent license.²⁹

Ives was born in 1856 into a farming community in Connecticut, New England that had a culture of self-reliance and invention. This distinguished New England Puritan farmers from the expansive ‘aristocratic’ style farms of the Southern States, which maintained a scale feasible only by slavery. Ives had moved on, from early employment as a farm labourer and trained on the job as a ‘journey-man’ printer: a ‘consultant’ to the booming American printing industry who could retain his own intellectual property, his skills and patents. Having “taken up photography on the side” on moving to Philadelphia, he dedicated himself to photomechanical research and received two US patents in 1881 for half-tone printing.³⁰ Ives worked independently from his own home, whether in America or England, with a religious dedication and a commitment to continue in his chosen vocation in the face of any adversity.³¹ This heroic, pioneering stance was to define the peculiar creativity of the nineteenth-century American inventor. Its most famous incarnation was Thomas Alva Edison, with his claim that so-called ‘genius’ is merely, “1% inspiration and 99% perspiration”. This robust masculine spirit was evident in Ives’ public demonstrations. They took the form of projected lanternslides with aphorisms intended to motivate a ‘mind-and-body unison’ as the means to commercial success: “Mental Sunshine Creates Physical Health: I Am Optimistic in Thought and Constructive in Action: Day-by-Day, I am Renewing and Vitalizing Every Organ of My Body”.³² In this manner Ives did not separate his personality or physical identity from his mechanical inventions in promoting his ideas to others.

In his own photography and instruments, Ives relied on superimposing three colour images optically over each other: a visually transparent theory, rendered with

²⁹ Jennings, “My first meeting with Mr Ward (tie in his bearskin), Too smiley-Too velvety-voiced, his hand Too Smooth and fishy—hiding his real feelings behind thick flowing Mutton Chop whiskers. An expansive (and expensive) man with big ideas and mean little ways, his cold grey shifty eye ever on the other fellow’s pocket book. ...Shakes hands with his fingers—Deaf to everything but himself—Smiles not with you but at you. A getter, but not giver. When Bill early in the game refers to you as the ‘father of Color Photography’ he shrugs and snorts and spits out: ‘we had Trichromate photography in England long before Ives was heard of’”.

³⁰ Siple, *A Half Century of Colour*, 13.

³¹ Patricia Roberts-Miller, *Voices in the Wilderness: Public Discourse and the Paradox of Puritan Rhetoric* (Tuscaloosa, London: The University of Alabama Press, 1999), 9.

³² Frederic E. Ives, *Undated Lantern Slides* (1992.co47.024: Photography Collection of the Smithsonian Museum of American History). Mental Sunshine Creates Physical Health: I Am Optimistic in

elegant mechanics (figs. 2.3+4). However, it was this apparently mundane and pragmatic approach to creating an image that was disappointing to the public and press in the late nineteenth century, as evident in *The Photographic News* report on Ives winning a gold medal for his *composite heliochromy* 1893:³³

Mr. Ives' process is not the kind of photography for which the world has been looking, and may never find, nor is it "photography in natural colours"... In a technical and scientific sense "natural colours" are those which are produced in any substance by the direct effect of light itself, acting according to the laws of nature.

The meticulous engineering and optical craftsmanship that Ives applied to photography was not enough. Ives was to protest: "one photographic worthy has described my process as 'looking at ordinary photographs through coloured glass!' I can't think why people should wish to distract from it. It is a perfectly honest scientific process".³⁴ ³⁵ Ives sought to realise colour *truthfully*, that is by visual demonstration with an accepted method that resulted in a beautiful realisation of product and image.³⁶ This was to disappoint many others.

Thought and Constructive in Action: Day by Day, I am Renewing and Vitalizing Every Organ of My Body.

³³ From the Philadelphia Photographic Society Correspondent, "A Gold Medal for Mr. Ives", *The Photographic News*, January 6, 1893, 13.

³⁴ Reprint, "Mr Ives and Photochromy", *The Photographic News*, September 1, 1893 (taken from *The Photographic Times*), 554-556, on 555.

³⁵ Steven Shapin, *The Social History of the Truth: Civility and Science in Seventeenth-Century England* (University of Chicago Press, 1994), 42. Protestant culture stressed the importance of continual self-interrogation

³⁶ Roberts-Miller, *Voices in the Wilderness: Public Discourse and the Paradox of Puritan Rhetoric*, 43, "...in puritan culture demonstration is preferable to persuasion as the basis for public discourse because demonstration is more true and equally effective".



Fig.2.3. Kromskop, stereo viewer, 1894, by Frederic Ives, in the collection of the Tokyo Metropolitan Museum of Photography. Sold with images of vases and masks.

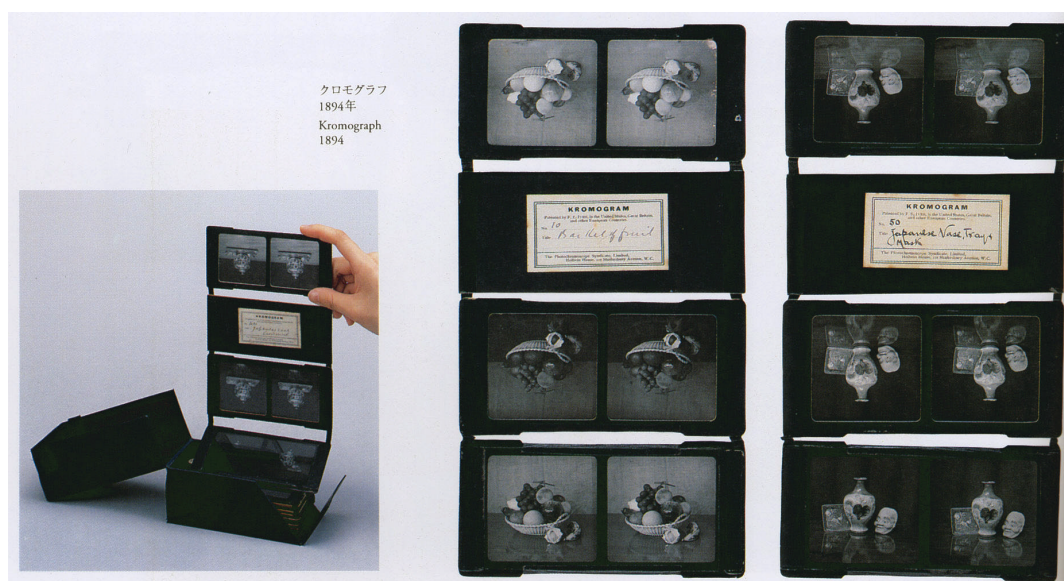


Fig.2.4. Kromographs by Frederic Ives, three-linked-sets of stereo pairs of the same subject, taken through three different colour filters, and designed to slide into the Kromskop. An internal system of prisms combined the three images.

Photography and historical memory

The general assumption, amongst photographers, was that anything other than a divinely inspired intervention with nature that could be compared to Fox Talbot's or Daguerre's 'discoveries' with sunlight was to be considered synthetic. A mere mechanical invention, one that creates coloured effects through artifice, was not a true 'natural'

process of colour. This belief dominated the reception of methods of producing colour in photography well into the twentieth century. It was, perhaps only suspended briefly by the French, in favour of Lippmann's interference photography. That invention was perceived as the *natural* successor to the daguerreotype.

What had generated this belief was a constant citation by photographers and writers of Tiphaigne de la Roche's prediction of 'photography' in *Giphantie*, 1761. This book prophesied a future image, that was to be realised through nature's forces, upon a glutinous substrate. The text had gained such a mythical significance amongst the photographic community that Josef Eder, the photochemist and historian, wrote of his despair over its dominance in his seminal book on photography first published in 1932. Eder quoted, Tiphaigne de la Roche's (following) 'prediction' in his book and warned his readers that: "It contains certain fanciful allusions to the possibility of producing photographic images and provoked even very recently a great deal of discussion".

We take from their purest source, in the luminous bodies, the colours which painters must extract from different materials, which time never leaves unchanged. The faithful rendering of the design, the truth of expression, the strokes of the brush more or less strong, the graduations of shading, the rules of perspective—all these we leave to nature, who, with a sure and never-erring hand, paints pictures on our canvas which deceive the eye... and make one's reason doubt, whether so-called real objects are not phantoms of the imagination which deceive not only eyes, and ears, and feelings, but all the senses together... The elementary spirit which entered upon some physical discussions: first, on the nature of the glutinous matter which intercepts the rays and retains them; second, on the difficulties of its preparation and use; third, on the struggle between the rays of light and this dried substance; three problems which I submit to the physicists of my time and leave to their discernment.

Eder, rejected this romantic narrative, reasoning instead—as a professional photochemist—that eighteenth-century experiments on chemical reactions to sunlight might have prompted Tiphaigne de la Roche's observations and text.³⁷ But this text endured in the historical memory of the photographic discipline, to the extent that in 1998 the text was the first exhibit displayed in the historical section of the George Eastman House Museum. The notion of a medium having been prophesied appealed to practitioners, historians, and the public more than overlooked experiments from the history of photochemistry. It reaffirmed that the ideal photographic solution was a colour image that imprinted itself onto a glutinous emulsion as quickly and perfectly as

³⁷ Eder, *History of Photography*, 89. Eder writes that Tiphaigne de la Roche would have based his ideas on the photochemical actions observed by Schulze b. 1687 or Beccaria b. 1716 see also Eder: Chap X and Chap XI.

a memory. This notion of memory as photography was an allusion that expanded into early twentieth-century literature.³⁸ However, in the late nineteenth century the text generated further confusion on the issue of a mechanical solution versus the possible existence of a 'natural' colour image. This was evident in the reply given by Ives who, when asked by an interviewer in 1893: "Why do you call your process of colour photography by such a long name?" replies:³⁹

Because, popularly speaking, it is not colour photography at all, and I do not wish to mislead. Colour photography, in the sense of reproducing directly the colours of nature in a camera, I believe to be an impossibility; and certainly no such picture has ever been produced.

Ives did not even perceive his *own* invention as one fitting the existing, and all pervasive, description of colour photography. What could be described as colour photography in the early 1890s had to match an existing recollection; and this had apparently already been agreed upon, way in advance of any human endeavour, patent or theory, and had been built on a long-awaited public anticipation for colour since the publication of the daguerreotype in 1839. As Walter Benjamin stated "One of the foremost tasks of art has always been the creation of a demand which could be fully satisfied only later".⁴⁰ Public expectations for the discovery of a 'natural' colour process delayed the acceptance of mechanical methods of colour photography and by 1891 there were already a number of differing proposals. However, many of these, as Isler-de Jongh has stated, employed disparaging technical terms such as 'chromo' that may have hampered interest merely by description.⁴¹ Ives' *composite heliochromy* was one unappealing example of such descriptive naming; and it was his assistant Jennings who had made a similar comment on Ives' *Kromskop*.

Ducos du Hauron wrote of the same historical assumption, which he felt had generated a destructive "widespread prejudice" towards his own invention. In a letter to the Lumières explaining the reception of both the public and photographers to his colour

³⁸ Siegfried Kracauer, *History: the Last Things before Last*, 1995 ed. (Princeton, NJ: Markus Wiener Publishers, 1969), 82. Kracauer cites Proust as the significant creator of this notion: "The process that mechanically occurred in my eyes when I caught sight of my grandmother was indeed a photograph", from *Remembrance of Things Past*, New York, 1932 and 1934, Vol.1, 814-815, translated by C.K. Scott Moncrief.

³⁹ Reprint, "Mr Ives and Photochromy", 555.

⁴⁰ Walter Benjamin, "The Work of Art in the Age of Mechanical Reproduction", in *Illuminations*, ed. Hannah Arendt (New York: Harcourt, Brace & World, Inc., 1968), 239.

⁴¹ Isler-de Jongh, "The Origins of Colour Photography: Scientific, Technical and Artistic Interactions", 113.

prints, he wrote of the origin of this prejudice—as with Ives—as one that existed within the photographic community itself:⁴²

... my system of colour photography did not fit in with received opinion as to how the grand puzzle of colour photography would be solved. The general public, and the world of photographers in particular, expected to be presented with a colour plate chemically and physically capable of capturing, at each point, the particular colour of the ray that strikes it....

But Ducos du Hauron conceded in the same letter that with *Lippmann photography* there was a possibility “that such an expectation could be met” in the face of public disappointment with his own labours. For the *Lippmann photograph* appeared to fulfil the mythological criteria, the process had an immediacy through the direct action of rays of sunlight penetrating the emulsion that resulted in a *natural* colour. And Lippmann had described this event as a *natural* process, one inherent to light's invisible energy: interference. This rhetoric was familiar to his peer group. Historical memory was intrinsically bound to description, and as such, its collective interpretation was to affect the reception of emerging photographic technologies. It seemed that the photographic inventor needed to create apt and persuasive descriptions to match existing assumptions.

Humbug theory: Frederic Ives the American critic

For Ives, it seemed that there was a hidden deceit to Lippmann's process, because Lippmann could never make ‘visible’ by demonstration the event described as interference. The sealed *Lippmann photographic* plates on display seemed suspiciously designed to thwart visual inspection, because the lamination prevented the photograph being viewed in transparency.⁴³ This was so unlike Ives' own products, which were made vulnerable to copying by others by virtue of their technical *honesty*: a visual inspection to the inside of his instruments would expose his clever geometrical arrangement of optics and mechanics. Without a visual demonstration a colour process would not be a logical, fair and honest process to Ives, who relied on patents and thus gained protection only through revelation.

Nor could Lippmann rely on his rhetoric outside his own peer group, or the terminology of physics or the eloquence of the French language in explanations to the English. English science was not presented so poetically. Whereas to the French,

⁴² Auguste and Louis Lumière, *Letters*, 7-9.

⁴³ F.E. Ives, “The Lumière-Lippmann Colour Photography”, *The Photographic News*, December 15, 1893, 795-796.

language was perceived as the main instrument to its cultural dissemination.⁴⁴ Also to the French—as the nineteenth-century realist author on religion and science Ernest Renan, saw it—English protestant science was inelegant and did not aspire to spiritual heights. Renan wrote that it was, “so lacking in loftiness, in philosophy”⁴⁵ and under a state church it was merely used as an educational tool, “A kind of petty process to knock a little bit of understanding into folk”.⁴⁶ For the English audience Lippmann attempted to provide a visual demonstration and a translated description of the event of interference. In 1897 Thomas Bolas, the photographic inventor and writer, reported with some scepticism on such a model demonstrated to a group of photographers at The Royal Photographic Society, as:⁴⁷

...a pretty illustration of the formation of so-called standing waves by reflection is obtained if a rope as thick as ordinary clothes-line and some thirty feet long...is fastened by one end to a nail and the other end is held in the hand and set in motion so as to produce waves...

This model failed to provide these British practitioners with a convincing demonstration of what may be occurring within the emulsion. Models were part of the descriptive process and these also needed to match their audience's expectation.

The critic Ives damned Lippmann's work in print before ever having seen it himself. Mr. Vidal, who was described in the Paris *Photo-Club* Bulletin as a 'savant' member, encouraged other members to defend Lippmann's process from Ives. Vidal claimed that Ives could not have even seen the excellent Lumières' work in this medium.⁴⁸ Ives' own belief in the impossibility of a 'colour photography' ever existing convinced him to state plainly and common-sensibly that: “A scientific friend of mine who has been to Paris to see it says the results are pure humbug. The colours got by it are due to interference of light by thin films on plates backed with mercury”.⁴⁹

Ives refers here to the visual phenomena seen on the surfaces of blown soap bubbles, or manifest in *Newton's Rings* between thin sheets of glass, both popular nineteenth-century educational experiments. These were typical exhibits in the London

⁴⁴ J.F.V. Keiger, *France and the World since 1870* (London: Arnold, 2001), 14.

⁴⁵ Ernest Renan, *The Future of Science: Ideas of 1848*, trans. A.D. Vandom and C.B. Pitman, translated from the French. (London: Chapman and Hall Ltd, 1891), 16.

⁴⁶ *Ibid*, 17.

⁴⁷ Thomas Bolas, “History and Development of Heliochromy”, in *Handbook of Photography in Colours*, ed. Thomas Bolas (London: Marion & CO, 1900), 9.

⁴⁸ M. Vidal, “An Open Letter to Members”, *Bulletin du Photo-Club de Paris*, 1893.

⁴⁹ Reprint, “Mr Ives and Photochromy”, 554-556, on 554.

display arena Ives operated in, as well as images Lippmann himself alluded to in describing his own process.⁵⁰ Ives admits to the existence of such effects but they cannot be considered a new theory or invention: “They are what we call iridescent simply, and are such as you can often see on the surface of stagnant pools...” To Ives such effects are uncontrollable and no one should claim authorship of them because, “The colours are an accidental effect, and vary according to the light in which they are looked at”. Nor are *Lippmann photographs* normal practice to Ives for “...they are not printed at all. By inclining the plate at a suitable angle to the light you can get a coloured effect; that is all”.⁵¹ ⁵² To Ives it seemed that Lippmann had concocted a theory to claim authorship over familiar and naturally occurring events.

Wave theory was *humbug* to Ives. It was outside the pragmatic understanding of normative photography. The rules of this photographic practice and its subsequent expectations were those that had already gained acceptance by Ives and his associates. Ives as an inventor had succeeded without theory, basing his inventions on a practical and craft understanding of geometrical optics. To the puritan Ives, obscure reasoning was not logical, and therefore not true. For example, Ives was to later admit unapologetically his own ignorance of Maxwell's colour theories from which—to professionals in the field—his own process was seen to have been derived.⁵³

Unknown to me, Prof. James Clerk-Maxwell had proposed a method of colour reproduction by making three negatives to represent the ‘primary’ colours, and projecting positives from these three through three magic lanterns, each by light of the colour which it recorded.

Misunderstandings or disappointments with Lippmann's process were compounded by the fact that Lippmann's initial pictorial images of 1892, when displayed to the public in the Champs de Mars, Paris, were less spectacular when not projected. Ives on finally seeing these *Lippmann photographs*, possibly in a cabinet in more diffuse lighting, describes the colours in the images of a parrot and a branch of holly, as “metallic and

⁵⁰ G. Lippmann, “On Colour Photography by the Interferential Method”, *Proceedings of the Royal Society*, 60 (1896), 12. “The colours reflected by the film are due to interference: they are of the same kind as those reflected by soap bubbles or by Newton's rings”.

⁵¹ “Mr Ives and Photochromy”, 554.

⁵² Beaumont Newhall, *The History of Photography* (New York: Museum of Modern Art and George Eastman House, 1964), 191-192. Newhall seemed to repeat the mistake that Ives made on Lippmann's process, writing that he: “...relied upon the phenomenon that a thin film such as oil upon water, will produce the colours of the rainbow”. This text was originally prepared as the catalogue for the seminal exhibition *Photography 1839-1937*, at the Museum of Modern Art New York, published in 1937.

⁵³ Ives, *The Autobiography of an Amateur Inventor*, 57.

changeable... not even confined to the coloured objects themselves, but spreading over objects that were uncoloured in the original".⁵⁴ When not projected *Lippmann photographs* had to be reconstructed within a narrow angle of view. For the viewer to be outside of this limited angle through their position or height—such as could occur with a small crowd around a cabinet—was to see nothing. To Bolas, viewing a *Lippmann photograph*—as if a print to be handheld where the viewer must find the correct angle of reconstruction—was “a matter by no means convenient”.⁵⁵ With projection through the *Megascope* into a dark room, the ‘projectionist’ fixed the all-important angle of reconstruction between the illuminating lamp and the photographic plate for the audience who, were ‘fixed’ in seats, thus attaining a highly controlled presentation of the image. Projected photographic media gained an authority in presentation, which Schivelbusch describes as, “...the illuminated scene in darkness is like an anchor at sea, this is the root of the power of suggestion exercised by the light-based media since Daguerre’s time”.⁵⁶ Lippmann achieved this degree of control with projection at the first showing, but photographs lying in a cabinet were received differently.

Ducos du Hauron, who exhibited his own prints alongside the *Lippmann photographs* in the Champs de Mars, wrote to the Lumières regarding the Lippmann process, informing them of the practical and economic view of a French artisan inventor:⁵⁷

remarkable as it is in scientific terms direct chromophotography is no more suitable for the multiplication of solar creation than the daguerreotype... It is absolutely certain that the twentieth century, as well as the nineteenth, will use a system of inking and only inking for its printing, whether black or white or in colour, the printer’s press will never use the sun’s own rays as part of its equipment.

To provide a credible public demonstration Lippmann relied on the Lumières, who were delegated the larger part of the public arena for presenting this new photography. In this way, Lippmann distanced himself further from non-scientific practitioners. Like Gabor, and his relationship to Leith and Upatnieks, there was a distinction and distance put into place between the theorist and the popularisers. However, Ives was to point out that this success was too late, the reception of Lippmann’s invention was already tainted by the

⁵⁴ Ives, “The Lumière-Lippmann Colour Photography”, 795-796.

⁵⁵ Bolas, “History and Development of Heliography”, 57.

⁵⁶ Schivelbusch, *Disenchanted Night: The Industrialization of Light in the Nineteenth Century*, 221.

⁵⁷ Auguste and Louis Lumière, *Letters*, 7-9.

initial inadequacy of Lippmann's own images when seen outside of the Académie des Sciences:⁵⁸

...when it was announced this year [1893] that the Brothers Lumière had succeeded in so far obtaining really satisfactory colour photographs of natural landscapes, people who have seen the photographs for which such extravagant and inaccurate claims were made a year before were naturally and very justly sceptical.

To experience the invention's attributes, the Lippmann photograph, like the hologram, required witnessing at first hand under controlled conditions. Lippmann's luminescent full-colour recording by 'interference', and the hologram's three-dimensionality, were both novel effects that were not reproducible in print. These inventions relied heavily on written reports—descriptions of the subjective viewing experience—in popular and professional journals to disseminate the imagery to readers. This mediation required readers to place their trust in the author to judge competently the validity of this new form of photograph. Ives defended his position, he saw himself as intentionally picked on merely, "...because I am so inoffensive and not a member of a close corporation like the French savants".⁵⁹ Judgements coming from an outsider were deemed to be of less importance than those from within the same community. This form of peer protection worked for both Lippmann and Ives, who represented two extreme social and disciplinary groups that had approached the same problem.

A successful public display of *Lippmann* photographs by the Lumière Brothers

It was the Lumières that photo-historian and historical witness, Eder, credited as producing the first 'satisfactory' images.⁶⁰ This presentation of *Lippmann photographs* was given in Geneva, in the evening of 22 August 1893, at the *International Photography Congress*, and these photographs then went on to be exhibited in London and the United States.

⁵⁸ Ives, "The Lumière-Lippmann Colour Photography", 795-796.

⁵⁹ "Mr Ives and Photochromy", 554.

⁶⁰ Eder, *History of Photography*, 670.



Fig.2.5. Lippmann photograph, size approximately 60 x 60 mm, attributed to Gabriel Lippmann, and in his possession at the time of his death. Reproduced with permission from the Musée de l'Elysée Lausanne, Switzerland. The bright 'light' to the right of the image is possible damage to the emulsion, such as might occur through frequent projection, or by the projectionist bringing the light closer to the image to show an enlarged 'detail', which would eventually 'burn' the emulsion. This may be one of a set of images taken by the Lumières, an 'out-take' from a photographic session, which then found its way into Lippmann's possession. This image matches a description by Eder of the Lumière work". It was a photograph of a girl, resting her head on her arm at a table with a green background of grape vine and a glass of red wine on the table".⁶¹

Amongst these images was the first human portrait; the Lumières had finally resolved a depiction of a young girl. Again these images were compared to the established medium of painting, as digital photographs or inkjet prints are often today. These *Lippmann photographs* were described by Vidal as having "...the effects of vivid watercolours" and of "luminous watercolours", soft gentle colours associated with roses, or a young girl's skin, were the ideal in nature and in artifice.⁶² The local Geneva newspaper reporter wrote of:⁶³

...a series of landscapes, views of villas and boathouses, as well as some portraits. The results are truly amazing. The countryside matches what the eye perceives of nature with groves of trees the most beautiful green, houses with white facades against a blue sky scattered with clouds.

Another achievement was considered to be the depiction of 'white', which in printing on paper was formed through an absence of colour: a lack of light and therefore a lack

⁶¹ Eder, *History of Photography*, 671.

⁶² Léon Vidal (Moniteur), "In Response to F. Ives", *Revue de Photographie, organe mensuel de la Société Genevoise de Photographie* (1893), 194-197.

⁶³ Chronique locale, "Photographie En Couleurs", *Journal de Geneve*, 24 August 1893.

of chemical reaction. However, with a 'white' formed out of light, as seen with an optical three-colour superimposition, white was the sum total of all colours. White had in the mid-nineteenth century been considered a 'scientific' colour for its relationship to this optical principle.⁶⁴ Now with this new 'paradox of white' recorded by instantaneous interference, the representation of white was all the more spectacular, enigmatic and 'scientific' to this audience. And it was this event that demonstrated that the Lumières' photographs could achieve critical acclaim, "in spite of the objections suggested by Mr. Ives..."⁶⁵

photography in colours is now an accomplished fact, which in the fullness of time, will be perfected and developed into a very practical process. ...colours can be produced without artifices...Truly there can be no comparison with these direct heliochromatic images and the polychromatic impressions of Ducos Du Hauron, Vogel, and Kurtz, Ives etc. Interesting as are all these methods of polychromatic reproduction, they have nothing in common with a direct process. They are in reality everything that is most indirect.

However, by the time these images arrived at the Royal Society *Conversazione*, London, in 1896, where Ives also presented his latest product (the three-dimensional stereo *Kromskop*) the press were far more interested in another new form of scientific photography: images taken with the new X-rays.⁶⁶

The corporate versus the independent inventor: the Lumière Brothers and Frederic Ives

The Lumières concentrated on the popular audience and Lippmann gave repeat presentations of his paper to the scientific and academic milieu. As image-makers, the Lumières were to provide Lippmann with the skills and eye of an audience-conscious visualiser. This co-operation lasted for three years. It was the Lumières who promoted the *Lippmann photograph* to a wider public arena, exhibiting images that were critical to the medium's public reception. In 1895, in return for their assistance to him, Lippmann nominated the Lumières to the Paris Académie des Sciences for a prize.⁶⁷ This brought

⁶⁴ D.R. Hay, house painter and decorator to the Queen, Edinburgh, *The Laws of Harmonious Colouring Adapted to Interior Decorations, &C to Which Is Now Added an Attempt to Define Aesthetical Taste*, 5th ed. (Edinburgh and London: Fraser and Co, W.S. Orr and Co, 1844), 35.

⁶⁵ Editor, "Editorial Preface", *The Photographic News*, December 15, 1893.

⁶⁶ Staff reporter, "Royal Society Soiree", *The Daily News*, 7 May 1896. *Collection Royal Society* "Roentgen rays (the new photography) the most popular exhibit..."

⁶⁷ Auguste and Louis Lumière, *Letters*, 17. Lippmann to Lumieres: "At tomorrow's session of the Académie I shall present your note together with its pretty photographs. I am sure you will be most successful. I should be grateful if you would let me have the pictures by Tuesday. They will be returned to you after the sitting... Yours ever, G. Lippmann".

recognition from an elite professional group the Lumière Brothers did not previously have direct access to, and further benefited their mutual interests.

Lippmann continued to present his own invention. This included the photography exhibit within the Paris Exhibition of 1900, an event that also featured the *Cinematograph* in its gigantic form. As part of this event, Lippmann hosted a projection-show for visitors in his spacious laboratory at the new Sorbonne, which now contained, according to Robert Fox, “the most lavish provision” made at a French university at this time.⁶⁸ Lippmann had moved here in 1894, the year the Lumière Brothers dropped the Lippmann process. In hosting the display in the new Sorbonne, Lippmann would have presented his invention as one designed for, and originated within the discipline of science and, in doing so, he would have lessened the association with the photographic community. However, the images he projected are reported as being similar to those acclaimed pictures presented by the Lumières, in Geneva in 1893: “the Garden of Versailles; the forest at Fontainebleau, Switzerland; the Pyrénées; Venice”.⁶⁹ The same imagery could function for both Lippmann and the Lumières across disciplinary borders with popular and elite audiences.

Using the new emulsion, they had developed from the production of *Lippmann photographs*, the Lumières pursued the patents purchased from Ducos du Hauron for their 1904 Autochrome process. This used a ‘pointillist’ technique of optically mixed coloured dots or fine starch grains. Isler-de Jongh has stated that the lack of a panchromatic emulsion—one sensitive to all wavelengths—prevented Ducos du Hauron from bringing this invention to fruition.⁷⁰ But other historians of photography have pointed to the large scale of investment and the “barrage of patents” the Lumière Brothers developed around the process. This investment included extensive research, into potato-starch grains and agricultural milling-machinery that drew upon traditional French skills in the linen and culinary trades.⁷¹ So interrelated were these processes, that in order to produce this emulsion commercially from 1904, the Lumière Brothers built a

⁶⁸ Fox and Guagnini, *Laboratories, Workshops, and Sites. Concepts and Practices of Research in Industrial Europe, 1800-1914*, 7.

⁶⁹ Lebon, *Gabriel Lippmann, Biographie*, 14.

⁷⁰ Isler-de Jongh, “The Origins of Colour Photography: Scientific, Technical and Artistic Interactions”, 111-119, 115.

⁷¹ Bertrand Lavédrine and Jean-Paul Gandolfo, “The Autochrome Process from Concept to Prototype”, *History of Photography*, 18, no. 2 (1994), 120-128, on 121. The Lumière Brothers took patents out on a number of options including yeast and pulverised enamel, either to protect their wide interests or to

factory close to where potatoes were harvested.⁷² As historian of science Thomas Hughes has pointed out, independent inventors in the late nineteenth century had more difficulty identifying the larger problems than those in the academy, or large-scale industry. Rarely was one patent or invention the ultimate solution, but rather a cluster was required to solve a problem.⁷³

Of American inventors in this period, such as Ives, Hughes describes their ambition as one whereby "...the ability of a self-made inventor to match wits with the presumably ill-gotten gains of financiers was believed wonderfully meritocratic".⁷⁴ By 1900 Frederic Ives had acquired a large portfolio of his own patents and he went on to form a partnership with Henry Hess the American steel magnate in 1911.

Patents by Ives varied widely, from new stereo devices, including a binocular microscope, and forms of stereo-photographs through to a mechanical player-piano. But most of the patents concerned colour photography and its production, although Ives abandoned his earlier artisan custom of selling his own imagery with his inventions. Ives also discarded the more nineteenth-century 'scopic' and scientific trope for his inventions. Titles such as *Photochromscope*, made way for 'modern' Americanised simplifications like *Hi-Cro*. One telling example of Ives' pragmatic approach to invention, was his medal-winning method of reproducing engraved metal diffraction gratings for spectroscopy—such as a plane ruled 'Rowland Grating'.⁷⁵ This was achieved by moulding a metal grating in a gelatine-emulsion to create a 'filmcast'.⁷⁶ Even if wave theory was humbug to Ives, he could see—from a *Lippmann spectrum*—that a gelatine emulsion could physically generate a spectrum but his solution was mechanical: 'casting and stamping' not interference.

The new scale of the photographic industry, driven by advertising and magazine publication, forced Ives to concentrate on marketing technology—in the form of

hide the true agent. They also tested various potato plants; for example, the Agricultural Department of Indochina sent 16 varieties of starch grains.

⁷² Ibid, 120-128, on 122.

⁷³ Thomas P. Hughes, "The Evolution of Large Technological Systems", in *The Social Construction of Technological Systems*, ed. W.E. Bijker, Thomas P. Hughes, and T.J. Pinch (Cambridge, Mass: MIT Press, 1994) 51-82, on 60.

⁷⁴ Ibid, 51-82, on 61.

⁷⁵ Klaus Hentschel, "Photographic Mapping of the Solar Spectrum 1864-1900, Part One", *Journal for the History of Astronomy*, XXX (1999). The American spectroscopist Henry Rowland distributed internationally his ruled gratings, which he manufactured at the John Hopkins University. Rowland's spectrum maps and techniques were to "epitomizes the photographic technique in this area".

⁷⁶ F. Ives, "Diffraction Grating Replica", in *New York Patent Library* (USA: Patent No. 818, 966).

patents—to the larger corporations. Still perceiving the French as the main competitors, in 1910 Ives wrote to his son Herbert of the competition and the market, which was now the *Autochrome* process:⁷⁷

The Lumière Co., notwithstanding the limitations of their process, and the very large percentage of failures, are absolutely unable to keep up with orders for autochrome plates, so wide has the interest grown. They are forming the Kindergarten class in color photography, and this is the psychological moment to prepare for the higher class. It only wants a small percent of the kindergarteners to be sufficiently impressed with the advantage of *Tripak* to develop a big business.

Ives keenly speculated that from this developing amateur market he could enlist the more specialist buyer. However, although there were opportunities in what suddenly seemed a larger sales arena, it became increasingly hard to compete as an independent. Despite Ives issuing patents in 1909 for an improved colour process called *Tri-Pak*, the big corporations would only purchase inventions they perceived to be already proven for production. This placed the responsibility on the inventor to turn the idea from a patent on paper into a product and at the same time, the corporations offered no money to inventors for this development. Here, in the same letter, Ives informs Herbert of the stumbling blocks to selling his new 'colour' process patents:

My best hope is to get the process taken over by Ansco [colour printers] or Eastman, who both have unlimited means and are interestedly watching my progress. The managers of both companies have been here to see me, but they will not talk business until I have a going business to show and prove practicability, and all patents issued. If it was possible for me to borrow in interest only enough money to reach the point where I might capture either Ansco or Eastman.

Ives desires to remain free from modern employment practices associated with big corporations, especially management, and the subsequent restrictions that might be tied to with any compromising funding deal:

Just now I do not need a N.Y. office, or offices or bosses or business management, but just means to provide for manufacturing facilities and materials and labor sufficient to start the business as a demonstration proposition.

For individuals like Ives, who had limited personal capital compared to the borrowing power of asset-rich corporations, inventing for this larger market became financially more risky and speculative:

⁷⁷ Frederic E. Ives to Herbert Ives, August 7, 1910, from the Collection of F. & H. Ives, Manuscript Division of the Library of Congress.

There is money ahead of Tripak, and the only question is how much, it may be a fortune, but that depends partly on how near fool proof I can make it, and it can at least be made a good paying business if I control the expenditures. Nearly my whole house can be turned into a manufactory...

Individual inventors in the early twentieth century were isolated from sources of research funding that were increasingly located in the academy and industry. This situation only changed with the First World War when, according to Hughes, individuals could apply to governments for development funds.⁷⁸

Modernising Lippmann's process in 1908, an American review by Herbert Ives

In 1908, the year Lippmann was to receive his Nobel Prize, Herbert Ives published a timely review of Lippmann's eponymous photograph: 'An Experimental Study of the Lippmann Color Photograph' in the *Astrophysical Journal*. Herbert Ives had undertaken this research for his PhD, at the John Hopkins University, an institution considered at the time to have pioneered the concept of a research university.⁷⁹ That Herbert Ives was a PhD student was no doubt instrumental to the paper having one author, at a time when sole authorship was becoming rarer and constituted just over 10 per cent of articles.⁸⁰

The supervisor of Herbert Ives was Robert Wood, a spectroscopist and authority on physical optics, who also invented a colour photographic technique. Wood shared some of Frederic Ives' scepticism towards French scientific methods. In an article in *Nature* published in 1904, Wood had denounced the French physicist (and former colleague of Lippmann) René Blondlot's observations of Blondlot's so-called N-Rays.⁸¹ Like the Lippmann photograph, this was an example of the disputes, occurring in the late nineteenth century between the demonstration and theory of invisible radiations. Only French experimenters trained by Blondlot could repeat his published experiment of 1903, whereas the Americans, British and Germans had failed.⁸² For both Frederic and Herbert Ives, attempting to recreate the excellence of the interference photographs attributed to Lippmann, or proving the Lippmann technique to be false, were two

⁷⁸ Hughes, "The Evolution of Large Technological Systems".

⁷⁹ J.J. Thomson, Sir, *Recollections and Reflections* (London: G. Bell and Sons, Ltd, 1936), 169.

⁸⁰ Derek J. De Solla Price, *Little Science, Big Science* (New York and London: Columbia University Press, 1963), 87. Citing unpublished research by Badash, L. at Yale University "Data from *Chemical Abstracts* show that in 1900 more than 10 percent of papers have a single author almost the rest were pairs".

⁸¹ W. Robert Wood, *Nature*, 70 (1904), 530. See also Malcolm Ashmore, "Theatre of the Blind", *Social Studies of Science*, 23 (1993), 61-106. F. Sean Johnston, *A History of Light and Colour Measurement: Science in the Shadows* (Bristol and Philadelphia: Institute of Physics Publishing, 2001), 59-60.

⁸² Johnston, *A History of Light and Colour Measurement: Science in the Shadows*, 59.

different outcomes that would have appealed. This research pursuit was well facilitated by the theoretical assistance from Wood and practical help in equipment building from Ives senior. On completing his studies that year Herbert Ives gained a qualification, which was, by 1910, to become the standard credential for an American research scientist seeking corporate employment.⁸³

The paper by Herbert Ives translated Lippmann's original publication into the plainer analytical language of the modern American physicist. The significance of this paper, for the French, is indicated by Herbert Ives winning a medal awarded by the Paris Académie des Sciences. Herbert Ives began his career in the modern spirit of international exchange, an aim reinforced by the new Nobel Prizes. Herbert's findings were to support Lippmann's process as a viable one. Herbert Ives set out to approach the theoretical and practical conditions Lippmann demanded, with the intention of discovering the difficulties posed for others in replicating this process. He first analysed the published results obtained by those few who had worked with Lippmann's process at the time of its original publication:⁸⁴

Good results have been obtained by the process as worked by these and other experimenters, (Wiener, Neuhaus, Valenta, Lehmann) but its difficulties have been found so great as to prevent its wide use. Some discrepancies with the theory have been found, and compromises with the best conditions as indicated by theory have been found necessary in practice.

Herbert, like earlier experimenters, sought the archaeology, the historical record of this physical process by inspecting the structure of the 'laminae' formed within the emulsion under a microscope. He confirmed the complexity of many laminae required to replicate the colour white, and the difficulty in recording it successfully. However, where Lippmann had described the events in terms of those found in *nature*, Herbert Ives modelled the mixing of colour on concepts established within the discipline of physics. Ives now perceived the events within the emulsion as being similar to "...the interference fringes that would occur in a Michelson interferometer".⁸⁵ Within his own paper he reproduces illustrations from Albert A. Michelson's papers to describe these

⁸³ Robert Kohler, "The PhD Machine: Building on the Collegiate Base", in *The Scientific Enterprise in America*, ed. Ronald L. Numbers, *Readings from Isis* (Chicago and London: University of Chicago Press, 1996), 103.

⁸⁴ Herbert E. Ives, "An Experimental Study of the Lippmann Color Photograph", *Astrophysical Journal* XXVIII, Jan-June (1908), 325-352 on 325-326.

⁸⁵ *Ibid.*

events.⁸⁶ Thus he introduced another historical standpoint, one of interferometry, into the review. Later Leith and Upatnieks also identified this application as a model.⁸⁷ With this change of description Herbert Ives retains the concept within the discipline of physics.

Herbert Ives also confirmed the patient labours and care required to produce these photographs:⁸⁸

A larger percentage of failures is to be expected in any process of color photography than with black and white, since the eye is more sensitive to errors of treatment where color occurs. The sensitiveness of the Lippmann process to slight deviations from correct conditions is, however, much greater than the three-color methods, and good results come only from repeated patient trials. When obtained they are extremely dependent on correct viewing conditions, to appear to any advantage.

The less efficient the image is in terms of brightness the stronger the reconstruction light will need to be, in order to see any results, and then this will only be visible at the correct viewing angle:

It is of extreme importance that they be observed by parallel light and shielded from all side light. The best conditions are given by a small opening in a wall facing a brilliant white sky. If the observer stands with his back to the opening and holds the picture at arm's length reflecting the sky it appears at its best.

Herbert Ives confirms the reliance of the viewer on specific viewing conditions; according to his paper he has to rely on sunlight—whereas the Lumière Brothers had developed the *Megascope*. Although this paper analyses the formation of the image, Herbert Ives also discusses the difficulties he experienced in reproducing the material substrate: the glass and emulsion onto which the photograph was recorded. He describes his own attempts to duplicate the material quality of the *Lippmann emulsion* from supplies he sourced from local American stores:

...the gelatine used was Elmer & Amend's 'Gold Label', Nelson's 'No.1', or a department store gelatine recommended as the best for puddings, etc., which was found very hard and free from grease. The emulsion was flowed on pieces of crystal plate glass cut three by three inches.

⁸⁶ A.A. Michelson, "On the Application of Interference Methods to Spectroscopic Measurement", *Phil. Mag.*, 5, no. 31 (1891). A.A. Michelson, "On the Application of Interference Methods to Spectroscopic Measurement", *Phil. Mag.* 5, no. 34 (1893).

⁸⁷ This I identify in the introduction as another possible historical antecedent to the three-dimensional laser hologram.

⁸⁸ Ives, "An Experimental Study of the Lippmann Color Photograph", 325-352 on 345.

Herbert Ives, and Wood his supervisor, might have assumed that the facilities at the John Hopkins University would have been comparable, or possibly superior, to those of Lippmann's laboratory at the Sorbonne University, Paris. Wood and Herbert Ives would have been unaware of the intervention of the Lumière Brothers and their factory resources in producing emulsion-coated plates for Lippmann. Evidence in the form of *Lippmann photographs* taken by Herbert Ives of the university courtyard from a window, now in the collection of George Eastman House, indicate that Herbert Ives failed to achieve any photographs comparable to those now credited to Lippmann, although he did achieve excellent results isolating and recording single colours using various light sources of differing wavelengths (fig.2.6). The existence of the poorer pictorial results by Ives, are evidence of the excellent ability of the Lumière produced *Lippmann emulsion* to record all the colours evenly in one exposure, and the peculiar success of the Lippmann-Lumière collaboration. Now in 1908, as *Lippmann photography* was brought to the attention of the scientific community again, through Lippmann receiving the Nobel Prize for Physics, Ives' paper exposed a new audience of American astrophysicists to this medium. Yet simultaneously his publication inadvertently concealed the Lippmann-Lumière collaboration, through the implication of Ives' complete command and scrutiny of the process. This overlooked aspect of Lippmann's success—the collaboration with the Lumière Brothers—was both hidden, and carried forward again, with the 'modernising' review by Herbert Ives through to the Lippmann-Gabor history.

A new use and discipline for Lippmann photography

In his pursuit of *Lippmann photography*, Ives was to apply the process to the emerging 'sub-discipline' of photometry, a vocational field pioneered by the John Hopkins University to improve electrical tuition.⁸⁹ Ives published a journal paper for the newly formed Optical Society of America, a group that initially started at Eastman Kodak in 1916, and one that would include photometry in its journal.⁹⁰ This is one example of a discipline that had grown, from what historian and scientist Derek De Solla Price described, in 1963, as the formation of "invisible colleges".⁹¹ These were newly formed collectives of practitioners, who were restricted to a group able to sustain a close

⁸⁹ Johnston, *A History of Light and Colour Measurement: Science in the Shadows*, 81. For a discussion of photometry as a peripheral science see also the Chapter: "An Undisciplined Science", 237-254.

⁹⁰ *Ibid*, 87-88.

⁹¹ De Solla Price, *Little Science, Big Science*, 83.

correspondence. The larger the original scientific discipline, the more likely sub-groups were to appear and these, De Solla Price states, can award their own “status pay-offs”.⁹² Early on in his career, Herbert Ives found a supportive arena and status within such a group.

This paper by Ives suggested that recording isolated colours or wavelengths with the Lippmann process was more applicable to the interests of modern photometric research science than producing representational photographs. Ives speculated on recording monochromatic light sources to use as filters, which could then be applied tools within spectral analysis, employing a *Lippmann photograph* in stella spectroscopy, for example, to isolate a wave-band rather than disperse out a larger spectrum (in the manner of a *Lippmann Solar Spectrum*). From what might have been considered a failure—the inability to produce full-colour pictorial images—Ives in producing isolated recordings of differing wavelengths, retrieved new possibilities from his review.⁹³ And Ives perhaps came closer to the process, first contemplated by the Soviet scientist Yuri Denisyuk, as a means of photographic recording than did Dennis Gabor. In principle, if Ives had introduced a ‘subject’, a speck of dust or a two-dimensional slide, into a monochromatic recording it might have appeared (under a microscope) three-dimensional—Gabor had only used a monochromatic source for his experiments.

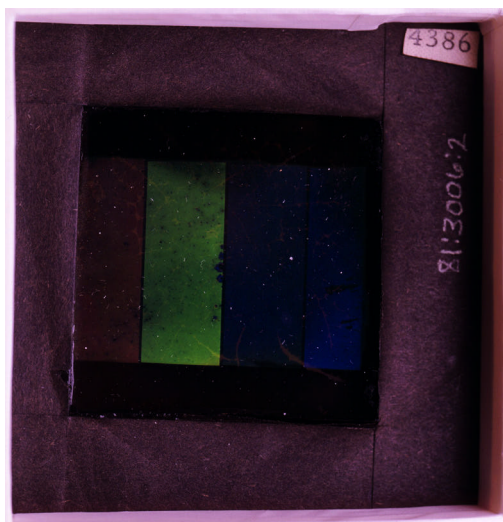


Fig.2.6. As a PhD student, in 1906 Herbert Ives succeeded in recording isolated colour or wavelength with the Lippmann process.

Reproduced with permission of George Eastman House Museum, Rochester, New York.

⁹² Ibid, 85.

⁹³ H. Ives, “Lippmann Color Photographs as Sources of Monochromatic Light in Photometry and Optical Pyrometry”, *Journal of the Optical Society of America* 1, March-May, 1917.

Lippmann's Nobel Prize and his proposal for a three-dimensional *virtual image*

The ability to produce well-received and spectacular full-colour imagery was important to the Nobel committee. This was evident when the President of the Swedish Academy of Science compared Lippmann's photograph to the lesser commercial product, the Lumières' *Autochrome*, on presenting Lippmann with the Nobel Prize. Professor K B Hasselberg applauded Lippmann's invention for its scientific and 'virtual' solution; colours that were not located directly on the photographic plate. "What are called virtual colours, are unalterable in composition and bright for as long as the photographic plate is intact". He then distinguished this scientific solution from mere mechanical and synthetic effects:⁹⁴

Thus Lippmann's photographs show up favourably in comparison with later attempts at solving this problem of colour reproduction—Lumière's photographs—so-called three-colour photographs, obtained by using pigment colours, a delightful discovery, which owing to the simplicity of the operational method has won a large measure of popularity.

Hasselberg celebrated Lippmann's invention as one that addressed the needs of science. In 1908 it appeared that such solutions should be distinguishable from those intended for commerce. In the twentieth-century the Nobel Prize was to become "the apogee of the reward system" a means to identify and elevate, in the public eye, the aims of professional science.⁹⁵ These aims and solutions were perceived as differing from industrial concerns and linked to individual, rather than corporate, authorship. Yet, in his Nobel Lecture, Lippmann claimed his photography was no more complex than any other popular product, and that he employed his process as casually as any bourgeois tourist: "Most of these pictures, taken while travelling, were developed on the mantelpiece of a hotel room, which proves that the method is easy enough to carry out". He then refers to the few other professional users, whose endeavours contributed towards obtaining a pictorial image, and whose images he then projects for the audience:⁹⁶

...Valenta in Vienna and the Lumières in Lyons found a means of coating the plates in grainless gelatine.... Dr Neuhaus in Berlin carried isochromatism to perfection. Thanks to the work of Messrs. Miethe, Krone, H. Lehmann, and others who I will not detain

⁹⁴ Professor Hasselberg K.B, President of the Royal Swedish Academy of Science, *The Nobel Prize in Physics 1908*, available online: www.nobel.se/physics/laureates/1908/press.html.

⁹⁵ J.M.B. Morrell, "Professionalisation", in *Companion to the History of Modern Science*, ed. R.C. Olby, et al. (London & New York: Routledge, 1996), 980-989, on 984.

⁹⁶ Gabriel Lippmann, *Colour Photography, Nobel Lecture, 14 December 1908*, 187. Available online: www.nobel.se/physics/laureates/1908/press.html

you by mentioning, the technique of colour photography has been perfected. Allow me to show you the projections of results obtained.

These resulting images are listed as: "...vases with flowers, views of Fontainebleau, Lake Annecy, Biarritz, Zermatt, Venice, and child portrait from life". Displaying photographs taken by a larger group would have enabled Lippmann to present the process as one applicable to the wider needs of a scientific community. This was appropriate to a colour photograph presented as a Nobel Prize winning invention. As historian of science Elisabeth Crawford has stated, where a technology was considered, the 'utility' of the invention became a selection criterion for the Swedish panel judges: the prize had to satisfy the condition as being 'for the benefit of mankind'.⁹⁷ Some of these photographs used by Lippmann for this Nobel Lecture—and described above—may now be among the 150 images given to the Musée de l'Elysée by his heirs and reproduced in this chapter.

However, in 1910 it was a German company, the Carl Zeiss Optical Works, which put a camera for *Lippmann photography* onto the market. This camera came packaged with instructions by the German photochemist H. Lehman, and plates manufactured to his formula by R. Jahr of Dresden.⁹⁸ The Zeiss camera represented an embarrassment to the French. One year later, Lippmann's biographer remarked pointedly on this commercial outcome as signifying apathy in France.⁹⁹

Unfortunately there is no interest from French industry in the interference photography. It is not the same in Germany: the company Carl Zeiss, of Zena, is active; the company of R. Jahr in Dresden is producing plates. It is not the first time that we find a French invention returned to us from abroad perfected so as to render it practical.

This was seen as one example of how well the Germans understood, what one French critic on the state of French industry described as, "the distance and difficulties that lay between the initial conception of a process or product and its full-blown exploration".¹⁰⁰

⁹⁷ Elisabeth Crawford, *The Beginnings of the Nobel Institution: The Science Prizes* (Cambridge, NY, Paris: Cambridge University Press & Editions de la Maison des Sciences de l'Homme, 1984), 164.

⁹⁸ Eder, *History of Photography*, 671. "With Lehman the technique of Lippmann's photochromy reached its highest point". The other practitioners named by Lippmann in his Nobel Prize Lecture are described here: In 1893, Herman Krone demonstrated that no mercury back was needed, the reflection from the glass photographic plate itself could be used. On the German perfection of emulsions, Dr R Neuhauss of Berlin in 1897, studied emulsions making microphotographs of cross sections at magnification of 2000 that showed lamellae of structure, he also demonstrated that "grainless" emulsions in fact contain silver grains of 0.005mm diameter.

⁹⁹ Lebon, *Gabriel Lippmann, Biographie*, 14.

¹⁰⁰ Robert Fox and Anna Guagnini, "Laboratories, Workshops and Sites: Concepts and Practices of Research in Industrial Europe, 1800-1914", *Historical Studies in the Physical and Biological Sciences*, 29, no. 2 (1999), 191-294, on 260. Citing Victor Cambon, *L'Allemagne au Travail*, Paris

The innovation and abundance of German products over French goods was perceived by the French as a possible result of a prevailing emphasis in French science education, on the *esprit théorique* rather than the application of theory to industrial techniques.¹⁰¹ The Lumière Brothers had abandoned *Lippmann photography* and no other French company had commercially taken up the process. However, the Nobel Prize demonstrated the superiority of French scientific theory and the review published that year by Herbert Ives, aided its further dissemination.

That same year, Lippmann published *Épreuves réversibles photographies intégrales*, a paper proposing a new form of three-dimensional photographic image. Again, this solution was one to distinguish itself from an earlier popular product, which between 1891 and 1908 was the stereoscope. The acme of its form was produced by the Richard Brothers of France: the *Richard Taxiphote* a large 'deluxe' mahogany viewing box, with a bell that rang when the viewer reached the end of a cassette of stereo-*Autochromes*. The eventual obsolescence of this device has been speculated upon, according to the historian Jonathan Crary, some say "the very close association of the stereoscope with pornography was in part responsible for its social demise as a mode of visual consumption".¹⁰² In the twentieth century there appeared to be a need for a superior form of three-dimensional image, one that could overcome for the viewer both the obvious physical restrictions of the earlier device and its popular associations. In 1931, Herbert Ives, as a research scientist at Bell Laboratories, wrote of Lippmann's invention "...which [was] never reduced to practical form", and stated that "...Lippmann's idea has been generally conceded to constitute an ideal solution to the problem of securing stereoscopic vision without a stereoscope".¹⁰³

Lippmann was poetic and grandiose in this paper, in contrast to his previous elegant brevity. Unlike the *Lippmann spectrum* he exhibited in 1891, Lippmann had no physical example or image to display; therefore Lippmann's claims for this new

1909, 42-43. Cambon attempts to alert the French to their complacency and lack of interest in practical development.

¹⁰¹ Ibid, 191-294, on 266-263. Robert Fox and Ann Guagnini, describe the debate within the French universities at this time, as essentially an argument between theory and practical skills, whereby one group hoped that a new educational philosophy, the "*Science industrielle* would avoid the artificial distinction between *science pure* and *science appliquée*". The term "*esprit théorique*" is cited from Léon Guillet, *L'enseignement technique supérieur à l'après-guerre*, Paris, 1899.

¹⁰² Jonathan Crary, *Techniques of the Observer*, 2nd ed. (Cambridge, Mass., London, England: MIT Press, 1990), 127.

¹⁰³ Herbert Ives, "Optical Properties of a Lippmann Lenticulated Sheet", *Journal of Optical Society of America*, 21, March (1931), 171-176, on 171.

invention appear even more literary. First, he asserted that any photograph failed the viewer:¹⁰⁴

La plus parfaite des épreuves photographiques actuelles ne montre que l'un des aspects de la réalité; elle se réduit à une image unique fixée dans une plan, comme le serait un dessin ou une peinture tracée à la main.

Lippmann prophesised more for this medium than what was already provided by the traditional fine arts or artisan invention; this was an objective full-colour three-dimensionality. In his choice of description, Lippmann evokes that historical memory of the ideal image—so familiar to both the artisan and professional photographer—in Tiphaigne de la Roche's *Giphantie*, 1761. Lippmann wrote:

Est-il possible de constituer une épreuve photographique de telle façon qu'elle nous représente le monde extérieur s'encadrant, en apparence, entre les bords de l'épreuve, comme si ceux d'une fenêtre ouverte sur la réalité?

Lippmann's hypothetical solution was to be an illusory window, for which he provided some theoretical guidance towards its eventual manufacture. For fabrication he suggested a structure formed in a transparent medium—celluloid—which when heated could be machine embossed into a raised pattern producing: “des petites lentilles”. On this structure would be a coating—of a collodion-based photographic-emulsion—on the back surface of the ‘lens’ facing the incoming light. In this paper Lippmann provided a minimal graphic drawing (fig.2.7), a plan elevation of a series of ridges that are to form the lenses. Each small lens will, “...constitue une petit chambre noir sphérique, pareille à un œil: la lentille en est la cornée transparente; la couche sensible remplace la rétine”. This eye-like optical system was to form a simulacrum of nature's cellular visual systems with a multitude of these lenses, forming in total, “... une œil simple, leur ensemble rappelle l'œil composé des Insectes”.¹⁰⁵ Again, Lippmann's description is typical of the nineteenth-century sciences; it alludes to solutions found in nature and perceived to be modelled on teleological concepts of form.¹⁰⁶

¹⁰⁴ G. Lippmann, “Épreuves Réversibles. Photographies Intégrales”, *Comptes. rendus*. 146 (1908).

¹⁰⁵ *Ibid*, on 447.

¹⁰⁶ M. Norton Wise, “On the Relation of Physical Science to History in Late Nineteenth-Century Germany”, in *Functions and Uses of Disciplinary Histories*, ed. Loren Graham, Wolf Lepenies, and Peter Weingart, *Sociology of the Sciences a Yearbook* (Dordrecht Boston Lancaster: D. Reidel Publishing Company, 1983), 3-34, on 10. Wise discusses Helmholtz's 1853 research on Goethe, and the belief that, nature reveals to us by direct intuition the several steps by which a conception is developed (Lippmann had studied from 1874-5 with Helmholtz).



Fig.2.7. Drawing by Gabriel Lippmann of a section of the screen.

In principle, this system provided both the camera—with an embossed convex lens at the front—and the recording medium; the photographic emulsion coating the ‘retina’, or the focal plane, to the rear. One need only take the system (shielded at first from the light) into the sun, stand it on a tripod in front of the desired subjects, and finally remove any cover to expose it. Then return the object (covered) to the darkroom following exposure, develop, and fix the entire structure: “Le résultat de ces opérations est une série des petits images microscopiques fixées chacune sur la rétine d’une des cellules”.

Theoretically this would be a perfect structure for supporting a *Lippmann emulsion*. The minuscule ‘cameras’ would record a microscopic image on the film that would have been faster in exposure time than an attempt to obtain one large *Lippmann photograph*.¹⁰⁷ Lippmann explained that in looking at the photographic structure, after chemical development, it would show no indication of the resulting image—like the hologram—it would be just an indistinguishable blur “...une couche grise uniforme”. But when the eye is in the correct location in front of the structure at “la place du système des petites images” and the object illuminated with bright diffuse lighting then, Lippmann concluded that: “...une seule image résultante projetée dans l’espace, en vraie grandeur”.¹⁰⁸

Lippmann theorised that the ‘correct’ location of the viewer’s eye was at the focal point of the light rays as they came through the structure, here: “Leur système constitue donc un objet virtuel à trois dimensions”. This visual sense of seeing objects in three-dimensions was to be engineered by virtue of optical geometry and stereoscopy, which Lippmann illustrated (fig.2.8). Each cell-like lens projects into the viewer’s eyes (at the

¹⁰⁷ Lippmann, almost as an aside at the end of his paper, wrote that commercially manufactured German glass by Schott of Jena, had a refractive index that exceeded “1,9” and ideally he required a material with a refractive index of “n=2”. Why would he need such a high refractive index? That was not stated in the 1908 paper, but it implies that Lippmann conceived of this invention for his interference *Lippmann photography*. A material with a high refractive index is of importance in considering the physical movement of the light waves as they travel through the material of the screen. A photographer, as opposed to a physicist, might be concerned only with the quantity of light rather than its behaviour.

¹⁰⁸ Lippmann, “Épreuves Réversibles. Photographies Intégrales”, 448.

focal point in the position marked 0) a different viewpoint (along the lines A 'B') onto the scene. By moving their head, the viewer will 'see' through many lenses, and pairs of stereo-images, onto one scene. Lippmann predicted one problem but also attempted to theoretically resolve it. The difficulty was that this *lensed* image might be inverted or inside out, and upside down, so that the viewer's eyes would be *in* a *virtual* image, rather than looking *at* it. To the viewer the image might appear as kaleidoscopic nonsense.

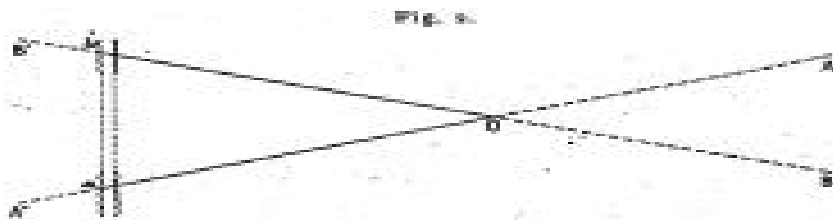


Fig.2.8. Drawing by Gabriel Lippmann of the proposed optics.

In principle, there was no limit to the number of lenses in a structure. The larger the structure, the greater the angle of view the window could provide onto a scene, the more of the panorama it will record. The full 'virtual' effect of reality could be obtained.¹⁰⁹

Avec une pellicule bombée comme le serait une portion de sphère ou d'ellipsoïde, on embrasserait le ciel et la terre en même temps que tout l'horizon et la ressemblance du système avec certains yeux d'insectes deviendrait plus complète.

Embossed in Celluloid—one can speculate—that the object might have resembled something more akin to a huge *Tiffany Lamp*, that popular award-winning American import to the Parisian department stores; they too took their designs from nature (fig.2.9). *Tiffany Lamps* were frequently based on microscope images of cellular structures; insect wings; dragonflies or leaves; and were hand assembled in leaded glass according to designs by Louis Comfort Tiffany.



Fig.2.9. A Tiffany Lamp

¹⁰⁹ Ibid, 450.

Under Lippmann's cellular structure, the hypothetical viewer would turn to view, without any visual aid, a complete 360-degree-vista in stunning three-dimensional, *virtual* interference colour; a brilliant stained-glass view of reality, where the eye followed "le tour de l'horizon". Lippmann's proposed 'lenticular' virtual reality was a piece of optical naturalism, an *art nouveau-like* photographic technology. Such *art nouveau* objects had an almost exaggerated comic elegance, as manufactured items sought to ape nature with their designs, functional objects appeared plant or animal-like. Of the movement *art nouveau* and its mannerisms, historian Debora Silverman writes that in France, it sought to "aristocratise the crafts", to raise the mundane functional object up to the higher arts. *Art nouveau* contrasted with the 'puritan' craft movements, such as the movement formed around William Morris, in nineteenth-century England.¹¹⁰ Morris sought to democratise art, to redeem the artisan's livelihood from its erosion by the machine by re-establishing the craft-skills of the people. French fin-de-siècle industry, art, and science, could all aspire to employ the aesthetics one might intuit directly from nature. In this period, according to historian of science Wiebe Bijker, industrial design did not exist, it only emerged as a separate discipline and profession from the arts after 1930; and until then only the most elite items would be 'designed'.¹¹¹

With this artful invention, Lippmann sought perhaps to civilise photography, to raise the aspirations of the medium above commerce, which merely served to replicate images as cheaply as possible for the mass market. A technology intended for the professional scientist should distinguish itself as such, from those in the mass market. Lippmann's technology would have been limited to one individual's private experience; only one person at any time could be accommodated in the correct optical position, and follow that mathematical construct—the horizon. This was the antithesis of the mass appeal of the Lumière Brothers' *Cinematograph*, which was experienced by 25,000 people in one sitting at the Paris Exhibition of 1900. Where would this image have transported its viewer? A very early and small *Lippmann photograph*, credited to Lippmann, is of *Versailles* (fig.2.10), recorded in overly prismatic colours. With the new *virtual* technology, a combination of interference-formed colour and stereoscopic geometry new images of the past could be created. The object itself alluded in its

¹¹⁰ Debora L. Silverman, *Art Nouveau in Fin-De-Siècle France: Politics, Psychology, and Style*, eds Victoria E. Bonnell and Lynn Hunt, *Studies on the History of Society and Culture* (Berkeley, Los Angeles, London: University of California Press, 1989), 12.

description to the memory of an ideal photographic medium and like memory itself it would selectively record and recall time; the future was already embedded in history. Lippmann proposes the *ideal* photographic solution free from market constraints and the restrictions of mechanical production. As Thomas Hughes has suggested, perhaps the academic imagination ranged more freely, unlike the mind of the inventor, it was not tied to industry but benefited from its acquaintance with technical literature.¹¹²



Fig.2.10. Lippmann photograph attributed to Gabriel Lippmann. Size approximately 30mm x 50mm. Reproduced with the permission of George Eastman House Museum, Rochester, New York.

Lippmann was to pursue small demonstrations of the concept, writing two later papers, the last in 1911, where he assembled a flat ‘screen’ of 12 convex lenses to expose and project an image in three-dimensions.¹¹³ Herbert Ives, who reviewed Lippmann’s concept through the modern application of ray tracing at Bell Laboratories, was to concede that Lippmann’s scheme would work. But for Ives and others who endeavoured to realise the elusive three-dimensional world, the problems of ‘geometric correction’ examined by Lippmann in his 1908 paper were to persist. Ives commented on this problem in modern terminology: “The occurrence of pseudoscopic relief [a ‘false’ inverted image], where stereoscopic relief [the ‘true’ real image] is sought is the *bête noir* of relief picture schemes...”¹¹⁴ Here was one persistent reality of the three-dimensional ideal that Lippmann had projected, this apparently intrusive optical phenomenon into the mathematical realm. The inverted false image was to plague attempts at three-dimensional image making. To Ives, with his ray-tracing methodology, it seemed not to matter whether you turned the hypothetical image through 180 degrees,

¹¹¹ Wiebe E. Bijker, *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change* (Cambridge, Mass., London, England: MIT Press, 1995), 179.

¹¹² Hughes, “The Evolution of Large Technological Systems”, 51-82, on 60.

¹¹³ G. Lippmann, *Societe Francais de Physique, Procès Verbaux* (1911), 69.

Lippmann's first suggestion to rescue the image from its nonsensical state, or viewed it in a mirror. It will not correct the geometry and therefore it will not be truly stereoscopic. However, it was well known to artisan practitioners of illusionistic tricks that pseudoscopic images could make *visual* sense. Hollowed out (inverted/negative) casts of plaster busts, or face masks seen from 'inside', for example could, under certain light, be perceived by the viewer as being solid, if only momentarily. But Lippmann's second suggestion, of making a copy, would be credible. Ives wrote that: "For a pseudoscopic copy of a pseudoscopic picture, becomes, by virtue of a double reversal, a picture in correct relief".¹¹⁵ Theoretical problems could be resolved descriptively. So paradoxically, either way—nonsensically pseudoscopic or correctly, geometrically stereoscopic—a viewer might have perceived that they did indeed witness the depicted illusory object.

Lippmann's project, as described, was dependent on classical geometrical optics to make *visual sense* to the viewer, but in its photographic recording like the hologram it relied on interference. The two notional devices at work here, geometry and wave theory, are often perceived to be opposing paradigms, the latter pertaining, as Jonathan Crary has suggested, to a modernistic visualisation, and the former to Renaissance perspective. Lippmann's early twentieth-century vision theoretically combined both, as would synthetic radar holography in the 1960s. These examples contradict the simple 'rupture', between geometry and wave-theory, which Crary believes exist.¹¹⁶

Lippmann was aiming for geometrically correct stereoscopic vision. If that could be achieved, then for Lippmann the image would, in principle, be a mathematical synthesis of reality. Unlike Renaissance perspective painting, which as the iconographer Erwin Panofsky has pointed out: "...transforms psychophysiological space into mathematical space", this *virtual* image would be rendered mathematically as apparent 'psychophysiological' space.¹¹⁷ This transformation is inherent in twenty-first-century digital virtual-reality and Lippmann proposes a similar synthesis. However, Lippmann's paper of 1908 lacks the insights of the emerging discipline of perception studies.

Lippmann was replicating an image by physically engineering a point-to-point analogue translation from the real to the virtual. Lippmann tested his theory with his

¹¹⁴ Ives, "Optical Properties of a Lippmann Lenticulated Sheet", 171-176, on 171-172.

¹¹⁵ Ibid, 176.

¹¹⁶ Crary, *Techniques of the Observer*, 1-4.

own empirical subjective observations of crude models in the laboratory. Herbert Ives was to simulate Lippmann's experiments more remotely, through mathematical ray-tracing, upon which Herbert Ives then must speculate, in order to ascertain for himself the subjective viewing experience. Ives tells us that Lippmann's lenticular screen could attain stereoscopic perfection but that the viewer would have to conform to the geometry:¹¹⁸

If we attempt to locate the image we observe that the two eyes must be *diverged* to pick up the corresponding images, that is, the object, if it can be considered as located in space at all, is behind the head! A second peculiarity obtrudes itself upon our attention. As the eye is moved to the right the projected rays show that the whole image moves in the same direction. Its motion is, in fact, as though the object were the fulcrum, the eyes the force, and the image the weight, of a lever of the third class'.

If the viewer is to move in order to experience the image as three-dimensional, then the image may also be perceived to be in locomotion, suggested Ives. Such movement might manifest a multitude of pseudoscopic viewpoints, or eclipsing stereoscopic views in apparently oscillating spectral colours. Paradoxically, perhaps, it was not materials or theories that were to consume much of three-dimensional imaging-research in the first half of the twentieth century. Rather, it was what Herbert Ives describes as controlling the "behaviour" of the image, attempting to produce for the viewer (as consumer) understandable constructs of visual perception: a depicted scene that could be visually interpreted as rapidly as the 'real' world.

Conclusion

Description, both visual and literary, influenced the reception of nineteenth-century colour photography and was inherent to the success of Lippmann's Nobel Prize winning invention. The nineteenth-century photochemist and historian of photography Eder, documented how such description endured within the historical memory of the photographic community. Social divisions between elite professional and artisan inventors were also applied to sites of publication. However, Lippmann through his collaboration with the Lumière Brothers, could widen the social appeal of his invention. The presentation of pictorial imagery was crucial to the invention's success, as was the presence of the Lumière Brothers to influence the studio-photographer. This combination suggested the invention could be a viable product.

¹¹⁷ Erwin Panofsky, *Perspective as Symbolic Form*, (Cambridge, MA.: MIT Press, 1997), 31.

¹¹⁸ Ives, "Optical Properties of a Lippmann Lenticulated Sheet", 174.

With the reviews by Herbert Ives of both Lippmann's 1891 and 1908 papers, we can identify how Ives changed the descriptive language of Lippmann's French nineteenth-century natural idealism and carried it into modern realm of the American twentieth-century physicist. Ives in his review of the *Lippmann photograph* both diverted and expanded the invention through experimentation and language. He also selected the interferometer, an invention of the American Nobel Laureate Albert Michelson, to model his interpretation of Lippmann's process onto. In doing so Ives participated, and published, in the new discipline of photometry. In his 1908 review of Lippmann's three-dimensional invention, Ives named this concept a 'lenticular screen' adapting it from Lippmann's 'les petites lentilles'. This paper carried the concept with new terminology into mid-twentieth-century usage. A reference to a lenticular structure can be tracked back through journal listings to H. Ives and Lippmann.¹¹⁹

This academic development of terminology contrasts with the commercial outcome. Eder as a historical witness, writing in 1932, documented the commercial fate of Lippmann's lenticular structure within the film industry. According to Eder, Lippmann's 'integral' or "insect eye arrangement" was pursued in a form re-named as a 'wart lens' by Albert Keller-Dorian to produce a colour 'movie' film in 1923. With 22 'wart lenses' to a square millimetre, the small lenses combined with three differing filters and enabled the recording of three colours on one panchromatic film: the K.D.B. process. However, following Keller-Dorian's death in 1924 the Eastman Kodak Company bought the rights to the process in 1928, and it was renamed 'kodacolor' and sold as film for amateur motion pictures.¹²⁰ Although the technology contained a physical residue of the original design, the labelling changed frequently with additional modifications and resale. As a material artefact, Lippmann's photographic emulsion continued in production into the mid 1960s but with a Kodak label. However, an academic paper (published by Denisjuk in 1962) enabled it to be re-identified.

Scientific descriptions, and terms, endure through the repeated use of citations taken from open academic journals by researchers. Whereas, descriptions used within a differing context—artisan, commerce or industry—are subject to being relabelled to appear as if 'new'. In commerce unappealing names are perhaps more prone to rapid

¹¹⁹ Andrew Warwick, *Masters of Theory: Cambridge and the Rise of Theoretical Physics*, (Chicago and London: The University of Chicago Press), 402. Warwick examines the "new meanings" and readings taken on by Cambridge scholars of Einstein's work.

¹²⁰ Eder, *History of Photography*, 672.

change. For academic science, distinct naming—that contributes to a discipline's developing terminology—combined with sole authorship on a journal paper permits easy historical retrieval and continued usage. Thus a description may endure within a discipline even when the invention or theory was never brought to practice.

The onset of the First World War was to end the optimism and market for Fin de Siècle invention. The Zeiss 'Lippmann' camera did not reappear as a product after war. The priorities of war placed an emphasis on small lightweight cameras and faster film. Colour was not a priority, but research into three-dimensional imagery was to remain a goal for both the military and industry.

CHAPTER THREE

Dennis Gabor's Hologram of 1949

The 'Lippmann-to-Gabor' narrative suggests a historical link between Lippmann's 1891 interference photograph and Gabor's 'hologram' of 1949. This chapter will review this comparison. First, I look at the unique social circumstances that permitted Gabor to publish his theory in the public domain. Then, I discuss the original discipline Gabor sought to address, and I look at early reviews of his proposal by other practitioners. I also look at Gabor's reaction to the new laser—in the mid 1960s—and its implication for his original concept. In the second half of this chapter, I review Gabor's paper, and his use of imagery, to locate the 'hologram' and the antecedents to this invention that Gabor chose to cite. Gabor worked in industry, the academy, and commerce, filing 172 patents in a discipline described as electron engineering. His life and inventions, from 1900 to 1979, span the twentieth century. Inventing against a background of two world wars, and the distrust encountered during the Cold War, his work reveals the period's social, technological, and consumer aspirations.

Gabor was born in 1900, into a bourgeois Jewish family in Budapest, Hungary, a city that by 1900 was one quarter Jewish. Hungary was then dominated by the ruling Magyar Christians, who were essentially aristocratic farmers, and feudal landlords. The Magyars were content for Jews to occupy city bureaucratic positions. The "policy of Magyar supremacy was social, not racial: it aimed not at the extinction or expulsion of non-Magyars, but at their assimilation".¹ Gabor's father was head of one of the largest industrial concerns, the Hungarian state coalmines, and his mother was an actress. Following military service in the First World War for the Austro-Hungarian Army, both Gabor and his brother André studied in Berlin—a privileged opportunity; Hungary was a country with only 7 per cent of its population literate by 1937.² Berlin was then a cosmopolitan city for the developing modernist cultural movements, and host to many foreign students and artists. Germany in the late nineteenth century and into the early

¹ John W. Mason, *The Dissolution of the Austro-Hungarian Empire 1867-1918*, 2nd ed., *Seminar Studies in History* (London and New York: Addison Wesley Longman Limited, 1997), 17.

² Ben Fowkes, *Eastern Europe 1945-1969: From Stalinism to Stagnation*, *Seminar Studies* (Harlow, England: Longman), 88.

twentieth century was considered to have the most progressive education system, awarding research degrees in the applied sciences.³ This reputation also extended to art and architecture. Germany attracted foreign fee-paying students including what was then considered a “migrant tide” from America.⁴

Gabor started his PhD in 1924, at the Technische Hochschule at Charlottenburg, a dedicated vocational institution that had opened in 1884, with outstanding facilities for the emerging German profession of *Elektrotechnik*.⁵ Historians of science Robert Fox and Anna Guagnini have described the educational trend in late nineteenth-century Germany for graduates in physics to take a practical ‘engineering approach’ motivated by public interest in electricity.⁶ This generated a new curriculum. *Elektrotechnik* was a course on the technologies of electrical and optical engineering aiming to supply German industry with ‘scientifically minded engineers’ with both the theoretical and technical-skills applicable to instrument design and manufacture. By contrast, a similar technical vocational school, the Institute of Applied Optics Rochester, New York, only opened in 1930.⁷

Technology and modernity

Since the 1880s, in an attempt to unite technology and the pure sciences, German mathematical education had pursued an applied ‘mathematical philosophy’ taught through a visual appreciation of the geometric form. One pioneer of the visual, the mathematician Felix Klein, desired to integrate the old universities with the newer technical colleges, who had reacted against the dominance of pure mathematics in the curriculum in the 1890s. “[Klein] hoped to reverse the trend of one-sidedly formal,

³ J.J. Thomson, Sir, *Recollections and Reflections* (London: G. Bell and Sons, Ltd, 1936), 136-137. Thomson recalls that the Cavendish Laboratory only admitted “Research Students” for a PhD from 1895, this was done because the MA did not allow graduates to call themselves Doctor and Cambridge students were seen to be at a disadvantage in comparison with those that studied in Germany

⁴ Robert Kohler, “The PhD Machine: Building on the Collegiate Base”, in *The Scientific Enterprise in America*, ed. Ronald L. Numbers, *Readings from Isis* (Chicago and London: University of Chicago Press, 1996), 98-122, 112. American universities hoped to stem the migrant tide to Germany. American critics suggested, “German autocratic professors did not develop the ‘executive’ qualities in their students”...these were qualities of “independence and entrepreneurial spirit” Kohler citing critic: Samuel Sheldon, “Why Our Science Students Go Abroad”, *Atlantic Monthly*, no. 62 (1889).

⁵ Robert Fox and Anna Guagnini, “Laboratories, Workshops and Sites: Concepts and Practices of Research in Industrial Europe, 1800-1914”, *Historical Studies in the Physical and Biological Sciences*, 29, no. 2 (1999), 191-294, on 217.

⁶ *Ibid*, 91-294, on 200-201.

⁷ T.R. Wilkins, “The Institute of Applied Optics of the University of Rochester”, *Journal of Optical Society of America*, 21, June (1931), 369-387 on 369. The institute was founded with funds by Bausch and Lomb Optical Co and Eastman Kodak Co, two local companies who also provided equipment and teaching staff.

abstract approaches to mathematics instruction by promoting practical instruction through the development of [visual] spatial intuition".⁸ Klein advocated aesthetic appreciation and applied mathematics through model building, to explore, "...the furthest frontiers of research in the area of algebraic surfaces",⁹ and he sought to motivate others with the slogan, which became "the famous notion in mathematics of *functional reasoning*".¹⁰

Gabor described his own personal enthusiasm towards science and technology as one essentially formed by his coming from an agricultural Eastern European society:¹¹

I came from Hungary and was born and brought up at a time when the young middle class of that country fell in passionate love with Western thought. 'Kultur', technical civilisation and political progress were worshipped with equal indiscriminating fervor, quite unimaginable for those who were born in the old countries in the West, with hundreds of years of creative tradition behind them.

In addition, he described a youth shaped by a Jewish emphasis on learning and manhood,¹² and his father's vision of the inventor as a social hero:

...my father instilled into me the worship of inventors, by talking of Edison and reading Jules Verne with me and my brother, ...he hoped fervently that I would become an engineer, which for him was synonymous with inventor and scientist.

This vision of a progressive modernity was a condition of the emerging *Constructivist* art movement: a new vision of the future that embraced technology and the machine as the determinant of a new democratic social order. Amongst the protagonists of this movement, who were in Berlin at the same time as Gabor, were other Hungarians of his generation: László Moholy-Nagy and Gyorgy Kepes. Both joined the faculty of the Bauhaus school in Weimar, led by German architect Walter Gropius, a celebrated institution that developed a *techno-aesthetic* that was seminal to the emerging twentieth-century discipline of 'industrial design' and the new *expressive* fine-arts: film and photography. These avant-garde media, particularly design, were pursued under the

⁸ Gert Schubring, "Pure and Applied Mathematics in Divergent Institutional Settings in Germany: The Role and Impact of Felix Klein" (paper presented at The History of Modern Mathematics, Vassar College, Poughkeepsie, New York, 1989), 184.

⁹ Gerd Fischer, *Mathematical Models from the Collections of Universities and Museums*, ed. Gerd Fischer (Braunschweig/Wiesbaden: Friedr. Vieweg & Sohn, 1986), v.

¹⁰ Schubring, "Pure and Applied Mathematics in Divergent Institutional Settings in Germany: The Role and Impact of Felix Klein", 188.

¹¹ Dennis Gabor, "Notes for a Profile in the New Scientist 15 July 1961", in *Dennis Gabor Papers* (Imperial College Archives).

¹² David G. Gilmore, *Manhood in the Making* (New Haven and London: Yale University Press, 1990), 125-127. Gilmore stresses the masculine Jewish tradition of the study and repetition of texts.

famous Bauhaus *form follows function* slogan towards a minimal and clinical appearance that rejected nineteenth-century decoration.

This rational and objective approach of '*functionalism*' towards a new visual culture was pervasive and it looked to science for a new visual model. Moholy-Nagy wrote of such scientific imagery:¹³

The X-ray pictures ...are among the most outstanding examples on the static plane. They give a transparent view of an opaque solid, the outside and the inside of the structure. The passion for transparencies is one of the most spectacular features of our time. We might say with pardonable enthusiasm, that structure becomes transparency and transparency manifest structure.

Exploring the immaterial or unseen was a concern in both science and in art. This vision endorsed light and transparency as if they were new media—which could displace traditional materials. It was also a vision that celebrated technology as utopian:¹⁴

this reality of our century is *technology*—the invention, construction and maintenance of the machine. To be a user of machines is to be of the spirit of this century... Before the machine, everyone is equal... There is no tradition in technology, no consciousness of class or standing.

Technology maintained a pervasive cultural appeal. It harnessed a social optimism in which its use was perceived to transform the past into the modern world of equality and it was considered as relevant to the scientist as it was to the avant-garde artist.

New professional classes emerged in societies that had access to technology and education. To be a scientist in nineteenth-century Europe was to be part of the cultivated bourgeois; it was a profession in which one could attain further social distinction in relation to the public perception of one's work. In early twentieth-century Europe the number of professional scientists and engineers increased and employment for a professional scientist, like Gabor, conferred membership of a mobile international and cultivated class, which was part of an emerging technocracy.

The fate of the untrusted researcher in Germany and Britain

Siemens & Halske, Berlin, an international company building large-scale machinery and generators employed Gabor on graduation.¹⁵ The company had also helped found the

¹³ L. Moholy-Nagy, "Space-Time and the Photographer", in *Moholy-Nagy an Anthology*, ed. Richard Kostelanetz (New York: Da Capo Press, Inc., 1970), 61-66 on 61.

¹⁴ L. Moholy-Nagy, "Constructivism and the Proletariat", in *Moholy-Nagy an Anthology*, ed. Richard Kostelanetz (New York: Da Capo Press, Inc., 1970), 185.

Technische Hochschule at Charlottenburg where he studied. However, in 1932, Siemens & Halske dismissed him on the imminent election of Hitler's National Socialist Party, and the imposition of this party's anti-Semitic employment laws, which forced the company to identify Gabor as Jewish. Before his dismissal, Gabor had conducted research on plasma discharge lamps and cathode ray tubes, types of light sources seminal to industry and television. Gabor's later resentment of this treatment was that he did not participate in the development of the first electron microscope that Siemens delivered in 1939. From his standpoint, Gabor claimed that, "The first electron microscope was actually constructed out of my old C.R.O. [cathode ray oscillograph] by Knoll and Ruska in the same institute, a few years after I left".¹⁶ Denied the social participation in what the group defined as the vital and important research of the time was felt by Gabor to invalidate his possible contribution to science and to exploit what contribution he had already made. This was to be the first time that Gabor was to find himself stigmatised and placed outside the trusted group.

After leaving Germany in 1932, Gabor returned to Hungary, working in the Tungfram Electron Tube Research Institute, Budapest, on a patent for a plasma tube.¹⁷ It was with this invention that Gabor sought to find employment in Britain. Other Hungarians, Kepes and Moholy-Nagy, also left Berlin for England, prior to their both finding employment in the USA.¹⁸ As an immigrant Gabor was forced into a modernity that required one to rewrite one's self to fit into the available social position on offer. As sociologist Zygmunt Bauman has described modern twentieth-century society, it required everyone to join the emerging class bound social types, and adopt models of conduct that must imitate and follow the prevailing social patterns. Whereas in the nineteenth century it was geographical "'Estates' as the 'locations of inherited belonging'", that determined the social status of the individual, this "... came to be replaced by 'classes'" and social "classes, unlike estates, had to be 'joined', and the

¹⁵ Robert Fox and Anna Guagnini, "Laboratories, Workshops and Sites: Concepts and Practices of Research in Industrial Europe, 1800-1914", 191-294, on 216.

¹⁶ Gabor, "Notes for a Profile in the New Scientist, 15 July 1961".

¹⁷ Tyler Wasson, ed., *Nobel Prize Winners* (New York: H.W. Wilson, 1987), 358-359.

¹⁸ Moholy-Nagy was invited to form the New Bauhaus in Chicago, in 1937, in which Kepes became a staff member. It lasted only a year and had to reform as the Institute of Design. Kepes was to eventually form the Center for Advanced Visual Studies at MIT, a department that received Cold War funding to engage the arts and sciences. The Nazis destroyed the Bauhaus.

membership had to be continually renewed”.¹⁹ As a professional scientist, in an internationally recognised discipline, his skills were transferable.

British Thomson-Houston, in Rugby, England, then employed Gabor to continue research on plasma lamps. This company was founded in the nineteenth century by Elihu Thomson (1853-1892), an independent American inventor with 696 patents. In 1936 Gabor married a fellow English employee, Marjorie Butler, but this did not entitle him to citizenship. Britain, at the onset of World War II, refused to accept further applications from the increasing influx of European refugees, so he remained an alien. Then, on the subsequent German invasion of Hungary, he found himself newly designated by the British Government, as an ‘enemy’ alien. Whereas trusted scientific employees of British Thomson-Houston worked on military applications, including radar and microwave generators. Gabor was then delegated with three civilian research applications: frequency compression, three-dimensional television, and improving the electron microscope (an instrument the company manufactured in conjunction with Metropolitan Vickers).

Later Gabor stated that, yet again, he had been personally denied the opportunity offered to others “to participate in the important developments of klystrons and magnetrons”.²⁰ He was also denied the professional and social attainment that could be achieved through military science, not simply patriotic duty; military research would also signify the validity of one’s skills for the public good. Clearly, he could not have observed the application of radar and microwave to surveillance technologies. His theory of ‘wave front reconstruction’ published formally for the Royal Society in 1949 was intended for the electron microscope. Yet, it was this obscure algorithmic translation function that was to be of interest to the United States Army who, from the start of the ‘Cold War’ in 1947, and initiated by the United States Containment Policy, sought improved surveillance technology, radar mapping of the earth in order to monitor communist movement. In principle Gabor’s wave front reconstruction could be applied to other parts of the electro-magnetic spectrum. It was ironic that Gabor published his paper in the public domain at this time given the circumstances under which he had been assigned the research. Yet, like Herbert Ives, who gained a sole-authored publication as a PhD student, Gabor gained sole-authorship because he was not trusted

¹⁹ Zygmunt Bauman, *Liquid Modernity* (Cambridge, UK: Polity Press, 2000), 32.

²⁰ Gabor, “Notes for a Profile in the New Scientist, 15 July 1961”.

to work in a team on the larger military-research project. British Thomson-Houston too, could not have equated the description within Gabor's proposal, with the wider implications for military use—as this theory could have easily been assigned classified status during the war. Gabor also took out a patent for British Thomson-Houston, but this was specific to improving an existing instrument. Gabor's theory was not, at the time, it seems, considered for anything other than microscopy. Evidence of this, is perhaps the fact that, Gabor was to remain unaware of the military use of his invention until the United States Army declassified it after 1968. Yet other British agencies might have developed and classified similar technologies, from 1949 onwards, that existed under a different mode of description.

Issues of professional worth and identity were to occupy Gabor immediately after the war. A letter sent in 1945 to British Thomson-Houston from the Home Office, in response to a request on Gabor's behalf, outlined the new conditions to be met for British citizenship. Applicants were now to compete for selection, in addition to having demonstrated that they had “become assimilated to our ways of life” by exhibiting both a “knowledge of the language and [British] character”. Selection would favour those that might “have earned their share of gratitude”, who had in the war “rendered valuable help as scientists and technicians...[or] that by profession [made] a substantial contribution to the economic welfare of the nation”. These candidates would have priority.²¹

Gabor's science and publications provided resources after the war that ensured his receipt of British nationality. He commented, “Fortunately one can become British, even if one cannot become English”.²² The latter probably represented to Gabor a class of characteristic ‘estate’ owners. Using this model of exchange, he offered the Soviet Embassy his scientific publications (intended for Soviet scientists) as an exchange for information on the whereabouts on his mother and cousin. His father had died in 1942. He also enquired after them at both the Soviet Embassy in London and the British Foreign Office in 1945. He finally located his mother in a camp in Budapest maintained by the Swedish for the protection of Jews—against Nazi deportation to the

²¹ H.W. Sandys, The Under Secretary of State to G.G. Macdonald Esq. The British Thomson-Houston Co. Ltd., 13 December 1945, “Letter and Statement on Naturalisation”, in *Dennis Gabor Papers*, Imperial College Archives (London).

²² Dennis Gabor to T. Raison, *New Scientist*, 23 July 1961, “M/N6”, in *Dennis Gabor Papers*, Imperial College Archives (London).

concentration camps—who could prove, to the Germans, that they had relatives abroad or foreign passports. In 1945 the British refused to issue her with an emigration visa.

Three-dimensional cinema and its relationship to Gabor, Lippmann and Herbert Ives

Gabor left corporate employment for a Readership at Imperial College, London, in 1949. On leaving, British Thomson-Houston loaned Gabor a prototype he produced for a three-dimensional cinema screen, for which he had taken out four British patents. This, along with the electron microscope, was one of Gabor's assigned civilian projects. Gabor later reminisced that this research was motivated by a visit from the founder of the British *Odeon* cinemas, an inspiring British-born son of a Hungarian émigré:²³

Just before the war, that great enthusiast and successful businessman, Oscar Deutsch, gave an address at a BTH [British Thomson-Houston] dinner, giving us a vision of the cinema of the future, which had to be of course 3-dimensional. The Director of Research, the late Sir Hugh Warren encouraged us to 'exercise our minds' on the problem.

This is one example of how, according to historian of science Thomas Hughes, with the emergence of large corporations the manager-entrepreneur had begun to displace the inventor as the one to identify the problem.²⁴ This type of organised corporate research Hughes stated was, when compared to the earlier radical independent inventor, essentially considered to be 'conservative invention'.²⁵ Corporate researchers were assigned problems from above, and three-dimensional imaging was a pervasive twentieth-century concern for consumer, scientific, and military imaging. It was to remain a constant resource for surveillance and military simulation.²⁶ Herbert Ives at Bell Laboratories was also occupied from the 1930s on three-dimensional imaging and television, as probably were most researchers at large engineering corporations; the new medium of television was considered a threat to cinema profits.²⁷

²³ Dennis Gabor, "Notes for a Profile in the New Scientist, 15 July 1961", in *Dennis Gabor Papers*, Imperial College Archives (London).

²⁴ Thomas P. Hughes, "The Evolution of Large Technological Systems", in *The Social Construction of Technological Systems*, ed. W.E. Bijker, Thomas P. Hughes, and T.J. Pinch (Cambridge, Mass: MIT Press, 1994), 51-82, on 66.

²⁵ *Ibid*, 51-82, on 74.

²⁶ Sharon Ghamari-Tabrizi, "Simulating the Unthinkable: Gaming Future War in the 1950s and 1960s", *Social Studies of Science*, 30, no. 2 April (2000), 134-145. Tim Lenoir, "All but War Is Simulation: The Military-Entertainment Complex", *Configurations*, 8 (2000), 289-336.

²⁷ Bryony Dixon, "Archiving the 1950s", in *British Cinema of the 1950s: A Celebration*, ed. Ian Mackillop and Ian Sinyard (Manchester and New York: Manchester University Press, 2003). Five new

Gabor's three-dimensional invention was based on the review by Herbert Ives of Lippmann's screen, now generically described as a 'ribbed lenticular' screen. Ives had modified Lippmann's original 1908 concept of a dome into a pragmatic flat screen—with ribs not wart-lenses—this was more suited to television and mass production; and Ives thought of using it with existing imagery, film and television, as opposed to recording directly from nature.²⁸ Gabor secured further authorship claims, with patents that made a simple change from the Ives version. Gabor projected an image onto the screen—using a mirror—from the front instead of, as Ives suggested, from the rear. In 1947, when he finally demonstrated it at British Thomson-Houston, no representatives of the British cinema industry turned up to view the prototype and he was informed that the American industry would offer him a similar reception.²⁹ Gabor claimed "...I produced, by 1948, what I think was quite an impressive show. But Oscar Deutsch had died in the meantime, and it was decided not to pursue the subject further..."³⁰ Having lost a potential investor British Thomson-Houston was later to abandon this project. However, it made one public appearance for the Festival of Britain in 1951, where ambitious technological prototypes represented the optimism of the post-war period. This was the first publicly screened three-dimensional film in Britain, and there were no commercially available British films for this type of cinema. One cinema enthusiast remarked on "...this little known group of patent specifications by Dennis Gabor" carried out for British Thomson-Houston as the best solution for three-dimensional cinema.^{31 32}

formats came out in the 1950s (Cinemascope, Cinerama, Techniscope, Vita Vision and Todd A-O) to compete with TV by being bigger and wider.

²⁸ Herbert Ives, "Optical Properties of a Lippmann Lenticulated Sheet", *Journal of Optical Society of America*, 21, March (1931).

²⁹ Dennis Gabor, 7 February 1953, "Lecture: Three Dimensional Moving Pictures for Home Entertainment", in *Dennis Gabor Papers*, Imperial College Archives (London).

³⁰ Gabor, "Notes for a Profile in the New Scientist, 15 July 1961".

³¹ Raymond Spotiswoode, "Progress in Three-Dimensional Films at the Festival of Britain", *Society of Motion Picture and Television Engineers* 58, April (1952), 291-303, on 303. According to the author, although welcomed by amateur enthusiasts, three-dimensional cinema seemed to lack the films and content to march the form.

³² See also: Spotiswoode, "Progress in Three-Dimensional Films at the Festival of Britain", 291-303, on 294. Sophie Forgan, "Festivals of Science and the two cultures: science, design and display in the Festival of Britain, 1951", *British Journal for the History of Science*, 31 (1998), 217-40. Sarah Easen, "Film and the Festival of Britain", in *British Cinema of the 1950s: A Celebration*, ed. Ian Mackillop and Ian Sinyard (Manchester and New York: Manchester University Press, 2003), 51-63, on 55-56.

Promoting technology in 1950s Britain

Gabor was to exhibit the prototype at the Royal Society *Conversazione* in 1954 (fig.3.1). With this exhibit he occupied the same platform that both Lippmann and Frederic Ives had secured for their inventions in the 1890s. This promotional scene was just as valid for the inventor in the 1950s as it had been for inventors in the 1890s. Similarly, the possession of a visually entertaining invention was still a qualification for inclusion in a *Conversazione*. If the management and production of science had changed, as Hughes has pointed out, the platforms—exhibitions and the press—on which individuals sought to promote themselves to the public remained the same. This event brought Gabor in contact with other Fellows; he was elected to the Royal Society two years later. He was also in contact with the science press prior to the emergence of the hologram. Gabor had also tried, unsuccessfully, to sell patents on this invention to Kodak and Paramount, visiting the USA for this purpose in 1951 and 1952, and retained throughout the 1960s a relationship with an American agent in the hope of a sale. Clearly, Gabor was involved with the pursuit of three-dimensional imaging before the hologram.

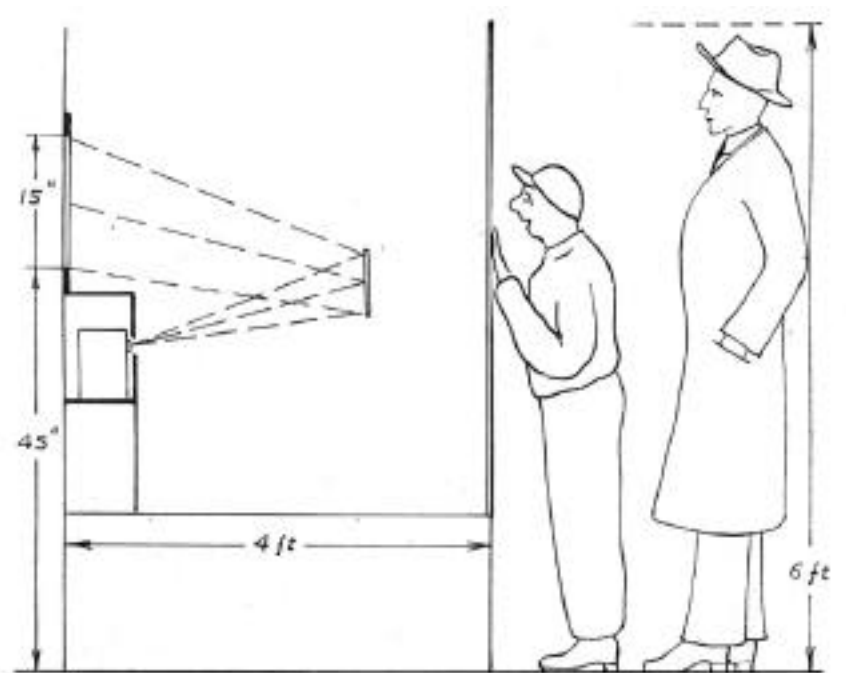


FIG. 1. THREE DIMENSIONAL MOVING PICTURES IN A SHOP WINDOW.

Fig.3.1. Drawing by Dennis Gabor, collection Dennis Gabor Papers reproduced with permission from the Imperial College Archives, London.

Text reproduced from the Royal Society, *Conversazione* catalogue, 1954:

Item 10: THREE-DIMENSIONAL PROJECTION WITHOUT SELECTIVE SPECTACLES

The British Thomson-Houston Company Research Laboratory, Rugby and Dr D. Gabor, Imperial College of Science and Technology, London

The projection screen consists of thin plastic sheets (Lentic Ltd) embossed on the front surface with 64 cylindrical lenticules per inch, whose focus is in the rear plane of the sheet. This rear surface carries a diffusely reflecting coating. Such a screen acts like a mirror. If an image is projected onto it through one small projector aperture, the image will not be seen except from a set of vertical line, of which one passes through the aperture, and the others are equally spaced to the right and left of it. This makes it possible to separate different views of a three-dimensional scene, so that one eye sees one view only, while the other sees a different view, which produces a three-dimensional illusion. A projector with 8 objectives is used, which projects simultaneously 8 views of a spatial scene, and allows a certain freedom of movement for the onlooker, without losing the three-dimensional effect.

As a salaried academic from 1948, Gabor could continue to promote his own intellectual property. In a letter to Peter Goldmark, a friend living in the United States, Gabor explained, “I am free to take up consulting activities to some extent, and to bring up my pay to subsistence level”.³³ In the new consumer society the desire to supply the needs of the key industries and markets began to dictate the type of research undertaken outside of the commercial corporation and inside of the academy. Whereas Lippmann in the nineteenth century distanced himself from the arena of commerce to distinguish his research as being undertaken for the public good, in the 1950s commerce and academic research could be combined. Gabor marketed his patents—through agents, visits and exhibitions—in a similar way to that of the more artisan inventor Frederic Ives, but he also promoted himself professionally through membership in elite male London societies, such as the Royal Society and the Athenaeum Club, in a manner more akin to Lippmann. Throughout his time at Imperial College, Gabor consulted on applications applicable to both civilian and military uses for large American corporations, as well as for British Government funded research agencies. Military applications are not revealed within the existing patent literature and only the description of the ‘technology’ exists.³⁴ Gabor’s patents reveal an engagement with the frontier development of twentieth-century electron engineering: from flat-screen and three-dimensional television, stereophonic sound, speech compression, holography, thermionic energy converters (of later use in space-technology by the Americans and Soviets) and many improvements to components to further advance these possibilities.³⁵

As a mid-twentieth-century scientist, Gabor aimed to retain the nineteenth-century old regime allegiances and status but professed a new social order through the promotion of technology as the means to social progress. He was part of what political

³³ Dennis Gabor to Peter Goldmark, on 13 November 1948, in *Dennis Gabor Papers*, Imperial College Archives (London). Gabor also states in this letter “It is very sad that in this country [UK] the middle-class subsistence level is at about £1,500”. Goldmark was an old student friend from Hungary, who later became the director of CBS Laboratories, Connecticut, USA. He shared technical interests with Gabor and although based in the USA, Goldmark was posted to Malvern during the war on a “special US technical mission” where he made contact with Gabor. It was Goldmark who offered Gabor a consultancy at CBS Labs after his retirement from Imperial College.

³⁴ D.E.H. Edgerton, “Science and War”, in *Companion to the History of Modern Science*, ed. R.C. Olby, et al. (London & New York: Routledge, 1996), 934–989, on 940. On military research during the Cold War: “The proponents of scientific freedom chose to ignore the extent to which even the purest of sciences were being directed to military ends, ...by redefining military science as ‘technology’...”

³⁵ P.G. Tanner and T.E. Allibone, “The Patent Literature of Nobel Laureate Dennis Gabor (1900-1979)”, *Notes and Records of the Royal Society of London*, 51, no. 1 (1997).

sociologist Alvin Gouldner defined in 1979 as “the New Class... a contradictory class...” which held professionalism to be “...its central *occupational* ideology”.³⁶ A group for whom:³⁷

The new ideology holds that productivity depends primarily on science and technology, and that society's problems are solvable on a technological basis, and with the use of educationally acquired competence.

These ideas Gabor expressed in a popular book *Inventing the Future*, published in 1963.³⁸ The art of self-presentation in writing became a survival tactic for Gabor, enabling him to present ‘in effect’ what social psychologist Erving Goffman calls his “virtual social identity” to meet those demands socially required him to reconstruct his identity as a British citizen. In text he could appear British in ‘character’, whereas in reality, what Goffman names his “actual social identity” was, to the English, with his thick accent, foreign.³⁹ As the chemist and novelist Carl Djerassi has pointed out with regard to the nature of a scientist's identity:⁴⁰

There is one character trait... his extreme egocentricity, expressed chiefly in his overmastering desire for recognition by his peers. No other recognition matters. It doesn't really matter who you are or whom you know, you may not even know the other scientist, but they know you — through your publications.

One group unsympathetic to the problems of the émigré were Gabor's students at Imperial College. Making his science comprehensible, in person, perhaps remained a communication problem for Gabor. One former student who wrote an obituary for *Nature* made it publicly known that in the classroom, Gabor presented:⁴¹

...a remarkable and, at first, unfathomable phenomenon to his research students. He had little comprehension of the difficulty encountered by ordinary mortals in attempting to gain an appreciation of his aims in a particular research endeavour, or to follow a leaping thought line without stepping-stones. His lecture courses on electromagnetic theory, statistical analysis, the plasma-state, electron optics, seemed memorable but hardly capable of assimilation... it was necessary to ‘know’ the subject before attending these occasions.

³⁶ Alvin W. Gouldner, *The Future of Intellectuals and the Rise of the New Class*, *Critical Social Studies* (London and Basingstoke: The MacMillan Press Ltd, 1979), 43.

³⁷ *Ibid*, 24.

³⁸ Dennis Gabor, *Inventing the Future* (London: Secker & Warburg, 1963).

³⁹ Erving Goffman, *Stigma: Notes on the Management of a Spoiled Identity*, 3rd ed.. (London: Penguin Books, 1990), 12.

⁴⁰ Carl Djerassi, *The Bourbaki Gambit* (Athens, Georgia: The University of Georgia Press, 1994), 18-19. As cited in Hugh Gusterson, “The Death of the Authors of Death”, in *Scientific Authorship: Credit and Intellectual Property in Science*, ed. Mario Biagioli and Peter Galison (New York, London: Routledge, 2003), 281-307, on 281.

Students in 1948, according to this author, regarded “holography as a laboratory curiosity”. This was a group unimpressed with the Nobel Prize. That holography was later to become an acclaimed invention was not the result of further publications by Gabor, but essentially due to the promotional efforts of others, and especially that of Leith and Upatnieks. They were to promote the popular hologram in a manner similar to the Lumière Brothers’ promotion of Lippmann and this relationship is one aspect overlooked in the Lippmann-to-Gabor narrative.

Gabor’s hologram: an imaging solution for electron microscopy

Dennis Gabor’s *Microscopy by Reconstructed Wave-fronts*, his paper that defined the *hologram*, was first published in the magazine *Nature* in 1948.⁴² The following year, the Royal Society published the theory more formally. Given the difficulties his students claimed he experienced in spoken explanation, it might have been fortuitous for Gabor that he was not yet an elected Fellow. Gabor’s paper was read before the Royal Society by Sir W. Lawrence Bragg, then Cavendish Professor of Experimental Physics at Cambridge University.⁴³ Just as Lippmann’s interference photography was conceived as being employed with the spectroscope, so Gabor’s new imaging invention was specifically for the electron microscope, an important instrument to the emerging twentieth-century research field of molecular biology (fig.3.2). Both these inventions were aimed at scientific audiences for whom imaging solutions—finding an objective way to record colour in the late nineteenth century and now imaging the three-dimensional resolution of molecular particles in the twentieth—were a pertinent concern. In 1948 improving the resolving power of the electron microscope was perceived to be strategic to resolving the then unseen structure of DNA (deoxyribonucleic acid), a visual enigma in genetic research, which was to be revealed later, in the early 1950s, as a double helix.⁴⁴ The microscope imagery by Rosalind Franklin that provided one insight to this solution was taken using X-ray crystallography, then an established microscope technique developed by W. Lawrence

⁴¹ Eric A. Ash, “Obituary, Dennis Gabor, 1900-1979”, *Nature*, 280, no. 2, August (1979), 431-433, on 432.

⁴² Dennis Gabor, “A New Microscopic Principle”, *Nature*, 161, no. 4098 (1948), 777-778.

⁴³ Dennis Gabor, “Microscopy by Reconstructed Wave-Fronts”, *Proceedings of the Royal Society*, 197, July (1949), 454-487.

⁴⁴ The Nobel Prize was awarded for the discovery of DNA in 1962 to Watson, Crick and Wilkins. Rosalind Franklin who had worked at Kings College, London with Maurice Wilkins died before 1962, and it is not clear that she would have been included in the award had she lived. James Watson and Francis Crick were employed at University of Cambridge, UK.

Bragg and his father, William Henry: together they had received a joint Nobel prize in 1915. This was the discipline that Gabor's paper sought to address. According to historian of science Paul Forman, it was a complex field lying between, and shared by, physics, chemistry, crystallography, geology, and now biology, for which, both the Braggs had worked to secure its reputation as more than a mere applied technique to these various disciplines.⁴⁵

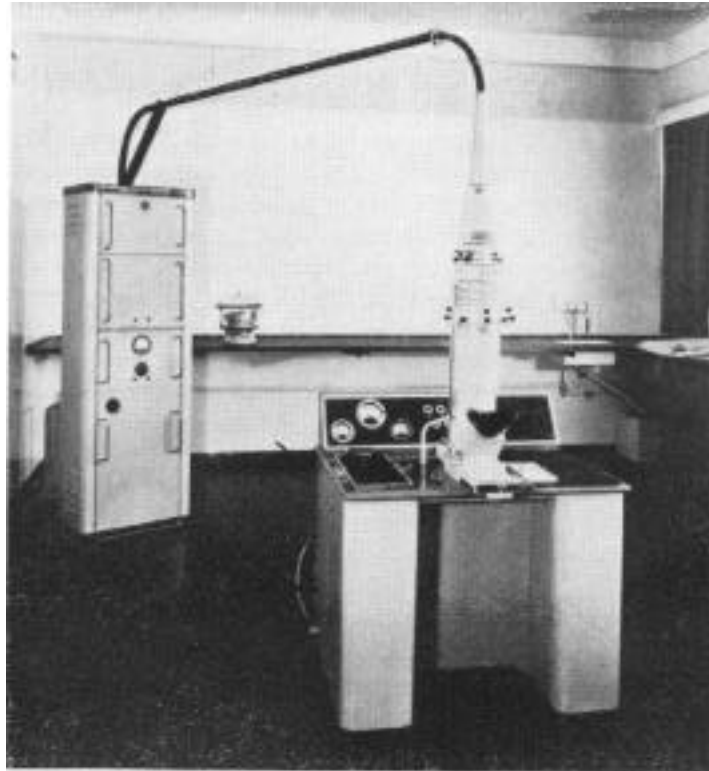


Fig.3.2. A 1949 British electron microscope, the Metropolitan Vickers E.M.3 reproduced from the 1968 publication *The Microscope Past and Present* by S. Bradbury. The original caption states “The common convention of placing the microscope column on a desk which also carries the controls has now been established. The cabinet in the background contains the electronic power supplies and stabilizers... the instrument offered the possibility to take [three-dimensional] stereo-micrographs”. These stereo images would only depict a relief of the surface of the sample not the interior. Gabor explored an in-line optical arrangement to function within a microscope column.

In his paper, Gabor cited as an antecedent to his new proposal the more recent work of W. Lawrence Bragg, who had tried since 1939 to further resolve three-dimensional atomic structures with a “new type of X-ray microscope”.⁴⁶ This involved imaging cells against a background of X-ray diffraction, generated as the ray passed through a crystal and a ‘holed’ brass plate, to form a pattern of scattered energy as it then passed through

⁴⁵ Paul Forman, “The Discovery of the Diffraction of X-Rays by Crystals; a Critique of Myths”, *Archive for the History of Exact Sciences*, 6 (1969), 38-71, on 40.

the sample's own structure. This 'image' was then recorded and revealed, according to Gabor, as a "projection of the electron densities, but only in certain cases when the phases are real, and have the same sign".⁴⁷ From this data mathematical analysis could then be applied to the densities or diffraction patterns generated to infer the structural form of the sample placed in the X-ray microscope. Bragg's method was also limited to certain types of subjects, what Gabor described as "a rather exceptional class of periodic structures". These were structures that permitted a sufficient amount of energy to pass through their body, in order to generate the required diffraction pattern. Gabor perceived that his invention was one that would improve upon Bragg's initial project and prove relevant to the electron microscope. In his paper he introduced these claims: "Thus it [now] becomes possible to extend the idea of Sir Lawrence Bragg's X-ray microscope to arbitrary objects, and use the new method for improvements in electron microscopy".⁴⁸ Clearly, the project was fully endorsed by W. Lawrence Bragg as being one of relevance to his discipline, and nowhere in his paper does Gabor cite Lippmann.

Dennis Gabor proposed an imaging technique that could be applied to microscope images recorded with electrons. His new technique would reconstruct, or convert, the electron image into one of photons, in order to overcome one very significant limitation to electron microscopy: that it failed to address three-dimensional subjects such as cells. To prepare samples for scanning with an electron beam, they had to first be coated with a metallic layer, for the beam to reflect off the sample. This restricted subjects to those seen only by surface or profile, a virus for example, but for objects like cells that have a three-dimensional structure, the metal coating obscured the inner depths.⁴⁹ This also meant that the interpretation of the final visual data was, to late twentieth-century commentators, more akin to reading a mapped surface of the subject, rather than observing it directly under magnification.⁵⁰ That the electron microscope imaged surface detail in high resolution only served to frustrate the observer's desire to visualise the depths of the subject. A user and historian of the instrument, writing in 1968, defined the problem:

⁴⁶ W.L. Bragg, "Letters to the Editor: A New Type of X-Ray Microscope", *Nature*, 143 (1939).

⁴⁷ Dennis Gabor, "Holography, 1948-1971" (paper presented at the Nobel Prize Lecture, Stockholm, 11 December 1971), 168-200, on 171-173, in *Dennis Gabor Papers*, Imperial College Archives (London).

⁴⁸ Dennis Gabor, "Microscopy by Reconstructed Wave-Fronts", 454-487, on 454.

⁴⁹ Nicholas Rasmussen, *Picture Control: The Electron Microscope and the Transformation of Biology in America, 1940-1960*, (Stanford California: Stanford University Press, 1997), 203.

...electron microscope images suffer from the drawback that they are entirely two-dimensional; if one is studying an 800 Angstrom-thick slice of a cell, which may be over 40 microns in thickness, it is obvious that in order to survey all the structures present in three dimensions about 480 sections would be required.

To model the three-dimensional structure each cell-slice, after extensive preparation, would be placed in the electron microscope and photographed, then the final 480 printed photographs would be assembled together in sections to produce “a three-dimensional reconstruction of the object”. This required such time consuming labour, that the “...task is full of difficulties and has very seldom been attempted”.⁵¹

Gabor, writing in 1961 for *New Scientist*, summarised his earlier intention: “I wanted to... make the instrument realise its full potential; the resolution of atomic lattices”. The ultra high resolving power of the electron microscope appeared to promise the means to image an individual atom, except that an electron ‘lens’ was physically unlike an optical lens, as Gabor explained: “Electron lenses could not be corrected. My idea was to break off the imaging process with electrons at a point where the picture was unintelligible, but contained the full information and finish it by light optics, correcting the aberrations of the electron lenses by optical lenses”.⁵² The observer could record the first analysis under an electron beam but then synthesise the data into a more visible and optical image for further resolution and examination, as if the original sample had been photographed with light.

Gabor's invention provided the possibility for microscopic subjects to be viewed with apparent optical ‘back illumination’. Following Gabor's ‘wave front reconstruction’ the electron images were to be brought into the visible optical realm. “In light optics a coherent background can be produced in many ways, but electron optics does not possess effective beam-splitting devices; thus the only expedient way is using the illuminating beam itself as the coherent background”.⁵³ The results depended on the manifestation of an image recorded with the coherent electron-beam, then undergoing transformation into an image with a coherent optical beam, although no such coherent light source was then available. A non-coherent source—which all visible spectrum

⁵⁰ Ibid, 19. See also Bruno Latour, “Drawing Things Together”, in *Science in Action*, ed. Lynch S. and S. Woolgar (Cambridge, Mass: Harvard University Press, 1987), 19-68.

⁵¹ S. Bradbury, *The Microscope Past and Present*, 1st ed. (Oxford, London, New York: Pergamon Press Ltd, 1968), 253.

⁵² Dennis Gabor, “Notes for a Profile in the New Scientist, 15 July 1961”, in *Dennis Gabor Papers*, Imperial College Archives (London).

⁵³ Gabor, “Microscopy by Reconstructed Wave-Fronts”, 458-487 on 455.

lamps were—produced more than one wave length, so the light diverged, resulting in a larger and blurred final image of the subject. The concept of using a coherent background Gabor described as stemming from the work of Dutchman Fritz Zernike, who had developed in the 1930s the ‘phase contrast microscope’, an instrument eventually manufactured in 1941 by Zeiss, Germany. Gabor explained this reference to a general audience in 1971: “The coherent background, on the other hand was used with great success by Fritz Zernike in his beautiful investigations on lens aberration, showing up their phase, and not just their intensity”.⁵⁴ Zernike used interference to discern aberrations that were inherent in the physical manner in which light travelled through a lens. What Gabor now added in his paper to the previous combined efforts of Bragg and Zernike—his definition of the hologram’s antecedents—was the concept of image reconstruction—or translation from one wave length to another.⁵⁵

Gabor’s ‘wave front reconstruction’ was essentially a mathematical theory, a prediction, but not yet an experimentally tested one. In his paper the process of reconstruction, the change from the original electron image to an optical one, was computed using a series of algorithms with added explanatory text as to their functions. This algorithmic model was then applied to an ideal circumstance—assuming the existence of a coherent light source, for example. The sole experiment Gabor undertook—in which he simulated the entire process throughout with light and a microscope—was merely to provide some photographic illustrations to accompany the published text. These illustrations were important for Gabor, who may have presumed that they might have made the paper more accessible to a wider audience amongst professional scientists, not all of whom might so easily comprehend his algorithmic function, in relation to its role within an electron microscope. Historian Ludmilla Jordanova has written of the ability of visual material to be inclusive, and to address subjects accessible to the non-literate.⁵⁶ It was the desire to produce some imagery—even if it did not represent Gabor’s theoretical ideal—that forced Gabor to produce and name what he described in his paper as the *hologram*, and Bragg might have made Gabor aware of the important role of photography in the development and

⁵⁴ Gabor, “Holography, 1948-1971”, 168-200, on 171-173.

⁵⁵ These references to Bragg and Zernike constitute an alternative antecedent—one of the six I name in the introduction—to the hologram, which is not included in the Lippmann-to-Gabor narrative.

⁵⁶ Ludmilla Jordanova, *History in Practice* (London, New York: Arnold & Oxford University Press Inc., 2000), 89.

dissemination of X-ray analysis; a point now emphasised by historians of science Paul Forman and John Law.⁵⁷

Gabor recorded the 'original' sample images, representing a 'prior to reconstruction' stage, using a high-pressure mercury arc lamp not an electron beam. This lamp emitted a greenish light, and had a condensing lens in front of its source, to focus the beam down to pass through a 0.2mm aperture and a colour filter. This array of optics provided the nearest approximation to a coherent light source: one that appeared to be an optical point at its source and emitted light in one wave length. Gabor also mentions employing a microscope objective (in reverse) that created an image of the aperture 40 times reduced. Gabor was an electrical engineer by training not an optical scientist. This optical system was inefficient. Much of the light from the mercury arc lamp would have been lost, as it reflected off the surfaces of the various optical devices. Regarding his choice of subjects for imagery, Gabor stated that "The objects were mostly microphotographs, sandwiched with immersion oil between polished glass plates..." and held in position against three locating pins.⁵⁸ Microphotographs (as small as one millimetre in diameter) were photographs prepared for viewing solely in a microscope. In the nineteenth century they were a popular visual entertainment for the household microscope and photographic companies including the Lumière Brothers produced and distributed microphotographs using their own products. The original pasted-up photographic artwork that Gabor prepared for publication reveals that his image of a protractor was a commercial sample, on a Kodak Maximum Resolution Plate, distributed to scientific laboratories by Messrs. Kodak Ltd.

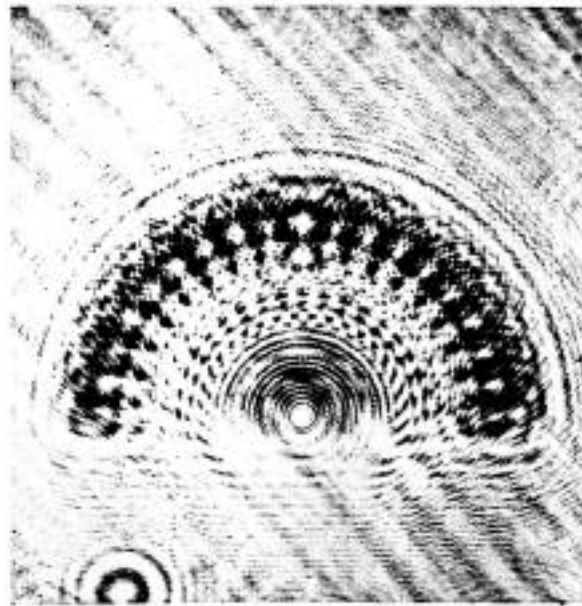
⁵⁷ Forman, "The Discovery of the Diffraction of X-Rays by Crystals; a Critique of Myths", 38-71, on 66. In the emergence of this field photographs were distributed before papers were published and no expense was spared on photography. John Law, "The Development of Specialities in Science: The Case of X-Ray Protein Crystallography", in *Perspectives on the Emergence of Scientific Disciplines*, ed. Gerard Lemaine, et al. (The Hague, Paris, Chicago: Maison des Sciences de l'Homme, Paris Publications, 1976), 132-152, on 130. Law stresses the importance of imagery to development, he informs us that until the work of Bernal in 1934 no good imagery of single crystals had been obtained. Bernal manipulated the subject by making the protein crystals more humid, so photographs could reveal information down to the atomic level.

⁵⁸ Gabor, "Microscopy by Reconstructed Wave-Fronts", 458-487, on 484.

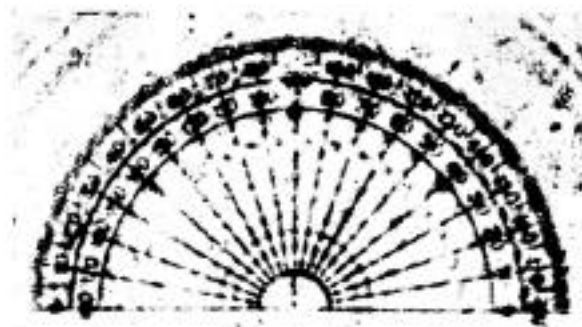
Gabor

Proc. Roy. Soc. A, volume 197, plate 17

original



hologram



reconstruction

FIGURE 12. Reconstruction with pinhole illumination and wave-length change. The original was a micro-protractor of 1 mm. diam. Same conditions as in figure 11, but the wave-length used in the reconstruction was $\lambda = 5461 \text{ \AA}$.

Fig.3.3. Gabor's image of a protractor was a sample microphotograph distributed by Kodak Ltd.

Gabor's resulting image of the protractor (fig.3.3) might, in form and fuzziness, be reminiscent to his readers of the textbook illustration of *Newton's Rings*, the emblematic woodcut that was a standard visual signifier of interference (see Chapter One, fig.1.1).

Gabor

Proc. Roy. Soc. A, volume 197, plate 15

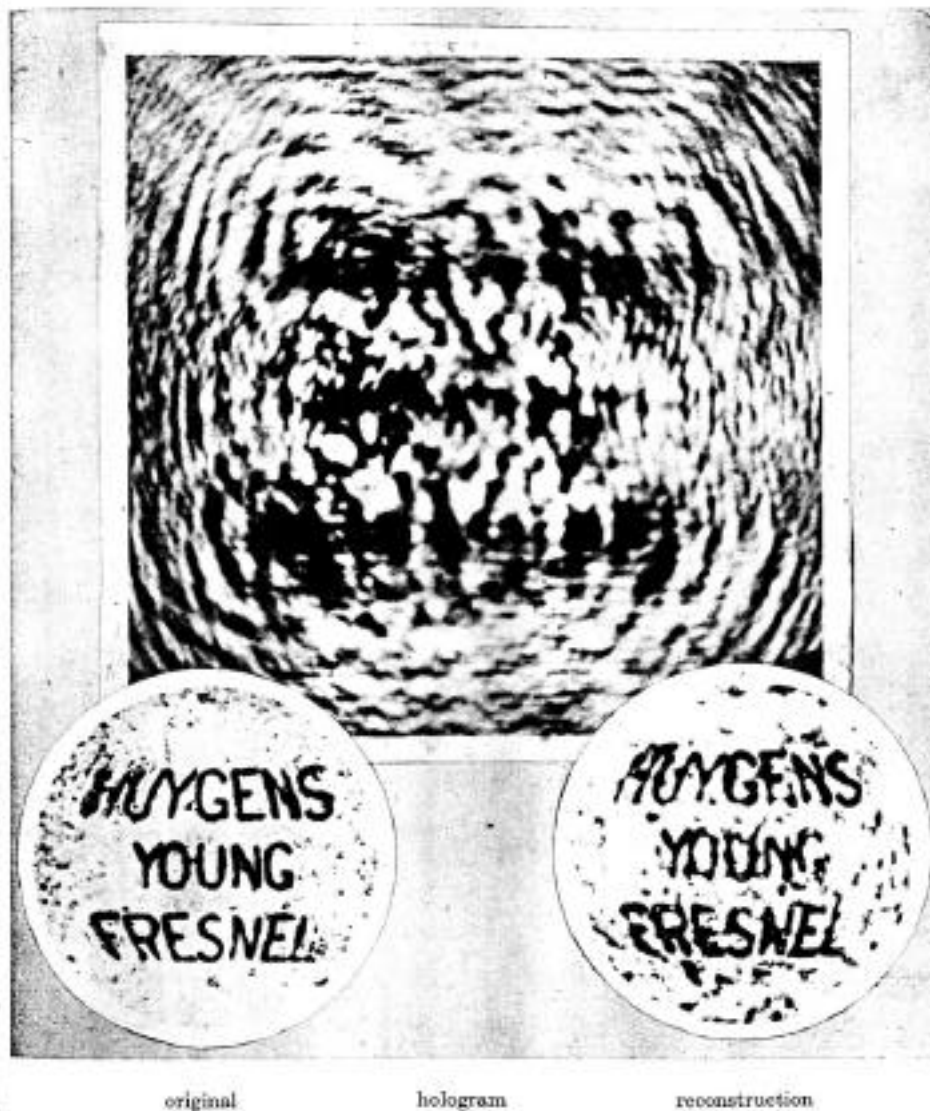


FIGURE 10. Optical reconstruction cycle. The original was a microphotograph of 1.5 mm. diam. Illuminated with $\lambda = 4358 \text{ \AA}$ through pinhole 0.2 mm. diam., reduced by a microscope objective to $\frac{1}{5}$ nominal diameter, at 50 mm. from object. Geometrical magnification 12. Effective aperture of lens used in reconstruction 0.025. Noisy background chiefly due to imperfections of illuminating objective.

(Facing p. 450)

Fig.3.4. Illustration from Gabor's 1949 paper 'Microscopy by Reconstructed Wave-Fronts'.

With this image Gabor brings his algorithmic *function* into the field of optics. With another subject—a micro-monument to Huygens, Fresnel, and Young, of his own fabrication—Gabor perhaps seeks to make his paper appeal directly to the more classically trained British optical scientist working in X-ray optics; those who might

apply themselves further to this pursuit (fig.3.4). Like Lippmann with his *Lippmann spectrum*, Gabor employed imagery to disseminate his concept to those scientists outside of his discipline; the image is used as both evidence and as a signifier of the entire process.

In his paper, Gabor then apologises for these optically produced photographic results, which demonstrate that “the [resulting] picture is very noisy... due to dust and an inhomogeneities in the two microscope objectives...” If the ‘reconstruction’ process was to be employed as Gabor suggested, the reader was to assume that such optical aberrations would not appear. Because, as Gabor theorised: “However imperfect an electron lens may be from the point of view of theoretical optics, it can contain neither dust nor ‘schlieren’, as the electromagnetic field smoothes itself out automatically, and in this respect any electron lens is superior to all but the best optical lenses”.⁵⁹

To synthesise the original images into virtual ‘reconstructed’ images (to be photographed) for the paper, Gabor changed the wave length of emitted light to simulate the change from electron to photon. Then finally placing the original recording into position: “The reconstructed image was viewed in a microscope, and photographed on [photographic] plates introduced into the eyepieces”. To reduce the optical noise within the instrument, Gabor removed the microscope objectives and the glass sandwich mounts intended to hold the samples on slides. He then produced his own basic pinhole of three microns diameter “pierced into tinfoil with a very fine needle”.⁶⁰ Assembling his own optics—to simulate the process—was an ad hoc approximation to the theoretical function his proposal addressed. Here Gabor sought to illustrate his predicted ‘diffraction function’, and not the undesirable but inherent aberrations. These effects were present because this diffraction photograph would also record any aberration present in the optical system: diffraction patterns around dust particles and actual *Newton's Rings* within the optics. The final image was intended to provide as optically clean a picture as possible, because it would be difficult for the reader to distinguish Gabor's new order of diffraction from mere unwanted diffraction or interference artefacts.

To further aid his reader, Gabor explained:

⁵⁹ Ibid, 458-487 on 485.

⁶⁰ Ibid.

As the photograph of a diffraction pattern taken in divergent, coherent illumination will be often used in this paper, it will be useful to introduce a special name for it, to distinguish it from the diffraction pattern itself, which will be considered as a complex function....

It is this barely discernable blur, which must now to be perceived as an operational 'complex function', that is the core invention Gabor's paper addresses. The diffraction 'photograph' is to provide the reader with a visual cipher to the 'wave front reconstruction' process. The image cannot truly depict what, to the eye, would be an invisible 'translation' process. To clarify this confusion, in print, over the actual, the operational and the virtual, Gabor gave this photograph another name:⁶¹

The name 'hologram' is not unjustified, as the photograph contains [hypothetically if taken with a coherent light source] the total information required for reconstructing the object, which can be two-dimensional or three-dimensional.

Gabor's *hologram* was the recording that had to be replayed or reconstructed under the correct coded conditions to create the final 'image'. This new element of the illustrated "cycle" would be present in any wave-front reconstruction process, irrespective of the part of the spectrum in which it operates, and it was a process, that by its verbal description (or by the marvel of the reconstructed image) could confuse an audience.⁶² 'Confusion' was later perceived as an inherent part of the hologram, and was to be visually represented in popular accounts of the process as a symbolic chaotic interference pattern.

The holograms—the operational data—that Gabor recorded and illustrated in the paper are all essentially flat (to those unfamiliar with the scale of the electron microscope): they were of flat subjects, such as a microphotograph 1mm in diameter, and were not illuminated by a highly coherent light source, and of course they were flat in print upon the page. However, Gabor's algorithms permitted him to predict the *true* nature of the *reconstructed hologram* if produced in the visible wave band with light.

The naming of the hypothetical result—the *hologram*—as well as the description of its role, is perhaps the most identifiable authored invention within the paper, for those readers who sought to locate the hologram retrospectively. This is perhaps the only

⁶¹ Ibid, 458-487 on 458.

⁶² Paul Virilio, "The Vision Machine", in *The Virilio Reader*, ed. James Der Derian (Malden, Mass. & Oxford, UK: Blackwell, 1998), 134-151 on 135. Virilio regarded this confusion of how the image was processed to be "one of the most crucial aspects of the development of the new technologies of digital imagery and the synthetic vision offered by electron optics".

example, given holography's subsequent history, of what John Law considers 'labelling undertaken by a strong actor'.⁶³ Gabor's strong position here is that he was later identified as the sole author.

In concluding this paper, Gabor speculated that "...probably the most interesting feature of the new method for light-optical applications is the possibility of recording in one photograph the data of three-dimensional objects".⁶⁴ Gabor was considering objects on a molecular scale, and *holograms* that a microscopist would reconstruct and 'rake' through—by focussing the microscopic objective into the depths of its image—to find its three-dimensional structure. A few microns are a significant measure of depth for the microscopist probing on the scale of an atomic lattice. To physicists who worked on a larger scale, the predicted 'data as three-dimensionality' would not have been obvious from Gabor's text, because all of Gabor's *function* exists within a microscope. For those familiar with optics and the notion of the two 'real and virtual images' created by light passing through a lens then being focussed to a point before expanding, Gabor's process, as illustrated, might not seem so different. A virtual optical image is on an optical bench, a projected form of image that exists in space and is only for convenience viewed upon a screen.

Other experimenters and the Gabor hologram

Gabor's paper received little attention, apart from those within X-ray microscopy, who were already familiar with the scale, language, and the decoding of diffraction patterns. In addition to W. Lawrence Bragg, the leading British exponent of this methodology, the paper was of interest to Paul Kirkpatrick. He was a comparable but younger researcher in X-ray optics, then based at Stanford University, the leading American centre for this technology. Stanford like Michigan University—the site of the three-dimensional laser hologram—received a significant source of funding for physics and engineering from the federal defence budget. Kirkpatrick, according to historian Rebecca Lowen, was one of the few staff that "objected to accepting military patronage of their research for moral or political reasons".⁶⁵ Kirkpatrick, when interviewed in the 1960s about Gabor's original work, said: "...I was motivated by the experimentalist's

⁶³ John Law, "Theories and Methods in the Sociology of Science: An Interpretive Approach", in *Perspectives on the Emergence of Scientific Disciplines*, ed. Gerard Lemaine, et al. (The Hague, Paris, Chicago: Maison des Sciences de l'Homme, Paris Publications, 1976), 221-131, on 224-225.

⁶⁴ Gabor, "Microscopy by Reconstructed Wave-Fronts", 458-487 on 486.

pardonable scepticism; Gabor's equations were irrefutable and they said it would work, but the experimenter properly asks 'how well?' and turns to his laboratory".⁶⁶ Kirkpatrick supervised a PhD student, Hussein El-Sum, on this research, which was published in 1952. In hindsight, according to Kirkpatrick this produced "many X-ray holograms but it was not an encouraging experiment".⁶⁷ However, Kirkpatrick and El-Sum exhibited within a microscope optically reconstructed 'Gabor holograms', taken from X-ray originals; these, they claimed, "produced good reconstructions even when the illumination radiation is far from monochromatic", and it was evident to them that with the reconstruction "any desired plane of the distributed object may be brought into focus".⁶⁸ The object could be explored in three-dimensions but only by one two-dimensional plane at a time. Kirkpatrick and El-Sum's first public demonstration of this technique was, perhaps unfortunately, only a conference poster session with a paper on refinements to Gabor's imaging process. These were only applicable to the X-ray microscope.⁶⁹

Gordon Rogers, who was a post-doctoral researcher employed at Dundee University, undertook (as Gabor initially did) all-optical experiments with a mercury arc lamp, publishing one paper in 1951, *Experiments in Diffraction Microscopy*.⁷⁰ Rogers stated that:⁷¹

although the application to electron microscopy has not been entirely forgotten; the work has been directed to the method in its own right. As a result a number of useful generalizations have been discovered empirically and verified theoretically which, though doubtless implicit in the many equations of Gabor (1949), can also with profit be stated explicitly in simpler physical terms.

In reviewing Gabor's paper, Rogers cited historical antecedents in the diffraction theory of physical optics—Fresnel and Cornu—and he compared the hologram as an optical 'object' to a Fresnel Zone plate. In doing so, Rogers attempted to expose and clarify the function within a more familiar context, of optics, than that originally defined by

⁶⁵ Rebecca S. Lowen, *Creating the Cold War University: The Transformation of Stanford* (Berkeley, Los Angeles, London: University of California Press, 1997), 153.

⁶⁶ Paul Kirkpatrick, "Holography", *Stanford Today* (Spring, 1966), 6.

⁶⁷ *Ibid.*, 11.

⁶⁸ Hussein M.A. El-Sum and Paul Kirkpatrick, "Conference Poster Session M: Microscopy by Reconstructed Wave-Fronts", *The Physical Review*, 35 (1952), 763.

⁶⁹ Kirkpatrick, P. and H.M.A. El-Sum, "Image Formation by Reconstructed Wavefronts: Physical and Methods of Refinement", *Journal of the Optical Society of America*, 42, no. 46 (1956).

⁷⁰ G.L. Rogers, "Experiments in Diffraction Microscopy", *Proceedings of the Royal Society of Edinburgh*, LX111, no. A, Part III (1950-51), 93-221.

⁷¹ *Ibid.*, 193-221 on 193.

Gabor's algorithms. Rogers employed lengthy references and diagrams from the wider history of optics, whereas Gabor's original citations to Bragg and Zernicke solely addressed recent microscopy inventions and living authors. This was perhaps an attempt by Gabor to site his paper firmly in an existing discipline, to advantage its chances of publication, and in doing so Gabor gained and acknowledged Bragg's attention, and possibly Zernicke's, whom Bragg knew personally.⁷² Gabor only pictorially referenced historical antecedents to his process within his illustrations.

Rogers may have been the typical optical researcher that Gabor's illustrations appeared to have been addressing; Gabor encouraged Rogers, visiting him in Scotland. Rogers invested far more time than Gabor on seeking out emulsions and filters, to improve the final photographic image, but the illustrations in Rogers's paper exhibit a dense blur of diffraction effects (fig.3.5a). It is impossible to distinguish the subjects within these illustrations that Rogers described as a "micrometer eyepiece scale" or a "reduced copy of a newspaper cutting with a chess problem".⁷³ One of Rogers's illustrations (fig.3.5b) of his optical set-up reveals that he worked with his optics—mirrors, lenses, microscope objectives—on a shelf attached to wall. This was a very basic optical arrangement that with a mercury arc lamp might have been vulnerable to physical problems that affected the recording such as vibration and stability. Rogers concluded at the end of his paper "it is worth putting on record that we have, in effect, produced a hologram in convergent light".⁷⁴

⁷² Dennis Gabor, to Sir Lawrence Bragg, FRS, on 17 November 1955, in *Dennis Gabor Papers*, Imperial College Archives (London), Gabor wrote to Bragg after Bragg had informed him of Zernicke's death: "I wish I could have met him... Holography is as you well know, the combination of Zernicke's coherent background with Bragg's two-step photography".

⁷³ Rogers, "Experiments in Diffraction Microscopy", 193-221 on 212.

⁷⁴ *Ibid.*, 193-221 on 220.

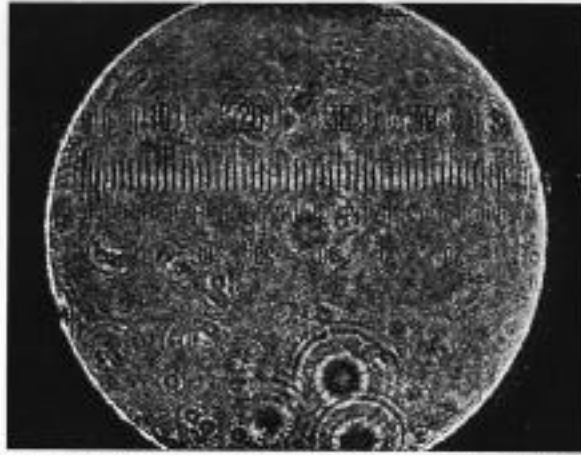


FIG. 10.—Composite image consisting of a reconstruction (above) alongside an image of the object (below), located in the plane of reconstruction, as used for the work of para. 7, using a Gabor system (fig. 6)



FIG. 15.—H 151, a hologram of a testgram

Fig.3.5a. The holograms reproduced from 'Experiments in Diffraction Microscopy', 1951, G.L. Rogers.

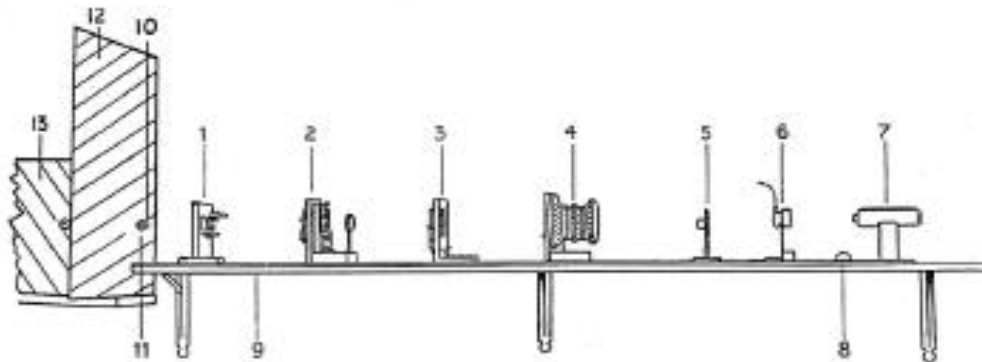


FIG. 8.—Etch Bleach drawing of the apparatus, based on a photograph. (1) Object holder. (2) Plate holder. (3) Hologram holder. (4) Aero-Ektar lens. (5) eyepiece. (6) Lensless camera. (7) Night microscope. (8) Spare objective for night microscope. (9) Shelf. (10) Microscope objective. (11) Knob for changing holes. (12) Screen. (13) Lamphouse.

Fig.3.5b. The optical set-up of G.L. Rogers reproduced from 'Experiments in Diffraction Microscopy', 1951.

None of these later experimenters had the ideal 'coherent' background, yet they concluded that they *had* reconstructed a visible image from a hologram. This was possible because these were all images intended to be mediated through an instrument or microscope. Both groups experimented with existing equipment and as such they could only improve upon Gabor's own ad hoc experiment. They confirmed the validity of the part of Gabor's paper where he undertakes to reconstruct an optical image. But they did not resolve the 'wave front reconstruction' process—in its ideal 'simultaneous' form, from an electron to an optical one using a coherent light source. This would require the design and construction of a fundamentally new instrument. If we judge that Gabor did invent the hologram, then it would be logical to state that these reviewers had produced holograms too. However, these papers are often overlooked and their contribution is not always explained in the Lippmann-to-Gabor narrative. This may occur because they are not identified with any disciplinary success: they are not essential carriers of linguistic or theoretical translation; and they create no new terminology, therefore, they are easily dropped from history.

Gabor's attempt to build an instrument

Between 1951 and 1956 Gabor worked with an assistant, William Goss, supported with funds from the Royal Society's Paul Instrument Fund, on the development of a prototype *Interference Microscope*.⁷⁵ This was essentially under the supervision of Bragg, who wrote to Gabor at the start of the project, warning him that he faced two obstacles: one was that "all our optical firms may not be able to prepare optics for this project due to defence applications". The other was the need to keep the photographic emulsion at an even thickness, in order to avoid what Bragg called "phase-changing film": ordinary emulsion coated unevenly so that it would have affected the recording by changing the 'phase' or synchronisation of the light waves as they travelled through

⁷⁵ Gabor, "Holography, 1948-1971", 168-200, on 176. Gabor also claims, that in 1950 he started a programme (as a consultant) in 'holographic electron microscopy' for the Research Laboratories of the Association of Electrical Industries, Aldermaston, supported by a grant from the DSIR (Directive for Science and Industrial Research), the first grant given by that body to an industrial laboratory. Gabor also experimented on an interference microscope and diffraction microscope. This may have had some military funding and purpose. See: Haine, M.E. and J. Dyson, "A Modification to Gabor's Proposed Diffraction Microscope". *Nature*, 166 (1950), 315-316. Haine, M.E. and T. Mulvey, "The Formation of the Diffraction Image with Electrons in the Gabor Diffraction Microscope", *Journal of Optical Society of America*, 42 (1952), 763-773. Mulvey, T. "Electron Beam Instruments", in *Twentieth Century Physics*, ed. Laurie. M. Brown, A. Pais and Sir. B. Pippard (Bristol & Philadelphia, New York: Institute of Physics Publishing, American Institute of Physics Press, 1995), 1582-1586.

it.⁷⁶ What Gabor required was the *Lippmann-emulsion* of a specific thickness designed to record the interference or diffraction pattern of light. It seemed that Bragg was far more aware than Gabor of the existence of such an emulsion. Like Lippmann, Gabor's paper primarily evokes the fundamental theory of the governing physical process but Gabor's research did not proceed far enough to consider differing photographic emulsions. It was to falter on the impracticalities, immediately after World War II, of finding supplies to build the instrument, just as Bragg had forewarned.

Gabor's correspondence with Bragg reveals that this prototype instrument required parts supplied to a very high technical standard which, according to Gabor, were never met:⁷⁷

When you last visited us, we had decided to get all the prisms reground, so their faces were no longer at right angles to the principal ray, to avoid the intolerable ghosts which arose in the reconstruction... The ghosts were eliminated, and we could take good photographs, but the apparatus was still not good enough for reconstruction... It turned out that the prism grinder had made a small error in the angle, ... and a large error in the thickness of the prisms, ... We tried to go down on our knees before the Ealing [Optical Company] people, to have the correction done quickly, but they had hearts of flint.

Then Gabor in his final report to Bragg stated that another problem prevented their realisation of the *Interference Microscope*: the need to import German optics into the UK, only to then find the lenses to be second-rate, owing to the German military retaining the best.⁷⁸ Gabor's 'wave front reconstruction' theory was proposed for circumstances not yet attainable. In his letter sent accompanying the final report, Gabor stated that:⁷⁹

To clear up the coherent background is only a matter of patience, and of perfect objectives, which I am afraid the British firms are unable to supply, they are all full of cementing specks. In my work on reconstructed wave-fronts I found that a production-line Zeiss objective was far better in this respect than the 2 selected objectives which Cooke-Troughton have picked out from a great number, as the best.

Nor could Gabor find any commercial industrial manufacturers to partner the research. In the same letter he wrote:

⁷⁶ W.L. Bragg to Dennis Gabor, 1951, in *Dennis Gabor Papers*, Imperial College Archives (London).

⁷⁷ Dennis Gabor to Sir Lawrence Bragg, FRS on 17 November 1955, in *Dennis Gabor Papers*, Imperial College Archives (London).

⁷⁸ Dennis Gabor, "Report to the Royal Society Paul Instrument Fund", 1956, in *Dennis Gabor Papers*, Imperial College Archives (London).

⁷⁹ Dennis Gabor to Sir Lawrence Bragg, FRS on 4 December 1956 in *Dennis Gabor Papers*, Imperial College Archives (London).

The British microscope firms who were approached by the R.S. and the N.R.D.C (Cooke Troughton & Sims, Watsons and Bakers) have adapted a very hesitant attitude... On the other hand Leitz, Wetzler, appear to be very interested...It would be certainly deplorable if a British development went to Germany, but it would be worse if all the work we have put into it would lead only to a paper and a patent.

He summarised this frustration more theoretically and elegantly in 1961, as one of:⁸⁰

Correction of the lens errors by any means whatever is bound to fail until certain quite trivial but extremely tough disturbances are eliminated, such as vibrations and stray magnetic fields, which at present, and probably, for a long time to come will limit the resolution at perhaps one-half of what could be theoretically achieved even with the present electron microscope lenses.

This imaging technique was conceived for an instrument that did not yet exist. For Gabor the invention and arrival of the American laser—the ultimate coherent light source—ushered in the possible renewal of interest for his original concept. This anticipation is expressed in a letter written in 1966:⁸¹

Yes, the holographic microscope on which W.P. Goss and I were working 1952-56 was dead for many years, but has now come to life again! I was so disappointed in 1956 when we finished work and could get nobody to take it up, that I did not write it up until ten years later.

However, public and professional interest was not directed towards the original discipline or application, upon which Gabor had speculated, but was directed by the press towards the creation of popular pictorial holograms produced with a laser.

When Gabor's 1949 paper was read retrospectively in the mid-1960s, it was by those physicists and university students who first encountered the *hologram* by reading accounts in the popular science press. For those readers, now seeking the original theory of the new three-dimensional laser image, it was a paper that was possibly disappointing, and obscure in its application to the electron microscope. In 1974 the author of a standard university textbook on optics, seeking to illuminate the content of Gabor's original paper for his reader, advised, "Admittedly, it's not at all obvious that by now shining a plane wave through the processed hologram one could reconstruct an image of the original object".⁸² Discerning the potential nature of the 'wave front reconstruction' was not possible from comparing Gabor's illustrative 'wobbly' before and after imagery. The physical origin of the three-dimensional laser image did not

⁸⁰ Gabor, "Notes for a Profile in the New Scientist, 15 July 1961".

⁸¹ Dennis Gabor, to R. Barer 31 May 1966, in *Dennis Gabor Papers MB/3*, Imperial College Archives (London).

appear to exist within the paper. The term *hologram* seemed to be the only similarity between Gabor's paper and what had very quickly been accepted as a new three-dimensional laser medium. In Gabor's text there was no mention of the 'surprise discovery' of a three-dimensionality that the general reader might have anticipated, or any obvious intention on the part of the author to invent what was to be heralded as the solution to representing three-dimensions. The paper did not provide any insights as to how to make a hologram with a laser, which by the late 1960s was the pressing information physicists sought, as many research laboratories gained access to this new tool. Neither did Gabor's illustrations of any three-dimensional subject match those now reproduced in the popular press.

Gabor's hologram was the noisy diffractive image, the emblem for the translation process—a process that, in principle, went from electrons to photons—and his illustrations a simulation that could only approximate his prediction. When the name *hologram* was applied to the popular three-dimensional laser image, it was in fact given to the part of the experiment that Gabor indicated in his illustrations with the term 'reconstruction'.

Conclusion

Gabor, like Herbert Ives, was able to publish as a sole author. Neither of these authors were included in larger research teams due to their social status—Ives was a PhD candidate and Gabor was not trusted with military research. Sole authorship can make a paper more identifiable, and sole authored papers were rarer after 1900. Both Gabor and Ives were instrumental in naming and labelling—for Ives this was to rename Lippmann's 1908 invention with the term *lenticular*, and to describe Lippmann's 1891 paper in the terminology of twentieth-century physics. Gabor labelled his new form of photograph the *hologram*. By employing linguistic invention—and through the eponymous labelling of the *Lippmann photograph*—a lineage of technical description may develop.⁸³ What may be carried forward in historical citation may rest as much on linguistic description, and new technical language, as it does in the fundamental science or proposal at stake. However, this may be more relevant for inventions that were not ever brought to fruition, such as Gabor's (as it was intended for an electron microscope)

⁸² Eugene Hecht, *Optics*, 2nd ed. (Reading, Mass: Addison-Wesley Publishing Company, 1987), 596.

⁸³ Derek J. De Solla Price, *Little Science, Big Science* (New York and London: Columbia University Press, 1963), 81.

and Lippmann's 1908 three-dimensional screen. These proposals exist primarily as a literary form.

Gabor cited the antecedents to his proposal as being the recent work of Bragg and Zernicke. His paper does not mention Lippmann; this antecedent has been constructed by others who perceived the hologram as a form of photographic image independent of any instrument. Given that the popular pictorial hologram does not appear to have been described in Gabor's paper, we can gain some insight into how the *Lippmann photograph*, and Lippmann's 1891 paper, could provide an historical photographic 'backdrop' to Gabor's *hologram*. I use the concept of the backdrop metaphorically here. With the comparison of the *hologram* to the *Lippmann photograph*, the hologram gains a pictorial and photographic provenance that was absent from Gabor's paper. With this approach, what was missing is replaced through historical citation. This appears to be a disciplinary creation of what, historian Raphael Samuel describes for the museum as a 'living history'.⁸⁴ Samuel describes, and is critical of, the use of old photographs to provide museum display backdrops to objects, in order to provide an historical context. Citations of historical papers can, and do, have the same effect in producing a context.

⁸⁴ Raphael Samuel, *Theatres of Memory* (London: Verso, 1996), 190.

Emmett Leith and Juris Upatnieks and the three-dimensional hologram

Introduction: Researching Cold War classified science

The first three chapters of this thesis introduced the key journal papers and the authors in the Lippmann-to-Gabor narrative. I have considered how Lippmann's 1891 paper may provide a pictorial and photographic perspective on the three-dimensional hologram, and how this element is missing from Gabor's 1949 paper. I have also looked at how differing descriptive modes, both visual and verbal, contribute to an invention's and a paper's future use in citation. This research reviewed published journal papers as primary material, with supporting press reports and archival manuscripts to assess an invention's reception.

The following chapters differ in their use of available research material. Here I review the emergence, in America in the early 1960s, of the popular three-dimensional laser hologram. I wish to stress here that the protagonists Emmett Leith and Juris Upatnieks are still alive and that my access to their personal files was limited. Leith is now Professor Emeritus at the University of Michigan, and Juris Upatnieks was, when interviewed, still an employee of E.R.I.M. (Environmental Research Institute of Michigan) the former military and industrial-sponsored Willow Run Laboratory, that was to separate from the University in 1972. In undertaking this research I visited the University of Michigan Engineering Department to interview both Leith and Upatnieks, (I was not invited to visit E.R.I.M.) and Leith, over a brief period of a week, kindly made available to me some of his personal files. I also witnessed university documents for which I could not be granted copyright permission. When interviewed Leith and Upatnieks recollected their time at Willow Run and their construction of the laser hologram on that site. In response to my query as to whether they were still working on military contracts at this time, Leith described "playing around in between contracts" and Upatnieks recalled how the laser they used came through a hole in the laboratory wall, to be shared with a team on the other side. Such interviews conducted a significant number of years after the events concerned often appear as memoir and anecdote.

Therefore, in my choice of materials, I have decided to use publications where possible and to make minimal reference to the interview. Both these protagonists have been interviewed on numerous occasions by the press since the mid 1960s. I also interviewed, for Chapter Five, Adam Kozma a former student of both Leith and Gabor, who became the source of some disagreement between them. In cases of debate involving a living person, for reasons of copyright, I have chosen to use Gabor's letters to provide a historical witness. Yuri Denisyuk, the former Soviet scientist who initiated, by his citation of Lippmann, this link to the hologram I interviewed by email. The difficulty of both collecting and using oral history as evidence has been considered by historian of science Soraya de Chadarevian, who shared some of her insights with me on the subject, prior to my visit.¹ Aware of these problems, I have used the interviews to inform my background and reading of published and archived material.

However, I wish to point out that had I not visited the University of Michigan I would not have seen the laser holograms, *Deep Train* and *Very Deep Train*, which remain in Leith's private collection; the model train that was used for the image is in the Smithsonian Museum of American History. The descriptions of these holograms, in this chapter, are based on my own experience of viewing them. These Leith set up in the department for some students and myself who had never seen them before. On seeing these, I was aware that the optical equipment and the optical bench that were recorded within the hologram along with the model train in the 'landscape' belonged to the former Willow Run Laboratory, and the circumstances of our viewing them now, in the university department, were entirely different. To me, this was as much an interesting recording of another research facility, as it was an image of a train; and Leith's graduate students responded to my interest by recalling the 'student' anecdotal history of the period: that it was Michigan University students who, in an anti-Vietnam War protest, had bombed the Willow Run Laboratory.

That Leith had worked as part of a larger team developing radar for military surveillance, prior to working on the optical laser hologram, is now public knowledge. Following the declassification of this technology in 1968, the former Willow Run research team published a joint paper and an article in *Scientific American*, which I cite here. Since its declassification, Leith has revised his own personal account of the

¹ Soraya de Chadarevian, "Using Interviews to Write the History of Science", in *The Historiography of Contemporary Science and Technology*, ed. Thomas Söderqvist (Harwood Academic Publishers,

development of Gabor's "wave front reconstruction" and its application to radar. However, as historian of science Hugh Gusterson has stated of military science, "...declassification of information does not always lead to recovering the human history". It may prove difficult to ascertain the role of individuals within a team, especially as any credit is typically given to those in authority. Rather, Gusterson has stressed that the contemporary historian, in cases of military classified science, will be reliant on what he calls "salvage history": these are histories written and motivated "by the increasing urgent desire of the pioneers ...now in their twilight years, to record their labours".² Leith's personal revision perhaps falls into this category. Also, since starting this thesis, another historian of science has begun to consider holography, and at a recent conference for optical physicists, Sean Johnston sketched out a brief overview of the field, which acknowledged that, "...much research is unpublished. For example, the side-looking radar research that lead to holography studies by Leith and Upatnieks was supported by the American military and is still confidential, in parts. The same is true of some of the expertise in Head Up Displays and Holographic Optical Elements".³ The later are holographic applications—known to optical physicists—that might be in current military use within aircraft or targeting devices, for example. And of course many other military uses may retain differing descriptions that do not match popular and civilian labels.

This is an area of research that may never be fully recoverable to the satisfaction of some historians. Historian of science Steven Shapin suggests that we cannot yet see the residue military secrecy has left on "...the effects on scientists' professed norm of openness".⁴ This is an issue that might affect interviews or a former employee's account even some years after the event, when some restrictions might have been lifted. Rather than attempt to recover what was, or might still be 'hidden' by military secrecy, in these following chapters, I wish to look at what was absent from the public domain, and perhaps will remain so. One element I can identify that was lost through Cold War containment and cannot be recovered was the loss to Gabor of what might have been a

1997), 51-70.

² Hugh Gusterson, "The Death of the Authors of Death", in *Scientific Authorship: Credit and Intellectual Property in Science*, ed. Mario Biagoli and Peter Galison (New York, London: Routledge, 2003), 281–307, on 284. Gusterson gives the example of "nuclear salvage history".

³ Sean F. Johnston, "Reconstructing the History of Holography", *Proceedings of SPIE-IS&T Electronic Imaging 5005*, Practical Holography XVII and Holographic Materials, IX (2003), 455-464, on 457.

⁴ Steven Shapin, "Science and the Public", in *Companion to the History of Modern Science*, ed. R.C. Olby, et al. (London & New York: Routledge, 1996), 990–1007, on 1004.

strong role in the formation of a discipline. Without military secrecy the science would have developed, or failed, more openly between 1947 and 1968.

Gabor's 'wave-front reconstruction' and the Willow Run Research Laboratories

The winner of the next war will be the side who made the most of the electromagnetic spectrum. Admiral Gorshkov, cited by Paul Virilio, in *The Vision Machine*.

The optical work that eventually developed into the popular three-dimensional hologram started to be released from the Willow Run Research Laboratories, the military research establishment of the University of Michigan, Ann Arbor, in the 1960s. Before then—unknown to the public and confined by military secrecy—'wave front reconstruction' had initially formed part of a new form of radar surveillance imaging that had been under development at The Willow Run Laboratories since the late 1940s. The start of the Cold War and the 'hot' development of the Korean War in 1950 had made manpower in physics a national security issue and an expanded air force was required to combat the threat of Soviet nuclear weapons.⁵ Two inventions which employed this airborne imaging system, *Side Looking Airborne Radar*, which was declassified in stages from 1968, and *Synthetic Aperture Radar*, declassified in 1970, utilised Gabor's 'wave front reconstruction' principle—within a purpose built processor—to reconstruct the gathered radar data into an optical 'photographic' image. This complex imaging technology was a significant Cold War surveillance tool enabling the American military to monitor communist movement, in such a manner that "Vast areas of Russia can be photographed by planes flying this side of the Iron Curtain".⁶ As early as 1960, the local Ann Arbor newspaper, *The Ypsilanti Daily Press*, on April 19, described this research activity on its front page as, "*University of Michigan Create Photo Radar*": a system of immediate photographic imaging 'taken' with radar or radio waves. The newspaper referred to an early technological development, in which "The Willow Run labs built the ground based computer synthesiser and processing

⁵ Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, Mass., London, England: MIT Press, 1996), 57. Edwards describes how the rapid transition from WWII to the Cold War left "little time for retrenchment into pre-war values". The occupation of Germany and Japan also required significant military investment. See also: David Kaiser, "Cold War Requisitions, Scientific Manpower, and the Production of American Physicists after WWII", *Historical Studies in the Physical and Biological Sciences*, 33, no. 1 (2002), 131-159, on 143.

⁶ Edwin C. Pipp, *Detroit News* April 20 1960. *Private Collection of Emmett Leith*.

equipment” and “Texas Instruments built the airborne portion L-23 aircraft” although the “exact ranges and details remain classified”.⁷

It was the hidden range and the ability to record detail that was the most awesome aspect of this new technology. It collected and recorded data using radar or microwaves, which scanned the earth from a plane. This was described later, in an article by the former Willow Run research team, as a system where a “short pulse of microwave energy is directed from a high-powered transmitter along a vertical fan-shaped beam by the antenna in the belly of the aircraft” and then:⁸

the intensity of the returned signal controls the intensity of a bright spot moving across a cathode-ray tube at a synchronised proportional velocity... An overlapping succession of such lines is traced on a strip of photographic film moving at right angles to the direction of the scan lines with a velocity proportional to the velocity of the aircraft.

This line data was essentially an analogy to Gabor's hologram; it formed lines of interference patterns from which an image could be ‘reconstructed’ into a visible image. When this data-film was illuminated with a beam of coherent light, the interference pattern from each line on the film was regenerated, and reconstructed, at a different but visible wavelength. And “In this way a miniature visible-light replica of the radar waves received by the antenna is formed, recreating a miniature [optical] image of original terrain”.⁹

In 1960 the imaging collection part of the instrument was airborne, with the receiver and synthesiser initially in a van on the ground.¹⁰ The airborne collection of data was dependent on the invention of *Synthetic-Aperture Radar*. This device and strategy developed from 1953 aimed to “realise [a] resolution comparable with the best optical aerial reconnaissance”, in order “to achieve optical comparability [the radar system] would need a large 3000 metre wide antenna”.¹¹ But a ‘synthetic aperture’ was one whereby a plane collected data from a number of different positions along a flight path. The resulting electronic data was then finally synthesised into a single image, as if

⁷ “University of Michigan Create Photo Radar”, *The Ypsilanti Daily Press*, April 19 1960. *Private Collection of Emmett Leith*.

⁸ Homer Jenson, L.C. Graham, Leonard J. Porcello and Emmett N. Leith, “Side-Looking Airborne Radar”, *Scientific American* (1977), 84-95, on 86-88.

⁹ *Ibid*, 84-95 on 90-91.

¹⁰ “University of Michigan Create Photo Radar”.

¹¹ Emmett N. Leith, “A Short History of the Optics Group of the Willow Run Laboratories” (Ann Arbor: The University of Michigan, undated), 1-25, on 1-2.

the original data had been collected from one large antenna.¹² Leith recently described the results as:¹³

the most astonishing observation: when the recorded data was illuminated with coherent light, the transmitted light was an optical regeneration of the original field that would be recorded by the airborne radar antenna as it was carried along the aircraft flight path. The process recreated in miniature the original microwave field, scaled down in both linear dimensions and in wave length—1000 feet of flight path was scaled down to about 20mm in the signal record, and the [radar] microwave wavelength was scaled down from about a centimetre to about 500 nm, the wave length of the [visible] light illuminating it.

The final imagery when reconstructed was photographic, but entirely synthetic, as if it had been taken from a large optical camera, positioned a number of miles directly above the site. This visual transformation was calculated upon the notion that with wave front reconstruction: “a radar image is thus roughly analogous to a photographic image made by a hypothetical camera situated in a line at right angles to a line connecting the object [the ground] to the radar antenna”.¹⁴ This calculation meant that the aircraft containing the radar scanning equipment never flew directly above the geographic territory it mapped. This surveillance system engaged the technological means to image communist army movement, from a vast distance and at a low angle to the subject, so that it imaged terrain that appeared to be beyond the ‘visible horizon’, as experienced by the aircraft pilot. The images appeared as if they were “...taken from a plane many miles away [yet] they appear almost as if from overhead”.¹⁵ This was achieved by flying outside of the enemy’s conventional radar and optical detection, alongside communist territory, but within the geographic borders of America’s Cold War allies. Microwaves and radar could image terrain in great detail, over a considerable range of miles, and these wavelengths could penetrate through cloud and smoke. One significant use of remote surveillance technology in the Vietnam War was, according to historian Paul Edwards, Operation Igloo 1967-1972.¹⁶

This technology was on an entirely different scale and wave length to Gabor’s original holographic electron microscope, but the theoretical principle for the synthesis

¹² This method was also to be employed in the 1980s in radio astronomy, using existing earthbound dishes sited around the earth to form one large antenna when observing the same object.

¹³ Emmett N. Leith, “Reflections on the Origin and Subsequent Course of Holography”, *Proceedings of SPIE-IS&T Electronic Imaging*, 5005. Practical Holography, XVII and Holographic Material, IX (2003), 431-438, in 432.

¹⁴ Jenson, “Side-Looking Airborne Radar”, 84-95, on 87-88.

¹⁵ “University of Michigan Create Photo Radar”.

¹⁶ Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America*, 3-4.

process, that reconstructed the microwave data into an optical image, was the same. It was this element that Leith claims was his contribution to the team.¹⁷ The development of Gabor's 'wave front reconstruction' during the Cold War, within a military funded American University, is similar to the fate of other imaging technologies invented before World War II.¹⁸ Its early release to Michigan University was perhaps prompted by the fact that this element of the American surveillance technology was already in the public domain—with Gabor's 1948 and 1949 papers—and could not be patented by the Army's corporate and industrial partners: Westinghouse Electric; Goodyear; Raytheon; Motorola.¹⁹ Furthermore, Leith and Upatnieks pursued an all-optical form of hologram imaging (without translation from one wave length to another) that was not subject to classification.

This in-flight surveillance imaging system was to be commercially manufactured by Goodyear Aerospace, and eventually the technology was incorporated into civilian, commercial geological and mineral surveys in the Amazon Basin, for example.²⁰ A similar optical military reconnaissance technology in the form of the *CORONA Satellite* system (employed from 1962) was also co-opted for civilian purposes, into the United States Geological Survey.²¹ When declassified, the 'synthetic aperture' technology was combined with *Landsat* surveys to produce highly detailed and falsely coloured maps. One scientist, who worked on the Amazon Basin project, stated that: "When this radar concept was first described, many [physicists] could not understand how its high

¹⁷ Leith has sent me a copy of an unpublished internal memo dated 1956 outlining his contribution. See also Leith, "Reflections on the Origin and Subsequent Course of Holography", 431-438, on 432. Leith describes here how he first came across the Kirkpatrick and El-Sum paper in Oct 1956 and only then Gabor's. See P. Kirkpatrick and H.M.A. El-Sum, "Image Formation by Reconstructed Wavefronts: Physical and Methods of Refinement", *Journal of the Optical Society of America*, 42, no. 46 (1956). This is also reviewed in Chapter Three.

¹⁸ Edward Yoxen, "Seeing with Sound: A Study of the Development of Medical Images", in *The Social Construction of Technological Systems*, ed. W.E. Bijker, Thomas P. Hughes, and T.J. Pinch (Cambridge, Mass: MIT Press, 1994), 281-303, on 284-285. Yoxen describes how an attempt with neurological imagery to interpret images in three-dimensions, the "Hyperphonogram", required some interpretation to be an efficient paper in 1947. This was an invention by University of Vienna staff member, Karl Dussik, who was born in 1908. The principle was to map the interior surface of the brain, by passing ultrasound through the brain, to create layers of two-dimensional imagery. This was taken up at the Acoustics Lab at Massachusetts Institute of Technology by Richard Bolt from 1949 onwards, and funded by the US Navy. Also on page 283, Yoxen describes the 'supersonic reflectoscope' using ultrasound which was produced by Floyd A. Firestone at Michigan University in 1940, the patents were taken out in 1942 but it was not published until after WWII. This concept was first suggested by a Soviet scientist, S.Y. Sokolov, in 1928.

¹⁹ Jenson, "Side-Looking Airborne Radar", 84-95, on 91-92.

²⁰ Ibid.

²¹ John Cloud, "Imaging the World in a Barrell: Corona and the Clandestine Convergence of the Earth Sciences", *Social Studies of Science* (2001), 231-511.

resolution would be maintained for all objects".²² Historian of science Pamela Mack describes in her book *Viewing the Earth: The Social Construction of the Landsat Satellite System* how the scientists involved fought for declassification. Initially, Mack states that, "The Department of Defense did not want reconnaissance satellite technology revealed by civilian use".²³ She described how the Cold War atmosphere of the early 1960s restricted the development of this new field of science because it used instruments developed for military purposes. The Pentagon refused to declassify and the Department of Defense refused to permit separate civilian research groups according to Mack. She cites, as seminal to the eventual declassification process, a conference held at the University of Michigan in 1962 organised by the Infrared Laboratory, under the U.S. Army's 'Project Michigan'. This agency also funded projects—including the early all-optical research by Leith and Upatnieks—in the Radar and Optics Laboratory. This conference brought together scientists keen to learn how to obtain declassification.²⁴

When the general public eventually, saw Landsat imagery it was often assumed to be a conventional photographic image taken from a satellite, rather than a synthetic radar construction. Such imagery, even though its initial premise was military, was promoted as both aesthetic and popular from 1969 onwards, by Beaumont Newhall, the Museum of Modern Art's first photographic curator who authored *Airborne Camera: The World from the Air and Outer space*. Newhall was the most prominent American promoter of post World War II photography as an art form, and had (in addition to being a curator) been an interpreter of aerial photography for the US Army Air Force.²⁵ With this 1969 publication, Newhall successfully introduced an aesthetic appreciation to aerial photography, by promoting American military and civilian imagery as a contemporary 'art' for public consumption.

It was against this background of obscured and classified military research, which continued into the 1970s, that 'wavefront reconstruction' was pursued as an all-optical

²² Winston E. Kock, "Extensions of Synthetic Aperture Radar Information Processing", in *Us-Ussr Science Cooperation Seminar on Optical Information Processing (Washington D.C. 1975)*, ed. Yu. E. Nesterikhin, George Stroke and Winston E. Kock (New York: Plenum Press, 1976), 117-128, on 118. Kock discusses the Amazon basin project; he also uses the term 'hologram' to describe the radar-to-optical processing.

²³ Pamela E. Mack, *Viewing the Earth: The Social Construction of the Landsat Satellite System*, ed. W.E. Biker, W.B. Carlson, and T.J. Pinch, *Inside Technology Series* (Cambridge, Mass., London, England: MIT Press, 1990), 11.

²⁴ *Ibid*, 38-39.

²⁵ Beaumont Newhall, *Airborne Camera: The World from the Air and Outerspace* (New York: Hastings House and George Eastman House, Rochester, NY, 1969), 40.

imaging technique, with laser holography, within the Institute of Science and Technology at Michigan University. Nevertheless, to the general press and public, the three-dimensional hologram, appeared to be pursued outside of the military confines of The Willow Run Laboratories, the industrial military and university-run complex. Like military aerial photography, the three-dimensional hologram was an example of how Cold War military science could extend beyond the confines of military secrecy to find a visual popularity. Social historian Mark Solovey, writing on this phenomenon of American Cold War university research, has remarked that: "Sometimes the civilian and military spheres seem to have been integrated in troubling ways".²⁶ Military and university collaboration created concerns regarding the nature of academic research; as to whether such research was solely military led and funded, or whether it could be perceived as independent or 'pure science'. This confusion of delegation and independence was to affect both the public's perception of university-employed science researchers, and the employees themselves. Staff and students at Michigan University campaigned from the mid-1960s for the eventual legal separation, in 1972, of The Willow Run Laboratories from the educational remit of the main institution. There was also, by 1970, an increasing surplus of PhD graduates seeking employment who added to their voice to this campaign.²⁷

However, the three-dimensional laser hologram was developed upon initial research, which had been military funded and undertaken by Emmett Leith, then a junior research team member.²⁸ As Solovey points out, such research was often constrained and influenced by the "...efforts to maintain a distinction between civilian and military science [which] were often elaborate, as barriers based upon national security requirements determined who could and could not access data, results and instrumentation from classified".²⁹ Military research also created, according to Derek de Solla Price, a "class of fractional authors...that is scientists who produce one *n*th of a

²⁶ Mark Solovey, "Science and the State During the Cold War: Blurred Boundaries and a Contested Legacy", *Social Studies of Science*, 31, no. 2 (2001), 165-170, on 167.

²⁷ Kaiser, "Cold War Requisitions, Scientific Manpower, and the Production of American Physicists after WWII", 131-159, on 150-151. Kaiser describes how following government appeals to increase the number of physicists in the 1950s there was a surplus and discontented group by 1970 which participated in the anti-war movement.

²⁸ Leith, "A Short History of the Optics Group of the Willow Run Laboratories", 1-25, on 5. On Synthetic Aperture Radar: "...as a very junior person, my contributions were comparatively small".

²⁹ Solovey, "Science and the State During the Cold War: Blurred Boundaries and a Contested Legacy", 165-170, on 167

paper”.³⁰ Yet, military research was sought after during the Korean and Vietnam wars because a scientist could avoid the draft while retaining both a patriotic and masculine identity. The only reasons that rendered one ineligible for military service were to be declared unfit or homosexual. Those who wished to avoid the draft often left the country. Non-military researchers also faced restrictions, historian of science Jessica Wang states that, “Wartime security clearances, originally conceived as a temporary expedient, became a permanent feature of Cold War Science”, as well as “loyalty inquiries” as to perceived communist sympathies.³¹

Emmett Leith served as a naval radar engineer in World War II, and was part of a generation who gained access to higher education through military service. He described his educational background and the choices he made within the research team at The Willow Run Laboratories: “I chose the optical processor... As a physics major among mostly electrical engineers... I had four optics courses... physical optics, ten courses in spectroscopy, and a course in X-rays and crystal structure”.³² In a paper published in 1968, *Synthetic Antenna Data Processing by Wavefront Reconstruction*, Leith and co-author A.L. Ingalls described the theoretical standpoint in their earlier classified research on, “the synthetic antenna concept, which was developed *almost entirely* within the bounds of military secrecy” (my italics):³³

Immediately after the development of the processor, we recognised that the synthetic antenna radar system, in combination with the coherent optical system could equally well be interpreted as a process of wavefront reconstruction (or holography, to use current terminology). There began a process of reinterpretation on which the theory of the system was completely recast from an optical viewpoint built around Gabor's theory of wavefront reconstruction. Since that time (1955) optical processing systems for synthetic antenna radar have been conceived and designed almost entirely within a holographic framework; this viewpoint appears to be more flexible than the communications theory...

In conceiving this analogue process to be an optical and holographic one, it amounted to what Leith described—for Gabor's theory—as “...a strange kind of revival that started

³⁰ Derek J. De Solla Price, *Little Science, Big Science* (New York and London: Columbia University Press, 1963), 90.

³¹ Jessica Wang, *American Science in an Age of Anxiety: Scientists, Anticommunism, and the Cold War* (Chapel Hill and London: The University of North Carolina Press, 1999), 2.

³² Leith, “A Short History of the Optics Group of the Willow Run Laboratories”, 1-25, on 5.

³³ E.N. Leith and A.L. Ingalls, “Synthetic Antenna Data Processing by Wavefront Reconstruction”, *Applied Optics*, 7 (1968), 539-544, on 539.

in 1956, but under military security”.³⁴ In one of their earliest joint research papers supported by ‘Project Michigan’, *Reconstructed Wavefronts and Communication Theory*, 1962, Leith and Juris Upatnieks, who was then a graduate researcher,³⁵ described in different terminology the “two-step imaging process discovered by Gabor, ...called a hologram...” whereby:³⁶

...from a communication-theory viewpoint... it is shown that construction of the hologram constitutes a sequence of three well-known operations: modulation, a frequency dispersion, and a square-law detection...in the reconstruction process, the inverse-frequency-dispersion operation is carried out.

Thus this process could be described from two differing standpoints: the electronic processing of signals, or the optical reconstruction, which was also named ‘holography’. For Leith it now seemed that, “the same optical system can be completely, accurately and succinctly described from two completely differing viewpoints is intriguing”.³⁷ Of the two disciplinary descriptions Leith felt that “between 1959 and 1962, holography was better known to the radar scientist than to optical scientists”.³⁸ A combination of descriptions might be more common in the field of radar, because historically it had, since its discovery, always been a combination of civilian and military science.³⁹ Prior to the discovery that holography could produce spectacular three-dimensional imagery, and before lasers were generally available in the laboratory, wave front reconstruction was considered a subject known under the term ‘optical processing’. The optics group within the radar laboratory at Michigan, of which Leith was head and Upatnieks was staff, was described by Leith as having been one of the largest devoted to coherent optical processing: “...we were a large group, extremely well funded, and with some very specific missions. The price paid for this enviable position was, at least until 1963,

³⁴ E.N. Leith, “Overview of the Development of Holography”, *Journal of Imaging Science and Technology*, 41, no. 3 (1997), 201-214, on 201.

³⁵ In 2001, Upatnieks was still an employee of the renamed Willow Run Laboratories now the Environmental Research Institute of Michigan: E.R.I.M.

³⁶ Emmett Leith and Juris Upatnieks, “Reconstructed Wavefronts and Communication Theory”, *Journal of the Optical Society of America*, 52, no. 10 (1962), 1123-1130, on 1123. This paper acknowledges the sponsors “This work was conducted by Project Michigan under a Department of Army Contract, administered by the U.S. Army Signal Corps”.

³⁷ E.N. Leith and A.L. Ingalls, “Synthetic Antenna Data Processing by Wavefront Reconstruction”, *Applied Optics*, 7 (1968), 543.

³⁸ Leith, “Overview of the Development of Holography”, 201-214, on 202.

³⁹ D.E.H. Edgerton, “Science and War”, in *Companion to the History of Modern Science*, ed. R.C. Olby, et al. (London & New York: Routledge, 1996), 934–989, on 940.

difficulty and long delays in publishing our work in the open literature".⁴⁰ Such isolation prevented the discipline developing openly along shared lines of concept and language.

Lensless photography: a press release in 1963

The public notification of this new optical processing, and its site of origin, took the form of a press release issued by the American Institute of Physics in December 1963. This described the invention in terms more easily understood by the lay public as 'lensless photography'. It was camera-less, and used the physical wave front of a diverging beam of light to image, and later reconstructs the image at another location within an optical system. Such a system, using a laser without any lens, would have the image or data throughout the apparatus and not just restricted to the focal plane of the lens. The *New York Times* wrote up this story, using the information in the press release. This press release was illustrated (fig.4.1) with two images: a reconstruction of a photographic transparency of Leith's daughter, and an image of its unreconstructed data in the form of an interference pattern; the text also speculated on future medical and military uses for this 'lensless camera'.⁴¹ The press release could not mention the classified military radar antecedent behind the system, nor did it mention the Army's "Project Michigan" funding, but it did cite "the earlier, theoretical development of the two-step imaging process by Dr Dennis Gabor..." which it claimed "...until now has never yielded high quality images". This press release was based on work undertaken with a laser, but was unlike Gabor's original 'in-line' set-up, which retained the optics in a linear path, intended for use within a microscope column. Leith and Upatnieks reconfigured the optics and used a 'reference beam' brought in at an angle on a table, constructing "...a two-beam interferometric technique", not unlike the optical arrangement found in the earlier 'Michelson interferometer'.⁴² (This provided another antecedent from the discipline of modern optical physics to the laser hologram, as I have indicated in the introduction to this thesis.) This new application they patented. The press release stated that this single improvement "led to the complete success of the two-step imaging system".

⁴⁰ Leith, "A Short History of the Optics Group of the Willow Run Laboratories", 1-25, on 25.

⁴¹ John A. Osmundsen, "New Camera Operating without Lens Shows Scientific Promise", *New York Times* (December 11, 1963).

⁴² Emmett N. Leith and Juris Upatnieks, "Wavefront Reconstruction with Continuous-Tone Objects", *Journal of the Optical Society of America*, 53, December (1963), 1377-1381. This paper acknowledges sponsorship from the A.F. Office of Aerospace Research, as part of the Project Agency's Vela Uniform Program.

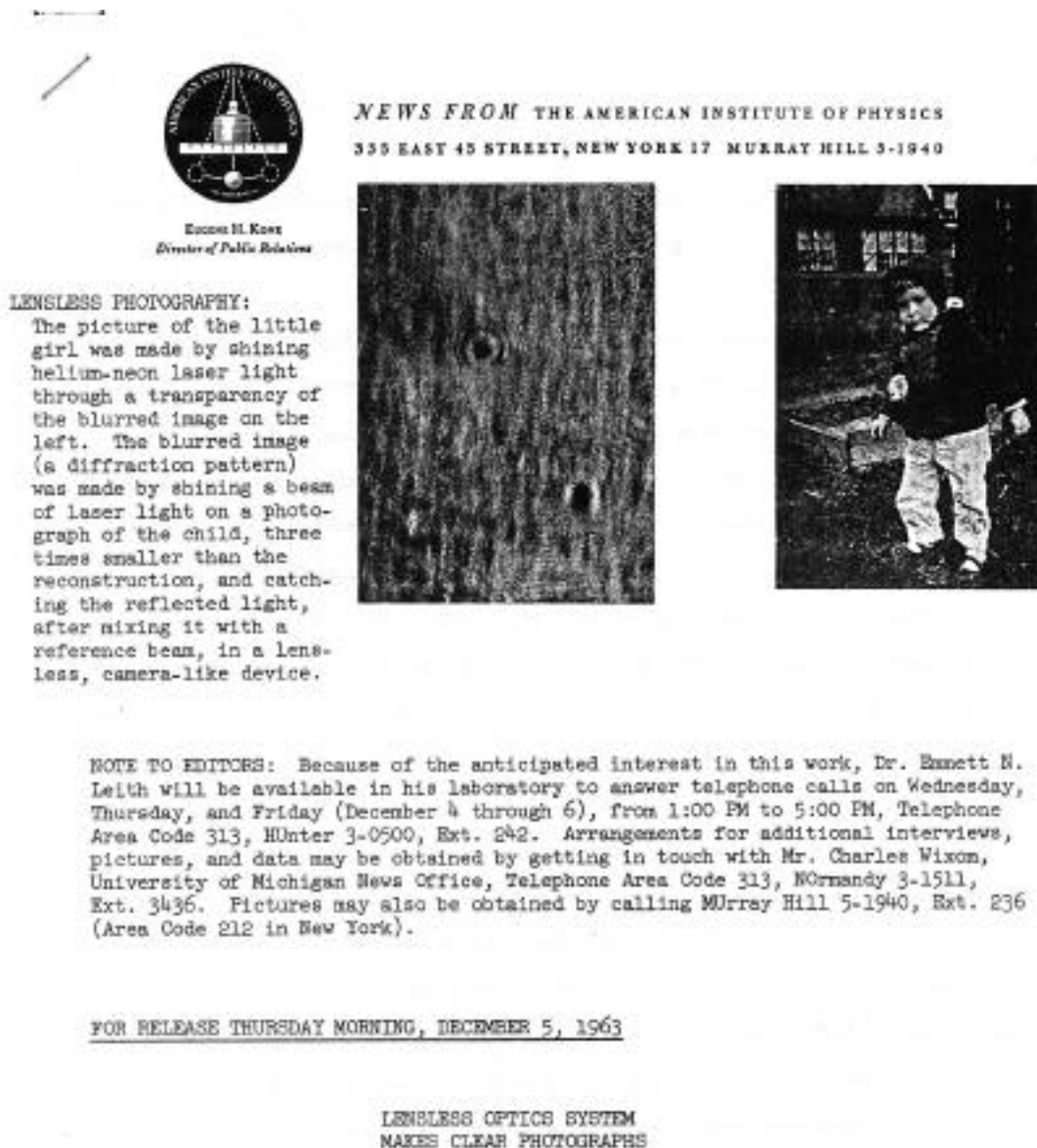


Fig.4.1. Detail from the press release on 'Lensless Photography', 1963.

Collection of the MIT (Massachusetts Institute of Technology) Museum, Cambridge, Mass.

Gabor's first knowledge of this work was from reading accounts published in the press in the early 1960s.⁴³ Leith, who had been previously prevented by military constraints, wrote to Gabor in 1969, explaining the military classification status of this technology, and inviting him to visit this heroic 'citadel' of holography:⁴⁴

⁴³ Dennis Gabor to Sir Lawrence Bragg, FRS, 7 May 1965 in *Dennis Gabor Papers*, Imperial College Archives (London). Writing to Bragg regarding his early experiments in holography, "...I think you will be glad to hear that after a long interval the subject has come to life again in the United States, by the work of Leith & Upatnieks..."

⁴⁴ Emmett N. Leith to Dennis Gabor, 13 February 1969, in *Dennis Gabor Papers*, Imperial College Archives (London), with copyright permission of Emmett Leith.

... I am glad that, after so many years of secrecy, we were allowed to communicate this work to you. In 1956, when I reinterpreted the process in terms of holography (or wavefront reconstruction, as it was then commonly called), I wondered if some day we would meet you and, if so, be able to tell you of this work... There are, however, yet other things to add; as our government permits, we will publish them and thus reveal them to you... I urge you to visit Ann Arbor soon and see what has, in the past year, transpired in this citadel of holography.

To Gabor, who had not been trusted by the British Government to work on microwave and radar in World War II, news of this classified military hologram was perhaps more theoretically interesting than that of the popular three-dimensional image. Gabor replied to Leith referring to this research as the "...ingenious work on the side looking radar, which is a bit of very advanced holography".⁴⁵

The background context of the military research laboratory provided Leith and Upatnieks with privileged access to the laser invented in 1961. They quickly gained access to this in 1962. The laser was a simulated coherent point source that emitted an ultra bright beam of light at one single wavelength, as if from some *infinite* distant source. The illumination travelled in a controllable straight line, and so did not diverge or blur the final image, like other sources of illumination. It was known, both to Gabor and other experimenters that in principle the nearest approximation to a point source would provide a better resolution to Gabor's hologram. The laser gave Leith and Upatnieks a technical advantage over other previous attempts to improve upon Gabor's original experiment. However, it was the combination of the laser and the rearrangement of the optics that rid the process of double images, the 'ghosts' Gabor complained of, and rendered sharp and distinct photographic transparencies.

Nethertheless, as most of the research at The Willow Run Laboratories had been achieved, with what many might now consider to be an incoherent source when compared to a laser—a mercury arc lamp—much of the practical skill brought to the process by Leith was also to remain obscured by the classification restrictions at this time.⁴⁶ The incremental practical development, from radar to optical, was never transparent. The later use of the laser by Leith and Upatnieks suggested to other

⁴⁵ Dennis Gabor to Emmett N. Leith, in *Private Collection of Emmett Leith* (11 May 1969).

⁴⁶ Leith, "A Short History of the Optics Group of the Willow Run Laboratories", 1-25, on 13-14, "by 1962 we had 15 staff, 6-7 well equipped laboratories, lenses, optical rails, benches, and a coherent light source an Hg arc lamp... Skilled experimenters could get quite impressive results using the Hg source".

physicists that their achievement rested solely on the existence of this technology. This is a notion that Leith now wishes to repudiate.⁴⁷

We have often been credited in the literature as being the first to apply the laser to holography. We have never claimed this to be the case, and it is in fact not true. Others, elsewhere, who had earlier access to lasers, used them to make holograms about a year before we did. The results had never been reported in the literature, but had been presented at technical meetings.

The context surrounding the emergence of the three-dimensional hologram: a technology with a well-defined military purpose that was obscured by military classification and description, yet simultaneously widely exposed in the press—as a visual novelty in search of an application created a paradox.

To see a flat transparency ‘sharply’ as imaged by the laser, floating in space in a lensless camera, was considered worthy of press attention in 1963. However, it was the ‘system’ of imaging and quality that was novel, not solely the floating image: transparent images could already be focused into ‘space’ and more commonly onto a screen, with a lens. To create from this camera-less system the laser-viewable and three-dimensional hologram—the novel form of optical image—solid objects not transparencies had to be imaged.⁴⁸ In order to create bright clear images suitable for public display, a considerable engagement with visual and photographic skill was required. These visualisation skills were no doubt also those required in the processing of radar data into visually presentable, and perspectively corrected photographs. The initial resulting photographic reconstructions of laser holograms were first documented with instant black and white Polaroid film. With this medium, these images would not have revealed any of the inherent three-dimensionality that Gabor predicted.⁴⁹ Even when Leith and Upatnieks had progressed to one-inch square photographic plates, these images offered no discernable ‘parallax’ or stereo opportunity to experience a three-dimensional scene: “...we could see into it with only one eye, hence the 3-D that had to be there was not perceivable”.⁵⁰ But these plates would have recorded the image as a

⁴⁷ Ibid, 1-25, on 17.

⁴⁸ Emmett Leith and Juris Upatnieks, “Wave-Front Reconstruction with Diffused Illumination and Three-Dimensional Objects”, *Journal of the Optical Society of America*, 54 (1964), 1295-1301.

⁴⁹ These Polaroid photographs are in the Holography Collection, the MIT Museum, Cambridge, Mass.

⁵⁰ E. Leith, “Some Highlights in the History of Display Holography”, in *Proceedings of the International Symposium on Display Holography*, ed. T.J. Jeong (Illinois: Holography Workshops, Lake Forest College, 1983), 1-4, on 2.

sharper laser reconstruction, than could be reconstructed again with a laser. A Polaroid, by comparison, merely documented the experiment.

The re-introduction of the Lippmann emulsion

The photographic glass plates that Leith and Upatnieks chose to work with were standard Kodak spectroscopy plates. This emulsion coated onto glass introduced a nineteenth-century recording medium to the laser hologram. The Kodak spectroscopy plate was by definition a *Lippmann emulsion*, capable of recording an interference pattern throughout the thickness of the gelatine substrate. Kodak identified the plates with the number 649-F.⁵¹ It was fortuitous that this emulsion was accessible to them in 1963 as a commercially available product. This photographic plate was an enduring residue from Gabriel Lippmann's much earlier 1891 invention for an interference colour photograph, which was successfully employed as a medium for spectroscopy. Leith and Upatnieks did not have to invent or perfect a photographic emulsion in order to record a hologram in the manner that the Lumière Brothers improved and produced the *Lippmann emulsion* for the *Lippmann photograph*.

In 1962, and prior to Leith and Upatnieks employing this medium, a Soviet scientist Yuri Denisyuk published a paper, *Photographic Reconstruction of the Optical Properties of an Object in its own Scattered Radiation*. That same year this was translated and published in the United States by the American Institute of Physics, this was intended to inform American physicists of Soviet research during the Cold War. Denisyuk proposed a three-dimensional image of an object recorded onto a *Lippmann emulsion* that could be viewed in white (sun) light. Denisyuk named his image a 'wave photograph' and stated that he had undertaken experiments to test the theory; recording spherical mirrors, and a micrometer, with an unnamed light-source of 5460 Å. He described the process as one of an "optical scattering operator". Soviet science in the communist era was not aligned to commercial interests.⁵² However, Denisyuk proposed that this technology could be applied to "...the development of optical imagery techniques, creating a complete illusion of reality in the reproduction of objects, as well as in structural analysis (electron structural analysis, X-ray structural analysis, etc)

⁵¹ Lloyd E. Varden, "Lenless Photography", *Photomethods for Industry*, 7, no. 1 (1964), 30.

⁵² Bruce Parrott, *Trade, Technology, and Soviet-American Relations* (Bloomington: Indiana University Press, 1985), 28-29. Parrott describes how the USSR had more researchers than any other country, including the USA, it also had no high-income consumers and did not import Western technology, which was not suited to Soviet needs.

sonar, radar, ultrasonic flaw detection, and in the preparation of dispersing elements of the diffraction grating type".⁵³ Denisyuk did not cite the work by Herbert Ives, but 'dispersing elements of the diffraction grating type' are very similar to the use Ives suggested physicists might make of Lippmann photography in his 1908 paper. Denisyuk, unlike Ives, has applied the technique to objects. Whereas Gabor was primarily focussed on the 'wave front reconstruction' as a translation process, from electron to photon. Denisyuk is concerned with the final 'photographic recording'. Denisyuk has stated that Soviet researchers gained access to the laser from 1964, although researchers might have been aware of the laser's prior development. Denisyuk cited Gabor's work but he stated that in the Soviet Union, "... Gabor was practically unknown to scientists until 1964 when photos of 3-D images were published in papers". Denisyuk states that when lasers became available to him in 1966 he resumed work on holography.⁵⁴

When laser holograms were eventually produced in the Soviet Union, Soviet researchers produced and improved their own emulsions; they did not have access to Western commercial products. This proposal in 1962 retained a literary importance amongst holographic physicists. Denisyuk's paper introduced with its citation of a *Lippmann emulsion*, a precedent, dated 1891 and, therefore, prior to Gabor and Leith and Upatnieks, for the emergence of a recorded image exploiting interference. Denisyuk's proposed technique, when combined with a laser, was eventually to form a holographic image viewable in ordinary white light, the colour of which was reconstructed by interference, as was the colour in a *Lippmann photograph*. By 1964, Leith and Upatnieks, in their paper on the three-dimensional laser hologram accommodated, by citing Denisyuk, the contribution of the *Lippmann emulsion*. During the Cold War, and prior to declassification, a Soviet research paper provided a provenance—with its insight drawn from a study of nineteenth-century interference and emulsions—for the American three-dimensional laser image.

⁵³ Yuri Denisyuk, "Photographic Reconstruction of the Optical Properties of an Object in Its Own Scattered Radiation Field", *Soviet Physics—Doklady*, 7, no. 6 (1962) 543-545, on 545. Translated from: *Doklady. Akademii. Nauk. S.S.S.R* 144, no. 6 (1962), 1125-1128.

⁵⁴ Yuri Denisyuk in an email to Susan Gamble, 24 January 2001: "Lasers in USSR were available since 1964, but at that time I quit for a while with holography and worked on laser radar for satellite location. I renewed the research in holography in 1966" (copyright Susan Gamble).

The first public display of the three-dimensional laser hologram

This realisation of the laser hologram as a three-dimensional image was to be what Leith later described as, an essentially unpatentable 'invention'.⁵⁵ Leith and Upatnieks attracted public attention with the first successful realisation and presentation of display-quality laser-recorded holographic imagery; the promotion and dissemination of which relied heavily on visual demonstration. This forced Leith and Upatnieks into the role of visual 'showmen' in the nineteenth-century and bohemian sense; they had to pursue an actual audience, not simply a readership of subscribers to academic journals. The three-dimensional holographic spectacle needed to be witnessed, by credible reporters. This manner of dissemination resembled the efforts of the Lumière Brothers in promoting the pictorial *Lippmann photograph*, which required the repetition of many projected picture-shows. The first public demonstration of the three-dimensional laser hologram off of the Michigan campus was in Washington, for an Optical Society of America meeting in April 1964. This accompanied the presentation of a paper on the image. The demonstration of holograms of a model train was held in a hotel room appropriated by laser manufacturers Spectra Physics, for displaying and selling lasers during this Washington meeting.⁵⁶ The paper Leith and Upatnieks presented, *Wavefront Reconstruction with Diffused Illumination and Three-Dimensional Objects*, still adhered to the formal scientific description.⁵⁷ This paper, unlike the two previous ones, did not acknowledge any military sponsor. Leith, in a letter to Gabor, explained how "These holograms were viewed by hundreds of attendees. By the end of the month we were being deluged with telephone calls from opticians all over the country, asking for advice on how to make holograms".⁵⁸ The emergence of the hologram was seen alongside the promotion of the laser, now a commercially available laboratory item: the image and the tool appeared together.

⁵⁵ Emmett Leith email to Susan Gamble, 19 June 2000: "Juris and I have many patents on holography, but mostly they relate to off-axis holography. I can't imagine being able to patent a laser viewable hologram-there's really nothing there to patent, same for laser-produced holograms" (copyright Susan Gamble).

⁵⁶ Susan Gamble, *Taped Interview with Emmett Leith, with Copyright Permission of Emmett Leith* (12 December 2000).

⁵⁷ Emmett N. Leith and Juris Upatnieks, "Wavefront Reconstruction with Diffused Illumination and Three-Dimensional Objects", *Journal of the Optical Society of America*, 54, no. 11 (1964), 1295-1301

⁵⁸ Emmett N. Leith to Dennis Gabor, 9 April 1969 in *Dennis Gabor Papers*, Imperial College Archives (London), with copyright permission of Emmett Leith.

Science in the popular press

Writing for academic journals was not the only means of dissemination to a wider scientific community. Leith and Upatnieks transcribed the technical terms and concepts of optical processing and radar communications into a simpler journalistic language for the popular science press. These texts were accompanied with many images, picture-story photographs and graphic representations, creating a narrative that produced magazine copy. Typically, this imagery was divided into three key visual ciphers for the reader; the interference pattern, noise, or *Newton's Rings*, to denote the recording: the bright graphic laser beam as the originator: and the final reconstructed, familiar and clear, picture of the object. This use of visual material is similar to Gabor's three-stage photographic depiction of wavefront reconstruction.

For many physicists, the popular magazine article by Leith and Upatnieks was the first encounter with the hologram. This was the case for two American science authors, of the 1960s and 1970s, David Bohm and Karl Pribram—who each explored and promoted alternative 'holistic' theories of either a holographic universe or holographic memory. Pribram, who wrote the book *Languages of the Brain*, while at the Center for Advanced Studies in the Behavioral Sciences, Stanford, admitted to the influence of these press accounts. He stated in an interview “In the mid-60s, he read a *Scientific American* article describing the first construction of a hologram, a kind of three-dimensional “picture” produced by lensless photography”.⁵⁹ Physicist David Bohm had written to Gabor, from Birkbeck College London, just one month after Leith had informed Gabor of the declassified military uses of his own invention. Bohm had lost his job in the United States at Princetown University, for having been identified as a former communist party member. He eventually moved to England in 1957, after living first in Brazil, and then Israel.⁶⁰ In his letter, Bohm revealed to Gabor his speculations on the hologram as a model of 'undivided wholeness',⁶¹ a concept Bohm was later to pursue. He outlined his ideas to Gabor, admitting he had yet to see a hologram:⁶²

⁵⁹ Marilyn Ferguson, “Karl Pribram's Changing Reality”, in *The Holographic Paradigm and Other Paradoxes*, ed. Ken Wilber (Boulder & London: Shambhala, 1982), 17.

⁶⁰ Jessica Wang, *American Science in an Age of Anxiety: Scientists, Anticommunism, and the Cold War* (Chapel Hill and London: The University of North Carolina Press, 1999), 211-213 and 277-278. Wang cites and discusses Bohm's case as an example of 1950s academic blacklisting.

⁶¹ David Bohm, *Wholeness and the Implicate Order* (London, Boston and Henley: Routledge and Kegan Paul, 1980), 145-7, 177-8, 189.

⁶² David Bohm to Dennis Gabor, 14 March 1969, in *Dennis Gabor Papers*, Imperial College Archives (London).

I have been thinking about holograms for a long time. It has struck me very forcibly that the hologram has an ever-greater significance for philosophy and for language than it has for technology. In short, as in the life of Hobbes, the lens, and the relationship of image and object, became a paradigm of human thinking, especially in science and art, so it seems that the hologram can now lead us to a new paradigm. The core order in the older paradigm was image-object correspondences. In the newer paradigm, it is a relationship of the whole to the whole.

It seems to me that the hologram helps lead us to a new informal language for discussing quantum theory, relativity, and other subjects. I would very much like to discuss this with you sometime. Also, I would like actually to see a hologram in operation.

Are you interested in discussing these matters?

Popular press accounts could inspire or motivate other professionals, and they strengthened by repetition the use of a descriptive popular terminology. Bohm and Pribram responded to the hologram as outlined in popular accounts, not the journal papers of Leith and Upatnieks, which retained formal terms. There is no archival evidence (at Imperial College) that Gabor had any interest in engaging in a dialogue on the hologram with Bohm, a theoretical physicist, who placed a value on the notion of an 'open dialogue'; although they had corresponded previously on the topic of the 'quantum inch'. Gabor did not reply to Bohm's request probably because he did not have any laser holograms of his own to show him, nor did he have the laser or optics for three-dimensional holography at Imperial College, London. The popular press also influenced students and their subject choices for study. This was to affect Gabor, on his retirement from Imperial College in 1965; he chose to provide the department with a small holography laboratory. Gabor stated his desire to leave to his successor, John Brown, "...something which is alive and new, because my electron physics and plasma lab is dying for lack of good students, who are no longer attracted by what they consider an unfashionable field".⁶³ Three-dimensional laser holography now displaced the original curriculum that Gabor had taught, and the discipline from which it had emerged. Popular accounts could fashion and influence the demand for products, educational courses and scientific disciplines. The popular science press could mediate a visual science in colour—with the aid of professional graphic designers, photographers and editors—and construct an upbeat context of 'newness' and optimism. Such

⁶³ Dennis Gabor to Prof. E.N. Leith, 3 November 1966, in *Dennis Gabor Papers*, Imperial College Archives (London).

expressions, both visual and textual, were not accommodated within academic journals, which could also take far longer to publish.

The three-dimensional hologram as featured in two popular colour publications.

Against a backdrop of anti-Vietnam War protest and anti-military sentiment, the hologram and the laser—well promoted by Michigan University in 1964 and 1965—attained a public arena and audience for this visual invention within the magazine. 1965 was the peak year of public protests against the Vietnam War, which had started in 1963. “Among the first actions, specifically targeting Vietnam were a series of teach-ins held on college campuses usually organised by the faculty. The first to achieve national attention occurred at the University of Michigan, on 24 March 1965. Three thousand people attended a series of lectures that ran all evening and into the next morning”. A further 120 such teach-ins followed in different American Universities that spring term.⁶⁴ By 1966 many protesters of the Vietnam War were also veterans of the war. In June 1966, the “Fort Hood 3” became the first American soldiers to refuse to go to Vietnam.⁶⁵ This in addition to the civil rights movement became a significant expression of public discontent. The promotion of the three-dimensional hologram in conjunction with the laser, as a new invention for civilian use from 1963 onwards, presented an optimistic outlook on technology that would have directed public attention away from military associations. This promotion also coincided with the 1963-1965 ‘modernising’ World’s Fair held in Flushing, New York, which showcased American technology and engineering in futuristic and consumer forms, for example, picture phones, colour television, three-dimensional movies, and space exploration.

⁶⁴ Mitchell K. Hall, *The Vietnam War, Seminar Studies in History* (Longman, 2000), 22.

⁶⁵ Priscilla Murulo and A.B. Chitty, *From the Folks Who Brought You the Weekend: A Short, Illustrated History of Labor in the United States* (New York: The New Press, 2001), 258.

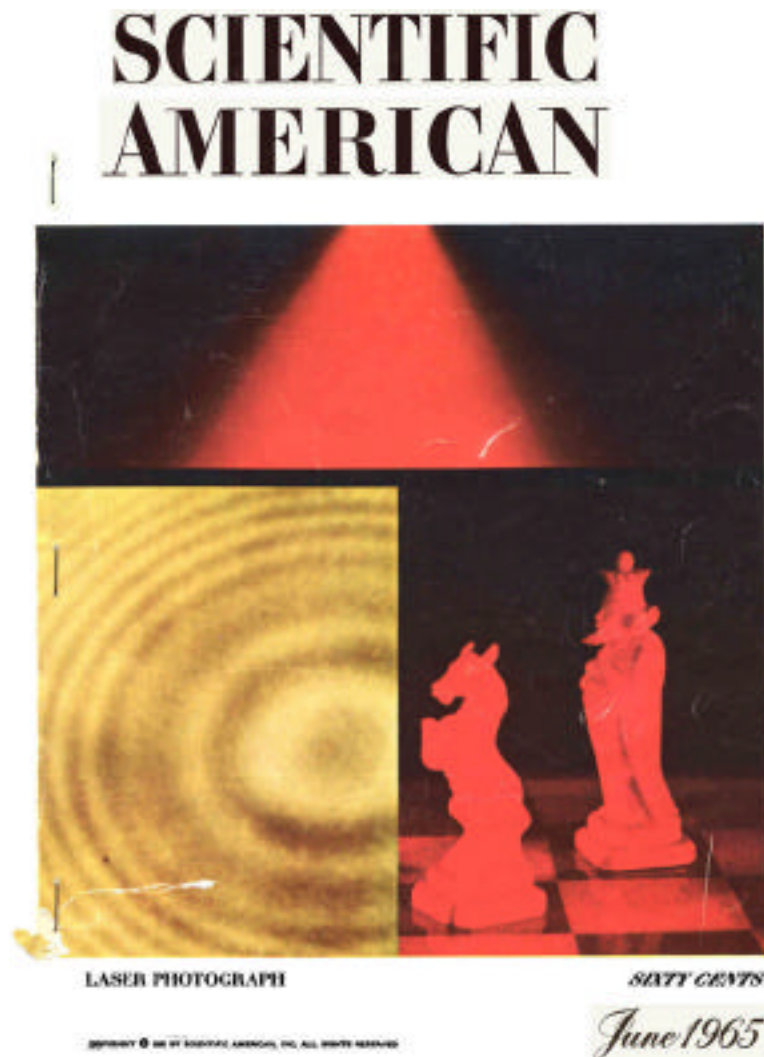


Fig.4.2. Cover Article on Laser Photography, *Scientific American*, June 1965.

Promoting the hologram was achieved through such press coverage as the June 1965 edition of *Scientific American*, which featured *Laser Photography* on its cover (fig.4.2). Inside, the article by Leith and Upatnieks ran to ten pages of pictorial depictions and explanations of modulation and wave formation. The picture editor had selected for the cover three bold graphic emblems: the expanding and grainy beam of laser light, reproduced in red against black: the chaotic interference pattern of rings appearing as if a *natural* grain in ochre: and the finally resolved sharp red masculine and territorial chess pieces.

But it was in *Life* magazine in 1965 that the hologram was defined as a new 'art form'.⁶⁶ *Life* was an expensively produced large-format and internationally distributed

⁶⁶ Fritz Goro, photographer, "In Holograms Lasers Give Picture a Third Dimension", *Life*, 61, no. 22 (1965), 116-117.

life-style magazine, which ran until 1972. This magazine was seminal in the promotion of American modernist social values—capitalism and individual freedom—values that would hold in check the spread of communist ideology. American ‘modern art’ was perceived to uphold those values; *Life* had covered ‘modern art’ in 29 stories of the American art scene from 1936 to 1942 and, from 1937 *Life* covered art in full-colour.⁶⁷ Whereas few art museums could finance or distribute colour catalogues at this time, *Life*'s coverage was on a lavish scale, which secured the magazine's role in promoting American culture. Not entirely patriotic, *Life* also published images of the Vietnam War that influenced both the genre of war photography and the anti-war movement.⁶⁸

In its treatment of this technology, *Life*'s editors removed the varying scientific, and confusing, descriptions of ‘laser photography’ or ‘wave front reconstruction’ and named this new photography as holography. *Life* magazine produced a more elegant version of *Scientific American*'s coverage that rid the image of textbook diagrams—or explanations of lasers and wave-theory—that had featured in the popular scientific press (fig.4.3). This issue of *Life* was entirely dedicated to photography and its history as a creative medium, a subject highly suited to the photo-magazine. The hologram was depicted alongside reproductions of images from collections of fine art photography. This presented the medium as one following a confident vision of progress, an invention after photography, in a photo-story with a minimal narrative.

To achieve this coverage, *Life* had dispatched its ‘scientific’ photographer, Fritz Goro, to Michigan. Goro was the originator of a genre of photography that is still ubiquitous today, favoured by science publications, and copied widely by institutional in-house photographers. Goro enlivened cold industrial-looking laboratories by bathing them in a warm *chiaroscuro* of coloured light. This lighting rendered grey hardware into something theatrical, and animated, with dynamically contrasting areas of bright colour and shadow. Goro would light masculine faces as they leant over brightly lit workbenches, up-lit as if by a laser, but in fact lit with spotlights and coloured filters. Goro's visual interpretation of science was an attempt to visually design and capture that ‘creative moment’ by re-staging it at the site of production in the laboratory. Goro

⁶⁷ Erika Doss, *Benton, Pollack, and the Politics of Modernism: From Regionalism to Abstract Expressionism* (University of Chicago Press, 1991), 175.

⁶⁸ Mary Marien Warner, *Photography a Cultural History* (New York, London: Henry Abrams Inc., 2002), 366–370. Warner cites that *Life*, 16 April 1965, gave coverage to 22 pictures including (the first) colour images of Vietnam by British war photographer Larry Barrys, which were seminal to the anti-war campaign.

often re-staged biological experiments for the camera. With commissions from *Time-Life*, Goro created for himself a photographic career representing science in the glossy magazines of mid-twentieth-century America.

Goro had arrived in the Willow Run Laboratories, Ann Arbor, and had found the holographic imagery of Leith and Upatnieks unsuitable for reproduction in this issue of *Life*. As Leith later recalled “He affirmed that our holograms were technically superb, but added that they were artistically atrocious...” Goro insisted that Leith and Upatnieks assist him as technicians while Goro ‘art-directed’ a more aesthetic holographic image that would aim to appear three-dimensional on a page. This holographic collaboration took two weeks and usurped the authentic results of Leith and Upatnieks from this *Life* magazine picture-history of photography.⁶⁹ The time taken over this image corresponds to the financial size of the commission given to Goro, to represent the hologram by the publisher.

⁶⁹ S.J. Gould, ed., *On the Nature of Things: The Scientific Photography of Fritz Goro* (New York: Aperture Foundation Inc., 1993), 35.



Fig.4.3. Fritz Goro's hologram *Goro's Blocks* as featured in *Life* magazine, December 1965. Photograph copyright of the New York Public Library.

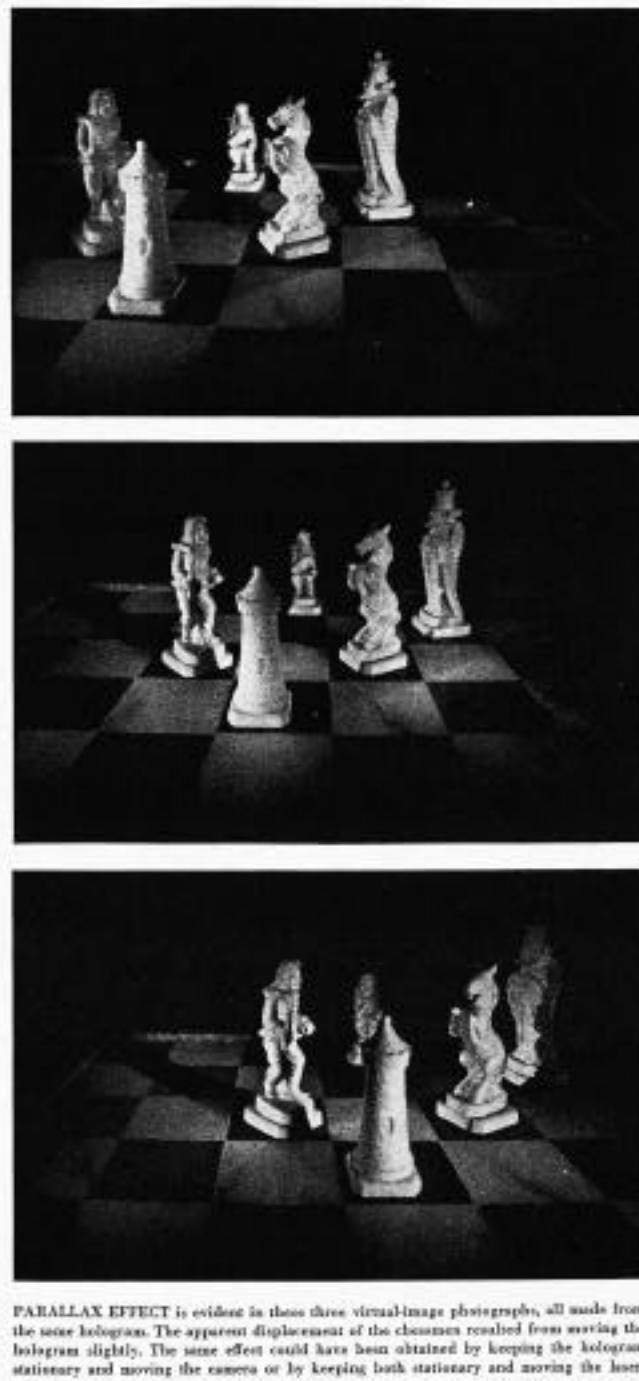


Fig.4.4. Illustration from Scientific American, June 1965.

Popular magazine reproduction became the prime site for the publication and dissemination of the hologram—promoted as a new visual medium—which by virtue of its laser-viewable, three-dimensional novelty was available only to a very limited audience. Also, in America lasers increasingly became to be perceived as unsuitable for

public display despite the interest in using them by artists.⁷⁰ The hologram was eventually to reclaim the gallery and exhibit space, for a modern twentieth-century form of scientific theatre. Events, such as *Light Fantastic* at the Royal Academy, London, in 1975, one of the largest exhibitions, created by physicist Dr Nick Phillips at Loughborough University, UK, and funded by the *Who* pop group, took place a decade later. Lasers were more easily obtainable in the 1970s, and the holograms produced for this gallery were one-metre square. The holograms of Leith and Upatnieks were eight-by-ten inches, and in 1965 there were not enough display quality holograms of the size required to constitute a public exhibition. The magazine was a more expedient and direct mode of international public communication, it immediately announced the time and site of publication. Leith and Upatnieks used the press as their prime display arena. Whereas in 1964 the young 'Pop' artist Andy Warhol used the press to feign the notion that he had an entire *Factory* in his working background,⁷¹ the military and university research laboratory was presenting to its foreground, technicians apparently pursuing a new medium of individual expression.

Leith and Upatnieks had dedicated two years, from 1963-1965, to producing a 'folk art' collection of display images, holographic chess pieces and model trains, imagery intended for an American male audience. In June 1965, these images featured in the pages of popular magazines such as *Scientific American*, and *Playboy*, for example, and at conference meetings (fig.4.4). These holograms then had to be photographed so that the resulting two-dimensional images functioned as flat printed copy that worked with the accompanying text and diagrams. This investment of time and energy by Leith and Upatnieks in the popular press essentially promoted the hologram to a large readership.

⁷⁰ Pace Wildenstein Gallery, "Press Release" (NY: 2004). In 1967 'Wavy Red Line' a laser artwork shown in 'Dark' a solo show by Robert Whitman (b.1937) at The Pace Gallery was closed by the New York Board of Health 22 days after it opened. The gallery restaged this work in 2004.

⁷¹ Caroline A. Jones, *The Machine in the Studio* (University of Chicago Press, 1996), 194-195. Warhol called his studio the *Factory* and covered the interior walls with tin foil to create an "illusory factory-décor".



Fig.4.5. Detail of *Deep Train*, a laser hologram by Leith and Upatnieks.
Photograph from the collection of the MIT Museum, Cambridge, Mass.

The model train images, exhibited in Washington in 1964, were titled *Deep Train*, and *Not-so-Deep Train*,⁷² referring to the increasing illusory space that the holographic image penetrated. In *Deep Train* the train appeared to travel on its tracks, from a deep and distant corner, down the lines in the diffuse red laser-beam or pictorial sunshine towards the holographic plate and the station. This model station was seen to be just inside and below the hologram's edge, where the viewer stood, as if looking through a very small window. This was in fact recorded on the laboratory vibration-isolated table (fig.4.5). *Deep Train* is an image that cleverly employs perspective, a geometrical device more typically used to give the appearance of depth to flat painting. Few holograms employed perspective. Holograms often depicted an object—a skull for example—suspended in an empty black space. But with this image, the viewer peered into *Deep Train*—an intimate experience associated with earlier peep shows—to find that the image extends in scale beyond the physical edge of the frame. It is not an image intended for viewing on a wall or to be seen from a distance, and as such would not have functioned in a public gallery; it also required a laser to illuminate it.

⁷² Photographs and documentary notes relating to these images are in the Museum of Holography Collection, MIT Museum, Cambridge, Mass.

Leith and Upatnieks arranged the model-railway tracks to point to an artificial distant vanishing point, to create another illusion of a false perspective within the hologram. They employed mathematical perspective to indicate notions of a pictorial space within apparent 'real' space. But it was this use of perspective that made a photograph of *Deep Train* appear graphically flat in print—on the magazine page—as if 'lensed' to a focal plane, like a photograph or painting. This produced a more conventional representation of space. Leith and Upatnieks had otherwise exploited that 'flatness' and sense of direction in print, where the railway-lines indicated the path of the laser beam towards the plate-holder, for readers of the science press. This was perhaps intended for physicists, in order to depict the optical layout on the laboratory table (fig.4.6).

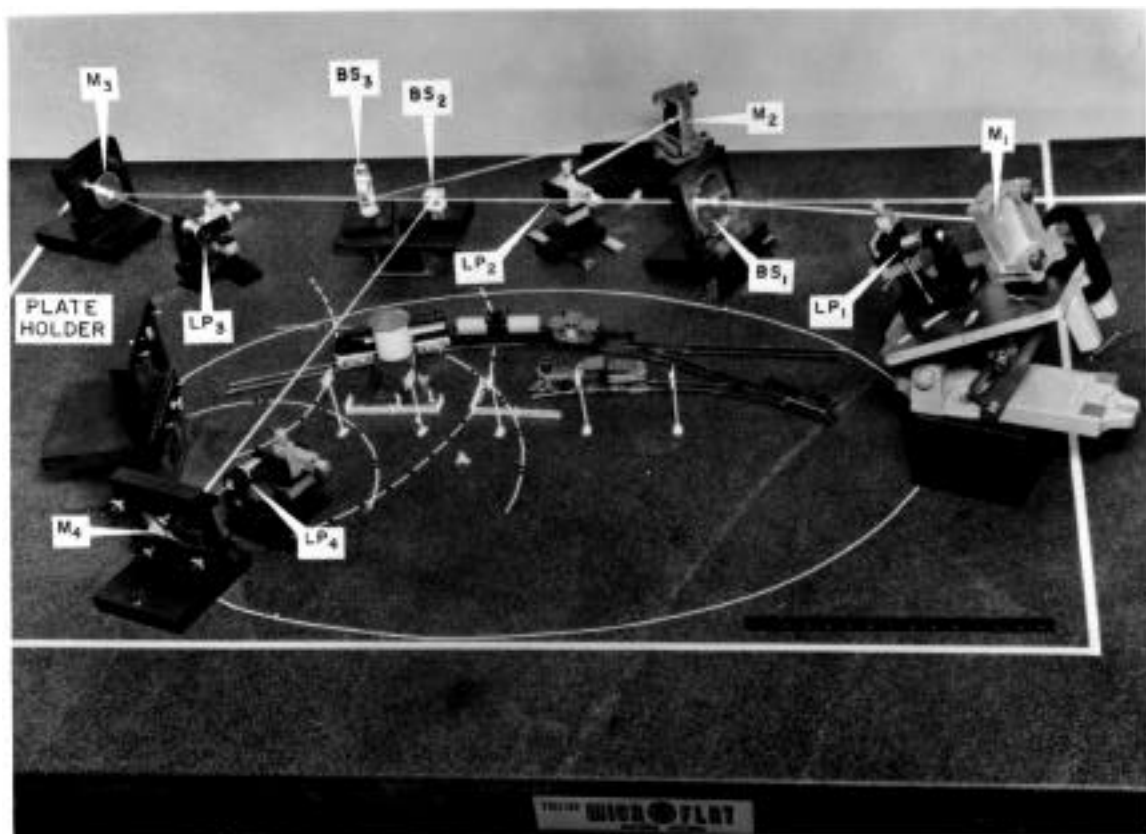


Fig.4.6. Leith and Upatnieks' optical set-up to hologram a train.
Photograph in the collection of the MIT Museum, Cambridge, Mass.

The synthetic reconstruction of microwave wave-fronts, into a geometrically corrected but flat representation of a three-dimensional landscape, was a technical requirement in the reconstruction of surveillance 'radar holograms'. This function created an artificial

but familiar viewpoint: that of a camera lens.⁷³ Electronically collected signals had to be reconstructed into a classical and geometrical visual framework for military purposes; the viewer cannot assimilate the raw data. This is an example, of how geometrical perspective and optics endured—in combination with electronic signal collection methods—to make this an analogue process.⁷⁴

Leith and Upatnieks had selected an American subject: a model *John Bull* train, symbol of the pioneering culture of the 'West'. The *John Bull* had gained this iconographic status from its depiction in the popular nineteenth-century American prints by Currier and Ives, as well as early twentieth-century movies (fig.4.7). Together with the chess pieces, these were all classic masculine images of territorial dominance; as such they probably rendered Leith and Upatnieks' own authored imagery unsuitable for representation in the urbane and international *Life*. This publication was intended for a mixed gender readership. Leith and Upatnieks had previously targeted a male readership through the popular science press. The photographic commission awarded by *Life* to Goro reveals the editorial intervention that went into constructing the early identity of holography as a new medium for image making.



Fig.4.7. Currier and Ives, *American Express Train*, 1864.

⁷³ Jenson, "Side-Looking Airborne Radar", 84-95, on 90-91.

⁷⁴ Leith, "Reflections on the Origin and Subsequent Course of Holography", 431-438. Leith has stated that "Had Synthetic Aperture Radar been invented in the age of computer, the signals impinging on the SAR antenna would have disappeared into a computer, and after much computation would have emerged as a finished product—a high resolution radar image, and the holographic aspect would have been entirely bypassed".

Goro's hologram of clear acrylic letters reads 'H O L O G R A M' for the *Life* magazine browser who instantly reads the blocks as text, in a photo-essay. The emerging 'Pop' artists, many of whom had backgrounds in graphic design and sign painting, also pursued the use of text as image. Artist Robert Indiana, created a 20 foot electric EAT sign for the New York Pavilion at the 1963-65 World's Fair, he also created paintings and sculpture using LOVE, which the USA post office later used on a stamp. Initially, also described as 'New Realists', they appropriated capitalism's visual forms and language.⁷⁵ Goro modelled his image style on the work of these young artists. HOLOGRAM is photographed from two differing viewpoints—to represent the parallax of vision that occurs as the head moves from side to side—it is an easily understood picture with, an identifiable message.

In the image, the bright red laser beam is a pictorial graphic device depicting the reconstruction of the hologram in the light. To reconstruct such a large hologram the laser would have to have been diverging through a lens to cover the area of the plate. Subsequently, the hologram known as *Goro's Blocks* has been presented in exhibitions as the first work of 'holographic art'; although Goro never took the original hologram away with him.⁷⁶ The original laser hologram remained with Leith and Upatnieks, in Ann Arbor, suggesting that the photograph and the magazine, rather than the hologram, was for Goro the prime publication and the art. Neither did Leith and Upatnieks create any more display holograms for the public's consumption, beyond those that succeeded to be represented in the press between 1963 and 1965, indicating that publicity and not image production was their ambition. For both art and science the magazine was now a prime site of dissemination.

Locating Dennis Gabor, the inventor, in 1963

Gabor discovered through reading the press accounts that his invention was now a potential new medium, without having undertaken any of the initial production or promotional work himself. Leith and Upatnieks had always cited Gabor as the inventor of the hologram, in both academic journals and the popular press. In 1963, *Inventing the Future*, a book by Gabor intended for a general audience, was published by Secker and Warburg, selling 20,000 hardback copies. It was then published in paperback. For those

⁷⁵ Steve Lafreniere, "Love, Robert Indiana", *Index*, 2004. Indiana applied to have LOVE copyrighted, but was informed by the US government that words cannot be copyrighted.

journalists who, after reading articles about the hologram, sought-out Gabor, they could—with this book—also locate him within the popular arena, rather than return to the realm of academic journals and his publications of 1948 and 1949. *Inventing the Future* helped Gabor to create a public persona as an ‘inventor’, the year of its publication, 1963, was identical to that of the first press release to announce ‘lensless photography’. As De Solla Price stated in that same year, “...the modern ease of transportation and the affluence of the elite scientist have replaced what used to be effected by the publication of papers... It has made the scientific paper in many ways, an art that is dead or dying”.⁷⁷ With sufficient material within the popular arena no readers, including scientists, need return to Gabor’s original text.

Gabor’s book was a generic future-cast of what science and technology lay ahead. Archival evidence suggests that the material came from an article he was requested to write for *New Scientist*. Gabor researched the article and the subsequent book, by writing circular memos to fellow staff members at Imperial College, requesting their predictions from within their own discipline.⁷⁸ This book, published in a time of increasing social and sexual liberalism, muses on the “three great dangers” that Gabor feels threaten “our civilisation”, which to Gabor in 1963, was white western civilisation. “The first is destruction by nuclear war, the second is being crippled by overpopulation, and the third is the Age of Leisure”.⁷⁹ Acknowledging the increasing pessimism of the general public towards technology, Gabor presents science and technology as the solutions to these issues. This publication is of a type that Nobel Prize winners often write; it is one in which the ‘intellectual and creative mind’ is assumed to have a wide ethical insight into society.⁸⁰ But in this case, Gabor wrote *Inventing the Future* before winning a Nobel Prize in 1971. This text provided Gabor with the means to promote and assimilate himself as ‘British’, to a British audience; this could be achieved in text,

⁷⁶ Leith and Upatnieks produced copies from Goro’s original, one is now in the Holography Collection, the MIT Museum, Cambridge, Mass.

⁷⁷ De Solla Price, *Little Science, Big Science*, 90.

⁷⁸ Dennis Gabor to Professor H.B. Squire, FRS, 30 November 1959. “Letters to Staff Mn/6”, in *Dennis Gabor Papers*, Imperial College Archives (London). “I have been asked by *New Scientist* to write a forecast of the next ten years of Applied Science. Will you please be kind enough to give me, in not more than ten lines, a summary of the most important developments which you expect in mechanical engineering?”

⁷⁹ Dennis Gabor, *Inventing the Future* (London: Secker & Warburg, 1963), II.

⁸⁰ A recent example of this genre is: Kary Mullis, *Dancing Naked in the Mind Field*, paperback ed. (New York: Random House, 1998). The back cover describes this Nobel Prize winner as writing; “from Global warming to the O.J. Simpson trial, from poisonous spiders to HIV, from scientific method to astrology” and “...the only Nobel laureate to describe a possible encounter with aliens”.

whereas in person his Hungarian accent defined him as foreign. His intent to appeal to a British readership was revealed in a letter to Harold Strauss, of the New York publishers Alfred Knopf Inc., “Knowing how unwilling they [the British] are to accept advice from anybody who was not born here... I preferred not to touch on any of Britain’s urgent problems”.⁸¹ Rather, in this text Gabor expressed his enthusiasm for the British Royal Family and the British upper-class male intellectual. These subjects were inherently bound up with Gabor’s belief in eugenics, what he defined as the “upbreeding of men” although he recognised this belief as “taboo” since the “criminal and amateurish attempts of Hitler”. To Gabor, even British “sceptics of eugenics J.B.S. Haldane, Bertrand Russell, and G.P. Thomson” were seen as evidence of the “living proof of successful eugenics”.⁸² The problem of heredity was further compounded for the educated male, because “The fertility rate is still higher among the less educated than the educated classes... [thus] the intelligence of nations is certain to deteriorate...” unless eugenics could be adhered to.⁸³ These concerns regarding the fateful demise of the educated white male, were no doubt among the ‘universal’ issues discussed by Gabor and his elite fellow club members, at The Athenaeum, London.

Gabor distributed this book sending copies to prominent male public personalities: the future Prime Minister, Harold Wilson; the Minister for Science, Lord Hailsham; the Duke of Edinburgh; television presenter, Malcolm Muggeridge; American philanthropist J.P. Getty; amongst many others. When no letter of thanks came forth from Buckingham Palace, Gabor enquired as to whether his book was received—as if soliciting comment—only to receive a brief receipt from Squadron Leader David Checketts. These letters, at least the non-negative ones, Gabor saved and filed. Using the book in this way Gabor on retirement introduced himself to prominent members of British society, communicating to them that his new technocracy was not intent on offending the existing aristocracy. Writing to one reviewer, he explained his distaste and lack of interest in one crucial political movement of the mid-1960s—women’s emancipation, which was to eventually alter women’s rights in both marriage and employment.⁸⁴ Gabor justified his standpoint as one of a foreigner, demonstrating how

⁸¹ Dennis Gabor to Harold Strauss, 31 December 1962, in *Dennis Gabor Papers*, Imperial College Archives (London).

⁸² Gabor, *Inventing the Future*, 146.

⁸³ Gabor, *Inventing the Future*, 147.

⁸⁴ Harold Perkin, *The Rise of Professional Society: England since 1880* (London and New York: Routledge, 1990), 431. Perkin discusses the changes to professional society “of the triumphs of the

he could opt out of maintaining his assimilated British identity, especially on the subject of women. He made it clear that.⁸⁵

I cannot think without horror at a world in which men will be even more domesticated and ruled by women than they are now in the United States, I have grown up at a time and in a country in which men were dominant.

Increasingly, as the hologram peaked in the publicity medium of the printed press in 1965, Gabor was able to forge a new public identity. He presented a 'talk' on the hologram in the United States, in 1965, which was illustrated with, "...some of the striking results obtained by the American workers".⁸⁶ This new fame brought opportunity in his retirement, although he lacked the academic position to reclaim holography as an active discipline for himself. In 1967, he wrote to Arthur Koestler, author, friend, fellow Hungarian and Athenaeum member, of his new contradictory position, which was that of a cynic with privileged choice.⁸⁷

...I am retiring from my chair in the Imperial College, I have prepared a nice schizophrenic design for living: 51/2 months per year as Life Consultant of the CBS Laboratories in Stamford, Conn. USA, to invent more electronic mischief and get paid for it, the rest of the year writing against the electronic mischief...

What ensued amongst the wider international scientific community, following the publicity of the new three-dimensional medium, was a race to claim commercial applications, patents and funding. This Gabor was to name in his Nobel Lecture as "the explosion in holography".⁸⁸ This was an event triggered by the public reception to the popular press. The press was gaining a wider influence within the scientific community, as editor Harold Strauss explained to Gabor in 1967:⁸⁹

...scientists who are hard put to keep abreast of their own field and must rely on semi-popular magazines such as *Scientific American*, and in the scientific books we publish for the general reader.

women's movement": The Divorce Reform Act of 1969, which made irretrievable breakdown of the marriage the sole basis for divorce, and The Matrimonial Property Act of 1970, which made the wife's contribution to the marriage, in kind or money, an equal claim to the marital property.

⁸⁵ "Es/9 Inventing the Future", in *Dennis Gabor Papers*, Imperial College Archives (London).

⁸⁶ Dennis Gabor to Sir Lawrence Bragg, FRS, on 7 May 1965, in *Dennis Gabor Papers*, Imperial College (London).

⁸⁷ Dennis Gabor to Arthur Koestler, 13 July 1967, "Ms.Mk/6", in *Dennis Gabor Papers*, Imperial College Archives (London: 1967).

⁸⁸ Dennis Gabor, "Holography, 1948-1971, Nobel Prize Lecture", in *Dennis Gabor Papers* Imperial College Archives (Stockholm: The Nobel Foundation, 1971), 168-200, on 190.

⁸⁹ Harold Strauss to Dennis Gabor, December 27 1967, in *Dennis Gabor Papers*, Imperial College Archives (London).

Conference proceedings on holography in journals peaked in 1965 and patents in 1971.⁹⁰ However, the application of military radar wavefront reconstruction was only declassified in stages beginning in 1968, and then in 1972. This created, in 1965, a popular new technology that was unable to acknowledge its immediate historical provenance.

Conclusion

The pictorial three-dimensional hologram was created as a cultural object in the printed media. The term 'hologram' as applied to a popular three-dimensional image was defined more by press accounts rather than the journal publications of Leith and Upatnieks. The press had a significant influence within the professional research laboratory; the press could send in photographers to stage imagery, editors could be hidden authors; and press articles were also read by other professional scientists. This permitted non-scientists to engage in the formative descriptive process. Holography was presented as a new medium without a defined application, while one successful application, a military imaging process, remained obscured. The success of the press reports, and the pursuit of their agency in publication, might have weakened the status of Leith and Upatnieks' own journal papers especially among scientists who adhered to the orthodox forms of dissemination.

However, new disciplines and new descriptions have been understood as emerging from Cold War containment.⁹¹ But holography is an example, of a discipline that was initiated—with Gabor's paper and its reviews by other practitioners—before the Cold War, and then developed in isolation for part of it. Military containment did alter the description of holography. The significant 'wavefront reconstruction' that translated one part of the electromagnetic spectrum to another, was to remain hidden, whereas only the optical 'hologram'—Gabor's photographic reconstruction—was to be named and revealed.

In a 1962 press release the University of Michigan presented the all-optical laser hologram as being 'independent' of any military sponsor. Yet two early joint papers by Leith and Upatnieks, on all-optical laser holography published in 1962 and 1963,

⁹⁰ Johnston, "Reconstructing the History of Holography", 455-464, on 457.

⁹¹ Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, Mass., London, England: MIT Press, 1996), 2. Edwards points out the interrelation between the Cold War and the development of computers, including their design, and the new discipline of cognitive science from artificial intelligence.

undertaken away from a larger team, and cited here, acknowledge military support (see footnotes 35 and 41). The 1964 paper on three-dimensional objects did not credit any Army support. Would one paper, produced using equipment and following on from a previous background of military funded work, be perceived by other scientists as independent research? Given the dominance in the USA of military-funded university physics during the Cold War, how was this science to be assessed within the science community at the time?

While assessing the role of the individual within a larger institution, historian Thomas Hughes, states that people "...are components of but not artefacts in the system".⁹² We should assume that they have a degree of freedom. Was this freedom to publish in open journals, for Leith and Upatnieks, a hard won battle? On page 130, I have cited the example presented by historian Pamela Mack, which reveals how, in 1962, scientists at Michigan University, organised a conference in order to gain declassification. However, the existing Lippmann-to-Gabor narrative conveniently does not address, these issues. Therefore, in 1965, at the peak period for holography conferences, others had to construct a background narrative for this technology in order to pursue it as a discipline.

Also, because of a lack of available material it is not transparent to the historian to what extent Leith and Upatnieks were participating in a larger promotional event organised by university administrators. During the Vietnam War, student activities attracted public attention. For example, Michigan University was the site of one of the first staff and student campus protests, and the Willow Run Laboratories were 'bombed' by students in 1968. According to historian Rebecca Lowen, such events were not solely anti-war protests; students also reacted to an unsatisfactory university culture. Universities with large engineering schools that received federal defence funds became increasingly dependent on this source funding. However, such contracts for applied research did not support basic undergraduate training nor did it support other programs in the humanities. Lowen has argued that university administrators "...favoured and promoted the development of the heavily subsidised scientific work and stressed the

⁹² Thomas P. Hughes, "The Evolution of Large Technological Systems", in *The Social Construction of Technological Systems*, ed. W.E. Bijker, Thomas P. Hughes, and T.J. Pinch (Cambridge, Mass: MIT Press, 1994), 51-82, on 54.

production of knowledge over the education of students”.⁹³ This policy led to a disgruntled student body that responded with protests to “the politicisation of their institutions”.⁹⁴ The novel hologram was produced at the Willow Run Laboratories which was both physically and socially isolated—due to its military-funded research—from the main campus. However, in 1968, this site eventually became a target for student dissatisfaction.

Also, tensions could occur between university departments. Lowen claims that university administrators began to see departments that failed to attract federal funding, for large graduate research programs, as “evidence of their low value” as well as them becoming a drain on the university.⁹⁵ Historian of technology Howard Segal, writing about the University of Michigan’s Engineering Department in the late 1960s, states that it boycotted the Humanities Department annual symposium on ‘Technology and Human Values’, and eventually “...succeeded in closing the Humanities Department itself. For the engineers, any serious criticism of technology was heresy”.⁹⁶ In the case of Michigan University, student protest did lead to the separation of the Willow Run Laboratories from the University. Lowen states that students did win on changes to the curriculum but only because those changes did not require a significant change to the funding structure.⁹⁷

From 1962, the laser hologram, and its promotional campaign, did receive the support of Michigan University’s administrators. Was the promotion of the laser hologram part of a larger appeal by military-funded university scientists for declassification, or, was the hologram promoted to divert public attention away from the university’s involvement with military applications? The successful press coverage of the novel three-dimensional hologram, which I have analysed in this chapter, might have supported both of these causes.

⁹³ Rebecca S. Lowen, *Creating the Cold War University: The Transformation of Stanford* (Berkeley, Los Angeles, London: University of California Press, 1997), 9.

⁹⁴ *Ibid*, 5.

⁹⁵ *Ibid*, 158-159. Lowen cites the example of Stanford University’s classics department and the views of the Provost Frederic Ternan.

⁹⁶ Howard P. Segal, “Technology, Pessimism, and Postmodernism: Introduction”, in *Technology, Pessimism and Postmodernism*, ed. Yaron Ezrahi, Mendelsohn Everett, and Howard P. Segal (Amherst: University of Massachusetts Press, 1995), 2.

⁹⁷ Lowen, *Creating the Cold War University: The Transformation of Stanford*, 234-235.

CHAPTER FIVE

Dennis Gabor's Nobel Prize for physics, 1971

In this chapter I review the history of the hologram Gabor constructed for his Nobel Lecture. This is a classic discipline narrative that historian of technology Steve Woolgar has named a 'discovery account': a presentation that no longer needs to persuade or argue for the invention's validity. Yet Gabor's story is produced retrospectively some considerable time after his 'discovery' and it also attempts to review the discipline.⁹⁸ First I explore, through archival material, the lack of communication between Gabor and Leith that was initially instituted through military secrecy and which was to provide later opportunities for dispute. What Gabor named the 'explosion' in holography that occurred after 1965, and prior to declassification, introduced competition internationally but also locally within the University of Michigan. This further fragmented the emerging 'discipline' with both priority and personal disagreements.

These disputes still exist between two living protagonists, Emmett Leith, and George W. Stroke (b.1924–), with both parties claiming differing versions of events; Stroke's version, for example, can be found in an interview published on the Internet.⁹⁹ This is perhaps a response to Leith's account, which would be known through verbal exchanges amongst a community of physicists. References to Stroke's papers have been dropped from the popular Lippmann-to-Gabor history composed as a citation list. Historian of science Sean Johnston has made this dispute the focus of a paper in which Johnston claims that Stroke manipulated Gabor, and consequently holography's historiography, to favour a narrative, which now overlooks the contribution of Leith and

⁹⁸ Steve Woolgar, "Writing an Intellectual History of Scientific Development: The Use of Discovery Accounts", *Social Studies of Science*, 6 (1976). This paper analyses differing accounts of the discovery of the pulsar.

⁹⁹ George Stroke, "George Wilhelm Stroke, Electrical Engineer, an Oral History Conducted in 1993 by William Aspray, IEEE History Center, Rutgers University, New Brunswick, NJ, USA", www.ieee.org/history_center/oral_histories/transcripts/stroke.html. In this text I cite the 2003 online version. The citations in this chapter are reproduced with the copyright permission of the History Center.

Upatnieks.¹⁰⁰ Here I reveal some of these disagreements in order to assess some of the claims made by Johnston.

In the second part of this chapter, I review Gabor's Nobel Lecture, which he read on receiving the Nobel Prize in 1971. The award prompted another round of press attention that cemented, in historical memory, conceptions of the hologram that began in 1964 with further popular narratives; some of these Gabor embellished himself with a "Eureka" account of his invention.¹⁰¹ In the previous chapter, I suggested that military secrecy did alter the description of the hologram by separating it into two elements: the classified 'wave length translation'; and the 'optical reconstruction', which became the all-optical hologram. By examining Gabor's Nobel Lecture, I examine Gabor's political strategy to realign the hologram to his original intention, as well as claim the new, three-dimensional, all-optical, form as his own creation. Although Gabor's lecture was endorsed by the Nobel Foundation it was never to function as a 'public history', nor was it to become the discipline's accepted history but it remains one of the alternative narratives that I identified in the introduction.

Disputes and new authors at the University of Michigan

With the increasing publicity generated by press accounts of the three-dimensional laser hologram, Gabor was called upon to publicly account for this invention. As Gabor provided a narrative and expansive development to his original paper, he also irritated Leith for incorrect assignment of authorship. The geographical distance between these two protagonists, and the previous lack of communication, began to generate some misunderstanding. This is perhaps an example of an absence of what, historian of science John Law has called, the "shared mechanical solidarity", the social framework that is required to form both a community and a discipline.¹⁰² Without this social attribute these key protagonists were unable to form a unified group.

¹⁰⁰ Sean F. Johnston, "Telling Tales: George Stroke and the Historiography of Holography", *History and Technology*, 20, no. 1 (2004) 29-51.

¹⁰¹ G. Myers, "Making a Discovery: Narratives of Split Genes", in *Narrative in Culture: The Uses of Storytelling in the Sciences, Philosophy, and Literature*, ed. Christopher Nash (London: Routledge, 1990), 102-126, on 102. Myers describes this as a popular account that embeds a "certain psychological or historical account" within the narrative.

¹⁰² John Law, "Theories and Methods in the Sociology of Science: An Interpretative Approach", in *Perspectives on the Emergence of Scientific Disciplines*, ed. Gerard Lemaine, et al. (The Hague, Paris, Chicago: Maison des Sciences de l'Homme, Paris Publications, 1976), 221-131, on 224-225.

For example, Leith had written to Gabor to thank him for sending on to the USA his recent Royal Institution *Discourse* text, but Leith had noticed that:¹⁰³

There are, however, two statements that distress me: that the explosion in holography was started in 1962 by E.N. Leith, J. Upatnieks, and George Stroke, and that diffused illumination was conceived simultaneously by Leith, Upatnieks and by Stroke.

Stroke was born in Yugoslavia, and educated in Germany and in France at the Sorbonne. In 1941, when he was a young man, in fear of being identified as a Jew, he fled from German occupied France into British Palestine. He arrived in the USA in 1952 and followed his brother to work at MIT, first working on diffraction grating ruling engines under Dean George Harrison. Having gained American citizenship and military clearance, he was appointed to MIT's Draper Instrumentation Laboratory to work on the Polaris nuclear submarine system. This was a large well-funded Navy project employing over 10,000 and Stroke claims to have earned \$13,000 a year in 1957. He returned briefly to France to complete a PhD in 1960, and in that same year, he took a post at the University of Michigan where he was appointed, in 1962, to a Chair in Electro-Optical Sciences. Stroke claims that he only accepted this position at Michigan on the condition that it was fully funded by the University, and that he had refused a position that was jointly funded by the Willow Run Laboratories.¹⁰⁴ This might have been, because Stroke's contacts for US military funding were now located within the Navy, whereas the Willow Run was essentially funded by the US Army and the Air Force. From his work on Polaris, Stroke was already aware of existing competition and tensions between Army and Navy funded research programmes.¹⁰⁵ This decision implies that Stroke either wished to seek his own choice of military sponsor or remain unencumbered by military restrictions.

Stroke arrived at Michigan with both a military research background and experience in the new electro-optical sciences. His academic role, according to James Wilson, the Acting Director of the Institute of Science and Technology at Michigan,

¹⁰³ Emmett N. Leith to Dennis Gabor, 13 February 1969, in *Dennis Gabor Papers*, Imperial College Archives (London), with copyright permission of Emmett Leith.

¹⁰⁴ Stroke, "George Wilhelm Stroke, Electrical Engineer, an Oral History Conducted in 1993 by William Aspray, IEEE History Center, Rutgers University, New Brunswick, NJ, USA". "They wanted to give me half my salary through Willow Run. I said, "No. Either you pay my salary full-time from the department, or else I don't come. I'm quite happy at MIT".

¹⁰⁵ *Ibid.* "The compartmentalisation between Army and Navy—we were Navy—especially fascinated me. [Chuckling] Literally next door in the MIT 'Woods Building' was the Air Force! We knew that they were three months ahead, and we were working on a very tight schedule, but there was no way we could get their information".

was to enable within the university, "...graduate students to work with modern developments in optics which have been advanced in industry and in defense and the space program conducted by the Federal Government". Although the university was conducting such research it was perceived that "...there was little in the way of formal teaching related to it".¹⁰⁶ The University of Michigan considered Stroke's optical expertise to be an addition to its teaching staff and one that might bridge the gap between the traditional academic and the new industrial-military funded research. Stroke also chose to pursue 'display holography' (the production of images) soon after arriving at the University of Michigan. However, he was initially funded to continue work on diffraction gratings with Office of Naval Research and NASA funding.¹⁰⁷

This disagreement between Leith and Stroke appeared to be over the actual date of the three-dimensional image, as Leith pointed out in the same letter to Gabor:

Our diffused-illumination holography was started many months before Stroke came to the U of M, and was publicly announced in the December 27, 1963 issue of *ELECTRONICS*, as well as in many other places, beginning early that month. Starting in November 1963, our diffused-illumination holograms were publicly displayed, both at U of M and elsewhere.

Leith refers to a popular technology journal as the first publication of this new holographic development, as well as to the displays on campus, which presumably Gabor could not be expected to have been aware of. None of these were formal academic publications; nor was there any defined journal earmarked for the technology's developments. As Gabor indicated in his reply: "This is distressing indeed! ...I did not know that your claims to diffused illumination go back to Nov. 1963. This indeed changes matters..." Stroke had previously presented himself to Gabor as being a collaborator of both Leith and Upatnieks, under contract to the military research

¹⁰⁶ "Institute of Science and Technology Establishes Lab in New Field of Study" *Ann Arbor News*, 2, October 1963, 37. As cited in Johnston, "Telling Tales: George Stroke and the Historiography of Holography".

¹⁰⁷ Stroke, "George Wilhelm Stroke, Electrical Engineer, an Oral History Conducted in 1993 by William Aspray, IEEE History Center, Rutgers University, New Brunswick, NJ, USA". "My friend Leo Goldberg was at the Harvard College Observatory. He was a very famous person who was at one time very closely related to the founding of Kitt Peak Observatory. One day, in a typical American way at a cocktail party, he said, "George, you are going to Michigan". I said, "Where is that?" [Laughter] I am exaggerating. The University of Michigan, he meant. "I have a friend there, Roger Heyns (who was later the Chancellor at Berkeley), and you are going to be a professor there". I said, "Great! But, I also need money for my research". "That's no problem! John Strong is retiring, and Charles Babcock is retiring, and Harrison is already retired, so there's no one to do the diffraction gratings. We need the diffraction gratings for the Kitt Peak Observatory and the space program. And you are going to do it". ...I said, "Well, how do I do it?" He said, "You call up Glazer at the Office of Naval Research", and so on, and Howard Smith, who was later the number two man at NASA. I said, "All right".

institute, the Willow Run Laboratories. Gabor wrote that, "I have seen a document of collaboration, and the only way of reconciling this fact with your story is that the document was drafted but never signed".¹⁰⁸ But Gabor pointed out his own effort to present Leith's work:

...I was anxious to point out that your revival of holography was not just 'my ideas of 1948 plus laser', but that you came to it via an admirable detour, the ingenious side-looking radar... Up to now I was in the belief there was some kind of collaboration, prior to your feud. This is not surprising, because feuds always arise between people who had close contact with one another, not people who had no contact. No contact, no friction! How then did the feud arise?

This 'misinformation' regarding Stroke, sent in a letter to Gabor, was later dismissed from a higher authority than Leith at the University of Michigan. Gabor informed Leith that he would have continued to believe in the existence of a collaboration "...had I not received a letter from Prof. W. Brown [Head of the Willow Run Radar and Optics Laboratory]".¹⁰⁹

Stroke claims that after arrival at Michigan he "had argued successfully... with my godfather [Gilbert B. Devey], and John Ide, who was the director of engineering at the NSF [National Science Foundation] in 1962, to keep this new field of "holography" as an open non-classified, scientific activity in the USA". Stroke felt, from reading Denisyuk's papers, that the Russians were already ahead on this technology. The NSF accepted this suggestion and responded, according to Stroke, with an invitation to make a proposal. Stroke states that "I immediately wrote a proposal with this fellow Leith, and I got the first grant. Then when the grant came, because they [?] were already aiming at taking something away, they asked that his name be taken off, and this would have meant another round. But then I had the Chancellor and whatnot, friends, intervene. I didn't have time to make another application". Stroke also claims that his name should have been on the 1964 paper *Wavefront Reconstruction with Diffused Illumination and Three-Dimensional Objects*¹¹⁰ and that he had returned from London where he first met with Gabor to find that it had been removed, leaving the names of Leith and Upatnieks.¹¹¹

¹⁰⁸ Dennis Gabor to Emmett Leith, 22 April 1969, in *Private Papers of Emmett Leith*.

¹⁰⁹ Dennis Gabor to Emmett Leith, 11 May 1969, in *Private Papers of Emmett Leith*.

¹¹⁰ Emmett Leith, and Juris Upatnieks, "Wave-Front Reconstruction with Diffused Illumination and Three-Dimensional Objects", *Journal of the Optical Society of America*, 54 (1964), 1295-1301.

¹¹¹ George Stroke, "George Wilhelm Stroke, Electrical Engineer, an Oral History Conducted in 1993 by William Aspray", IEEE History Center, Rutgers University, New Brunswick, NJ, USA.

As a visual technology the three-dimensional laser hologram had relied on dissemination through publicity, which was not academically credible or unlikely to be witnessed outside of the USA. This generated a number of differing forms of publication: displays, press accounts, journal papers, and patents. Therefore, issues and disputes regarding the priority on developments of this imaging technology were not transparently obvious to those on the outside—as Gabor was—of the University of Michigan. Significantly, this *new* discipline did not have, since its emergence in 1963, an effective powerful leader—a role traditionally provided by the inventor. According to John Law, the presence of such a discipline leader could, by the promotion of a set of strong normative rules, prevent any deviant behaviour.¹¹² Stroke had attempted to claim both an academic disciplinary position, and expertise, by producing the first textbook on holography in 1965, which was later published in Russian in 1968.¹¹³ In this book he reproduced Gabor's original papers on holography for which he later paid Gabor royalties.¹¹⁴ Possibly he reproduced these to uphold the example of theory above any technical developments by Leith and Upatnieks.

Historian of science Michael Aaron Dennis cites, as an example of how World War II classified science was successfully repackaged within the university, a textbook by MIT's Charles Draper, who founded the Draper Instrument Laboratory.¹¹⁵ Stroke, who worked in this Lab, may have modelled his book's role on Draper's example. Textbooks also present an abbreviated historical account that can be written without reference to the social and contextual history of the topic as they adhere to outlining techniques and promoting the notion of origination from key papers. Given the numerous forms of publications to choose from for his Nobel Lecture (not all of which were academic) Gabor chose representations of three-dimensional holograms depicted within Stroke's book, rather than the successful images produced for the press by Leith and Upatnieks. Gabor emphasised the textbook as a relevant disciplinary object over and above any exposure given to the hologram in the popular press.

¹¹² Law, "Theories and Methods in the Sociology of Science: An Interpretative Approach".

¹¹³ George W. Stroke, *An Introduction to Coherent Optics and Holography*, 2nd ed. (1st ed. 1965) (New York, London: Academic Press, Inc., 1969).

¹¹⁴ 23 April 1967 George Stroke to Dennis Gabor, in *Dennis Gabor Papers*, Imperial College Archives (London). Stroke sent Gabor a royalty check for \$1,051.50 USD

¹¹⁵ Michael Aaron Dennis, "'Our First Line of Defense': Two American Universities in the Post-war American State", *ISIS*, 85 (1994), 427-455, on 429.

Two teams seek the attention of the press

Stroke, and Leith and Upatnieks, now headed two different and competing research teams within the same institution. Stroke also carried with him to Michigan his earlier suspicions from his time at MIT, "I had the brilliant idea of putting their lab next to my lab. In a university lab, everybody has every key".¹¹⁶ Differences between the two teams are evident from two separate press releases, issued for the March 1966, Washington, 50th Anniversary Meeting of the Optical Society of America, on apparently similar developments to the three-dimensional laser hologram. These press releases reveal the changing nature of the field, and the subsequent social fragmentation, as the number of holographic researchers increased to compete for publicity in the same arena. That the two teams send out press releases is an example of the changes produced in the university with Cold War military and industrial funding. Historian Rebecca Lowen has stated that in seeking applied contract funds, the university gave rise to a "...loose collection of academic entrepreneurs... perpetually promoting themselves and their research to potential patrons".¹¹⁷

Here the influence of the press, directed towards the three-dimensional hologram, has similarities with the announcement of the discovery of DNA in 1953. This history was also formed around protagonists' accounts written at the time. Holography, like molecular biology, was also marginal to a larger field and these histories served to form a new identity.¹¹⁸ Historian of science, Soraya de Chadarevian, has described the role of the double helix's iconographic image within the press.¹¹⁹ Both discoveries successfully employed imagery. Historian of science, Pnina G. Abir-Am, cites James Watson's statement on public attention to his discovery. Watson described how the science of DNA and its institutionalism appeared, at that moment, to be "up for grabs..." and Abir-Am states that the collective memory formed at that time still holds long term social, political and ethical implications for the discipline.¹²⁰ The effect of the press was to

¹¹⁶ Stroke, "George Wilhelm Stroke, Electrical Engineer, an Oral History Conducted in 1993 by William Aspray, IEEE History Center, Rutgers University, New Brunswick, NJ, USA".

¹¹⁷ Rebecca S. Lowen, *Creating the Cold War University: The Transformation of Stanford* (Berkeley, Los Angeles, London: University of California Press, 1997), 3.

¹¹⁸ Wolf Lepenies and Peter Weingart, "Introduction", in *Functions and Uses of Disciplinary Histories*, ed. Loren Graham, Wolf Lepenies, and Peter Weingart, *Sociology of the Sciences a Yearbook* (Dordrecht Boston Lancaster: D. Reidel Publishing Company, 1983), ix-xx, on xvii.

¹¹⁹ Soraya de Chadarevian, "Portrait of a Discovery: Watson, Crick, and the Double Helix", *ISIS*, 94 (2003), 90-105.

¹²⁰ Pnina G. Abir-Am, "Commemorative Practices in Science: Historical Perspectives on the Politics of Collective Memory", *Osiris* 14 (1999), 324-372, on 358.

determine the development of Gabor's own "discovery" account, a narrative Woolgar suggests "supports instantaneous revelation or sudden perception".¹²¹ Gabor then formalised this into his Nobel Lecture.

Stroke's press release (fig.5.1) for colour holographic images stated that it is based on the previous work of Gabriel Lippmann (1891) and Soviet scientist Yuri Denisyuk (1962). Stroke also claims to have invented the term 'holography' in honour of Dennis Gabor, the originator of the term 'hologram'. This text is written in an exaggerated manner, appealing to the style and rhetoric of the popular press. Stroke is quoted, in the press release, as claiming his research to be "based on a hair-thin balance between sophisticated mathematics and extremely refined experimentation" which has now led to "two new miracles... comparable to a successful moon shot in this field". Stroke compared his research programme to the more recent high point of the Apollo launch, which had secured the full attention of the international media. His press release sets out to suggest this "breakthrough" will "set the stage for 3-dimensional" television and "a possible multi-million industrial explosion in electro-optics".

In his press release, Stroke referred to Leith and Upatnieks, the competing team, as the defence-research team of the Radar and Optics Laboratory.¹²² The press release issued on behalf of Leith and his research partners, for example, was more conventional in its use of language; issued on behalf of a larger research team with military funds it might have required formal approval. However, it appears to claim priority over a similar invention, of creating colour holograms, which are viewable in white light (and animated images); this release cites both Lippmann and Denisyuk as being, in addition to Gabor, the prime source for these recent developments. Prior to this public notification, Leith et al, from the Radar and Optics Laboratory, the Willow Run Laboratories, of the Institute of Science and Technology, had been under contract from the Air Force to investigate further techniques in holography including colour.¹²³ This was similar to the situation of Leith and Upatnieks' 1964 publication on three-dimensional objects (disputed by Stroke), which followed on from defence-funded

¹²¹ Woolgar, "Writing an Intellectual History of Scientific Development: The Use of Discovery Accounts", 395-422, on 417.

¹²² This team included Emmett Leith, Juris Upatnieks, Adam Kozma, James Marks, and Norman Massey.

¹²³ Willow Run Laboratories Radar and Optics Laboratory, Institute of Science and Technology, the University of Michigan, Ann Arbor, prepared under contract, AF, 33 (615)-3100, "Investigation of Hologram Techniques, Second Interim Engineering Report, 1 December 1965 to 31 March 1966" (Air Force Avionic Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, July 1966).

research, but cited no military research sponsor. Except now one team had military funding and restrictions in the background of their research environment.

As Stroke described Leith's team: "They were very productive, I can tell you that. They had an army of people. They were defense-funded, and I was non-defense-funded".¹²⁴ Whereas the smaller team, of Stroke and one research student, now had the academic freedom to publish and develop what was in the public domain with the cited papers of Lippmann (1891), Gabor (1948), Denisyuk (1962) and Leith and Upatnieks (1961, 1963, 1964).

¹²⁴ Stroke, "George Wilhelm Stroke, Electrical Engineer, an Oral History Conducted in 1993 by William Aspray, IEEE History Center, Rutgers University, New Brunswick, NJ, USA".

FRANK BELMERE PREPARED BY SPECIAL REQUEST FROM Dr. Eugene H. Koon

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DEPARTMENT OF ELECTRICAL ENGINEERING
 50th Anniversary Meeting of the OPTICAL SOCIETY OF AMERICA
 WASHINGTON, D.C. March 14-18, 1966

12 March 66

FOR RELEASE: WEDNESDAY, MARCH 16, 1966 PM

Paper title: "Three New Advances in Optical Holography", by GEORGE W. STROKE

FOR ANY ADDITIONAL INFORMATION, CONTACT:

Professor George W. STROKE at: 1. SHOREMAN HOTEL, Washington, D.C. (March 14-18, 1966)
 2. UNIVERSITY OF MICHIGAN 313-764-5270
 3. HOME: 313-663-3872

**THREE-DIMENSIONAL COLOR PICTURES
 FROM BLACK-AND-WHITE HOLOGRAMS
 OBTAINED IN ORDINARY WHITE LIGHT!**

BREAKTHROUGH IN "LENSLESS PHOTOGRAPHY" SETS STAGE FOR
 3-DIMENSIONAL HOME COLOR TELEVISION AND A POSSIBLE
 MULTI-MILLION INDUSTRIAL EXPLOSION IN ELECTRO-OPTICS

The discovery of a new type of hologram (3-dimensional lensless photograph), capable of reconstructing three-dimensional objects in full color from black-and-white holograph negatives, and this with ordinary white light (from an electric light or the Sun, for example) was announced today before the Optical Society of America by Dr. George W. Stroke, Professor of Electrical Engineering at the University of Michigan, and Head of its Electro-Optical Sciences Laboratory.

Hitherto, and indeed in their original form, holographically reconstructed "lensless images were not only generally single colored, but they could only be viewed in laser light (a dangerous practice at best— indeed the field has sometimes been described as "laser photography"), and holography appeared to some destined to become another among the many novel tools of important laboratory value, but perhaps mostly only a passing scientific curiosity.

Originated by Professor Stroke with one of his students, Antoine Labeyrie (here under a Fulbright grant this year from France), the revolutionary new type of "white-light reflection hologram" was obtained under a National Science Foundation grant in a culmination of close to three years of research by Professor Stroke and his students, in work "based on a hair-thin balance between sophisticated mathematics and extremely refined experimentation", as he likes to put it.

Fig.5.1. Press release 1966, 'Three New Advances on Optical Holography', by G. W. Stroke. Collection of the MIT Museum, Cambridge, Mass.

Dennis Gabor re-positions himself in the new discipline

Gabor was well aware of the tensions between competing 'holographic physicists' at Michigan. Adam Kozma, a former research student and team member of Leith's, went on to Imperial College, London, to pursue a PhD. Kozma, on arrival at Imperial College, had found to his surprise that Dennis Gabor was not familiar with the discipline Kozma associated with holography, which he described as 'coherent optics', nor did Gabor have any facility for this. Rather, Gabor had hoped Kozma would assist in

setting-up one before he retired. Kozma had written an informal letter back to Leith and everyone in his former department, about London and Imperial College, with instructions for it to be pinned up on the department's notice board.¹²⁵ But Stroke, on seeing Adam's letter in the Institute of Science and Technology, Michigan, sent a telegram to Gabor in London, followed by a copy of Adam's letter, which is now in Imperial College's archive. This act is an appeal to Gabor to respond in the role of discipline leader. It put him in the position of having to comment on issues arising in another department, on the other side of the Atlantic. Gabor made it clear that his own participation, and even a possible collaboration in holography, should not be discounted.¹²⁶

I presume that this silly letter is an outcome of the unhealthy tension, which has developed between your laboratory and George Stroke... I am indebted both to you and your team and to George Stroke for having so beautifully expanded and developed the field of holography. There is room in this field for more than one team, and I hope also for me, because I am trying for a comeback, as you will probably soon hear from Holotron. If a deal with Holotron comes about, I hope that there will be a friendly cooperation between us. [This deal did not appear to materialise]

I will pass over this letter were it not that the letter was posted on your notice board. Adam Kozma has consented to write a [another] letter to you, and ask you to have it posted on your notice board side-by-side with the one he now heartily regrets.

Regarded as the 'inventor', Gabor claimed the authorship of this new medium and now attempted to maintain its disciplinary activities. He also perceived that any other "workers" as he referred to Leith and Upatnieks, in a letter to W. Lawrence Bragg, merely expanded upon his own project.¹²⁷ This was how Gabor viewed Leith and Upatnieks, and Stroke. At 66 years old, retiring from his professorship, Gabor found himself drawn into arguments regarding both the developments and the promotion of three-dimensional holograms. These concerns younger men now appeared to be competing over for their own professional advancement and financial reward. Johnston implies, with regard to the Kozma incident, that Stroke "...sought to limit contacts between and to alienate, Gabor and Leith, on one occasion reporting 'a gross attempt at slander' of Gabor by another member [Kozma] of the Willow Run Labs who

¹²⁵ Adam Kozma to Emmett Leith, 1 October 1966, copy, in *Dennis Gabor Papers*, Imperial College Archives (London).

¹²⁶ Dennis Gabor to Prof. E.N. Leith, 3 November 1966, in *Dennis Gabor Papers*, Imperial College Archives (London).

inadvertently had had his letter displayed on the notice board near Stroke's office".¹²⁸ However, Gabor accepted this as normal and sent patriarchal comment and condolences back across the Atlantic. As social historian Brian Easlea has stated with regard to a totally male dominated science, as the fields of radar and electrical engineering were in the 1960s:¹²⁹

...as in other hierarchical male-dominated activities, getting to the top invariably entails aggressive, competitive behavior. Scientists themselves recognize that such masculine behavior, though it is considered unseemly to dwell upon it, is a prominent feature of science.

As Gabor stated in a letter to Leith: "I know of course he [Stroke] is very ambitious, so are we all! Only it is easier for you and me, whose merits have found world-wide recognition to be generous". And Gabor would appear unperturbed—if not slightly arrogant—by concerns over citations and their implication for future recognition, "I do not mind in the slightest that the reference list of papers on holography now start more often with Leith than Gabor, you deserve it (they never start with Stroke)!"¹³⁰ His claim to the original authorship of the hologram would remain unchanged despite the 'deserving' labours of others. The other protagonists already acknowledged him as the initial 'inventor'. Gabor, like Lippmann and his eponymous photograph, could retain a distinct lineage of authorship through the constant endurance of a descriptive label. As historian of science Augustine Brannigan has pointed out, the two most enduring forms of recognition were the eponymous invention in the nineteenth century and, in the twentieth century, the institutionalised Nobel Award.¹³¹

But Gabor, who had made it clear to Leith that he wished to 'make a comeback', did collaborate with Stroke and not with Leith. Stroke had the academic position as a 'Chair' to collaborate with Gabor, as well as to pull academic rank over Leith who was only appointed as a university Research Engineer in 1965—at the peak of holography's 'explosion'—and then to a full Professorship in 1968. Leith's lack of academic status

¹²⁷ Dennis Gabor to Sir Lawrence Bragg, FRS, 7 May 1965: "I enclose with compliments the abstract of a talk which I gave recently in the U.S. and which contains reproductions of some of the striking results obtained by the American workers", in *Dennis Gabor Papers*, Imperial College Archives (London).

¹²⁸ Johnston, "Telling Tales: George Stroke and the Historiography of Holography", 29-51, on 42.

¹²⁹ Brian Easlea, "Patriarchy, Scientists, and Nuclear Warriors", in *Beyond Patriarchy: Essays by Men on Pleasure, Power, and Change*, ed. Michael Kaufman (Toronto, New York: Oxford University Press, 1987), 195-215, on 196.

¹³⁰ Dennis Gabor to Emmett Leith, April 22 1969, in *Private Papers of Emmett Leith*.

¹³¹ Augustine Brannigan, *The Social Basis of Scientific Discoveries* (London and New York: Cambridge University Press, 1981), 56.

was an issue for Stroke who, in 1963 prior to the public emergence of any three-dimensional imagery, had written to the Director of the Institute of Science and Technology, J.T. Wilson, to complain that:¹³²

...the lack of a PhD by such people as Leith, is not only a lack in adequate terminal training in areas outside narrow specialisations, but it shows up in a lack of appreciation of the process of a PhD thesis and more generally basic educational responsibilities and basic scientific research work, such as those on which a great university must insist.

Can military-funded research function in the academy?

Stroke addressed one of the difficulties of merging the military funded Willow Run staff into the social architecture of the academy. Leith had undertaken a considerable period of research under military contract, which would not have enabled him to gain a PhD; academic science as opposed to corporate or military science requires open publication. Leith only gained a PhD in 1978 at nearby Wayne State University, not at Michigan University. Military research had left Leith lacking a preparatory qualification for academic science. Nor was Stroke bound by any military classifications as Leith was until 1968. Stroke was well positioned to undertake, with Gabor, some of the more social 'discipline forming' activities that were, as historian of science Paul Forman has pointed out (and I have already cited in this thesis), a seminal part of open academic activity. Clearly rank and personality are agents that act, in addition to publications, and contribute to the social adhesion of a newly forming discipline.

Stroke took an interest in the application of holography to the electron microscope, which would have appealed to Gabor, who *never* lost interest in the subject. Gabor had stated, in a letter to W. Lawrence Bragg, that he had encouraged Stroke's participation in this.¹³³ Social contact as an instrument for discipline development was important to Gabor. In reviewing his 1949 Royal Society paper¹³⁴ in Chapter Three, I reveal that Gabor clearly defined the discipline (X-Ray Crystallography) that his paper addressed and he had enlisted the early support of Bragg (the accepted discipline leader) before publication and it was Bragg who read it before the Society. Johnston states that

¹³² Johnston, "Telling Tales: George Stroke and the Historiography of Holography", 29-51, on 37.

¹³³ Dennis Gabor to Sir Lawrence Bragg, FRS on 12 November 1965, in *Dennis Gabor Papers*, Imperial College Archives (London), "...the optical 'total reconstruction microscope' I have taken up again, because the laser has made it possible to take the two photographs on one plate in an interlaced pattern. The experimental work, on my suggestion, is now being carried out by Prof. G.W. Stroke and his team".

¹³⁴ Dennis Gabor, "Microscopy by Reconstructed Wave-Fronts", *Proceedings of the Royal Society*, 197, July (1949), 454-487.

Stroke manipulated Gabor. Yet there is no archival evidence at Imperial College, of 'manipulation', or that Leith, on the other hand, had expressed any interest in collaborating with Gabor, or in Gabor's original application. Rather the archives reveal Gabor delegated to Stroke. In 1968 Gabor and Stroke presented a joint paper *The Theory of Deep Holograms*¹³⁵ at the Royal Society London. Gabor wrote to Stroke requesting photographic slides,¹³⁶ and Stroke wrote to Gabor apologising for not getting his PhD student to program Gabor's equations.¹³⁷ This paper is not featured in the popular Lippmann-to-Gabor narrative as it appears in journal citations, nor does Johnston refer to it. Rather, Johnston claims that in addition to disparaging Leith, "Stroke ... ignored, or belittled the generality, of Denisyuk's accomplishments".¹³⁸ Yet this paper actively supports Denisyuk's proposal of combining Lippmann's method to form imagery and, for example, 'Denisyuk' is the first name to appear in the abstract. With regard to Leith, Gabor and Stroke stated that, "Wavefront reconstruction had a spectacular revival in 1963 when the laser was first applied to it (Leith and Upatnieks 1962, 1963, 1964; Stroke 1964, 1966)".¹³⁹ Why was this paper dropped? Was it perceived to have ignored Leith?

This is an example of the Lippmann-to-Gabor narrative in use: it selectively ignores some contributions from those it now considers to be outside of the smaller acknowledged group of 'display holographers' or three-dimensional image makers. The Stroke versus Leith disputes are a social aspect of this history that the discipline has chosen to 'forget' by omitting Stroke from its citation lists. The narrative also ignores Gabor's papers that attempted to reposition him in the discipline, suggesting that Gabor was not a widely accepted authority on three-dimensional laser-holography. Stroke, on leaving Michigan, pursued holographic microscopy and the application of holography to medical imaging, from the State University of New York-Stony Brook. After 1965 subgroups formed to pursue specific industrial applications and Gabor aligned himself to those wishing to develop his original program. Stroke spoke both Russian and French

¹³⁵ D. Gabor, FRS and G. Stroke, "The Theory of Deep Holograms", *Proceedings of the Royal Society of London*, Series A, no. 1487 (1968), 275-289. The paper acknowledges that Stroke was sponsored by the US National Science Foundation and the Office of Naval Research.

¹³⁶ Dennis Gabor to George Stroke, 3 January 1967, in *Dennis Gabor Papers*, Imperial College Archives (London).

¹³⁷ George Stroke to Dennis Gabor, 12 November 1966, in *Dennis Gabor Papers*, Imperial College Archives (London).

¹³⁸ Johnston, "Telling Tales: George Stroke and the Historiography of Holography", 29-51, on 44.

¹³⁹ Gabor and Stroke, "The Theory of Deep Holograms", 275-289, on 275.

and clearly advocated the Lippmann-to-Gabor narrative. He may have sought to locate the new technology in the wider field of optical science through the introduction of these antecedents. This would have been an aspect of disciplinary activity required to merge the Willow Run developments with the open published science, which was part of Stroke's original academic brief. Rewriting the narrative would have been useful to Gabor who sought to represent his original work within the context of the later achievements. As historian of science Peter Galison had pointed out, "It always gives added weight to a current research program if older, established theories mesh with new theories in a natural way".¹⁴⁰ Although Stroke may have been a key protagonist of the Lippmann-to-Gabor narrative after Denisyuk, this form of the history has been appropriated to leave him out.

Johnston claims that Stroke also lobbied the Nobel committee to omit Leith, stating without evidence that, "The Nobel Prizes are susceptible to cynical influence or manipulation..."¹⁴¹ This conclusion perhaps stems from the fact that the garrulous Stroke boasts that he did promote Gabor for this prize. However, as I have already explained in this thesis, Gabor succeeded in promoting himself with *Inventing the Future*, his popular book published in 1963 the same year the initial story of 'wavefront reconstruction' appeared in the press. Gabor was well positioned socially to canvas his own support through his membership of elite societies: the Royal Society, the Athenaeum Club and, from 1972, the Club of Rome (an international technocratic 'think tank' on global problems which was limited to 100 members). Gabor also maintained, for his own work, the lifelong interest of W. Lawrence Bragg who, as a former Nobel Prize winner might have nominated Gabor for the prize before his death in 1971. Archival evidence reveals that Gabor lobbied for Bragg's son Stephen to be made a Fellow of the Royal Society on a 'fast track' appointment; an act that Bragg expressed gratitude for.¹⁴² Such social exchanges are part of a gift culture, as is the gifting of

¹⁴⁰ Peter Galison, "Re-Reading the Past from the End of Physics: Maxwell's Equation in Retrospect", in *Functions and Uses of Disciplinary Histories*, ed. Loren Graham, Wolf Lepinies, and Peter Weingart, *Sociology of the Sciences a Yearbook* (Dordrecht Boston Lancaster: D. Reidel Publishing Company, 1983), 35-51, on 49.

¹⁴¹ Johnston, "Telling Tales: George Stroke and the Historiography of Holography", 29-51, on 43.

¹⁴² Sir Lawrence Bragg, FRS to Professor Dennis Gabor, FRS, 11 November 1965, in *Dennis Gabor Papers*, Imperial College Archives (London).

authority—Gabor to Stroke—in a joint research paper; these are instrumental agents in the formation of networks and disciplines.¹⁴³

Johnston points to Stroke's deviant behaviour: the 'stealing' of an image of a fly wing created by Upatnieks to present as his own, as an example of how Stroke abused Leith and Upatnieks' authorship. In contrast (and unremarked upon by Johnston) Stroke names what he describes as the "gauche" behaviour by Leith and Upatnieks: offering Gabor, on a visit to Ann Arbor, 10,000 US Dollars to sign a contract stating that their 'hologram' was significantly different from his original. Stroke describes their attempt to apply for a patent on which he was called as an expert witness:¹⁴⁴

The patent was not valid because in the process of writing back and forth to the Patent Office, they had sworn they had never published what in fact they had published. Then their big claim in that patent—it was the same story; science is also not elegant—that they supposedly never published the reconstruction, just the recording. That was pure nonsense. You know a little bit about holography. Holography means recording and reconstruction basically.

These disputes are bound with issues of description and authority: is scientific authorship inherent to an image? Whose literary description of the hologram carries authority? Who has authority to audit a patent application? With regard to the patent application, the story has some parallels with the complex notion of authorship of the laser where, according to historians of technology and Robert A. Myers and Richard W. Dixon, there are possibly six contenders for the shared title of inventor. Like the three-dimensional hologram, the laser could be described as an all-optical form or version, of the earlier the maser. In this case one earlier contributor, Nicolaas Bloembergen, did not opt to pursue what Myers and Dixon perceived were later infringers.¹⁴⁵ Challenging disputes was difficult and required an investment of time and money. These historians cite one 'infringer', Charles Townes, who claimed that it was considered normal behaviour if "the owners of a patent do not vigorously defend it, outsiders feel free to help themselves to the relevant technology".¹⁴⁶

¹⁴³ Corynne McSherry, "Uncommon Controversies: Legal Mediations of Gift and Market Models of Authorship", in *Scientific Authorship: Credit and Intellectual Property in Science*, ed. Mario Biagioli and Peter Galison (London: Routledge, 2003), 225-250, on 234. McSherry explores co-authorship as a mutual exchange, in this discussion of a copyright dispute between student and supervisor.

¹⁴⁴ Stroke, "George Wilhelm Stroke, Electrical Engineer, an Oral History Conducted in 1993 by William Aspray, IEEE History Center, Rutgers University, New Brunswick, NJ, USA".

¹⁴⁵ Robert A. Myers and Richard W. Dixon, "Who Invented the Laser: An Analysis of the Early Patents", *HSPS*, 34, no. 1 (2003), 115-149, on 136.

¹⁴⁶ *Ibid*, 115-149, on 139. Citing: Charles C. Townes, *How the Laser Happened* (New York, 1999), 112.

Johnston acknowledges that Stroke was one of the few practitioners to promote a historical account of the holograms in the early 1960s and, therefore, according to Johnston, he manipulated Leith out of more deserving position in history. Given that a historical account was required—from the 1965 peak of holography's popularity as a research activity—I regard this as an example of a disciplinary activity that Leith was either unable to, or failed to, participate in. If military restrictions withheld Leith's account of how he identified the 'problem'—through the hidden development of radar—then publishing the solution, without reference to this classified background, was not perceived by other practitioners as a full contribution to the open literature. This perception appears to have been held by Gabor and it can be found embedded within his Nobel Lecture. Stroke also voiced his own moral condemnation of researchers accepting public (military) funds and then attempting to patent the results. These are examples of the difficulties in perceived roles between military and civilian researchers and those individuals that undertake the complex 'hybrid' of both forms of research.

Gabor's 1971 Nobel Lecture: an account of his invention

In 1971 following the public notification of Gabor's Nobel Prize, another layer of public information was added to the persona of the inventor. At the time of the award, Gabor was in the United States on a part-time contract with CBS Laboratories. On hearing of the award, Gabor presented himself to the *New York Times* interviewer, John Noble Wilford, as a regular 'guy', a worker, and a figure more broadly appealing in American society, than a retired British professor or elite Fellow of the Royal Society:¹⁴⁷

Most people get the Prize for one thing they spent a long life in science to accomplish. I'm an outsider. I've worked in **industrial** laboratories all my life, and industrial workers rarely get the Nobel Prizes. What I did was not pure science. I consider it an invention.

Wilford then described how the 71-year-old Gabor, "Came upon the idea of three-dimensional imagery that would bring him fame as he was waiting for a tennis court at Rugby, England, in 1947". Inspirational insights, the divine "Inner Vision" associated traditionally with the creative mythology of artists and, more frequently, "the modern-day worship of genius" were introduced into the popular narrative of the hologram.¹⁴⁸

¹⁴⁷ John Noble Wilford, "Holography a Long-Time Dream", *The New York Times*, November 3, 1972, in *Dennis Gabor Papers*, Imperial College Archives (London).

¹⁴⁸ Ernst Kris, Otto Kurz, *Legend, Myth and Magic in the Image of the Artist*, trans. Alistair Laing, 1979 ed. (New Haven and London: Yale University Press, 1934), 49.

This is the first time this particular 'discovery account' appears. Prior to that, for his own peer group, Gabor had emphasised the application and the research, this is in keeping with Brannigan's notion that the scientist must appear to be "doing research".¹⁴⁹

On holography, Wilford stated that it was "...the most exciting development in modern optical science".¹⁵⁰ The award for holography was to increase the credibility of this technology as both a research science and as a popular display medium. Gabor appeared to acknowledge the role of the press and the importance of the popular laser hologram in his award. This is evident in a hand-written note he sent to Leith and Upatnieks, from CBS Laboratories on hearing of his award:¹⁵¹

Dear Emmett and Juris, of all the big heap of congratulatory telegrams I answer yours first, because it was your work which helped me to win the Nobel Prize.

This gratitude, expressed in this informal salutation, was not to be formalised publicly by Gabor. Nor did any other party share the Nobel Prize with Gabor. This was taken to be disappointing news in Michigan. *The Ann Arbor News*, May 21, 1972, in an article headed *Young Researchers Intrigued*, expressed the opinion on behalf of the local research community, that "there are many who feel the Nobel Prize should have been awarded jointly..."¹⁵² As the inventor, and now Nobel Prize winner, Gabor sought to 'map out' a new disciplinary position with his Nobel Lecture *Holography, 1948-1971*, the account traditionally read by the winner at the award ceremony. In this text, Gabor reinforced the notion of 'discovery' and he made it clear regarding his invention that:¹⁵³

the most spectacular result...was holography of three-dimensional objects...[but] Holography was of course three-dimensional from the start, but in my early, small holograms one could see this only by focussing through the field with a microscope.

¹⁴⁹ Augustine Brannigan, "Naturalistic and Sociological Models of the Problem of Scientific Discovery", *The British Journal of Sociology*, 31, no. 4 (1980), 559-573, on 566, "That a discovery is 'possible' also refers to the perception that the discovery was the outcome of a course of inquiry that was substantially scientific; i.e. relevant to science". See also: Thomas Nickles, "Discovery", in *Companion to the History of Modern Science*, ed. R.C. Olby, et al. (London & New York: Routledge, 1996), 148-165, on 149. Nickles discusses the flash of insight theory and its problems for historians: "...it is disastrous for history, since it leaves the historian little to say about theory construction except to relate anecdotes about strange conditions under which ideas popped into the heads of great scientists and to describing the ensuing empirical tests".

¹⁵⁰ Wilford, "Holography a Long-Time Dream", 28.

¹⁵¹ Dennis Gabor to Emmett Leith and Juris Upatnieks, November 2 1971, sent from CBS Laboratories, Stamford, Connecticut, USA, in *Private Papers of Emmett Leith*.

¹⁵² Larry Bush, "Young Researchers Intrigued", *The Ann Arbor News*, Sunday May 21 1972, *Private Collection Emmett Leith*.

¹⁵³ Dennis Gabor, "Holography, 1948-1971" (paper presented at the Nobel Prize Lecture, Stockholm, 11 December 1971), 168-200, on 180, *Dennis Gabor Papers*, Imperial College Archives (London).

Gabor engaged this audience with a history starting from his early attempt to improve the imaging capacities of the electron microscope, using illustrations from his Royal Society publication of 1949,¹⁵⁴ which would have been projected for this event. Gabor had always advocated the application of his invention to electron microscopy even on his first hearing of the laser and he emphasised in this 1971 presentation that it was still a candidate for research funding: “Now, 20 years later, would be the right time to start on such a programme ...”¹⁵⁵ This presentation ended with an image of a ‘scanning transmission electron micrograph’ illustrating the improvement to electron microscopy, produced by holography, with the new technique of “holographic deblurring” this was shown to be an achievement of George Stroke (fig.5.2). The final illustration reaffirmed that this new laser holography was indeed the same as his earlier concept, and that it could now be re-applied to the same problems. Gabor, in his history, maintained the virtue, and currency, of his original theory and application.

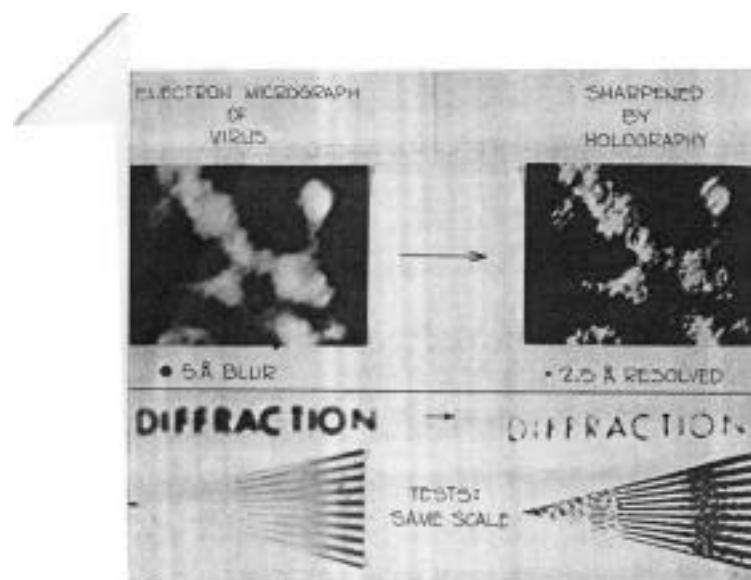


Fig.5.2. Illustration of ‘holographic deblurring’ in Gabor’s published Nobel Lecture.

In this Nobel Lecture, Gabor avoided all references to popular journals, or to the role of the press in promoting this technology. Gabor did not reproduce (as slides or within the published text) any of the imagery that had been identified, since 1963, with the early laser three-dimensional hologram produced by Leith and Upatnieks. He rejected imagery that had been seminal both in alerting the international scientific milieu of this

¹⁵⁴ Dennis Gabor, “Microscopy by Reconstructed Wave-Fronts”, *Proceedings of the Royal Society*, 197, July (1949). See Chapter Two for reproductions of these illustrations.

¹⁵⁵ Gabor, “Holography, 1948-1971”, 168-200, on 176.

invention, and explaining the process to them: the trains, chess pieces, or even *Life* magazine's artful *Goro's Blocks*. In terms of images Gabor avoided the well produced, art-directed and dramatic, and by doing so he presented holography not as a developing popular visual medium. Rather, Gabor in this lecture illustrated a new industrial and scientific tool. In order to illustrate a three-dimensional laser hologram, he presented a photograph of an optical set-up, showing a three-dimensional hologram about to be recorded; the pictorial element now a small item amongst the optics. For this illustration, Gabor chose a reproduction from Stroke's 1965 textbook. This tactic permitted him to avoid identifying an additional author of the first three-dimensional laser hologram, or in having to name the individual, which might have suggested to this audience that the three-dimensional hologram was a different invention from the wave front reconstruction 'hologram' of 1948 and 1949. Gabor's lecture discounted the popular holographic imagery, created from 1963 onwards, as not being relevant to this audience or to this holography.

Gabor credited Leith and Upatnieks with producing the first laser holograms of two-dimensional transparencies. Making it clear that "When the laser became available in 1962, Leith and Upatnieks could at once produce results far superior to mine, by a new, simple and very effective method of eliminating the second image". Gabor was now aware of the military application of his former wave front reconstruction, which was only finally fully declassified in the previous year, 1970. On this application and Leith, he is brief, remarking on the length of time and the team, and also on the 'hidden problem' that Leith's theoretical ideas addressed first:¹⁵⁶

Their success was due not only to the laser, but the long theoretical preparation of Emmett Leith, which started in 1955. This was unknown to me and to the world, because Leith and his collaborators, Cutrona, Palermo, Procello and Vivian applied his ideas first to the problem of 'side-looking radar' which at the time was classified... Their results were brilliant, but to my regret I cannot discuss them for lack of time.

Gabor implies the three-dimensional hologram was not the fundamental invention to which Leith had applied his theory. The American military imaging capability is not fully described, if the American military were unable to reveal it publicly, then Gabor is not obliged to promote it on this platform. In ignoring this, Gabor avoids promoting, what he himself admitted was very advanced holography. The work of Leith and Upatnieks is presented as two-dimensional photographic transparency reconstructions

from formal academic papers by the team—the flattest of images (fig.5.3). Gabor adheres to the science Leith and Upatnieks produced for academic journals and in doing so he discounts the press as a form of publication. Leith made his objections known to Gabor, who responded:¹⁵⁷

I am sorry if in the Nobel Lecture I have not sufficiently emphasised that your 1960-62 work was pioneering far beyond being the first application of the laser.

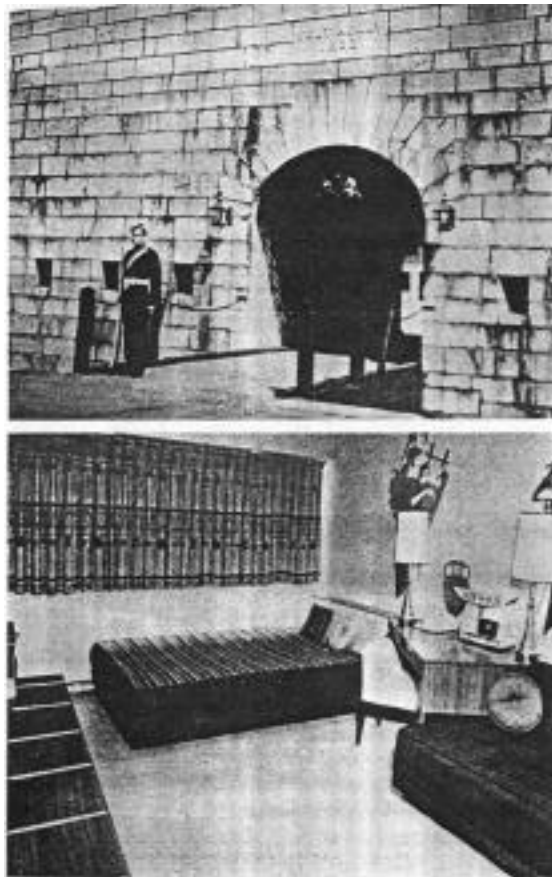


Fig.5.3. The imagery of Leith and Upatnieks, as illustrated from their academic papers, in Gabor's published Nobel Lecture.

Gabor concentrated on the many industrial applications that emerged after 1962 that had not received public attention and which demonstrated the wide scientific usage of this technology. For example, Gabor illustrated the work of other research teams at the University of Michigan who worked on developing holographic interferometry. This was a form of analytical imaging that exploited a holographic double image, for industrial purposes. When the original subject was observed in situ, seen through a

¹⁵⁶ Ibid, 168-200, on 177.

¹⁵⁷ Dennis Gabor to Emmett Leith, November 2 1972, sent from CBS Laboratories, Stamford, Connecticut, in *Private Papers of Emmett Leith*.

previously taken transparent hologram of the subject itself—a practice confined to a laboratory—grainy, striped, interference patterns, that were observed across the subject's surface, would indicate movement, material or fabrication weaknesses. In his lecture Gabor demonstrated this application with five images. This holographic discipline had never attracted the same attention from the public and press. One news report published in 1966, summed-up the visual results disappointingly as: “The double exposure technique has been dubbed ‘good physics but bad photography’”.¹⁵⁸ Although a vital and enduring technique for the ‘non-destructive’ testing of highly expensive and individual products, which could not be broken down into physical samples, aircraft-tires for example, it never provided the aesthetic photographic ‘copy’ to compete as a newsworthy science or attract commercial speculation. By comparison to what the press had experienced of holography it did not appear to be three-dimensional photography and it produced difficult imagery. Holographic interferometry lacked the ‘public face’ that was manifest by photography and therefore—to the public—remained a hidden industrial activity. Yet its development was to run parallel to the popular imagery.

Claiming the popular three-dimensional image as his own

In his Nobel Lecture, Gabor predicted upon the three-dimensional image, as if it were yet to exist in a form more spectacular than was currently manifest. Gabor appealed to historical memory and the audience's concept of an ideal image. He also forwarded his own historical account into the future. That three-dimensional holography could be *something* in the future—implying that it was not yet what its inventor intended—was both a perception and an expression of doubt that was to accompany holography throughout its visible presence in the public arena. For Gabor, this was another means of avoiding having to define the current status of the three-dimensional hologram. Gabor claimed this future holography to be of his own creation and he described it as an ‘art’, therefore, distancing popular image making from the discipline of science.¹⁵⁹

Now let us take a more radical step into the future. I want to mention briefly two of my favorite brainchildren. The first of these is Panoramic Holography, or one could call it Holographic Art.

Gabor then asked a question of holography that is continually addressed to all new visual media, and was asked of photography in the nineteenth century: what is the ideal

¹⁵⁸ Anne Ewing, “Three-D Home TV Foreseen”, *Science News*, 89, 468, June 11 (1966), 468-471, on 471.

medium?¹⁶⁰ Gabor's text recalls literary descriptions of the ideal image, which are reminiscent of both Tiphaigne de la Roche's, prophesy of photography in *Giphantie* 1761, and Lippmann's 1908 paper *Épreuves réversibles. Photographies intégrales*:¹⁶¹

All the three-dimensional holograms made so far extend to a depth of a few meters only. Would it not be possible to extend them to infinity? Could one not put a hologram on the wall, which is like a window through which one looks at a landscape, real or imaginary?

This future holography was, according to Gabor, to be recorded on a *Lippmann emulsion* that formed a screen produced in small pieces—or lens-like lenticular components—that directed a left or right image to the corresponding human eyes, to produce an anticipated stereoscopic three-dimensionality. Of course, Gabor when delegated with non-military applications during World War II had as a British Thomson-Houston employee undertaken research into three-dimensional cinema screens. He mentioned in this lecture, that:¹⁶²

I had spent some years on this problem, just before holography, until I had to realise that it is strictly unsolvable with the orthodox means of optics, lenticules, mirrors, prisms.

He suggested that he could overcome technical problems, unresolved by others, through theory. This is reminiscent of Lippmann's 1891 theoretical solution to colour photography, and of its appeal to the nineteenth-century scientific elite because theory distinguished itself from mere mechanical artisan solutions. Again, like Lippmann in 1908, Gabor presented his ideal solution, a speculation never physically realised, the same year he was awarded the Nobel Prize in Physics. The following year in 1972, Gabor, in his second popular book to be published, *The Mature Society*, stated, when reiterating again his solution to three-dimensional imagery:¹⁶³

There exists a special optical screen, invented by Gabriel Lippmann (1908), which returns each ray, but spreads it out a little, vertically, so that the viewer can have his eyes a little below the projector. This, however, is difficult to make.

¹⁵⁹ Gabor, "Holography, 1948-1971", 168-200, on 195.

¹⁶⁰ Gabor, "Holography, 1948-1971", 168-200, on 195.

¹⁶¹ G. Lippmann, "Épreuves Réversibles. Photographies Intégrales", *Comptes. rendus*. 146 (1908).

¹⁶² *Ibid*, 168-200, on 197.

¹⁶³ Dennis Gabor, *The Mature Society* (London: Secker & Warburg, 1972), 127-128.

Here Gabor presents alternative pasts and futures that are, according to Mat Matsuda, inherently “propelled by virtual realities and information technologies”.¹⁶⁴ Gabor reinforces the comparison of the hologram to the work of Lippmann, first made by Yuri Denisyuk, and later promoted by Stroke, and Leith, who both cited these earlier authors. As historian of technology Michael Mulkey has pointed out, with regard to scientist’s own histories, “...redefinitions of the problems, and alterations of the intellectual perspective...” are part of a subject’s development.¹⁶⁵ Gabor through his use of prediction for a better ‘art’ and his adherence to orthodox scientific publications, as opposed to the press accounts, avoided describing the reality of holography, the popular display medium that Leith and Upatnieks had promoted since 1963. With this tactic, Gabor no doubt steered clear of the priority disputes that were beginning to appear. He may also have found the position held by Leith and Upatnieks, one of having undertaken classified military research but yet appearing in the general press and to the public to be independent researchers, a confusing dichotomy. Especially, as by 1971, the recent declassification by the US Army of the hologram exposed one of ‘wave front reconstruction’s’ most significant achievements. To Gabor, it may have appeared that ‘independent research’ in holography, was that which could be defined as having been undertaken by those *denied* or *lacking* military contracts. By substituting prediction and nineteenth-century history in place of the present reality within his Nobel Lecture, Gabor further contributed to the popular history of his own invention—that the three-dimensional hologram was indeed a development of Lippmann’s ideas of 1891 and 1908. This was a history that further obscured the contribution of the American Military to wave front reconstruction. This was a strategic address that sought to legitimate his disciplinary role, and the validity of his original invention, as well as to counteract change in a new field with an emerging number of competing subgroups and applications. As Wolf Lepenies and Peter Weingart have stated, “In all cases historiography is used strategically, which suggests that it is as powerful and political a tool in science as it is in society at large”.¹⁶⁶

¹⁶⁴ Matt K. Matsuda, *The Memory of the Modern* (New York, Oxford: Oxford University Press, 1996), 16. See also: Jeffrey Sconce, *Haunted Media: Electronic Presence from Telegraphy to Television* (Durham & London: Duke University Press, 2000), 8-9. On re-occurring fictions in new media.

¹⁶⁵ M.J. Mulkey, “Methodology in the Sociology of Science: Some Reflections on the Study of Radio Astronomy”, in *Perspectives on the Emergence of Scientific Disciplines*, ed. Gerard Lemaine, et al. (The Hague, Paris, Chicago: Maison des Sciences de l’Homme, Paris Publications, 1976), 207-220, on 212.

¹⁶⁶ Lepenies and Weingart, “Introduction”, ix-xx, on xviii.

A virtual inventor: the holographic portrait of Dennis Gabor

That this Nobel Prize was associated with the visual and popular three-dimensional laser hologram, that Gabor in his lecture attempted to suppress, was confirmed by the Nobel Prize committee's award to Gabor at the ceremony. Gabor was honoured with his own holographic portrait—a technical 'state of the art' for this medium—this gift sealed the notion that holography was indeed a three-dimensional image. This green pulsed-laser image captured the public's desire to identify and frame the inventor in a frozen moment, and it was this 'image', not solely a picture, but also a role, that the inventor accepted at the ceremony. The portrait rendered him in a nano-second pulse of light—an ultra-fast speed at which even human blood did not move—in that ghostly manner and characteristic hue of objects 'hologramed' in argon-green. A copy of this hologram in which Gabor was depicted in a suit, writing at a desk, was placed on display at the Science Museum, Stockholm Sweden, immediately after the ceremony.

As Ludmilla Jordanova has pointed out with regard to commissioned works, "Portraits are frozen moments of elaborate processes; as such, they reveal social negotiation, not individual character".¹⁶⁷ Such portraits represent human and cultural forms of information, which are more flexible than biographies or obituaries.¹⁶⁸ In this case, the public need never read the original theory, or the discipline's history, their engagement with science is mediated entirely through the images and texts found in the magazine and the museum; what constitutes public history is here is constructed with popular accounts. Such popularisation is part of the tradition of science's engagement with the public. The public was to perceive Gabor through the very illusory medium of his own invention, and it was this popular image of holography that Gabor had to finally accept as 'his hologram', in receiving the Nobel Prize. As Jordanova has stressed, with regard to the twentieth-century fashion to commemorate living individuals, such occasions and portraits manifest the "fresh significance of memory for a psychoanalytic age".¹⁶⁹ Gabor's portrait and award assisted the public's recollection of him, and his invention, in his own lifetime. These 'fashioned' memories were to constitute the 'public history' of the hologram and it was a desire of Gabor's to see, if not have, a holographic portrait. In 1967 he appealed to Stroke who he clearly perceived as an

¹⁶⁷ Ludmilla Jordanova, *Defining Features: Scientific and Medical Portraits 1660—2000* (Reaktion Books in association with the National Portrait Gallery, London, 2000), 169.

¹⁶⁸ *Ibid.*, 70.

activist for his own ambitions: “You would greatly oblige me by pushing the holographic portraiture scheme. Without you it would probably go to sleep”.¹⁷⁰

Gabor's portrait was produced by the McDonnell Douglas Electronics Company, Missouri, USA, a major aviation-engineering corporation with significant military investment. This company had speculated on producing ‘display holography’ utilising resources intended for industrial and military applications. The Science Museum of Stockholm wished to retain the hologram on display, and wrote to McDonnell Douglas Electronics Company requesting that the portrait become a permanent donation or even a possible purchase. However, the Holography Marketing Manager informed the museum for McDonnell Douglas, that “They are simply not for sale to anyone...”¹⁷¹ Gabor had also wished to endow a copy of his holographic portrait to the Science Museum, London. However, McDonnell Douglas informed Gabor, that they preferred to make the donation to the Science Museum in their own name under a renewable loan agreement. Gabor did not possess the ownership or copyright in his holographic image. There is no archival evidence of a contract between the McDonnell Douglas Electronics Company and Gabor, or that he ever considered charging a fee for this ‘image’ of himself. Yet, Gabor's holographic image was not to be disengaged from the corporate identity of the sponsor.

Gabor had, on accepting the Nobel Prize, stepped into the arena of publicity and spectacle that had been generated in the USA. It was explained to Gabor that only eight holographic versions of him existed, one was now in his possession, one was owned by Agfa-Gevaert, the holographic plate manufacturers, and two were earmarked for display purposes “throughout the world”; this included the loan to the Science Museum, Stockholm. But one of these surreal, holographic portraits of Gabor, that had according to the marketing manager, been “...designated for display at the Salvador Dali exhibit in New York, was broken through improper handling by the user”, and “Because of this we consider your holographic portraits to be of significant value, we are presently

¹⁶⁹ Ludmilla Jordanova, “Presidential Address: Remembrance of Things Past”, *British Journal for the History of Science*, 33 (2000), 387-406, on 389.

¹⁷⁰ Dennis Gabor to George Stroke., 3 January 1967.

¹⁷¹ K.C. to Professor Erick Ingelstam Kierzek, cc. Dr Dennis Gabor, 30 November 1972, in *Dennis Gabor Papers*, Imperial College Archives (London).

refusing to ship any of your holographic portraits to anyone...”¹⁷² Gabor's holographic image and its perceived value was not within his control.

As Jordanova has pointed out with regard to institutional portraits, they are “in the business of more or less knowingly generating and cultivating corporate identities”.¹⁷³ The portrait of Gabor was later to be marketed by McDonnell Douglas Electronics Company within a folio of holographic images (fig.5.4). These included such generic images as a shark, an American bar scene, and a hand holding a diamond bracelet, which was commissioned by the Cartier jewellery company, New York, for their Fifth Avenue shop window.¹⁷⁴ In promoting these images the McDonnell Douglas Electronics Company had appropriated Gabor's label ‘hologram’, from the Greek words meaning ‘the whole message’, as their commercial slogan. This new medium was marketed in the brochure as a corporate ‘communication’ tool, the visible and commercial manifestation of the classified military one. The hologram as an imaging medium was to excel at rendering iconographic subjects with a brilliant green and stark three-dimensional realism. As cultural commentator Umberto Eco has remarked: “Holography could prosper only in America, a country obsessed with realism, where, if a reconstruction is to be credible, it must be absolutely iconic, a perfect likeness, a ‘real’ copy of the reality being represented”.¹⁷⁵ It was presumed by the public that Gabor, as the inventor, had himself made this type of hologram, whereas it appeared, in his Nobel Lecture, that he attempted to distance himself from the very medium that framed him and the portrait ensured his popular identity was firmly associated with the three-dimensional image.

¹⁷² Ibid.

¹⁷³ Jordanova, “Presidential Address: Remembrance of Things Past”, 387-406, on 397.

¹⁷⁴ A Touch of the Future”, *Display World*, January 1973.

¹⁷⁵ Umberto Eco, “Travels in Hyperreality”, in *Faith in Fakes* (London: Secker & Warburg, 1986).



Fig.5.4. The McDonnell Douglas brochure featuring Dennis Gabor's holographic portrait, in the collection of Imperial College Archives (London).

Searching for a three-dimensional hologram by Gabor

Before his death in 1979, Gabor willingly promoted the three-dimensional image. In 1978, Gabor had accepted the position of Honorary Chairman of the Board of the newly formed *Museum of Holography*, a 'museum' and registered charity in Mercer Street, Soho, New York. This was a public role, which involved him attending exhibition openings and in this way Gabor provided a useful function as the inventor to a new audience. This anachronistically titled institution—a museum of the new—was to promote and catalogue art exhibitions. It was essentially a non-profit art gallery, which, as it ran out of money in the mid-1980s, began to promote and partner industrial and commercial corporations. The museum was perceived by others as a marketing concept, and was copied internationally with 'holography museums' forming a type of show room that appeared in many European cities throughout the early 1980s. The lesser generic versions often purchased holograms and goods from the New York museum's store catalogue.

In 1978 Gabor donated funds to the *Museum of Holography* for a basement holographic 'art' studio. Rosemary Jackson, the Director, wrote to him regarding his donation, and informed him of "the twenty five thousand visitors that [first] year" and revealed her perception of the inventor's role and responsibility:¹⁷⁶

I am so glad you are pleased with the Honorary Chairmanship. Frankly, I cannot imagine having a Museum of Holography without you as Chairman of the Board. After all, the child always bears the father's name. ...Everyday there are more holographers working, more new processes being developed (by artists now, not just scientists!) and more eager young people who desperately want to learn. See what you started?

Gabor was perceived as responsible for all aspects and histories of the hologram; this position was not possible to renege. With regard to the donation of funds for a laboratory, Jackson asked him:

Would you mind if we called it the Gabor lab? I know its not CBS...We think the philosophy behind it is in line with what you have done for and contributed to holography.

This contribution was seen as having generously invented a new visual medium that was now available to all and further providing the funds to ensure its fruition as an art form. A popular new visual medium quickly required an inventor, a history, and a museum, to

¹⁷⁶ Rosemary H. Jackson to Professor and Mrs Dennis Gabor, 2 February 1978, "Museum of Holography Archives", in *MIT Museum*, Cambridge, Mass. (with copyright permission from Rosemary Jackson).

provide the archetypal structure of a new tradition.¹⁷⁷ The institutionalisation of the 'new' through collections and expertise promoted through educational courses, textbooks, and histories, formed part of the emerging commerce of this technology. The award of the Nobel Prize to Gabor was a seminal part of this social institutionalisation.

The *Museum of Holography's* existence ran parallel to the public attention and expectation of the hologram's development into a satisfactory medium. This was a consumer anticipation in the 1990s, which was to be directed towards another medium: digital virtual reality. The Museum was dependent on fee-paying visitors, a group that dropped in numbers, from that experienced in the late 1970s. The *Museum of Holography* went bankrupt in the early 1990s and its archives and holograms were purchased by the Massachusetts Institute of Technology, for the MIT Museum, Cambridge, USA. In its brief existence, and by default of its liquidation, it became a 'museum'. It was the first and only collector of holographic documents and material acquired contemporary to events. However, many of the 'art' holograms the 'museum' produced itself—through visiting 'artist residencies' in the *Gabor Laboratory*—to maintain enough new exhibits to satisfy public demand.

Following Gabor's death in 1979, Rosemary Jackson, on behalf of the *Museum of Holography* made enquiries through her lawyer to André Gabor, brother and executor of Gabor's estate, then a lecturer in economics at Nottingham University. Jackson believed that Gabor had promised her, and the museum, his original holograms, despite the fact that the estate on Gabor's death had already donated to the *Museum of Holography*, one of Gabor's original 'holograms'. This was one of the surviving images that was produced from his first experiment, a flat black and white paper photograph that was used as an illustration to his published papers. Jackson still anticipated that Gabor had produced some three-dimensional holograms, that he might have been an image-maker. Such images would be seminal—as an early William Henry Fox Talbot *Talbotype* is to a photography collection—to the *Museum of Holography's* collection of three-dimensional holograms.

¹⁷⁷ Eric Hobsbawm and Terence Ranger, eds, *The Invention of Tradition* (Cambridge University Press, 1983). I refer generally to Hobsbawm's notion of new traditions.

André Gabor, in his reply to this enquiry, first points out that Dennis Gabor, to his knowledge, never made any three-dimensional holograms:¹⁷⁸

After that 1947 experiment Dennis did never again attempt to produce any holograms... that first experiment was of interest to him only insofar as the results demonstrated the validity of the principle of holography. What he was interested in was the application of the method to electron microscopy and with the development of the mathematical theory, which he then beautifully presented.

André explained the search he had undertaken on behalf of Jackson, for this “promised transfer of (non-extant) holograms”, the existence of which even Dennis Gabor's wife Marjorie, was confused about:

I told Marjorie at the time that the item concerned [the ‘hologram’ from the 1947 experiment] was not only the earliest but in fact the only original record Dennis retained...

I went several times through the contents of the files... [and] the only places where Dennis might have kept the kind of item Mrs Jackson is claiming, and I can assure you there was nothing of the sort there. I can not imagine what could have made Marjorie think that either the apartment at Vicarage Court or Dennis' room at Imperial College held any holograms other than those on display: a portrait of a girl, a portrait of Dennis and a glass vessel decorated with holograms. These were not Dennis's work, they were presented to him, in America, by the Museum of Holography, I believe... The same applies to the holographic pendants of which Marjorie had one or two... I hope that settles the matter.

The only holograms in Gabor's possession were those presented to him by the very institutions that required him to adopt the public role of the inventor. These institutions participated in the social construction of his public persona: the Nobel Foundation that awarded him his ‘virtual’ holographic image, and the Museum of Holography, which decorated his office with holographic products from their shop. These gifts can be identified from the Museum of Holography's catalogue. They were probably a holographic, lenticular, stereogram of a woman who blows a kiss as the spectator moves, and a glass jar, the insides of which were coated with an emulsion, then hologramed to create the illusion of it containing money. In this office, an honorary public space made available to him by Imperial College, Gabor could administer his role as a British Nobel Prize winner. Here he was accompanied by his own holographic portrait, and by those images of masculine success—women and money—that here in their illusory form also represented his own invention. The holographic pendant

¹⁷⁸ André Gabor (deceased) to F.H. Kitchen, 2 April 1982, in *Museum of Holography Archive, MIT Museum* (Cambridge, Mass.).

necklaces probably embellished Mrs Marjorie Gabor. During her husband's tenure at Imperial College she was a prominent member of the college's *Wives Club*, an institution that facilitated a social life between other male staff members and their wives. The club especially encouraged junior and senior staff interactions through social dinner invitations. This was Marjorie Gabor's only 'professional' role after marriage—to offer both the institution and her husband her domestic support, through the extension of their home to his colleagues. She too, it seemed, expected that Dennis might have made holograms. The archives reveal that Dennis Gabor left his holographic portrait to the Science Museum, London.

Conclusion

In this chapter I have identified a number of differing social factors that contributed to the fragmentation of the new discipline at the very core of its emergence. The protagonists (Leith and later Stroke) of three-dimensional laser holography at the University of Michigan were unable to form themselves into a cohesive and effective group. This may have put their work at a disadvantage when assessed by others outside of Michigan, including the Nobel Committee, and this may have advantaged Gabor. Military secrecy had prevented Leith communicating to Dennis Gabor, which would have been an anticipated discipline-forming activity for an open academic science. This lack of communication would have been obvious to Gabor, who had communicated and supported the work of G.L. Rogers, for example. Leith lacked the academic rank to engage jointly in later discipline-building activities with Gabor. Leith also lacked a PhD. Many of these factors indicate the difficulty of merging military scientific pursuits into academic activity. It is also difficult to evaluate (from archival material) the perception amongst academics (other than Stroke and Gabor) of former military researchers who attempted to continue military research while at the same time attempting to transfer from a military institution to an academic one. Leith occupied a 'hybrid' position, of both military and civilian, a situation that was common in the USA after World War II.¹⁷⁹

Between 1963 and 1965, Dennis Gabor did not engage in the promotional activities of producing three-dimensional holograms and preparing articles for the press: Leith and Upatnieks undertook this activity. Publicity, and the subsequent Nobel Prize,

created a competition in which issues of personality, personal history—length of scientific career, and rank, were to be assessed in addition to journal papers. Historian of science Elizabeth Crawford has pointed out with regard to the Nobel Prize that in considering a work of technology the “utility of inventions... became a criterion of choice” and the prize had to be “for the benefit of mankind”.¹⁸⁰ Gabor’s original theory was both of scientific use (as emphasised in his Nobel Lecture) as well as openly published for all, whereas, any background context of military classification would not ‘benefit mankind’. Also the work of Leith and Upatnieks may not have found support amongst European researchers who were sceptical of the large American post-war joint military and academic research institutes. Historian of science Michael Aaron Dennis, writing on World War II military research laboratories stated, “Universities acquired monies for otherwise unaffordable research, staff, and equipment, while researchers found a rich new source of technically interesting problems with the penumbra of national security”.¹⁸¹ The perception that the scientific ‘problem’, for which the solution was then discovered, was one identified under military classification and then represented as civilian research might have negatively influenced the reception amongst academic researchers.

On a technical issue, (that would explain why Leith did not jointly receive a Nobel Prize) Johnston also supports the notion that, “The laser’s coherence was, of course, essential for producing holograms of three-dimensional objects but not for two-dimensional transparencies used by investigators up to 1963”. Then Johnston states, with regard to the assumption that Leith merely benefited from the laser, that such narratives are historical slippages: “This mis-telling of the story, unconscious as it almost certainly was, nevertheless provided a satisfying explanation for why the directions taken up at Willow Run had not been pursued earlier by Gabor and his collaborators”.¹⁸² As I have already pointed out in Chapter Three, the earlier experimenters, following Gabor, did work with three-dimensional objects but they were on a microscopic scale and ‘electron microscopists’ would argue—as Gabor did—that a photographic transparency is three-dimensional. Denisjuk also stated in his 1962 paper

¹⁷⁹ Dennis, “‘Our First Line of Defense’: Two American Universities in the Post-war American State”, 427-455, on 454.

¹⁸⁰ Elizabeth Crawford, *The Beginnings of the Nobel Institution: The Science Prizes* (Cambridge, NY, Paris: Cambridge University Press & Editions de la Maison des Sciences de l’Homme, 1984), 164.

¹⁸¹ Dennis, “‘Our First Line of Defense’: Two American Universities in the Post-war American State”, 427-455, on 428.

that he had recorded objects without a laser. However, the laser provided a number of beneficial attributes over the mercury arc lamps. Leith pointed out some of these in a letter to Gabor: it reduced the time of the exposure from minutes to seconds, and one did not need to equalise beam paths.¹⁸³ However, transparencies produced with a laser would have also been brighter and clearer to see and to photograph. The original press release of 1963 (reproduced in Chapter Three), that notified the press of the pre-three-dimensional work of Leith and Upatnieks did specify that the transparencies were taken with a laser. The notion that Leith and Upatnieks *only* achieved success due to the laser was, and is still, difficult for Leith to disprove given that he could not reveal, due to military secrecy, the problem to which the research addressed. Furthermore, the opinion of practitioners was quickly formed on hearing of the three-dimensional hologram. W. Lawrence Bragg, for example, wrote to Gabor in 1965, "...the laser has been the answer to wave-front reconstruction. Of course it must be".¹⁸⁴ Yet despite Leith's re-evaluation of his Willow Run research the Lippmann-to-Gabor narrative has endured.

Gabor was privileged, through his Nobel Lecture—to be the historian of his own invention. His history successfully obscured the contribution of the US military, and that of Leith and Upatnieks. Gabor's 'history' is not referred to, or repeated, amongst display holographers. This suggests that Gabor was not an accepted discipline leader, despite the assistance of Stroke to aid, what Gabor named as, his 'comeback'. However, Gabor was the acknowledged 'symbolic' inventor. It also suggests that the Nobel Lecture was read as legitimating Gabor's interests and not those of the post-1963 group that asserted three-dimensional laser imaging. On leaving Imperial College, Gabor was invited by his friend Peter Goldmark to work on a part-time contract for CBS Laboratories. At CBS he continued to collaborate with Stroke on 'deep holographic imaging', and 'sonar-radiography'. The group of three-dimensional image-makers adhered to the Lippmann-to-Gabor narrative. In his lecture Gabor embellished further, with his own prediction, the 'historical narrative' that had already emerged to form an enduring popular comparison with Lippmann. Stroke's contribution was undoubtedly the further promotion of the Lippmann-to-Gabor narrative; Leith by contrast was unable to provide—at the peak of holography's popularity in 1965—the alternative antecedents

¹⁸² Johnston, "Telling Tales: George Stroke and the Historiography of Holography", 29-51, on 47.

¹⁸³ 17 October 1972 Emmett Leith to Dennis Gabor, in *Dennis Gabor Papers*, Imperial College Archives (London).

and history (radar and communication) because of military restrictions. These antecedents would not have benefited the collective of three-dimensional holographers who had already claimed an antecedent with Lippmann's photograph.

Because Gabor's original application was never brought to practice before 1963, any physical difference between his original 'hologram' and the three-dimensional laser image developed by Leith and Upatnieks could not be explored. Any subsequent review of his original theory—from 1963 onwards—was perhaps to gain and benefit from the fact that it remained in a literary form. The archive at Imperial College reveals that it was the Chemistry Department at Michigan University, who in 1974, were to resolve—Gabor's original desire—'heavy atoms' with improved 'holographic wavefront reconstruction'.¹⁸⁵ Furthermore, an electronic data-base search on the *Science and Citation Index* revealed that, in 2003, there were 127 citations of Gabor's paper, many of which were related to 'biomedical' applications' of microscopy, including X-ray microscopy. This implies that this is still an ongoing area of research, for which Gabor's paper provides a foundation, and that a Nobel Prize will distinguish a useful theory.

¹⁸⁴ Sir Lawrence Bragg, FRS to Professor Dennis Gabor, FRS, on 11 November 1965, in *Dennis Gabor Papers*, Imperial College Archives (London).

¹⁸⁵ 5 April 1974, L.S. Bartell to Dennis Gabor, in *Dennis Gabor Papers*, Imperial College Archives (London).

Conclusion

A Cold War technology with a revivalist history

In the introduction to this thesis, and throughout the body of its work, I have stressed the fragmented and post-modern quality of the hologram's development. It has not been my aim to reduce this story to something simpler or more classical. Rather, I have sought to explain how the narrative came into being, and to enlarge on its details. With this new account in hand, realised in the first five chapters, we can now determine the significance of the Lippmann-to-Gabor narrative for those optical-physicists who sought, from the mid 1960s, to form a disciplinary activity around the three-dimensional laser hologram. For this group the narrative reduces a complex and diffuse development to two antecedents.

In Chapters Four and Five, I explained how this popular history was adhered to despite both the introduction of both Gabor's own historical account, which emphasised his original application to the electron microscope, and Leith's later revisions—of his time at the Willow Run Laboratory—that brought to the foreground the military radar research. Furthermore, neither Gabor, nor Leith, was in a strong enough disciplinary position to advance an acceptable developmental account of the three-dimensional hologram to the wider group. However, it also appeared that of these two disciplinary applications, electron microscopy and radar, none were perceived by the emerging group of practitioners as useful antecedents to the popular three-dimensional hologram. In this case, an emerging popular history won over the inventors' (Gabor and Leith) accounts to provide an acceptable 'disciplinary history'. Such disciplinary histories are rightfully acknowledged by historians of science Wolf Lepenies and Peter Weingart as, "powerful instruments because the lay public lacks the knowledge with which to evaluate disciplinary histories critically".¹ Some of the ways in which this account has been used by practitioners themselves, and by historians other than optical physicists, are mentioned in the introduction. So in reviewing the Lippmann-Gabor narrative, I have sought to gain insight into its origin and function for the group it serves.

¹ Wolf Lepenies and Peter Weingart, "Introduction", in *Functions and Uses of Disciplinary Histories*, ed. Loren Graham, Wolf Lepenies, and Peter Weingart, *Sociology of the Sciences a Yearbook* (Dordrecht Boston Lancaster: D. Reidel Publishing Company, 1983), ix-xx, on xvi.

I can identify that this Lippmann-to-Gabor history provided, from 1962 onwards, a contextual nineteenth-century ‘backdrop’ to a speedily promoted and highly popular, technological novelty of Cold War origin. The Lippmann-to-Gabor narrative was a construction by the Soviet optical-physicist Yuri Denisyuk. His 1962 paper was located, by American researchers Leith and Stroke, in the translation by the American Institute of Physics of the Proceeding of the Soviet Academy of Science, and then re-cited. These translations, according to the American Institute of Physics, were funded with a grant from the National Science Foundation in order to give American researchers access to Soviet science. The Lippmann-to-Gabor narrative can also be employed by others to omit its Soviet originator, Denisyuk. The narrative is a Cold War invention. If we assume that Soviet state-funded Cold War science was just as obscured behind the diversionary tactic of open journal publication and systems of security classification—as was certainly the case in the United States—the narrative is also an illusory one.

The historian of science Michael Aaron Dennis has suggested that the system of security classification both connects and conceals the linkage between the civilian and military realms in post-World War II American science.² With regard to the hologram, classification has created a paradox of the highly visible (the three-dimensional illusion, the images in the press, the open publications) existing against a background of the hidden (the military applications, classified science, the state-defined status of researchers). This duality is a constant repeating pattern that emerges in the thesis, and it is perhaps, a paradigm of the Cold War scientific culture. I have identified, in Chapter Three, that such duality occurred with the onset of World War II and Gabor being given, in 1943, both ‘enemy-alien’ status and a civilian, rather than a military research project to work on—the electron microscope.

I reveal, in this thesis, how this duality continued. For example, Paul Kirkpatrick who, in the 1950s, with his research student H.M.A. El-Sum produced X-ray holograms, was one of the few staff at Stanford University to reject military applications and presumably maintained his own research interests. He was also one of the few to pursue Gabor’s original application. Also, the physicist David Bohm who developed the theoretical model of the holographic universe did so after losing his American academic

² Michael Aaron Dennis, “‘Our First Line of Defense’: Two American Universities in the Post-war American State”, *ISIS*, 85 (1994), 427-455, on 454.

position, having been identified as a former member of the communist party. Later, other physicists and students were to perceive Bohm's work as an alternative standpoint to the orthodox research that dominated the American Cold War physics departments.³ Nevertheless, the emergence from the Willow Run Laboratories at Michigan University, of the three-dimensional laser hologram was entangled in the diffuse hybrid academic and military culture that was a phenomenon of the Cold War University. All these fragmented and differing forms of publication take place against a background of the Cold War containment of science that was initiated by the United States in 1947. And historian of science Mario Biagioli employs Bohm's model to unify disparate contributions of authorship, "In the end, scientific authorship seems to work like a hologram in which each fragment 'contains' the whole".⁴ In this thesis I have demonstrated how authorship is created and maintained through the publication of journal papers, and how invention is pursued through the definition and repetition of both literary and visual descriptions. In addition to such formal publications, I have also examined some of the more unpredictable, but nevertheless, significant popular accounts that contributed to defining the hologram as a cultural artefact.

In Chapter Four, I have argued that Cold War military research essentially split Gabor's original theory of applied 'wave-front reconstruction' into two parts. It did so by employing both classification and description, to define and separate a new all-optical three-dimensional laser hologram from military radar applications. In his 1949 paper, Gabor had proposed a theoretical process that *both* translated, and then optically reconstructed, one part of the electromagnetic spectrum to another. He gave the hypothetical example—intended for the electron microscope—of an electron 'image' being realised in three-dimensions within the visible part of the spectrum. The 1960s presentation of the hologram in the popular press isolated and defined the three-dimensional laser hologram as a 'novelty', a technology that was promoted without having any proven or identifiable application at the time. This presented a solution without a problem, and, as I have pointed out in Chapter Five, publishing the solution

³ Brian Easlea, "Patriarchy, Scientists, and Nuclear Warriors", in *Beyond Patriarchy: Essays by Men on Pleasure, Power, and Change*, ed. Michael Kaufman (Toronto, New York: Oxford University Press, 1987), 195-215, on 196. Easlea a former physicist who, as student, attended a course by David Bohm writes of Bohm's example, "...that physics was not solely a means for manipulating nature or a path to professional mundane achievement thorough the publication of numerous, uninteresting papers, but ideally was an essential part of human nature".

⁴ Mario Biagioli, "Rights or Rewards?" in *Scientific Authorship: Credit and Intellectual Property in Science*, ed. Mario Biagioli and Peter Galison (London: Routledge, 2003), 253-279, on 264.

without acknowledging the problem it addressed, was not necessarily perceived, by other scientists or historians of science, as the ‘full’ account for an open public science.⁵ Gabor’s appeal in his Nobel Lecture was not solely to remind his audience of his original discipline, it was also an attempt to promote, and revive, a unified theory of ‘wave-front reconstruction’.

In addition to this ‘descriptive’ splitting, a social fragmentation was also taking place at Michigan University. Two competing teams, one headed by Leith the other by Stroke, employed the Lippmann-to-Gabor narrative to advance and support the notion that the practice of producing pictorial laser holograms was located within the wider published literature. In Chapter Five, I outlined how Stroke’s promotion of this narrative was in keeping with his original mission, delegated by Michigan University, to support the transfer of knowledge from its military research base into the academy. However, Stroke’s active pedagogical lead-taking appeared to act divisively in splitting his role away from that of Leith’s, in promoting the new three-dimensional hologram. This competition for publicity, and ultimately, civilian research contracts was typical of the change in the Cold War university research environment. Historian Rebecca Lowen has pointed out that “fame and power” for staff, were seen as a means to build up research empires which were then “entangled with the university’s system of rewards and penalties”.⁶ Publishing in research journals alone was not enough to build up a public profile of activity; hence researchers sought, and strongly competed for, publication in the general press. This internal competition gave rise to a situation where there was no clear discipline leadership at Michigan University, the site of publication for the popular laser hologram. However, as I have revealed in Chapter Five, Stroke appealed to Gabor to provide disciplinary leadership; but Gabor was too removed, both geographically and academically, from the new developments at Michigan University, to fulfil this role.

The historical backdrop provided by the Lippmann-to-Gabor narrative is charmingly pictorial. It proposes a popular photographic lineage which omits the more complex elements of twentieth-century electron-optics. It thus provides a kind of ‘living

⁵ Augustine Brannigan, “Naturalistic and Sociological Models of the Problem of Scientific Discovery”, *The British Journal of Sociology*, 31, no. 4 (1980), 559-573, on 566. “That a discovery is ‘possible’ also refers to the perception that the discovery was the outcome of a course of inquiry that was substantially scientific, i.e. relevant to science”. The discoverer must be seen to be doing research that leads to the solution.

⁶ Rebecca S. Lowen, *Creating the Cold War University: The Transformation of Stanford* (Berkeley, Los Angeles, London: University of California Press, 1997), 236.

history' like that described by the historian Raphael Samuel in his reflections on museums and heritage. And like that complex of heritage and visibility, it gives its living history a contemporary resonance to current consumer interests.⁷ In this case the Lippmann-to-Gabor history serves the interests of 'display' or image holographers. The narrative achieves this by leaving out the more (unpopular) scientific and technical descriptions of wave-theory, electrons, and radar, in favour of simpler photographic analogies. However, the story also overlooks the difficult twentieth-century social contexts that exist in the field of electrical engineering; a discipline prone to disputes because it overlaps military, industrial and consumer interests. Those specific contextual issues, I have revealed in Chapters Four and Five: the military Cold War development, and the priority disputes arising at Michigan University between Leith and Stroke. These issues others chose to omit, from 1965 onwards, no doubt because issues of classification and priority might also impinge, with possible restrictions, on any future research and funding opportunities.

Also in mid-1960s America, after the Korean War and during the Vietnam War, the American public was unsympathetic towards the military and the political justification of these wars. Hollywood films, such as *The Manchurian Candidate* (1962) depicted the communist Korean 'brainwashing' of captured American Prisoners of War. According to historian of film Charles Young, the film showed a changing and unpatriotic image of American forces: one that revealed a 'lack of masculinity and national spirit'.⁸ The climate of the 1960s was unlike the situation after World War II, where an American and allied victory made such critical introspection unnecessary. The highly protested Vietnam War would have also affected the public disclosure by researchers of military connections. This contrasts with earlier perceptions of military service. For example, during the First World War, Herbert Ives, as an American Army Major in the Air Service, undertook an aerial photographic survey and flight over Germany, for which he received the highest US military-award. The public image of Major Ives was perceived more favourably; it matched that of the squadron of First World War aerial-bombers depicted in the 1930s cult movie *Hell's Angels*. This film was produced by wealthy magnate Howard Hughes whose company both produced and

⁷ Raphael Samuel, *Theatres of Memory* (London: Verso, 1996), 194-195. Samuel describes living history as that engaged with museum shops and historical reproductions.

⁸ Charles S. Young, "Missing Action: POW Films, Brainwashing and the Korean War, 1954-1968", *Historical Journal of Film, Radio and Television*, 18, no. 1 (1998), 49-74, on 54.

glamorised, by association, the technologies of aircraft and movie-films. Both Herbert Ives and Leith had undertaken classified research on military-aerial-surveillance imagery. However, Ives was able to publish after the end of the war, *Airplane Photography* in 1920.⁹ This was a book encouraging civilian use of this technology. After the First World War no future war was envisaged to restrict its publication.

For those optical-physicists wishing to pursue three-dimensional laser holography, a nineteenth-century antecedent provided, in a citation list, a flexible and popular point of departure. For example, it was flexible enough for Gabor to refer to it in his Nobel Lecture. It suggested the conceptual framework had been in the public domain since 1891. Furthermore, it was a history that could be in agreement with the type of hologram found within the press—such as *Life* magazine's photo-story, which described the hologram as a new photography. However, although the Lippmann-to-Gabor 'backdrop' supported a popular form of three-dimensional hologram, as well as the relationship of popular pictorialism and science, it also skipped over the labours of Leith and Upatnieks. It achieved this with a form of historical 'foreshortening' that emphasised and privileged Nobel-winning theory above image production, and cast the role of the picture-maker into a lesser more artisan position. With this emphasis, Leith's position might now be compared to that of the nineteenth-century American inventor Frederic Ives (see Chapter Two). By making such a comparison, we can discern that both Leith and Ives had produced imagery and invention that was published in popular arenas; both had difficulty in asserting credibility outside of the United States; and both admitted to having 'discovered' that their 'invention' had been published earlier by others. In Ives' case, he was to discover that his invention had been preceded by James Clerk Maxwell's demonstration of three-colour photography. Whereas for Leith, it was Gabor's 1949 paper on 'wave front reconstruction', which Leith claimed he read *after* he had produced an internal memo, at Willow Run, with an identical solution.

The validity of the Lippmann-to-Gabor narrative could be achieved because the general reader, of both journal citation lists and popular articles, assumed that the description for the pictorial three-dimensional hologram was embedded within Gabor's original publication. Therefore, the reader might assume that Leith and Upatnieks had achieved their results by applying the laser to Gabor's original hypothesis. In this case, the reader could assume that the two Nobel-winning theories of Lippmann and Gabor

⁹ Herbert E. Ives, *Airplane Photography* (Philadelphia and London: J.B. Lippincott Company, 1920).

could explain the modern spectacle. However, in exploring Gabor's 1949 paper in Chapter Three, I reveal that the hologram Gabor defined differed in function from the popular three-dimensional one. The Lippmann-to-Gabor history suited the attempts to promote three-dimensional pictorial holography as a separate discipline, and it did not serve this group of holographic researchers to refer to either Gabor's original application to the electron microscope or, even after de-classification, radar surveillance. More broadly it suited the need for a history that could be offered to the public, as part of the creation of the discipline's public image and appraisal. As historian of science, Dominique Pestre has stated, with regard to CERN physicists and the development of a collective memory as history, "...they still wanted to perceive themselves as descendants of the moral savants.... Hence their stress on pure intellectual achievements, their preference for nobility".¹⁰

By exploring the Lippmann-to-Gabor narrative throughout this thesis, the reader can discern how a group selectively seeks to attribute authorship. In Chapter Five, evidence of such attribution at work is found within Gabor's own selective discovery account—and his omission of Leith and Upatnieks successful popular imagery—within his Nobel Lecture. Historians of science Lepenies and Weingart have pointed out that such historical reconstructions of the past are frequently designed to suit current research endeavours and support.¹¹ Gabor's Nobel Lecture is a good example of this reconstruction process.

This Lippmann-to-Gabor narrative maintains—with sole-authored papers—a nineteenth-century ideal of noble, independent and academic science. In doing so it de-emphasises what, Thomas Hughes calls 'conservative science'; the reality of twentieth-century research undertaken by large teams, addressing problems essentially handed down through a hierarchy of management within corporations or military programs. The narrative leaves open the possibility, after Gabor's 1949 paper, to add further individual contributions. Those who use this history as their backdrop then insert whatever research application they wish to highlight. It is a narrative that leaves the history open, after Gabor's 1949 paper, for further additional contributions. Lepenies has suggested that since the 1960s and the rapidly diminishing belief in the progress of modern science "... a growing scepticism and a loss of disciplinary history can be identified in many

¹⁰ Dominique Pestre, "Commemorative Practices at CERN: Between Physicists' Memories and Historians Narratives", *Osiris* 14 (1999), 203–216, on 215.

sciences. One form of reaction and, sometimes, consolation consists in the re-historisation of a field”.¹² This re-introduction and revival of Lippmann’s 1891 process helped form a new history that made the narrative post-modern. Post-modern constructs are distinguished by their enthusiasm for revivalism.¹³

As I have explored in Chapters Two and Four, the *Lippmann emulsion*—in the form of a Kodak photographic plate—did provide Leith and Upatnieks with a vital resource that they did not have to research and produce, in the manner that the Lumière Brothers assisted Lippmann. This emulsion is emphasised in Denisjuk’s 1962 paper. Yet this legacy, of a material culture, is not the comparison that the narrative highlights, it selects celebrated Nobel Prize-winning theory, avoiding the thread of products, patents and uncelebrated inventions and authors. Scientists construct a history upon journal citations, often publishing historical accounts in the very same journals, which further applauds the authority of the publication to create what Pestre names as the, “self-proclaimed historical studies of the discipline”.¹⁴ For those protagonists constructing a history in this manner, many alternatives in the forms of an extant material culture will be overlooked.

Three-dimensional imagery: Gabor, H. Ives, Lippmann, and the Lumière Brothers

Like military science, commercial research will often engage in a policy of secrecy. Archival resources reveal that some of the early twentieth-century endeavours of Lippmann, the Lumière Brothers, and Frederic and Herbert Ives are attempts to produce consumer three-dimensional imagery. The desire to realise a commercial consumer three-dimensional image is a linking factor that, at some time, engaged all the protagonists of this thesis. In addition to Gabor’s pursuit of three-dimensional film, Leith and Upatnieks also published, with other authors, two papers on holographic television.¹⁵ These research activities, as in Gabor’s case, might have been motivated initially by the interests of industrial patrons. In Cold War America large commercial

¹¹ Lepenies and Weingart, “Introduction”, ix-xx, on xvi.

¹² *Ibid*, ix-xx, on xiii.

¹³ Frederic Jameson, *Postmodernism, or, the Cultural Logic of Late Capitalism* (London, New York: Verso, 1991), 296.

¹⁴ Pestre, “Commemorative Practices at CERN: Between Physicists’ Memories and Historians Narratives”, 203–216, on 204.

¹⁵ E.N. Leith et al., “Requirements for a Wavefront Reconstruction Television Facsimile System”, *Journal of the Society of Motion Picture and Television Engineers*, 74, no. 10 (1965), 893-896. Also E.N. Leith et al., “Hologram Visual Displays”, *Journal of the Society of Motion Picture and Television Engineers*, 75, no. 4 (1966).

corporations offered an alternative to military-funded research, however, the two were often closely allied to State interests. According to Rebecca Lowen, “Cold War rhetoric linked economic prosperity and military might as the two pillars of America’s defense against the Soviet threat”,¹⁶ and three-dimensional television was possibly undertaken, at Michigan University, as a suitable application for both civilian and military investors.

Correspondence between Lippmann and the Lumière Brothers—from after the First World War in 1919 until Lippmann’s death in 1921—reveal that they did attempt to realise his 1908 proposal for a three-dimensional-lenticular screen.¹⁷ This 1908 paper by Lippmann was reviewed by Herbert Ives and mentioned by Gabor in his Nobel Lecture. However, the practical development by the Lumière Brothers did not occur until after the war because the Lumière Brothers voluntarily dedicated their resources to the French war effort. Letters reveal the difficulty of obtaining celluloid—an American product that was a standard component of movie-film production—and in experiments to find an alternative substrate, which was to thwart their efforts. The Lumière Brothers were reluctant to import celluloid because of the expense, and possibly because they did not wish to alert the American competitors to their concept. The motivation to achieve a new three-dimensional medium, especially one that did not require projection, as Lippmann had proposed, might have been driven by the increasing success of the American movie industry, which had made significant inroads into France by the 1920s. Historian of film Jens Viff-Møller states that from 1916, American operators such as Paramount operated a block booking system, whereby a French cinema could only show select ‘high-end’ American films if it agreed to take a number of ‘low-budget’ fillers. This gave rise to a situation where 80 per cent of the films screened in France were imported. By contrast independent French cinemas were subject to taxes. Viff-Møller argues that “France had an old tradition of restrictions on public amusements—taxes, licenses...” and nobody thought it necessary to protect French film production.¹⁸ A popular three-dimensional product was perceived, between the wars, as a possible successor to cinema. There is no extant material evidence of these experiments. This ‘commercial’ research and collaboration between savant and industrialists was to

¹⁶ Lowen, *Creating the Cold War University: The Transformation of Stanford*, 135.

¹⁷ Auguste and Louis Lumière, *Letters*, ed. Jacques and Yvelise Dentzer Rittuad-Hutinet, trans. Pierre Hodgson (London, Boston: Faber and Faber, 1995). This is documented in correspondence, between the Lumière Brothers, Lippmann, and subcontracted technicians from page 178 onwards.

¹⁸ Jens Viff-Møller, “The Origin of the French Film Quota Policy Controlling the Import of American Films”, *Historical Journal of Film, Radio and Television*, 18, no. 2 (1998), 165–182, on 171.

remain hidden—as personal correspondence—from other researchers such as Herbert Ives, who would have sought published papers.

However, Lippmann's 1908 paper for a three-dimensional image was reviewed by Herbert Ives at Bell Laboratories with the intent of producing three-dimensional television or film. Bell Laboratories was a large statewide company that fostered a modern approach to managed science for corporate enterprise.¹⁹ Papers published by Ives in the early 1930s indicate that he successfully demonstrated a flat three-dimensional ribbed 'lenticular screen' using projected imagery from a 'battery' of cameras. Nevertheless, Ives was to encounter similar problems to those experienced by Lippmann and the Lumière Brothers and documented in their correspondence.²⁰ However, one new issue Ives identified in attempting to create three-dimensional versions of a cinematic-style imagery to satisfy commercial predictions, was that of scale, and its relationship to perception. According to Ives, in his 1932 paper *The Problem of Projecting Motion Pictures in Relief*, objects seen in standard movie projections were not "...reproduced in natural sizes", owing to such cinematic moves as 'close-ups', or 'zooming or panning of the camera-lens'. Theoretically, for Ives, translating two-dimensional imagery into three-dimensional movies created a paradox whereby "... if the screen images be magnified, the separation of the eyes of the observers should be increased in the same proportion", in order for the viewer to perceive the image as three-dimensional. He suggested that the solution to seeing three-dimensional 'relief' required discipline on the part of the viewer:²¹

All that is necessary, therefore, to achieve projection in relief is to train our audiences to control their optic axis by making themselves cross-eyed, or the reverse, during the projection period. While this method of stereoscopic projection is entirely feasible for an audience of optical experts who have had a little training and practice, it does not appear promising for popular use.

¹⁹ Patrick J. McGrath, *Scientists, Business, and the State, 1890-1960* (Chapel Hill: University of North Carolina Press, 2002), 40-41, on 38.

²⁰ Herbert E. Ives, "Pan-Stereoscopic Photography and Cinematography: The Traill-Taylor Memorial Lecture before the Royal Photographic Society, 3 October 1933, London", in *F. & H. Ives Papers, Manuscript Division of the Library of Congress* (Washington), 19 and 28. Technically, Ives had problems with the registration of the film because celluloid expanded with temperature. This expansion and shrinkage created changes to the registration of imagery onto the screen, plus Ives' required film speeds of 1/1000th of a second that were not available.

²¹ Herbert E. Ives, "The Problem of Projecting Motion Pictures in Relief", *Transactions of the Society of Motion Picture Engineers*, 18 (April 1932), 417-439, 428.

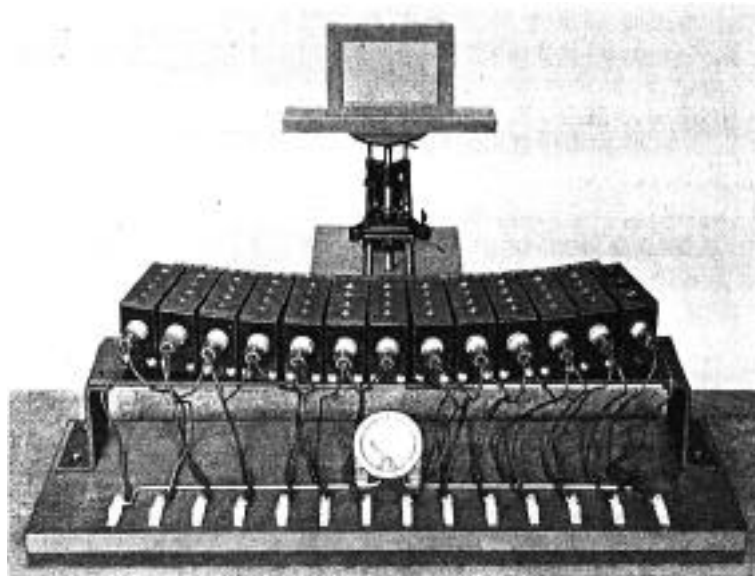


Fig.6.1. Apparatus for projecting three-dimensional imagery produced at Bell Laboratories by Herbert Ives. F. & H. Ives Papers, Manuscript Division of the Library of Congress (Washington).

Despite Ives' published conclusions on the inherent problems of seeing three-dimensional film or television, it was to remain a desirable consumer product throughout the twentieth-century. The difficulty, described by Ives, of attaining projected three-dimensional imagery, perhaps permits an insight into why the hologram was so successful. The popular hologram offered three-dimensionality without any need for special spectacles, screens, or visual training, although it did not, at first, offer movement or full-colour. Those aspects—movement and colour—remained part of the future promise for this new medium, which was linked with a consumer desire to acquire a total simulation of reality. This desire, for three-dimensionality, was as embedded in the popular twentieth-century imagination as the desire for *natural* colour was within the historical memory of late-nineteenth-century photographers. Historian Jeffrey Sconce has stated that in the twentieth century, it was “consciousness and electrons” that converged in the “cultural imagination” to create those reoccurring fictions of other realities and teleportations.²² Herbert Ives attempted to resolve an illusory virtual reality with a knowledge of human perception and electro-optical technology. Whereas, Lippmann had sought to engage with nature's inherent solution—interference. In the nineteenth century the fictive cultural metaphor was still nature's divine force.

²² Jeffrey Sconce, *Haunted Media: Electronic Presence from Telegraphy to Television* (Durham & London: Duke University Press, 2000), 93.

In exploring differences and comparisons inside the Lippmann-to-Gabor narrative, I have examined the changes in descriptive modelling, as well as the means by which such descriptions endured. Lippmann's 1891 paper provided an interesting model. It appealed to light as an immediate force of nature, yet historically it marked a departure away from the older photographic craft towards a more authoritative academic discipline, physics. Subsequently, with the 1908 review by Herbert Ives, it gained the modern descriptive terminology that has enabled it to function for the late twentieth-century physicist. Ives re-modelled Lippmann's elegant description of interference, for an American audience, by employing the concept of the interferometer by the first American Nobel-laureate Albert Michelson. Leith and Upatnieks also adopted the interferometer in describing their own invention. This example reveals that reviews of existing papers are important to a discipline's development, because reviews permit new descriptions to develop and gain usage. The reviews of Lippmann's work, by Herbert Ives, were the significant, but uncelebrated link, to bringing Lippmann's concepts into the twentieth-century discipline now known as electro-optics.

In Chapters One and Two, I described how *Lippmann photography* was essentially a medium for the emerging late-nineteenth-century professional photochemist, and how the process failed to be of use to the amateur or studio photographer. That so little exists within the history of photography on Lippmann, perhaps confirms the fact that Lippmann's photographic invention marked a discipline change, as aspects of image production merged with professional science away from artisan associations. This disciplinary move was furthered, in the twentieth century, by the work of Herbert Ives.

Visual descriptions played a vital role in the promotion of both Lippmann's 1891 theory and Gabor's 1949 paper. Furthermore, it was only as visual artefacts that the Lippmann photograph and the hologram gained a popularity and mediation that enabled their success. To this end both forms of images pursued a scientific and highly objective form of pictorial realism employing familiar subjects such as parrots and trains. One overlooked linking factor I have identified, in both cases, is that others undertook the visual production of imagery: the Lumière Brothers, and Leith and Upatnieks, although it was easily assumed, by the general public, that the inventors were also image-makers. This production, of both inventions, was highly skilled and

involved not solely image-making but also distribution and promotional activities. Yet, the resulting separation of academic theory from both the visual and the popular is at its most pronounced in the case of the hologram. Unlike the Lumière Brothers—whose intentions for developing the *Lippmann photograph* were commercial photographic plate-production, and as industrialists, recognition from the French savants—Leith and Upatnieks were participating, with published papers, within a similar arena of academic and industrial research as Gabor. However, their most successful promotional activities of the hologram took place in popular journals and magazines that physicists could opt to ignore. Subsequently, as the laser hologram promoted by Leith and Upatnieks drew public attention to Gabor's original theory, their efforts were eventually obscured, first by the Lippmann-to-Gabor narrative and later with Gabor's own revival, achieved with his Nobel Prize and its accompanying lecture. Was this merely the sheer preference for theory within a discipline? Or was the lack of transparency surrounding the University of Michigan's Cold War military research an inherent problem to assessing their role? These questions remain unanswerable because the Nobel archives are not available to scholars. However, they are also the questions that are hidden by the historical backdrop of the Lippmann-to-Gabor narrative, and as this thesis has demonstrated, this ideal historical-revival omits all the inherent complexities of the hologram's development in the Cold War period. The revival reconstructs an image of a nobler and far simpler past.

Bibliography

I include all works cited in the thesis plus additional texts which have informed my thoughts on this subject. All manuscripts and patents are listed by author. Unauthored reports in newspapers are listed under 'Staff reporter', unless they are identified in the main text as by the 'Editor', for example. Since I started this thesis, I understand that Emmett Leith has deposited some of his private papers in the Bently Historical Library, at The University of Michigan, Ann Arbor. However, I refer to them here as the *Private Papers of Emmett Leith*.

- A.S. "Obituary Notices of Fellows Deceased". *Proceedings of the Royal Society of London, Series A* 101 (1922): i-iii.
- Abir-Am, Pnina G. "Commemorative Practices in Science: Historical Perspectives on the Politics of Collective Memory". *Osiris* 14 (1999), 324-372
- Aesthetic Club, Edinburgh. DC.2.58 *Manuscript Collection*, Edinburgh University.
- Alschuler, W.R. "In the Physical and Visual State of 100 Year Old Lippmann Color Photographs". *Proceedings of the SPIE*, 3358 Sixth International Symposium on Display Holography (1998): 84-94.
- Appell, Paul. *Funeral of Gabriel Lippmann*. Paris: Institute de France Academie de Sciences, 1921.
- Arnheim, Rudulphe. "On the Nature of Photography". In *New Essays on the Psychology of Art*, Berkeley, Los Angeles, London: University of California Press, 1986.
- . "Splendour and Misery of the Photographer". In *New Essays on the Psychology of Art*, Berkeley, Los Angeles, London: University of California Press, 1986.
- Arnold, H.P. *William Henry Fox Talbot*. London: Hutchinson Benham, 1977.
- Ash, Eric A. "Obituary, Dennis Gabor, 1900-1979". *Nature* 280, August (1979): 431-433.
- Ashmore, Malcom. "Theatre of the Blind". *Social Studies of Science* 23 (1993): 61-106.
- Bailes, Kendall E. "The Technical Specialists". In *The Social Context of Soviet Science*, edited by Linda L. Lubrano and Susan Gross Soloman, 137-171. Boulder, Colorado and Folkstone, England: Westview Press and Dawson, 1980.
- Baran, Neil. "Films in Depth". *Mini-Cinema* 5, no. 9 (1951): 32.
- Barrell, John. *The Political Theory of Painting from Reynolds to Hazlitt*. New Haven and London: Yale University Press, 1986.
- Barry, William. *Ernest Renan, Literary Lives*. New York: Charles Scribner's Sons, 1905.
- Bartell, L.S. to Dennis Gabor, 5 April 1974. In *Dennis Gabor Papers Imperial College Archives*, London.
- Baudrillard, Jean. *Revenge of the Crystal: Selected Writings on the Modern Object and Its Destiny*. Edited by Paul and Julain Pefanis Foss. London and Concord, Mass: Pluto Press, 1990.
- Bauman, Zygmunt. *Intimations of Postmodernity*. London, New York: Routledge, 1992.
- . *Liquid Modernity*. Cambridge, UK: Polity Press, 2000.
- . *Memories of Class*. London & Boston, Mass.: Routledge & Keegan Paul Ltd, 1982.
- . *Postmodernity and Its Discontents*. Cambridge, UK: Polity Press, 1997.
- Becquerel, Edmund. "Photographie.--Observations De M. Edm. Becquerel Sur Las Communication De M. Lippmann Au Sujet De Las Reproduction Photographique Des Couleurs". *Comptes Rendus à l'Academie des Science* 112 (1891): 275-277.
- Bell, Clive. "The Aesthetic Hypothesis: Significant Form and Aesthetic Emotion". In *The Philosophy of the Visual Arts*, edited by Philip Alperson, 119-126. New York Oxford: Oxford University Press, 1992.
- Benjamin, Walter. "The Image of Proust". In *Illuminations*, edited by Hannah Arendt. New York: Harcourt, Brace & World, Inc., 1968.

- Benjamin, Walter. "The Work of Art in the Age of Mechanical Reproduction". In *Illuminations*, edited by Hannah Arendt. New York: Harcourt, Brace & World, Inc., 1968.
- Berthelot, Daniel. *Funeral of Gabriel Lippmann*. Paris: Institute de France Academie de Sciences, 1921.
- Biagioli, Mario. "Rights or Rewards?" In *Scientific Authorship: Credit and Intellectual Property in Science*, edited by Mario Biagioli and Peter Galison, 253-279. London: Routledge, 2003.
- Bijker, Wiebe. E. *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*. Cambridge, Mass. London, England: The MIT Press, 1995.
- Bjelkhagen, Hans I. "Lippmann Photographs Recorded in Dupont Color Photopolymer Material". *Proceedings of the SPIE 3011, Practical Holography XI and Holographic Materials III* (1997): 358-356.
- . "Lippmann Photography: Reviving an Early Colour Process". *History of Photography* 24, no. 2 (1999): 274-280.
- Bohm, David. *Wholeness and the Implicate Order*. London, Boston and Henley: Routledge and Kegan Paul, 1980.
- Bohm, David to Dennis Gabor, March 14 1969. In *Dennis Gabor Papers Imperial College Archives*, London.
- Bolas, Thomas. "History and Development of Heliochromy". In *Handbook of Photography in Colours*, edited by Thomas Bolas. London: Marion & Co, 1900.
- . *The Photographic Studio*. London: Marion & Co, 1895.
- Boon A, James. "Why Museums Make Me Sad". In *Exhibiting Cultures: The Poetics and Politics of Museum Display*, edited by Ivan and Steven D. Lavine Karp, 255-277. Washington and London: Smithsonian Institution, 1991.
- Bothamley, C.H. "Letter to the Editor". *NATURE* 54, no. 1385 (1896): 77.
- Bourdieu, Pierre. *Distinction: A Social Critique of the Judgement of Taste*. 7th English ed. London: Routledge & Kegan Paul Ltd, 2003.
- Bracegirdle, Brian, and James B. McCormick. *The Microscopic Photographs of J.B. Dancer*. Chicago: Science Heritage Ltd, 1993.
- Bradbury, S. *The Microscope Past and Present*. Oxford, London, New York: Pergamon Press Ltd, 1968.
- Bragg, W. Lawrence. "Letter to the Editor: A New Type of X-Ray Microscope". *NATURE* 143 (1939): 678.
- Bragg, W. Lawrence, to Dennis Gabor, 1951. In *Dennis Gabor Papers Imperial College Archives*. London.
- Bragg, W. Lawrence to Dennis Gabor, on 11 November 1965. In *Dennis Gabor Papers Imperial College Archives*. London.
- Brannigan, Augustine. "Naturalistic and Sociological Models of the Problem of Scientific Discovery". *The British Journal of Sociology* 31, no. 4 (1980): 559-573.
- . *The Social Basis of Scientific Discoveries*. London and New York: Cambridge University Press, 1981.
- Brewster, David, to Henry Fox Talbot. 12 February 1839. In *Selected Correspondence of W.H. Fox Talbot 1823-1874*, edited by L. Schaaf, 18. London: Science Museum and the National Museum of Film and Photography, 1994.
- Briggs, Asa. *Victorian Things: The University of Chicago Press*, 1988.
- Briggs, Asa and Peter Burke. "A Social History of the Media: From Gutenberg to the Internet". Cambridge: Polity Press, 2002.
- Brown, R.G.W., and E.R. Pike. "A History of Optical and Optoelectronic Physics in the Twentieth Century". In *Twentieth Century Physics*, edited by Laurie. M. Brown, A. Pais and Sir. B. Pippard, 1414. Bristol & Philadelphia, New York: Institute of Physics Publishing, American Institute of Physics Press, 1995.
- Brück, H.A., and M.T Brück. *The Peripatetic Astronomer*. Bristol: Adam Hilger, 1988.
- Brush, Stephen G. *Scientists as Historians*. *Osiris* 10 (1995): 217-228
- Buckley, Oliver E. and Karl K. Darrow. *Herbert E. Ives 1882-1953 a Biographical Memoir, National Academy of Sciences*. New York: Columbia University Press, 1956.

- Buerger, Janet E. "The Genius of Photography". In *The Daguerrotype a Sesquicentennial Celebration*, edited by John Wood, London: Gerald Duckworth & Co Ltd, 1989.
- Buerger, M.J. "Generalised Microscopy and the Two-Wave Length Microscope". *NATURE* 21 (1950): 909-917.
- Bush, Larry. "Young Researchers Intrigued". *The Ann Arbor News*, Sunday May 21 1972, *Private Collection of Emmett Leith*.
- Callen, Anthea. "Doubles and Desire: Anatomies of Masculinity in the Later Nineteenth Century". *Art History* 26, no. 5 (2003): 669-699.
- CARL ZEISS of JENA, 1910. (product catalogue) "Special Appliances for Interference Colour Photography". London. Collection of the Rowland Institute, Cambridge, Mass.
- Caulfield, J. "Holography in the U.S". In *Handbook of Optical Holography*, edited by T. Jung, Academic Press: New York, 1979.
- Chadarevian, Soraya de. "Portrait of a Discovery: Watson, Crick, and the Double Helix". *ISIS* 94 (2003): 90-105.
- . "Using Interviews to Write the History of Science". In *The Historiography of Contemporary Science and Technology*, edited by Thomas Söderqvist, 51-70: Harwood Academic Publishers, 1997.
- Chadwick, Owen. *The Secularization of the European Mind. Canto*. Cambridge: Cambridge University Press, 1995.
- Cloudy, C.H. "The Romance of Invention—Frederic E. Ives, Wizard of Colour and Light, and Father of the Half-Tone". *Scientific American*, July 31 1920, 104 and 112-114.
- Cloud, John. "Imaging the World in a Barrell: Corona and the Clandestine Convergence of the Earth Sciences". *Social Studies of Science* (2001): 231-511.
- Connes, P. "Silver Salts and Standing Waves". *Journal of Optics (Paris)* 18, no. 4 (1987): 147-166.
- Conversazione*, the Royal Society London. May 6, 1891 (catalogue). *Archives of the Royal Society*.
- Correspondent from the Philadelphia Photographic Society. "A Gold Medal for Mr. Ives". *The Photographic News*, January 6 1893, 13.
- Crary, Jonathan. *Techniques of the Observer*. 2nd ed. Cambridge, Mass London, England: MIT Press, 1990.
- Crary, Jonathon. *Suspensions of Perception: Attention, Spectacle, and Modern Culture*. Cambridge, Mass, London, England: MIT Press, 1999.
- Crawford, Elizabeth. *The Beginnings of the Nobel Institution: The Science Prizes*. Cambridge, New York, Paris: Cambridge University Press & Editions de la Maison des Sciences de l'Homme, 1984.
- . "German Scientists and Hitler's Vendetta against the Nobel Prizes". *Historical Studies in the Physical and Biological Sciences* 31, Part 1 (2000): 37-53.
- Crook, J. Mordant. *The Rise of the Nouveaux Riches: Style and Status in Victorian and Edwardian Architecture*: London: John Murray, 1999.
- D'Haurt, Emile. "Extract from a Paper on Colour Photography...". In *Gabriel Lippmann, Biographie*, edited by Ernst Lebon, 40 Paris: Gauthier-Villars, 1911.
- Darmester, Madame James (A. Mary F. Robinson). *The Life of Ernest Renan*. Boston and New York: Houghton, Mifflin and Company, 1898.
- De Solla Price, Derek J. *Little Science, Big Science*. New York and London: Columbia University Press, 1963.
- Denisyuk, Yuri. "The Development of Initial Ideas". *Journal of Optics, Paris* 22, no. 6 (1991): 275-280.
- . *Fundamentals of Holography: Lectures*. Lenigrad: State Optical, S.I Vavilov Institute, 1978.
- . "Photographic Reconstruction of the Optical Properties of an Object in Its Own Scattered Radiation Field", [English] *Soviet Physics—Doklady*, 7, no. 6 (1962), 543-545. Translated from: *Doklady. Akademii. Nauk. S.S.S.R* 144, no. 6 (1962), 1275-1278.
- . "My Way in Holography". *Leonardo* 25, no. 5 (1992): 125-130.

- Denisyuk, Yuri., and V. Gurkov. "Advancement of Holography: Investigations by Soviet Scientists". *History and Technology* 8, no. 2 (1992): 127-131.
- Dennis, Michael Aaron. "'Our First Line of Defense': Two American Universities in the Postwar American State". *ISIS* 85 (1994): 427-455.
- Dewhurst, H. *Three-Dimensional Photography in Motion Pictures*. London: Chapman & Hall, 1954.
- Dixon, Byrony. "Archiving the 1950s". In *British Cinema of the 1950s: A Celebration*, edited by Ian Mackillop and Ian Sinyard, 205-212. Manchester and New York: Manchester University Press, 2003.
- Doss, Erika. *Benton, Pollack, and the Politics of Modernism: From Regionalism to Abstract Expressionism*. Chicago: The University of Chicago Press, 1991.
- Easen, Sarah. "Film and the Festival of Britain". In *British Cinema of the 1950's: A Celebration*, edited by Ian Mackillop and Ian Sinyard, 51-63. Manchester and New York: Manchester University Press, 2003.
- Easlea, Brian. "Patriarchy, Scientists, and Nuclear Warriors". In *Beyond Patriarchy: Essays by Men on Pleasure, Power, and Change*, edited by Michael Kaufman, 195-215. Toronto New York: Oxford University Press, 1987.
- Eco, Umberto. "Openess, Information, Communication". In *The Open Work*. UK: Hutchinson Radius, 1989.
- . "Travels in Hyperreality". In *Faith in Fakes*. London: Secker & Warburg, 1986.
- Eder, Josef M. *History of Photography*. Translated by E. Epstein. 4th ed. New York: Columbia University, 1945.
- Edgerton, D.E.H. "Science and War". In *Companion to the History of Modern Science*, edited by R.C Olby, G.N. Cantor, J.R.R. Christie and M.J.S. Hodge, 934-989. London & New York: Routledge, 1996.
- Editorial Preface. *The Photographic News*, December 15 1893, 795.
- Edwards, Elizabeth. *Raw Histories: Photographs, Anthropology and Museums*. Oxford New York: Berg, 2003.
- Edwards, Paul N. *The Closed World: Computers and the Politics of Discourse in Cold War America*. Cambridge, Mass. London, England: The MIT Press, 1996.
- El-Sum, Hussein, and Paul Kirkpatrick. "Conference Poster Session M: Microscopy by Reconstructed Wave-Fronts". *The Physical Review* 35 (1952): 763.
- Everett, Mendelsohn. "The Politics of Pessimism: Science and Technology Circa 1968". In *Technology, Pessimism and Postmodernism*, edited by Yaron Ezrahi, Mendelsohn Everett and Howard P. Segal, 151-173. Amherst: University of Massachusetts Press, 1995.
- Ewing, Anne. "Three-D Home TV Foreseen". *Science News* 89, June 11 (1966): 468-471.
- Ferguson, Marilyn. "Karl Pribram's Changing Reality". In *The Holographic Paradigm and Other Paradoxes*, edited by Ken Wilber. Boulder & London: Shambhala, 1982.
- Fischer, Gerd. *Mathematical Models from the Collections of Universities and Museums*. Edited by Gerd Fischer. Braunschweig/Wiesbaden: Friedr. Vieweg & Sohn, 1986.
- Forman, Paul. "The Discovery of the Diffraction of X-Rays by Crystals; a Critique of Myths". *Archive for the History of Exact Sciences* 6 (1969): 38-71.
- Fournier, Jean-Marc. "Interference Color Photography: One Hundred Years Later". *Journal of Optics, Paris* 22, no. 6 (1991): 259-266.
- . "An Investigation on Lippmann Photographs: Materials, Processes, and Color Rendition". *Proceedings of SPIE 2176 Practical Holography VIII* (1994): 144-152.
- Fournier, Jean-Marc, B.J. Alexander, P.L. Burnett, and S.E Stamper. "Recent Developments in Lippmann Photography". *Proceedings of the SPIE 3358 Sixth International Symposium on Display Holography* (1998): 95-102.
- Fournier, Jean-Marc and P.L. Burnett. "Color Rendition and Archival Properties of Lippmann Photographs". *Journal des Optics (Paris)* 38, no. 6 (1994): 507-512.
- Fowkes, Ben. *Eastern Europe 1945-1969: From Stalinism to Stagnation, Seminar Studies*. Harlow, England: Longman.

- Fox, Robert. *The Culture of Science in France, 1770-1900*. Aldershot, UK and Vermont, USA: Ashgate Publishing Ltd, 1992.
- Fox, Robert and Anna Guagnini. *Laboratories, Workshops, and Sites. Concepts and Practices of Research in Industrial Europe, 1800-1914*. Berkeley: University of California, 1999.
- . and Anna Guagnini. Laboratories, Workshops and Sites. Concepts and Practices of Research in Industrial Europe, 1800-1914". *Historical Studies in the Physical and Biological Sciences* 29, no. 2 (1999): 191-294.
- Friedberg, Anne. *Window Shopping: Cinema and the Postmodern*. Berkeley Los Angeles Oxford: University of California Press, 1993.
- Friedman, Joseph S. *History of Color Photography*. Boston: The American Photography Publishing Company, 1944.
- Gabor, Andre to F.H. Kitchen, April 2 1982. In *Museum of Holography Archive*, MIT Museum. Cambridge, Mass.
- Gabor, Dennis. "Holography, 1948-1971". Nobel Prize Lecture, Stockholm, December 11 1971. In *Dennis Gabor Papers Imperial College Archives*, London. Also published in *Science* 177 (1972), 299-313, and online at The Nobel e-Museum: www.nobelprize.org/physics/laureates/1971/gabor-lecture.html
- . *Inventing the Future*. London: Secker & Warburg, 1963.
- . "Lecture: Three-Dimensional Moving Pictures for Home Entertainment". 7 February 1953. In *Dennis Gabor Papers Imperial College Archives*, London.
- . *The Mature Society*. London: Secker & Warburg, 1972.
- . "Microscopy by Reconstructed Wave-Fronts". *Proceedings of the Royal Society* 197, July, (1949): 454-487.
- . "A New Microscopic Principle". *NATURE* 161, (1948): 777-778.
- . "Notes for a Profile in the New Scientist 15 July 1961". In *Dennis Gabor Papers Imperial College Archives* (London).
- . "Report to the Royal Society Paul Instrument Fund". 1956 In *Dennis Gabor Papers Imperial College Archives*. London. London.
- Gabor, his correspondence cited in chronological order:
- . to Professor H. B. Squire FRS., 30 November 1959. "Letters to Staff". In *Dennis Gabor Papers Imperial College Archives*, London.
- . to T. Raison, New Scientist, 23 July 1961. In *Dennis Gabor Papers*.
- . to Harold Strauss, 31 December 1962. In *Dennis Gabor Papers*
- . to Prof. C. H. Waddington, 16 December 1963. In *Dennis Gabor Papers*
- . to W. Lawrence Bragg FRS, 12 November 1965. In *Dennis Gabor Papers*
- . to W. Lawrence Bragg, FRS, 10 May 1966. In *Dennis Gabor Papers*
- . to R. Barer, 31 May 1966. In *Dennis Gabor Papers*
- . to Emmett Leith, 3 November 1966. In *Dennis Gabor Papers* Gabor,
- . to George Stroke, 3 January 1967. In *Dennis Gabor Papers*
- . to Arthur Koestler, 13 July 1967. In *Dennis Gabor Papers*
- . to Emmett Leith, 11 May 1969. In *Private Papers of Emmett Leith*, Ann Arbor, Michigan.
- . to Emmett Leith and Juris Upatnieks, from CBS Laboratories, Stamford, Connecticut, 2 November 1971. In *Private Papers of Emmett Leith*.
- Gabor, Dennis. FRS, and G. Stroke. "The Theory of Deep Holograms". *Proceedings of the Royal Society of London, Series A*, 1487 (1968): 275-289.
- Galison, Peter. *Image and Logic: A Material Culture of Microphysics*. Chicago and London: The University of Chicago Press, 1997.
- . "Judgement against Objectivity". In *Picturing Science Producing Art*, edited by Caroline A. Jones and Peter Galison, 327-359. New York London: Routledge, 1998.
- . "Marietta Blau: Between Nazis and Nuclei". *Physics Today* 50, no. 42 (1997).
- . "Re-Reading the Past from the End of Physics: Maxwell's Equation in Retrospect". In *Functions and Uses of Disciplinary Histories*, edited by Loren Graham, Wolf Lepinies and Peter Weingart, 35-51. Dordrecht Boston Lancaster: D. Reidel Publishing Company, 1983.

- Gay, Peter. *Pleasure Wars. The Bourgeois Experience: Victoria to Freud*. New York London: W.W. Norton & Company, 1989.
- Georgel, Chantel. "The Museum as Metaphor in Nineteenth-Century France". In *Museum Culture*, edited by Daniel J. Sherman and Irit Rogoff, 113-122. Minneapolis: University of Minnesota, 1994.
- Ghamari-Tabrizi, Sharon. "Simulating the Unthinkable: Gaming Future War in the 1950s and 1960s". *Social Studies of Science* 30, no. 2 April (2000): 134-145.
- Gilbert, G.Nigel. "The Development of Science and Scientific Knowledge: The Case of Radar Meteor Research". In *Perspectives on the Emergence of Scientific Disciplines*, edited by Gerard Lemaine, Glenn Macleod, Michael Mulkay and Peter Weingart, 187-204. The Hague Paris Chicago: Maison des Sciences de l'Homme, Paris Publications, 1976.
- Gilmore, David G. *Manhood in the Making*. New Haven and London: Yale University Press, 1990.
- Goffman, Erving. "The Lecture". In *Forms of Talk*, 162-195. Oxford: Basil Blackwell, 1981.
- . *The Presentation of Self in Everyday Life*. 4th ed. London: Penguin Books, 1990.
- . *Relations in Public: Microstudies of the Public Order*. London: Penguin Books, 1971.
- . *Stigma: Notes on the Management of Spoiled Identity*. 3rd ed. London: Penguin Books, 1990.
- Golinski, Jan. "The Care of the Self and the Masculine Birth of Science". *History of Science X*, no. 1 (2002): 126-145.
- Gombrich, Ernst. *The Sense of Order*. London: Phaidon, 1979.
- Goro, Fritz, photographer. "In Holograms Lasers Give Picture a Third Dimension". *Life* 61, no. 22 (1965): 116-117.
- Gould, S.J., ed. *On the Nature of Things: The Scientific Photography of Fritz Goro*. New York: Aperture Foundation Inc., 1993.
- Gouldner, Alvin W. *The Future of Intellectuals and the Rise of the New Class, Critical Social Studies*. London and Basingstoke: The MacMillan Press Ltd, 1979.
- Grau, Walter. *Virtual Art: From Illusion to Immersion, Leonardo*. Cambridge, Mass.: Massachussets Institute of Technology, 2003.
- Gréard, Octave. "Introduction". In *Monographie De Nouvelle Sorbonne*, edited by H.-P. Nénot, 19-20. Paris, 1903.
- Gusterson, Hugh. "The Death of the Authors of Death". In *Scientific Authorship: Credit and Intellectual Property in Science*, edited by Mario Biagoli and Peter Galison, 281–307. New York London: Routledge, 2003.
- Haine, M.E., and J. Dyson. "A Modification to Gabor's Proposed Diffraction Microscope". *NATURE* 166 (1950): 315-316.
- Haine, M.E., and T. Mulvey. "The Formation of the Diffraction Image with Electrons in the Gabor Diffraction Microscope". *Journal of Optical Society of America* 42 (1952): 763-773.
- Hall, Marie Boas. *All Scientists Now: The Royal Society in the Nineteenth Century*. Cambridge: Cambridge University Press, 1984.
- Hall, Mitchell K. *The Vietnam War, Seminar Studies in History*: Longman, 2000.
- Harré, Rom. "Some Narrative Conventions of Scientific Discourse". In *Narrative in Culture: The Uses of Storytelling in the Sciences, Philosophy, and Literature*, edited by Christoph Nash, 81-101. London: Routledge, 1990.
- Harrison. "The Effects of Landscape". In *Landscape and Power*, edited by W.J.T. Mitchell, Chicago: Chicago University Press, 1994.
- Hasselberg K.B, Professor, President of the Royal Swedish Academy of Science. *The Nobel Prize in Physics 1908*. Nobel e-Museum. Available online: <http://www.nobel.se/physics/laureates/1908/press.html>.
- Hay, D R. *The Orthographic Beauty of the Parthenon*. Edinburgh & London: William Blackwood and Sons, 1853.
- Hay, D.R., house painter and decorator to the Queen, Edinburgh. *The Laws of Harmonious Colouring Adapted to Interior Decorations, &C, to Which Is Now Added an Attempt to*

- Define Aesthetical Taste*. 5th ed. Edinburgh and London: Fraser and Co, W.S. Orr and Co, 1844.
- Hawkes, P.W. "Electron Microscopy and Analysis: The First 100 Years". *Proceedings of the Institute of Physics Electron Microscopy and Analysis Group Conference*. Electron Microscopy and Analysis 1997. (1997): 1-8.
- Hecht, Eugene. *Optics*. 2nd ed. Reading, Mass: Addison-Wesley Publishing Company, 1987.
- Hentschel, Klaus. "Photographic Mapping of the Solar Spectrum 1864-1900, Part One". *Journal for the History of Astronomy* XXX (1999): 92-119.
- . "Spectroscopic Portraiture". *Annals of Science* 59, no. 1 (2002): 57-82.
- Hobsbawm, Eric, and Terence Ranger, eds. *The Invention of Tradition*. Cambridge: Cambridge University Press, 1983.
- Homberger, Eric. *Mrs. Astor's New York: Money and Social Power in a Gilded Age*. New Haven and London: Yale University Press, 2002.
- Houghton, Walter. E. *The Victorian Frame of Mind*. New Haven and London: Yale University Press, 1957.
- House Committee Soiree Minutes for 13 April 1874. *Archives of the Royal Society*, London.
- Hughes, Jeff. "Plasticene and Valves: Industry, Instrumentation and the Emergence of Nuclear Physics". In *The Invisible Industrialist: Manufactures and the Production of Scientific Knowledge*, edited by Jean-Paul Gaudillière and Ilana Löwey, 58-101. Basingstoke and New York: Macmillan Press Ltd and St.Martin's Press, Inc., 1998.
- Hughes, Thomas P. "The Evolution of Large Technological Systems". In *The Social Construction of Technological Systems*, edited by W. E. Bijker, Thomas P. Hughes and T.J Pinch, 51-82. Cambridge, Mass.: MIT Press, 1994.
- Isler-de Jongh, Ariane. "The Origins of Colour Photography: Scientific, Technical and Artistic Interactions". *History of Photography* 18, no. 2 (1994): 111-119.
- Ives, Frederic E. *The Autobiography of an Amateur Inventor*. Philadelphia: Privately Printed by Innes & Sons, 1928.
- Ives, Frederic E. "Diffraction Grating Replica". Patent No. 818,966. In *New York Patent Library*. New York Public Library, New York.
- Ives, Frederic E. to Herbert Ives, 7 August 1910. In *F. & H. Ives Papers*, Manuscript Division of the Library of Congress, Washington.
- Ives, Frederic .E. "Lecture: The Ives Levanthal Plastigrams, 1924". In *F. & H. Ives Papers* Manuscript Division Library of Congress. Washington.
- Ives, Frederic. E. "Composite Heliochromy (in Two Parts)". *The Photographic News*, June 10 & 17 1892, 379-382, 389-391.
- Ives, Frederic E. "The Lumière-Lippmann Colour Photography". *The Photographic News*, December 15 1893, 795-796.
- Ives, Frederic. E. "The Lumière-Lippmann Colour Photography (concluded from page 796)". *The Photographic News*, December 29 1893, 819-820.
- . *Undated Lantern Slides*. Collection number: 47.024. In the *Photography Collection of the Smithsonian Museum of American History*, Washington.
- Ives, Herbert E. *Airplane Photography*. Philadelphia and London: J. B. Lippincott Company, 1920.
- . "An Experimental Study of the Lippmann Color Photograph". *Astrophysical Journal* XXVIII, Jan-June (1908): 325-352.
- . "Lippmann Color Photographs as Sources of Monochromatic Light in Photometry and Optical Pyrometry". *Journal of the Optical Society of America* 1, March-May, (1917): 49-62.
- . "Optical Properties of a Lippmann Lenticulated Sheet". *Journal of Optical Society of America* 21, March (1931): 171-176.
- . "Pan-Stereoscopic Photography and Cinematography: The Traill-Taylor Memorial Lecture before the Royal Photographic Society, London, October 3, 1933". In *F & H. Ives Papers, Manuscript Division of the Library of Congress*, 28. Washington.
- . "The Problem of Projecting Motion Pictures in Relief". *Transactions of the Society of Motion Picture Engineers* XVIII April (1932): 417-439.

- Ives, Mary Olmstead to (an unidentified) Dear Friend, January 22 1897. In the *Collection of F. & H. Ives*, Manuscript Division of the Library of Congress, Washington.
- Ives, Mary Olmstead, diary entry 16 January, 1896. In the *Collection of F. & H. Ives*, Manuscript Division of the Library of Congress, Washington.
- Jackson, Rosemary. H. to Professor and Mrs. Dennis Gabor, February 2 1978. "Museum of Holography Archives". In *MIT Museum*. Cambridge, Mass. (with copyright permission from Rosemary Jackson).
- Jameson, Frederic. *Postmodernism, or, the Cultural Logic of Late Capitalism*. London New York: Verso, 1991.
- Jennings, W.N (Coast-To-Coast Photo-Service) to Friend Fred on Nov 25 1930. In *F & H Ives Papers*, Manuscript Division of the Library of Congress, Washington.
- Jenson, Homer, L.C. Graham, Leonard J. Porcello and Emmett N. Leith. "Side-Looking Airborne Radar". *Scientific American* (1977): 84-95.
- Jeong, T.J., and R.J. Ro. "In the Physical and Visual State of 100 Year Old Lippmann Color Photographs". *Proceedings of the SPIE* 3358, Sixth International Symposium on Display Holography (1998): 72-83.
- Jeremy, David J. *Artisans, Entrepreneurs, and Machines: Essays in Technology Transfer in the Early Anglo-American Textile Industries, 1770-1840s, Variorum Collected Studies Series*. Aldershot, UK and Brookfield, Vermont, USA: Ashgate Publishing House, 1998.
- Johnston, Sean F. *A History of Light and Colour Measurement: Science in the Shadows*. Bristol and Philadelphia: Institute of Physics Publishing, 2001.
- . "Reconstructing the History of Holography". *Proceedings of SPIE-IS&T Electronic Imaging* 5005, Practical Holography XVII and Holographic Material IX (2003): 455-464.
- . "Telling Tales: George Stroke and the Historiography of Holography". *History and Technology* 20 (2004): 29-51.
- Jones, Caroline A. *The Machine in the Studio*. Chicago: Chicago University Press, 1996.
- Jordanova, Ludmilla. *Defining Features: Scientific and Medical Portraits 1660—2000*: Reaktion Books in association with the National Portrait Gallery, London, 2000.
- . *History in Practice*. London New York: Arnold & Oxford University Press Inc., 2000.
- . "Presidential Address: Remembrance of Things Past". *British Journal for the History of Science*, 33 (2000): 387-406.
- Kaiser, David. "Cold War Requisitions, Scientific Manpower, and the Production of American Physicists after World War II" *Historical Studies in the Physical and Biological Sciences* 33 (2002): 131-159.
- Kant, Immanuel. *Observations on the Feeling of the Beautiful and Sublime*. Translated by John. T. Goldthwait. 1991 ed. Berkeley: University of California Press, 1764.
- Keiger, J.F.V. *France and the World since 1870*. London: Arnold, 2001.
- Kemp, Martin, ed. *The Oxford History of Western Art*. Oxford New York: Oxford University Press, 2000.
- Kierzek, K.C. to Professor Erick Ingelstam, and copied. to Dr. Dennis Gabor, 30 November 1972. In *Dennis Gabor Papers Imperial College Archives*. London.
- Kipnis, Nahum. *History of the Principle of Interference of Light*. Vol. 5, *Science Networks Historical Studies*. Basel Boston Berlin: Birkhäuser Verlag, 1991.
- Kirkpatrick, P. and H.M.A. El-Sum. "Image Formation by Reconstructed Wavefronts: Physical and Methods of Refinement". *Journal of the Optical Society of America* 42, no. 46 (1956): 825-821.
- Kirkpatrick, Paul. "Holography". *Stanford Today*, Spring (1966): 6.
- Kock, Winston E. "Extensions of Synthetic Aperture Radar Information Processing". In *US-USSR Science Co-operation Seminar on Optical Information Processing (1975: Washington D.C.)*, edited by Yu. E. Nesterikhin, George Stroke and Winston E. Kock, 117-128. New York: Plenum Press, 1976.

- Kohler, Robert. "The PhD Machine: Building on the Collegiate Base". In *The Scientific Enterprise in America*, edited by Ronald L. Numbers, 98-122. Chicago and London: The University of Chicago Press, 1996.
- Kozma, Adam, letter to Emmett Leith (copy), October 1 1966. In *Dennis Gabor Paper Imperial College Archives*, London
- Kracauer, Siegfried. *History the Last Things before Last*. 1995 ed. Princeton, NJ: Markus Wiener Publishers, 1969.
- Kris, Ernst and Otto Kurz. *Legend, Myth and Magic in the Image of the Artist*. Translated by Alastair Laing. 1979 ed. New Haven and London: Yale University Press, 1934.
- Lafreniere, Steve. "Love, Robert Indiana". *index* 2004, 57-61.
- Latour, Bruno. "Drawing Things Together". In *Science in Action*, edited by Lynch S and S Woolgar, 19-68. Cambridge. Mass: Harvard University Press, 1987.
- Lavédrine, Bertrand, and Jean-Paul Gandolfo. "The Autochrome Process from Concept to Prototype". *History of Photography* 18, no. 2 (1994): 120-128.
- Law, John. "The Developemnt of Specialities in Science: The Case of X-Ray Protein Crystallography". In *Perspectives on the Emergence of Scientific Disciplines*, edited by Gerard Lemaine, Glenn Macleod, Michael Mulkay and Peter Weingart, 132-152. The Hague Paris Chicago: Maison des Sciences de l'Homme, Paris Publications, 1976.
- . "Theories and Methods in the Sociology of Science: An Interpretative Approach". In *Perspectives on the Emergence of Scientific Disciplines*, edited by Gerard Lemaine, Glenn Macleod, Michael Mulkay and Peter Weingart, 221-131. The Hague Paris Chicago: Maison des Sciences de l'Homme, Paris Publications, 1976.
- Lebon, Ernest. *Gabriel Lippmann, Biographie*. Paris: Gauthier-Villars, 1911.
- Leith, Emmett N. to Dennis Gabor 9 April 1969. In *Dennis Gabor Papers Imperial College Archives*, London
- . to Dennis Gabor 13 February 1969. In *Dennis Gabor Papers Imperial College Archives*, London
- . to Dennis Gabor, 17 October 1972. In *Dennis Gabor Papers Imperial College Archives*, London.
- . "Overview of the Development of Holography". *Journal of Imaging Science and Technology* 41, no. 3 (1997): 201-214.
- . "Reflections on the Origin and Subsequent Course of Holography". *Proceedings of SPIE-IS&T Electronic Imaging 5005, Practical Holography XVII and Holographic Material IX* (2003): 431-438.
- . "A Short History of the Optics Group of the Willow Run Laboratories". 1-25, on 1-2. Ann Arbor: The University of Michigan, undated. In *Private Papers of Emmett Leith*, Ann Arbor, Michigan.
- . "Some Highlights in the History of Display Holography". In *Proceedings of the International Symposium on Display Holography*, edited by T.J Jeong, 1-4. Illinois: Holography Workshops, Lake Forest College, 1983.
- Leith, Emmett N., A. L. Ingalls. "Synthetic Antenna Data Processing by Wavefront Reconstruction". *Applied Optics* 7 (1968): 539-544.
- Leith, Emmett N., Juris Upatnieks. "Reconstructed Wavefronts and Communication Theory". *Journal of the Optical Society of America* 52, no. 10 (1962): 1123-1130.
- . "Wavefront Reconstruction with Continuous-Tone Objects". *Journal of the Optical Society of America* 53, no. December (1963): 1377-1381.
- . "Wavefront Reconstruction with Diffused Illumination and Three-Dimensional Objects". *Journal of the Optical Society of America* 54, no. 11 (1964): 1295-1301.
- Leith, Emmett N., Douglas B. Brumm, and Stephen S. H. Hsiao. "Holographic Cinematography". *Applied Optics* 11, no. 9 (1972): 2016-2019.
- Leith, Emmett N., Juris Upatnieks, B.P. Hilderbrand, and K. Haines. "Requirements for a Wavefront Reconstruction Television Facsimilie System". *Journal of the Society of Motion Picture and Television Engineers* 74, no. 10 (1965): 893-896.

- Leith, Emmett. N., Juris Upatnieks, Adam Kozma, and N Massey. "Hologram Visual Displays". *Journal of the Society of Motion Picture and Television Engineers* 75, no. 4 (1966): 323-326.
- Lenoir, Tim. "All but War Is Simulation: The Military-Entertainment Complex". *Configurations* 8 (2000): 289-336.
- Lenoir, Timothy. "Helmholtz and the Materialities of Communication". *Osiris* 9 (1994): 185-207.
- Lepenies, Wolf, and Peter Weingart. "Introduction". In *Functions and Uses of Disciplinary Histories*, edited by Loren Graham, Wolf Lepenies and Peter Weingart, ix-xx. Dordrecht Boston Lancaster: D. Reidel Publishing Company, 1983.
- Lerebours, N.P. *A Treatise on Photography Containing the Latest Discoveries and Improvements to the Daguerrotype*. London: Brown, Green, and Longmans, 1843.
- Lippmann, G. "On Colour Photography by the Interferential Method". *Proceedings of the Royal Society* 60 (1896): 11-13.
- . "Épreuves Réversibles. Photographies Intégrales". *Comptes Rendus à l'Academie des Science* 146, (1908): 446-451.
- . "La Photographie Des Couleurs". *Comptes Rendus à l'Academie des Science* 112, Feb (1891): 274-275.
- . *Societe Francais de Pyhsique, Procès Verbaux*, (1911): 69.
- Lippmann, Gabriel. *Colour Photography, Nobel Lecture, December 14, 1908*. Nobel e-Museum. Available from <http://www.nobel.se/physics/laureates/1908/press.html>.
- Livingston, Dorothy Michelson. *The Master of Light: A Biography of Albert A. Michelson*. New York: Charles Scribner's Sons, 1973.
- Lohman, A. "Optische Eiseiitenbandubertragung Angewandt Auf Das Gabor-Mikroskop". *Optica Acta* 3 (1956): 97-100.
- Lois Ducos du Hauron, translated by Philip Hypler. "Colours in Photography the Problem Resolved (Original Publication: Les Coleurs En Photographie: Solution Du Problème, Paris: A. Marion 1869)". *History of Photography* 23, (1999): 281-293.
- Lorber, Judith. *Paradoxes of Gender*. New Haven and London: Yale University Press, 1994.
- Lovell, D.J. *Optical Anecdotes*. Reprint 1983. Washington: SPIE-The International Society of Optical Engineering, 1981.
- Lowen, Rebecca S. *Creating the Cold War University: The Transformation of Stanford*. Berkly, Los Angeles, London: University of California Press, 1997.
- Lumière, Auguste and Louis. *Letters*. Translated by Pierre Hodgson. Edited by Jacques and Yvelise Dentzer Rittuad-Hutinet. London Boston: Faber and Faber, 1995.
- Mack, Pamela E. *Viewing the Earth: The Social Construction of the Landsat Satellite System*. Cambridge, Mass., London, England: The MIT Press, 1990.
- Marien, Mary Warner. *Photography and Its Critics, 1839-1900*. Cambridge: Cambridge University Press, 1997.
- Markus, T "Buildings and the Ordering of Minds and Bodies". In *Philosophy and Science in the Scottish Enlightenment*, edited by Peter Jones, Edinburgh: Edinburgh University Press, 1988.
- . *Buildings and Power*. London: Routledge, 1993.
- . *Order in Space and Society*. Edinburgh: Mainstream, 1982
- Mason, John W. *The Dissolution of the Austro-Hungarian Empire 1867-1918*. 2nd ed, London and New York: Addison Wesley Longman Limited, 1997.
- Matsuda, Matt K. *The Memory of the Modern*. New York Oxford: Oxford University Press, 1996.
- Maugue, Annelise. *L'identité Masculine En Crise Au Tourant Du Siècle*. Paris, 1987.
- McElhone, John P. "The Signature of Light: Photo-Sensitive Materials in the Nineteenth Century". In *Beauty of Another Order*, edited by Ann Thomas, 60-75. New Haven, London, Ottawa: Yale University Press, National Gallery of Canada, 1997.
- McGrath, Patrick J. *Scientists, Business, and the State, 1890-1960*. Chapel Hill: University of North Carolina Press, 2002.

- McSherry, Corynne. "Uncommon Controversies: Legal Mediations of Gift and Market Models of Authorship". In *Scientific Authorship: Credit and Intellectual Property in Science*, edited by Mario Biagioli and Peter Galison, 225-250. London: Routledge, 2003.
- Meldola, R. "Letter to the Editor". *NATURE* 54, no. 1385 (1896): 28.
- Michelson, A.A. "On the Application of Interference Methods to Spectroscopic Measurement". *Phil. Mag.* 5, no. 31 (1891): 338-346.
- Miller, Michael B. *The Bon Marché: Bourgeois Culture and the Department Store 1869-1920*. Princetown New Jersey: Princetown University, 1987.
- Moholy-Nagy, L. "Constructivism and the Proletariat". In *Moholy-Nagy an Anthology*, edited by Richard Kostelanetz, New York: Da Capo Press, Inc., 1970.
- . "Space-Time and the Photographer". In *Moholy-Nagy an Anthology*, edited by Richard Kostelanetz. New York: Da Capo Press, Inc., 1970.
- Morrell, J.M.B. "Professionalisation". In *Companion to the History of Modern Science*, edited by R.C Olby, G.N. Cantor, J.R.R. Christie and M.J.S. Hodge, 980-988. London & New York: Routledge, 1996.
- Mort, J. *The Anatomy of Xerography: Its Invention and Evolution*. Jefferson, North Carolina, and London: McFarland & Company, Inc., Publishers, 1989.
- Mulkay, M.J. "Methodology in the Sociology of Science: Some Reflections on the Study of Radio Astronomy". In *Perspectives on the Emergence of Scientific Disciplines*, edited by Gerard Lemaine, Glenn Macleod, Michael Mulkay and Peter Weingart, 207-220. The Hague Paris Chicago: Maison des Sciences de l'Homme, Paris Publications, 1976.
- Mulkay, M.J., and D.O. Edge. "Cognitive, Technical and Social Factors in the Growth of Radio Astronomy". In *Perspectives on the Emergence of Scientific Disciplines*, edited by Gerard Lemaine, Glenn Macleod, Michael Mulkay and Peter Weingart, 153-186. The Hague Paris Chicago: Maison des Sciences de l'Homme, Paris, 1976.
- Mullis, Kary. *Dancing Naked in the Mind Field*. New York: Random House, 1998.
- Mulvey, T. "Electron Beam Instruments". In *Twentieth Century Physics*, edited by Laurie. M. Brown, A. Pais and Sir. B. Pippard, 1582-1586. Bristol & Philadelphia, New York: Institute of Physics Publishing, American Institute of Physics Press, 1995.
- Murulo, Priscilla, and A.B. Chitty. *From the Folks Who Brought You the Weekend: A Short, Illustrated History of Labour in the United States*. New York: The New Press, 2001.
- Myers, G. "Making a Discovery: Narratives of Split Genes". In *Narrative in Culture: The Uses of Storytelling in the Sciences, Philosophy, and Literature*, edited by Christoph Nash, 102-126. London: Routledge, 1990.
- Myers, Robert A., and Richard W. Dixon. "Who Invented the Laser: An Analysis of the Early Patents". *Historical Studies in the Physical Sciences* 34, no. 1 (2003): 115-149.
- Nareid, H. "A Review of the Lippmann Color Process". *Journal of Photographic Science* 36 (1988): 140-147.
- Newhall, Beaumont. *Airborne Camera: The World from the Air and Outerspace*. New York: Hastings House and George Eastman House, Rochester, NY, 1969.
- . *The History of Photography*. New York: Museum of Modern Art and George Eastman House, 1964.
- Nickles, Thomas. "Discovery". In *Companion to the History of Modern Science*, edited by R.C Olby, G.N. Cantor, J.R.R. Christie and M.J.S. Hodge, 148-165. London & New York: Routledge, 1996.
- Norton Wise, M. "On the Relation of Physical Science to History in Late Nineteenth-Century Germany". In *Functions and Uses of Disciplinary Histories*, edited by Loren Graham, Wolf Lepenies and Peter Weingart, 3-34. Dordrecht Boston Lancaster: D. Reidel Publishing Company, 1983.
- Nye, Mary Jo. *Before Big Science: The Pursuit of Modern Chemistry and Physics 1800-1940*. New York: Twayne Publishers, 1996.
- Oettermann, Stephan. *The Panorama: History of a Mass Medium*. New York: Zone Books, 1997.
- Osmundsen, John. A. "New Camera Operating without Lens Shows Scientific Promise". *New York Times* (1963, December 11): 5.

- PaceWildenstein Gallery. "Press Release". NY, 2004
- Panofsky, Erwin. *Perspective as Symbolic Form*. Translated by Christopher Wood. 1997 ed. Cambridge Mass: MIT Press, 1927.
- . "Style and Medium in the Motion Pictures". In *Three Essays on Style*, edited by Irving Lavin. Cambridge, Mass: MIT Press, 1995.
- Parrott, Bruce. *Trade, Technology, and Soviet-American Relations*. Bloomington: Indiana University Press, 1985.
- Perich, Shannon Thomas. "Process and Three-Dimensional Materials, Natural History Museum of American History". *History of Photography* 24, no. 1 (2000): 37-41.
- Perkin, Harold. *The Rise of Professional Society: England since 1880*. London and New York: Routledge, 1990.
- Pestre, Dominique. "Commemorative Practices at Cern: Between Physicists' Memories and Historians Narratives". *Osiris* 14 (1999) 203-216.
- Phillips, N.J. "Links between Photography and Holography: The Legacy of Gabriel Lippmann". *Proceedings of SPIE*, 523 (1985): 313-18.
- Phillips, N.J., H. Heyworth, and T. Hare. "On Lippmann's Photography". *Journal of Photographic Science* 35, no. 5 (1984).
- Pinch, T.J, and W. E. Bijker. "The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other". In *The Social Construction of Technological Systems*, edited by W. E. Bijker, Thomas P. Hughes and T.J Pinch, 17-50. Cambridge, Mass.: MIT Press, 1994.
- Pipp, Edwin C. *Detroit News* April 20 1960, in *Private Collection of Emmett Leith*, Ann Arbor, Michigan.
- Pribram, Karl H. "What the Fuss Is All About". In *The Holographic Paradigm and Other Paradoxes*, edited by Ken Wilber, 32. Boulder & London: Shambhala, 1982.
- Radar and Optics Laboratory, Willow Run Laboratories, Institute of Science and Technology, the University of Michigan, Ann Arbor, "Investigation of Hologram Techniques, Second Interim Engineering Report, 1 December 1965 through 31 March 1966". Prepared under contract AF 33(615)-3100 for the Air Force Avionic Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, July 1966.
- Rasmussen, Nicholas. *Picture Control: The Electron Microscope and the Transformation of Biology in America, 1940-1960*. Stanford California: Stanford University Press, 1997.
- Renan, Ernest. *The Future of Science: Ideas of 1848*. Translated from the French by A.D. Vandom and C.B. Pitman. London: Chapman and Hall Ltd, 1891
- Rich, C.C. and L. Dickerson. "Lippmann Photographic Process Put to Practice with Available Materials". *Proceedings of the SPIE 2688 Holographic Materials II* (1996): 88-95.
- Roberts-Miller, Patricia. *Voices in the Wilderness: Public Discourse and the Paradox of Puritan Rhetoric*. Tusaloosa and London: The University of Alabama Press, 1999.
- Rogers, G.L. "Experiments in Diffraction Microscopy". *Proceedings of the Royal Society of Edinburgh*. LX111, no. A, Part III (1950-51): 193-221.
- Samuel, Raphael. *Theatres of Memory*. London: Verso, 1996.
- Sandys, H.W. The Under Secretary of State, to G.G. Macdonald Esq. The British Thomson-Houston Co., Ltd. 13 December, 1945. "Letter and Statement on Naturalisation". In *Dennis Gabor Papers Imperial College Archives*. London.
- Saunders, Barbara. "The Spectre of Colour: A Sociobiological Paradigm". *Science as Culture* 8, no. 4 (1999): 483.
- Schaaf, L. *Out of the Shadows: Herschel, Talbot and the Invention of Photography*. New Haven London: Yale University Press, 1992.
- Schapiro, M. "Style". In *Anthropology Today*, edited by A.L. Kroeber, 287-312. Chicago: Chicago University Press, 1953.
- Schivelbusch, Wolfgang. *Disenchanted Night: The Industrialization of Light in the Nineteenth Century*. Translated by Angela Davis. English ed. Berkeley Los Angeles London: The University of California Press, 1988.

- Schneer, Jonathon. *London 1900: The Imperial Metropolis*. New Haven & London: Yale University Press, 1990.
- Schubring, Gert. "Pure and Applied Mathematics in Divergent Institutional Settings in Germany: The Role and Impact of Felix Klein". *Paper presented at the The History of Modern Mathematics Conference* 1988, Vassar College, Poughkeepsie, New York, 1989.
- Sconce, Jeffrey. *Haunted Media: Electronic Presence from Telegraphy to Television*. Durham & London: Duke University Press, 2000.
- Segal, Howard P. "Technology, Pessimism, and Postmodernism: Introduction". In *Technology, Pessimism and Postmodernism*, edited by Yaron Ezrahi, Mendelsohn Everett and Howard P. Segal, 2. Amherst: University of Massachusetts Press, 1995.
- Senior, Edgar. "The Diffraction Process of Colour Photography". In *Handbook of Photography in Colours*, edited by Thomas Bolas, 291-301. London: Marion & CO, 1900.
- Sennett, Richard. *The Fall of Public Man*. New York London: W.W. Norton & Company, 1974
- Shapin, Stephen. "Science and the Public". In *Companion to the History of Modern Science*, edited by R.C Olby, G.N. Cantor, J.R.R. Christie and M.J.S. Hodge, 990-1007. London & New York: Routledge, 1996.
- Shapin, Steven. *The Social History of the Truth: Civility and Science in Seventeenth-Century England*. Chicago: Chicago University Press, 1994.
- Sheldon, Samuel. "Why Our Science Students Go Abroad". *Atlantic Monthly*, 62 (1889): 463-466.
- Sherman, Paul D. *Colour and Vision in the Nineteenth Century: The Young-Helmholz-Maxwell Theory*. Bristol: Adam Hilger Ltd, 1981.
- Silverman, Debora L. *Art Nouveau in Fin-De-Siècle France: Politics, Psychology, and Style*. Edited by Victoria E. Bonnell and Lynn Hunt, *Studies on the History of Society and Culture*. Berkeley, Los Angeles. London: University of California Press, 1989.
- Siple, Louis Walton. *A Half Century of Colour*. New York: The Macmillan Company, 1951.
- Smyth, Charles Piazzi. *On the Antiquity of Intellectual Man*. Edinburgh: Edmonston and Douglas, 1868.
- . "The Great H&K Solar Spectrum Lines, 1891-1892". The British Association, 1891-1892.
- . *The Great Pyramid, Our Inheritance In*. Steinerbooks 1977 ed. London: Daldy, Isbister & Co., 1877.
- Solovey, Mark. "Science and the State During the Cold War, Blurred Boundaries and a Contested Legacy". *Social Studies of Science* 31, no. 2 (2001): 165-170, on 167.
- Spotiswoode, Raymond. "Progress in Three-Dimensional Films at the Festival of Britain". *Society of Motion Picture and Television Engineers* 58, April (1952): 291-303.
- Staff reporter. "Ladies Night at the Royal Society". *The Globe*, June 17 1891. Press cuttings from the *Archives of the Royal Society*, London
- . "Mr Ives and Photochromy". *The Photographic News*, September 1 (taken from The Photographic Times) 1893, 554-556.
- . from the Paris correspondent of the Daily News. "Photography in Colours". *The British Journal of Photography*, no. February 20 (1891): 121.
- . "Photographie En Coleurs". *Journal de Geneve*, 24 August 1893. Library of the University of Geneva, Switzerland.
- . "Professor Lippmann's Presentation at the Royal Society, April 23". *NATURE* 154, no. 1384 (1896): 12-13.
- . "The Royal Society Conversazione". *The Daily Telegraph*, May 7 1891 Press cuttings from the *Archives of the Royal Society*.
- . "Royal Society Soiree". *The Daily News*, 7 May 1896. Press cuttings from the *Archives of the Royal Society*.
- . "University of Michigan Create Photo Radar". *The Ypsilanti Daily Press*, April 19 1960, (front page) in *Private papers of Emmett Leith*, Ann Arbor, Michigan.
- Stafford, Barbara Maria and Frances Terpak. *Devices of Wonder: From the World in a Box to Images on a Screen*. Los Angeles: Getty Research Institute, 2001.

- Sternberger, Dolf. *Panorama of the Nineteenth Century*. Translated by Joachim Neugroschel. 1977 ed, *Mole Editions*. Oxford: Basil Blackwell, 1955.
- Strauss, Harold, to Dennis Gabor, December 27 1967. In *Dennis Gabor Papers Imperial College Archives*. London.
- Stroke, George to Dennis Gabor, 12 November 1966. In *Dennis Gabor Papers Imperial College Archives*. London.
- . to Dennis Gabor, 23 April 1967. In *Dennis Gabor Papers Imperial College Archives*. London.
- Stroke, George. “George Wilhelm Stroke, Electrical Engineer, an Oral History Conducted in 1993 by William Aspray, IEEE History Center, Rutgers University, New Brunswick, NJ, USA”. Available online at: www.ieee.org/history_center/oral_histories/transcripts/stroke.html.
- Stroke, George. W. *An Introduction to Coherent Optics and Holography*. 2nd ed., New York & London: Academic Press, Inc., 1969.
- Summerson, John. *The Classical Language of Architecture*. 1996 ed., *World of Art*. London: Thames and Hudson, 1963.
- Taine, Hippolyte. *Notes on England 1860–1870*. Translated by Edward Hyams. English Edition with Introduction. London: Thames & Hudson, 1957.
- Tanner, P.G., and T.E. Allibone. “The Patent Literature of Nobel Laureate Dennis Gabor (1900–1979)”. *Notes and Records of the Royal Society of London* 51, no. 1 (1997): 105–120.
- Thomson, J.J. Sir. *Recollections and Reflections*. London: G. Bell and Sons, Ltd, 1936.
- Travis, Stephen N. “Seeing Is Believing: The Development of Microwave Radar in Britain, Summer 1940”. *History of Technology* 18 (1996): 113–137.
- Turner, Stephen. *The Social Theory of Practices: Tradition, Tacit Knowledge and Presupposition*. Cambridge: Polity Press, 1994.
- Valenta, Eduard. *Die Photographie in Natürlichen Farben*. Wilhelm Knapp, 1894.
- Vander Lugt, Anthony. “Signal Detection by Complex Filtering”. *Proceedings of the IEEE. Information Theory* IT-10 (1964): 139–145.
- Varden, Lloyd E. “Lenless Photography”. *Photomethods for Industry* 7, no. 1 (1964): 30, *Private papers of Emmett Leith*, Ann Arbor, Michigan.
- Veblen, Thorstein. *The Theory of the Leisure Class*. Boston: Houghton Mifflin Company, 1973.
- Vidal, Léon (Moniteur). “In Response to F. Ives”. *Revue de Photographie, organe mensuel de la société Genoivoise de Photographie* (1893): 194–197. In the Collection of the *Photographic Library of Geneva*, Switzerland.
- Vidal, Léon. “An Open Letter to Members”. *Bulletin du Photo-Club de Paris* 1893. On microfilm, *Library of the Metropolitan Museum*, New York.
- Viff-Møller, Jens. “The Origin of the French Film Quota Policy Controlling the Import of American Films”. *Historical Journal of Film, Radio and Television* 18, no. 2 (1998): 165–182.
- Virilio, Paul. “A Travelling Shot over Eighty Years”. In *The Virilio Reader*, edited by James Der Derian, 95–116. Malden, Mass. & Oxford, UK: Blackwell, 1998.
- Wall, E.J. *The History of Three Colour Photography*. 1975 ed. London and New York: The Focal Press, 1925.
- Wallace, Alfred Russel. *The Wonderful Century*. 2nd ed. London: Swan, Sonnenschein & Co, Limited, 1903.
- Wang, Jessica. *American Science in an Age of Anxiety: Scientists, Anticommunism, and the Cold War*. Chapel Hill and London: The University of North Carolina Press, 1999.
- . “Scientists and the Problems of the Public in Cold War America, 1945–1960”. *Osiris* 17 (2002): 323–347.
- Warner, Mary Marien. *Photography a Cultural History*. New York London: Henry Abrams Inc., 2002.
- Warwick, Andrew. *Masters of Theory: Cambridge and the Rise of Theoretical Physics*. Chicago and London: The University of Chicago Press, 2003.
- Wasson, Tyler, ed. *Nobel Prize Winners*. New York: H.W. Wilson, 1987.

- Wiener, Otto. "Über Farbenphotographie Durch Körperfarben, Und Mechanische Farbenanpassung in Der Natur". *Wiedemann's Annalen* 1 (1895): 225-281.
- Wilford, John Noble. "Holography a Long-Time Dream". *The New York Times*, November 3 1972, 28. Private papers of Emmett Leith, Ann Arbor, Michigan.
- Wilkins, T.R. "The Institute of Applied Optics of the University of Rochester". *Journal of Optical Society of America* 21, June (1931): 369-387.
- Winship, Janice. "New Disciplines for Women and the Rise of the Chain Store in the 1930s". In *All the World and Her Husband*, edited by Maggie Andrews and Mary M. Talbot, London and New York: Casell, 2000.
- Winston, Brian. *Media Technology and Society: A History: From the Telegraph to the Internet*. 2nd ed. London and New York: Routledge, 1998.
- Winter, Irene J. "The Affective Properties of Styles: An Inquiry into Analytical Process and the Inscription of Meaning in Art History". In *Picturing Science Producing Art*, edited by Peter Galison and Caroline A. Jones, 55-77. New York & London: Routledge, 1998.
- Wolff, John, Nick Phillips, and Anton Furst. *Light Fantastic*. London: Bergström & Boyle Books Ltd, 1977.
- Wood, Robert W., "The *n*-rays". *Nature* 70, no. 1822 (1904): 530-531.
- Woolgar, Steve. "Writing an Intellectual History of Scientific Development: The Use of Discovery Accounts". *Social Studies of Science* 6 (1976): 395-422.
- Young, Charles S. "Missing Action: POW Films, Brainwashing and the Korean War, 1954-1968". *Historical Journal of Film, Radio and Television* 18, no. 1 (1998): 49-74.
- Yoxen, Edward. "Seeing with Sound: A Study of the Development of Medical Images". In *The Social Construction of Technological Systems*, edited by W. E. Bijker, Thomas P. Hughes and T.J Pinch, 281-303. Cambridge, Mass.: MIT Press, 1994.
- Zenker, Wilhelm. *Lehrbuch Die Photochromie*. Reprint 1900. Braunschweig: Friederich Vieweg und Sohn, 1868.