Robert Hooke's Microscope:

The Epistemology of an Instrument

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This thesis is dedicated to my father, brother, and the memory of my mother:

Julia, Rob, and David Lawson.

Chapter 1: Introduction

The Nature of Art

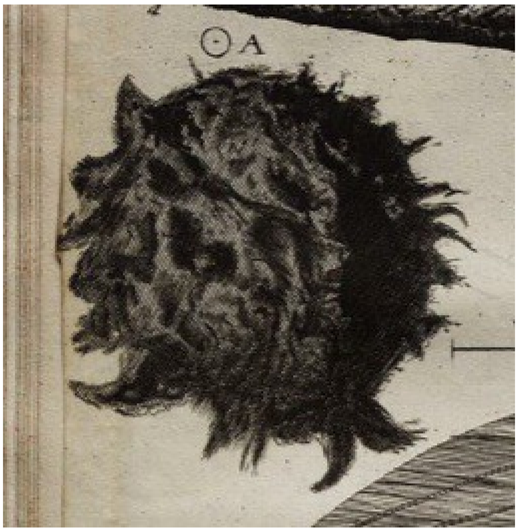

Figure 1.1: Full stop. Micrographia scheme 2 detail, opposite p. 1.

Robert Hooke's *Micrographia* is a work of contradiction. On the first page of this 1665 catalogue of objects scrutinised with a microscope, Hooke reported to his readers how printed pages appear to enlarged eyesight. Even the most delicate engravings turn “disfigur'd” and “irregular” when examined through a lens. A full stop, made with runny ink impressed by moulded type on rough, laid paper, makes a “great splatch of *London* dirt” (Figure 1.1). Engraved lines become the “*smutty daubings*” of an extinguished firebrand.[1] The products of the finest artistry do not stand up to such close examination; they grow ugly when “examin'd with an organ more acute then that by which they were made.”[2] The irony is that the rest of the book, of course, uses exactly these arts to represent the intricacies of tiny nature in enlarged, graphic detail. Giant fleas fold out of the large folio book, and slices of cork reveal

1 Hooke, *Micrographia*, 3.
2 Ibid., 2.

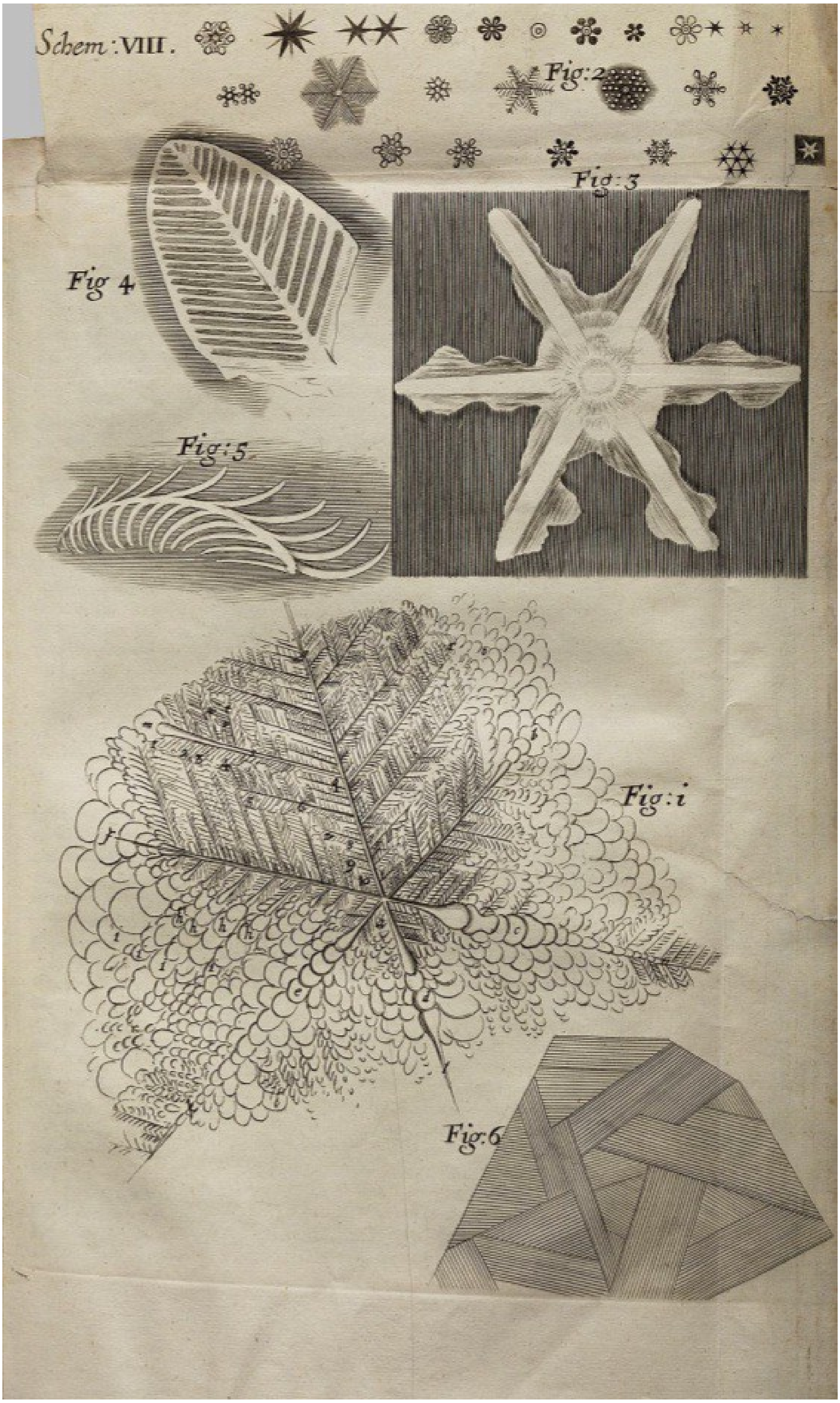

Figure 1.2: Figures observable in frozen water and urine. *Micrographia*, scheme 8, opposite p. 88.

chambers like so many monk cells.[3] Hooke's gigantic flies, frosts, and feathers, though engraved and printed seem to invite as close a scrutiny as their live muses (see Figure 1.2).[4]

Far from undermining his work, this irony is Hooke's message. Hooke was translating nature to a human scale.[5] It was revelatory to find that the smallest creatures display the same signs of life as larger ones, or that crystals resolve into geometric patterns. In contrast to artifice, natural bodies "shew us the greatest Excellencies" when magnified.[6] This was both an argument for naturalists to pay attention to the vanishingly small as well as the large – perhaps the most fundamental aspect of Hooke's approach to natural philosophy – and an apology for the book itself.[7] The utility of art was that it could make nature available to us in a way that it ordinarily was not. Hooke had provided a document of inhuman nature which was accessible to a human. *Micrographia* was the inverse of the tiny writing which was fashionable at the time – and which did not escape his attention. When Hooke looked through his lens at a coin-sized scrap of paper onto which were crammed several bible verses, he found "pitifull *bungling scribbles* and *scrawls*," and reading it "wanted a good fantsy well preposest to help one through" reading it.[8] His engravings, on the other hand, needed no such imaginative interpretation, only plain observation.[9] They displayed marvellous nature writ large through art, not art itself as a superficial marvel, destined to collapse on closer inspection. His crafted images of insects magnified to the size of small mammals were exactly intended to be examined with organs the same size as those by which they

3 Hooke's description is the origin of the modern biological use of the word 'cell.' See his Observation 18.

4 For more on early modern printing practices, see Johns, *The Nature of the Book*. Johns discusses these same observations of Hooke (430-431). Joseph Glanvill mentions another irony also found in Hooke: that of printing in a book the belief that to advance knowledge people need to move past the knowledge found in libraries and begin a fresh investigation of nature. See Glanvill, *The Vanity of Dogmatizing*, sig. A5r.

5 Throughout this thesis I silently 'correct' Hooke's and others' use of "Man" to "human." That this is not always a correction at all but often alteration of a deliberate and important part of their thought I have been recently been made aware of through a talk given by Moira Gatens.

6 Hooke, *Micrographia*, 2.

7 For the former aspect, see for instance Hooke's words in *Micrographia*, sig. A2r.

8 Hooke, *Micrographia*, 3.

9 See also Adrian Johns' point that the presentation of craft knowledge in a book such as *Micrographia* was for the education of gentlemen, not as an instruction manual for other craftspeople. Using the instrument was not necessary for Hooke's audience to follow him through the microworld: Johns, *The Nature of the Book*, 107. See for example Samuel Pepys' excitement at reading "the most ingenious book that I ever read in my life:" 21 January 1665: Pepys, *The Diary of Samuel Pepys*, 1971, 5:18. Though Pepys did later buy a microscope for entertainment, he can not be called a microscopist in the vein of Hooke, Leeuwenhoek, Malpighi, Swammerdam or Grew.

were made: the gross art of the burin was suited to fat human eyes.

Hooke's microscopy was underwritten by certain assumptions about nature, humans, and knowledge. This thesis investigates this epistemology embodied by the instrument. Behind his famous drawings lies a lesson not only about his subjects, but about the person watching them – about the person for whom the world looks a certain way. From microscopical and astronomical observations to wondering how the world would appear to a fly, Hooke's experimental philosophy was underwritten by an attentiveness to the fact that things look different in different conditions, to different creatures, from different perspectives. "[T]hose things seem pleasant in the Smell to other Creatures Senses," he observed, "which to our Senses seem quite otherwise."[10] If the natural world revealed itself so differently to different creatures and different senses, what kind of knowledge of it might we realistically hope for? Was the hum of an insect's wing only audible to us, but visible to that insect? Even as it revealed our limits, artifice could help us escape our limited perspective. Hooke's instrument use was premised on the recognition that natural philosophy is a human endeavour, and that knowledge of the world is constructed not by interrogating the world 'directly,' but by making natural qualities available to the limited senses of humans.

Before outlining my project in detail, it will be useful to situate my particular interests in some context, both biographical and historiographical.

Context

It is a platitude in the history of science that Hooke was an early advocate of experiment and instrument use in natural philosophy.[11] Even before he was Curator of

10 "General Scheme," in Hooke, *Posthumous Works*, 8.

11 The field of Hooke scholarship has blossomed since the last decades of the twentieth century. Particularly important is the classic collection of essays – a good way to approach his life as a polymath, multiply-employed and tireless worker – in Hunter and Schaffer, *Robert Hooke: New Studies*. Since then a similarly multi-faceted approach has been taken in Bennett et al., *London's Leonardo*; Cooper and Hunter, *Robert Hooke: Tercentennial Studies*; Chapman and Kent, *Robert Hooke and the English Renaissance*. For more directed studies of particular aspects of his work, see Drake, *Restless Genius*; Gal, *Meanest Foundations and Nobler Superstructures*; Hunter, *Wicked*

Experiments for the early Royal Society of London, he was a member of John Wilkins' experimental philosophy group at Wadham College in Oxford.[12] He helped to design, build, and operate the air pump, that emblematic machine of natural philosophy in seventeenth century England, as well as instruments for grinding lenses, projecting images, plumbing the depths of the sea, regulating clocks, mounting telescopes, and measuring refraction.[13]

Hooke had arrived at Christ Church, Oxford in 1653, following John Locke and Christopher Wren from Westminster School.[14] In 1654 he began living with and working for the doctor and experimentalist Thomas Willis, whose father-in-law knew Hooke's father from the Isle of Wight.[15] While he joined Locke, Wren, and others in working with Willis, a more apprentice-like position ensured his education differed from their more traditional bachelor degrees. Under Willis he was likely engaged in glass-making, brewing, tanning, smelting, and other mechanical arts needed for chemical practice. His Oxonian philosophical acquaintances broadened when he joined John Wilkins' group, which included future Royal Society Fellows John Wallis, Jonathan Goddard, William Petty, and Robert Boyle, the last of whom Wilkins had succeeded in enticing to move from Dublin around the same time Hooke had arrived in town. In 1656 Hooke went to live with Boyle, and their famous pneumatic collaborations began.

Micrographia grew out of a task delegated to Hooke in 1661 by the newly founded Royal Society – in fact the first thing they ever asked him to do. In 1655, Wren had been preparing an illustrated book of microscopical observations.[16] Though he likely never finished the project, in early 1661 he presented the newly restored King Charles II with a present of drawings of a louse, a flea, and the wing of a fly.[17] Charles told the Society he would like some more, but when the

Intelligence.

12 Often with good reason seen as the precursor of the Royal Society. For the founding of the Society, see especially Hunter, *Establishing the New Science*; Webster, *The Great Instauration*.

13 For biographical works on Hooke, see: 'Espinasse, *Robert Hooke*; Inwood, *The Man Who Knew Too Much*; Jardine, *The Curious Life of Robert Hooke*; Chapman, *England's Leonardo.* For the air pump as the grounds of the contest between the Royal Society and its critics, see especially Shapin and Schaffer, *Leviathan and the Air Pump*.

14 For Hooke at Westminster, see Smith, "Hooke and Westminster."

15 For more on Hooke's Oxford life, see Kent, "Hooke's Early Life at Oxford."

16 Bennett, *The Mathematical Science of Christopher Wren*, 73. Bennett's book includes a typographical error which gives the date as 1665.

17 Both Christiaan Huygens and Balthasar de Monconys reported seeing these images in the king's cabinet. See

Fellows wrote to Wren to relay the king's charge, he asked to be "eased" of the task.[18] At the suggestion of Wilkins, the Society instead enlisted Hooke.[19]

Hooke's appointment as Wren's successor probably had a lot to do with his skill as a draughtsman. Seeing something through a microscope was not a straightforward thing, but drawing it was another complication. In his *Brief Lives*, John Aubrey described Hooke as a "precocious painter" – he had been apprenticed to the portraitist Peter Lely before leaving his workshop complaining of headaches.[20] Though there is little indication of Hooke's early experience with practical optics, Willis' and Wilkins' groups were using both telescopes and microscopes.[21] Wren had pioneered a method of making observations with both eyes open, allowing him to draw as he observed his object, which he presumably taught to Hooke. Hooke's prefatory words in *Micrographia* indicate his excitement at his opportunity, his awareness of its importance, and his admiration for his friends and fellow experimenters.

> I was to follow in the footsteps of so eminent a Person as *Dr. Wren*, who was the first that attempted any thing of this nature; whose original draughts do now make one of the Ornaments of that great Collection of Rarities in the *Kings Closet*. This *Honour*, which his first beginnings of this kind have receiv'd, to be admitted into the most famous place in the world, did not so much *incourage*, as the *hazard* of coming after *Dr. Wren* did *affright* me.[22]

Hooke has certainly benefited from the recent trend in the history of science scholarship which has focused on these sorts of social and material circumstances of knowledge production.[23] Perhaps overlooked by early twentieth century historians looking back to precursors

Ibid.

18 Birch, *The History of the Royal Society*, 1756, 1:21; Wren, *Parentalia*, 210–211.

19 They also solicited a Van der Diver, who has not been identified. Moray, who gives the names in a letter to Wren, also appears to have been unfamiliar with him. (See Wren, *Parentalia*, 211). For Wilkins' involvement, see Hooke, *Micrographia*, sig. G2r.

20 Aubrey, *Brief Lives*; "The Life of Dr. Robert Hooke," in Hooke, *Posthumous Works*, iii; For Hooke's artistry, see Hunter, "Hooke's Figurations"; Doherty, "Discovering the 'True Form.'"

21 Though see Neri, "Some Early Drawings by Robert Hooke." I discuss this further in Chapter 2.

22 Hooke, *Micrographia*, sig. G2r.

23 There is also something odd about the pervasive idea that Hooke's reputation has suffered due to the machinations and agendas of his contemporaries (see Jardine, "Robert Hooke: A Reputation Restored").

of a particularly systematic and theoretical idea of science, he awaited the attention of scholars eager to reconstruct the quoditian craft and skill of the naturalist's enterprise.[24] His persona in the story of the scientific revolution has become that of the the workman. If René Descartes has been thought of as the philosopher of the scientific revolution, Hooke is the ingenious builder and operator – mechanically minded, unsystematic and slightly eccentric, bent and altered physically and mentally by his service to such a physical grasp of knowledge.[25] Much of the recent attention on him has been a project of restoring his reputation, highlighting his many and varied achievements which were occluded by history's lack of interest in labourers.[26] His is the name we can now put on the invisible mechanic, performing the experiments of those of higher social standing, or which more 'systematic' minds integrated and made rigorous.[27]

Thesis Topic

As a complement to existing scholarship, in this thesis I will interrogate the epistemology gestured at by words like 'instrumentalism,' 'ingenious,' or 'empirical:' words that follow Hooke through both contemporary and historical literature.[28] I will focus particularly on Hooke's microscope use as a proxy for his wider instrumentalism, and examine the knowledge he produced in *Micrographia*. This thesis is, to use Peter Dear's term, an epistemography – an "attempt to give an empirical account of knowledge-practices."[29] I will not give a biography of Hooke, nor comprehensive history of his microscopy, but move backwards and forwards

Responsibility lies with us as historians of science to find in the past those things that count in that narrative. Even Joseph Priestley, in his considerable history of theories of light and vision, does not write of Hooke as though he were his intellectual forebear as a Man of Science. See Priestley, *The History and Present State of Discoveries Relating to Vision, Light, and Colours*, 146, 172.

24 See especially Ofer Gal's work on how Hooke's programme for celestial mechanics arose from his craft skill in optics and mechanics: *Meanest Foundations and Nobler Superstructures*.

25 Shapin, "Who Was Robert Hooke?"; Feingold, "Robert Hooke: Gentleman of Science"; Pumfrey, "Ideas Above His Station"; Jardine, "Robert Hooke: A Reputation Restored."

26 As well as the sources already mentioned, see Pugliese, "The Scientific Achievement of Robert Hooke"; Cooper, *"A More Beautiful City."*

27 Or stole. See again Gal, *Meanest Foundations and Nobler Superstructures*.

28 Jim Bennett has championed this approach since the 1980s. See especially his "Instruments and Ingenuity."

29 Dear, "Philosophy of Science and Its Historical Reconstructions," 71.

between his activities in the workroom and the public lecture space, and broader anthropological and metaphysical issues, to tread a path between micro-history and the big picture of the rise of experimental philosophy. *Micrographia* was produced in such a liminal space, at the crossroads of literary and material technology. It was a printed encapsulation of the highly skilled craft of early microscope use, which could be stabilised in print only in the institutional setting of the Royal Society. Hooke could argue this highly contingent situation would contribute to natural philosophy only given certain assumptions about human nature and the nature of knowledge.[30] For example, Jim Bennett has insightfully suggested that 'ingenuity' performed for Hooke a role similar to that which clarity and distinctness did for Descartes. As a virtue of an experimenter, it mimics the virtues of the world itself, and so secures a link between the philosopher and nature.[31] The idea that the assumption of mechanical nature influences the very values of the investigator is an excellent place to begin: if nature is a machine, knowledge of it would not only come through experiment, but could well be expressed in machines rather than axioms. The point of connection and difference with Hooke's near-contemporary is pertinent too. To look at Hooke is see someone both wedded to his context and outside it. The influences especially of Descartes and Francis Bacon loom large in Hooke's philosophy, as well as, more immediately, the likes of Wilkins and Wren. But Hooke figured so prominently in his world that it morphed around him: his work was the creation of a new approach to natural philosophy.

A more historiographical motivation for my thesis is the very fact that so much Hooke scholarship has been a recovery project, which indicates the importance of being attentive to Hooke's own objectives and epistemic ideals. When his copper-plates were reprinted in 1745 as *Micrographia restaurata*, it may have been good news for coffee table naturalists, but it was not the sort of legacy he wanted for his work.[32] Hooke's approach to natural philosophy in no small part

30 The Society certainly struggled to extend the meaning of their experiments beyond their meeting room, and universalise their findings. See Shapin, "Pump and Circumstance"; Shapin and Schaffer, *Leviathan and the Air Pump*.

31 Bennett, "Instruments and Ingenuity," 75.

32 Hooke, *Micrographia Restaurata*. The subtitle makes clear the diminished importance of natural philosophy in the reprint: 'the copper-plates of Dr. Hooke's wonderful discoveries by the microscope, reprinted and fully

involved its reform into an iterative and snowballing endeavor, where successive generations would build on the work of their predecessors. As we understand our limited senses and our place in nature better, we can hope for new inventions, and "*new* matter for Sciences may be *collected*, the *old* improv'd, and their *rust* rubb'd away."[33] The provenance of discoveries should be remembered only insofar as it affects the trustworthiness of the knowledge, "or at most nothing but the bare Name of the Person" should be noted. "Epithets taken from Antiquity or Novelty, or Honour, or Greatness, or Will, or Eloqeunce" are irrelevant to the accretion of knowledge.[34]

The successful institutionalisation of Hooke's own approach to natural knowledge predicted his overshadowing. Only because people continued to be "rather taken with the *plausible* and *discursive*, then the *real* and the solid part of Philosophy," do we focus on the systematisers.[35] If this sits uneasily with Hooke's anger at not receiving credit for his design of a spring-balanced watch, or the numerous irritated precedence claims scattered through his work, Larry Stewart reminds us: there is the history of the institutionalisation of experiment, and the history of its discontents.[36] For John Desaguliers, one of Hooke's successors as a public experimenter, only true philosophers could navigate between "the Scylla and Charybdis of patents and false projects."[37] If the "true" course of philosophy ran between the two evils of projecting and metaphysics, but the *job* of the philosopher was increasingly defined by institutional norms, anyone but a saint would be disgruntled by the award of credit to the wrong person.

Good historical work has recovered and synthesised his fragmented opus, and important philosophical work has interpreted the meanings of his mechanical demonstrations or his interactions with craftspeople and nobility alike. But there is a complement to these kinds of

explained: whereby the most valuable particulars in that celebrated author's Micrographia are brought together in a narrow compass.'

33 Hooke, *Micrographia*, sig. B2v.

34 "General Scheme," in Hooke, *Posthumous Works*, 63.

35 Hooke, *Micrographia*, G1r.

36 For the watch controversy, see Adams and Jardine, "The Return of the Hooke Folio."

37 Stewart, *The Rise of Public Science*, xix.

story which is the basis of this thesis. Hooke's connections with canonical inventions or discoveries of the scientific revolution which in some way legitimise the gaze of the historian are interesting, but it is important also see his success in crafting the kind of approach to knowledge of which we now consider it important to understand the origins: institutionalised, empirical, consensus-driven investigation. It is not enough to call Hooke an 'experimenter' or simply note that he worked for an institution founded on 'Baconian' ideals, when he was himself integral in shaping the categories we pick out with these words.

Chapter Outlines

As I mentioned, my approach will revolve around the microscope. Chapters 2 through 5 relate directly to this instrument, before I take a broader view and situate Hooke's work both in a philosophical and an institutional context. In Chapter 2 I deconstruct the microscope, and in doing so Hooke's method in using it. Hooke's process was a kind of tacit, craft knowledge: he mobilised different materials and techniques contingent on one another, loosely gathered around what it was he wanted to examine. Out of this material milieu came a surprising result, which I turn to in Chapter 3: a theoretical explanation of coloured light. As Hooke learnt how his lenses and other materials altered the appearance of specimens, what he was learning to manipulate was the light entering his eye, and how it had been affected by passing through his instrument. This kind of auxiliary knowledge demonstrates both the way particular norms of reporting discovery were becoming entrenched in the experimental community, and the inseparability of practice and theory for Hooke.

Chapters 4 and 5 approach the microscope from a more conceptual angle. First I address the optimism its advocates had for it at its surge in popularity in the mid-seventeenth century. While naturalists who adopted the instrument with enthusiasm often associated it directly with a particular matter theory – corpuscularianism – for Hooke the most important aspect of microscopy was its ability to alter appearances. His exploration of the micro-world was not the search for *explanans* of higher level phenomena, he often uncovered objects which were themselves mysteries to be analogically explained by their likeness to more familiar, macroscopic objects. For him, the microscope indicated that things would look different to creatures with different eyes. Margaret Cavendish, an early critic of his work, and experimental philosophy generally, pointed out exactly the inhuman nature of this perspective. Her outsider's view of the Royal Society lets us see the implicit values and assumptions Hooke was making, and on which the meaning of experiment depended.

The microscope was thus part of more general themes in seventeenth century thought. Chapter 6 looks at how Hooke responded to the optical revolution sparked by Johannes Kepler and Descartes, within the Baconian context of Restoration England. I will look at Hooke's ideas on vision, memory, and cognition, which supplement the elements of experimental philosophy which take place outside the head: the work of the eyes and hands. Finally, in Chapter 7 I will turn to Hooke's explicitly methodological works, and interpret them both as descriptions of an ideal approach to philosophy, and a prescription of Hooke's own role in that philosophy. The two facets are inextricable: Hooke's actions as the Royal Society's most important experimenter shaped the meaning of experiment and instrument.

Chapter 2: Robert Hooke's Microscope

The Frustrations of the Early Modern Microscopist

What did Hooke do? When he first moved to London and started observing things with the microscope, what did this actually entail? He stayed with Boyle's sister Lady Katherine Jones, Viscountess Ranelagh, at her house in Pall Mall. There are a few things that suggest it was a comfortable enough arrangement: they had their disagreements, but Hooke repeatedly visited Lady Ranelagh after moving to Gresham College in 1664, often to visit Boyle who moved there in 1668, but sometimes alone.[1] Though Boyle had Hooke design a laboratory for the house in the 1670s, a decade earlier Hooke probably had a simple room in which to do his work.[2] What it was like we can only guess. There were two houses, now 83 and 84 Pall Mall, that were both occupied by the Ranelaghs, but the earliest image of the site dates from after they were refronted or rebuilt shortly after Lady Ranelagh and her brother both died in 1691. They were significantly altered again by the autioneer James Christie in the late eighteenth century, then demolished in 1850.[3] Lady Ranelagh was an important node in an intelligence network of natural philosophers, writers, and activists, but the house would have been large enough to avoid crowds of visitors, and for Hooke these days are before the busyness which characterises his diary entries.[4] He probably had

1 See for instance Hooke, *The Diary of Robert Hooke, 1672-1680*, 1935, 1:42. As for arguments, on 20 January 1673/4 Hooke records "Dind at Lady Ranalaughs. Never more," (81) and again on 20 June 1678 "she scolded &c. I will never goe neer her againe nor Boyle" (364). Of course he did not stick to his resolutions. Her name recurs throughout his diary, and Margaret 'Espinasse counts at least thirty dinner visits in 1677 alone: 'Espinasse, *Robert Hooke*, 111.

2 Hooke, *The Diary of Robert Hooke, 1672-1680*, 1935, xvi-xvii, 280ff. See also Shapin, "The Invisible Technician."

3 Sheppard, "Pall Mall, South Side, Past Buildings: Nos 83-84 Pall Mall: Lady Ranelagh's House: Christie's: Board of Ordnance," 367–368.

4 Hooke never mentions the company at her house, but for a while Henry Oldenburg lived next door and tutored her son, and Charles Webster has speculated that in the 1640s the Invisible College may have met at her house: Hall, *Henry Oldenburg: Shaping the Royal Society*, 23; Webster, *The Great Instauration*, 62. For more on Lady Ranelagh, see: Pal, "Katherine Jones, Lady Ranelagh: Many Networks, One 'Incomparable' Instrument."

few friends in town – at least Wren and Boyle were not in London – and he had no nieces to fret about or apprentices to train. In Westminster he was a fair distance from the Royal Society meetings in Gresham College, in the City of London, and when they found him lodgings in the College a large part of the reason seems to have been to make him more available to them.[5] The Fellows rarely recommended observations, let alone dropped by Pall Mall to bring curios to examine or instruments to use.[6] Hooke was anxious about the opportunity, and has he was slowly encouraged by the approval the Royal Society showed towards his work, his observations probably took up a good deal of his time.[7] He had a south facing window, probably large, letting in essential sunlight, and we can imagine an ornate compound microscope on a table nearby.[8]

"The *Microscope*, which for the most part I made use of, was shap'd much like that in [Figure 2.1]," wrote Hooke.[9] It was about "six or seven inches long, though, by reason it had four Drawers, it could very much be lengthened, as occasion required." It was fitted with "three Glasses; a small Object Glass [...] a thinner Eye Glass [...] and a very deep one" in the middle of the tube. This last could be added or removed, again as occasion required.[10] The microscope was made by Richard Reeve, who had a reputation at this time for being the best lens grinder in England, and likely bought for Hooke by Robert Boyle.[11] It would have cost a pretty penny at around £5 10s – when Samuel Pepys bought one from him on 13 August 1664 he justified this price to himself with the claim that "[Reeve] makes the best in the world."[12]

5 See Chapter 7.
6 See Chapter 4.
7 Hooke, *Micrographia*, sigs. G2r-v.
8 Hooke, Micrographia, sig. D2v.
9 Ibid., sig. F1r.
10 Ibid., sig. F1r.
11 This is A. D. C. Simpson's suggestion: Simpson, "Robert Hooke and Practical Optics," 43, footnote 36. For more on Reeve see Simpson, "Richard Reeve - The 'English Campani' - and the Origins of the London Telescope-Making Tradition."
12 13 August 1664: Pepys, *The Diary of Samuel Pepys*, 1971, 5:240. This was roughly the same as a printing press, and a fifth of the cost of an air pump: Johns, *The Nature of the Book*, 76; Shapin and Schaffer, *Leviathan and the Air Pump*, 34. At its founding, the Royal Society's operator (not the Curator – see Chapter 7) was to be paid £4 per year. Presumably the idea was that experiments may be carried out by such a person, but the equipment would be purchased by the Society.

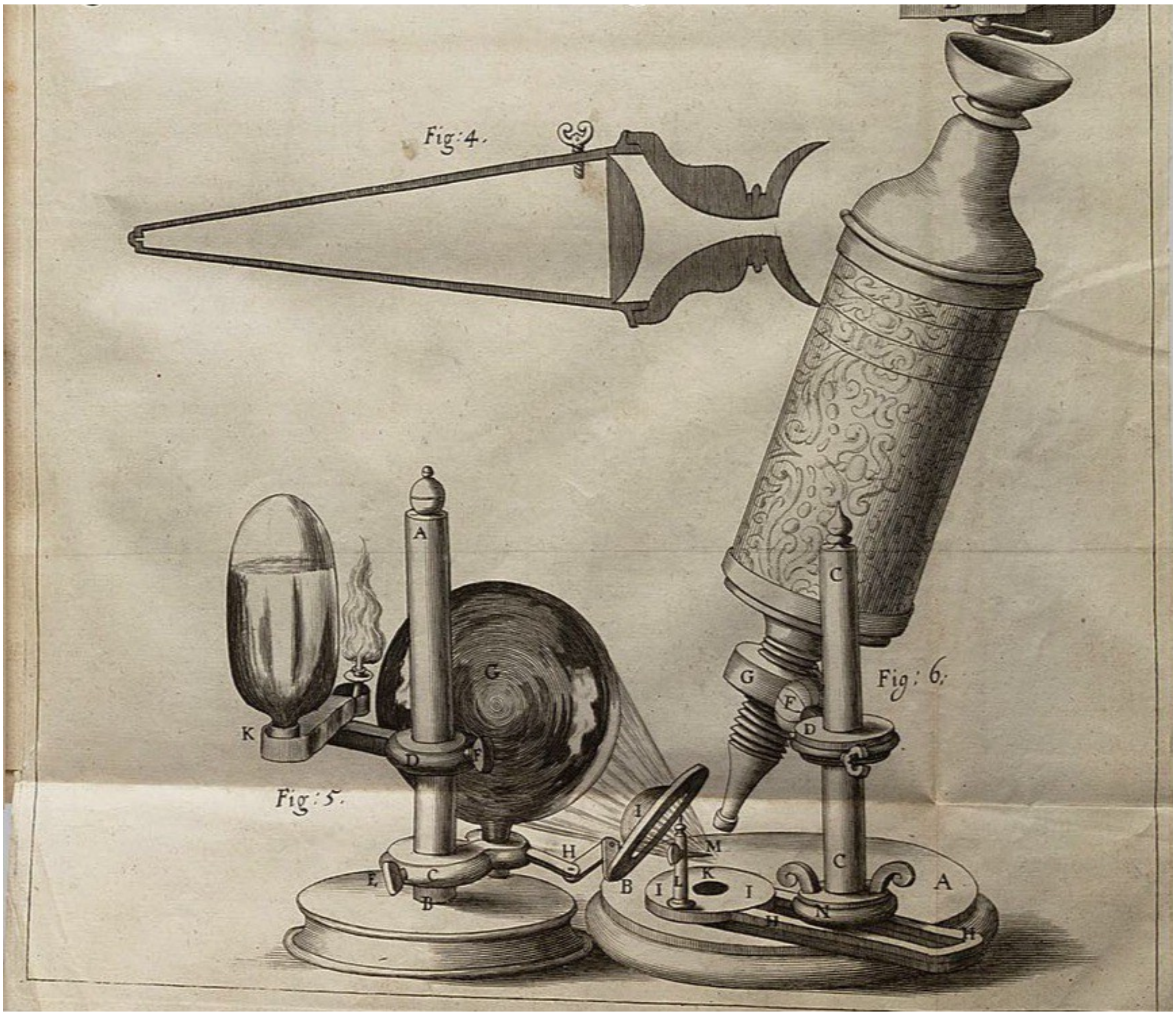

Figure 2.1: Hooke's microscope. *Micrographia* scheme 1, fig. 6, opposite. p. 1. The objects fig. 4 and fig. 5 are different instruments, to which I shall return below.

We can imagine him, narrow-faced and long haired, hunched over a book. His blue eyes moving side to side and thin lips moving silently, he is engrossed in a traveller's tale or a recent natural philosophical treatise.[13] It is early autumn.[14] About to turn the page, Hooke spies an insect creeping over the paper. "Having a *Microscope* by me, I observ'd it to be a creature of very unusual form." Here is a learned, scholarly man with the innate curiosity of a diligent naturalist. He drew a quick picture of a 'crab-like insect' with eight pointy legs and two large claws growing out of its

13 The description of his appearance comes from Waller's introduction to Hooke, *Posthumous Works*. Waller's 'grey eyes' are likely what we would these days call blue, as Leah Marcus has discussed (and Rita Angus's recent portraits of Hooke depict): Marcus, *Unediting the Renaissance*, 12. For more on Hooke's appearance, see Aubrey, *Brief Lives*; Jardine, *The Curious Life of Robert Hooke*, 15–19; Jensen, "A Previously Unrecognised Portrait of Joan Baptista Van Helmont (1579-1644)." Jensen's paper is a response to Jardine's.

14 The following observation took place in September: Hooke, *Micrographia*, 207.

head (Figure 2.2).

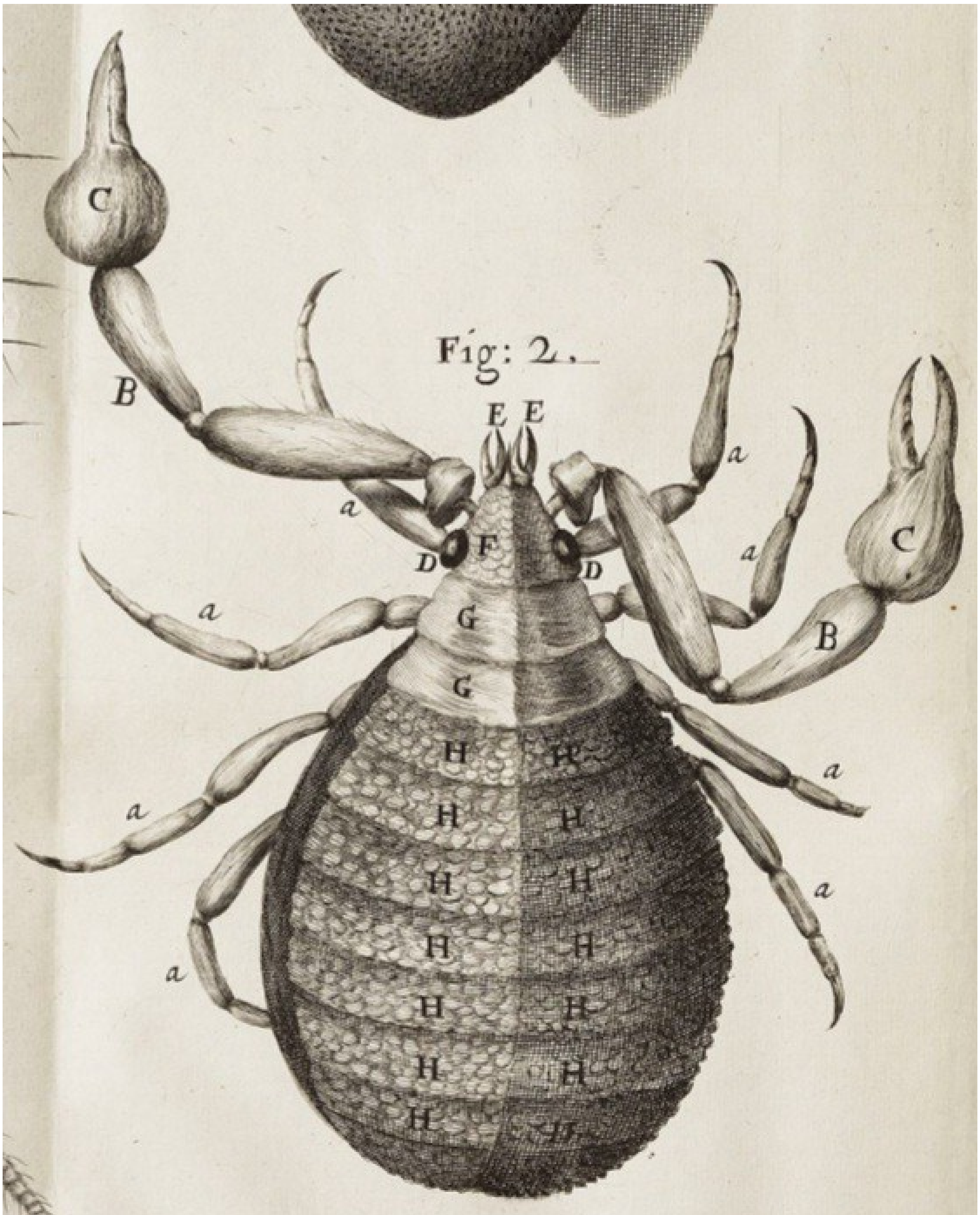

Figure 2.2: The 'Crab-like Insect', *Micrographia*, scheme 33, fig. 2, opposite p. 207.

This sort of textual evidence about the details of Hooke's isolated activity requires some interpretation; his descriptions of his observations are not always faithful. Such a picturesque description – drawn from Hooke's account in *Micrographia* – belies the vexations and limits of the microscopist's task. One does not just pick up a microscope and examine a scuttling insect through it for long enough to ink such a detailed picture, not now any more than in the 1660s. Viewing a live specimen through a compound microscope was an arduous and time-consuming task. The wriggling creature had to be mounted, lit, then peered at from various angles, and drawn. Each step took time and was dependent on the others for success.

A more accurate account of the process comes from comparing Hooke's published narrative to his notes accompanying an early draft of the insect from 1661, which Janice Neri has brought to light (see Figure 2.3).[15] Hooke's description of this picture gives more information: "A Kind of Teek found creeping upon paper, it was drawn dead."[16] That gave him time to examine it. But there are more disparities between the early draft and the published account which beg for an explanation. The draft is dated 11 April 1661. In *Micrographia*, Hooke says he only ever found one such creature, and that was in September. Both drawings are surely of the same specimen: not only are their shapes similar but Hooke depicted them in the same pose, one claw up, one claw down.[17] Even more mysterious is that the earlier picture shows an insect with six legs, but in the later picture it has eight. Neri's plausible explanation for these discrepancies is that the 1661 picture is a draft of a master drawing which went to the engravers, and that neither image was in Hooke's possession when he wrote the insect's description for *Micrographia*.[18] He was relying on his memory to serve him with a date,[19] and the image itself transformed under the requirement to produce intricate and impressive pictures for engraving. The claws made Hooke think of the creature as 'crab-like', and he filled in details with facts he had read about crustaceans: crustaceans have eight legs, he knew, so he drew this crustacean like creature with eight legs, despite his initial

15 Neri, "Some Early Drawings by Robert Hooke."
16 Quoted in Ibid., 46, footnote 3.
17 The left-right inversion could simply be the result of *Micrographia*'s printing.
18 Ibid., 44. Only one of the original drawings that the engravings in *Micrographia* were made from is known to surivive, as Royal Society Classified Papers 20/7: 'figures frozen in urine'. The others were possibly lost in the Great Fire of 1666. See Harwood, "Rhetoric and Graphics in Micrographia," 126–127.
19 For an estimation of Hooke's leaky memory, see again Aubrey, *Brief Lives*.

observation of it.[20]

Figure 2.3: Draft of 'A Kind of Teek'. Original held in British Library, Add. 57495, fol. 113v John Covel, "Natural history and commonplace notebook," c. 1660 – 1713. Reproduced in Neri, "Some Early Drawings by Robert Hooke."

Hooke's famous method of dunking an ant in brandy so it sat still for long enough to draw is more revealing of his practice, but even then he downplays the toil. He used the method because fixing an ant's feet with glue it would still "so twist and wind its body, that I could not any wayes get a good view."[21] Killing insects often made them shrivel unbeautifully, as he had learnt in 1661 when dealing with a beetle "soe unruly I could not put his legges and body into a posture to drawe him alive[,] wherefour I cut off his head."[22] He found that leaving an ant in fortified wine for an hour immobilised it for the same length of time. He did this twice, observing it then catching it when it stirred and ran off, before leaving it "some hours" in the

20 Particularly, Neri supposes, from Willem Piso's *Historia Naturalis Brasiliae* (1648): Neri, "Between Observation and Image," 98.
21 Hooke, *Micrographia*, 203.
22 Quoted in Neri, "Some Early Drawings by Robert Hooke," 46.

brandy, which gave him three or four more hours to examine it.[23] How he came to this method he does not say: how many ants drowned and how many other spirits did he try? Even from the hours he does mention though, already a whole day has passed. The light through his window was in "continual variation" and necessitated continual adjustments to his instrument,[24] and each time the ant was inebriated he had to "put its body and legs into a natural posture."[25] Quite how he did this he does not say – only his eyes, not his fingers, were assisted by the microscope, it was no doubt a fiddly task! Such frustrations were common for the early modern microscopist. Antoni van Leeuwenhoek reported spending several days and killing over one hundred mosquitos trying to present one to his instrument so as to get a good look inside its mouth.[26] Marian Fournier quotes Marcello Malpighi's appraisal of the line of work:

> My dissertation on *Bombyx* [*De Bombyce*, 1669] was an occupation to the last degree laborious and fatiguing, because of the novelty, minuteness, fragility and entanglement of the parts. Hence the prosecution of the task made it necessary to develop entirely new methods. And since I pursued this exacting work for many months without respite, I was afflicted in the following autumn with fevers and inflammation of the eyes. Nevertheless in accomplishing these researches, which brought to my notice so many strange marvels of nature, I experienced a pleasure which no pen can describe.[27]

Malpighi's retrospective is an unusually candid account from an early microscopist of the trials of his task, while *Micrographia* is, in a sense, a highly disingenuous report of Hooke's microscopical observations. In his text Hooke confesses, even makes into a virtue of, the fact that many drawings in Micrographia are composed of multiple observations. Still, when he asks us to believe in the creature in Figure 2.2 above, it is not merely composite of different views, it is an

23 Hooke, *Micrographia*, 204.
24 Hooke, *Micrographia*, sig. E1r.
25 Ibid., 204.
26 Ruestow, *The Microscope in the Dutch Republic*, 151.
27 Quoted in Fournier, *The Fabric of Reality*, 39.

image modified away from observation by Hooke's acquired knowledge of the abstract classification of animals. But the finished book is a polished, bound, complete work; trustworthy and comprehensive. It disguises well the extent of the difference between observing and reproducing.[28]

In this respect he differed from other contemporary microscopists. When the scholar and travel writer Zacharias von Uffenbach visited Antoni van Leeuwenhoek in 1710 he recorded seeing hundreds of microscopes, each with a different object attached.[29] He entered a showroom, a museum almost, with lots of small instruments each dedicated to a single view of one tiny object, like so many little windows into the microworld. Likewise when Leeuwenhoek dedicated 26 of his microscopes to the Royal Society on his death, they arrived with specimens attached – or detached only in the rough transit.[30] Leeuwenhoek made a different instrument for each different observation: they were discrete, self-contained units, each instrument a separate *experimentum*. He went to great pains to prepare each vision, and once prepared it stayed prepared. This method lasted. In the eighteenth century, writers like Henry Baker and George Adams began to popularise the microscope, and write practical introductions to the instrument. They focused largely on mounting specimens in such a way as to preserve them, providing the collection of ready-made observations needed for the microscope's growing use as a parlour toy.[31]

In contrast, Hooke's visions were much more ephemeral. Leeuwenhoek crafted rigid experiences of observation which Von Uffenbach could pick up and partake in. Hooke's observations were stabilised only on the page. The lasting artifact he produced was *Micrographia*, a book not an experiment, containing views clearer and more distinct than anyone could hope for

28 See Pamela Smith's work on craft knowledge: Smith, *The Body of the Artisan*; Smith, "In a Sixteenth-Century Goldsmith's Workshop."

29 Ruestow, *The Microscope in the Dutch Republic*, 151.

30 Baker, "An Account of Mr. Leeuwenhoek's Microscopes."

31 Fournier, *The Fabric of Reality*, 34; Turner, "The Impact of Hooke's Micrographia and Its Influence on Microscopy." Henry Baker's works included *The Microscope Made Easy* (1743) and *Employment for the Microscope* (1753), George Adams wrote *Essays on the Microscope* (1787).

through a lens. The drawings in it are composites, combining the information from observations made under different lights, of different individual specimens, under different aspects, with abstract knowledge gathered from books and communication. Hooke's experiences depended on the angle of light and whether he diffused it through paper, on the clarity of his lenses, and the quality of the material he used as specimen mounts. His drawings contain none of these contingencies. The first book to popularise the view through the microscope is not at all a realistic account of what things actually *looked like*. Lady Ranelagh, peering over her lodger's shoulder, would not have seen objects as they are depicted in *Micrographia*.

It is worth mentioning a caveat to this. the figures and decriptions on the manuscript drafts Neri discusses are signed off with initials "R. H.," but some descriptions also include other initials: "R. G. being present," "D. C. being present," "E. T. Ocul. Testis (eye witness)."[32] It is notable that E. T., the only 'eye witness' was also the only observer who added information to the sketch: the colour of the insect. The others were purely silent presences. It is speculative, but in these early days perhaps Hooke was practicing the art of microscopy, or of drawing his observations. These initials lend credibility to Hooke's drawings, affirming they represent what others, as well as Hooke, saw. The jury vanishes from Hooke's assured, single-authored publication.[33]

With these general points in mind, the rest of this chapter focuses on what Hooke did in order to see the things which he then translated onto the page. This translation was an act of interpretation and artistry, but even observation itself required creativity and ingenuity. To the extent that it was easy to see anything at all through an early microscope, it was easy to see things that were not there.[34] Colours and shapes were distorted, absences looked like presences,

32 See Figure 1, Folio 113v. of Covel's notebook, reproduced by Neri. Neri's suggestion is that one presence could be Ralph Greatorex, an instrument maker who collaborated with Hooke on the air pump around this time, and Stephen Gaukroger has suggested to me that another could be Daniel Colwall, a rich Londoner and early patron and Fellow of the Royal Society. See: Neri, "Some Early Drawings by Robert Hooke"; and for Colwall: Hunter, *The Royal Society and Its Fellows*.

33 Neri, following Steven Shapin, suggests that *Micrographia* became the work of Hooke alone because he was anxious to establish for himself the persona of the reliable and solitary observer, disengaged from the idols of the mundane world: Neri, "Between Observation and Image," 99.

34 See Leeuwenhoek's 'discovery' that many different types of body were made of small globules, and his later

imperfections in the lens looked like markings on an insect. Letting the microscope produce its visions was not straightforward, and different difficulties needed different responses. Hooke knew that there were certain technical or theoretical advantages to certain forms of microscope, but to make his drawings he most often fell back on the standard compound microscope. The best microscope was the one he could grab and move easily, set up and leave alone, and come back to tomorrow. The overruling desideratum of his practice became convenience.

In Hooke's later writing, as he began to lament the failure of the philosophical community to embrace the microscope, he gives more clues as to his practice, especially about the range of materials he used. What surrounded him while he laboured away, one eye transported down a tube into the microworld, the other the same scale as his hand which drew what he saw, was a system of interrelated objects and processes. Lenses, looking glass plates, glass balls full of water, sheets of mica, sunlight, and water-filled tubes were all constantly being swapped, changed, and altered. As several of these objects switched back and forth between being parts of the instrument and objects of inquiry themselves, Hooke gained more familiarity with his apparatus than with many of the subjects of his observations. The story of these materials is the focus of this chapter.

The Perfection of Lenses

As we dissect Hooke's microscope, it is important to see how it fits back together, and how its parts are mutually dependent. The aim of a microscope is not to change the direction of travel of a ray of light, the aim is to provide a clear, magnified image. The things which enabled this – light, refraction, the indefinite complexity of nature – were the same things that made it difficult. There were three main technical bugbears of early microscopy: aberration, illumination, and specimen preparation.[35] Aberration came in two major varieties, chromatic and spherical. But

discovery that these were just apparitions and misleading appearances through his lenses: Phinney, "A Revisionist History of Microscopical Sciences," 126. See also Chapter 4 of this thesis, footnote 71.

35 The technical development of the microscope has been well documented, and I will not repeat it here. See:

calling these things 'problems' obscures the reality of the practice. They were simply inextricable effects of lens use – 'problems' so deeply a part of the instrument's form that a 'solution' would have been a change to the operation of the entire system. Thus, though the technical imperfection of lenses has been a favourite explanation for why the microscope failed to achieve the iconic status of the telescope, even on occasions when theoretical optics suggested to Hooke that he should alter the instrument he was using, the choice not to do so was not an uneducated choice, and rarely due simply to a lack of the technical ability to reach theoretical perfection.[36]

This was especially evident in the case of aberration. Hooke knew that refraction was what gave his compound microscope its power:

> first, [by] augmenting the figure in the [microscope] Tube, by the smallness of the object-Glass, and the length of the Tube: and secondly, by the augmenting that image in the bottom of the eye; and that is by the Eye-glass.[37]

The light coming from an object and into the eye is refracted en route. Consequently what the eye sees is that object stretched out into a larger image. Unfortunately, rays which refract from the outer area of a spherical lens focus at a different point to those rays which refract from its centre. The focus of a spherical lens is not a point but a line, which means the image from it is not all in focus to a viewer at a particular location, but fuzzy and distorted. This is spherical aberration, a widely discussed issue in early lens use. The challenge was to create a lens that brought things into clear focus, and a challenge it was. Ibn al-Haytham (Alhacen) made the issue central in optical writing, and seventeenth century attention focused on conic section lenses following Descartes' *Dioptrique* of 1637. Descartes suggested that an elliptical shape – now known as Cartesian ovals – would not suffer the problematic fuzziness and built a lens grinding

Turner, *Essays on the History of the Microscope*; Disney, Hill, and Baker, *Origin and Development of the Microscope*; Bennett, "The Social History of the Microscope."

36 See: Hacking, "Do We See Through a Microscope?"; Lüthy, "Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy."

37 Hooke, "Microscopium," 101.

machine for the purpose, but with little success.[38] A technical solution was widely sought: Constantijn Huygens worked with Descartes on the problem in the 1630s, Wren designed another lens grinding machine in the 50s, and Newton experimented with non-spherical glasses in the mid-1660s.[39] In early 1668, Francis Smethwick showed the results of his new way of grinding aspherical lenses to the Royal Society which were found to give clearer magnification than the "common, yet very good" instruments they were tested against.[40] While working on *Micrographia*, Hooke himself experimented with reflection microscopes, and with lenses made of gum, resin, salt, arsenic and oil.[41] But the clearest, cheapest, and most convenient were usually simply ground glass spherical lenses. They were so much simpler to make (*Micrographia* details a machine for grinding them)[42] that despite any theoretical advantages and even the odd technical success, in practice spherical lenses out-performed aspherical ones. In other words, the very provenance of lenses inhibited their use. The easiest and most successful way to overcome aberration was just to restrict the viewing area to the centre of the lens. This meant less aberration but the side effect was a smaller lens area, meaning less light could enter, and a darker, more indistinct image.

Consequently, the rule of thumb that came to underlie Hooke's microscope use was that as far as lenses were concerned, "the more the worse."[43] Though it was what granted magnification, he actively sought to *reduce* the number of refractions in his microscopes, because "always the fewer the Refractions are, the more bright and clear the Object appears."[44] He rarely made use of the third (field) lens he could insert in his Reeve microscope which allowed him to see more of his subject at once, preferring a smaller but much clearer image, and he began

38 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*. See especially *Optics* discourse 8. See also Dijksterhuis, "Constructive Thinking"; Gaukroger, *Emergence of a Scientific Culture*, 390; Schuster, *Descartes-Agonistes*.

39 Burnett, "Descartes and the Hyperbolic Quest."

40 "An Account of the Invention of Grinding Optick and Burning-Glasses, of a Figure Not-Spherical, Produced before the Royal Society."

41 Hooke, *Micrographia*, sig. F2r.

42 Ibid., sigs. E1r-v.

43 Hooke, "The Uses and Advantage of Microscopes."

44 Hooke, *Micrographia*, sig. F1v.

making for himself simple microscopes, with single lenses – the style more commonly associated with Leeuwenhoek (see Figure 2.4). Hooke wrote to Boyle on 3 July 1663 to tell him: "[I] made a microscope object glass so small, that I was fain to use a magnifying glass to look upon it." Unfortuntely, it "did not succeed so well as I hoped; but I suppose it might be, because this being the first I had made, the tool was not very true, nor my hand well habituated to such an employment."[45] He persevered, and in the preface to *Micrographia* described the process of making such small lenses by holding a shard of glass over a flame until it melted and a droplet formed. He filed the droplet into a bead and polished it smooth, then attached it with wax against a small hole punched through a metal plate. Holding an object very close to one side of the bead, and with his eye very close to the other, he could see things greatly magnified.

The quality of such a lens was essentially a process of trial and error – its optical performance was dependent on the shape, size, and clarity of the glass, and the amount of control in creating a bead a few millimetres across would surely have been minimal. When they were good they were very good. Nicolaas Hartsoeker claimed to achieve a magnification of up to 770 times with his best such lens.[46] He seems to have produced simple microscopes more powerful than those Hooke was making – when Hooke sent one of his creations to Boyle in November 1664, he said it would "magnify the object, and make it as clear, when conveniently placed, as one of Mr. *Reeve's* largest."[47]

45 Hooke to Boyle, 3 July 1663. In Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 2:98.
46 Ruestow, *The Microscope in the Dutch Republic*, 14.
47 Hooke to Boyle, 21 November 1664. In Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 2:364.

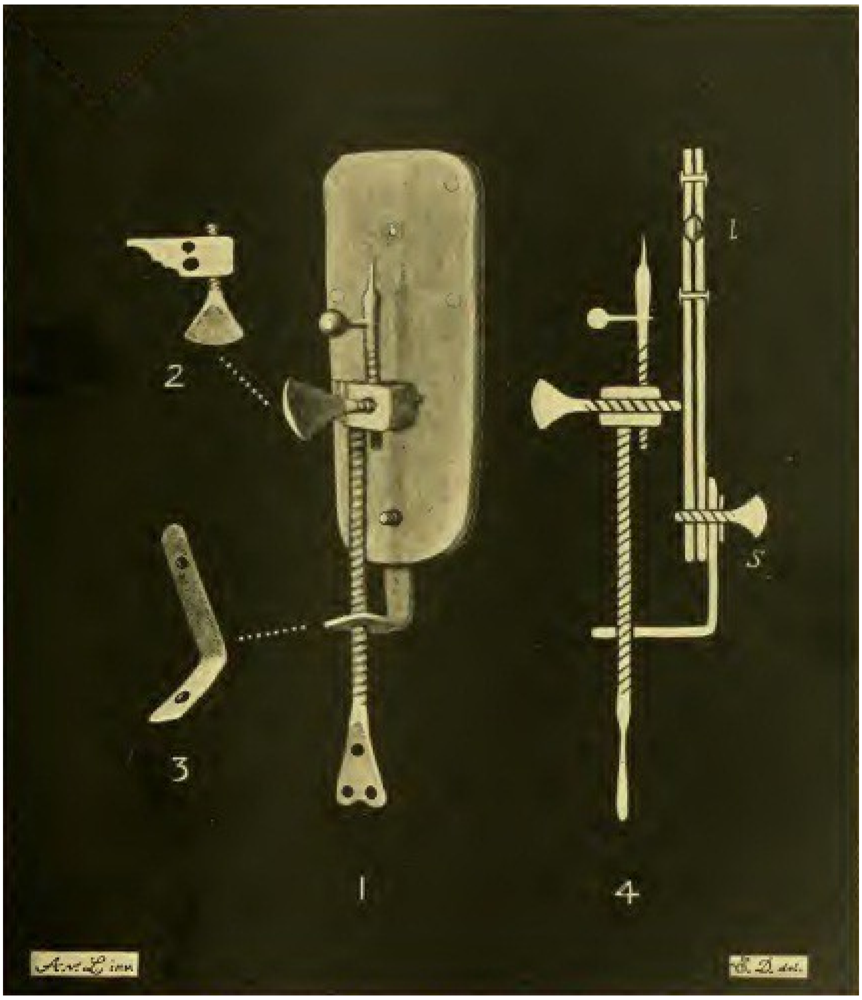

Figure 2.4: Leeuwenhoek's microscope. The lens is the small blister near the top of the metal plate. The specimen is placed on the spike, and can be adjusted both laterally and vertically. From Dobell, *Antony van Leeuwenhoek and His "Little Animals,"* 328.

Unfortunately, he also found them "very troublesome to be us'd."[48] Though they could be made at home with some old glass and a lamp – surely an advantage to a waged Curator new to London and lodging in someone else's townhouse – it must have been a tedious process filing, afixing, and using glass beads so small they themselves needed to be viewed through a magnifying glass. They were fiddly and delicate; he broke the first one he tried to send to Boyle.[49] To add pain to inconvenience, Hooke repeatedly claimed that they were all very well for those people who

48 Hooke, *Micrographia*, sig. F1v.
49 Hooke to Boyle, 21 November 1664. In Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 2:364. He sent a complete instrument later in the month: see Hooke to Boyle, 28/29 October 1664. In Ibid., 2:371.

could endure it, but the tiny lenses hurt his eyes.[50] Optical performance was not his only consideration, and Hooke made little use of simple microscopes despite recognising their clear benefits. He published a description of the instrument, and later lamented that no one had followed it.[51]

Another related benefit was that they did not produce as many of the "colours which do much disturb the clear vision in double Microscopes."[52] Because different colours of light refract different amounts, when white light refracts through even the same part of a lens, the different colours focus to different points, producing a fuzzy coloured halo around images, known as chromatic aberration (Figure 2.5).

Figure 2.5: The slight chromatic aberration of a flea. The left image is a photo taken through an eighteenth century microscope, and shows a coloured halo, though not enough to completely obscure the image. (Image copyright The Whipple Museum of the History of Science, University of Cambridge [Wh.0080]). The right image, for comparison of the detail visible, is Hooke's flea from *Micrographia*, scheme 34 detail, opposite p. 210.

50 Hooke, "Microscopium," 96.
51 Ibid., 99; Hooke, "Hooke Folio," f. 96. Leeuwenhoek was probably the most prolific simple microscope user, but even after death he was secretive about his instruments. Though he left some to the Royal Society, even then he probably withheld his best instruments. See Baker, "An Account of Mr. Leeuwenhoek's Microscopes."
52 Hooke, "Microscopium," 97.

Achromatic lenses, made from two types of glass with differing refractive qualities, were reliably made by the middle of the eighteenth century.[53] Before that, Hooke was not without more feats of instrumental dexterity as he sought to decrease the number of refractions still further. When examining a liquid through a microscope, it was possible to:

> spread a little of the liquor on the Looking-glass plate, then apply the said plate with liquor, next to the Globule (lens), till the liquor touch. [… T]his liquor being of a specifique refraction, not much differing from glass, the second refraction is quite taken off, and little or none left but for that of the convex side of the Globule next to the eye.[54]

A one-refraction instrument seems ideal, "capable of the greatest clearness and brightness that any one kind of Microscopes can possibly be imagined susceptible of."[55] Hooke, preferring not to use simple microscopes, even made a compound version: a water microscope. This was a tube, filled with water, with a plano-convex lens at each end (Figure 2.6).

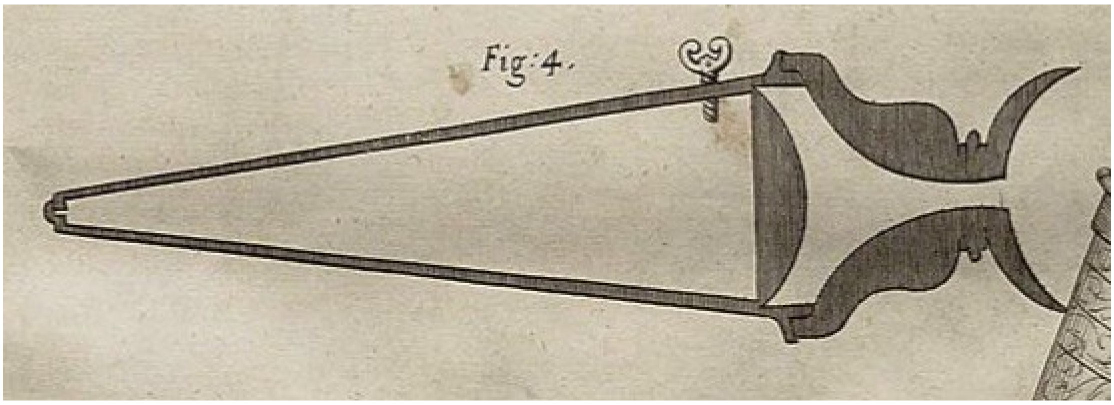

Figure 2.6: Hooke's water microscope in cross section. The object lens is at the far left, the eye piece at the right. The screw at the top can be removed to pour in water. *Micrographia*, scheme 1 detail, opposite p. 1.

53 Priestley, *The History and Present State of Discoveries Relating to Vision, Light, and Colours*, 729; Hutchison, "Idiosyncracy, Achromatic Lenses, and Early Romanticism."
54 Hooke, "Microscopium," 98–99.
55 Ibid., 98.

By using water instead of air inside the tube, light refracts less when it leaves the object lens, and enters the eyepiece lens. Less refraction means less magnification, and less aberration. Hooke's particular design may have been new, but Descartes had suggested something similar, and Newton would later agree it "perform[ed] the office of *one Glass*."[56] Unfortunately, optical performance was again trumped by practical matters. Unspecified "inconveniences" meant Hooke hardly used this instrument.[57] The water needed to be incredibly clear, the tube well made and water-tight. Perhaps it leaked, or the water softened the wax seal around the lenses and caused them to shift.

In Hooke's inventive approach to his instrument, the things he found important and the things that stymied his pursuit of them, we can see a constant interplay between aims, theory, material and ability. Ingenious he certainly was. Ofer Gal has called Hooke's willingness to replace two lenses with one "anti-theoretical" – what theory there was to practical optics in Hooke's time was based on the interactions of two lenses of different shapes or sizes.[58] Indeed, the same could perhaps be said of the decision to use well made spherical, rather than badly made hyperbolic, lenses.[59] In general, it is too simplistic to say that aberration necessitated workaround solutions. After all it is the same process, refraction, that both produced the unwanted aberrations and the sought-after magnification, as Hooke well knew.[60] In the 1670s, Hooke and Newton debated the likelihood of creating a refracting instrument with sharp focus, and wondered whether or not it wouldn't be better to focus on constructing reflecting instruments.[61] Hooke was not prompted by a conception of the microscope as purely a magnifying instrument, but rather by the requirements of his immediate task to gain clear and bright views of the micro-world, and arrived at his own rules of practice independent from the theoretical optics of the time which

56 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 120; Newton, "Mr Isaac Newtons Answer to Some Considerations upon His Doctrine of Light and Colors," 5085.

57 Hooke, *Micrographia*, sig. F2r.

58 Gal, *Meanest Foundations and Nobler Superstructures*, 50.

59 For another instance of Hooke emphasising that the best instrument is the one suitable for the situation see his "Animadversions on the First Part of the Machina Coelestis," 8.

60 Hooke, *Micrographia*, sig. D2v.

61 See their letters and replies to one another in Turnbull, *The Correspondence of Isaac Newton*, 1:92, 110, 171.

ostensibly explain the operation of the instrument. Daily work and physical contraint made Hooke innovate, and move back time and again to his store-bought, rather fashionable parlour instrument, its size and stability the most important considerations for making observations day in, day out.

The Invisible Material: Light

Perservering with this instrument meant a balancing act, and Hooke began to manipulate something other than his lenses. The one truly essential ingredient of the whole instrumental milieu was light. The vehicle of vision, it was refracted through lenses to provide magnification. But more magnification brought more aberration. Reducing aberration meant using a tiny aperture, and a tiny aperture meant a darker image. "[G]ive therefore light enough to the object, and you may increase the image at the bottom of the eye to what proportion you shall desire."[62]

The light through his window was in "continual variation," and even on sunny days Hooke found he could rarely complete an observation in daylight hours.[63] Lamplight was a start, and Hooke certainly worked hard at improving lamps. He designed a lamp which would burn with an even flame and for as a long a time as possible – both strong desiderata for the microscopist.[64] But working through the night with his eye to the microscope, even lamplight by itself was not enough. Hooke amplified it through a glass globe full of water.

This is the globe marked G in Figure 2.7, and seems to have been a fairly standard means of light amplification in the seventeenth century. When Samuel Pepys bought a microscope from Richard Reeve, it came with a 'scotoscope'; "a curious curiosity it is to [see] objects in a darke room with."[65] Though he does not describe it, and there is some ambiguity

62 Hooke, "Microscopium," 101.
63 Hooke, *Micrographia*, sig. E1r.
64 Hooke, *Lampas*.
65 13 August 1664: Pepys, *The Diary of Samuel Pepys*, 1971, 5:240.

about what the now-obsolete word refers to, R. H. Nuttall's convincing suggestion is that it is identical with the device Hooke describes in his preface.[66] "By means of this instrument […] the small flame of a Lamp may be cast as great and convenient a light on the Object as it will well indure." Often he would diffuse the light through a piece of oily paper so the specimen could be evenly lit, without any hard shadows or glare.[67]

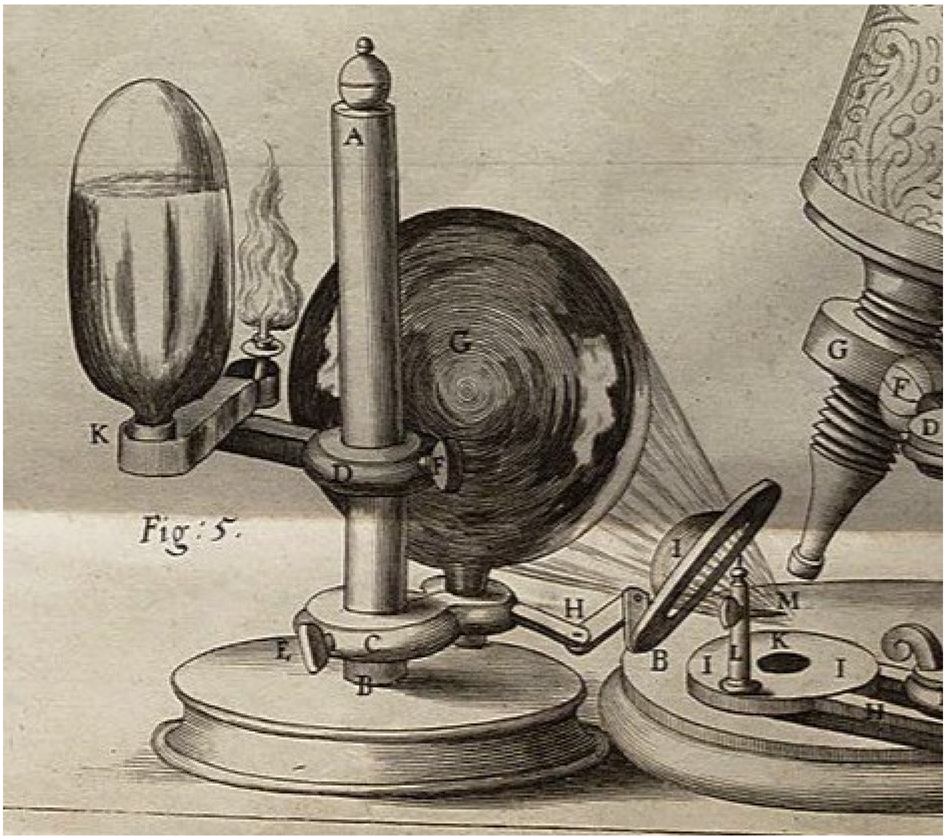

Figure 2.7: The scotoscope, from *Micrographia* scheme 1, figure 5, opposite p. 1.

As well as the quantity of light, the angle it lit a specimen from was crucial. Again and again in *Micrographia* and the later "Microscopium" Hooke mentions that objects look like one thing in one light, and another in another.[68] He agreed with Henry Power that under certain light flies' eyes looked like a lattice of tiny holes, but in brighter sunlight they turned into a surface

66 Nuttall, "That Curious Curiosity: The Scotoscope."
67 Hooke, *Micrographia*, sig. E1r.
68 e.g. Ibid., sig. F1v; Hooke, "Microscopium," 92; Birch, *The History of the Royal Society*, 1757, 3:349.

covered in nails or pyramids. Often, rather than finding just the right way to illuminate something, Hooke found it more useful to light and view it from various angles, and be wary of those features which altered.[69] It was not just the specimen or the light that Hooke moved to get a good view. His drawing of his instrument in *Micrographia* (Figure 2.1 above) appears to be the first depiction of a microscope mounted as it is, on a pillar by a ball and socket joint, rather than sitting immobile on a tripod. The way he describes the instrument in "Microscopium" implies this was his own innovation – perhaps Reeve supplied only the tube and lenses.[70] Though in fact both the pillar and the tripod designs persisted into the eighteenth century – indication perhaps that ease of use or optical quality were not the only arbiters of design for an instrument that was a fashionable accessory and a toy more often than a philosophical instrument – Hooke's method has clear advantages.[71] The microscope tube itself was mobile in any plane, allowing Hooke to shift his lens, the specimen, and the light in "what posture I desir'd."[72] The able microscopist, it is clear, was not only reliant on the ability of lens grinders to approach theoretical optical perfection, but would possess a good degree of mechanical ingenuity too. In a lecture from 1693, Hooke criticised Philippo Bonanni for using a microscope with "too much apparatus and clutter and yet [...] wanting of many accommodations for examining or as it were handling & turning the Object into all postures & for all lights."[73]

Seeing What Was There: Specimens

The design of a microscope and what you wish to see through it are not things that can be changed independently of one another. An object needs to be placed so close to the lens of a simple microscope to be magnified by it – even touching it – that the instrument is useless for

69 I return to his point in Chapter 4.
70 Hooke set aside "the common pedestal hitherto made use of in Microscopes," and instead "I fix into the bottom of the Tube of the Microscope, a cylindrical rod of Brass or Iron." Hooke, "Microscopium," 91.
71 See Bennett, "The Social History of the Microscope."
72 Hooke, *Micrographia*, sig. F2r.
73 Hooke, "The Uses and Advantage of Microscopes," f. 4. See Appendix.

viewing opaque things. Attach a fly to the underside of the glass bead, and it cannot be illuminated from above or the side, but only behind, casting a giant shadow on the microscope lens. Conversely, when using a compound instrument "the transparency of most Objects renders them yet much more difficult then if they were *opacous*".[74] The wrong angle of light added shadows to or changed the appearance of anything, but translucent subjects amplified the problem. Again magnification was not the only game in town. Loyalty to a particular subject matter could determine the form of the instrument used, and *vice versa*. At the extreme end of this contraint is Margaret Cavendish's absurd request to see a whale under the microscope in her story *The Blazing World*. The hapless experimenters she asks ready their largest microscope, "but alas! The shape of the whale was so big, that its Circumference went beyond the magnifying quality of the Glass."[75]

Marian Fournier has pointed out that though these kinds of aspects of microscopy were much less discussed than optical aberrations, they were equally if not more important in determining research with the instrument.[76] Hooke's microscopical inspiration were the drawings of insects Wren had given Charles II, and he was probably further prompted by Henry Power's observations, also made with a compound instrument.[77] Despite his knowledge of, and his willingness to make, new instruments, Hooke's chosen subjects helped determine to some extent the instrument that he used. Through use, the reverse also became true: Hooke found it much easier to use a compound than a simple microscope; lighting specimens for the latter was a "great inconvenience," and his eyes were pained by their tiny lenses.[78] The form of the instrument and the programme of its use were mutually reinforcing considerations. If there was a limitation to Hooke's work in magnifiying his senses, it was not so much theoretical optical knowledge nor technical ingenuity as the material bodies of the plants and insects he observed.

74 Hooke, *Micrographia*, sig. F2v.
75 Cavendish, "The Blazing World," 32. I return to Cavendish in Chapter 5. See also Bacon's words on the microscope: *Novum Organum* book 2, aphorism 39, in Bacon, *The Oxford Francis Bacon*, 11:345.
76 Fournier, *The Fabric of Reality*, 34.
77 See Chapter 4.
78 Hooke, "Microscopium," 92.

Hooke and Power used mainly compound microscopes to look at (mainly) insects, plants, and seeds. The simple microscopists like Leeuwenhoek and Jan Swammerdam wrote much more frequently on anatomy, blood cells, spermatozoa, and the tiny nematodes in liquids. When Leeuwenhoek wrote to the Royal Society and told them about these tiny animals in pepper-infused water, the two programmes crossed paths. In October 1677, Hooke dusted off his old instruments. "I put in order such remainders as I had of my former Microscopes (having by reason of a weakness in my sight omitted to use them for many years) and steeped some black pepper in River water."[79] Little thereafter was straightforward. His recreation of Leeuwenhoek's observations was not an exact replication – he persevered with a compound instrument, confident he could see things at the scale Leeuwenhoek claimed to have, even if his instrument was of a different type.[80] The episode demonstrates how tricky it could be simply to see what there was to see, even when you knew it was there.

For one thing, preparing a specimen is not easy. Ian Hacking has said that in order for the microscope to become a successful and fashionable parlour toy, it needed to be packaged with a box of specimen slides, which would routinely have cost more than the instrument itself.[81] Limiting though they did the objects one could view, and therefore the microscope's usefulness and interest as an investigative tool, without such preparations most people would not have been able to view anything at all. When Pepys bought his instrument from Reeve, he and his wife thumbed through Power's *Experimental Philosophy* to get an idea of what to expect, sat down with their instrument, and still had "great difficulty before we could come to find the manner of seeing any thing."[82] When Hooke sent Boyle his first simple microscope, he thoughtfully attached a "small brush of hairs" for him to look at.[83] In Hacking's words, "[y]ou did not just put a drop

79 Ibid., 82. Leeuwenhoek's letter is reproduced by Hooke in this same lecture. The following events are patched together from "Microscopium," the minutes in Birch, and extra meeting information omitted from Birch but in the Hooke Folio, Royal Society MS 847.

80 Birch, *The History of the Royal Society*, 1757, 3:346; Hooke, "Microscopium," 82, 89.

81 Hacking, "Do We See Through a Microscope?," 138.

82 14 August 1664: Pepys, *The Diary of Samuel Pepys*, 1971, 5:241.

83 Hooke to Boyle, 28/29 October 1664. In Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 2:371.

of pond water on a slip of glass and look at it."[84] For one thing, as Hooke tells us, the slip of glass needs to be "very clear and thin[, ...] very smooth and plain on both sides, and clean from foulness," so artifacts in the glass are not mistaken for discoveries.[85] For another, the pond water must have in it the things you wish to see. On 1 November, Hooke looked for Leeuwenhoek's pepper worms for the first time and saw nothing.[86]

It was not immediately clear to the Fellows of the Royal Society what to blame the failure on. Either the microscope or the specimen could have been culpable. Leeuwenhoek did brag about the tiny size of the animals he could see, and he refused to divulge secrets of his microscope design.[87] Perhaps Hooke's microscope was not strong enough. Then again, this first observation was made with plain water, *not* infused with pepper.[88] The Fellows resolved to change both the instrument and the specimen for the next meeting.[89] Hooke himself blamed the interface between the two – the specimen mount. Leeuwenhoek used thin glass pipes to hold the liquid, and Hooke conjectured the pipes themselves must have been acting as magnifying glasses, doubling the effect of viewing them through a lens.[90] His own mounts did not have the same effect.

Hooke used different techniques for mounting different objects. A solid body could simply be placed on a pin under the object glass (see M in Figure 2.7 above), or placed on a small sheet of mica (which Hooke calls 'muscovy glass') attached to it. Mica can be split very thin, until it is "hardly perceivable by the eye," perfect for an unobtrusive slide.[91] A liquid could likewise be spread across such a slide; a viscous or uneven fluid like "Fat, Oyl, Brains, Rhobs, Pus, tough

84 Hacking, "Do We See Through a Microscope?," 138.
85 Hooke, "Microscopium," 93.
86 Birch, *The History of the Royal Society*, 1757, 3:347; Hooke, "Microscopium," 82–83.
87 See for instance his letter to the Royal Society of October 1676: after estimates at the size and quantity of the tiny animacula, he says that "the make of the Microscopes, employed by me, I cannot yet communicate." Leeuwenhoek, "Monsieur Leewenhoeck's Letter to the Publisher," 845.
88 This is according to the minutes in Birch, and despite the fact that he implies it was pepper water in "Microscopium". On a couple of occasions Birch and Hooke's later recollection do not match. I have tended to follow the minutes, which at this time, post-Oldenburg, were in any case taken by Hooke.
89 Clearly they had never played *Cluedo*.
90 Birch, *The History of the Royal Society*, 1757, 3:346–347.
91 Hooke, *Micrographia*, 47.

concreted Flegm, and the like" he would press flat between two thin plates of looking glass. Small threads like tendons he would stretch between two tweezers.[92]

The next trial was at the meeting of 8 November. Hooke had a more powerful compound microscope, and he had adapted it to hold Leeuwenhoekian glass tubes. One tube was attached to a brass plate, perforated to allow light through, which could slide along another piece of brass fixed below the object lens, allowing different angles and views.[93] It was filled with water steeped with pepper for three days. Still there were no worms. Again the Fellows conjectured why not. Thomas Henshaw blamed the season. It was late autumn; perhaps not the time of year pepper worms generate. Daniel Whistler thought maybe the black flecks of pepper they could see floating about were Leeuwenhoek's "imagined creatures."[94] This response, though seeming uncharitable, is pure reasonableness: what they could see what all that exists. They were convinced to keep trying for two reasons, one evidential and one testimonial. Leeuwenhoek had written about seeing the worms both alive and dead. The floating specks were clearly not swimming creatures, begging the question of how he could have noticed a difference if they were all he had seen. And perhaps more importantly, the Dutchman's first observation had been also witnessed by two ministers, a public notary, and five other "persons of good credit."[95] Such 'virtual witnessing' helped to universalise what was otherwise a private and contestable experience, and was an important part of how the Royal Society themselves vindicated their experimental endeavour.[96]

After the failure, Hooke fell back on explaining how, by keeping both eyes open, he could measure the magnification of a microscope. It was suggested to him that next time he put this skill to use and bring a more powerful microscope. The Fellows were still equating the quality

92 Hooke, "Microscopium," 91–95.

93 Birch, *The History of the Royal Society*, 1757, 3:349. These minutes just say the mount was highly adjustable, the detail is taken from an account of the following observation (15 November) in Hooke, "Hooke Folio," f. 109.

94 Birch, *The History of the Royal Society*, 1757, 3:349.

95 Ibid., 3:347.

96 See especially: Shapin, *A Social History of Truth*; Shapin and Schaffer, *Leviathan and the Air Pump*; Dear, "Totius in Verba."

of an observation with the size of the image.[97]

In fact, Henshaw was not far wrong: what was needed was patience. The worms needed longer to generate inside the pepper water, and Hooke began to notice them the following week. "[A]s if I had been looking upon a Sea, I saw infinite of small living Creatures swimming and playing up and down in it, a thing indeed very wonderful to behold."[98] At the meeting on 15 November, he showed an excitied crowd. The charmed onlookers saw tiny creatures like bubbles or pearls wriggling to and fro. The tiny, erratic movement convinced them they were seeing animals, and "there was no longer any doubt of Mr. Leewenhoeck's discovery."[99]

Figure 2.8: Hooke's illustration of vinegar eels from *Micrographia*, scheme 25, fig. 3, opposite p. 181. Hooke was astonished to see creatures one hundredth the size of one of these tiny worms (see 'Microscopium,' p. 83).

Excitement quickly gave way to sober inquiry. The Fellows suggested more iterations: replace the pepper with wheat, barley or nothing; replace the water with blood or another liquid. The official minutes record a triumph of collaborative experimental philosophy. An experiment perfected in private by Hooke was repeated in front of witnesses, whose names and titles are duly recorded. But intriguingly, the minutes – taken by Hooke in his new role as Secretary – do not seem to document the whole meeting. Whether an intentional omission or not, both Hooke's

97 Birch, *The History of the Royal Society*, 1757, 3:349.
98 Hooke, "Microscopium," 92.
99 Birch, *The History of the Royal Society*, 1757, 3:352.

"Microscopium" and the lost minutes in the "Hooke Folio" reveal more details which make this simple *experimentum* account much more ambiguous.

Firstly, the published minutes break off after suggestions for further trials, but before the discussion turned more speculative. Hooke thought the worms might have hatched from eggs laid on the pepper before it was steeped, while Henshaw, Wren, and William Holder argued they were generated directly from the pepper. Henshaw supported this view by analogy with another case. The heat of the pepper fermented the mixture, which then produced worms; exactly as happens when horses' tails or lute strings steeped in water turn into snakes.[100] That such hypothetical explanation should be omitted deliberately from the official record is an enticing idea, but I do not want to overstate it. The Fellows engaged fairly freely in this sort of excited discussion after observations or experiments were performed for them.

There is also a discrepancy in the form of the microscope described. Hooke, in his omitted notes, goes on to describe the Leeuwenhoekian thin pipes, attached to brass plates, that held the pepper water. In "Microscopium", the published version of what was originally a public lecture at Gresham College, he claims he saw pepper worms on a slide of muscovy glass: a better method "at least for those Microscopes I make use of; what it may be for those which Mr. *Leeuwenhoeck* uses I know not."[101] The discrepancy could be another example of Hooke's leaky memory marring a later account, or perhaps he succeeded using both ways. He suspected that a drop of liquid on a sheet of muscovy glass would itself act like a lens and, like Leeuwenhoek's tubes, magnify things within it, as a leaf looks magnified through rain drops.[102] He could of course have been emphasising his microscopical prowess, in succeeding by his own methods. Or perhaps he recognised Leeuwenhoek's desire for secrecy, and omitted the details of the device out of respect for an experimenter for whom he had great admiration and whose observations were – as Hooke's were for him – an important part of his livelihood.

100 Hooke, "Hooke Folio," f. 109.
101 Hooke, "Microscopium," 91.
102 Birch, *The History of the Royal Society*, 1757, 3:351.

In "Microscopium" Hooke emphasises another detail lacking in Birch: the ambiguity of the observations themselves.

> When the water began to dry off, the bending of the superficies of the liquor over their backs, and over the tops of other small motes which were in the water made a confused appearance, which some not used to these kind of examinations, took to be quite differing things from what they were really; and the appearances here are so very strange, that to one not well accustomed to the phaenomena of fluids of differing figures and refractions, the examinations of substances this way will be very apt to mis-inform, rather than instruct him.[103]

Was Hooke taking the opportunity of a public lecture to emphasise his expertise, how “accustomed” and “used to these kind of examinations” he was, something out of place in the official minutes, a text more appropriately limited to sober accounts of collective certainty?

For whatever reason, the published minutes do not contain the whole account. My explanations of these three disparities are speculative, but there is a more general lesson. As with the observations in *Micrographia* with which I began this chapter, it is only by looking through the details Hooke openly gives us in the official texts of the Royal Society to clues in his other writings that we catch a rare glimpse of a classical microscopist admitting the difficulty of making observations.

Crafted Knowledge

Hooke's tinkering brought an end to a year long raised eyebrow about Leeuwenhoek's claim to see so many creatures in so little water – he had first communicated his observations in a letter of October 1676.[104] The process of the investigation was one of constant iterative manipulation. Behind the the register of the witnesses' gratified assent to Leeuwenhoek's

103 Hooke, “Microscopium,” 92.
104 Ibid., 81.

observation in the Royal Society minutes, as behind the drawings in *Micrographia*, lie the details of the microscopist's task. Hooke had objects to investigate that he knew were within the horizons of his lenses, but still it was not easy. When the Fellows urged him to use a more powerful microscope, what did this mean? Bigger lenses? Smaller lenses? A different specimen mount? More light? All of these things were aspects of Hooke's microscope which he could and did alter, both quantitatively and qualitatively, searching for an accurate vision of an object that he had never seen before.

My purpose in this chapter has been to foreground Hooke's activities. To say with Pepys, and with any number of more contemporary writers, that Hooke's microscopical work is "ingenious" is not inaccurate but it is vague.[105] *Micrographia* was not simply a book intended to impress its readers, or a testament of the power of a artifice to widen the limits of human knowledge. It was both of these things, but it was also a painstaking work of craftsmanship by someone who, in the process, became an expert at manipulating certain material objects. The microscope's holistic form was constrained by physical limitations: the subjects of Hooke's enquiries, the quality of his lenses, the length of the English day. Things material, meteorological, human, and perhaps above all, expedient.

The dissected microscope consisted of lenses, scotoscopes, mica, looking glass plates, water, lamp oil, and light itself. The ulterior motive of this chapter has been to acquaint us with these components. I will revisit them in the following chapter, where I will show that Hooke's theoretical ideas about light stem from his microscope use, and is based on the other ingredients of the instrument. Without his microscope – without composing *Micrographia*, Hooke would not have arrived at his theoretical ideas about light and colour production.

105 21 January 1664/5: Pepys, *The Diary of Samuel Pepys*, 1972, 6:18.

Chapter 3: The Colours in Thin Plates

The Importance of Materials

We have just seen that there were few stable parts of Hooke's microscope. He tried different numbers of lenses of different shapes and materials, different ways of displaying specimens, and different light sources. But light itself was always there. We know something of the lengths he went to to change the direction and shape of the light reflecting of his subject and into his eye. In this chapter I will explain the detailed views of light and colour Hooke presents in *Micrographia*, and his later adaptations of them. These theoretical, considered ideas in fact turn out to be the result of the manipulative, instrumental expertise I discussed in the previous chapter. Perhaps he later performed directed trials designed to interrogate the nature of light, but his ideas are fundamentally grounded in the different parts of his microscope, and in a very real sense the limits to his knowledge of light are set by the materials he used to manipulate it.

Observation 9 of *Micrographia* is titled 'Of the Colours observable in Muscovy Glass, and other thin Bodies.' Muscovy glass was the common early modern English name for muscovite, or mica, so called because it was a cheap replacement for glass windows in medieval Russia. Mica, Hooke says, has as many "Curiosities in its Fabrick as any common Mineral."[1] Importantly, it could be split into thin transparent plates, making it ideal for microscope slides. But when he looked at these slides through his instrument, Hooke noticed something else: colours. There were coloured rings, radiating out from central white dots; there were thin multi-coloured threads winding around like country roads; and there were larger splashes of uniform

1 Hooke, *Micrographia*, 48.

colours.[2] The phenomena could scarcely have escaped his attention after a year and a half of peering down his tube at the stuff.

Hooke makes a good deal of the benefits of investigating colour in this context rather than waiting for "the occasion of examining the Colours in Peacocks, or other Feathers."[3] Feathers he looks at in Observation 36, but every "position of it to the light makes it perfectly seem of another form and shape," so much so that it was one of the few objects Hooke was not confident he managed to get a good view of.[4] Mica, on the other hand, was easy to handle. With it he could produce colours regularly and predictably. In preferring it to feathers, Hooke was both using the materials he had to hand, and also explicitly privileging their immediacy over historical precedence. Before Kepler and Descartes there had been a long-standing distinction made between 'apparent' or 'emphatic' colours, produced by light, and 'real' colours, which were properties of bodies. Shimmering peacock feathers, whose colours change in different angles and lights, made it obvious that even real colours depended on light in some way, and they became an important example in discussions of colour.[5] In seventeenth century mechanical philosophy light became the sole vehicle of visual information, and the separation could not be sustained.[6] Descartes had found he could not "approve the distinction made by the philosophers when they say that there are some true colors, and others which are only false or apparent. For because the entire true nature of colors consists only in their appearance, it seems to me to be a contradiction to say that they are false, and that they appear."[7] By the 1660s this was the accepted view. In 1664 Boyle noted that the distinction between real and apparent did not exist for the proper objects of our other senses.[8] We call all sounds 'true sounds', whether they reach our ears directly or by echoing off other surfaces, and all odours 'true odours'. Given all colours affect our vision, the

2 Ibid., 48–49.
3 Ibid., 49.
4 Ibid., 168.
5 See Guerlac, "Can There Be Colours in the Dark?"
6 I return to this optical revolution in Chapter 6.
7 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 338.
8 *Experiments and Considerations Touching Colours* in Boyle, *The Works of Robert Boyle*, 1999, 4:53.

distinction should be collapsed, and all colours called 'real'. When Hooke marshalled his inquiry into colour around mica, he both placed himself in this tradition, and sought to extend it.

All colour was coloured light, and light was the paradigm case for Descartes' mathematised physics.[9] Light, he thought, was the action of particles on the eye. The particles themselves did not actually move, only 'tended' towards a certain direction, like grapes in a barrel 'tending' to move down but prevented from really doing so by the particles already resting in that place.[10] In his *Météors*, Descartes showed that when light refracts, light particles begin to rotate. His first trials were with water balls to emulate the raindrops of a rainbow but then, "remembering that a prism or triangle of crystal causes similar colors to be seen," he abstracted to the general case.[11] The eye perceived different particles as differently coloured depending on their ratio of rotational motion to linear tendency: white light is particles that are not rotating, and other colours are different speeds of rotation.

Hooke thought this was incomprehensible. A true *emission* theory, he later agreed, would quickly exhaust the material of the luminous body and fill the surrounding space.[12] But Hooke could not understand how Descartes' "propension" was supposed to replace the genuine motion required by all mechanical effects, including vision. When a mason holds his chisel against a stone and taps it with his hammer, Hooke analogised, the chisel must really move, albeit imperceptibly, if the stone is to break.[13] What is more, if light globules do not themselves move from light sources to the eye, Hooke wondered, how can they communicate their rotation? "It cannot be by means of every one[']s turning the next before him; for if so, then onely all the *Globules* that are in the odd places must be turned the same way with the first[. ... B]ut all the *Globules* interposited

9 See his *Le Monde, ou Traite de Lumiere*, in Descartes, *The Philosophical Writings of Descartes*, 1:81. See also Gaukroger, *Descartes: An Intellectual Biography*, 256.

10 See the first discourse of his *Optics* and chapter 13 of *Le Monde*.

11 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 335. Descartes may well have remembered producing colours quite by accident as well – he measured the refraction of glass using prism shaped pieces placed against wooden props (*Optics*, p. 137). For Descartes' shift to prisms as an abstraction of colour production, see also Gal and Chen-Morris, *Baroque Science*, 38.

12 "Lectures of Light," in Hooke, *Posthumous Works*, 74.

13 Ibid., 130.

between them in the even places [...] must be quite the contrary."[14] The result, says Hooke, would be "no distinct colour generated, but a confusion."[15] More troublingly, Hooke references Descartes' *Principia* and interprets him as saying that every light particle is always rotating about its centre.[16] How could the eye possibly distinguish between this inherent motion and that which is due to refraction? Surely sometimes the latter would conflict with the former, and particles would be *static* after refraction. Hooke was playing Descartes at his own mechanical game, applying the principles of simple machines to the constituents of nature. But the most powerful criticism he levelled at Descartes was the very thing Hooke presented as his motivation for investigating colour: muscovy glass. Descartes, thought Hooke, had failed to give "any plausible reason of the nature of the Colours generated in the thin *laminae*" of the material.[17]

> [I]t is most observable, that here there are all kind of Colours generated [...] where there is properly no such refraction as *Des Cartes* supposes his *Globules* to acquire a *verticity* by.[18]

Hooke's reading of Descartes was that the latter's theory required one and no more than one refraction. The rotation caused by light entering one side of a body with parallel sides would be cancelled by the refraction it suffered when leaving the other. Hooke wielded his mica as that powerful Baconian weapon, an *experimentum crucis*, clearing the ground for a new theory.

> This Experiment therefore will prove such a one as our *thrice excellent Verulam* calls *Experimentum Crucis*, serving as a Guide or Land-mark, by which to direct our course in the search after the true cause of Colours. Affording us this particular negative Information, that

14 Hooke, *Micrographia*, 61. Henry More also pointed this out. More concluded not that Descartes was wrong, but that mechanical principles are not the only part of Descartes' hypothesis – it needs the 'Hylarchic Principle'. See More, *Enchiridion Metaphysicum*, 252; Jacob, *Henry More's Manual of Metaphysics*, 2:155.

15 Hooke, *Micrographia*, 61. Stephen Gaukroger has pointed out to me that Hooke and More are wrong about this: Descartes' theory does not depend on *direction* of rotation, only speed.

16 Ibid. Hooke references Descartes: Part 3, Section 86: "the globules of the second element move in various different ways at the same time; and as a result they become completely spherical" Descartes, *The Philosophical Writings of Descartes*, 1:262.

17 Hooke, *Micrographia*, 61 Anglophone readers had recently been made aware of the limited application of Descartes' theory through Boyle's more comphrehensive, phenomenological text on colours.

18 Ibid., 54.

> for the production of Colours there is not necessary either a great refraction, as in the Prisme; nor Secondly, a determination of Light and shadow, such as in both the Prisme and Glass-ball. Now that we may see likewise what affirmative and positive Instruction it yields, it will be necessary, to examine it a little more particularly and strictly; which that we may the better do, it will be requisite to premise somewhat in general concerning the nature of Light and Refraction.[19]

Mica lies at the intersection of two related themes in Hooke's methodology: the relationship between theory and instrument, and the acceptable presentation of observation and *historia* in the early Royal Society. In *Micrographia*, the mineral was simultaneously a representative of Hooke's dedication to pay attention to the full extent of nature as the foundation of a complete natural philosophy, and (an unmentioned) part of his microscope. This latter role it shared with every other trial Hooke mentions in his discussion of the generation of colours. Recognising this will help us understand the nature of Hooke's ideas on colours: arising from his instrument use, they were fundamentally manipulative. Though the elaborate metaphysics I will outline below were clearly not suggested to Hooke directly by his lenses and slides, his limits on metaphysical possibility are the extents of his ability to manipulate light. Understanding this requires seeing through Hooke's presentation of his ideas in *Micrographia* – a book printed by the Royal Society and explicitly positioned as an example of their observational methodology. As Peter Dear and others have demonstrated, ideas about what were acceptable ways of describing experiment and the knowledge derived from them were solidifying in Hooke's time.[20] My main focus is Hooke's theory itself, but both themes will emerge through my exploration of it.

19 Ibid.

20 Dear, "Totius in Verba." See also Harwood, "Rhetoric and Graphics in Micrographia." The tendency of writers who have looked at Hooke's light and colour ideas has been to treat them explicitly as a theory, and a violation of the Royal Society's methodology. See: Sabra, *Theories of Light from Descartes to Newton*, 187.

Hooke's Ideas on Colour Production

The colour phenomena that mica produces, which I mentioned above, stem from Hooke's observations of other materials through his microscope. Split into sheets of varying thickness, mica produced coloured rings or lines. More even plates are coloured with more even patches. When Hooke spread a thin layer of liquid over a plate he found more colours, and the oils and fats he would prepare for observation by squeezing between two plates provided the final generalisation that "wheresoever you meet with a transparent body thin enough, that is terminated by reflecting bodies of different refractions from it, there will be a production of these pleasing and lovely colours."[21]

Because of these particular instances, and how reliably he could produce them, Hooke considered mica the ideal material to use to investigate colours. In fact though, as it had been for Descartes, his primary colour generation method was that of refraction. He only extended the story to cover thin plates after arriving at a theory which explained the more traditional cases as comprehensively as Descartes' did. To begin with, Hooke took a "large *Chimical Glass-body*, about two foot long, filled with very fair Water," and over the top put a screen with a small hole in it. By angling it just so toward his window, the sun's rays would refract down the tube, and if he held some paper against the bottom of the tube, "there will appear [on it] all the colours of the Rain-bow" (Figure 3.1).[22]

Why? Because of a physical change in light during refraction. Light, said Hooke, is the visible effect of the parts of a body vibrating rapidly. The vibrations cause pulses which spread outward through the surrounding aether, and are experienced as bright when they affect our eyes.[23] The idea of vibrations he arrived at by considering the sorts of things that glow: fiery bodies; sparks; rotten wood and putrifying fish; the 'Bononian stone' (Bolognian phosphorus);

21 Hooke, *Micrographia*, 53.
22 Ibid., 58.
23 For the similarities of Hooke's ideas and those of Hobbes, whom he certainly read but does not name, see Shapiro, "Kinematic Optics." Hooke later refers to Hobbes' treatise on light published by Mersenne but appears unaware who its author was (Hooke, *Micrographia*, 100.) The text says "Moreanus" but is corrected to "Mersennus" in the errata.

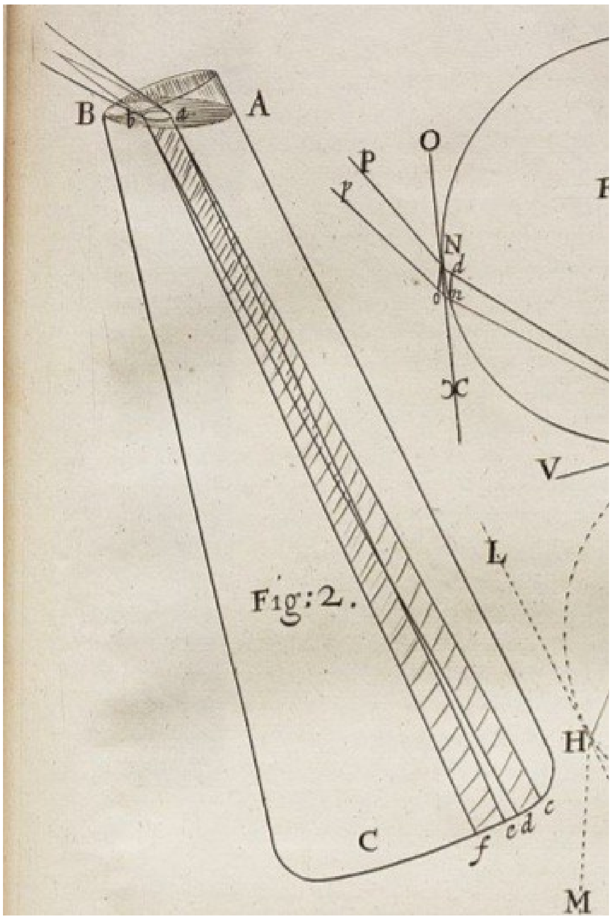

Figure 3.1: Light rays refracting in a tube of water. Sunlight enters through a small peephole in the top, refracts on entering the water, and displays a spectrum across c d e f at the bottom. *Micrographia*, scheme 6, fig, 2, opposite p. 62.

and diamonds "rub'd, struck, or heated in the dark"; sea water breaking on rocks or disturbed by oars (again presumably phosphorescence); cats' eyes; and the bellies of glow worms.[24] The glowing motion must therefore be fast, because it is able to break down the body of a rotting fish; and vibrative, because diamonds remain hard and do not shrink as they would with circular or linear motion.[25] This eclectic list Hooke draws from was actually fairly standard, at least in England, appearing in both Hobbes and Boyle, both of whom Hooke read.[26] Descartes, the godfather of this kind of mechanical explanation of light as motion, had considered the sun as

24 Hooke, *Micrographia*, 54–55.
25 Ibid., 55–56.
26 *Experiments and Considerations Touching Colours*, in Boyle, *The Works of Robert Boyle*, 1999., Hobbes *Tractatus Opticus I*, published by Mersenne in his *Cogitata Physico-Mathematica*.

his primary example of a luminous body, and considered the movement a circular one.[27] Hooke had no such ideal or privileged light source. A. I. Sabra has suggested it was exactly his prosaic examples which led Hooke to his different conclusion, though as Mary Hesse has discussed, vibrative motion often played the role of a fundamental cause for Hooke, grounding his explanations of various phenomena.[28]

So light is pulses spreading out in concentric sphere from vibrating bodies. When travelling in a homogeneous medium, the sphere of light grows uniformly.[29] That is, at all points of the sphere the direction of travel (outwards from the centre) and the pulse itself (around the centre) are at ninety degrees to one another. But when part of a pulse meets a new medium, refraction changes the direction of travel. And this, says Hooke, changes the angle between the pulse and the direction – the angle becomes *oblique*.[30]

Figure 3.2 shows light refracting by, for instance, entering water from air. AD, BE, CF represents a section of a pulse moving through the air L toward the surface, O, of the water M. The pulse is longitudinal, so each vibration of the glowing body sends the pulse from AD to BE to CF and so on. AB can be considered something like the 'length' or 'strength' of the pulse. Hooke is vague about these details and they are not so important here, but I will return to them below. The lines that bound the pulses, AC and DF, are mathematical rays – geometrical abstractions which are the direction of the pulse's trajectory. When the pulse hits O, the light changes direction. At this point, this figure actually represents two possibilities: light could be moving from air to water, or water to air. If M is a denser medium than L, the rays will refract toward the perpendicular: ABC – CHK, but if M is rarer they will move away: ABC – SRI. The same two things happen for either option which give Hooke his oblique pulses, so I will only

27 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 67. See also the end of chapter 13 of his *Le Monde.*
28 Sabra, *Theories of Light from Descartes to Newton*, 188–190; Hesse, "Hooke's Vibration Theory and the Isochrony of Springs."
29 See Hooke's later 'Lectures of Light' for his more extended treatment of this, and his geometrical explanation of the inverse square law: Hooke, *Posthumous Works*, 114, 131.
30 Sabra and Shapiro are the main commentators on the details of Hooke's theory, though both treat it as part of a developmental story in some sense, the "wave theory" from Hobbes to Hooke to Huygens, or as a precursor to Newton. Sabra, *Theories of Light from Descartes to Newton*; Shapiro, "Kinematic Optics"; Shapiro, "Newton's Definition of a Light Ray."

describe the former case where M is denser than L. First, the ray is refracted by a certain *angle*, and second the light changes *speed*. For the direction, Hooke divides the pulse FG, into four equal units, and draws a circle with a radius of three of these units around point C. This is the smaller dotted arc in the diagram. This gives him point T, the point on this circle with a tangent that intersects G. BC refracts towards T. But T is not where the pulse ends up. To calculate the speed, which gives the *position* of the pulse after refraction, Hooke *reverses* the quantities. He divides the pulse before refraction into *three* units, and it moves *four* of these after refraction: FG is three quarters of CH, giving the pulse GH, oblique to the direction of movement.

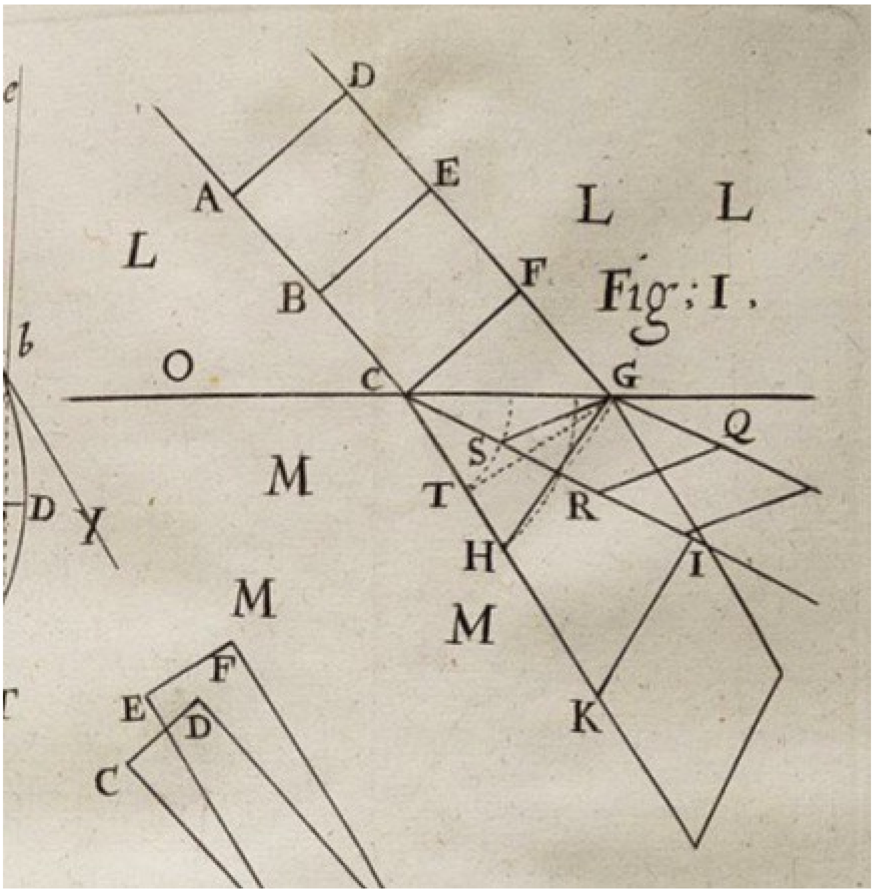

Figure 3.2: Oblique pulses of light, after refraction from medium L into medium M. *Micrographia*, scheme 6, fig. 1, opposite p. 62.

The issue is confused because both calculations appear to rely on the speed of light, in one case moving slower after refraction and in one case quicker. In fact, while the ratio 3:4 is given by the relative densities of the media, the calculations are quite separate from one another. For the direction of refraction he only gives a geometrical construction (not an *explanation*), based on the sine law and consistent with observation.[31] He was following Descartes in assuming that denser media transmit light more quickly than rarer, whereas Hobbes, Huygens, and Fermat all thought the reverse. This is a fundamental part of Hooke's mechanism of colour generation, and from there his explanation of light. Hooke rejected that light moves slower in water because it was "impossible from that supposition, that any colours should be generated from the refraction of Rays; for since by that *Hypothesis* the *undulating pulse* is always carried perpendicular [...] with the Ray."[32] An explanation of refraction was no explanation unless it showed how colours resulted, and colours simply *had* to be a geometrical change in light.[33]

Undoubtedly successful and in many ways unremarkable, the physical nature of Hooke's refraction trial is still worth taking notice of. The first thing to say about it is that it is not a prism. Prisms were common enough objects, available in London, and not too expensive. Isaac Newton was buying them from county fairs and on visits to London in the 1660s, some for a shilling a piece, some for up to sixteen.[34] They were common in natural magic texts as harmless deceivers, used to cast delightful colours around for entertainment and decoration – figures like Giambattista Della Porta, Thomas Harriot, and, a little later, Jan Marek Marci all used them expressly to create colour. Simon Schaffer has traced their increasing status in natural philosophy following Descartes – the following generation, Boyle described the glass prism as "the usefullest Instrument Men have yet imploy'd about the Contemplation of Colours."[35] Hooke had read this

31 See Shapiro, "Kinematic Optics," 197, and Sabra, *Theories of Light from Descartes to Newton*, 192–195, for lamentations about the apparent contradiction in Hooke's ideas which 'prevent' him from arriving at the concept of a wave front. Hooke designed and built a device for easily measuring refractive indices – see his *Micrographia*, sigs. E2r-F1v, and scheme 1, fig. 2.

32 Hooke, *Micrographia*, 100.

33 See also Hooke's criticism of Huygens' ideas about light: they were incomplete because they did not explain colour. It is published in Hall, "Two Unpublished Lectures of Robert Hooke," 221–222.

34 Schaffer, "Glass Works," 79.

35 Schaffer, "Glass Works." See also Shapiro's critique of Schaffer's constructivist approach to the acceptance of Newton's optical theory, and his emphasis on the importance of theoretical issues: Shapiro, "The Gradual Acceptance of Newton's Theory of Light and Colour." Boyle, *Experiments and Considerations Touching Colours*, in Boyle, *The Works of Robert Boyle*, 1999, 4:117.

accolade. He also read Henry Power, who used the instrument in his *Experimental Philosophy,* and Descartes.[36] But despite belonging to this new generation of colour theorists, he was not part of the emerging instrumental norm.

Instead he used a device that bears a strong resemblance to his water microscope. A tube full of water, with a small hole at one end and a larger one at the other. The water microscope was designed for exactly the opposite purpose as the water glass – to minimise chromatic aberration in microscopic observation. These opposite purposes are the results of the same underlying process manipulated differently. Changing the shape of the interface between air and water – by adding a small lens – caused light rays to converge into the eye instead of diffusing into a spectrum. The lack of the "usefullest Instrument" in Hooke's experimental apparatus is another good indication that his optical ideas arose during his microscope use. In Pall Mall Hooke was not surrounded by the plethora of philosophical instruments he would later be in his Gresham lodgings, he had his microscope and those things he supplemented it with lamps: glass, mica, lamps, and tools to make lenses with.

Hooke had discovered a way that light was altered through refraction. But with his ontology, only one such change is possible. That is, after refraction every pulse of light would have the same angle relative to the direction it was moving in. How could this produce the multi-coloured phenomena that Hooke observed? Light that refracts closest to the perpendicular turns blue, and that furthest away turns red. There must be some further difference in the pulses at either edge of a ray of light.

Oblique pulses have a leading edge and a trailing edge. Hooke supposes that the preceding edge of the pulse "must necessarily be somewhat more *obtunded,* or *impeded* by the resistance of the transparent *medium* than the other part or end of it which is subsequent, whose way is, as it were, prepared by the other."[37] The aether is resistant. Figure 3.3 shows another

36 Power, *Experimental Philosophy*, 73.
37 Hooke, *Micrographia*, 62–63.

refracted light ray. This time Hooke adds a detail. The vibrations of the pulse at H are 'deadened' as they travel from B to O. This deadening affects the pulses more and more the further the pulse travels after refraction, causing a triangle BOR, of weaker vibration, weakest at O and stronger at R. The other side of the pulse, A, remains strong because it has not had to forge a path through the medium. Strong enough, in fact, that it excites the aether beside it, again an effect which increases the further the pulse travels. Another triangle is created, NAM, this time outside the mathematical ray, strongest at N and weaker at M.[38] Different colours appear in different places depending whether the weak part of the pulse or the strong part of the pulse arrives first.

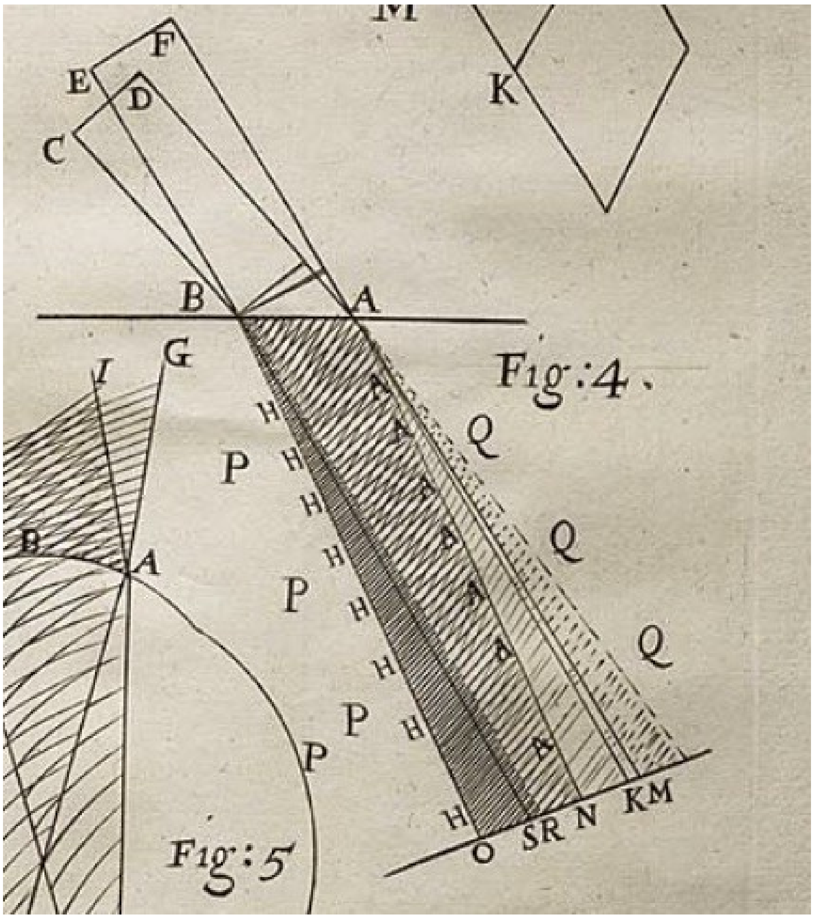

Figure 3.3: The compounding of oblique pulses to form colours. *Micrographia* scheme 6, fig. 4, opposite p. 62.

38 Figure 3.3 actually illustrates what happens when *two* light rays are incident on the refractive surface. The details are the same but this mixing effect is enhanced.

Hooke concludes:

From the consideration of the proprieites of which impressions, we may collect these short definitions of Colours: That *Blue is an impression on the Retina of an oblique and confus'd pulse of light, whose weakest part precedes, and whose strongest follows*. And that *Red is an impression on the Retina of an oblique and confus'd pulse of light, whose strongest part precedes, and whose weakest follows*.[39]

Hooke does not emphasise this but colour, properly speaking, is not an oblique pulse at all but an impression – a 'secondary quality', though Hooke does not use the term – resulting from the mechanical interaction of the world and the senses. Light pulses are focused onto the retina, and the resulting impressions are coloured (Figure 3.4).

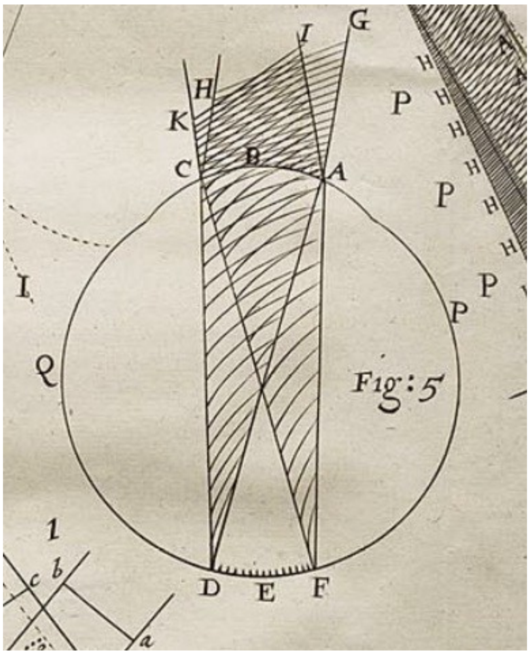

Figure 3.4: Coloured light focused to a point by the cornea CBA. *Micrographia* scheme 6, fig. 5, opposite p. 62.

For Hooke, the range of colours in the spectrum is created by three different mechanisms. First there are the primary colours of blue and red, which are the only direct results

39 Hooke, *Micrographia*, 64.

of refraction altering white light. Second, these colours can be strong or diluted to light blue and yellow respectively. They are strongest when they are adjacent to a dark medium, and diluted when they are in the middle of a projected patch of light. Finally, where different colours overlap – where different pulses arrive at the same point – they mix. He writes about this last in a striking way.

> [After refraction] there will be generated the two principle colours, *Scarlet* and *Blue*, and all the *intermediate* ones which arise from the composition and dilutings of these two, that is [...] *Scarlet* [...] is diluted into a *Yellow*; [… and] deep *Blue* [...] is gradually [...] diluted into a pale *Watchet-blue*. [… T]he two *diluted* colours, *Blue* and *Yellow* are mixt and compounded into a *Green*; and this I imagine to be the reason why *Green* is so acceptable colour to the eye, and that either of the two extremes are, if intense, rather a little offensive, namely, the being plac'd in the middle between the two extremes, and compounded out of both those, *diluted* also, or somewhat qualifi'd, for the *composition*, arising from the mixture of the two extremes *undiluted,* makes a *Purple*, which though it be a lovely colour, and pretty acceptable to the eye, yet it is nothing comparable to the ravishing pleasure with which a curious and well-tempered *Green* affects the eye.[40]

Diluted yellow and pale blue mix to give green, and undiluted red and blue give purple. Both purple and green Hooke apparently prefers to the primaries, which seem a little 'offensive'. But green is singled out as especially pretty, which is not only a mixture, but a mixture of already diluted colours. Hooke uses his personal phenomenology in an evidentiary manner. It is plain to see that green is the nicest colour to look at, and this makes perfect sense if it is a tempered mixture of the extremes.[41]

40 Ibid., 58.

41 The general idea that colours are nicer to look at because of some sort of underlying harmony goes back as far as Theophrastus' *De Coloribus*. Hooke's reasoning is reminiscent of Mersenne's in his *Harmonie Universelle*, in which he wondered which musical instrument was the finest, based on the qualities of their sound.

Another thing worth noting about the refraction in Figure 3.3 but not explicitly mentioned by Hooke is the dispersion of light following refraction. The ray of light grows wider, illuminating a larger area than does the ray before refraction. This is the feature of the spectrum that Newton would later claim stimulated his investigations in the area.[42] Dispersion was a necessary effect of refracted pulses for Hooke, as he says in his critique of Newton's first optical writing: "that the Ray of Light is as twere split or Rarifyd by Refraction, is most certaine."[43] He could see nothing much new in Newton's observations, and claimed that the obliquation that a pulse undergoes in refraction explains the phenomenon of dispersion. In fact, in his later 'Lectures of Light' Hooke reversed the explanation to make obliquation the result of dispersion: on refraction a ray is "dispersed, split, and opened by its Refraction […] and from a Line is opened into a diverging Superficies, and so Obliquated."[44]

Hooke is clear to point out that oblique pulses are created both by single refractions and the double refraction of the water ball, ensuring that both of Descartes trials were within the scope of his explanation.[45] The water ball was another element of his microscope set up, the scotoscope, as discussed in the previous chapter. Hooke could scarcely have been unaware of its tendency to tinge his careful observations with spectral colours. After reaching a coherent explanation of these canonical colour generation instances, Hooke extends the story to thin plates like mica and to solid bodies.

[These] properties, as they have been already manifested, in the Prisme and falling drops of

42 Newton, "A Letter of Mr. Isaac Newton ... Containing His New Theory About Light and Colours." Hooke's failure to explicitly address the topic leads to a difference in opinion of two main commentators on his theory. Sabra correctly sees dispersion as implicitly taken account of by and essential for Hooke's colours: Sabra, *Theories of Light from Descartes to Newton*, 257. Shapiro takes it to be an ad hoc adjustment to fit observation which "played no further role" in colour generation: Shapiro, "Newton's Definition of a Light Ray," 198. Shapiro's misreading is summed up by a diagram on p. 198 of this paper. He depicts blue and red as the results of oblique and *acute* pulses respectively. Given the change in angle is produced by a single refraction, in a single direction, it is difficult to see how this could be the case, and indeed Hooke denies the possibility explicitly in *Micrographia*, 67.

43 Hooke to Oldenburg, 15 February 1671/2. In Turnbull, *The Correspondence of Isaac Newton*, 1:111.

44 "Lectures of Light," in Hooke, *Posthumous Works*, 82. It is possible he had by this time altered his view in response to Newton's ideas (see below).

45 Hooke, *Micrographia*, 59–61. In fact, Hooke claims the water ball contradicts Descartes' own ideas. I will return to this below.

> Rain, to be the causes of the colours there generated, may be easily found to be the efficients also of the colours appearing in thin *laminated* transparent bodies, for the explication of which, all this has been premised.[46]

Hooke's casual "may be easily found" disguises a complex situation.

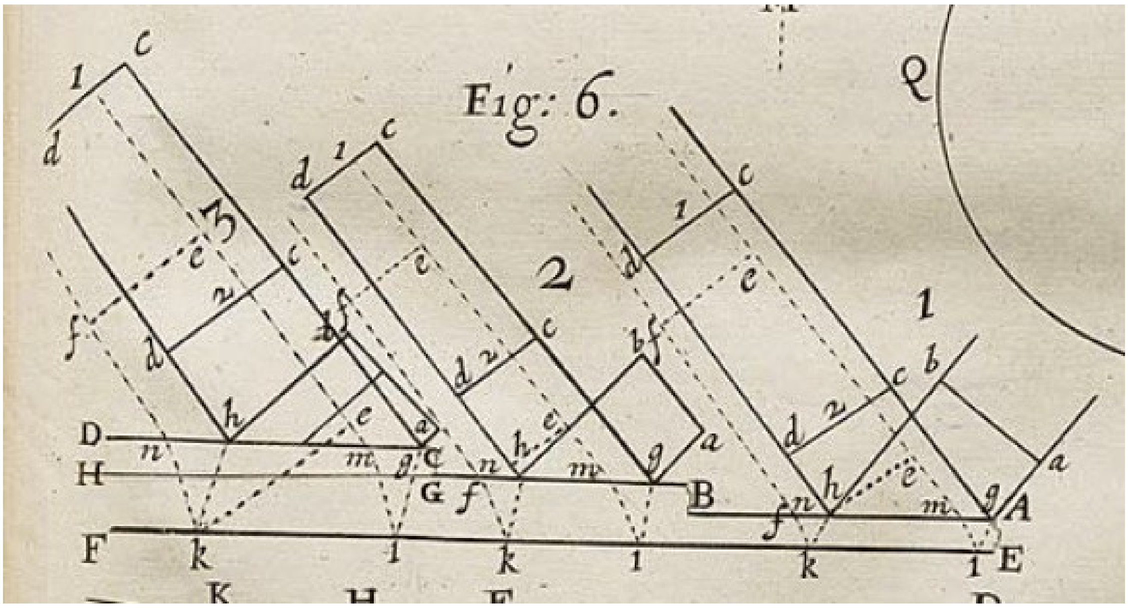

Figure 3.5: Light rays reflecting off a transparent plate of varying thickness, *Micrographia* scheme 6, fig. 6, opposite. p. 62.

A pulse of light, ab on the far right of Figure 3.5, approaches a plate of mica, which is thinner at the end AE and thicker at DF.[47] Most of the light reflects off the top of the plate, but some passes through and reflects off the bottom of the plate instead. This light follows the rest of the ray out the top, but has been refracted twice, on entering and leaving the mica. Thus, two pulses depart the mica where only one approached: a "confus'd or *duplicated* pulse, whose strongest part precedes, and whose weakest follows."[48] This, recall, is perceived as red. Different

46 Ibid., 64.

47 Hooke notes that this figure is "wholly Hypothetical." He was unable to measure the thicknesses required for certain colours. Newton is now eponymous with the phenomenon ('Newton's Rings') following his later success at doing so. This became a point of contention between him and Hooke in 1675 when priority claims briefly became important between the two men: see Newton to Oldenburg, 21 December 1675. In Turnbull, *The Correspondence of Isaac Newton*, 1:406.

48 Hooke, *Micrographia*, 66.

plate thicknesses produce different gaps between the stronger and weaker pulses. When the weaker pulse lags so far behind the stronger that it preceeds the next one, the it is perceived as blue. In between we get green, and the other mixed colours. The story is similar for solid bodies. Hooke supposes everything must be covered in a "tinging substance," distributed over the surface of bodies. Some of the light incident on a body is reflected immediately, and some passes through the tinging substance and is then reflected. Again a single incoming pulse splits into a confused double pulse, one stronger and one weaker.[49]

The description of red and blue perceptions is the same in all colour generation, but there are confounding dissimilarities between these latter ones and that of refraction. Refraction causes an "oblique and (therefore) confus'd" pulse, thin plates and solid bodies cause a "confus'd (because) duplicated" one. Refraction clearly results in only two primary colours, whereas thin plates appear to produce all colours directly by the geometry of light pulses – colour depends on the distance between the strong and the weak pulse, not on dilution or mixing. In fact, Hooke held firmly to his two-colour idea, and it became the major point of disagreement between Newton and himself in 1672, following the former's 'Theory About Light and Colours.' The issue turns on what Hooke meant by 'diluted' and 'mixed'. Because colours are after all *perceptual* qualities, mixed colours are mixed *perceptually*, not metaphysically. When Hooke says of colours in thin films that "when the weaker pulse is just in the middle between two strong ones, then is a deep and lovely *Purple* generated," this just *is* mixing. Purple is a mixture of the *impressions* one gets when looking at a preceding strong pulse (red) and a preceding weak one (blue), but it does not mean the blue- and red-generating pulses mix *ontically*.[50] In Observation 10 of *Micrographia* he presented an experimental argument for the primacy of red and blue, using two liquid-filled glass wedges, one of a red tincture which diluted to yellow at the tip, and the other a blue which diluted to light blue. Holding the wedges in front of two pinholes in a dark room, he could

49 Ibid., 68–69.

50 As opposed to Descartes' and Newton's corpuscular accounts. See Hooke's discussion of dilution: *Micrographia*, 70ff.

present various thicknesses of the wedge to the light, and so vary the hue of the colour, making "the Paper [opposite] appear of what colour I would[. ...] Whence I experimentally found what I had before imagin'd, that all the varieties of colours imaginable are produc'd from several degrees of these two colours."[51] It did not necessarily have to be the same mechanical action which caused all instances of purple. So long as every perceivable colour could result from blue and red only, these were the primary colours.[52]

Crafting a Novel Experience

Hooke concluded: "By this *Hypothesis* there is no one experiment of colour that I have yet met with, but may be, I conceive, very rationally solv'd."[53] The mechanisms which produce colour are very different in different situations, but they are unified by the idea of a 'confused pulse' – a vibration in the aether.

All of this was grounded in mica. Mica was not only expedient but emblematic: that it was not peacock feathers demonstrated Hooke's modernity, and that it was not the prism demonstrated that he was moving *beyond* other moderns. This was largely rhetoric, and Hooke overstated its importance as a guide to theory. In fact, the relationship between observations and metaphysics in Descartes was too vague for the colours in thin plates to be an *experimentum crucis*. Descartes had started by saying that "there must be at least one refraction, and even one such that its effect was not destroyed by another," but this was only his conclusion from trials with prisms.[54] His more pressing lesson was the collapse of the distinction between real and apparent colours, that all colour is mechanically produced in the eye by rotating light particles. The colours of solid bodies forced Descartes to admit that refraction itself was "not always necessary." Instead, the "size, shape, situation, and movement of the particles of bodies we call coloured can

51 Hooke, *Micrographia*, 73–74.
52 It may have been an old – ancient – idea, but adapted to mechanical philosophy and the collapse of real and apparent colours, Hooke's primary colours bear more resemblace to Helmholtz's than Aristotle's.
53 Hooke, *Micrographia*, 69.
54 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 335.

variously compete with light, in order to increase or diminish the rotation of [light particles]."[55] Hooke no doubt read enough Descartes to have reached this statement. But when he presented his ideas, he elected to privilege a colour phenomenon which Descartes had said *could* be explained, but had not in fact explained.

Whether it proved what he claimed it did, Hooke's presentation of mica as an *experimentum crucis* is illustrative of the importance of poetics in his new science.[56] The words themselves are important. '*Experimentum crucis*', that much-vaunted phrase so associated with Isaac Newton, came to Hooke, via Boyle, from Francis Bacon's '*instantia crucis*'. What this meant was that when a given effect may seem to be equally well follow from various causes, certain observations will show that only one cause is "constant and indissoluble" in producing the effect, while the others are "variable and separable." Bacon called such decisive observations 'instances of the fingerpost,' pointing the way to accurate knowledge.[57] The shift from *instantia* to *experimentum* was not innocuous. Hooke also levelled an *instantia crucis* against Descartes, and it was a subtly but importantly different kind of thing.

Hooke's *instantia* was the water ball – an old and reputable optical instrument used by Ibn al-Haytham, Roger Bacon, Theodoric of Freiburg, and Descartes. As we have seen, it was a common item outside philosophical treatises too: Hooke and Pepys both used them as scotoscopes to amplify the sun's rays. Descartes knew that if white light enters a water ball at certain angles, after two refractions and a reflection coloured light will emerge.[58] Yet Hooke thought the phenomenon showed Descartes' theory was wrong. He argued that because the two refractions were of equal angles, "according to the [...] *Cartesian* principles there should be no colour at all in a Ball of Water or Glass."[59] The rotation gained from the first refraction would be

55 Ibid., 339.
56 See Aït-Touati, "'The Spirit of Invention.'"
57 *Novum Organum*, book 2 aphorism 36. In Bacon, *The Oxford Francis Bacon*, 11:320. Boyle coined the phrase '*experimentum crucis*' in his 1662 *Defense Against Linus*.
58 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 332–335.
59 Hooke, *Micrographia*, 60. Hooke quotes a section of Descartes at length on p. 59, from p. 335 of Olscamp's translation of Descartes' *Optics*.

cancelled by the second. Hooke labelled it an "*Instantia crucis*, as no one that I know has hitherto taken notice of."[60] Least of all Descartes!

Hooke was wrong about this too, as Henry More later pointed out, because the two refractions happen in the same direction.[61] Descartes himself had said that "refractions that occur on the same side cause [particles] to turn in the same direction."[62] If anything the rotation would be augmented. In any case it is difficult to see how Hooke's explanation would succeed while Descartes' failed in such a straightforward refraction case.[63]

There was nothing novel about Hooke's water ball. It produced a routine phenomenon which was agreed on by Descartes and Hooke. Hooke's objection was purely metaphysical – an assumption about how hypothetical globules of light might behave. With mica, on the other hand, Hooke could point to an experience Descartes had not had. Frédérique Aït-Touati has suggested that the linguistic shift to '*experimentum*' perhaps signifies the increasingly dominant role of instruments and experiments in crafting and creating natural philosophical knowledge.[64] Hooke was not observing ordinary happenings, he was intervening. Hooke split muscovy glass into thin plates himself, smeared them with liquids, and examined them through magnifying lenses to make colours appear. He contrived the phenomenon, and he was not discussing something familiar. His use of the term *experimentum crucis* emphasised his activity in crafting a new paradigmatic colour phenomenon that needed explaining.

But had Hooke crafted the phenomenon? He certainly crafted his presentation of it. To read *Micrographia*, he stumbled across an observation which falsified the dominant existing theory and thus necessitated a new explanation. He introduced his investigation into colours as if his interest had just been piqued. "It will certainly be very well worth our inquiry, to examine the

60 Ibid., 59.

61 For More's discussion, see More, *Enchiridion Metaphysicum*, 246–259; Jacob, *Henry More's Manual of Metaphysics*, 2:151–155. Hooke was not convinced, he retorted that if *this* were the case mirrors would colour their reflections too: Hooke, *Lampas*, 36–41.

62 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 336.

63 Unless, presumably, reflection changed the direction of spin of the globules.

64 Aït-Touati, "'The Spirit of Invention,'" 118.

causes and reasons of [coloured rings in mica], and to consider, whether from these causes demonstratively evidenced, may not be deduced the true causes of the production of all kind of Colours."[65] Nowhere did he mention that while he was diligently examining gnats and nettles his microscope slides, his light amplifier, and even certain of his microscopes themselves were tinging the English sunlight with spectral colours. Such an admission would surely have been out of place in a book advertising the usefulness of the instrument to natural philosophy.

In fact, Hooke generally accepted that crucial instances or experiments were not the sort of thing one stumbled across.

> Such Experiments therefore, wherein Nature is as 'twere put to Shifts and forc'd to confess, either directly or indirectly the Truth of what we inquire, are the best if they could be met with: But these being hard to find at the beginning, it will be best to be first a little acquainted with the Method of Nature, in her most evident Manifestations of her self.[66]

Through practice and manipulation, and through instruments, Hooke certainly had been acquainted with evident manifestations of colour. This introduces a general philosophical point which will recur throughout the rest of this thesis: through naïve work, the natural philosopher must craft surprises to gain insight. This is what Hooke did with his muscovy glass. He began noticing rainbows of colour in his microscope slides. It was no doubt an annoyance which obscured and tinted his observations of other things. But then he began to notice patterns. Those plates he had split to a particular thickness would show one colour, and those of variable thickness would show rings ordered like a secondary rainbow. It was only in combination with more work with light and studying Descartes' ideas that muscovy glass became anything like crucial. And only in Hooke's presentation that it became an *experimentum*. As Hooke himself wrote, natural philosophy is to begin with the "Hands and Eyes, and to proceed on through the

65 Hooke, *Micrographia*, 49.
66 "General Scheme," in Hooke, *Posthumous Works*, 34. See Paul Feyerabend for a classic articulation of the idea that facts only become refutations when made sense of in alternative theories: Feyerabend, *Against Method*.

Memory, to be continued by the Reason; nor is it to stop there, but to come about to the Hands and Eyes again."[67] Hooke's first acquaintance with white light tinged with colours came from his muscovy glass microscope slides, but reasoning more theoretically about the phenomenon allowed him to place the material more centrally in his presentation of his colour theory. From this position it became again an important material to observe. Hooke's ideas were the novel results of novel practices, crafted both as he observed specimens through his microscope, and again as he marshalled his insights about colour into an Observation in his book.

The Irony of Acceptance: Newton's Influence on Hooke

Hooke's *experimentum crucis* did not have a glorious career. The novelty of mica was meant to move light and colours away from Descartes' ideas. When Henry More objected, it illustrated the danger of relying on new materials. More discussed Hooke's criticisms of Descartes, particularly those to do with refraction, as with the water ball mentioned above. When it came to mica, he concluded it was not worth worrying very much about such non-paradigmatic cases because the material was "greatly uncertain and irregular," and its unknown internal texture might move light particles in any number of erratic ways.[68] Mica was not immediately a trustworthy material. By the time Hooke responded to More's "Subterfuge" in *Lampas* (1677), the objection was in any case out of date, at least within the Royal Society. But it was not clear that the coloured rings showed all that Hooke said they did.[69]

Isaac Newton had also been investigating the colours in thin plates since the early 1670s, and at the end of 1675 his letters about light and colour prompted much excitement and discussion in Society meetings.[70] Newton professed, at least, to be completely uninterested in the

67 Hooke, *Micrographia*, sig. B2r.
68 More, *Enchiridion Metaphysicum*, 250. "Sed de hac prima Objectione non est quod simus adeo foliciti, cum sit in materia magis incerta ac inaequali, cujus interna contextura videatur globulorum motus variis modis posse mutare." See also Jacob, *Henry More's Manual of Metaphysics*, 2:153.
69 Hooke, *Lampas*, 37.
70 Westfall, *Never at Rest*, 269, footnote 95. See Birch, *The History of the Royal Society*, 1757, 3:272–278, 280-295, 296-305.

kind of mechanical, 'simple machine' criticisms that Hooke had against Descartes. He wanted a different *kind* of explanation of observable phenomena: not an hypothetical ontology which was consistent with observations, but a more general "doctrine" about the necessary relationships between different colour *phenomena*.[71] In 1672 he and Hooke had disagreed about this. While trying to remain agnostic about the ontic nature of light, Newton argued for the primacy of spectral colours, and that they combined to produce white light. Hooke could not find reason enough to accept this from the experimental evidence, and maintained white light's primacy and that colours resulted from its modification.[72] Importantly, Newton denied Hooke's conclusion that there were only two primary colours even though he accepted the importance of muscovy glass. His claim that his observations about the behaviour of colour were inconsistent with Hooke's metaphysical hypothesis were much more damaging to the Curator than More's mere scepticism. In 1675 the two "prickly" men notoriously clashed again, but their argument and Newton's ideas generally are largely beside my point here.[73] Here, as an epilogue to Hooke's light and colour theory, I want to entertain the prospect that Hooke changed his ideas because of Newton's observations, and that 1675 was a possible episode of collaboration, rather than dispute, between the two men.[74] I intend this not so much as a contribution (or antidote) to the idea of lifelong antagonism between the two, but as a further exploration of Hooke's methods of mechanical philosophy.

71 See his 'Hypothesis of Light' read at the Royal Society, Birch, *The History of the Royal Society*, 1757, 3:247–260. Especially 249. Newton's views on matter theory have been written about at length: see Gaukroger, *Emergence of a Scientific Culture*, 379–399; Walsh, "Did Newton Feign the Corpuscular Hypothesis?"

72 See Newton, "A Letter of Mr. Isaac Newton ... Containing His New Theory About Light and Colours"; Hooke's considerations in Birch, *The History of the Royal Society*, 1757, 3:10–15. Newton replied with "Mr Isaac Newtons Answer to Some Considerations upon His Doctrine of Light and Colors."

73 'Prickly' is Westfall's term for Hooke, Westfall, *Never at Rest*, 272. They disagreed about the importance of their respective contributions to the investgation of colour. For Oldenburg's possible role in the fracas, see also Shapiro, "Twenty-Nine Years in the Making," 425–426; Inwood, *The Man Who Knew Too Much*, 225–231; Hall, *Henry Oldenburg: Shaping the Royal Society*, 174–175. Though any antagonism was quickly mollified by private correspondence (see Turnbull, *The Correspondence of Isaac Newton*, 1:412–413, 416-417), the dispute has been suggested as the cause of Newton's delaying publication of his *Opticks* until the year following Hooke's death in 1703. This is the view of A. Rupert Hall (Hall, *All Was Light*, 92,) Sabra (mentioned in private communication with Shapiro – see the latter's "Newton's Experiments on Diffraction and the Delayed Publication of the Opticks,") and Westfall (Westfall, *Never at Rest*, 638). See also Shapiro, "Twenty-Nine Years in the Making," for the contrary view that there was simply no *Opticks* to publish until then (435).

74 Prompted by a brief note from 1967: Hall and Westfall, "Did Hooke Concede to Newton?"

Newton first visited the Royal Society on 18 February 1675, when he met, among others, Hooke.[75] They were apparently on friendly terms. That evening Hooke took the visitor to the Crown Tavern where they talked about Newton's "way of polishing metall on pitch." They met a few more times outside Royal Society meetings, mostly at other Fellows' houses, and maybe going bookshopping together.[76] Newton also mentions "discoursing" with Hooke about reflection and possible optical experiments with the air pump.[77] Newton left London before the winter recess and famously wrote to Oldenburg his thoughts about colour which Oldenburg, infamously, read at the Royal Society.[78] In the first that was read, Newton's 'Hypothesis Explaining the Properties of Light', Newton referred to his earlier disagreement with Hooke before noting:

> I was glad to understand, as I apprehend, from Mr. Hooke's discourse at my last being at one of your assemblies, that he had changed his former notion of all colours being compounded of only two original ones [...] and accommodated his hypothesis to this my suggestion of colours, like sounds, being various, according to the various bigness of the pulses.[79]

Hooke records that Newton left town on 17 March, which would make the last meeting he attended that of the 11th.[80] On this day, the person scheduled to give a discourse did not arrive, and an old observation of Boyle's about "shining flesh" was read instead. This prompted Hooke to hold forth about light. He recorded in his diary: "I propounded my hypothesis of Light and Colours by the Lenth [*sic.*] of the pulse."[81] This comment, brief though it is, seems to directly

75 Birch, *The History of the Royal Society*, 1757, 3:181. The same meeting in which Oldenburg related, to a surprised Hooke, Huygens' discovery of a spring-regulated watch.

76 Hooke, *The Diary of Robert Hooke, 1672-1680*, 1935, 1:148. Hooke's diary references to 'Mr. Newton' are presumably those times when they met outside meetings: Feb 21, 25, and March 16. On this last, Hooke notes "At Dean Tilotsons. Sir W. Jones. Newton. Duck Lane" – a street known for its booksellers before sliding into the slum of Dickens' 'Devil's Acre'.

77 Birch, *The History of the Royal Society*, 1757, 3:247.

78 See the above references on the 'Hooke-Newton controversy', footnote 73.

79 Birch, *The History of the Royal Society*, 1757, 3:248.

80 Hooke, *The Diary of Robert Hooke, 1672-1680*, 1935, 1:153.

81 Ibid., 1:152.

corroborate Newton's 'apprehension'. The suggestion that he refers to in his letter was from his reply to Hooke's objections of 1672, and was that his observations could be accounted for by Hooke's vibration hypothesis, if only the Curator would accept that:

> Vibrations in the *æther* [were] of various depths or bignesses, which being promiscuously propagated through that *Medium* to our Eyes, effect in us a Sensation of Light of a *White* colour; but if by any means those of unequal bignesses be separated from one another, the largest beget a Sensation of a *Red* colour, the least or shortest, of a deep *Violet*, and the intermediat ones, of intermediat colors; much after the manner that bodies, according to their several sizes, shapes, and motions, excite vibrations in the Air of various bignesses, which, according to those bignesses, make several Tones in Sound.[82]

Hooke even repeated the same analogy. The minutes of the meeting of the 11th record Hooke saying that:

> light is a vibrating or tremulous motion in the medium [...] produced from a like motion in the luminous body, after the same manner as sound was then generally explained by a tremulous motion of the medium conveying sound [...] and that, as there are produced in sounds several harmonies by proportionate vibrations, so there are produced in light several curious and pleasant colours, by the proportionate and harmonious motions of vibrations intermingled.[83]

That "proportionate" vibrations themselves would "intermingle" certainly seems like a departure from his earlier view that it is possible to create the *phenomenal* experience of all colours from one oblique pulse. But we are left with records of lectures, rather than the lectures themselves, of Hooke's "Lenth of the pulse." Whether he revised his mechanistic account is speculative, though there are some further developments worth briefly recounting.

82 Newton, "Mr Isaac Newtons Answer to Some Considerations upon His Doctrine of Light and Colors," 5088.
83 Birch, *The History of the Royal Society*, 1757, 3:194.

Intriguingly, at the following meeting – on 18 March – Hooke delivered another lecture to the Royal Society about "several new properties of light," much of which Newton had apparently heard despite having returned to Cambridge the previous day.[84] "Mr. Hooke, you may remember," he later wrote to Oldenburg, "was speaking of an odd straying of light, caused in its passage near the edge of a razor, knife, or other opaque body in a dark room."[85] Indeed Hooke had, in his lecture on the 18th, described an odd shaft of light cast into the shadow of a razor held across the pinhole of a camera obscura.[86] Likely Hooke's discourses of the 11th and 18th overlapped: Newton also says that "some days before" (on the 11th?) he had heard Hooke compare the same phenomenon to sound straying around corners.[87] Or perhaps the apparent conflict in dates is explained by their extra-Societal talks, or an ambiguity in Hooke's chronicling.[88] What is interesting about Hooke's later talk, whether or not Newton was there to applaud him for saying it, is that he shied away from discussing the "Nature and Essence of Light." Having "many Doubts in my own Thoughts concerning the same," he said, "I have made it my aim [...] to examine and inquire farther into the Nature thereof, by such Observations and Experiments as I judged might be any ways helpful. [...] I have not been altogether unsuccessful, having discovered several Proprieties therein, whereof before I had no Notion or Information."[89] Had Hooke realised his muscovy glass was not the decisive experimentum it had been a decade previously? The loss of his emblematic material threatened his hypothesis, and now it was the eyes' and hands' turn to do some work, to find some further observations with which to refine his theory.

84 Ibid. The lecture is apparently that published by Waller: Hooke, *Posthumous Works*, 186–190.
85 Birch, *The History of the Royal Society*, 1757, 3:268.
86 Hooke, *Posthumous Works*, 187.
87 Birch, *The History of the Royal Society*, 1757, 3:268. See also pp. 193-194 for the record of Hooke's discourse. Newton mentions that William Petty asked a question of Hooke, but neither Birch nor the Hooke Folio (which for these meetings generally does not add anything much beyond Birch) mention Petty on either day. Newton also says that Hooke was due to perform his (Newton's) *experimentum crucis* for the Society but the day was cloudy, and Newton left town before another meeting. On 11 March Hooke was ordered to prepare the experiment for the next meeting (Ibid., 3:194). Newton arrived back in Cambridge on the 19th (Turnbull, *The Correspondence of Isaac Newton*, 1:417, footnote 3).
88 Hooke's entry for 17 March simply says: "Newton out of towne." Maybe he took a day trip? Hooke, *The Diary of Robert Hooke, 1672-1680*, 1935, 1:153.
89 Hooke, *Posthumous Works*, 186.

References to the topic of colours in Hooke's later writing are either vague, non-committal, or both. After Oldenburg read Newton's 'Hypothesis' at the Society in December, Hooke felt he had heard little he had not discussed in *Micrographia*.[90] Then, on New Year's Day 1676, Hooke, Wild, Hill and Wren had the first meeting of their 'New Philosophicall Clubb', and talked *sub sigillo* about light.[91] Here Hooke confided that Newton had adopted *his* "hypothesis of [...] a double puls moving together[,] the one a stronger or quicker and the other a weaker or slower puls."[92] It is difficult to know what to make of these two comments. The first possibly refers only to Newton's attention to the colours in thin plates, and Hooke was again reiterating the novelty of his *experimentum* in *Micrographia*. The second seems like a misunderstanding of Newton's hypothetical explanation of this phenomenon.[93] Possibly Hooke is picking up on Newton's idea that when light impacts the retina it sends vibrations of varying strength up the optic nerve, causing perceptions of various colours, and equating it to his hypothesis.

Two years later, in *Lampas,*[94] Hooke reiterated that colour is caused by an oblique angle between a pulse and the direction of its travel. The form of the explanation is certainly familiar, but there is nothing like the intricate mechanism in *Micrographia*. He mentions neither the 'bignesses' nor 'length' of pulses, nor – importantly – the idea that there are two primary colours, from which all the others are compounded.[95] Hooke's 'Lectures of Light,' delivered in the early 1680s, are largely a geometric analysis of light and how it affects the eye. Here Hooke also mentions colour only as the result of oblique pulses, and gives no further details.[96] Despite this,

90 Birch, *The History of the Royal Society*, 1757, 3:269. Which comment Oldenburg reported to Newton, prompting an aggrieved reply (Turnbull, *The Correspondence of Isaac Newton*, 1:405.)

91 Robinson and Adams note this was the first attempt to form such a club in the Royal Society (Hooke, The Diary of Robert Hooke, 1672-1680, 1:205, footnote). Hooke was an active political campaigner in the Society, scheming to bump Viscount Brouncker from the presidency and of course Oldenburg from the Secretaryship. See Hunter, *Establishing the New Science*, chap. 6. For an interesting discussion of what they discussed in a more private context, see Poole, "The Genesis Narrative in the Circle of Robert Hooke and Francis Lodwick."

92 Hooke, *The Diary of Robert Hooke, 1672-1680*, 1935, 1:206.

93 Newton explained reflection and refraction by recourse to vibrations in the aether, but explicitly stated that light itself was *not* these vibrations: Birch, *The History of the Royal Society*, 1757, 3:262–269.

94 Lampas bears the date 1677, but throughout this 1675 episode I have been discussing Hooke was bringing designs for lamps along to meetings which appeared in the text. When he wrote the digression addressing More I do not know.

95 Hooke, *Lampas*, 39–40.

96 'Lectures of Light,' in Hooke, *Posthumous Works*, 82.

colour remained an important topic for Hooke. In his comments on Huygens' *Traité de la Lumierè* in 1690, he implied that an explanation of light which did not explain colour was no explanation at all:

> This *Phenomenon* therefore (I say) of the Coloration of the Rayes by Refraction becomes a watch word, Lapis Lydius or touch-stone by which the various hypotheses of Authours ought to be tried. for if they doe not answer to this they must necessarily be fals and Sophisticate.[97]

In summary, Newton's visit to London in the spring of 1675 profoundly influenced Hooke's approach to explaining colour. He did not reject his vibrating matter ontology – as Newton said, this itself was not inconsistent with observations – but neither did he cling to the details of colour production. He reiterated the importance of his emblematic material, mica, and his precedence in investigating it. The problem, if anything, was Newton's gracious acceptance of this. The Lucasian Professor wrote to the Curator of Experiments saying Hooke had "added much" to the investigation of light, "especially in taking y^{e} colours of thin plates into philosophical consideration."[98] Hooke's ideas, though, had arisen ultimately from his instrument use, they were not systematic trials. Further into this famous letter of Newton's it is hard not to see cynicism in his certainty that Hooke had "divers very considerable experiments besides those you have published." This was an era in which the very word 'experiment' was contested, let alone the powerful but nascent idea of an *experimentum crucis*. Hooke and Newton both fashioned crucial experiments from their messy experience of hundreds of observations.[99] What an experiment meant could shift across contexts and people. Did the colours in mica still mean the same thing to someone who did not have Hooke's familiarity with it? Or who had only read about it in his *Micrographia*? The emerging rhetorical style of the experimental philosophy required a particular narrative presentation of experience. In private communication, both Hooke

97 Hall, "Two Unpublished Lectures of Robert Hooke," 222.
98 Newton to Hooke, 5 February 1675/6. In Turnbull, *The Correspondence of Isaac Newton*, 1:416.
99 See again Schaffer, "Glass Works."

and Newton appeared to acknowledge the potential for this to obscure the nature of the explanation that was at stake.

Hypotheses and Practical Knowledge

The point I wish to make is not simply that Hooke had stumbled into a debate he had not, in fact, made the experiments to equip him for. Hooke's ideas about light and colours had arisen ultimately from his instrument use. Of course, looking through a microscope did not itself impart his elaborate metaphysics, any more than looking at a prism told Descartes anything about rotating particles. While the troubled relationship the early Royal Society had with such metaphysical hypotheses is well known, this story seems the reverse of the official party line. The Society wanted philosophical knowledge, but thought philosophical hypotheses ought to be left out of initial investigations, until they could be made certain. Hooke, on the other hand, arrived at the metaphysical nature of light as part of his investigation of it. In practice, hypothesis was necessary. As Newton wrote:

> I have observed the heads of some great virtuosos to run much upon hypotheses, as if my discourses wanted an hypothesis to explain them by, and found, that some, when I could not make them take my meaning, when I spake of the nature of light and colours abstractedly.[100]

Hooke was one of the main culprits Newton was obliquely referring to. It was an astute diagnosis. Hooke never questioned Newton's experimental results, but for him observation and hypothesis never neatly separated. So when Newton calmly accepted the importance of mica but disputed Hooke's metaphysics of light, it challenged the reliability of Hooke's knowledge. Mica was the point of difference with Descartes, that he had laid down as a reason and motivation for a new metaphysical account. After Newton severed this connection, an uneasy vagueness

100 Birch, *The History of the Royal Society*, 1757, 3:249.

characterises Hooke's subsequent discussions of colour.

Hooke used his microscope successfully, and successful use meant knowledge of light just as it meant knowledge of lenses. The material, dynamic process of microscopical observation detailed in the previous chapter was no more reliant on the objects involved than the more speculative ideas discussed in this. Observation, while not naïve, did not require knowing what will happen next. But *manipulation* relied on prediction, and knowing what the effect of changing an instrumental set up would be implied at least a guess as to why the things that are happening are happening. To get clear views of everything from crab-like insects to sparks to specks of hoar frost, Hooke had to manipulate light with increasing skill. When light entered his window he could not only focus it onto a specimen, he could foresee its behaviour in his apparatus. It bounced around his water ball and curved through his lenses, it diffused over specimens, and concentrated down a tube and into his eye. It changed colours and changed back again. When it rained it dimmed, and when the sun came out it returned not only brighter but harsher. Concentrating it to a point might "singe or burn the Paper" he positioned to soften the shadows, while refraction and inflection would cause the white light to break into "all the colours of the Rain-bow."[101] This manipulative expertise is exactly what the theoretical treatment of colour in *Micrographia* lacks.

This and the previous chapter together form a kind of material micro-story which exhibits many of the themes that will arise more explicitly from now on. How an experimenter like Hooke conceives of their apparatus influences their experimental programme and the knowledge they can create. The particular material conditions which began Hooke's association with microscopes gave him an aim which was initially more aesthetic than epistemic. In the clear and accurate images intended for the King's cabinet, Hooke saw the opportunity to view objects in a way not naturally available to humans. Instead of conceiving of a microscope as a magnifier, a sharper eye, he had a sloppy, open-ended system of materials. He incorporated new techniques

101 Hooke, *Micrographia*, sig. E1r, 58.

and materials for theoretical and anti-theoretical reasons: for convenience, comfort, and through frustration. Many of them then traversed the line between black-boxed instrument and object of inquiry.[102] The more he used them, the more he learnt, and the more he was able to do: knowledge, practical and theoretical, arose simultaneous with manipulation. Ultimately the single essential ingredient of microscopy, light itself – "the most obvious, though yet the most abstruse" thing of all – found itself interrogated by Hooke's instruments even as it was harnessed by them for the observation of specimens.[103]

102 "Epistemic thing" and "technical object," in the parlance of Rheinberger: Rheinberger, *Towrads a History of Epistemic Things*, 24.
103 "Lectures of Light," in Hooke, *Posthumous Works*, 71.

Chapter 4: The Man with Microscope Eyes

The Hope of the Microscope

By 1665 the microscope was a recognisable instrument.[1] By 1692, Hooke was lamenting that it had already run through "Invention, Improvements, Use, Neglect and Slighting." Only Antoni van Leeuwenhoek was using the instrument as something other than a "Diversion and Pastime", a portable toy, "easy to be carried in one's Pocket."[2] The objects revealed in it were more familiar and easier to comprehend than were celestial novelties through a telescope, and observations of insects, plants and anatomy fascinated and shocked men and women alike.[3] The instrument was being *used*, but apparently not for what Hooke thought was the right purpose.[4] Arguably it remained a fringe instrument, unnecessary for serious research, into the Victorian era. The Microscopical Society of London (later the Royal Microscopical Society) was founded in 1839 with the stated aim of "the advancement of the science of the microscope," But even then it was unclear what this science was.[5] Other Societies were being founded not around instruments but areas of research: geology, chemistry, or astronomy – where the telescope found a home.

Several historians of the microscope have attempted to explain this apparent fall out of love with it as an instrument of inquiry, and the consequent asymmetry with its cousin the telescope, but Harry Phinney has argued that even the narrative we get from Hooke is hugely

1 For the coining of the term by Giovanni Faber of the Accademia dei Lincei, see Lüthy, "Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy."

2 "Discourse Concerning Telescopes and Microscopes," in Hooke, *Philosophical Experiments and Observations*, 261.

3 Marjorie Nicolson has recorded the effect of the 'terra-incognita' of the microworld on the English imagination, and its influence on themes in literature, metaphysics, aesthetics and ethics: Nicolson, *The Microscope and English Imagination*.

4 See also Hooke's review of Filippo Bonanni's attempt to "revive" the art in Italy with his *Micrographia curiosa* the following year (in the lecture reproduced in the Appendix to this thesis).

5 Bennett, "The Social History of the Microscope," 276.

exaggerated.[6] Publications on microscopical observations were made steadily throughout his lifetime, and did not fall off much after Leeuwenhoek's death.[7] Microscopical research programmes in biology and anatomy were productive in the eighteenth century. More to the point of this chapter is, as Catherine Wilson and C. H. Lüthy have separately pointed out, that such a story of promise, unfulfilled or not, can only make sense if we recognise what the promise *was* in the first place.[8] The problem with this is that in fact the technology in the microscope was hardly novel. Magnifying lenses were commonplace items, which in Europe had most typically been used as a straightforward aids or correctives for artisans' and scholars' eyes. Jewellers, illustrators, and transcribers working in monasteries all used them to create more miniature and detailed work.[9] Lüthy's evocative phrase is that "the microscope was never invented."[10] It is the sudden enthusiasm of philosophers like Hooke which transformed magnifying glasses into a stable instrumental form which is more mysterious than the subsequent wane of that fashion.

What could a microscope do? Now that we have seen something of the skill and craft in manipulating them, and the optical knowledge that Hooke gained by doing so, in this chapter I will consider the instrument from a more conceptual angle. Hooke may have adopted it to make drawings with, but the reason the Royal Society thought these drawings would make a suitable gift for Charles II was because they were made with an instrument symbolic of their new experimental natural philosophy. What was the philosophical lesson to be learnt from the microscope? Why was it adopted by natural philosophers, and what was it that they hoped for from it?

Hooke's 1692 lament is also a call to arms. He and other seventeenth century advocates of the microscope often wrote of it answering a real and present need.

6 See for instance Fournier, *The Fabric of Reality*, chap. 2.
7 Phinney, "A Revisionist History of Microscopical Sciences," 129.
8 Wilson, *The Invisible World*; Lüthy, "Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy."
9 See Gal and Chen-Morris, *Baroque Science*, chap. 2; Enoch, "The Enigma of Early Lens Use."
10 Lüthy, "Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy," 2.

> [W]ith the present Generation of Men the Opinion prevails, that the Subjects to be enquired into are exhausted, and no more is to be done. […] But those, who make such Estimates, may, perhaps, find themselves very much mistaken in their Judgment. […] I may observe that a further Improvement and Use of them, will, in all Probability, afford much greater, and more considerable [knowledge(?)], not only for the perfecting and compleating the Knowledge of those Particulars which have been already, in Part, detected; but also for making of other new Discoveries, which as they are yet much further removed from the Power of the Senses to comprehend, so they have been, upon that Account, never afforded Entrance into the Imagination and Intellect; if at least *Aristotle's* Maxim be true, That there is nothing in the Intellect, but what was first in the Sense.[11]

Francis Bacon had warned that "the testimony and information of the sense is always made to the measure of man and not the universe."[12] Our senses do not tell us about nature as it is, only as it seems to us, and the mid-century experimenters that followed him assumed a straightforward identity between the limits of the senses and the limit of knowlege. Hooke was aware of the philosophical consequences:

> [T]he limits, to which our thoughts are confind, are small in respect of the vast extent of Nature it self; some parts of it are too large to be comprehended, and some too little to be perceived. And from thence it must follow, that not having a full sensation of the Object, we must be very lame and imperfect in our conceptions about it.[13]

To listen to this rhetoric, imperfect knowledge was a problem for which the microscope was a simple and necessary remedy.[14] Henry Power gushed in the preface to the first English work on microscopy: "How much therefore are we oblig'd to modern Industry, that of late hath

11 "Discourse Concerning Telescopes and Microscopes," in Hooke, *Philosophical Experiments and Observations*, 261–262.

12 "The Plan of the Work," in Bacon, *The Oxford Francis Bacon*, 11:34.

13 Hooke, *Micrographia*, sig. A1v.

14 Bacon too mentioned the "recently invented glasses" in his *Novum Organum*, book 2 aphorism 39, in Bacon, *The Oxford Francis Bacon*, 11:343.

discover'd this advantageous Artifice of Glasses[?]"[15]

How much indeed?[16] Wilson and Lüthy point out that Power's unambiguous gratitude to the "darling Art" of microscopy glosses the fact that his descriptions of microscopical observations owe as much to earlier traditions of nature observation as they do to the instrument. He repeatedly refers to Thomas Moffett, for instance, and as Lüthy says, historians have been unable to decide if Moffet used a magnifying lens when making his observations.[17] So what did it really mean for Power to explicitly advertise his work as 'New Experiments Microscopical'?

The microscope was a corpuscularian's instrument.[18] Though Francis Bacon himself was less sure of its benefits, he felt sure Democritus "would have been overjoyed" to see a microscope, thinking "that a means of seeing atoms […] had been discovered."[19] In the seventeenth century, exactly Democritus' style of minute physical substructure was redescribing the Renaissance idea of the subtlety of nature.[20] Scholastic thought described objects as monoliths, compounded of Forms which did not exist independently but mixed to produce objects with unified inner essences. Mechanical philosophy dissolved these monoliths into phenomena that were the productions of a concealed structure, structure which existed spatially and was potentially visible.[21] The idea that understanding an object required looking beyond its superficial appearance became redescribed. Now all there was was surfaces, not just of macroscopic objects but of their microscopic parts, and looking beyond the surface became

15 Power, *Experimental Philosophy*, sigs. C2r-v.
16 See also Power's ode to the microscope: Cowles, "Dr. Henry Power's Poem on the Microscope." Wren's accession speech to the chair of astronomy at Gresham: Wren, *Parentalia*, 200.
17 Power, *Experimental Philosophy*, sigs. C2v, 155; Lüthy, "Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy," 2. See also Wilson, *The Invisible World*, 85. For comparison see Thomas Moffett's *Theatrum Insectorum* (1634).
18 Wilson and Lüthy approach the same issue from opposite directions. Both associate the popularity of the microscope with the rise of corpuscularianism, but where Wilson sees the instrument playing an integral role in the imaginative availability of such micro-structure, Lüthy emphasises the influence of matter theory on the popularity of the instrument. They are both undoubtedly accurate, the difference produced by the historian's job of condensing an era of thought into a single narrative.
19 *Novum Organum*, book 2, aphorism 39, in Bacon, *The Oxford Francis Bacon*, 11:343. Bacon continues to describe useful possible observations which are very reminiscent of those in Hooke's *Micrographia*.
20 See especially Wilson, *The Invisible World*, chap. 2.
21 See also Hutchison, "What Happened to Occult Qualities in the Scientific Revolution?"

literally a task for the sight.

Much of the evidence that the microscope could provide for this sort of view was clearly analogical. In 1648, John Wilkins, the man in whose group Hooke first encountered microscopical work, wrote:

> For ought we know, there may be some *Organicall* bodies, as much lesse then ours, as the earth is bigger. We see what strange discoveries of extream minute bodies, (as lice, wheal-worms, mites, and the like) are made by the *Microscope*, wherein their severall parts (which are altogether invisible to the bare eye) will distinctly appear: and perhaps there may be other insects that live upon them as they doe upon us. 'Tis certain that our senses are extreamly disproportioned for comprehending the whole compasse and latitude of things.[22]

What excited Wilkins was not the bracketed whealworms and mites but the general lesson, the gap between the limits of perception and extent of nature. The space outside our visual awareness was populated by whole creatures, their bodies as complex as anything visible to the naked eye. The nematodes that appeared thriving in apparently clear water were not just more life, they were a previously unimagined scale of existence.

As such, a lot of the praise for the microscope was directed at its future, at what discoveries could be made with further improvements.[23] There is something curious about this. Lenses were the aspect of the microscope which attracted the most discussion by early modern microcopists, but they were also the most ancient ingredient. It was only with the new importance of eyesight for discovery in the fashionable mechanical philosophy that they became an object of fascination and optimism. A popular way to talk about the microscope in seventeenth century England became as a 'sharper eye' or a 'perfection' of the sense of vision. Christopher Wren wrote that lenses made sight "infinitely advanc'd," and Power and Joseph

22 Wilkins, *Mathematicall Magick*, 115–116. See also Wilkins, *Discourse Concerning the Beauty of Providence*, 49.
23 The hunt was on for hyperbolic lenses, as I mentioned in Chapter 2. See also Power's preface, and the extended quote from Hooke's 1692 lecture above (footnote 9).

Glanvill both compared the microscope to the eyesight of Adam, the perfect human.[24] Even in 1713 George Berkeley wrote that "microscopes make sight more penetrating, and represent objects as they would appear to the eye in case it were naturally endowed with a most exquisite sharpness."[25] While much of this language was undoubtedly intended to be poetical, it nevertheless hints at a particular function imputed to the microscope; that of bringing the world into sharper focus, to make the perception of objects clearer and more distinct.[26] Perhaps the lens, that familiar corrective tool of vision, carried with it the idea of sharp eyesight into the new philosophy. The epistemic consequence seems to have been that if lenses made eyes better, and eyes were the source of knowledge, then lenses would give better knowledge. They would reveal the consituents of nature.[27]

John Locke would criticise this view in the last decade of the century, but a close look at Hooke reveals a different picture from him as well. Just because a community of people could look at an object and call it by the same name does not imply that they all meant the same thing by that name, and certainly does not imply they all agreed on what to do with it. In this chapter I will outline the epistemology of Hooke's microscope, an epistemology influenced both by the nature of his initial task drawing pictures, and his more general approach to natural knowledge, as I will discuss in following chapters. The microscope as Hooke used it bore a strong similarity to the *camera obscura* as used by Vermeer to aid his painting: it was an instrument of appearances.[28]

24 And perfect philosopher – a theme I will return to in the following chapter. Wren, *Parentalia*, 204; Glanvill, *The Vanity of Dogmatizing*, 5; Power, *Experimental Philosophy*, sig. A4r.

25 Berkeley, *Three Dialogues*, 27. See also Boyle's words in *Experiments and Considerations Touching Colours*: Boyle, *The Works of Robert Boyle*, 1999, 4:40.

26 The evocation of Descartes' requisite for ideas is intentional and, if anachronistic, not completely out of place. Jacques Rohault gave a very optical reading of Descartes' phrase in his *Traite de Physique*: Clarke, *Rohault's System of Natural Philosophy*, 1:248.

27 Jonathan Gil Harris' notion of 'palimpsested matter' captures nicely this idea of the meaning of an old technology incorporated into a new, and the danger of finding too much novelty in something we conceptualise as a 'new invention.' See Harris, *Untimely Matter*, chap. 1.

28 Though the mention of an artist is not intended to be a comparison of entirely dissimilar enterprises. See for instance Hunter, *Wicked Intelligence*; Alpers, *The Art of Describing*; Jardine, *Ingenious Pursuits*.

Drawing Pictures

By March 1663, Hooke's task was underway. At a meeting on the 25th he was "solicited to prosecute his microscopical observations, in order to publish them," and the very next meeting he was reminded again "to bring in at every meeting one microscopical observation at least."[29] On 8 April Hooke showed his first picture, of "the appearance of common moss," which was apparently approved of – he was "desired to continue." He did so, bringing over 40 observations to meetings throughout the rest of the year.[30]

Despite the clear importance the Royal Society attached to the task of drawing pictures for the king, Hooke's observations themselves have a curious place in Society meetings. When he recreated Leeuwenhoek's pepper worm observation, the Fellows apparently joined him in looking through the microscope.[31] But before August 1664, when Hooke moved into Gresham College full time and the Society held their meetings in his rooms, he probably made most of his observations at Lady Ranelagh's house in Pall Mall. For this early work, neither the instrument nor the process of observation were objects of the scrutiny or testimony of the gentlemen gathered at Society meetings. Hooke's *pictures* were. Only once during these years was he asked to bring a microscope with him to a meeting, in order to examine the Earl of Belcarre's bezoar stone.[32] As it happened the next meeting was cancelled, and the instrument presumably remained in Pall Mall. He produced a drawing of the stone a two weeks later. Michael Dennis has suggested this separation of observation and presentation was elided by the intricacy and representativeness of Hooke's drawings, which make present to the viewer the distant process of microscopical observation. The 'virtual witnessing' required by the Society's collaborative approach was produced through "disciplined seeing." The Fellows did not directly observe demonstrations, so their presence was replaced – by Boyle with textual descriptions of his air

29 Birch, *The History of the Royal Society*, 1756, 1:213–215.
30 Ibid., 1:216. John Harwood has compiled a helpful table of Hooke's microscopical observations: see Harwood, "Rhetoric and Graphics in Micrographia," 124–125.
31 See Chapter 2 of this thesis.
32 Birch, *The History of the Royal Society*, 1756, 1:292.

pump experiments, and by Hooke with detailed illustratration. As Dennis says, "we see through Hooke to the 'things themselves.'"[33]

If this is the effect of viewing Hooke's images, it does not tell us anything about what they show. What do we learn from looking at the things themselves? Mostly, the Fellows seem to have been as uninterested in the natural philosophical implications of Hooke's observations as they were in the practical optical experience of looking down a microscope. Typically Hooke's drawings are merely noted in the minutes: "Mr. Hooke brought in two microscopical observations, one of leeches in vinegar; the other of a bluish mould upon a mouldy piece of leather."[34]

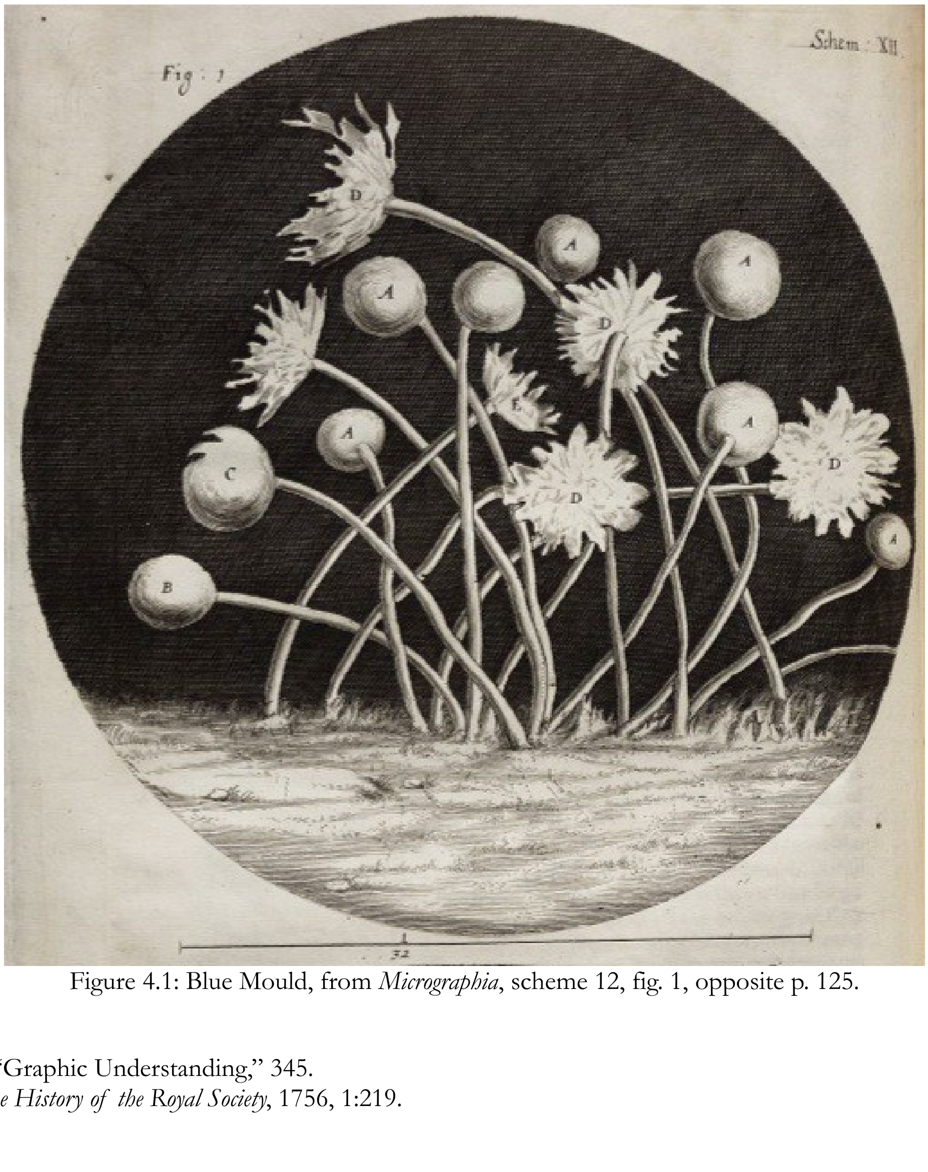

Figure 4.1: Blue Mould, from *Micrographia*, scheme 12, fig. 1, opposite p. 125.

33 Dennis, "Graphic Understanding," 345.
34 Birch, *The History of the Royal Society*, 1756, 1:219.

No subsequent discussion is noted. It was Leibniz who later drew the philosophical lesson from Hooke's work that phenomenal changes in bodies have microstructural explanation: "Hooke shows […] in his *Micrographia* that iron rust is a minute forest which has sprung up; so rust is therefore an alteration in iron but a generation of little bushes."[35]

When Hooke showed the Society a "spider appearing to have six eyes," the minutes note that "this latter was not yet perfectly drawn."[36] Whether this is Hooke's or someone else's opinion is not recorded, but either way it was explicitly the the artifact of the *drawing* being criticised; not the natural knowledge it displayed, nor its means of production. *Micrographia* is full of detailed descriptions of how Hooke prepared his specimens, and the difficulty both of observing and illustrating the micro-world. It is very possible that these descriptions in fact echo his presentation of the images at Society meetings, but the minutes are notable for their lack of discussion.

The Fellows likewise showed general lack of interest in the topics he observed. There were very few occasions when Hooke was asked to investigate something in particular. Eels in vinegar were a common subject of early microscopy which he was asked to look at early on. Occasionally someone would bring in an interesting found object, as Jonathan Goddard did with a piece of petrified wood. Even that Hooke was given only "in order to see, whether it would polish," before it later became the subject of microscopical scrutiny.[37] A remark from George Ent about how deer hide reacts to being submerged in water prompted Wilkins to explain its appearance under the microscope, which Hooke was asked to verify.[38] As far as I can tell, only twice more was he ordered to make a particular observation for the purpose of discovery: to see if sage leaves had pores large enough for spiders to hide in, and to look for "little insects" in animal blood.[39] It seems he never performed the second, his dislike of dissection perhaps

35 Wilson, *The Invisible World*, 58.
36 Birch, *The History of the Royal Society*, 1756, 1:231.
37 Ibid., 1:244.
38 Ibid., 1:342. See also Doherty, "Discovering the 'True Form.'"
39 Birch, *The History of the Royal Society*, 1756, 1:250, 270. Sage's bitterness was thought to be due to the tiny spiders that lived in it.

preventing him.

There is plenty more to be said about the pictures in *Micrographia*. Hooke's copper plates remained the gold standard of microscopical drawings for two hundred years, and were reproduced or copied several times for books published in England and abroad until eventually superseded by photographic images in the late nineteenth century.[40] I will return to them later in the chapter, but first I will turn in more detail to Hooke's transformation into a serious microscopist. By the time *Micrographia* received its imprimatur from the Society's Council on 23 November 1664, Hooke was a Fellow of the Royal Society, living in London, and rewarded with a salary. A lot had changed in a year and a half. During Hooke's transformation from unpaid sub-contractor to lynchpin of the Royal Society, *Micrographia* developed from a set of decorative illustrations to a classic of early modern natural history. It was not only the first tome which illustrated tiny nature in such intricacy and detail, it also explicitly vindicated the methods of the new experimental philosophy.

Dr. Power Comes to Town

On 24 June 1663, Dr. Henry Power arrived at the Royal Society to be elected a Fellow, and presented at the meeting his own microscopical observations.[41] Hooke wrote to Boyle with the following review:

> There is very little in Dr. *Power*'s microscopical observations but what you have since observed; only there is a pretty experiment he tried with the leeches in vinegar, that survived the freezing of the vinegar they lived in; and another pretty experiment he has in his philosophicall reflections upon his observations, which is of making a certain kind of coals kindle into a fire and flame, by throwing water on them, when newly dug out of the mine. I am sorry to see, that he intends to publish several experiments about colours, which I am confident might be

40 Turner, "The Impact of Hooke's Micrographia and Its Influence on Microscopy."
41 Birch, *The History of the Royal Society*, 1756, 1:266.

> originally yours. He will likewise publish the experiment of freezing an eye, to find the shape of it, whose invention he ascribes to another. There is not much more besides, that is very considerable in it, and therefore I shall refer the further account of it till your return, till when I shall keep the book by me.[42]

Power's work seems to have been known to the Fellows already: Boyle had apparently seen some, and they were familiar with the leeches in vinegar. The way Hooke mentions "Dr. Power's microscopical observations" with no further introduction implies they had been waiting to see more. Certainly Power's philosophy in general well known in London, and he was recommended for Fellowship in 1661 but could not travel to London for the meeting. William Croune communicated regularly with him instead, and the Society learnt about his work on magnetism, subterranean observations, and pneumatics, this last playing a significant part in the discovery of Boyle's Law.[43] "The book" Hooke refers to is most likely the first part of Power's later publication, *Experimental Philosophy in Three Books: Containing New Experiments Microscopical, Mercurial, Magnetical.* It was printed in 1664 but was a long time in the writing: the Preface is dated August 1661 and the microscopical part was probably completed by then also.[44] All of the things Hooke relates to Boyle appear in this part, so it seems likely what Power presented to the Society was an advance copy of this section.[45] Upon seeing it, Wilkins, Wren, and Hooke "were appointed to join together for more observations of the like nature."[46]

42 Hooke to Boyle, 3 July 1663. In Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 2:98.

43 Birch, *The History of the Royal Society*, 1756, 1:22, 50, 77, 80, 86, 105, 125, 130. Power's book concludes with a short section on 'Subterraneous Experiments' which was the direct result of the correspondence with the Society, and appears in Birch (1:133-136) as a letter received by Croune. For Power's interaction with the Society see also Webster, "The Discovery of Boyle's Law"; Webster, "Henry Power's Experimental Philosophy."

44 Webster quotes a letter from Power to Reuben Robinson from September 1661 (British Museum Sloane MS. 1326, ff. 20-21) stating that he and his circle of natural philosophers owned four microscopes and that he had already completed one hundred observations: Webster, "Henry Power's Experimental Philosophy," 158. This is also the year of Power's poem on the microscope (which I come to below), every line of which refers to some observation or comment in *Experimental Philosophy* (see footnote 64). It recevied an imprimatur in August 1663 from George Stradling (a London-based engraver) which Power (who lived in Yorkshire) perhaps received on the same trip as his visit to the Society.

45 The eels in vinegar are on pp. 32-36, and the coal which ignites with contact with water on pp. 63-64. A short discourse on colours is included after the observations, pp. 72-77, and 'Anatomical Considerations about the Eye' concludes the section, pp. 78-83.

46 Birch, *The History of the Royal Society*, 1756, 1:266.

Was this, a few months after Hooke began to make regular obervations, the beginning of *Micrographia* as a book, rather than a series of drawings? There are a few details that point to the importance of Power's work in inspiring Hooke, and there is certainly more to it that Hooke freely admits. A few weeks after the Doctor's visit, Hooke wrote to Boyle that he was "taking order about the engraving of my microscopical pittance, which I hope will be very well done."[47] This reference to pictures is the only mention of his microscopical work in a series of letters to Boyle which are otherwise fairly comprehensive accounts of his work and the Society's meetings.[48] It seems that even at this stage, the quality of the engravings remained the important aspect of Hooke's work. This was the impression Power had as well. He alerts his readers to "expect shortly from Doctor Wren, and Master Hooke [...] the Cuts and Pictures drawn at large, and to the very life of these and other Microscopical Representations."[49]

It is interesting that Power mentions Wren as Sir Christopher has been proposed as the artist behind some of the more iconic images in the book.[50] Whether this is the case or not, the collaboration with Wilkins and Wren was clearly important to Hooke, and both men are singled out for generous acknowledgement in his Preface. Wilkins' involvement is especially notable. Hooke's first natural philosophical mentor, Wilkins' opinions on certainty and evidence in natural philosophy are represented strongly in Hooke's *Micrographia*, a point the rest of this chapter will move towards. Wilkins was also the co-author of the Baconian apologetic *Vindiciae Academiarum* (1654), and the main guiding hand behind Thomas Sprat's *History of the Royal Society* (1667).[51] It seems likely the other major apologetic work of the early days of the institution – *Micrographia's* Preface – was written partly with his guidance too.

47 Hooke to Boyle, c. 10 July 1663. In Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 2:100.

48 For example, a comparison of Hooke's letter to Boyle on 5 June 1663, in Ibid., 2:81–84., to the minutes of the meeting of the 3rd as recorded in Birch, *The History of the Royal Society*, 1756, 1:250–253., shows Hooke conscientiously reporting proceedings to his employer, and only breaking off when his "long scribble" reached several pages.

49 Power, *Experimental Philosophy*, 83.

50 See Power, "Sir Christopher Wren and the Micrographia."

51 Wood, "Methodology and Apologetics."

The similarities between the observations in *Micrographia* and Power's *Experimental Philosophy* led Charles Webster to suggest that the former was essentially an "aggrandized version" of the latter: now with added pictures.[52] Webster refused to speculate further on the influence of the one on the other, but it is true that Hooke certainly thought there was room for improvement on Power's efforts. He wrote in the Preface:

> After I had almost completed these Pictures and Observations (having had divers of them ingraven, and was ready to send them to the Press) I was inform'd, that the Ingenious Physician *Dr. Henry Power* had made several *Microscopical* Observations, which had I not afterwards, upon our interchangably viewing each others Papers, found that they were for the most part differing from mine, either in the Subject it self, or in the particulars taken notice of; and that his design was only to print Observations without Pictures, I had even then *suppressed* what I had so far proceeded in.[53]

Hooke is clearly being free with historical detail. When he reviewed Power's book for Boyle, less than half of the observations that would comprise *Micrographia* had been presented at Royal Society meetings, though it is true that some were in the process of being engraved.[54] Power could well have inspired the choice of subjects to look at, as almost every observation in the earlier work is replicated by Hooke. Hooke is right that the "particulars taken notice of" did differ. Sometimes this meant Hooke explicitly correcting Power for inaccurate observations, though where he felt the Doctor did a good job he gave credit and referred to the other's book.[55] The main difference between the two books is that which Hooke points out: illustrations. Power included three woodcuts, all small and margin-bound, and all rather schematic (Figure 4.2).

52 Webster, "Henry Power's Experimental Philosophy," 161.
53 Hooke, *Micrographia*, sig. G2r.
54 See the table in Harwood, "Rhetoric and Graphics in Micrographia."
55 Hooke corrected Power particularly on the wings of butterflies and the eyes of flies, but was happy with his observations of the eels in vinegar: *Micrographia*, sig. F2r, observations 46 and 57.

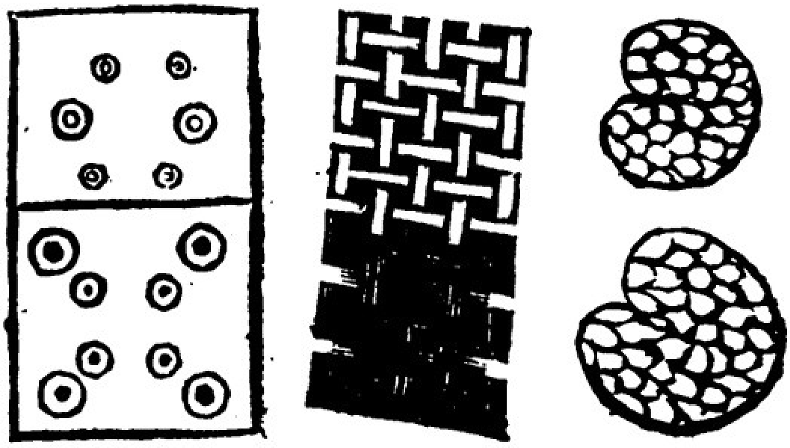

Figure 4.2: Power's illustrations. From left: spider eyes (p. 13), silk texture (p. 46), corn poppy seeds (p. 49).

Hooke's drawings on the other hand are still notable for their number, intricacy, detail, and sheer size.[56] Much more than his words, they are what one remembers after closing the book. He took great care in preparing them and obvious pride their final forms, even protecting himself from criticism by mentioning when the engravers had made mistakes.[57] Elsewhere Hooke emphasises the benefits of visual over linguistic description: "there are many things that cannot be made as plain to the Understanding, by a large Description in Words, as by the Delineation of them in a quarter of a Sheet of Paper."[58] Illustration was a philosophically loaded device, not mere expedience or decoration:

> "[I]t will be often necessary to add the Pictures of those Observables that will not otherwise be so fully and sensibly exprest by Verbal Description: But in doing this, as a great Art and Circumspection is to be used in the Delineation, so ought there to be very much Judgement and Caution in the use of it. For the Pictures of things which only serve for Ornament or Pleasure, or the Explication of such things as can be better describ'd by words is rather noxious than useful, and serves to divert and disturb the Mind, and sways it with a kind of Partiality or Respect."[59]

56 See Meghan Doherty for more on the method and knowledge behind Hooke's compositions that simply was not available to Power: Doherty, "Discovering the 'True Form.'"

57 e.g. Hooke, *Micrographia*, sig. F2r, 181, 204.

58 "General Scheme," in Hooke, *Posthumous Works*, 20.

59 Ibid., 64.

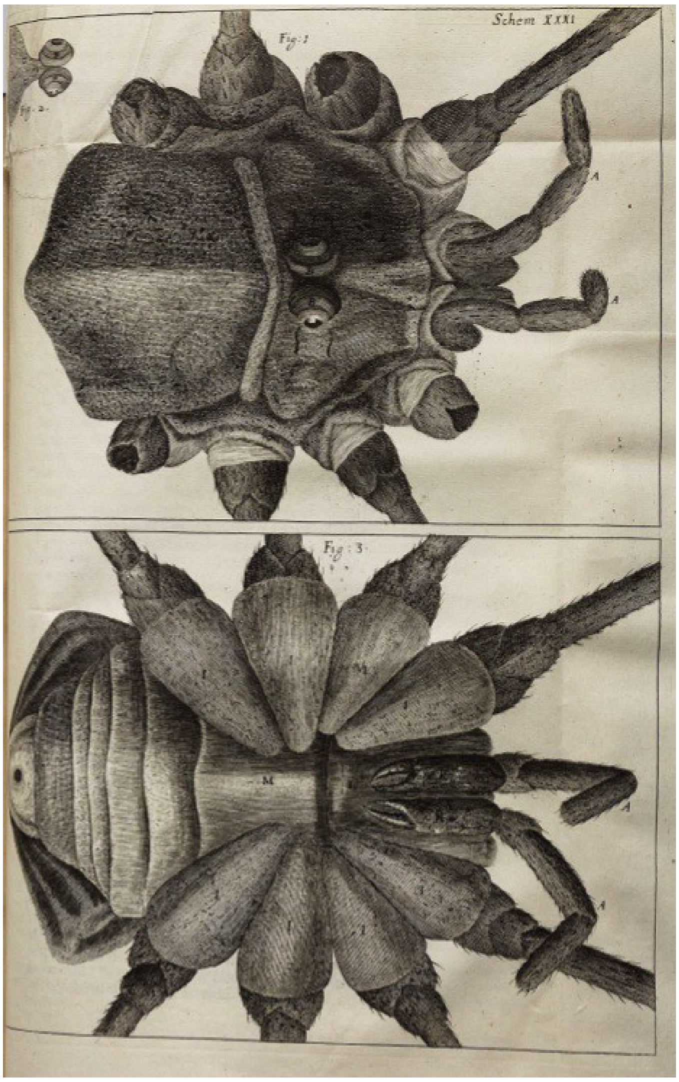

Figure 4.3: The belly and back of a long legged spider,
Micrographia scheme 31, opposite p. 198.

How much does the addition of desciptions Hooke's original drawings beg for an explanation? It is Dennis' view that the descriptions given in *Micrographia* are much as they would have been at the meetings of the Society. In fact he sees this as an important part of the rhetoric of the finished book. In describing at once the picture and the object of the picture, Hooke collapsed the re-presentations of his observations in front of the Fellows into his own private observations themselves, and thereby converted his audience into eyewitnesses, testifying to the knowledge they conveyed.[60]

Whether or not the undeniable similarities between Hooke's and Power's books are the result of direct influence, the important point is their essential difference. The two authors used the microscope to produce works of different types. As authors of complete, contemporaneous works, Power and Hooke make an interesting comparison both in terms of words and action, in both their rhetoric and the natural philosophical stances embodied by their publications. Power was wildly optimistic about the instrument, and was also a rampant Cartesian. *Experimental Philosophy* is the result of these things combined. Hooke, on the other hand, produced a more visually oriented work in which the 'sharper eye' of Power's lenses is replaced by a kind of pragmatic scepticism about both appearances and existing philosophy. Before turning to Hooke it will be helpful to make the distinction clearer by saying a little more about the way the microscope appeared in Power's writing.

The World Through a Microscope

Power was older than Hooke: born in Halifax, Yorkshire, in 1623, he belonged more to the generation of Hooke's employers than to Hooke's own. He was aged 45 at his death in 1668.[61] While a student at Christ's College, Cambridge, he began to correspond with Sir Thomas Browne, a friend of his parents, who would have a lasting influence on Power. Cambridge was also the home of Francis Glisson, experimental physiologist and later head of the London College of Physicians, and the Platonists Ralph Cudworth and Henry More. Like Hooke at Oxford, Power was a member of an active group of natural philosophers.[62]

Unlike Hooke though, Power studied an established profession – medicine – and returned to Yorkshire to work as a physician while Hooke, the philosophers' apprentice, moved

60 Dennis, "Graphic Understanding," 344.
61 For more on Power's life see Webster, "Henry Power's Experimental Philosophy."
62 One which Webster has also suggested was connected to another institution meant to epitomise Bacon's 'Solomon's House' – the College of Physicians under Francis Glisson: Webster, "The College of Physicians."

to London. As I mentioned earlier, Power did remain active in philosophy, and communicated with the Royal Society, who asked him to perform experiments in Yorkshire coal mines on the effect of altitude on gravity. Hooke would later repeat the experiment from atop Westminster Abbey.[63]

When he was engaged In his own philosophical work, Power had very clear aims. Just as the title to *Micrographia* gives away the most important aspect of the book, so to does Power's *Experimental Philosophy: With some Deductions, and Probable Hypotheses, raised from them, in Avouchment and Illustration of the now famous Atomical Hypothesis*. He had not escaped Cambridge without being infected by Henry More's enthusiasm for Descartes' philosophy.[64] A letter from Power to his Cambridge associate Reubin Robinson suggests his work was always intended to be a complete vindication of Descartes:

> Descartes … (the Author you know I have so long since admired) you see how every day his Hypothesis gaines upon the world and begins now to be made out by mechanicall experiments, his Atoms & the various figurations of them by the Microscope, his aetherial substance by the [mercurial] experiments, his Doctrine of the Lodestone, by new Magneticall Demonstrations.[65]

Experimental Philosophy works systematically through Cartesianism, seeking to justify different aspects of it in turn. In fact, the only section of the finished book *not* devoted to this task that on the subterranean experiments which the Royal Society asked him to carry out. Throughout the rest, Power aims his experiments at verifying his matter theory, and the microscope was certainly no exception. Though the things that explain phenomena are too small to be seen with the naked eye, microscopes would bring knowledge of those things which "govern Nature principally."[66]

63 See Birch, *The History of the Royal Society*, 1756, 1:133–136, 163-165. If Hooke is often characterised as the working man of the Royal Society, here the architectural comparison is in his favour.
64 For which, see Hutton, *Henry More*.
65 Power to Robinson, 25 September 1661. Quoted in Webster, "Henry Power's Experimental Philosophy," 168.
66 Power, *Experimental Philosophy*, sig. C2r.

In 1661 Power wrote an ode 'In commendation of the Microscope' which rings with excitement, and echoes Bacon by relating to Democritus that he has finally been shown correct:

> Of all th' Inventions, none there is Surpasses
> the Noble Florentine's Dioptrick-glasses.
> For what a better, fitter, guift Could bee
> in this world's Aged Luciosity.
> To Helpe our Blindnesse so as to devize
> a paire of new & Artificall eyes.
> By whose augmenting power wee now see more
> than all the world Has ever donn Before.
> Thy Atomes (Brave Democritus) are now
> made to appeare in bulk & figure too.[67]

In a more sober mood Power admitted that seeing such constituents of nature was impossible with current instruments. When the anatomist and physician Nathaniel Highmore reported magnetic particles had been seen emanating from a lodestone, Power, believing he possessed the best microscopes in England, was sceptical.[68] But he did not find the prospect absurd. His self-confessedly "hyperbolic" hope was that if lenses reached theoretical perfection, we could view not only the fine effluvia of the magnet, but the grosser electrical or aromatical ones too, atoms, the light globules of Descartes, and the springy air particles of Boyle.[69] The mechanical philosophy's explanations of phenomena would be visually confirmed. This kind of talk was not uncommon. Descartes urged instrument makers to build microscopes so visual

67 For the whole poem see Cowles, "Dr. Henry Power's Poem on the Microscope." I have silently altered some of the punctuation, and converted 'u' to 'v'. The last couplet's rhyme makes more sense in Power's Yorkshire dialect.

68 Highmore reported his observation in his Highmore, *The History of Generation*, 117. Power mentions and dismisses Highmore's claim twice more: Power, *Experimental Philosophy*, 57, 155. See Webster, "Henry Power's Experimental Philosophy." for a letter from the Doctor to his associate in which he claims to be using the best microscopes in the land.

69 Power, *Experimental Philosophy*, sig. C3r-v, 57-58, 155-156.

evidence could be gathered for his matter theory over Aristotelianism.[70] Constantijn Huygens, Theodore Mayerne, and, more ambiguously, Pierre Gassendi and Walter Charleton joined him in relating the promise of the instrument to corpuscularianism.[71] Robert Boyle hoped microscopes would reveal corpuscles of various shapes and sizes, and Isaac Newton thought better and better microscopes might show us all the different sized light particles that produced colour.[72] Leeuwenhoek actually thought he had found that a remarkable number of bodies consisted of small round globules, before later realising they were artifacts of his microscope, and what he could see of his subjects were much more varied and irregular parts.[73]

The idea of one day really seeing this sort of texture seems to ignore the fundamental insight for which doing so would provide evidence – that observable phenomena are explained and composed by an unobservable substructure. This substructure is unobservable not only because it is tiny, but also because it is precisely due to *composition* that it produces visual phenomena through the mechanical action of light. Colour is the result of arrangements of corpuscules. How a lens could magnify and isolate one of these corpuscles and it still be visible is somewhat mysterious. The appearance of an arrangement of corpuscles is just exactly what an object looks like to the naked eye! When I see a brown dog in a green field, corpuscles don't cause me to see these *objects*, I am just seeing corpuscles. If the microscope's revelation of tiny details provided evidence for objects being composed of sub-visible particles, hoping to see these particles was surely impossible.

John Locke pointed this out. If we could see, he wrote, the "real Constitution on which [objects'] sensible Qualities depend, I doubt not but they would produce quite different *Ideas* in us."[74] What would a corpuscule look like? For instance, colours would disappear, and instead we

70 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 172.

71 See Lüthy, "Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy," 15.

72 *Experiments and Considerations Touching Colours*, in Boyle, *The Works of Robert Boyle*, 1999, 4:40. Newton, *Hypothesis Concerning Light and Colour*, in Birch, *The History of the Royal Society*, 1757, 3:303.

73 Leeuwenhoek, "Microscopical Observations from Mr. Leeuwenhoeck"; Leeuwenhoek, "More Observations from Mr. Leewenhook"; and for his recantation: Leeuwenhoek, "Microscopical Observations of the Structure of Teeth and Other Bones"; Leeuwenhoek, "Microscopical Observations of the Structure of Hair"; see also Phinney, "A Revisionist History of Microscopical Sciences," 126.

74 Locke, *An Essay Concerning Human Understanding*. Book 2, chapter 13 section 11, p. 139.

would see a "Texture of parts of a certain Size and Figure."[75] Locke illustrated his idea with the observation that things change colour when viewed under a microscope: despite blood's appearance to the naked eye, magnification shows it is mostly clear with only a few red "Globules" mixed in.[76] Unlike other authors, Locke is clear that this evidence is analogical. Red blood globules are not corpuscules, nor are they like them. It is "uncertain," he says, how these red globules themselves would appear under a stronger lens. Peter Alexander has argued that the role of the microscope in Locke's discussion is only to show that things look *different* through it, and that our human ideas are contingent on the nature of our senses.[77] He does not think a microscope is a step on the way to seeing the "real Constitution" of objects. Rather, when Locke imagines 'seeing' corpuscles directly he is imagining a sense wholly different from that of eyesight.[78]

In fact, Locke thinks it is just as well that we do not have eyes that let us see the "real Constitution" of things. Our senses are attuned to the size and composition of the human body – by his time a fairly common idea in experimental philosophy – and more acute senses would be totally useless in daily life, which is after all what God designed us for.[79] Our very constitution prevents us from having visual access to the fabric of reality.

Locke acknowledged the theoretical reasons to think that corpuscles would remain invisible, no matter how enlarged. It was thus limited to providing a kind of analogical evidence for corpuscularianism, in a sense a return to Bacon's idea of the instrument: an measured hope that while someone wedded to atomism might have outrageous hopes for the instrument, its practical benefit was more likely in just giving closer views of familiar objects.[80] As such, Locke is

75 Ibid.
76 Ibid. Vanishing colour was a fairly common conceit of early modern microscopy, but Locke is different in making clear the colourless globules are unlike corpuscles in that they are still visible. See also Hooke, *Micrographia*, 71; Boyle, *The Works of Robert Boyle*, 1999, 4:40; Clarke, *Rohault's System of Natural Philosophy*, 1:230.
77 Alexander, "Microscopes and Corpuscles."
78 Ibid., 87ff.
79 Locke, *An Essay Concerning Human Understanding*. Book 2, chapter 13 section 12, p. 140. See also Hooke, *Posthumous Works*, 8–9; Power, *Experimental Philosophy*, sig. B1r.
80 See also Wilson, *The Invisible World*, 57–60.

ultimately pessimistic about the instrument's usefulness in natural philosophy.[81] He allows himself an "extravagant conjecture" about a person who could adjust their senses at will, and see at one moment "the Figure and Motion of the minute Particles," and at the next "the shape and motion of [whole] Animals themselves." How much more knowledgeable than the average man would this person be?[82] This duality is the stuff of Angelic knowledge; at no point does Locke consider that this might be exactly the experience of the microscopist.[83]

The idea the microscope might provide direct evidence for mechanism seems tied to conceiving of it as a 'sharper eye'. If knowledge had been restricted, Power and Hooke followed Bacon in saying, to those things we can see, then the microscope's extension of our visual scope also implied an extension of *truth*. There was a direct connection between seeing things and knowing about them. In a community for whom truth increasingly meant knowledge about the fundamental structure that underlay nature and from which phenomena emerged, the most obvious hope for microscopical enquiry was a view on corpuscles.

In a sense, Locke and Power represent the two extremes of this view. Locke emphasises the inaccessibility of the level of reality at which truth was to be found, and it is not too much of a stretch to to see in him the kind of neoclassical restriction of philosophy that led Alexander Pope to later write that the "proper study of Man is Man."[84] If you cannot see corpuscles, what is the point of magnifying things? All you get is a distorted picture of mundane objects. On the other hand, Power's optimism is unlimited. There are occasional glimpses in his work not of Descartes' philosophy but that of Henry More, his teacher at Cambridge who argued that the causal power of matter in motion was complimented by immaterial spirits. Power hazarded that

81 Interestingly, Phinney quotes Thomas Sydenham saying that although nature acts on the body by small particles, they are too small to ever be seen "even by the assistance of glasses, or any other invention." His amanuensis, taking down this note, was none other than John Locke. Phinney, "A Revisionist History of Microscopical Sciences," 126.

82 See Gal and Chen-Morris' discussion of Galileo's and Kepler's related musings about the telescope as an extension of reason, and what kind of eye reason would want if it could have one: Gal and Chen-Morris, *Baroque Science*, 94–97.

83 Locke, *An Essay Concerning Human Understanding*. Book 2, chapter 13 section 13, p. 141.

84 From his *Essay on Man*. I will return to this idea in the following chapter, through the work of Margaret Cavendish.

microscopes might even facilitate "at last the discovery of Spiritualities themselves."[85] He concluded his ode:

> Nay then yow pretty sprits & fairy Elves
> that hover in the aire, Looke to your selves.
> For with such prying Spectacles as these
> wee shall see yow in yr owne essences.
> Then shall I see a soule just when tis gone
> as cleere as now I doe our Will & John.[86]

The poem is packed full of the observations Power would publish in sober philosophical prose a few years later in his *Experimental Philosophy*. To conclude it on such a note might have been hyperbolic, but it was not facetious.

But the thing about Power which makes him a particularly illustrative comparison for Hooke is that he did not wait for the improvements of microscopes, he wrote a book explicitly advocating Cartesianism based entirely on observations made with the actual microscopes of the 1660s. Though he could not observe light globules or magnetical effluvia directly, he thought, for instance, that the 'eels' he saw wriggling in vinegar:

> very neatly illustrate the Doctrine of the incomparable *Des-Cartes*, touching Fluidity: (*viz.*) That the particles of all fluid bodies are in a continual and restless motion, and therein consists the true nature of fluidity: for by this ocular example, we see there may be an intestine restless motion in a Liquor, notwithstanding that the unassisted eye can discover no such matter.[87]

85 Power, *Experimental Philosophy*, 58.
86 Cowles, "Dr. Henry Power's Poem on the Microscope," 73. See Cowles' notes for connections between lines of the poem and Power's *Experimental Philosophy*. This last line is apparently a reference to Henry More's 'aetherial genii' – a soul on its way to heaven. See More, *The Immortality of the Soul*; Power, *Experimental Philosophy*, 156.
87 Power, *Experimental Philosophy*, 36. He adds Observation 13, Mites in Meal, as evidence to this same conclusion.

What was important was the wriggling, not the wriggler. What matters for Power is the existence of motion not visible to the naked eye. Power had thought, theoretically, that motion was everywhere without us being able to observe it. Now he had evidence that this was the case. For Power, gaps between hypothesis and evidence – between ontology and observation – could be bridged by the understanding. Where "both our Natural and Artificial Eyes fail […] we have another more Intrinsick Eye [...] and that is the piercing Eye of Reason."[88] Reason allows us to slide from the visible to the invisible, and eels become evidence for continual corpuscular motion.[89] Likewise, having watched a snail slide along the other side of a pane of glass, Power concluded the "little stream of clouds [that] channel up her belly from her tail to her head" were a "gale of Animal Spirits" and "the cause of her progressive motion."[90] He is prompted into a digression about the Animal Spirits: they are not generated in the bodies of animals, but universally distributed through all things in the world but only become visible when immersed in "grosser matter." They "give fermentation and concretion to Minerals; vegetation and maturation to Plants; life, sense, and motion to Animals; And indeed, [are] the main (though invisible) Agent in all Natures three Kingdoms Mineral, Vegetal, and Animal."[91] Seeing things that were ordinarly invisible gave Power a license to reason beyond even these observations, and explain visual phenomena with an assumed matter (and spirit) theory.

Of course, Power's book was predominantly a description of magnified objects – the speculative parts are few and far between, and for the most part there is significant overlap with Hooke's descriptions in *Micrographia*. But the places they do diverge are illustrative. Hooke did not use the microscope primarily to justify a pre-existing belief in a particular system of the world,

88 Ibid., 155.

89 Webster, in his account of Power's philosophical thought, finds in it a tendency to reach quickly for such analogies "in searching for generalisations of wide explanatory value, [and] in the absence of incontrovertible evidence... This reduced the difficulties in moulding experimental evidence to the requirements of [Cartesian] theories:" Webster, "Henry Power's Experimental Philosophy," 167. This molding to fit hypotheses was exactly what someone like Boyle was cautioning *against* in advocating an experimental approach to philosophy, but this only serves to demonstrate the wide array of stances possible in that general approach. For more on experiments performed with a particular matter theory in mind, see Gaukroger, *Emergence of a Scientific Culture*, chap. 10.

90 Power, *Experimental Philosophy*, 38–39.

91 Ibid., 61.

but as a messier tool of enquiry which could generate novel and unfamiliar views.[92] It is therefore possible to identify, even between contemporary users of the instrument, two very different ideas about why the microscope was useful for natural philosophers.

Visual Epistemology

In both Hooke and Power, microscopes pushed the limits of knowledge beyond the limits of naked eyesight, and in both analogies are wielded as explanatory bridges to cross the gap. But the devil is in the details. Power's observations were visual evidence for invisible things; he used analogy and likeness to move from the observable to unobservable. The way Hooke used analogy returns us to the pictorial origins of Hooke's microscopy. An image is always of a *particular* thing: in the words of Raz Chen-Morris, "the painted picture can create, as if by magic, a perfect deception, but only of a particular accident. It cannot convey or recreate the essence of a physical object."[93] For this reason, the relation between pictorial representation and philosophical knowledge in the early modern period is as fascinating as it is complex. Hooke, for one, emphasised the importance of images for the natural historian, as I mentioned above. Pictures helped the historian both "express his Ideas the better to himself [...] and also for the better informing and instructing of others."[94] Such informing and instructing take place precisely by describing a particular accident – *not* attempting to 'recreate the essence of a physical object,' but by showing it from a limited perspective. What this meant through the microscope was that Hooke's images frequently became pictures of other objects.

Unlike Power's, Hooke's analogies are not between the observable and the unobservable, but between the familiar observed and the unfamiliar observed.[95] Descriptions of

92 Where he mentions Cartesian ideas in *Micrographia* it is more frequently to *refute* Descartes' specific ideas: for example on the production of colours, see Chapter 3.
93 Chen-Morris, "From Emblems to Diagrams," 135.
94 "General Scheme," in Hooke, *Posthumous Works*, 20.
95 Alan Gabbey has identified these two as prominent explanatory categories in early modern mechanical philosophy: Gabbey, "Mechanical Philosophies and Their Explanations." See also Gaukroger, *Explanatory Structures*.

insect eyes like rubies, or seeds like honey-comb can be found in Power, but with nothing like the regularity or liveliness of those comparisons Hooke makes: purslane seeds are nautilus shells, the razor's edge is an axe blade. The power of these analogies resides not in Hooke's descriptions but his giant images. A picture circumvents the necessity, present in verbal description, to analyse an object or a process into discrete, separate parts, each of which can be regarded as similar or dissimilar to another object or process. The viewer, not the reader, observes an object's form holistically, and directly understands through the image's similarity with what it represents. The power of this likeness need not be directly explanatory, but more broadly suggestive of continuities within nature or between nature and art. Hooke's visual analogies are 'horizontal' within the phenomenal realm rather than 'vertical' from the observed to the unobservable.[96] They are not themselves *explanans* of unobservable processes or a transcendent reality, but more often objects of mystery themselves, to be presented to ocular interrogation.

A quick tour of some of his images will be useful. The first of the book's thirty-eight schemes is of the great microscope itself. Thereafter, many other images appear presented on specimen slides or enclosed by circular frames: now we have seen the impressive system, we as readers look down through its lenses, partaking in the experience of the experimenter.[97] Our experience comes drawn to a scale, and labelled with letters for reference in the accompanying text. Take note, says Hooke, of the things hidden in an eighth of an inch. Here is the world, but not as you normally see it (see Figure 4.4).

96 See Gaukroger, *The Collapse of Mechanism and the Rise of Sensibility*, chap. 5.

97 See for instance schemes 2, 3, 5, 7, 9, 10, 11, 12, 14, 15, 21, 23. The parallel with the first book of *telescopic* observations are notable: in Galileo's *Sidereus Nuncius* the telescope "stretches out beyond the text [and] the reader and the viewer's sites are aligned," says Elizabeth Spiller: Spiller, *Science, Reading, and Renaissance Literature*, 110.

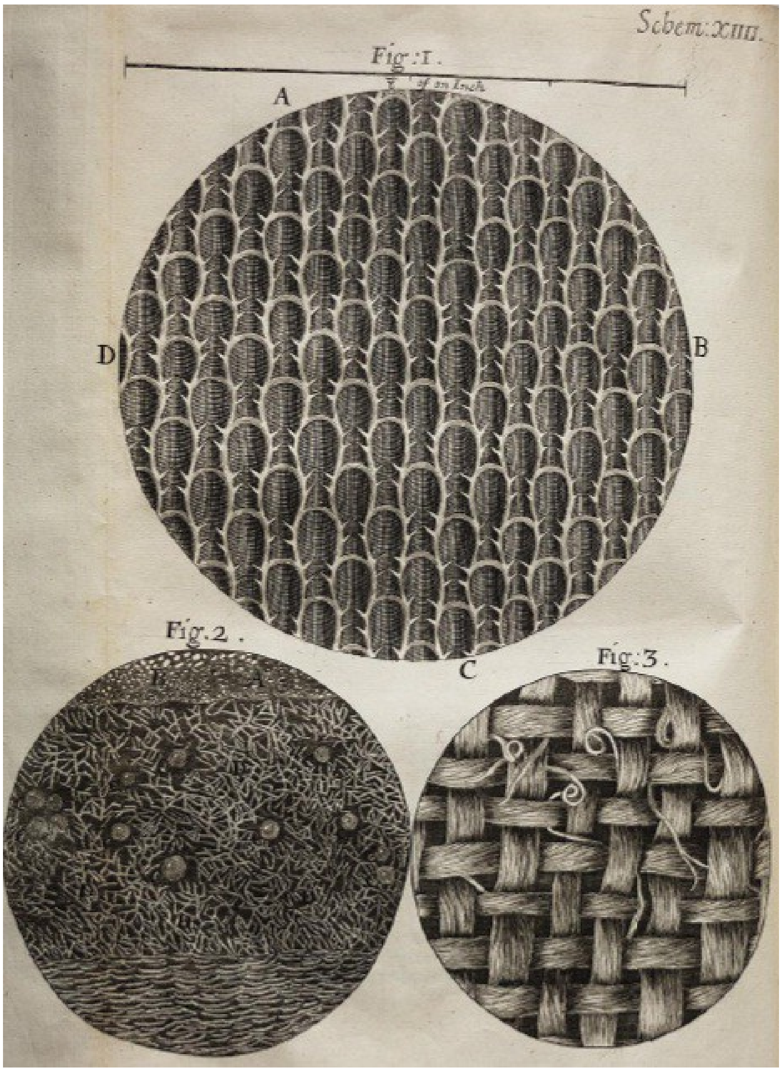

Figure 4.4: Surfaces of seaweed, rosemary leaf, and fine lawn, *Micrographia*, scheme 14, opposite p. 141.

After our first peek into the micro-world, the instrument becomes curiously transparent. In Scheme 18, thyme seeds spill uncontained across the page, and the climactic images of the ant, the flea, and the louse cannot be held by the book's bindings themselves – the last of these images folds out to four times the size of the large folio book. Immersed in the image and completely unaware of the instrumental mechanism behind our vision, as Michael Dennis says, Hooke's "microscopes and circumstances vanished into the page's white background."[98]

The diagrammatic letters that cling to these formidable insects are small reminders that the images are pedagogical, but the main thing we are aware of is confronting these creatures as

98 Dennis, "Graphic Understanding," 341.

our incongruent equals. Our perspective has changed – we no longer experience them as humans would. Hooke writes of "the strength and beauty" of a flea, the "great claws" of crustaceans, the "horns" of a gnat "almost like the horns of an Oxe."[99]

Figure 4.5: Tufted Gnat, from *Micrographia*, scheme 28, opposite. p. 193.

99 Hooke, *Micrographia*, 210, 178, 185.

These are the qualities of the oversized creatures of the images – of giants not of small insects. Hooke's images, made through transformed eyes, do not reflect *human* sensibility.

The point of the comparison with Power's work is not that the unillustrated *Experimental Philosophy* does represent things from a human perspective. It is rather that Power's experimental approach leads him directly to objective knowledge of things, a view from nowhere. Hooke's extension of his natural vision simply replaces it with a different kind of vision. The objects Hooke depicts really look like – really become – *other* objects. Smooth silk is a woven net, seaweed is scales. When Hooke shows us that thyme seeds look like a bowl of lemons, we are no closer to seeing the essence of thyme seeds. The art that he makes through his microscope can be seen as a kind of anamorphosis. There is a clear discord between the armoured giants we see and their familiar and vulgar insect names. Knowing how to view the images – knowing that they were made through a magnifying lens – resolves the confusion, as standing to the side of Hans Holbein's *The Ambassadors* makes makes sense of the smear across the foreground.

Lookalikes

Stuart Clark has suggested the popularity of anamorphic images in the seventeenth century indicates an uneasiness in the period about whether visual evidence could be considered objective, even as such objectivity was becoming formalised in mathematical rules of perspective. The anxiety increased as the importance of visual evidence swelled with the rise of empiricism.[100] Certainly the way some people read optical instruments denied that they might possibly lead to objective knowledge. Margaret Cavendish concluded from Hooke's images that a "natural figure may be presented in as monstrous a shape, as it may appear misshapen rather than natural."[101] A microscope showed things exactly as they are not. Magnified out of recognition, a louse looks like a crab, appears as big as an elephant, but is after all still a louse. But what is this 'natural' state

100 Clark, *Vanities of the Eye*, 91–96.
101 Cavendish, "Observations upon Experimental Philosophy," 8.

that a magnifying glass never represents? For Cavendish it was exactly what the object is to a human. We can be sure of this verity through function: a knife that is sharp to the touch looks blunt when magnified.[102] But "if the edge of a knife or the point of a needle were naturally and really so as the microscope presents them, they would never be so useful as they are."[103] Her words are of course directed at Hooke – the needle and the razor's edge are the first two observations in *Micrographia*.

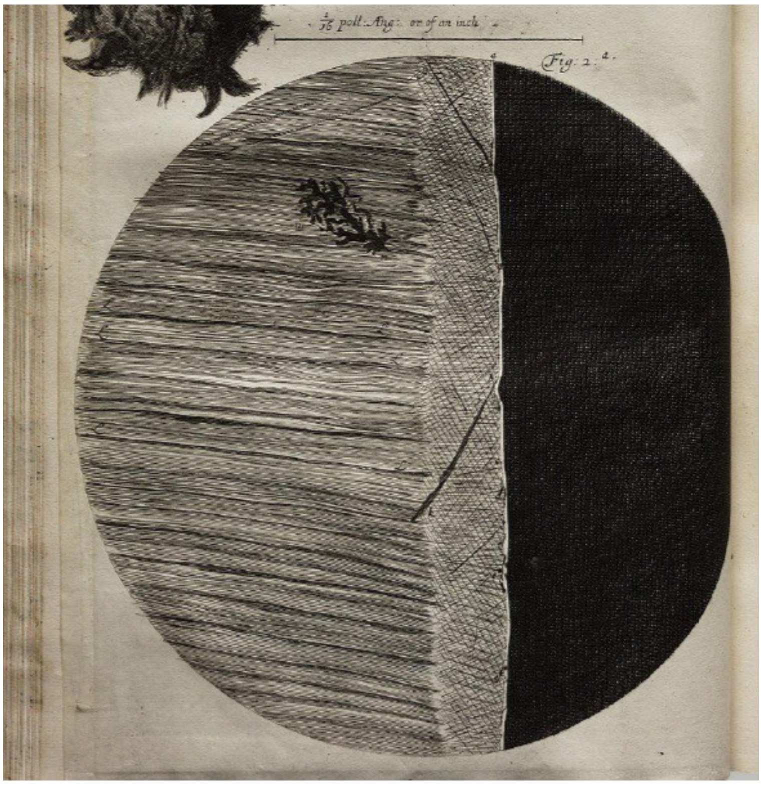

Figure 4.6: Hooke's drawing of a razor's edge, *Micrographia*, scheme 2, fig. 2, opposite p. 1.

Interestingly, Hooke agrees to a certain extent. If the razor "had been really such as it appear'd through the Microscope, it would scarcely have serv'd to cleave wood, much less to have cut off the hair of beards." But then he relates its new function, as a new object. "Unless," he continues, "it were after the manner Lucien merrily relates Charon to have made use of, when

102 This contrasts interestingly with Bacon's view of the relationship between the senses, truth, and utility, as I will return to in the following chapter.
103 Cavendish, "Observations upon Experimental Philosophy," 9.

with a Carpenter's Axe he chop'd off the beard of a sage Philosopher, whose gravity he very cautiously fear'd would indanger the oversetting of his Wherry."[104]

Hooke implies that as long as you are aware of the perspective, there is little unnerving about anamorphic images. They are merely visions occulted from the causal observer. No doubt the razor's normal function is impaired, but it now it has become a different object, with a different use. Hooke makes the Cavendish's worry into a joke. Lucian's Charon stood ready to ferry his passengers across the styx, but he warned his boat was small and leaky. The passengers must leave all their baggage on the shore. One by one they are dispossessed, youths leaving behind their beauty and tyrants their cruelty. Menippus the Cynic, who had already left his baggage at home, takes great delight in pointing out the baggage of the philosopher: "idle questionings, prickly arguments, intricate conceptions; humbug and gammon and wishy-washy hair-splittings without end," to name a few, and cut his beard off with an axe.[105] Hooke's agenda is clear. The microscope-enlarged edge of a razor is not as it is to the naked eye. But this alteration itself has a function: robbing philosophers of their preconceived ideas, and teaching us that things are not what they seem. No deception is intended, merely a change of perspective. Berkeley later pointed out that an insect must see its own legs as "bodies of some considerable dimension."[106] The similar insight is that vision at a human-scale is not the only possible view. Or as John Wilkins wrote in his speculative work *A World in the Moon*, objects might have a dual role, one for humans and one for other beings. The same body could be "a World, and a Moon; a World for Habitation, and a Moon for the use of others, and the Ornament of the whole Frame of Nature."[107] In a quote I gave at the beginning of the chapter, he made a similar point about lice: "there may be other insects that live upon them as they doe upon us."[108] Hooke's objects

104 Hooke, *Micrographia*, 5.
105 Lucian, *Dialogues of the Dead*, 'Charon and Hermes'. In Fowler and Fowler, *The Works of Lucian of Samosata*, 1:121.
106 Berkeley, *Three Dialogues*, 32. Compare with the Aristotelian objection to atomism that creatures with differently sharp eyes would live in different worlds to one another: Lüthy, "Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy," 11 ff.
107 Wilkins, *The Discovery of a World in the Moone*, 43.
108 Wilkins, *Mathematicall Magick*, 115–116.

likewise have one appearance to the human sense, and another to microscope eyes.

Through his lenses Hooke encountered the very same forms and figures on different scales. The same processes and mechanisms that we are familiar with in macroscopic processes – the operation of a lever for instance – exist and explain nature at the micro-scale as well. Seeing such tiny machines suggested to him not a gap but a continuity of nature.

> [T]here is but a small difference between Earth and strong Concretions, between such Concretions and Salt, between the crystallizing, and shooting of Salt, and the Vegetation of Mould, and less between the Vegetation of Mould and Mushrooms, and but a very little between the Vegetation of Mushrooms and Moss, and as little between Moss and Grass, and between Grass and the most bulky Vegetable, and no great matter between the Vegetation of Plants and Zoophyts, and there is no great Difference between Maritime Zoophyts and Oysters, Blubbers and the like; between those and Periwinkles, and other kinds of Shell-fish, between Shell-fish and crustaceous Creatures, between those and Fishes, between Fishes and amphibious Creatures, such as Morses and Sea-Calves, and the like, between those and Aerial Animals, &c.[109]

By replacing natural vision with artificial senses we can move seamlessly through different scales of nature. By holding his eyes in his hands, by adopting the sense of a different creature, Hooke divorced his observations from the human scale. Here again is the anamorphosis of his images.

> [A thyme seed] affords a very pretty Object for the *Microscope*, namely, a Dish of Lemmons plac'd in a very little room; should a Lemmon or Nut be proportionably magnify'd to what this seed of Tyme [*sic.*] is, it would make it appear as bigg as a large Hay-reek (haystack), and it would be no great wonder to see *Homers Iliads*, and *Homer* and all, cramm'd into such a Nut-shell.[110]

109 "General Scheme," in Hooke, *Posthumous Works*, 47.
110 Hooke, *Micrographia*, 153.

Pictures, the original purpose of *Micrographia*, gave Hooke the freedom to reconceptualise minute objects as larger ones, relatable and understandable by their *visual* similarity to familiar things. Hooke's allusion to the legend of the *Iliad* written so small it could be stored inside a nut, while not exactly lending plausibility to the story itself, recognises that microscopical discoveries make such things credible. Size doesn't matter; a man could be the size of a lemon.

With the “new visible World” that the microscope reveals, familiar objects are made to look alien, and then familiar again by analogy with a different object.[111] Interesting in connection with this idea is the relative lack of neologisms that Felicity Henderson has noted in *Micrographia*. Hooke's contemporaries and fellows were great linguistic innovators, and it could be expected that a book so full of unfamiliar visions would be full of new phrases and words to describe the unfamiliar things he was seeing. Instead, Hooke chose to use familiar terms and similar objects to relate them to his audience (think of his famous coining of the word “cell” for its biological use).[112]

The epistemological import of all this is two-fold. One aspect is a general one about the new accessibility of nature to humans, and the other is more specifically about the benefits of looking at tiny things. I will return to a comparison with Henry Power to bring out the connection Hooke maintained between mechanical philosophy and the microscope.

The Machines of Nature

Hooke was much more ambiguous than Power about the connection between instruments and a particular ontology. At his most extravagant he suggests that it is:

111 Hooke, *Micrographia*, sigs. A2r-v.
112 Henderson, “Door-Mats and Penumbras.”

> not unlikely, but that there may be yet invented several other helps for the eye, as much exceeding those already found, as those do the bare eye, such as by which we may perhaps be able to discover *living Creatures* in the Moon, or other Planets, the *figures* of the compounding Particles of matter, and the particular *Schematisms* and *Textures* of Bodies.[113]

But this is a contrast between such helps and the microscope. As in Locke, the possibility of seeing the "compounding Particles of matter" would not come from merely sharper eyesight, but from a different sense. All a lens does is reveal more detail about an object, not a fundamental explanation. The underlying epistemological insight of Hooke's microscope is, as we saw in Wilkins at the beginning of this chapter, not really about the observed things at all but ourselves. Our senses are not for the direct acquisition of knowledge but to suit our daily business. Hooke and Wilkins took seriously Bacon's idea that the senses were made to the "measure of man."

Of course this was not completely divorced from mechanical philosophy. Hooke thought that microscopes helped by revealing things humans cannot naturally see:

> the subtility of the composition of Bodies, the structure of their parts, the various texture of their matter, the instruments and manner of their inward motions, and all the other possible appearances of things. [… A]ll which the ancient *Peripateticks* were content to comprehend in two general and (unless further explain'd) useless words of *Matter* and *Form*.[114]

Hooke was unsatisfied with Aristotelian hylomorphic ideas of nature, and wanted to reduce them to lower level explanations. But within this broad mechanistic worldview his microscopical programme is almost the reverse of Power's. Power sought unseen but assumed effluvia or particles, to add visual evidence to his warrant for believing in them. Hooke sought different and surprising ways to look at objects he had already seen: the "other possible

113 Hooke, *Micrographia*, sig. B2v.
114 Ibid., sig. A2v.

appearances of things." His methodology in adding "*artificial Organs* to the *natural*" is an extension of his practice *with* the instrument: examining an object many times in different conditions before beginning to think that he had "discover'd the true form."[115] The key to knowing an object is to pay attention to its many different guises. For Hooke, holding a microscope was an opportunity to see things differently, and not be limited by our human perspective. From there we could "compare the several Informations we receive of the same thing, from the several Impressions it makes on the Organs of Sense and (by a Rejection of what is not consonant) by degrees to find out its Nature."[116] I will return to these compounded several informations, from instruments and unassisted senses, in Chapter 6, after leaving the experimental community to look more at Cavendish's criticisms in Chapter 5. Here I will conclude with a more particular connection between mechanical philosophy and Hooke's microscope.

If the main lesson is the contingency of human vision, the idea that objects are just little or big depending on one's perspective came with an important caveat.

> [I]n general […] the mechanical operations of [...] minute bodies are quite differing from those bodies of greater bulk, and the want of considering this one thing hath been the cause of very great absurdities in the Hypotheses of some of our more eminent modern Philosophers: For he that imagines the actions of these lesser bodies the same with those of larger and tractable bodies, will indeed make but *Aristotle's* wooden hand at best.[117]

Aristotle had said that shape and colour could not be all there was to an object, there must be some inner essence too.[118] Hooke agreed, but he thought such essence should be explained compositionally. Thus it was important to remember thyme seeds really were *not* lemons, only appeared on a continuum with them. The difference between different levels on the

115 Ibid., sigs. A2r, F2v.
116 "General Scheme," in Hooke, *Posthumous Works*, 9.
117 Hooke, "Microscopium," 94–95.
118 Aristotle, *On the Parts of Animals*, book 1, part 1.

chain of being was one of complexity: from the "elemental kingdom" of earth, water, and air, up to the "smallest and most despicable fly," there is at every step – mineral, vegetable, animal – an increase in the complexity of "Mechanisms and contrivances."[119] Here is the flip side to the limitations of our senses. All things are equipped with faculties to help it within the niche of nature it was designed for. But if our eyes produce vision by reacting to combinations of corpuscules, maybe smaller things react to simpler qualities in nature, and examining them could give us insight into these processes.

> [I]t were very worth while […] to see what Information may be learn'd of the nature, or use, or virtues of bodies, by their several forms and various excellencies and properties. […] Who knows, but the Creator may, in those characters, have written and engraven many of his most mysterious designs and counsels, and given man a capacity, which, assisted with diligence and industry, may be able to read and understand them.[120]

An important part of mechanical explanations of phenomena is conceiving of "the secret workings of Nature, almost in the same manner as we do those that are the productions of Art, and are manag'd by Wheels, and Engines, and Springs, that were devised by humane Wit."[121] This quest to find such "small *Machines* of *Nature*" was more than mere metaphor for a mechanistic description of the world.[122] Hooke really searched through the micro-world for natural machines. Seeds of thyme are moved by the sun like little "automatons or Engines;" spider legs are "long Leavers;" gnats are automata, "the excellent contrivance of their machine, [...] excite[s] and force[s] them to act after such and such a manner."[123] The beard of the wild oat, Hooke relates more fully, has often been an object of mystery and showmanship: magicians call it an Arabian spider leg, and mutter mystically while it unfurls by itself from a coil into a stiff,

119 Hooke, *Micrographia*, 154.
120 Ibid.
121 Hooke, *Micrographia*, sig. A2v.
122 Ibid., sig. G1r.
123 Ibid., 154, 199, 190.

straight line. In fact, Hooke tells us, moisture causes this motion. Through his microscope he could see the beard was a spongy substance which expands when it soaks up water, forcing it to straighten.[124] The natural phenomenon is explained by the structure and composition of the object's parts – cylinders and pores – just like a machine.

Once he had made this discovery, Hooke constructed an artificial machine from the natural one (Figure 4.7). Fixing a beard to a pointer, he could measure the moisture content of the air. Variations in humidity cause the beard to furl or unfurl, turning the pointer against a dial face.[125] What really illustrates the difference between Hooke and Power is that Hooke explicitly described this hygroscope, and a barometer he also built, as ways of "sensibly perceiving the *effluvia* of Bodies."[126]

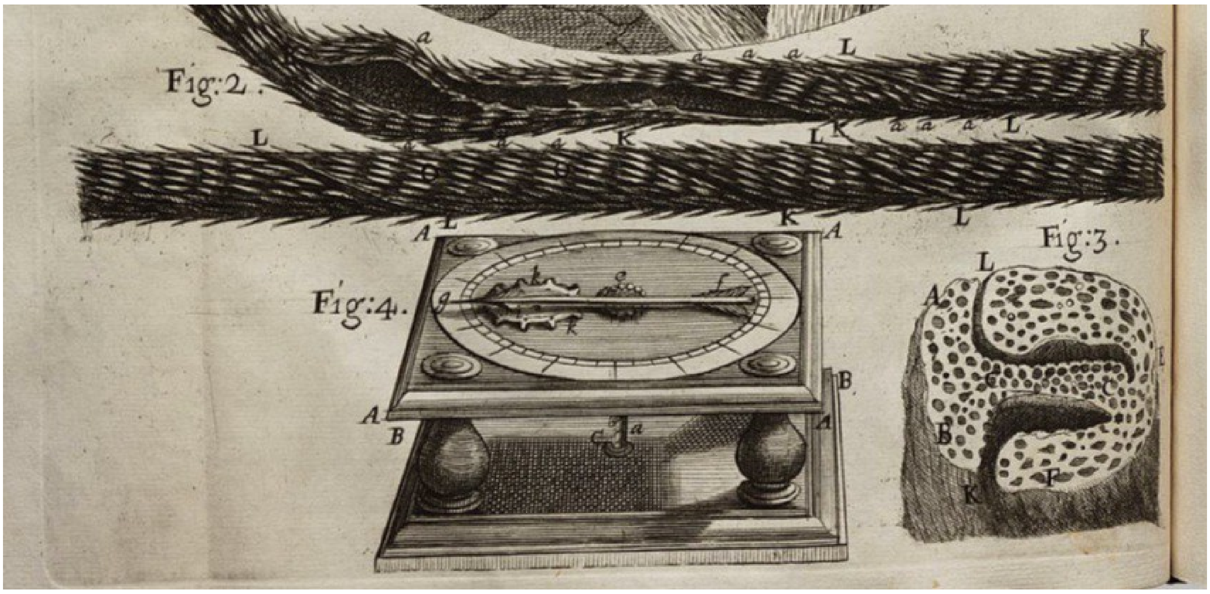

Figure 4.7: Hygroscope: Hooke's figures 2 and 3 are the beard of a wild oat, and his figure 4 is the hygroscope he built from it. *Micrographia*, scheme 15 detail, opposite p. 143.

124 Ibid., 147–149.

125 Koen Vermeir has written of, in a sense, the reversal of this story: Athanasius Kircher's sunflower seed clock. This was a device which appeared to react to sunlight but in fact was operated by magnet. Vermeir, "'Bent and Directed Towards Him.'"

126 Hooke, *Micrographia*, sig. C1r.

Hooke was not optimistic at one day *seeing* such effluvia, as Highmore had claimed to do. And where Power had analogised from the invisible motion of eels in vinegar to the invisible motion of corpuscles, Hooke identified a need to translate phenomena through instruments so as to make them measureable. Because a "sense" was just something that detected a certain kind of motion in or quality of a medium, any instrument that similarly reacted to natural qualities was "a way of improving some one sense."[127] Many of Hooke's instruments – the thermometer, the barometer, air pump or spring balance watch – can be seen as ways of allowing humans to observe invisible natural qualities: the structure of insects, air pressure, or time's passage.[128] If the microscope could never provide such direct experience of fundamental matter, it could help us design things that could.

Under the Surface

In 1693, the year after Hooke lamented that everyone except Leeuwenhoek was giving up on serious microscopy, he gave an illustrative analogy for the experience of the microscopist.[129] Imagine a "wild Indian" was given a watch inside a leather case, and told that this object divided each day from noon to noon into 24 hours, and would tell him at the end of each division how many hours had passed. The Indian, suggested Hooke, would surely put this remarkable ability down to a "very cunning creature" living inside the case, keeping time. But as he peels back the outer layers of the mysterious thing in his hand, he would understand more and more about its operation. Being a microscopist was like being this uneducated but inquisitive man. As each surface is taken away, the "spirit of the watch" gradually recedes into smaller and smaller parts of the device. When the Indian takes the watch out of its case, the spirit moves beneath the dial face, and makes the hands move and the bells toll. When he opens the face to reveal the movement, it sinks into the mechanism. But there is a limit. On seeing the wheels tick

127 Ibid., D1r.
128 See his discussion on Ibid., sig. C2v.
129 The following is from his lecture "The Uses and Advantage of Microscopes." See the Appendix.

and the springs rebound, the Indian surely "would still be at a Losse what twas that made these move," and would conclude that the spirit resided in those tiny machines.[130]

The microscope can pierce many surfaces that are opaque to the naked eye, revealing the operation of things within.[131] But with springs we reach the kind of minute mechanism that resists further ocular analysis. In 1679 Hooke explained the elasticity of springs in terms of vibrating particles.[132] His account here is in an entirely different mode, built *up* from definitions of body and motion, rather than analysed down from the behaviour of macroscopic bodies.[133] As we saw in the previous chapter, the importance for Hooke of such ultimate, matter theoretic explanations – as opposed to pragmatic, manipulative knowledge – is a difficult question, and one which will continue to raise its head in the remainder of this thesis. Whatever it was though, such stories owe both everything and nothing to his microscope. Everything in terms of being suggested by the intricate bodies revealed by his augmented senses, and nothing in terms of being inherently disconnected from immediate visual experience.

130 Hooke, "The Uses and Advantage of Microscopes," f. 2–3.
131 Ibid., f. 1–2. See Hooke's famous observation of the innards of a louse: Hooke, *Micrographia*, 211. Power makes this same observation, but does not emphasise this aspect of microscopy anything like as much.
132 This was his research which made him eponymous with the law of springs: "The Power of any Spring is in the same proportion with the Tension thereof" Hooke, "Of Spring," 1.
133 See Hooke, "Of Spring", especially 6ff. He begins with a mathematical analysis of the behaviour of springs, before switching quite deliberately to matter theoretic explanation.

Chapter 5: Inhuman Pursuits

The Philosophical Duchess

If there was disagreement about the role of the microscope between experimental philosophers, its status outside this community was even more disputed. From one extreme way of looking at it, the way a microscope displays things to an observer is plainly fraudulent. Objects are altered from the way they naturally appear. Such optical tricks that bent and distorted vision had a history as objects of play and wonder. The idea that the microscope might therefore be in some way be useless, if not dangerous, perhaps strikes us as quaint, but was still a viable view in the mid-seventeenth century. Hooke was aware of the possible view, and wondered if Hevelius refused to use lenses for his astronomical observations in case they had a "hidden, un-intelligible, and mysterious way of representing the Object."[1] Hooke's own knowledge of theoretical optics perhaps made the idea seem silly, but ignorance was not the only or even the main feature of opponents to lens use.

In this chapter I will look at how the microscope and Hooke himself feature in the writing of a critic of the instrument and of experimental philosophy generally: Margaret Cavendish.

> I will not say, but Art may help to mend some defects, errors, or irregularities in Nature, but not make better that which Nature has made perfect already. Neither can we say, Man is defective, because he cannot flie as Birds: for flying is not his Natural and proper Motion; We should rather account that Man monstrous that could flie.[2]

1 Hooke, "Animadversions on the First Part of the Machina Coelestis," 11.
2 Cavendish, "Observations upon Experimental Philosophy," 32.

This invective was probably directed squarely at Hooke – he had expressed his aerial ambitions in his *Micrographia*, which was the main target of the lengthy critique of the experimental philosophy Cavendish published in 1666: *Observations upon Experimental Philosophy*.[3] But while this may have been a fairly mainstream view on what was still a fairly taboo aspiration in the seventeenth century, Cavendish's anti-instrumentalism extended also to activities that seem less obviously inhuman.[4] Hooke's late-century lament about the demise of the microscope with which I began the previous chapter was directed at people using the instrument but not for natural philosophical purposes. Cavendish thought we should call a spade a spade. The microscope would only ever produce distractions, not philosophical knowledge.

She was not naïve to microscopy. Despite claiming never to have practiced the art, her husband William owned some and Cavendish had read Hooke closely, and probably Power too.[5] She noted microscopists themselves admitted that objects appear differently under different conditions.[6] But rather than wonder how they could tell which was the true view, her opinion was that none of them could possibly be, for "the more the Figure is by Art magnified, the more it appears mis-shapen from the Natural."[7] Her general opinion of the art was that:

> those that invented Microscopes, and such like Dioptrical Glasses, at first, did, in my opinion, the World more injury than benefit; for this Art has intoxicated so many Mens brains, and wholly imployed their thoughts and bodily actions about Phaenomena, or the Exterior Figures of Objects, as all better Arts and Studies are laid aside. […] But though there be numerous Books written of the wonders of these Glasses, yet I cannot perceive any such, and at best, they are but superficial wonders.[8]

3 Hooke, *Micrographia*, sig. D1v.
4 See Viktoria Tkaczyk's work on early modern flight: Tkaczyk, *Himmels-Falten*; Tkaczyk, "Ready for Takeoff."
5 Cavendish, "Observations upon Experimental Philosophy," 7, sigs. A3r-v. Ironically, in *A Room of One's Own* Virginia Woolf used the very same instrument as an emblem of the scientific education that Cavendish, as a woman, had missed: "she should have had a microscope put in her hand."
6 Ibid., 9.
7 Ibid.
8 Ibid., 10.

In a sense, as I discussed in the previous chapter, seeing the surface was exactly the aim of many microscopists. Cavendish was certainly no corpuscularian, as we will see below. But that men's minds are "intoxicated" by an instrument that alters their bodies from "perfect" to "monstrous" suggests we need to look further than such differences to understand her concerns.

Cavendish had her own philosophy of nature, and she neither rejected all artifice nor did she advocate an uncomplicated rationalism over the experimenters' empirical bent.[9] My aim in examining her criticisms of the Royal Society, and Hooke's microscopical work in particular, is to give somewhat of a stranger's account of the then-as-yet-unproven experimental philosophy.[10] While the early Royal Society agonised over the king's entertainments and fought to establish the fruits of their work as anything other than ridiculous, Cavendish looked on and saw this struggle clearly. Inside Royal Society meetings it was accepted that the air pump or the microscope made natural phenomena available for the Fellows to examine. But from outside the community, the view was different. They were wasting their time with equipment that was known to be deceitful, and objects that were vulgar and unimportant.[11] Lenses straightforwardly distorted vision. And the experimentalists suggested that they might offer insight not in spite of this but *because* of it. Looking in more detail at Cavendish's complaints will help enrich to Hooke's position on artificial organs and the knowledge they provide.

A very literal instance of conflict between Cavendish and the Royal Society, which provides *in vivo* a peek at her view of the experimenal philosophy, was her famous visit to Arundel House on 30 May 1667. She was already their critic in print, and though Henry More was accurate in his prediction that as a woman "she may be secure from any one giving her the trouble of a reply," demonstrating their work to her seems to have caused the Society some

9 For Cavendish's contemporary relevance, see: Battigelli, *Margaret Cavendish and the Exiles of the Mind*; Sarasohn, *The Natural Philosophy of Margaret Cavendish*; Clucas, *A Princely Brave Woman*; Dear, "A Philosophical Duchess."

10 See Keller, "Producing Petty Gods." On the other hand, William Newman has found in Cavendish's radical criticism of art an "unwarranted extension of a reasoned objection well beyond its sphere of usefulness" (Newman, *Promethean Ambitions*, 288). Newman's work is valuable in placing Cavendish is the broader debate about the relation between nature and art, and he demonstrates the undeniable continuity of some of her views with those of earlier anti-alchemical figures (see pp. 286-287).

11 This was of course not a unique criticism. For example, for Hobbes' views see Shapin and Schaffer, *Leviathan and the Air Pump*. I will discuss other critics below.

anxiety.[12] The visit was proposed by a Fellow, Cavendish's friend Walter Charleton, but the Council debated hotly before allowing her visit, believing it would undermine their gravitas and "the town [would] be full of ballets of it."[13] She arrived to the meeting with her friends and attendants, and watched various experiments the Fellows had planned. Samuel Pepys did not hear her say "any thing that was worth hearing, but that she was full of admiration, all admiration. [...] After they had shown her many experiments, and she cried still she was full of admiration, she departed."[14] The only ballad written was by one of the Society's own, John Evelyn.[15] The occasion was not mentioned again, and the whole affair has an air of much ado about nothing.

It is fascinating to speculate on the complex dynamics of Cavendish's visit glossed by Pepys' disappointed sarcasm.[16] Hooke, a more laconic notetaker than Pepys, simply reported "Dutchess of newcastle intertayned," perhaps somewhat wishfully, with "weighing the air in a glasse."[17] This was of course exactly the experiment Charles II had chosen to mockingly sum up the Society's work in 1664.[18] In fact, the experiments prepared for Cavendish were mostly the same as those mooted to impress the king should he ever visit – that list so agonised over by Moray and Wren, conscious to show both the impressive and illuminating sides of experimental philosophy.[19] What did it mean for these experiments to be 'admired'?

Perhaps they hoped for a little more engagement from a natural philosopher they knew was critical of their ideas. To agree with them would have been ideal; to criticise would at least have been to engage. But to 'admire' was to treat them like entertainers: their greatest insecurity.

12 O'Neill, "Disappearing Ink," 23.
13 30 May 1667: Pepys, *The Diary of Samuel Pepys*, 1974, 8:243.
14 30 May 1667: Ibid.
15 Grant, *Margaret the First*, 24–26.
16 He seemed to have been so looking forward to meeting her too. In March, seeking to "understand her better," he had been to see a play of hers (30 March 1667), and when she visited London the following month, intrigued that "all she do is romantick" (11 April 1667), he spent a good deal of time and energy trying to run into her (26 April 1667; 1 May 1667; 10 May 1667). But when he finally did at the meeting, she did not please him. "I do not like her at all," he reported, and later called her a "mad, conceited, ridiculous woman" (18 March 1668) and her husband William mad to put up with her.
17 Hooke, "Hooke Folio," f. 64.
18 1 February 1663/4: Pepys, *The Diary of Samuel Pepys*, 1971, 5:33.
19 Compare the two lists: the King's in Birch, *The History of the Royal Society*, 1756, 1:312; the Dutchess' in Birch, *The History of the Royal Society*, 1756, 2:177. See again the letter from Christopher Wren to Viscount Brounker, 30 July/9 August 1663. In Birch, *The History of the Royal Society*, 1756, 1:288.

The Dutchess arrived in her own time, she stayed for a polite while, then left without comment. Barred from appearing as an equal or an interested observer as a male visitor to the Society might, Cavendish in any case treated her visit to Arundel House rather like any other London entertainment; a trip to the theatre or bear garden, accompanied by friends, surrounded by ladies and earls, with boys playing up and down the aisles.[20]

What made Cavendish discount any philosophical importance in the experimenters' work? The new forms of experience available through new instruments were intimately tied to a radical shift in the early modern understanding of humanity's place in the world. What the microscope's exact promise was, as we saw in ther previous chapter, was contentious. But adopting it in the first place relied on a certain view of the relationship between the understanding and the world, human nature, and the aims of a perfect natural philosophy. Within this shifting landscape, disagreement was non-trivial. Peter Harrison's contention that the main preoccupation of early modern natural philosophy was not straightforwardly methodological but anthropological offers a way to situate their disagreement.[21] Cavendish subverted the serious labours of the experimental philosophy by playing both on the experimenters' own assumptions about what they were doing and the very idea of what it was to be human. She was not simply a conservative reactionary nor an early modern technophobe, but a representative of a different view of nature and the purpose and possibility of human knowledge.

The Bear Necessities: the Form of Cavendish's Critique

A large part of the enthusiasm of the likes of Hooke and Wilkins was for the microscope as an imaginative aid; what it implied about the world was often more important than the magnified objects themselves.[22] Cavendish took a similarly imaginative but radically different

20 Pepys, *The Diary of Samuel Pepys*, 1971, 5:243.
21 Harrison, *The Fall of Man and the Foundations of Science*, 8.
22 I am grateful to Megan Baumhammer for this idea. See her Masters' thesis for more on this topic: Baumhammer, "Optical Instruments and the Early Modern Imagination."

approach to extra-human knowledge through a fictional journey in *The Description of a New World, Called the Blazing World*. Published in 1666 alongside her *Observations upon Natural Philosophy*, *The Blazing World* is a sort of proto-science fiction travel narrative of utopian invention.

The Blazing World is a place that is home to Cavendish's foundational metaphysics, a dense nest of invented realms, fictional counterparts, and fantastic hypotheticals. Towards the end, the author appears in the narrative as a character – imagined into the story world by the protagonist (who it is difficult not to think is *also* Cavendish's avatar), and the two of them imagine an infinity of imagined worlds of their own to live in. The book is easy to read as an allegory which plainly signifies anything.[23] But the disorienting narrative is anchored in evocative imagery which ties the Blazing World to our own, and playfully but forcefully criticises the intellectual climate of Cavendish's England. Such an anchor is the natives of the world: philosopically inclined animal-human hybrids. The beastial forms of the winged, finned, and furry philosophers arrests the reader's attention far more than the details of their discussions of contemporary natural philosophy. Particularly in the light of Cavendish's talk of monstrous or perfect nature, they provide an insight into Cavendish's particular beef with the experimental philosophy.

The story begins when the protagonist, a young Lady from a seaside town, is abducted by a travelling merchant. He is below her in birth and wealth, but driven by his passion to snatch her away while she's gathering shells on the beach. Out at sea, a swelling storm forces the ship off course, and towards the Arctic. It enters the Blazing World, a different world, connected to the first at their poles. If the Lady's world echoed Hobbesian mechanism – the merchant's actions, driven by his passions, were only overpowered by the greater violence of the storm – in the Blazing World, qualities and nature overrule physics. The ship glides through precipices of

23 The importance of rhetoric and imagination in Cavendish's works is well established and well discussed. Since Marjorie Nicolson passed over the 'ponderous tome' (*Voyages to the Moon*. there has been much excellent scholarship around the significance of the work's structure and form. See: Keller, "Producing Petty Gods"; Spiller, *Science, Reading, and Renaissance Literature*; Battigelli, *Margaret Cavendish and the Exiles of the Mind*; Bowerbank, "The Spider's Delight"; Lilley, *The Blazing World and Other Writings*.

ice, and the merchant and crew all freeze to death, but the Lady, protected by "the Light of her Beauty" and 'the heat of her Youth' survives. Her nature interrupts the mechanistic cause and effect of the freezing cold.[24] The blazing world thus instantiates Cavendish's natural philosophy: according to her, the ultimate causal and organising principle of the universe is self-knowledge.[25] In hylozoic fashion, nature, as one unified, infinite whole, is all there is.[26] As *The Blazing World* suggests, this matter is not inert and moved only by external forces but rather moves itself. Self-knowledge tells things how to act, and self-motion is how they act. A ball moves not because it is directly propelled by the throwing hand, but because it *perceives* the hand, and *knows* the appropriate motion to give itself.[27] Without this internal defining knowledge, the world would be chaos and "would run into Confusion: for, there could be neither Order nor Method, in Ignorant motion; neither would there be distinct kinds or sorts of Creatures."[28] Thus, the form of an object is both due to and imputes to it a form of self-knowledge relevant to it and to its surroundings. Knowledge and Kinds are inseparably linked – knowledge *creates* kind, and kinds have a particular domain of knowledge. The same is as true for humans as for anything else, our knowledge is limited to what is naturally available, as will become clear below. When the Lady's boat is pulled to shore by a group of "strange Creatures, in shape like Bears, only they went upright as men," we catch a first glimpse of an explicit, outward manifestation of these inner qualities.[29]

24 Cavendish, "The Blazing World," 2.
25 Cavendish, "Observations upon Experimental Philosophy," 280.
26 While her view is entirely monistic, Cavendish describes matter in different ways: 'rational' or 'sensible' if it is animate, and 'inanimate' if it is not. Animate matter is that which is self-moving and self-knowing, though in fact rational *and* sensible matter both move *and* know, and there is little difference between the two activities (see for instance Ibid., 278). The difference seems to lie in rational matter "being purer, and so more agil and free" than sensible. This seems intended quite literally – rational matter, existing presumably in the brain, is more separate from and less encumbered by inanimate matter than is the sensible matter that makes up the body. Because it can move more "agil and free" it can create more easily than can sensible matter (Cavendish, *Grounds of Natural Philosophy*, 5.). Hence Cavendish's rationalism: understanding implies creating, which implies motion, and it is easier to create a situation in your head than it is with your hands. Hence, in part, the narrative form of *The Blazing World*.
27 See: Michaelian, "Margaret Cavendish's Epistemology."
28 Cavendish, *Grounds of Natural Philosophy*, 7.
29 Cavendish, "The Blazing World," 4. The resonance of the polar connection between worlds and the furry arctic inhabitants with the search for the north-west passage has been discussed by Cottegnies, "Utopia, Millenarianism, and the Baconian Programme of Margaret Cavendish's The Blazing World."

All the denizens of the Blazing World are hybrids of human and other: sentient and civil, yet physically suited to their environment. The Lady travels south from the bear-men's cold home and meets bird-men on islands; satyrs in forests; worm-men, giants and people with green or azure skin. Like Hooke looking through a microscope, the Lady is awed and bewildered by the novelty and variety of the new world. At last she meets the Emperor, who offers to worship her as a goddess. When she refuses he marries her instead and vanishes from the story.[30] As Empress she gains absolute governance over the whole world, and with political power comes epistemic privilege: her position brings her the attention and loyalty of the animal-men, who all turn out to be astute students of their various habitats, and she is able to question them at length.

Each animal-man's profession was "most proper for the nature of their Species:"

> The Bear-men were to be her Experimental Philosophers, the Bird-men her Astronomers, the Fly- Worm- and Fish-men her Natural Philosophers, the Ape-men her Chymists, the Satyrs her Galenick Physicians, the Fox-men her Politicians, the Spider- and Lice-men her Mathematicians, the Jackdaw- Magpie and Parrot-men her Orators and Logicians, the Gyants her Architects, *&c.*[31]

Some she receives better than others. The insectile natural philosophers are a particular hit, offering intimate knowledge of the air, sea, and earth their tiny bodies are built to live in. The Empress dismisses out of hand the ape-men's mimicry of nature with chymistry, and while the bird-men veer into flighty speculation too often for her liking, their observations are acceptable.[32] Only her generous arctic hosts, the unfortunate bear-men experimenters, she engages in an extended argument. They "intertayn" her with observations lifted straight from *Micrographia* – surprising visions of lice as big as elephants, mites like whales, eyes that look like pearls. The

30 Cavendish's feminism has been a point of contention philosophy has been discussed by, among others: Sarasohn, "A Science Turned Upside Down"; Boyle, "Margaret Cavendish's Nonfeminist Natural Philosophy"; Keller, "Producing Petty Gods"; Dear, "A Philosophical Duchess."

31 Cavendish, "The Blazing World," 15–16.

32 See Newman for the parallel between her criticism of chymistry and those of earlier writers: Newman, *Promethean Ambitions*, 286–287.

bear-men show the Empress that nothing was as it seemed.[33] For them, as for Hooke, this was of course the point of the instrument. When the Empress baits them by suggesting that "perhaps their Microscopes did not truly inform them?" they grow coy and "smilingly answer:" perhaps it was the Empress who did not fully understand microscopes? The instrument does not deceive, but "rectifie and inform the Senses." Echoing Hooke's preface, they tell her "the World […] would be blind without them, as it has been in former ages."[34] Cavendish is clearly familiar with Hooke's rhetoric as well as his observations, but she remained unmoved. The Empress tears apart the bear-men's ideas about charcoal, stinging nettles, fleas and lice.[35]

Most species-profession fits have a resonance still obvious to us now, and others come out in their conversations. As for the bears, mid-sized and mammalian, they have no radically different insight into nature from humans, nor any particular skill in manipulating instruments. Cavendish's audience would have been familiar with the animal from one main form in Tudor and Stuart England: objects of brutal entertainment. They were chained to stakes in bear gardens, where they were made to fight waves of trained dogs.[36] The bear garden, carried by association into the Blazing World, colours the Empress' visit to her experimental philosophers with a particular view of the people of that profession. The laboratory was a place inhabited by unfortunate creatures, engaged with mortal seriousness in a pursuit ultimately ridiculous and entertaining for others. While they laboured gradually for the improvement of the human condition, outsiders looked on and laughed.

Cavendish's treatment of Hooke as a bear-man has a particular bite. He was not naïve about his practices, and the animal caricature leans on Hooke's own self-conception of artifice allowing him to leave his human limits. The bear-men are a burlesque subversion of this

33 Cavendish, "The Blazing World," 29. For the corresponding observations in Hooke's work, see his *Micrographia*, 211, 205, 175.

34 Cavendish, "The Blazing World," 30. p. 30. See for parallels: Hooke, *Micrographia*, sig. D1v; Power, *Experimental Philosophy*, sigs. A4v-B1v.

35 Cavendish, "The Blazing World," 31–32. See also Cavendish, "Observations upon Experimental Philosophy," 9. For Hooke's observations, see again his *Micrographia*, 100, 142, 210, 211.

36 Lisa Sarasohn makes this connection: Sarasohn, *The Natural Philosophy of Margaret Cavendish*, 165–170. This was likely a peculiarly English resonance. In France, 'bear' was the nickname of skilled printers operating a press, whereas in England they were known as 'horses.' See Johns, *The Nature of the Book*, 92.

ambition: a caricature of the willful and deliberate transgression of human nature that instruments appeared to allow. The furry forms of Cavendish's story reverse the expected direction of enquiry: instead of the bear-men teaching the Empress about nature, we learn from their interaction an important lesson about the experimenters and the experimental space.

The Royal Society's Early Critics, and Their Responses

Cavendish was of course not alone in mocking the Royal Society and contrasting their ignoble work with their rhetoric of betterment and improvement. While the Fellows stressed that useful knowledge was the goal of their approach, it was not easy to read much of this in their early works. In 1670, Henry Stubbe summed up the mechanical philosophy as teaching "*Aphorisms of Cider, planting of Orchards, making of Optick Glasses, magnetick* and *hortulane Curiosities*." This is not a bad summary of the first books written by people belonging to the tradition in England: Gilbert's *De Magnete*, Evelyn's *Sylva* and the microscopical works of Hooke and Power. In contrast, it was "*useful* and requisite" Humanist learning which Stubbe thought deserved public encouragement.[37] The force of the criticism came from the idea that the aim of philosophy was to understand ourselves, our relation to the natural world, and thus to God. Stubbe was fairly acquainted with experimental philosophy, and not always opposed to its results, but Meric Casaubon pointed at a more essential conflict between experiment and usefulness.[38] The most useful philosophy, he argued, is that which concentrates on the eternal rather than the temporal, and he chastised the Royal Society for not focusing on moral philosophy and theology.[39]

In fact, a general fruitlessness or misguidedness is the point of most jibes at the early Royal Society, from Thomas Shadwell's *Virtuoso* to their patron Charles II, and indeed Margaret

37 Stubbe, *The "Plus Ultra" Reduced to a "Non Plus,"* 13.
38 See Stubbe's mockery of Glanvill for not understanding Hooke and Boyle's work on pneumatics (Ibid., 165), and Hooke's inaccurate microscopical observations compared with Niccolo Zucchio's *Optica philosophia* (1656) (175).
39 See his Casaubon, *A Letter of Meric Casaubon*.

Cavendish.[40] Responses to this attack – the most important coming from Boyle, Sprat, and Glanvill – tended to follow on from the ideas of their figurehead Francis Bacon.[41] Partly through a particular theological anthropology which I will discuss more fully below, Bacon elided practical and moral usefulness – what was beneficial in this life also prepares one for the next.[42]

A small example will illustrate this, and bring us back to microscopes more particularly. In the late 1650s, when Hooke was in Oxford with Wilkin's Wadham College group, the political writer James Harrington criticised their work, and Matthew Wren responded. Harrington likewise chastised the group for being distracted by unimportant things. The "University Wits," he wrote, are "good at two Things, at diminishing a Commonwealth and at Multiplying a Louse."[43] Wren found this particular phrase "a little less intelligible then so fine a piece ought to be," and corrected it: "What he cals Multiplying a Louse ought to have been Magnifying, for the thing is done by a Microscope or Magnifying Glass."[44] What seems merely pedantic is in fact quite revealing about the opposing views on the practice. Wren spent two pages expanding on and clarifying Harrington's passing comment, and in doing so betrays a belief that if people were more aware of the method behind microscopy, they would accept it. The "multiplied" louse is a dangerous prospect, wrestling the attention of learned men away from more important civic philosophy. Wren was keen to impress on his readers that this was a distortion of the art. His cousin Christopher carefully measured the magnifying power of his lenses, and drew detailed pictures of things to scale. This was no unruly multiplication but a deliberate and measured exercise. Wilkins' group's microscopical work was safe and methodical. They may have been convinced God's wisdom was no less on display in the parts of a louse than in an elephant or camel, but they still knew it was, after all, a louse. Their drawings were not only delightful and

40 Harrison, "'The Fashioned Image of Poetry or the Regular Instruction of Philosophy?.'"

41 Boyle, *Usefulness of Natural Philosophy*, in Boyle, *The Works of Robert Boyle*, 1999; Sprat, *The History of the Royal Society*; Glanvill, *Plus Ultra*.

42 Harrison, "'The Fashioned Image of Poetry or the Regular Instruction of Philosophy?.'" See also Vickers, "Bacon's so-Called 'Utilitarianism'"; Rossi, "Bacon's Idea of Science."

43 Harrington, *The Prerogative of Popular Government*, sigs. A2r-v.

44 Wren, *Monarchy Asserted*, sig. A7v. Interestingly, in recounting the published debate, Wren's obituary silently corrects Harrington with Wren's phrasing too: Birch, *The History of the Royal Society*, 1757, 3:65.

instructive, but politically important, having been "received with applause by Foreign Princes," and even edifying: Wren relates Gassendi's story of Nicolas Pieresc learning to master his passions after watching a louse grow distracted and tormented through a microscope.[45] Finally, having defended microscopy, he collapses the lesson back onto Harrington himself. Harrington is an angry and tormented author, flailing and bristling about things he does not understand, "and yet an haire is enough to hold him."[46] With a diminuitive metaphor and an emphasis on the mathematical rigour of the group's method, Wren shows it is Harrington, not microscopists, who dangerously conflate large and small issues. The story is similar to Hooke's reference of Lucian I discussed in the previous chapter. The value of microscopy is exactly the recognition that it does not produce human visions.

Casaubon had also read Gassendi's story about Pieresc, and was of course unimpressed by it. He had probably "made this pretty story […] to gratifie some friends, who would be glad to hear what use can be made […] of a microscope."[47] Such unmitigated scepticism about the usefulness of the instrument is one extreme of a range of views. At the other end we find Hooke or Power arguing that it would provide the foundations of a reformed natural philosophy. As I mentioned above, Cavendish was herself a natural philosopher, and even agreed with the improvement of worldly conditions through certain artifice. When she disagreed with microscopical work in particular it was because she and the experimenters differed on their ideas of nature and humanity's place within it. To see the specifics of this I will first turn to the place of experimental philosophy generally, and the microscope specifically, within more general apologetics for the study of nature. This will let us see precisely on what terms Cavendish and Hooke diverged.

45 Wren, *Monarchy Asserted*, sig. A8r. He references Gassendi's *Vita Piereskii*, book 6.
46 Ibid., sig. A8r.
47 Casaubon, *A Letter of Meric Casaubon*, 32.

The Study of Nature: Animals and Instruments

As with Pieresc and the louse, early microscopes became appended to more general apologetic themes in early modern naturalism.[48] Henry Power, for instance, lifted whole phrases of his *Experimental Philosophy* almost verbatim from Thomas Browne's *Religio Medici*. *Religio Medici* was explicitly a defense of physicians against the charge of atheism – the older doctor was an avowed advocate of natural philosophy's reverent aspect. He wrote:

> The world is made to be inhabited by beasts, but studied and contemplated by man: 'tis the debt of our reason wee owe unto God, and the homage wee pay for not being beasts; without this the world is still as though it had not been, or as it was before the sixth day when as yet there was not a Creature that could conceive or say there was a World.[49]

The investigation of nature not only leads to a greater appreciation of God's great design, but is itself an act of reverence and even Creation. This was an extension of an older tradition of the study of nature as reading God's 'second book.' As the thirteenth century theologian Thomas of Chobham wrote:

> The Lord created different creatures with different natures not only for the sustenance of man, but also for their instruction, so that through the same creature we may contemplate not only what may be useful to use in the body, but also what may be useful in the soul [. … T]here is no creature in which we may not contemplate some property belonging to it which may lead us to imitate God, or some property which may move us to flee from the devil.[50]

Virtues and vices were on display in particular animals – nature could be studied as a way to redemption. "Go to the ant, thou sluggard," Solomon commanded. "Consider her ways,

48 See Harrison for the rising need for apologetics in natural philosophy as the idea that Man was a microcosm of the natural world gave way, and study of nature stopped also being the study of Man: Harrison, "'The Fashioned Image of Poetry or the Regular Instruction of Philosophy?.'"

49 Browne, "Religio Medici," 18.

50 From his *Summa de arte praedicandi*, quoted in Cohen, *Animals as Disguised Symbols in Renaissance Art*, 46.

and be wise."[51] Animal behaviour offered human lessons. The ant was a model of piety, bees of industry, the emergent butterfly was an allegory for Jesus. This physico-theology was a widespread defense of natural study throughout the Renaissance, and was inherited by the seventeenth century experimental philosophers as a justification of their active, investigative approach to natural knowledge. After Bacon advocated learning about natural processes through the operation of art and machinery, physico-theology reappeared under the microscope.[52] Suddenly, with his microscopes, Hooke could tell us that Aristotle's and Pliny's natural histories contained only the "obvious things" in the world.[53] Power wrote it was only "ruder heads" who still stood amazed at the "Collosean pieces of Nature, as Whales, Elephants, and Dromedaries;" whereas it was in the "narrow Engines" of insects where a more "curious Mathematicks" was displayed.[54] It was an astonishing discovery to see that such tiny bodies had mouths and stomachs and generally so many of the same parts and functions as larger ones.[55] Christopher Wren concluded that "the Perfection of Telescopes, and Microscopes [...] seems to be the only Way to penetrate into the most hidden Parts of Nature, and to make the most of the Creation."[56]

The English experimenters of the mid-seventeenth century placed emphasis on two aspects of this apology more specifically. One was the utility of nature not only for learning lessons in piety but for making mortal life easier.[57] The other was the growing idea that artifice replicated natural effects, most importantly those which were innately inaccessible to humans. Hooke thus opened *Micrographia* with this instrumentalist echo of Thomas Browne:

51 Proverbs 6:6. Casaubon was predictably unimpressed by even this venerable instruction, noting it was meant for sluggards who themselves are little better than ants, not learned men. Besides, the communal ant is one thing, the bloodsucking louse quite another. Casaubon, *A Letter of Meric Casaubon*, 33.

52 Wilkins used the discoveries of the microscope as analogical evidence for the obscurity of the providential lessons we could learn from nature: Wilkins, *Discourse Concerning the Beauty of Providence*, 49.

53 "General Scheme," in Hooke, *Posthumous Works*, 3.

54 Power, *Experimental Philosophy*, sigs. B3r-v.

55 For example, see Ibid., 20.

56 Wren, *Parentalia*, 204.

57 Especially noteable is Power's reference to Charles Butler for the civic lessons that can be learnt from bees, and his emphasis that Butler is "an experimental and not theoretical writer on that subject." Power, *Experimental Philosophy*, 4.

> It is the great prerogative of Mankind above other Creatures, that we are not only able to *behold* the works of *Nature*, or barely to *sustein* our lives by them, but we have also the power of *considering, comparing, altering, assisting,* and *improving* them to various uses. And as this is the peculiar priviledge of humane Nature in general, so is it capable of being so far advanced by the helps of Art, and Experience, as to make some Men excel others in their Observations, and Deductions, almost as much as they do Beasts.[58]

The responsibility that human reason bestowed on Browne, to admire and admit of nature's wonders, for Hooke was a privilege to be used for our benefit. Instruments would benefit those who used them as much as "humane Nature" benefited humans over other animals.[59] Instruments were not distractions, and they did not produce new and unnatural effects but natural ones. Boyle held that the "true Naturalist" was "ennabled by his skill not barely to understand several Wonders of Nature, but also partly to imitate, and partly to multiply and improve them."[60] Natural philosophy ought not to be a contemplative art but one that granted imitative skill.[61] Cesare Ripa's *Iconologia*, a compendium of emblematic representations drawn from various traditions first published in 1593, illustrated idea of art mimicking nature. Artifice was illustrated with a man, the richness of his dress reflecting the nobility of artifice, laying his hand on a perpetual motion machine while gesturing to its equivalent in nature – the industrious bee (Figure 5.1).[62]

58 Hooke, *Micrographia*, sig. A1r.

59 Note also Hooke's Baconian shift of emphasis, away from Browne's "reason" to "humane nature in general" – I will return to the experimenters' general pessimism about the faculty of reason below.

60 *Usefulness of Natural Philosophy*, in Boyle, *The Works of Robert Boyle*, 1999, 3:211–212. James Harrington defined 'art' as "the Observation or Imitation of Nature:" *The Prerogative of Popular Government*, sig. A2r. See also Bennett, "Robert Hooke as Mechanic and Natural Philosopher," 37.

61 This idea is found in Browne as well, see Browne, "Religio Medici," 18.

62 Ripa, *Nova Iconologia*, 38. In fact, a motivation for the notorious early modern view, particularly attributed to Descartes and Hobbes, that animals were mere automata was the success – reported or actual – various people had had in mimicking animals with actual autonoma: Regiomontanus' fly and eagle for instance.

Figure 5.1: 'Artifice' from Cesare Ripa's *Nova Iconologia* (1618 edition), p. 38.

Just as Bacon had elided the relevance of natural philosophy with that of moral, some animal behaviour was important to study not for direct instruction in piety but because it could be replicated through artifice, and could thus improve mortal life. In 1619, the clergyman Thomas Adams wrote suggestively that each animal belonged to a "particular schoole:" a phrase reminiscent of Cavendish's animal-men philosophical societies. Different animals had different sensory attributes and held different lessons for philosophers.

> Many beasts doe excell Man in many naturall things[. ...] The Bore excels us in hearing, the spider in touching, the Vulture in smelling, the Lynx in seeing, the Ape in tasting. Some have observed, that the art of curing the eyes was first taken from the Swallowes. The Eagles have taught us architecture: we received the light of Phlebotomie from the Hippopotamus. The Egyptian bird *Ibis* first gave Physicians knowledge, how to use the Glister. The Spider taught us

to Weave. Here the *Serpent* instructs us in Policie, the *Dove* in simplicitie.[63]

Animal attributes were commonly appropriated symbolically in a way which – like the microscope – simultaneously acknowledged the shortcomings of human senses and suggested a possibility of defying them. The lynx, in particular, appeared literature from Pliny to Chaucer as a figure of superhuman vision.[64] According to George-Louis Buffon in the eighteenth century it had been the folly of "most naturalists" before him to bestow the mammal with the eyes of her mythic namesake Lynceus, "of which the antients said that his sight penetrated most opaque bodies."[65] Thus when the Accademia dei Lincei (lynx-eyed) chose the animal as their emblem, the creature was a deliberate metonym for the organisation: "with lynx-like eyes," their studies penetrated the mere appearances of things and gained knowledge previously inaccessible to humans.[66]

Could artifice genuinely mimic what was being suggested figuratively, and replicate the vision of non-human animals? Hooke certainly thought so. "[W]ho knows," he supposed, "but that the Industry of man [...] may find out wayes of improving this sense (sight) to as great a degree of perfection as it is in any Animal, and perhaps higher[?]"[67] The lynx's eyes were being crafted in the workshop. The title page of *Micrographia* even bears a couplet from Horace:

> You may not be able, with your eyes, to see as far as Lynceus,
>
> Yet you would not on that account scorn to anoint them, if sore.[68]

63 Adams, *The Happines of the Church*, 187–188.

64 For more on Lynceus and the lynx, see Lüthy, "Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy"; Taylor, "Chaucer's Eye of the Lynx and the Limits of Vision."

65 Smellie, *Buffon's Natural History*, 5:214.

66 From the Preface to Giambattista Della Porta's *Magiae Naturalis* (1589) Della Porta was a hero of the young Federico Cesi, the early leader of the Linceans. Lüthy, "Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy," 6–11. For a history of this academy, see Freedberg, *The Eye of the Lynx*.

67 Hooke, *Micrographia*, sig. C2r.

68 Ibid. title page. Hooke quotes Horace in Latin, the translation is from Lüthy, "Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy."

In Hooke's appropriation, the sore eye is just that of a human, and the salve is the microscope. In 1657 Christopher Wren joked:

> imagine how much the ancient laborious Enquirers would envy us [...] that a Time would come, when Men should be able to stretch out their Eyes, as Snails do, and extend them to *fifty* Feet in length.[69]

Behind the joke was a serious point – in looking through a fifty foot telescope the eye was really altered. Descartes had suggested in *Dioptrique* that looking down a tube of liquid, sight would "take place in the same way as if Nature had made the eye longer than it is."[70] A generation later Hooke gave this axiom of geometrical optics an explicitly inhuman – even animalian – expression. To return to the lesson of the previous chapter, for him the point of microscopy was to examine the different ways the same body appeared to differently proportioned senses. Bodies of different complexity reacted to different qualities in nature, as thyme seeds moved in sunlight or the beard of wild oat unfurled in humid air. He likewise suggested that different species of animal had different "Sensations of the same *Effluvia*." Because of this:

> if there were another Species of Intelligent Creatures in the World, they might have quite another kind of Apprehension of the same thing, and neither perhaps such as they ought to be, and each of them adapted to the peculiar Structure of that Animal Body in which the Sensation is made.[71]

That our ideas about objects "ought" to be a certain way echoes in Locke's later thought that if we could see the "real Constitution" of bodies we would have "quite different *Ideas*."[72]

69 Wren, *Parentalia*, 250.
70 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 120.
71 "General Scheme," in Hooke, *Posthumous Works*, 8.
72 Locke, *An Essay Concerning Human Understanding*. Book 2, chapter 13 section 11, p. 139. See Chapter 4 above.

Neither thinker considered directly seeing fundamental matter a realistic aim. What Hooke did think was that different creatures' senses reacted to differently to the same qualities in nature.

> Dogs and other Creatures have so strong a Faculty of smellling the Scent of Animals, or the Flesh of them, which are very hardly discoverable to a Man. On the other side, in probability Man is sensible of many things, as the Smell of Flowers, Herbs and Fruits, which possibly a Dog does very little, if at all scent.[73]

The senses of other animals were sensitive in ways ours were not. The small creatures he examined under his microscope also saw differently. "[T]hose lesser Creatures that we discover, tho' possibly they cannot hear the Sounds which we hear, but are able to distinguish every Turn and Return of the Vibrations of [a string] by the quickness and aptness of their Sight," he suggested. "They may have as great variety in the differences of Sounds wholly imperceptible to us, as we have within the reach of our Ears."[74] Some animals may even have an as yet undiscovered sense "more wonderful than that of Sight."[75] Here is a surprising ramification of the visual epistemology I outlined in the previous chapter. The general benefit of the instrument was to alter ordinary human vision so as to collect the various guises of a particular object, viewed under as many different conditions as possible.[76] But what if those different conditions were the senses of other species?

Through the lens Hooke could imaginatively adopt an inhuman perspective and investigate the microworld as an insect. When detailing the anatomy of flies, he speculated about what the world would look like through their compound eyes.[77] When he turned to the ant, he did so not to examine its industry or piety but its "protuberant eyes," its "indented jaws," and its

73 "Lectures of Light," in Hooke, *Posthumous Works*, 142.
74 "Lectures of Light," in ibid., 135.
75 "Lectures of Light," in ibid., 120.
76 I will return to this idea of combining appearances to arrive at the truth about an object in the following chapter.
77 Hooke, *Micrographia*, 178. See also Power's discussion of the multiple eyes of a spider: Power, *Experimental Philosophy*, 12. Leeuwenhoek, too, frequently examined the eyes of insects through his instruments: see Alpers, *The Art of Describing*, 84.

horns that "serve for a kind of smelling."[78] He sought the ant's impression of the world. His microscope figured as these animal senses and projected his reason into insect's body to grasp the reasons behind its "seemingly rational actions." If he could know what it saw he would know why it reacted as it did.

The apologetic idea that we could learn from the bodies and behaviour of animals encompassed the instrument itself. The microscope was not simply a sharper eye but combined with imagination became a different one altogether, an inhuman eye. Though Hooke did not literally conceptualise his lens use as recreating the eyesight of a fly, that flies perceived the same objects in a different way to humans lent rhetorical weight to the idea that in altering vision, a microscope was not deceiving but was – like all artifice – imitating nature. Human perception would not constrain human knowledge. By adopting his artificial organs, Hooke was becoming a new *species* of knower. This was what Cavendish found "monstrous."

Inhuman Knowledge

When Cavendish echoed Hooke on the "narrowness and wandring of our Senses," she was agreeing that we are finite creatures inhabiting a small nook of creation.[79] Different parts of nature were disclosed to those creatures that lived there. But while seventeenth century philosophers generally are infamous for denying beasts had reason or knowledge, Cavendish differed. She wrote in an earlier work:

> [W]hat Man knows, whether Fish do not Know more of the nature of Water, and ebbing and flowing, and the saltness of the Sea? or whether Birds do not know more of the nature and degrees of Air, or the cause of Tempests? or whether Worms do not know more of the nature of Earth, and how Plants are produced? or Bees of the several sorts of juices of Flowers, then Men? And whether they do not make there Aphorismes and Theoremes by their manner of

78 Hooke, *Micrographia*, 204.
79 Cavendish, "Observations upon Experimental Philosophy," 5.

> Intelligence? For, though they have not the speech of Man, yet thence doth not follow, that they have no Intelligence at all.[80]

The imaginative aspect of her animal-philosophers was thus not their animal knowledge itself but this translation of their "aphorisms and theorems" into human language: in one of the plainest imaginings of *The Blazing World*, animals are given the "speech of Man." When the Empress talks to her insect-men natural philosophers, she queries inhuman nature directly, and is "very well satisfied" and "wonderfully taken" with what she hears.[81] This is the kind of privilege Hooke dreamt of – direct access to the "secret workings of Nature."[82] But Cavendish disagreed that artifice could extend our limited domain. Neither "natural causes nor effects can be over-powred" by artifice, she wrote.[83] Her hylozoic, self-knowing nature could not be escaped: our animal bodies restricted the kind of natural knowledge that we were privy to.

Cavendish deliberately subverts the microscopist's work. Hooke's method was a meticulous, collaborative labour which artificially amplified natural qualities so they were perceptible to humans. Hers was a fanciful and invented absolute reign over a menagerie whose snouts, gills, and beaks *naturally* gave them extra-human knowledge. Anna Battigelli has suggested that the radical invention of Cavendish's narrative as a whole is an indirect rebuttal to Hooke's "sincere hand and faithful eye;" the methodical, automated empiricism of the Royal Society. If whole worlds of difference could be created by the flippant and eccentric mind, how could a method of collaboration between different observers produce reliable, unified knowledge?[84] The contrast displays the important epistemic concern of this chapter. Hooke's experimental ambition was to push himself beyond the limits of his species for new natural knowledge. For Cavendish the only way to do this was the imagination. The nature of a creature and the knowledge it could attain are inalienable, and the experimental ambition was futile.

80 Cavendish, *Philosophical Letters*, 40–41.
81 Cavendish, "The Blazing World," 36, 43.
82 Hooke, *Micrographia*, A2v.
83 Cavendish, "Observations upon Experimental Philosophy," 6.
84 Battigelli, "Between the Glass and Hand."

This is also the rhetorical force of hybridising experimentalists with bears. Erica Fudge has interpreted the bear garden as a place of direct contradictions, where both difference and sameness between humans and bears is revealed. On display amongst the blood and flying fur was a lesson in the character of the animal combatants. As bears, bulls, dogs and apes were brutalised figuratively and literally – blinded and tortured and whipped, their animal status was emphasised in opposition to that of their human captors. It was a carnal assertion of the ability of human reason to overcome the body, even bodies as physically powerful as bears. But significant though the triumph of will over flesh was, it was spectacle steeped in ambiguity.[85] The dehumanisation of animals suggests likewise a sense of the inner brute of the former, and the entertainment relies on the captivity of the the baying, bloodthirsty audience themselves.[86] Simultaneously, the animals were frequently watched with a not-wholly-demeaning anthropomorphism. The report of a spectator in 1575 describes a discourse of queries and clever responses, the animals made to "argu the pointz cum face to face. They had learn'd counsel also a'both partis. Very feers both t'one and t'other, and eager in argument."[87] Bears were the protagonists in a scripted narrative, and many gained fame and popularity, their names – human names like George Stone and Harry Hunks – appeared often on flyers, adverts and in reports.[88] Particular bears were regular combatants – the premise of the violence was not the Manichean contrast of life with death, but the revelation of the qualities which characterised that life.[89] What these qualities were seems to have been quite well established in early modern England. *The Parable of the Bear-Baiting*, an anonymous pamphlet from 1691 damned English bureaucracy during the Nine Years War, and delivered its message entirely through animal characters. Many of the associations are still familiar – the jackals are cunning but cowardly, the ape slow and naïve.

85 See Erica Fudge's work on the construction of the animal as other in early modern England: Fudge, *Perceiving Animals*. Many of the nuanced interpretations of the bear garden come from the connection between those entertainments and Tudor and Stuart theatre. I draw heavily on Jason Scott-Warren's work for a sense of the development of the literature in this field: Scott-Warren, "When Theaters Were Bear-Gardens."

86 Fudge, *Perceiving Animals*, 19 and chap. 1 generally.

87 From an eyewitness report from 1575 reproduced in Smith and Woodworth, *Festivals, Games and Amusements*, 108.

88 Chambers, *The Elizabethan Stage*, 2:457.

89 This is also Scott-Warren's contention: Scott-Warren, "When Theaters Were Bear-Gardens," 71–74.

The bear in this case was "a great overgrown French Bear, the greatest in the World" – the French navy. While he was the enemy, and overcome by English and Dutch mastiffs, he was nonetheless respected as a threat.[90] Several of Shakespeare's scenes feature baiting, and this idea of bears as "overgrown." Most notably, Malvolio story in *Twelfth Night*. Sir Toby vows: "we'll have the bear again, and we will fool him black and blue, shall we not, Sir Andrew?" Malvolio is a conceited and bumbling but not unsympathetic character, as the uneasy feeling with which his unjust treatment leaves the viewer is testament. "I'll be reveng'd on the pack of you," he tells the snapping taunters. In *The Merry Wives of Windsor*, Master Slender's brag to the unimpressed Anne Page that he had seen Sackerson, the most famous bear of all, "loose twenty times" captures something of the futile bluster of the bear garden.[91] The role of the bear was a particular one – slightly bumbling; certainly self-important; forceful; naïve; and, crucially, preoccupied with an immediate task, unaware of their place in a larger context.

To assume Cavendish intended her bear-men to evoke very particular associations in her readers is speculation. On the other hand, the character of the bear seems fairly precisely established in Cavendish's time, and not to see it through the mere cruelty and mockery of the bear garden borders on Whiggish. The safe middle ground is that the experimental philosophers of the Blazing World are a synecdoche for nature constrained and made entertaining for a human audience.

Hooke followed Bacon in talking about constraining "Protean nature" with instruments, and so forcing it to confess its true essence.[92] In the bear garden it was those creatures Cavendish associates with the Curator who were constrained by artifice – by chains, gates, and turnstiles – and have their inner essence revealed. While Cavendish's specific criticisms of his observations have their point, the very forms of the animalian philosophers make a more general one: a burlesque transformation of the experimental ambition. Jacques Rancière has written that

90 *The Parable of the Bear-Baiting*.

91 See Scott-Warren, "When Theaters Were Bear-Gardens," 65 ff.

92 Hooke, *Micrographia*, 8; "Preparative Towards a Natural and Experimental History," in Bacon, *The Works of Francis Bacon*, 1858, 8:363.

burlesque in cinema has been "the instrument that derailed every fable."[93] Cavendish uses it to the same effect, moving pictures notwithstanding. Fable here is meant in the Aristotelian sense: "the arrangement of necessary and verisimilar actions that lead the characters from fortune to misfortune, or vice versa."[94] We are surprised by the very form of the Blazing World's characters, and any assumptions about how the narrative should progress are disrupted. The chain of action (artifice) and effect (knowledge) veers away from the experimenters' aims.

Hooke would have thought it ridiculous to place a microscope in the hand of a bear-man: a creature who is *already* a hybrid of human reason and animal sense. Quite so, but Cavendish's imagery has subverted this logic and introduced a new one; one in line with her hylozoic metaphysics. By association with the bear garden, Hooke's activities are situated in a larger context, his skilled mimickry of nature transformed into a Promethean task both endless and fruitless. Far from trapping nature in his instruments, Hooke himself is trapped by forces beyond his control – human nature. The bear-men's microscopical observations are doomed from the start to fail to impress the Empress, seeing as she does this broader view.

His bear form was not a mockery of Hooke's person, but a caution against aggrandising his actions beyond their actual standing. Objects of miserable fun, the bears teach us about the nature of the experimental space. The early modern bear garden limited the brutish power of animals until it became entertaining. Cavendish's experimenters are likewise potentially damaging, but acceptable within confines. The Empress is concerned by their arguing, and orders them to break their instruments to end dispute. The bear-men, horrified, kneel down "in the humblest manner" and admit their real objective: they "take more delight in Artificial delusions, then in Natural truths," and use lenses to amplify disagreement.[95] Far from harmonious conclusions on useful matters of fact, they seek the joy of argument and quarrel within their little community. The Empress relents: as long as they would agree to keep their disputes inside their school and

93 Rancière, *Film Fables*, 12.
94 Ibid., 1.
95 Cavendish, "The Blazing World," 28.

not disturb polite society, they are entertaining enough. Only when they overstep their constraints – by talking about truth – do they become worthy of reproach. Bumbling, humble, "full of joy," the bear-men thank her. The price is to confess their disinterest in providing knowledge useful in improving the human condition. If what they saw on stinging nettles were indeed poison sacks, it was the physicians' worry why this should not make them dangerous to eat. The goal of looking at a louse was not preventing its bite: that worry was "below that noble study of Microscopical observations."[96] The Royal Society had become the thing they professed to be united against: an exclusive membership of disputation and debate, unconcerned with either the truth of their ideas or their application to the world outside the laboratory.

Philosophy for Humans

At best experimenters were child-like entertainers: "Boys that play with watry Bubbles," their instruments "pretty toys to employ idle time."[97] What were they at worst, when they refused to accept their proper place? What kind of danger do unchained bears imply?[98] It is important to recall that in the first encounter the Empress has with bear-men, they carry her across the ice, shelter her in their dwellings, and feed her. She leaves because her constitution is not suited to their home. They are noble and gentle, it is their instruments which distract them and make them act out of character.

Cavendish differed from many critics of the Royal Society in that she was amenable to a large part of their ambition. Her bear-men differ from Shadwell's characterisation of Hooke as a frivolous virtuoso who, though generally lost in his own world, angered London's ribbon-makers with his machine inventions.[99] Nick Wilding has briefly traced this sort of disgruntlement with

96 Ibid., 31–32.
97 Cavendish, "Observations upon Experimental Philosophy," 11, 102–103.
98 Lisa Sarasohn's evocative phrase for Cavendish's view of the productions of art is "unnatural nature." Sarasohn, *The Natural Philosophy of Margaret Cavendish*, 163.
99 See Shadwell, *The Virtuoso.* Hooke was sure the character of Sir Nicholas Gimcrack was based on him. "Damned Doggs," he recorded in his diary. "*Vindica me Deus.* People almost pointed." Hooke, *The Diary of Robert Hooke, 1672-1680*, 1935, 1:235.

technologically-minded philosophy to a culmination in Marx.[100] Cavendish on the other hand was supportive of inventions to ease labour and improve life. The problem with experimentalism was it did not do this.

> [B]efore the Vulgar sort would learn to understand [experimental philosophers], the World would want Bread to eat, and Houses to dwell in, as also Clothes to keep them from the inconveniences of the inconstant weather. But truly, although Spinsters were most experienced in their Art, yet they will never be able to spin Silk, Thred, or Wool, &c. from loose Atoms; neither will Weavers weave a Web of Light from the Sun's Rays; nor an Architect build an House of the Bubbles of Water and Air, (unless they be Poetical Spinsters, Weavers, and Architects.)[101]

Aside from its intrinsic interest and invention, Cavendish's hybridisation is illustrative for the way it inverted Hooke's own story about what he was doing. The 'fable' reversal I referred to above can be thought of as a difference in their anthropological views, a dislocation of humans from one natural and historical narrative and into another. What is at stake for Hooke is not only the reliability or universalisability of particular experiences, which the experimenters strove to construct through the plain reporting of experiment and the disinterested assent of gentlemen witnesses.[102] There was also a broader concern about the aim of natural philosophy. To pinpoint the disagreement between Cavendish and Hooke, Peter Harrison's notion of theological anthropology is useful. The approriate methods and aims of philosophy depend on an assumed, constructed, and learned relationship between humans and nature.

At the centre of this is the narrative of Genesis: the creation of man, Adam's naming of the animals, the fall of man, and the flood.[103] Views of the Fall varied widely over centuries

100 Wilding, "Graphic Technologies," 133.
101 Cavendish, "Observations upon Experimental Philosophy," 11.
102 See Shapin and Schaffer, *Leviathan and the Air Pump*; Shapin, "Pump and Circumstance"; Dear, "Totius in Verba."
103 Charles Webster is particularly important for demonstrating the importance of the Fall of Man to early modern natural philosophy: Webster, *The Great Instauration*, especially chap. 5. Joanna Picciotto and Peter Harrison have also written extensively and interestingly on the subject; see Picciotto, *Labors of Innocence*; Harrison, *The Fall of Man and the Foundations of Science*. For some figures with more divergent views, see also Poole, "The Genesis

and cultures. In the early modern period it was a widely accepted explanation for the possibility of error in a providential Creation.[104] A general idea with which to begin is that of the Garden of Eden as both a natural and an "epistemological paradise," where the ideal philosopher, Adam, had lived with dominion over nature and knowledge of the essences of everything in Creation.[105] With the Fall came ignorance. As Abraham Cowley wrote in his ode prefacing Sprat's *History of the Royal Society*, early modern philosophy was a relic of Adamic knowledge:

> the great and only Heir
> Of all that Human Knowledge which has bin
> Unforfeited by Mans rebellious Sin.[106]

The Fall had made humans more like beasts: ignorant, overcome by passions, floundering in an unknown and hostile world. The particular view of the Fall displayed by the experimenters in their first official apologetic work was particularly suggestive of experimentalism, and largely inherited from Bacon.[107] The Royal Society's figurehead had written:

> [B]y his fall man lost both his state of innocence and his command over created things. However, both of these losses can to some extent be made good even in this life, the former by religion and faith, the latter by the arts and sciences. For the curse did not quite put creation into a state of unremitting rebellion, but by virtue of that injunction 'In the sweat of thy face shalt thou eat thy bread,' it is now by various labours (not for sure by disputations and the idle ceremonies of magic) at length and to some degree mitigated to allow man his bread or, in other words, for the use of human life.[108]

Narrative in the Circle of Robert Hooke and Francis Lodwick"; Schaffer, "Halley's Atheism."

104 See especially chapters 1 – 3 of Harrison, *The Fall of Man and the Foundations of Science*.

105 Picciotto, *Labors of Innocence*, 34, and chapter 1 more generally.

106 Abraham Cowley, 'To the Royal Society', in Sprat, *The History of the Royal Society*, sig. B1r.

107 See Harrison, *The Fall of Man and the Foundations of Science*, for more on the distinction between, roughly, optimistic Catholic and pessimistic Calvinist views on the Fall and their consequences for the restitution of knowledge. Descartes is the usual point of comparison with the the English empiricists. The Catholics had a more optimistic view of the Fall, whereby reason was little altered, and could still innately lead an inquirer to the truth.

108 Bacon, *Novum Organum*, book 2, aphorism 52. In Bacon, *The Oxford Francis Bacon*, 11:447.

Bacon's Great Instauration slotted into a specific Puritan eschatology in which the end of days would be preceded by invested work and activity.[109] This was a development tied to a time and a place: millenarianism was on the rise in England. In the 1650s, Bishop James Ussher dated the creation of the world to 4004BC, and the widespread death, crisis, and misery of the Thirty Years War and English Civil wars combined with the tradition that the world had a life-expectancy of six thousand years to lend an urgency to proceedings. Bacon quoted and interpreted the apocalyptic prophecy from the Book of Daniel: "'*Many shall pass to and fro, and science shall be increased*;' as if the opening of the world by navigation and commerce and the further discovery of knowledge should meet in one time or age."[110] That age was his age, and the increase of science was a prerequisite for the second coming and salvation.

Restoration of the human condition was thus to come through the improvement of philosophy: it was our capacity for knowledge that was our species' the defining feature – not the faculty of reason itself. Bacon's most famous metaphor, that of the mind as a mirror, "capable of the image of the universal world, joying to receive the signature thereof as the eye is of light," hints at the appropriate method of post-lapsarian philosophy.[111] With the inner light dimmed by the Fall, the mind was to receive the image of Creation by observation, not illuminate it with reason. Only, now we needed some assistance. Humans were "deficient, amputated creatures in need of prosthetic support," as Joanna Picciotto has eloquently put it.[112] The experimenters sought to reconstruct the ideal human via instruments and experiments. The kind of inhuman experience found in *Micrographia* would make humans *more* human.

109 Harrison, *The Fall of Man and the Foundations of Science*, chap. 5.
110 Bacon, *Novum Organum*, book 1, aphorism 93. In Bacon, *The Oxford Francis Bacon*, 11:32.
111 *Valerius Terminus of the Interpretation of Nature*, in Bacon, *The Works of Francis Bacon*, 1858, 6:32.
112 Picciotto, *Labors of Innocence*, 11. For a related point see Erica Fudge's discussion of a 'paradox in Bacon's methodology': in the maturation of the human from child-like ignorance to adult understanding, humanity is both defined by its formative, childlike state, and inadequately distinguished from animals by it. Fudge, "Calling Creatures by Their True Names."

At least, this is the view, largely inherited from Bacon, found in Sprat. In the middle of the century, details differed between Royal Society members. For instance, had Adam really had such encyclopaedic knowledge? Joseph Glanvill felt sure he had, and had obtained it through observation. "*Adam* needed no Spectacles;" he could see by looking whether or not the magnet attracted by "Atomical *effluviums*" and, somewhat queasily, feel the earth's motion as we do its stillness.[113] Henry Power, on the other hand, was certain that "the Constitution of *Adam's* Organs was not divers from ours, nor different from those of his Fallen Self." [114] Those things he could not see he might guess at by analogy, but "doubtless the Minute Atoms and Particles of matter, were as unknown to him, as they are yet unseen by us." We had already surpassed his theoretical knowledge, and optical instruments promised to move us "beyond the reach of [Adam's] natural Opticks," to confirm the existence of things unknown to the first human.[115]

Boyle was likewise unsure that Adam's knowledge was so considerable. He studied the animal names mentioned in the Hebrew bible and found no great insight into nature.[116] Besides, even if Adam had known about everything about his time, there was more to the world now than nature: art had added so much to the world that he would be lost in the early modern age. "If Adam were now alive," Boyle wrote:

> and should Survey that great Variety of Man's Productions, that is to be found in the shops of Artificers, the Laboratories of Chymists, and other well-furnished Magazines of Art, he would admire to see what a new world, as it were, or set of Things has been added to the Primitive Creatures by the Industry of His Posterity.[117]

113 Glanvill, *Plus Ultra*, 5–6. See also his disclaimer in his preface: if his eyes were restricted by physical optics, at least his rational faculty behind them was so powerful he could make do with less ocular evidence than we can. For more on early church opinions about Adam's physical constitution, see Harrison, *The Fall of Man and the Foundations of Science*, chap. 1.

114 Power, *Experimental Philosophy*, sig. A4r.

115 Ibid., sig. A4r.

116 Harrison, *The Fall of Man and the Foundations of Science*, 218.

117 *Usefulness of Natural Philosophy.* In Boyle, *The Works of Robert Boyle*, 1999, 3:212.

Philosophy was not about recreating Adam. In fact, Boyle reversed the order of Bacon's method. Where the Lord Chancellor thought we must advance the sciences before the End of Days, Boyle thought the study of theology would bring salvation, and only afterwards would we learn the secrets of Creation.

Hooke's view is different again. In the preface to *Micrographia* he suggested:

> as at first, mankind *fell* by *tasting* of the forbidden Tree of Knowledge, so we, their Posterity, may be in part *restor'd* by the same way, not only by *beholding* and *contemplating*, but by *tasting* too those fruits of Natural knowledge, that were never yet forbidden.[118]

This is not only an explicit reference to the the Fall, but a call for a sense-based study of nature which would 'restore' mankind to an implied former perfection.[119] But what Hooke's view of the Fall was in particular, and therefore what being "restor'd" to a pre-lapsed state would entail, is unclear. He had a long running interest in chronologies other than that given in the Hebrew tradition and interpreted by Ussher. He considered Chinese writing to be older than Hebrew, denying biblical universalism and the applicability of its chronology to all humanity, and thought that natural evidence told a different story again.[120] He lectured about the extinction of species and a shifting, unstable nature in which earthquakes turned seas to mountains; and interpreted biblical events like the flood, Sodom and Gomorrah, and the longevity of biblical patriarchs naturalistically.[121] Unlike Glanvill and Power, Hooke did not compare the microscope to Adam's eyesight, but rather to the "vast *Plains*, *high Towers*, and *clear Air*" of the Babylonians and Egyptians: these never gave them "so great advantages over us, as we have over them by our *Glasses*.[122] Instruments were compared to instruments and other conditions of observation. In fact, in *Micrographia* he wondered if Adam named the animals after similar close scrutiny, with the

118 Hooke, *Micrographia*, sigs. B2v-r.
119 Not necessarily, it should be noted, of knowledge.
120 Poole, "The Genesis Narrative in the Circle of Robert Hooke and Francis Lodwick."
121 Drake, *Restless Genius*; "A Discourse on Earthquakes," in Hooke, *Posthumous Works*, 279–450.
122 Hooke, *Micrographia*, sig. D1v.

Boylean caveat: "if at least his names had any significancy in them of the creature's nature on which he impos'd it; as many (*upon what grounds I know not*) have suppos'd."[123]

Hooke considered the "great prerogative of Mankind above other Creatures" not to be contemplative knowledge but "that we are not only able to *behold* the works of Nature, or barely to *sustein* our lives by them, but we have also the power of *considering*, *comparing*, *altering*, *assisting*, and *improving* them to various uses."[124] Hooke's optimism for philosophy was for knowledge that would assist in practical and temporal things, "inabling a Man to understand how [...] he may be able to produce and bring to pass such Effects, as may very much conduce to his well being in this World."[125] If there was any question of restoring humanity to a pre-lapsarian state, it was according to the letter of the quotation from Bacon above: that nature might be tamed again, and we might not toil as much for our food.[126] Adam may not have been the perfect philosopher but in a sense the perfect artisan. Though, as I will return to in Chapter 7, for Hooke the two are parhaps not so different.

In any case, we have gone past the point at which Cavendish disagreed. She found this restorative rhetoric paradoxical. She was concerned that philosophy ought to reflect humanity's relationship with nature, not in a past and inaccessible state but in its current. For her, error was not the fault of the human limits caused by the Fall but of the human ambition that had itself *caused* the Fall:

> [Man] would fain be supreme, and above all other Creatures, as more towards a Divine Nature: he would be a God, […] at least God-like, as is evident by his Fall, which came meerly from an ambitious Mind of being like God.[127]

123 Ibid., 154. The brackets are Hooke's but I have added the emphasis).
124 Hooke, *Micrographia*, sig. A1r.
125 Hooke, *Posthumous Works*, 3.
126 See Genesis 3:17-19
127 Cavendish, "Observations upon Experimental Philosophy," 280.

The experimenters' actions were continuing not Adam's innocent labour in the Garden, but his arrogant desire to have more than that which was his. Extending our limited faculties beyond their natural limits had nothing to do with natural philosophy, and everything to do with vain ambition. Addressing Boyle directly, she wrote:

> 'Tis true, if *Adam* were alive now, he might see more variety, but not more Truth; for there are no more kinds and sorts of natural Creatures, then there were at his time, though never more metamorphosed, or rather I may say disfigured, unnaturally and hermaphroditical issues then there are now.[128]

If there was a growing tradition eliding art and nature, there was a continuing one which held the one was largely irrelevant to the other. William Newman has written of Cavendish's opposition to artifice as a caricature of earlier anti-alchemical arguments.[129] But it is also possible to read her in a more contemporary – even forward looking – light, concerned with themes common in Augustan literature like human historicity and and self-conscious authorship.[130] The place of humans in nature was not an issue which died with the foundation of the Royal Society. Such an authorial stance reacted against the desire for objectivity, and emphasised an awareness of one's limits as a producer of works and knowledge. As Alexander Pope wrote in 1734:

> Why has not Man a microscopic eye?
> For this plain reason, Man is not a Fly.[131]

As we have seen, Cavendish's idea of nature restricted beings to their natural place, their knowledge and right behaviour limited to a particular domain.

128 Ibid., 271.
129 Newman, *Promethean Ambitions*, 284–288.
130 See for instance Zwicker, *Cambridge Companion to English Literature 1650-1740*, especially John Mullan's contribution, "Swift, Defoe, and Narrative Forms."
131 From his *Essay on Man*, Epistle 1, VI, line 21.

Tis proper for a lively *Horse* to *neigh*,

And for a slow, dull foolish *Asse* to *bray*.

For *Dogs* to bark, *Bulls* roare, *Wolves* houle, *Pigs* squeak,

For *Men* to *frowne*, to *weep*, to *laugh*, to *speake*.[132]

These lines, from her 1653 verse 'A Morall Discourse betwixt Man, and Beast', have the air of imperative about them, but the 'proper' of the first line has a tone as much metaphysical as fastidious. The horse neighs because it is lively, and the poor ass, crippled with adjectives, has no choice but to bray. Their right actions are expressions of their natures. The Great Chain of Being, clearly visible in Pope's *Essay on Man*, is not out of place in Cavendish either. We saw in the previous chapter how the continuities between links of the chain licenced Hooke to reason analogously across different scales and domains. In Cavendish it was a restrictive force. To acquire knowledge was to acknowledge the nature of humans, not attempt to defy it.

It is worth noting the similarity of her thought with that of John Locke, Hooke's friend and Fellow of the Royal Society. Locke did not say that a microscope produced error, as Cavendish did. In fact he wrote that a man with "Microscopical Eyes" may "come nearer the Discovery of the Texture and Motion of the minute Parts of corporeal things; and in many of them, probably get *Ideas* of their internal Constitutions." But both questioned the instrument's relevance. What use is this information, when such a person would live in "a quite different World from other People[?]"[133] Inhuman senses only lead to inhuman thought, whereas true knowledge, the aim of philosophy, ought to be calibrated to our position in nature. Cavendish asked:

> [I]f a Painter should draw a Lowse as big as a Crab, and of that shape as the Microscope presents, can any body imagine that a Beggar would believe it to be true? but if he did, what advantage would it be to the Beggar? for it doth neither instruct him how to avoid breeding

132 'A Morall Discourse betwixt Man, and Beast' in Cavendish, *Poems and Fancies*, 102.
133 Locke, *An Essay Concerning Human Understanding*. Book 2, chapter 13 section 12, p. 140.

> them, or how to catch them, or to hinder them from biting.[134]

The painter is not wrong to do this, but what of the knowledge in the image? Cavendish's emphasis on utility is notable, particularly as it appears the reverse of Bacon. For him it was the thing as it was in itself which was both true and useful; for Cavendish usefulness and truth come from a thing as it is known to a human.[135] An image of a louse is not to be judged by other microscopists, naturalists, or learned philosophers, but by beggars. Beggars were the real lice experts, the people who *as people* were the most intimately familiar with the creatures, through unaided human experience. Which was certainly imperfect, and may not have reveалled the hidden workings of nature, but was good enough to know that a louse is not the size of a crab.

Other Worlds

Cavendish's criticisms of Hooke emphasise how contingent, localised, and exclusive the 'community' of experimental philosophers was. She advocated the study of nature, and knowledge that was useful for our temporal lives. What she denied was that the experimenters' techniques were teaching us anything that was useful. Surprisingly, her criticisms reveal that it is Hooke who was speculating imaginatively about distant, unattainable dreamlands. "The truth is, *My Lord*," Cavendish wrote to her husband, "That most Men in these latter times, busie themselves more with other Worlds, than with this they live in."[136] This may seem a strange criticism from the author of such extravagance as *The Blazing World*. But exactly by acknowledging her work as deliberately fanciful she was able to ridicule the ambitions of others – Hooke's delving into the microworld was more problematic by far than the Empress' fanciful travel. Her playful narrative shows that just as she imagines a world where she can overhear the

134 Cavendish, "Observations upon Experimental Philosophy," 11.
135 For Bacon, see Rossi, "Bacon's Idea of Science." For more on Cavendish's utilitarianism, see Smith, "Margaret Cavendish and the Microscope as Play."
136 From the dedication 'To His Grace the Duke of Newcastle', Cavendish, "Observations upon Experimental Philosophy", sig. A3r.

animals, Hooke likewise only imagined a world of philosophical knowledge visible through a lens.

Chapter 6: Eyesight and Ideas

Building an Eye

The past four chapters have focused on Hooke's microscope, both materially in terms of its form, and epistemically in terms of the knowledge that he sought through its lenses. In this chapter and the next I will take a broader view, and situate the epistemology embodied by his instrument in a wider context. We have seen something of the craft and ingenuity it took to operate the instrument, the knowledge it brought him of the behaviour of light, the place it held in his methodology, and the broad hidden assumptions that underwrote this approach. In this chapter I will discuss the connection between eyesight and ideas. His observations and his instrument use are only the external part of a natural philosophical endeavour which also relied on the operation of the eye, the memory, and reason. Hooke was not naïve about these things.

Rather than moving away from materials, I will continue to approach Hooke through his instruments, as he did his work. The focal point for this chapter are two remarkable objects of public philosophy which Hooke used to demonstrate the operation of vision to an audience: two artificial eyes he constructed in his workshop and displayed at a lecture in Gresham College. The lecture was part of a series Hooke delivered in the late 1670s and early 80s about "the first and most obvious, though yet the most abstruse" of all subjects: light.[1] He was speaking as Geometry Professor of the College, but likely intended some or all of the lectures to be read to the Royal Society too: several times the records mention a discourse on a similar topic at or around the same time.[2] Occasionally, and rarely for the Royal Society records, a reaction is noted. Hooke was

1 The series has been collected together and published as the "Lectures of Light" by Richard Waller: Hooke, *Posthumous Works*, 71–148.

2 E.g. Birch, *The History of the Royal Society*, 1757, 4:84, 90. See also Taylor-Pearce, "Time, Soul, Memory."

requested to repeat one of the last lectures, on the topic of memory, in front of a larger audience the following week. Word had spread about what Evelyn called Hooke's "ingenious Hypothesis of Memorie."[3] This particular lecture has received some attention from historians, and the ideas on memory and cognition in it will be important to me later in this chapter. Hooke's demonstration of eyesight is harder to pin down. The only possible mention of it in his diary is typically laconic: "Sund 5 [June 1681]. Still better. very Diuretick. Lecture. Haak."[4] Did his audience nod in satisfaction at his explanation of light's nature, and flock around the devices he brought in to represent the human eye? Did he in fact bring the devices, or simply describe them? Did anyone even attend the lecture, or did he arrive to an empty room?[5]

Still, we have the texts of the lectures. After explaining some basic eye anatomy, Hooke described "a large artificial Eye made with Glass, Water, and Jelly." With the glass 'cornea' pointed toward a bright object, a picture of the outside world would appear against the 'retina', and vision could be seen at work.

> In this Picture are remarkable not only all the Lines and Proportions, but the Lights, Shadows, Colours, Motions of the Objects themselves. So that from a clear Understanding of this, the Reason, Cause, and Manner of Vision will be clearly understood.[6]

It may have been useful in a smaller setting, but Hooke had mixed feelings about this curious object as a public demonstration. It required a good understanding of theoretical optics to make, and was tricky to manipulate. He mentioned it more so "that such as have a Mind to be curious in it, may, if they please, prepare the like."[7] Homework for dilligent listeners assigned, he moved on to a further demonstration. This was a "darkened Room, or Perspective Box, in which

3 20 June 1682: Evelyn, *The Diary of John Evelyn*, 4:284.
4 Henderson, "Unpublished Material from the Memorandum Book of Robert Hooke," 149.
5 Hooke did often note in his diary when he delivered a lecture, and noted who was in the audience, if anyone. E.g. Thursday 17 June 1680: "Attended morning Lecture, none came, not one." Hooke, *The Diary of Robert Hooke, 1672-1680*, 1935, 2:446.
6 "Lectures of Light," in Hooke, *Posthumous Works*, 127.
7 "Lectures of Light," in ibid.

all the Appearances that are made in the Eye are in some manner represented."[8] The perspective box was a tube, four or five feet long, with a concave screen at one end and the other tapering towards a convex lens (Figure 6.1).

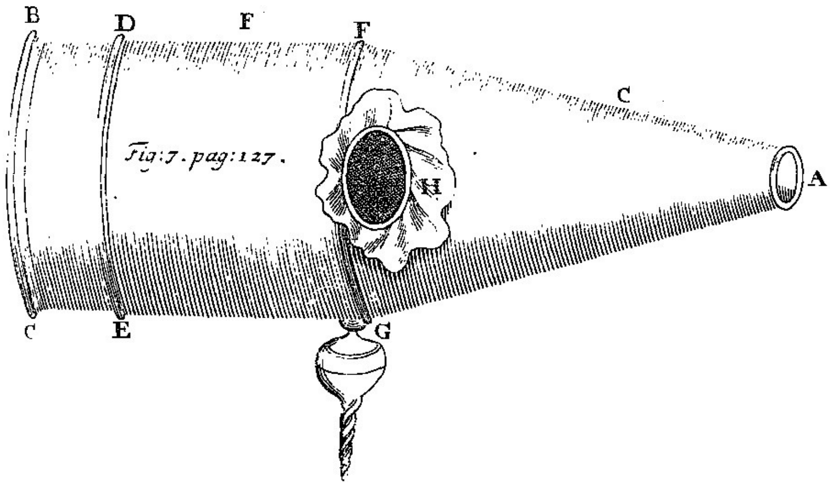

Figure 6.1: Hooke's 'perspective box'. From 'Lectures of Light,' *Posthumous Works*, plate 1, fig. 7, p. 127.

Through the lens, A, light would refract and cast an image on the screen at BC. The tube was mounted to swivel around G for easy orientation towards a light source, and the image could be focused by sliding the section BDCE in and out of the main tube. Hooke even recommended cutting various holes of various sizes and shapes out of pasteboard to hold over the lens, to replicate a pupil's dilation. The glaring disanalogy with a natural eye is of course H – a hole in the side, swathed in leather or wool. From here, face pressed against the hole, a viewer could watch the eye in action, and see "what Light is in the Eye, and what Effects it there produces."[9]

Neither of these objects were novel with Hooke. Following Kepler's optical work, by the middle of the seventeenth century the eye was often connected to the *camera obscura*, and even

8 "Lectures of Light," in ibid.
9 "Lectures of Light," in ibid., 128.

such custom-built apparatus were not uncommon.[10] Christoph Scheiner similarly described a glass eye, and Jacques Rohault made one in the form of the one in Figure 6.1 from paper and vellum.

Understanding vision had importance beyond intrinsic interest. If knowledge was to be gained from the senses, then its reliability is contingent on an understanding of this process. Rohault wrote in 1671 that it was worth studying the eye because observational natural philosophy "depends in some measure, upon Observations made by the Help thereof, so that it is necessary to know all the Circumstances of this Sort of Sensation, which is the most wonderful of any that we are possessed of."[11] The preceding chapters have shown that an important aspect of Hooke's information gathering was to all the while remain aware of his own activity in doing so – what the effect of the external world was on the eye of an observer.

When he turned explicitly to this topic, the eyes Hooke showed his audience self-consciously placed him in a particular visual paradigm which gives us more epistemic background to his instrument use and his aims for a completed natural philosophy. Svetlana Alpers has discussed the kind of vision implied by equating a *camera obscura* with an eye, and associated it with the emergent naturalism of northern European art.[12] Hooke features in the story as a figure central to this "observational craft," his *Micrographia* typifying the idea of knowledge captured in carefully crafted but lifelike or 'natural' pictures – intended to reproduce the experience of the naked eye.[13] More recently, Ofer Gal and Raz Chen-Morris' idea of the "disappearing observer" has emphasised the essentially mediated nature of vision that such naturalistic images imply.[14] If a canvas can reproduce the perspective of an observer, then it does so because the naked eye has

10 Della Porta, Kepler, Scheiner, Galileo, Descartes, Rohault, Huygens, Zahn, and Molyneux all used them, for instance. See Lefèvre, *Inside the Camera Obscura*; Alpers, *The Art of Describing*; Wettlaufer, *In the Mind's Eye*.

11 Clarke, *Rohault's System of Natural Philosophy*, 1:233. Rohault features regularly in this chapter as a successor to Descartes, as opposed to Malebranche or Arnauld, who is a foil for Hooke – less an epistemologist and more of a causal physicist.

12 Alpers, *The Art of Describing*. See also Crary, *Techniques of the Observer*, for more on the construction of the observer with various optical technologies.for more on the construction of the observer and comparison with various optical technologies.

13 Alpers, *The Art of Describing*, 72.

14 Gal and Chen-Morris, *Baroque Science*, chap. 1.

likewise become a screen onto with the world is painted. Rather than an immediate connection with the world, viewing happens from behind a barrier, and we must interpret visual information rather than directly absorbing it.

This general idea is of central importance to this chapter, with one major caveat. Hooke did not think of *knowledge* itself as pictorial. What exactly he did think knowledge was is a tricky question which is perhaps the largest issue behind these next two chapters. But still, the tropes of a naturalistic picture correspond in an important way to the information Hooke thought we gained directly from the senses, even if they do not describe the resulting conception of the world. In fact, the objects that Hooke used to teach his audience about eyesight themselves reflect this – they are three-dimensional, interactive objects which *make* pictures, but they themselves are not pictures.[15]

To pick apart the implication of Hooke's artificial eyes it is important to see something of the background of the devices themselves. There are two main threads to this historical context. The first is the use of similar devices as metaphors for the eye before Hooke, and what they tell us about optics and instruments. And second is the history of the particular instruments that Hooke used, and their associations with different visual contexts. These two threads of making and learning merge to inform the more internal part of the experimental philosophical enterprise which lay behind the retinal screen.[16]

The Tradition of the *Camera Obscura*

When he explained an eye "by the Similitude of it to a dark Room," Hooke was self-consciously following a growing tradition in optical writing.[17] He names Descartes, Kepler,

15 For more on Hooke's model demonstrations: Hunter, "Experiment, Theory, Representation."

16 Though the main source I draw on here is a series of lectures Hooke gave 15 years after he wrote *Micrographia*, I still take the lessons we can learn from them about Hooke's epistemology to relate to his earlier career. As we will see below, he draws on the works of other writers from a generation before him, and likely his daily work and more theoretical speculations informed one another.

17 "Lectures of Light," in Hooke, *Posthumous Works*, 98.

Scheiner, Della Porta and Galileo. Though Giambattista Della Porta is the earliest of these writers, it was Kepler who was first considered that it was the impact of light on the surface of the retina at the back of the eye that is the cause of vision, as implied by the analogy with a *camera*.[18] Della Porta held the more traditional view that the 'crystalline humour' – the lens of the eye – was the seat of vision, and received not light but 'species' – the formal likenesses of objects which emanated outwards in all directions from them.[19] From the crystalline humour the forms would be directly present to the soul.

For Della Porta it was the *inwardness* of a *camera obscura* which suggested the analogy with an eye. What he meant was the death of the extramission theory of vision, whereby visual rays left the eye and species travelled back to the observer along them. Instead, he thought, "the Image is let in by the pupil, as by the hole of a window."[20] It was a remarkable comparison for the Neapolitan to have made. Gal and Chen-Morris point out that Della Porta was original in thinking of light as the vehicle by which the forms of objects arrive in the eye, but light was not the "causal agency" of vision itself.[21] In his analogy, light carries forms to the eye's crystalline humour, which "stands in stead of a Crystal Table" in a dark room.[22] The objects of our vision were three-dimensional forms of the objects in the world outside.

When Kepler adopted from him this general model, he modified it in light of the anatomical work of Felix Platter, who had argued the the retina was the sensitive part of the eye, and shown the optic nerves behind it were solid rather than hollow.[23] For Kepler, the front of an eye was a pinhole, and the back really was a screen onto which the world outside was optically

18 Vision "occurs when an image (*idolum*) […] is set up at the […] concave surface of the retina." Kepler, *Optics*, 180. Elsewhere Kepler is more particular about vision 'occuring' through *pictura* – pictures, rather than images. See footnote 33 below.

19 See particularly David Lindberg's work, his collected essays are a good overview of medieval optics: Lindberg, *Studies in the History of Medieval Optics*.

20 Della Porta, *Natural Magick*, 365 (book 17, chapter 6).

21 Gal and Chen-Morris, *Baroque Science*, 27.

22 Della Porta, *Natural Magick*, 365 (book 17, chapter 6).

23 For Kepler's critique of Della Porta, see Dupré, "Inside the Camera Obscura," 237–243. Della Porta wrote that this his eye mechanism was "declared more at large in our Opticks," though Kepler probably did not see this other work. Robert Goulding has noted that recent scholarship suggests Kepler likely saw not only *Magia Naturalis* but also perhaps a precis of his later *De Refractione*: Goulding, "Thomas Harriot's Optics," 145, footnote. 24. For Kepler's reference to Platter, see Kepler, *Optics*, 171–179.

projected.

According to Gal and Chen-Morris, Kepler equated the eye with the *camera obscura* out of a desire to legitimate the instrument, rather than explain the organ of sight.[24] Projected images were useful for making astronomical observations, as Kepler, Galileo, and Scheiner all did to monitor sunspots, protecting their eyes from blinding sunlight. But while such projected images were, to follow Sven Dupré's terminology, "empirically familiar," they were "conceptually alien."[25] The perspectivist tradition of optics before Kepler could make no sense of them. Kepler sought to understand projected images – whether in the eye or on a tabletop – as material entities caused by light.

This was an important departure from his predecessors, for whom seeing was always the action of the *object* itself on the eye, via species. Because images were not objects they did not emanate species – as Dupré points out, images were made of "all kinds of spirits" rather than of light.[26] Perceiving them always involved deception – "they were misapprehensions only," as Antoni Malet says.[27] For instance, in the thirteenth century, John Pecham wrote that images were "the appearance of an object outside its place. [… I]t is the object that is really seen in a mirror, although it is misapprehended in position."[28] The eye still received the form of an object, but the mind was tricked into thinking the object was somewhere other than it really was. Gal and Chen-Morris argue it was Kepler's commitment to physical (rather than mathematical) astronomy, and a concomitant concern to show that observing images could reveal material truths about the

24 Gal and Chen-Morris, *Baroque Science*, 24 and chap. 1 generally. The status of the analogy in Kepler's work is the subject of earlier debate. Stephen Straker argued Kepler's comparison between the *camera* and the eye was what led him to the revolutionary insight that vision operated when an image was projected onto the retina (Straker, "Kepler, Tycho, and the 'Optical Part of Astronomy.'" David Lindberg's Kepler, on the other hand, is the culmination of the perspectivist tradition, and his main concern was how to understand the course of light through the variety of fluids and lenses of the eye. How to guarantee a one-to-one correlation between points in the world and points in the eye was a problem that had plagued previous intromission theories, an issue "had no analogue at all in the theory of the *camera*" (Lindberg, *Theories of Vision from Al-Kindi to Kepler*, 206 See 178-208 for his views on Kepler.)

25 Dupré, "Inside the Camera Obscura," 222.

26 Ibid., 223.

27 Malet, "Keplerian Illusions," 2.

28 Quoted by Ibid. See also Roger Bacon's similar views in Lindberg, *Roger Bacon and the Origins of Perspectiva in the Middle Ages*.

heavens, that led him to consider light as the mechanistic cause of vision. This process guaranteed that "all celestial observation takes place through the mediation of light and shadow," whether with instruments or without.[29] The eye and the *camera obscura* were alike in being passive receivers of light.[30]

How or why does a retinal image create vision? Kepler, in reinventing vision as the action of light, distinguished between a 'projected image' (*pictura*) and a 'perceived image' (*imago*).[31] The *imago* was subjective, a product of the imagination. The *pictura* was a material entity, existing at the point where light rays focus. Though vision "occurs" when a *pictura* is projected on a retina, Malet has pointed out that its 'existence' *as* a picture – its capacity to be seen if a screen is placed at the right point in space – is not the causally relevant part of Kepler's story.[32] The important thing is that the retina is in the way of incoming light rays, and in clear vision it is at the focal point of the eye's lens.[33] Kepler denied that there is really a 'picture' which travels from the retina up the optic nerve to present itself directly to the soul as species did in older theories. He knew the eye received light, but he also knew from Platter that the optic nerve was a dark and twisted tunnel. The eye's retina was like the *camera's* screen in being the end of an optical story, after which the process must change radically.[34] Kepler famously left it to "natural philosophers (*physici*)" to debate how the mind received impressions from the eyes.[35]

Kepler thus bequeathed subsequent philosophy a mechanically reworked version of an old Aristotelian problem. The disembodied eye could never explain vision, Aristotle said, because

29 Quoted in Gal and Chen-Morris, *Baroque Science*, 24.
30 The story is similar for Christoph Scheiner, who described the "wonderful concordance of nature and art" in his *Rosa Ursina* (1626) (quoted in Gorman, "Projecting Nature in Early-Modern Europe," 38.) Like Kepler he arrived at the comparison of retinal and *camera* images from a background in observational astronomy, and considered the 'tubes' and 'eyes' both as simply systems of lenses. See also Gorman, "A Matter of Faith?"
31 See Malet, "Keplerian Illusions"; Dupré, "Inside the Camera Obscura"; Chen-Morris, "From Emblems to Diagrams."
32 As Kepler's noncommital verb choice of "occurs" implies. "Visionem fieri dico, cum totus hemisphaeri mundani, quod est ante oculum, & amplius paulo, idolum statuitur ad album subrufum retinae cauae superficiei parietem." Relatedly, Kepler simply writes of light as light propogating by a "local egress" (*Optics*, 20.) It is later, with Descartes, Gassendi, Hobbes, Huygens, and Hooke that it explicitly becomes local *motion* of *matter*.
33 Malet, "Keplerian Illusions," 13–21.
34 Kepler, *Optics*, 180.
35 Ibid.

"when seeing is removed the eye is no longer an eye, except in name – it is no more a real eye than the eye of a statue or a painted figure."[36] After Kepler, Rohault agreed that nothing could be learnt about an eye "inclosed in the Head of any Animal." When he recommended removing it to sketch its figure, the lesson he sought was one of optics rather than eyesight.[37] But now the eye was always disembodied, pending the "philosophers'" story about the connection between it and the mind. The retina was always a screen between the mind and the world. The image that has become emblematic of the divorce is Descartes' drawing of his ox-eye experiment – also essentially a *camera obscura* (Figure 6.2).[38]

This image, and the experiment it illustrates, appear in the Fifth Discourse of Descartes' *La Dioptrique*, 'On the Images That Form on the Back Of the Eye'. Here Descartes mentions several possible ways of exhibiting the eye's mechanism, including a dark room with a pinhole for light, or an artificial eye made from glass. But he spends most of the discourse describing an experiment with the eye of an ox, which would make "more certain" of the operation of the eye. Cut the outer membrane off the back of the eye of a dead animal, and replace it a translucent material like thin paper or eggshell. Then if the eye is placed in a hole in a screened off window, the experimenter will see, "not perhaps without admiration and pleasure, a picture which will represent in natural perspective all the objects which will be outside."[39] Numerous writers reported on the satisfaction of carrying out this observation. Gaspar Schott repeated it in 1657, Rohault described it in 1671, Hooke found kittens' eyes well suited, and Scheiner claimed to have used "many animal eyes."[40]

36 Quoted in Gal and Chen-Morris, *Baroque Science*, 49.
37 Clarke, *Rohault's System of Natural Philosophy*, 1:233.
38 See Gal and Chen-Morris, *Baroque Science*, 42–51; Alpers, *The Art of Describing*, 34.
39 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 93.
40 For Schott see Wenczel, "The Optical Camera Obscura II," 24; Clarke, *Rohault's System of Natural Philosophy*, 1:243; "Lectures of Light," in Hooke, *Posthumous Works*, 127; and for Scheiner see Daxecker, "Christoph Scheiner's Eye Studies," 34.

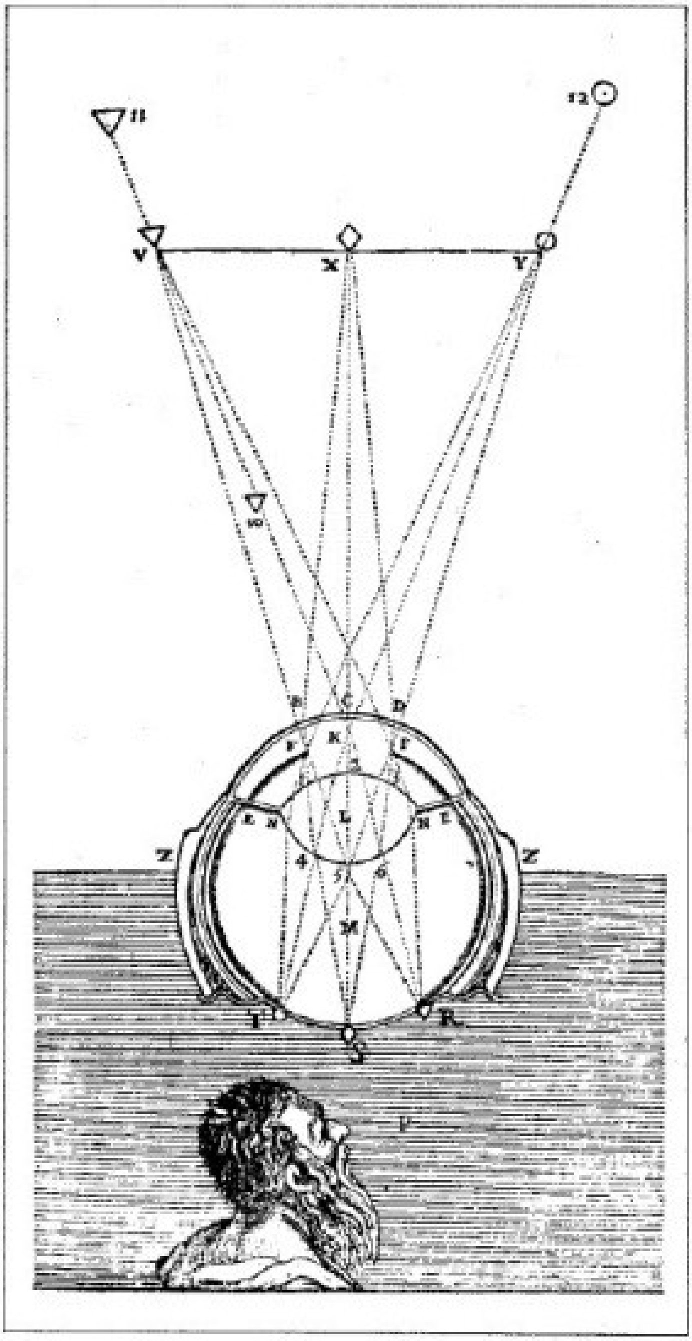

Figure 6.2: Descartes' observation of an ox eye. From Descartes, *The Philosophical Writings of Descartes*, 1:171.

The gap between the eggshell retina and the bearded observer at the bottom of the image is exactly that which Kepler left open. Objects' images are projected onto an opaque screen, at which point any neat pictorial, optical story has to end.[41] The epistemic anxiety of

41 For Descartes on the vision not working by resemblances, see Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 89–90.

mediated vision is the climax of Gal and Chen-Morris' narrative about the disappearing observer:

> [Descartes] invents the eye of the mind, modeled on but completely independent from the eye of the flesh. It is an invention that reverses the epistemological role of vision: from being the vouchsafe of our knowledge and a paradigm of direct acquaintance, it becomes a metaphor for mediation.[42]

The point is not the absurdity or redundancy of pushing the explanation of the visual process back into a point in the mind, it is the impossibility of doing so. The "eye" appears figuratively in the mind as an emblem of the apparently representational nature of our knowledge. Descartes of course denied its literal existence: it was not "as if there were yet other eyes in our brain with which we could apprehend" pictures from our eyes.[43] His contribution was to reduce representation to a causal mechanism:

> [I]t is only a question of knowing how [images] can enable the mind to perceive all the diverse qualities of the objects to which they refer; not of knowing how the images themselves resemble their objects; just as when the blind man […] touches some object with his cane, it is certain that these objects do not transmit anything to him except that, by making his cane move in different ways according to their different inherent qualities, they likewise and in the same way move the nerves of his hand, and then the places in the brain where these nerves originate.[44]

For Descartes, *picturae* reduced in any case to the motive tendency of microscopic particles, which motion the animal spirits would carry up the dark, twisted passage of the optic nerve. But while mechanical philosophy could guarantee visual experience by this mechanism, the

42 Gal and Chen-Morris, *Baroque Science*, 51.
43 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 101.
44 Ibid., 90.

implication was that what we see is not what we know, or at least not why we know it.[45]

Two things emerge from this quick look at the optical writers Hooke mentions. The first is this fundamental insight that perception does not happen because objects are directly present to the mind through an uninterrupted channel.

Secondly, the comparison between the natural eye and artificial instruments was generally motivated by the need to justify observations made through artifice. It is important that Descartes' simile of eye and *camera obscura* appears in *La Dioptrique* rather than *Le Monde ou Traité de la Lumiere*. Descartes' discussion of light in *Le Monde* was a triumphant application of his mechanical philosophy.[46] Following Galileo's condemnation though, the more circumspect *La Dioptrique* detailed the unobservable facts about light more for predictive rather than explanatory reasons – to show how optical instruments could be improved rather than as part of an holistic system of the world.[47] Descartes wanted to show how different optical instruments would affect the sight; the explanation of light was secondary.[48] He was also clear about his aim to "make [himself] intelligible to everyone," to reach an uneducated audience: "the execution of the things of which I shall speak must depend on the skill of artisans, who ordinarily have not studied."[49] In other words, his aim in *La Dioptrique* was not to directly convince Scholastics of his new philosophy, but rather to provide a way to gain evidence for it – *La Dioptrique* was an *apologia* for

45 See also Clarke, *Rohault's System of Natural Philosophy*, 1:243ff. The disagreement between Malebranche and Arnauld is the locus classicus for the subsequent debate on the nature of our ideas and their relation to the world, while the 'British Empiricist' tradition moves through Locke, Berkeley and Hume. For more contemporary treatments, see especially Richard Rorty's influential *Philosophy and the Mirror of Nature*; as well as John Yolton: *Perceptual Acquaintance from Descartes to Reid*; *Perception and Reality*. Gal and Chen-Morris conclude by suggesting there is something right about Rorty *philosophically*, despite "all his historiographical inaccuracies." *Baroque Science*, 49.

46 Gaukroger suggests Descartes theory of matter was directly motivated by his theory of light, see Gaukroger, *Descartes: An Intellectual Biography*, 256.

47 See his letter to Mersenne from November 1633, quoted in Ibid., 290–291.: "if this view (heliocentrism) is false, then so too are the entire foundations of my philosophy."

48 When he replied to Morin he implied that instruments were a test of the truth of a theory of light. "If light can be imagined some other way by which one can explain all of its properties that are known by experience, one will see that everything that I have demonstrated about refractions, vision, etc. can be deduced from it as well as from the way that I proposed." Descartes to Morin, July 1638. Quoted in Clarke, *Descartes*, 165. Following the same form a generation later, Rohault likewise wrote that "to prove the Truth of some of those Suppositions which we have made about Vision; we ought now to consider, whether or no all those Things, which upon these Suppositions ought to come to pass, when we look through different Sorts of Perspective-Glasses or upon Looking-Glasses, be agreeable to Experience." Clarke, *Rohault's System of Natural Philosophy*, 1:258.

49 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 66.

optical instruments and an instruction manual for telescope makers.[50] The purpose of the ox-eye experiment, however symbolic it became of its context, was to show that modifying vision with instruments did not involve a subversion of the true visual process, as it had for perspectivists. Like Kepler, Descartes was invested in establishing the veracity of mediated observations.

In the process of examining instrumental observation, the eye came to be recognised as little other than an optical instrument itself. In Hooke a generation later, we find the logic shifted slightly. If Descartes or Kepler justified instrument use by looking at the eye, Hooke wanted to teach his audience about natural, unassisted vision by looking at instruments. Before coming to this lesson, I will return the story to Hooke himself, and introduce the artificial eyes he constructed.

The Genealogy of Hooke's Instrument

By the time Hooke delivered his lectures on vision, the instruments with which he represented the eye were several years old. They were again the results of an order from the Royal Society to prepare entertainments for the king. When the Royal Society Council met on 12 October 1663 to delegate experiments of royal entertainment to different Fellows, and among those that fell to Hooke were:

> To make an artificial eye.
>
> To try the casting of a picture on a wall in a light room; and to bespeak a concave glass for it.[51]

Christopher Wren, an experienced optician himself, suggested at least the first of these. He had dissected a horse's eye to learn its structure. Such anatomy, he confessed to Brouncker, was very enlightening, but it did tend to be "sordid and noisome."[52] Instead, he followed

50 See: Dijksterhuis, "Constructive Thinking," 66ff.
51 Birch, *The History of the Royal Society*, 1756, 1:313.
52 Ibid., 1:289.

Descartes' suggestion, that if an eye could be made of glass, in human proportions but larger, "the images formed [on the retina...] would be to that extent more visible," and the eye's work clear to behold.[53] Wren ultimately suggested gifting the king a compass and a way-wiser (odometer) to entertain him on his jaunts around London, but among other possibilities he touched on such an "artificial eye [...] at least three inches in diameter," made of glass and water, to "represent the picture as nature points it."[54]

What ought to be shown off to Charles, felt Christopher Wren, was something "luciferous in philosophy, and yet whose use and advantage is obvious without a lecture; and besides, that may surprise with some unexpected effect, and be commensurable for the ingenuity of the contrivance."[55] Many of these desiderata translate naturally to the setting of a public lecture. From their very inception, Hooke's eyes were intended as impressive objects, "obvious without a lecture:" intuitive spectacles that would not so much explain anything to their audience in a rigorous sense as prompt imagination and delight. Though they were initially separate requests, through Hooke's tinkering and rebuilding, they grew together. The eye just *became* nothing more than the instrument for casting pictures.

On 9 March 1664 John Wilkins reported to the Council on Hooke's progress. Hooke had worked out how to project images onto the wall of a light room, and the artificial eye had been "dispatched."[56] Whether this meant it was completed, the design had been given to a glass blower, or the idea had been dropped, the object disappears until Hooke's Gresham lecture 17 years later.

The light room image projector was published in the *Philosophical Transactions* in 1668, though the publisher (presumably Oldenburg) noted that he had had the pleasure of attending the device's debut "some years" before.[57] Hooke describes a something of a mixture between a

53 Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, 99.
54 Birch, *The History of the Royal Society*, 1756, 1:290.
55 Ibid., 1:288.
56 Ibid., 1:391.
57 Hooke, "A Contrivance," 743.

camera obscura and a magic lantern – a popular seventeenth century entertainment device which projected shapes that originated *within* the device, created by translucent paint on a mirror or shapes cut out of a sheet.[58] The problem was to make a pinhole image visible in a lit chamber, and Hooke's solution was just to illuminate the object to be projected more strongly. This object is placed just on the other side of the pinhole, and so much the better if it can be inverted in its place so the image will be the right way up. If it cannot be, "as 'tis pretty difficult to do with Living Animals," then a further lens should be used to right the image. He then surrounded it with mirrors and lenses which amplified the sunlight shining on it. The method is "easy and obvious," he acknowledged, but "hath not, that I know, been ever made by any other person this way."[59] Like the magic lantern, such a device is a poor analogue of the eye: they throw images out into the world, as in the old extramission theory of vision. Only the *camera obscura* brings the world inside.

There is a coincidental but not insignificant similarity between Hooke's description of his method and Della Porta's use of a *camera obscura* a century earlier which is worth pausing on. Both devices were intended as entertainment sources of wonder, making objects that were not actually present flicker into view. In Della Porta's *Magia Naturalis*, the magician and dramatist wrote about what he could perform for his amazed audiences with the *camera obscura*. "One may see as clearly and perspicuously, as if they were before his eyes, Huntings, Banquets, Armies of Enemies, Plays, and all things else that one desireth," he proclaimed. Hooke's audience, too, could see "Apparitions of Angels, or Devils, Inscriptions and Oracles on Walls; the Prospect of Countryes, Cities, Houses, Navies, Armies; the Actions and Motions of Men, Beasts, Birds, &c. the vanishing of them in a cloud, and their appearing no more after the cloud is vanisht."[60] Through presenting experiments so often at the Royal Society, Hooke was clearly practiced at entertaining an audience and and capturing their attention.

58 For more about this instrument, see Vermeir, "The Magic of the Magic Lantern."
59 Hooke, "A Contrivance," 741.
60 Ibid., 742.

But there was an important difference, already hinted at above. When Della Porta "shewed this kind of Spectacle to my friends, who much admired it, and took pleasure to see such a deceit," a deceit it surely was. The audience experiencing the visions "cannot tell whether they be true or delusions," and Della Porta "could hardly by natural reasons, and reasons of Opticks remove them from their opinion."[61] His audience felt they were seeing the objects themselves, displaced by trickery, and could not understand how this could not be the case. Hooke's description, on the other hand, contrasts the success of his instrument with deceptions and magic of earlier ages:

> [H]ad the *Heathen* Priests of old been acquainted with it, their Oracles and Temples would have been much more famous for the Miracles of their Imaginary Deities. For by such an Art as this, what could they not have represented in their Temples?[62]

Hooke intimates that by his time the opportunity for deception was a thing of the past. It was only those "Spectators, not well versed in *Opticks*" who might be tricked into feeling "all those passions of Love, Fear, Reverence Honour, and Astonishment," that are the "natural consequences" seeing something miraculous or supernatural.[63] To the modern reader, Hooke's prosaic description belies the myth about the audience's reaction to the Lumière brothers' moving picture *L'Arrivé d'un train*.[64] Already, by the mid-seventeenth century, image projection lacked the ability to make spectators truly react to the projected objects as if they were visible but not there. Hooke's audience saw what was in front of them – an image, while Della Porta's saw what really was not – the objects, "*as if* they were before [their] eyes."[65]

61 Della Porta, *Natural Magick*, 365 (book 17, chapter 6).
62 Hooke, "A Contrivance," 742.
63 Ibid.
64 See Loiperdinger and Elzer, "Lumière's Arrival of the Train: Cinema's Founding Myth." I do not mean to make much of the comparision – I agree completely with Gorman's well-placed caution that image projection had its own status in early modern Europe, with understood meaning and import, and is undervalued when discussed merely as cinematic pre-history. Gorman, "Projecting Nature in Early-Modern Europe."
65 Della Porta, *Natural Magick*, 364 (book 17, chapter 6).

Hooke's secular and unproblematic display confirms Michael Gorman's conclusion that "from being a wonder in the 16th century, the projected image became in the seventeenth century, a philosophical demonstration of central importance."[66] Image projection devices were not the objects of mistrust and wonder they had been a century earlier. They were products of skilled craftsmanship which began to bring trust and assurity to a topic that was characterised by mistrust and anxiety in early modern Europe – human vision.[67] The images inside *cameras obscura* were no longer "conceptually alien," to return to Dupré's description of them before Kepler's time. They were stabilised as a predictable and explicable part of a causal mechanical process.

By the end of the 1660s, even the specific form of the perspective box that Hooke would later use as an eye was fairly standard equipment. Two years apart, Rohault and Boyle described almost exactly the same device.[68] This was a "portable darkned Roome," in which images would form on "a fine sheet of Paper stretch'd like the Leather of a Drum-head at a convenient distance from the remoter end; where there is to be left an hole covered with a Lenticular Glasse." As with Hooke's, the screen could be moved in and out to focus the image.[69]

Boyle's interest in the instrument was what it showed about geometric optics rather than vision. Everywhere an image was visible, the air must have been full of "visible Species, which cannot be intelligibly explicated without the Locall motions, of some minute Corpuscles, which, whilst the Air is enlightened, are alwaies passing thorow it."[70] Boyle's apparent innocence of Kepler's and Descartes' optics highlights the centrality and importance of Hooke's work in the English context. None of the writers Hooke mentioned and I discussed above were English: he was following a tradition he likely read about himself rather than one he was taught at Oxford or Westminster.[71] Of course the continent was not far away. The likes of Boyle went on tours, and

66 Gorman, "Projecting Nature in Early-Modern Europe." Dupré also discusses perspectivist opticians who used their knowledge of image creation to dispell the impression that such were created by demonic magic, and Kepler's own admission that his audiences enjoyed his projections "all the more for realizing that they were games." Dupré, "Inside the Camera Obscura," 235.

67 See Clark, *Vanities of the Eye*.

68 Clarke, *Rohault's System of Natural Philosophy*, 1:243–244.

69 *Of the Systematicall or Cosmicall Qualities of Things*. In Boyle, *The Works of Robert Boyle*, 1999, 6:295.

70 *Of the Systematicall or Cosmicall Qualities of Things*. In Ibid.

71 Thomas Harriot was probably the foremost early seventeenth-century English optician, but was not a prolific

the likes of Henry Oldenburg were in constant communication with European philosophers. Nevertheless, Hooke was an important conduit of learning into England. His mechanical skill in the workshop was complimented by scholarly learning which went well beyond the walls of his room. His lectures brought new ideas not just to the public of London but the philosophers of the Royal Society too.[72]

In fact, Hooke was working on the instrument around this time as well, and Boyle's note that he had "caused" it to be made "severall years agoe," since when several people had copied it, implies they were perhaps collaborating on instruments again. Hooke's interest in it was as a portable drawing aid. He brought it to meetings several times, adapting it more and more for this purpose, until finally someone could stand inside it and trace the images projected on a screen in front of them.[73]

The engraving in Figure 6.3 appears in the collection of Hooke's papers posthumously published by William Derham in 1726. Hooke apparently showed the device depicted to the Royal Society on 19 December 1694, though he completed it many years before that.[74] In the accompanying text Hooke never actually describes the form of the 'Instrument of Use to take the Draught, or Picture of any Thing,' and the drawing is not his hand.[75] But the picture does match the operation of the "small Picture-box" which Hooke was particularly keen to promote for illustrators of travel books.[76] Hooke, like Kepler, like Vermeer, knew all about the *camera obscura's* usefulness in drawing. In 1666 he told Pepys it was a better aid for drawing than Alberti's

publisher. For more on him see Goulding, "Thomas Harriot's Optics."

72 Hooke certainly often corrected them in meetings. For example, in 1679 Dr. Croune suggested the dilation of the pupil caused objects to look larger or smaller. Hooke gently corrected him, saying the iris was to protect the eye against light too strong for the eye, and does not affect the size of objects perceived. Birch, *The History of the Royal Society*, 1757, 3:502. See also Hooke's tutoring Boyle on the principles of Cartesianism: Davis, "'Parcere Nominibus.'"

73 Birch, *The History of the Royal Society*, 1756, 2:436, 440, 442. It is reminiscent of a portable *camera* of Kepler's which Constantijn Huygens wrote glowingly about, as well as earlier devices described by Barbaro and Kircher. See Wenczel, "The Optical Camera Obscura II."

74 He says it is "not a new Design" and notes its similarity to something he "long since" showed the Royal Society. Hooke, *Philosophical Experiments and Observations of the Late Eminent Dr. Robert Hooke*, 293–296.

75 Though I have been unable to find this particular image in manuscript form, where I have been able to compare two versions of the same figure in Hooke's manuscripts and Derham's publication, the latter are more idealised and somewhat starker, redone for printing.

76 Hooke, *Philosophical Experiments and Observations of the Late Eminent Dr. Robert Hooke*, 296.

grid technique, and in 1675 he dropped by the studio of his old master Peter Lely to talk about "helping the sight and of picture box."[77] Hooke's image projector began as a delightful entertainment, became an picturing tool, then finally appeared as an eye in his lectures about light.

Figure 6.3: Picture-box, from Hooke, *Philosophical Experiments and Observations*, 295.

77 21 February 1665/6: Pepys, *The Diary of Samuel Pepys*, 1972, 7:51; Hooke, *The Diary of Robert Hooke, 1672-1680*, 1935, 1:204. For a comparison of these two techniques and the versions of 'seeing' they engendered, see Alpers, *The Art of Describing*, 41ff. Hooke also told Pepys about the perspectographs of Wren and Prince Rupert – the idea of mobile drawing aids must have been attractive to Wren and Hooke once they were employed surveying London following the Great Fire. Rupert's perspectograph was 'perfected' by Hooke (Birch, *The History of the Royal Society*, 1756, 1:329, 333, 334, 337, 348). and Wren's appeared in the *Philosophical Transactions* in 1669 (Wren, "The Description of an Instrument").

Hooke's Demonstration of Eyesight

This lecture series began with the nature of luminous bodies and ended with a decription of memory and the perception of time. The editor of Hooke's *Posthumous Works*, Richard Waller, notes that Hooke apparently never completed his planned discussion of light and apologises for the apparent change of subject of the last section. But it is easy to read the topics successive: as Jack MacIntosh has suggested, Hooke's model of memory is "the final move in the process of making the explanation of light in terms of touch an interior one."[78] "To find the Nature of Light," supposed Hooke, "we must examine first, what it is in the Luminous Body that is the Fountain, and emits or causes it; Secondly, what it is in the Medium that propagates and conveys it; and Thirdly, what it is in the Eye, or the subject that receives it, and is affected or acted by it."[79] This last step, how the subject is affected, turns his topic from strictly optical into visual – from the behaviour of light as Kepler considered it into an epistemological story.

Hooke's lectures thus form a narrative which pivots around the reception of light by the eye. This was how he could sidestep the old problem of observing eyesight itself – vision *was* visible, if not in description alone then through performance. As with metaphors in text, the demonstration of an analogous mechanism could allow the audience to imagine and thus conceive how something could operate. Koen Vermeir has shown that in the salons of the French *philosophes*, inventing analogies to bring mechanistic explanations of phenomena to life became a sort of game for the entertainment of the gentry, and this tradition was sometimes adopted as an explanatory model by philosophers. Making an occult or unfamiliar process imaginable by referencing to a more familiar mechanism was a way to explain it – what Vermeir calls "analogical demonstration."[80] Similarly, so much of Hooke's natural philosophical work was a live performance that a kind of semi-theatrical display was a common feature of it. He used models constructed in the workshop to test ideas about the operation of distant or inaccessible

78 MacIntosh, "Perception and Imagination in Descartes, Boyle and Hooke," 328.
79 "Lectures of Light," in Hooke, *Posthumous Works*, 85.
80 Vermeir, "The Magic of the Magic Lantern," 151–154.

objects, and he read metaphysical lessons off the behaviour of his instruments.[81] In his lectures about light, the perspective box stood for something inaccessible, the seeing eye. It made the "invisible visible."[82]

Hooke explained that as the pulses of light disperse through the surrounding medium, its power dimishes according to the inverse square law. The first thing the eye must do is collect and concentrate the rays back to (almost) a point, as with a burning glass.[83] In doing so, "the Eye may not improperly be called a Microcosm, or a little World[. … W]hen a Hemisphere of the Heavens is open to its view, it has a Hemisphere within it self."[84] Hooke *told* his audience that the world was visible on the retinas of eyes removed from their sockets. But then he *showed* them it with the perspective box.[85] This performative aspect allowed the lesson to extend beyond geometric optics and encompass the whole process of vision. With their faces pressed to the hole in metal and glass cylinder, his audience saw the operation of the eye. A picture was cast on the screen, and suddenly it was not the objects that they were looking at that were present to their minds, but those that the eye was facing. The observer was corporeally excluded from the box. Separated from their own body and unaware of their own perspective, they adopt instead that of the artificial eye they were inside. If the problem with understanding vision post-Kepler was the separation of inner representation and external reality, acting with a perspective box could collapse everything to inner representation.[86] The audience became Descartes' 'eye of the mind', perceiving what a dislocated eye was seeing.

Later, Locke explicitly drew the analogy between the understanding and a *camera obscura* which "let[s] in external resemblances, or *Ideas* of things without."[87] That he did so when fully

81 See Bennett, "Robert Hooke as Mechanic and Natural Philosopher," 41–43.
82 Vermeir, "The Magic of the Magic Lantern," 153. Recall Gorman's note on the authoritative status of the projected image as "a key instrument of persuasion in public demonstration lectures." Gorman, "Projecting Nature in Early-Modern Europe," 50.
83 "Lectures of Light," in Hooke, *Posthumous Works*, 122–123.
84 "Lectures of Light," in ibid., 121.
85 "Lectures of Light," in ibid., 127.
86 See Crary, *Techniques of the Observer*, especially "The *Camera Obscura* and its Subject," for more on the experience of using a *camera* obscura and the visual paradigm it implied.
87 Locke, *An Essay Concerning Human Understanding*. Book 2, chapter 11 section 17, p. 72.

aware of the more usual analogy with vision prompted John Yolton to wonder if Locke was not "transferring Hooke's microcosmic notion to the understanding? Was there some temptation to think of our awareness being like the face at the perspective box?"[88] I would suggest that yes, not only was it tempting, this is exactly the power of such a demonstration with a perspective box. That the mind worked visually as Locke suggested was a recognisable trope in early modern literature and philosophy.[89] It was evocative and persuasive then as it is now.

It is time to turn to Hooke's epistemology, and draw the threads traced above together into a lesson about his observation, instrument-based approach to natural philosophy. Straightforwardly representational vision could be recreated by an artificial eye, but it is important to be careful about the manner in which Hooke's idea of vision was pictorial. Strictly speaking it is not that pictures cause us to see, but rather that pictures and vision are produced in the same way, through the mechanical operation of light. As long as we are careful about the distinction between the pictorial story and the causal mechanical one, the language we use to describe pictures allows us to say interesting things about the epistemic implications of this equivalence for how Hooke and others in the same tradition conceived of visual information.

The Eye as Instrument

If Kepler's optics and Descartes' scepticism created "the fundamental epistemological problem of the Baroque," then Hooke reveals himself to be something of a modern and a constructivist in response.[90] For Hooke, a worker in Francis Bacon's Great Instauration, the new, light-based, indirect theory of vision which bequeathed philosophy such subsequent epistemic unease was good news.

88 Yolton, *Perceptual Acquaintance from Descartes to Reid*, 127.
89 The phrase 'the mind's eye' was famously used by Hamlet (1.2.185). See also the frontispiece to Robert Fludd's 1617 *Ars memoriae*, featuring the *Oculus imaginationis*.
90 Gal and Chen-Morris, *Baroque Science*, 51.

> Though [philosophy] has always made a fair shew of flourishing; yet upon Examination, it has been found to yield Leaves instead of solid Fruit, to be a Knowledge very confus'd and imperfect, and very insignificant as to the inabling of Man to practise or operate by it.[91]

This was no wonder, if perception had been so routinely misunderstood. Approaches to studying the natural world had laboured under the misconception that the eye marked a direct channel from the world to the soul. But vision was not governed by species. For Hooke this was a moderate sceptical realisation which licenced moving away from the "Worm-eaten Volumes of Antiquity" and beginning a "new Inquiry into the Nature of Things;" one of careful and patient reasoning from collected observations.[92]

In his lecture, before describing the eye's anatomy and demonstrating its operation, Hooke betrayed what he took to be of the greatest philosophical import about the eye: how *clever* it was. He wondered aloud:

> How could it have entred into the Imagination of Man to conceive, how it should be possible for such an Atom of the Universe as Man is, to be informed at the Instant that a thing is done, how and where it is done, though Million of Millions of Miles distant? Certainly no more than we now imagine it should be possible for any Man here in *London* to know the particular Thoughts or Inclinations of any one single Man in *China* or *Japan* or of all the *Chinese* or *Japanese* together, at the same Instant they are thought there.[93]

This curious admiration is for an organ which connects us somewhat to the vast expanse of nature, despite our limits and insignificance. The eye is the most transporting and immediate sense, and lets us know what is taking place outside our heads. But there are others, which all have a particular benefit. Hooke's epistemology of the senses is one of instrumental

91 "General Scheme," in Hooke, *Posthumous Works*, 3.
92 "Lectures of Light," in ibid., 105. The idea is similar to Daniel Garber's take on Descartes' scepticism: it is an attack on previous philosophies which clears the way for a new system of the universe. See Garber, *Descartes Embodied*, especially "Semel in Vita."
93 "Lectures of Light," in Hooke, *Posthumous Works*, 121.

design: some parts of our bodies are sensitive to certain qualities that exist in the world, and when they get in the way of that quality it creates "such an Impression as becomes sensible to the Animal Faculty."[94] Perception does not happen because the eye connects the world to the soul, it happens because the eye is sensitive to light. The purpose of the sense-instruments is to allow us to navigate the world.

> The Sight [is] for discovering Conveniences and Inconveniences at a greater Distance as well as near at hand: The Ear, for receiving Warning or Information from Sound, where the Eye could not assist: The Nose, for distinguishing by the Effluvia of Bodies, of wholsome or unwholsome Nourishment: The Taste for the same purpose, by the Dissolution of them in the Mouth, and for the determining of the Quantity requisite to be taken at a time: The Feeling, for the Sensation of External Textures or Motions.[95]

Crucially, in terms of philosophical knowledge, the senses by themselves "afford little as to what we are looking after."[96] For all its ingenuity, the eye was a severely deficient instrument. But this brought it within the scope of the mortal, as well as divine, craftsman. We could copy the original plan. The optical instruments of the seventeenth century showed we could extend or alter the eye, but the perspective box showed we could simply *make* one. Hooke's picture box was also an object designed to get in the way of light. It not only demonstrated the working of the eye, it let people share their experiences.[97] People could make artificial eyes, give them to others, and see what they had seen.

A facetious comparison of Hooke's picture box with Descartes' ox-eye experiment (Figures 6.3 and 6.2 respectively) reveals something surprisingly telling about the connection of Hooke's ideas about vision and natural philosophy. The bearded observer of Descartes' drawing

94 "Lectures of Light," in ibid., 120.
95 "General Scheme," in ibid., 8.
96 "General Scheme," in ibid.
97 For the importance of shared visuality in the modern scientific project, with some interesting historical insights about the instrumental origins of much shared vision, see Latour, "Visualisation and Cognition: Drawing Things Together."

(is he wearing a toga?) gazes distantly up at the retinal screen, separated from it by void. The well-dressed Georgian traveller in Hooke's (or Derham's) image is thoroughly situated inside the *experimentum*. The gap between retinal screen and his own eyes is bridged by his arm and hand in the act of drawing. The mystery persists about how an image represents the world to the mind, but the strong implication is that the reductive mechanisation of vision guarantees at least its reproduceability. The problem with previous philosophy in the Baconian project was that the world had been ignored and abstract claims made too hastily. But the world was so vast and complex that no one person could hope to observe it all. The project rests on exactly this ability to share experience, which the instrumentalised eye provides.

Hooke wrote in the preface to his friend Robert Knox's *An Historical Relation of the Island of Ceylon* (1681) that the book would no doubt be entertaining and interesting to people of all sorts of professions, but was invaluable to the "Philosopher and Historian." This was ideally true of all travel books which recounted the flora, fauna, and customs of foreign lands, just as long as the author took note of those things that were "pertinent and considerable, to be observ'd in their Voyages and Abodes," and, crucially, made good accounts of their observations.[98] Hooke's suggestions for how to do this were twofold. First are administrative issues: travellers should be taught which aspects of foreign places to focus on – a concern which emphasises the importance Hooke placed on the public sponsorship of knowledge collection. Second, people must record observations accurately. Pictures give us far more information than words, he thought, and his description of the picture box published by Derham was explicitly aimed at promoting it for use by travellers (Figure 6.3 above). The device ought to be promoted by "all such, as desire to be rightly and truly informed" about other people's experiences.[99] Hooke railed against fanciful images he had seen in travellers' accounts: the extravagant height of hills, the sudden descents of valleys, mountains over-hanging for "half a Mile, or a Mile, which, tho'

98 Knox, *An Historical Relation of the Island Ceylon*, sigs. A3r, A2r.
99 Hooke, *Philosophical Experiments and Observations*, 294.

the Mountain were made of cast Iron, were impossible to be sustain'd."[100] The true author of such drawings was invariably "some Picture-drawer, or Engraver, here at Home, who knows no more the Truth of the Things to be represented, than any other Person."[101] Any draughter using a picture-box, on the other hand, could "but use his Pen, and trace the Profile of that what he sees ready drawn for him." As with so much of Hooke's instrumental rhetoric, little rests on the human operator, the result is the effect of natural processes given artificial direction. The observer has disappeared. "Mr. Engraver's Fancy," was no longer needed, the picture is "[al]ready drawn." It would take a willful act for the the operator to produce anything *other* than a "true Draught of whatever he sees before him."[102]

'Truth' itself was thus built into the operation of the instrument – the same sort of truth one feels about one's own personal perceptions. Hooke's mentor Wilkins wrote that "nothing can be more manifest and plain to me, than that I now see somewhat which hath the appearance of such a colour or figure."[103] Though Wilkins freely admitted he did not know how sensory experience happens, in terms of light-based vision this was exactly because the light that forms a picture of such a colour or figure is *really there*, regardless of whether it is an eye or a sheet of paper which gets in its way. Alpers finds this Keplerian visual idea expressed in the art of Jan Vermeer and the northern naturalists generally: "the world compressed onto a bit of paper with no prior viewer to establish a position or a human scale."[104] In the case of the artist standing inside a *camera obscura* and tracing a lens projection, the splashes of colour and darkness appear prior to cognition, created simply by the mechanical action of light. This is the same information one gets from the natural eye before it is synthesised into a conception of the world. As Alpers has written of what has become the paradigmatic case of depiction by a *camera obscura*, Jan

100 Ibid., 293.

101 Ibid. He even singles out the "Books of Theodore de Brie concerning the East and West Indies[, ...] Sir Thomas Herbert's Travels; and those of Mr. Ogylby's Asia, Africa, and America; which are copies of the Dutch Originals." In light of this, Lisa Jardine's suggestion that Hooke may have helped Knox's brother with the engravings seems odd. Jardine, *The Curious Life of Robert Hooke*, 273.

102 Hooke, *Philosophical Experiments and Observations*, 295.

103 Wilkins, *Of the Principles and Duties of Natural Religion*, 5.

104 Alpers, *The Art of Describing*, 41.

Vermeer's *View of Delft*, the scene is "hardly grasped, or taken in – it is just there for the looking."[105]

Figure 6.4: Jan Vermeer, *View of Delft*, 1662

Earlier, Lawrence Gowing noted that Vermeer "seems almost not to care, or not even to know, what it is that he is painting. What do men call this wedge of light? A nose? A finger?"[106] The artificial eye is ignorant of the learnt meanings of objects and blind to natural qualities other than that which it is attuned to. It enacts Bacon's metaphorical recommendation that to gain knowledge one must be appropriately situated: one must withdraw the intellect from the messy

105 Ibid., 27. For more on lens use in art, see also Hockney, *Secret Knowledge*.
106 Quoted in Alpers, *The Art of Describing*, 37.

world far enough that "the images and rays of natural objects meet in a point, as they do in the sense of vision; whence it follows that the strength and excellency of the wit has but little to do in the matter."[107] Vermeer, and Hooke, could position the eye a certain distance from an object, select the appropriately dilated pupil, and the outside world would be immediately known to whoever was inside.

Certainty

Understanding the senses as instruments did not only imply the possibility of manipulating them, but of trusting them. For Descartes, sight was analogous with that of a blind man feeling his way with a cane, an image which Hooke also repeats. "[T]he eye becomes," he said in his lecture, "as it were a Hand, by which the Brain feels, and touches the Objects, by creating a Motion in the *Retina*, the same, and at the same Instant, with the Motion of the lucid Object it self."[108] The pseudo-Aristotelian text *De Sensu* had ridiculed the atomists for reducing all perception to the motion of atoms and therefore to touch. In Aristotelian thought, touch was the "primary form of sense," meaning it was the most entangled and bodily, and the least intellectual.[109] To see, by comparison, was to receive the essence of an object. After Kepler though, in the absence of a visual theory which gave us direct access to objects' forms, it was this physico-mechanical causal story which allowed seventeenth century epistemologists to depend visual information.

Directness and reliability goes hand in hand with grossness and insensitivity. If a hand is too large to feel the texture of a fine weave, or too warm to feel the heat of water, the mind will not be informed about these qualities. The eye likewise only sees things it is attuned to. Ideas are *of* things, but *from* a perspective. When Wilkins wrote of the assuredness with which he

107 From the preface to the *Instauratio Magna*, quoted in Desroches, *Francis Bacon and the Limits of Scientific Knowledge*, 100. See also Desroches' discussion of the metaphor.
108 "Lectures of Light," in Hooke, *Posthumous Works*, 124. The analogy is repeated throughout Descartes' *Dioptrique*.
109 Wolfe, "Early Modern Epistemologies of the Senses," 3.

experienced the colours and figures in front of him, it was the kind of indubitableness of private phenomenology, rather than of the blind man's cane.[110] Understanding the former in terms of the latter – phenomenology as the turning dial of an instrument, Hooke departed from the epistemology of Wilkins. Wilkins held that "there is an universal agreement in the sensation of outward Objects; The *Eye* and the *Ear* of all sensitive Creatures, having the same kind of perception of *visible* and *audible* things. Those things which appear Green, Blew, or Red to one, having the same appearance to all others."[111] As we saw in the previous chapter, Hooke went further in thinking that not only was the perspective of a particular person was arbitrary, depending on where they stood, but the perspective *of humans* also, depending on their natural optical instruments. A dog may be able to smell flesh where a human cannot, or an insect watch a string vibrate when we can only hear it.[112] The senses that a creature has, and therefore which natural qualities were available to that creature, were dependent on its body.

This, finally, is the real importance of using instruments as well as natural senses. The *camera obscura*, which allowed a visual artist like Vermeer to mark his paper with whatever is 'there', rather than whatever he *perceives*, replaced the confident human apprehension of forms with a view 'hardly grasped' diminished the power of vision. But it increased the power of vision-*like* senses. The artistic tradition which Alpers discusses considered the memory as a storehouse of *images* – visual ideas which could be brought out later and painted. This idea persisted in later philosophy, but for Hooke, on the other hand, this was not enough.[113] The kind of visuality of the eye as represented by the *camera obscura* gives an objective 'view from nowhere' only in a limited sense, as recent sociologists of science have pointed out.[114] If this universal perspective is at all the object of philosophical enquiry, it would have to be supplemented. If a sense, natural or

110 Wilkins, *Of the Principles and Duties of Natural Religion*, 5.
111 Ibid., 56–57. See also Rohault, who suggests that perceptions are caused by the shape and size of the incoming corpuscles, not their relation with the organs of sense: Clarke, *Rohault's System of Natural Philosophy*, vol. 1, chap. 27.
112 "Lectures of Light," in Hooke, *Posthumous Works*, 142, 135.
113 See Yolton, *Perception and Reality*, 49ff.
114 See e.g. Haraway, "Situated Knowledges."

artificial, presents an object not as a complete re-presentation, but insofar as it has certain qualities, which move through a certain medium, to a creature with a particular sensitive constitution, then the phenomena available through such instruments might rightly be called a view from 'anywhere'. Their power was in their new multiplicity.

After the Eye

The senses give us ideas. This is the topic of Hooke's last two Gresham lectures on light. What happens after light hits the retina? Descartes appropriated a metaphor from Aristotle and explained that in perception the "external shape of the sentient body [is] really changed by the object in exactly the same way that the shape of the surface of the wax is altered by the seal."[115] Hooke used the same metaphor. "It has pleased the al wise [*sic.*] contriver of the Universe to send man into the world almost ready tempered, like a piece of soft wax to receive those impressions and stamps, which he has thought it most convenient to receive."[116]

For Hooke, ideas are likewise caused directly by the motion the senses receive, and are composed materially of something internal. The motion of light continues up the optic nerve and into the brain, where it helps to form an 'idea,' which was a piece of the brain.[117] A material part of the brain is formed, by the power of "attention," into a shape, which is then animated with the motion incoming from the senses. Ideas are "inserted into and inclosed in the common Repository" of the memory.[118] The memory lies coiled like a rattlesnake around a central point in the brain where the soul sits. The outer reaches are the earliest memories of a person's life, and

115 *Regulae* Rule 12, in Descartes, *The Philosophical Writings of Descartes*, 1:40.

116 From a lecture transcribed in Oldroyd, "Some 'Philosophicall Scribbles' Attributed to Robert Hooke," 17. I have changed 'u' to 'v' and thorns to 'th'.

117 Though he concentrates on light and therefore vision, the story is essentially the same for the other senses. See John Yolton's table of the various descriptions of 'idea' in seventeenth and eighteenth century England: Yolton, *Perception and Reality*, 46.

118 "Lectures of Light," in Hooke, *Posthumous Works*, 140. B. R. Singer has discussed the English context of similar ideas, particular those of Henry More and John Locke: Singer, "Robert Hooke on Memory, Association and Time Perception," 124ff. To this list Oldroyd adds Thomas Willis: Oldroyd, "Some 'Philosophicall Scribbles' Attributed to Robert Hooke," 25. The similarity with Descartes' model from his *Regulae* is striking, though this last was only published after Hooke's lecture.

the central point the latest idea they have had. Ideas' motion have a causal power too: the motion of a strongly excited idea can resonate throughout the memory and cause similar ideas to become excited too, attracting the attention of the soul and forming conscious links between ideas.[119] Hooke acknowledges that neither he nor anyone else "does further or more intelligibly explain" what exactly this 'attention' is, but he does give a striking analogy.[120] The soul is like the sun at the centre of the universe, and radiates attention like light towards all the objects that surround it. An idea can even 'eclipse' more distant ideas by blocking the attention of the soul. And like the light of the sun, the power of the soul diminishes as it travels further into the memory – even, Hooke suggests, according to the same inverse square law.[121] Disanalogously, we can choose to focus attention on particular parts of the repository so we are not in constant confusion from the variety around our souls. When focused on an idea, the soul both receives and renews that idea's motion, noting its details and rewriting it in the memory. Left ignored, ideas move further and further from the soul, and may be forgotten. Sensory impressions are motions in the mechanistic world to which our senses are sensitive. But without the activity of the soul they would not give us ideas about things – sensing is not just a passive reception but a mental activity.

After the senses and memory comes reason, and an individualisting reprisal of the entire Baconian project. If the memory only contained things available to unaided, natural eyesight, philosophy would be restricted to knowledge of these things. This is why Hooke wrote that the best remedy for this "prejudice" was to:

119 How the immaterial soul and the material ideas interact Hooke simply says he "cannot conceive," but that they do is plain from our ability to sense, think, and remember. "Lectures of Light," in Hooke, *Posthumous Works*, 147. The materiality of the model has attracted the attention of historians and contemporaries alike. Waller in his editorial notes felt the need to clarify that Hooke did not claim there was no such thing as immaterial objects. See MacIntosh, "Perception and Imagination in Descartes, Boyle and Hooke"; Wilding, "Graphic Technologies"; Yeo, "Before Memex."

120 "Lectures of Light," in Hooke, *Posthumous Works*, 140.

121 "Lectures of Light," in ibid., 144. The thought seems motivated by geometry: light obeys this geometric law of the surface area of an expanding sphere because it is so subtle a matter, so surely the power of the soul must also. Diminish though it does, he does not rule out the possibility that the influence of the soul can be felt beyond the body, possibly explaining some kinds of bewitching and *lupus in fabula* ('the wolf in the conversation' – roughly the English idiom 'speak of the devil and the devil appears'). "Lectures of Light," in ibid., 147.

> compare the several Informations we receive of the same thing, from the several Impressions it makes on the several Organs of Sense, and (by a Rejection of what is not consonant) by degrees to find out its Nature, and thereby to inform the Intellect with a Notion of the thing; which is not according to this or that Idea, rais'd from the Impression of this or that Sense, but by a comparative Act of the Understanding from all the various Informations 'tis capable of receiving, more immediately by any of the Senses, or more mediately by various other Observations or Experiments.[122]

As I mentioned in Chapter 4, this was the philosophical importance of microscope use – creating different impressions on the senses. The wholesale use of instruments Hooke which advocated was motivated not so much by an optimism that they would make our senses better but from this causal story of how it is that ideas of things arise from even the naked senses. In his Gresham lectures on light, he cashed out the story in psychological terms. Thinking was the action of the soul on ideas, either creating new ones or perfecting those already existing by comparing and adding together various sensory impressions.

> And thence I conceive the Body of one Idea [...] may have many and various Impressions and Motions annexed to it, possibly of 100, nay of 1000 Moments, whence that Idea maybe supposed to be more compleat and perfect in it self.
>
> […]
>
> And this I conceive to be that Action of the Soul which is commonly called Reasoning; and the Conclusion is the new Impression made upon the Idea informing from the comparison of other Ideas which may be contain'd in the major and minor Propositions.[123]

This is not two simple ideas being combined to form one complex one – the process of reasoning really alters the *existing* ideas.[124] Knowledge consists of real material proxies in the brain

122 "General Scheme," in Hooke, *Posthumous Works*, 9.
123 "Lectures of Light," in ibid., 145.
124 Unlike many contemporary accounts of ideas: again see Yolton, *Perception and Reality*..

which come to more and more closely resemble objects outside the brain. In this way the soul "forms to it self a Microcosm, or Picture of the Macrocosm, in which it radiates, and is sensible of everything contain'd therein."[125] But when a person's ideas become more like their object, they will less and less resemble what that object *looks like* to that person. Not only are objects not directly present to the mind through their forms, they are not even known by how they appear.

This process is Hooke's microscope use writ large. At the beginning of Chapter 2, I mentioned the differences between Hooke's draft of an creature and how that same crab-like insect finally appeared in *Micrographia*. The image not only increased in size and clarity, the insect itself grew two more legs. If, as Neri supposes, these limbs are the result of Hooke's erstwhile study of other authors' natural historical observations, then the finalised image is the result of "many and various Impressions" compounded into an idea. The same can be said of all of Hooke's micrographs, insofar as they tread the line between particular observation and ideal specimen. But the "true forms" depicted in Hooke's engravings are not meant as the final word. Here is how these objects look, the book says, through this microscope, to Robert Hooke. The value of a book like *Micrographia*, or like Knox's *Ceylon* or Piso's *Historia Naturalis Brasiliae*, was as a way to share perpectival knowledge with others.

Perhaps an indication that Hooke was aware of how far he was moving from older species-based theories of vision, and the knowledge of essences that it conferred, is his recognition that there is a sense in which images projected on the retina or in the *camera obscura* are nothing like our real *experience*, let alone accurate knowledge. Retinal images are of course inverted; a fact that caused great worry for many people who wondered if the retina could be the sensitive part of the eye.[126] Gassendi and Pieresc eventually hypothesised that the retina must be a concave mirror, reflecting light onto the back of the lens and reverting the images in the process, presenting the mind with "the object in its natural position."[127] In August 1679 the Fellows of the

125 "Lectures of Light," in Hooke, *Posthumous Works*, 147.

126 And, according to David Hockney, is the reason why so many painter's models in Dutch naturalistic art are left-handed: Hockney, *Secret Knowledge*, 118.

127 Quoted in Fisher, *Pierre Gassendi's Philosophy and Science*, 36. See also Alpers' note that Van Beverwyck "puzzled

Royal Sociery debated exactly this issue. William Croune asked why it was that objects are seen the right way up, and Nehemiah Grew suggested that the optic nerve corkscrewed around to stand perceptions back on their feet.[128] Hooke, though, noted the lack of anatomical evidence for this. His view was that the mind, not the eye or the optic nerve, reverts objects after the optical process has ended – just as it interprets whether a certain wedge of light is a nose or a finger. A week earlier he had delivered a lecture to the Royal Society on corrective convex (rather than concave) eyeglasses.[129] To read a book the wearer would have to hold it upside down, but Hooke thought little of the inconvenience – in time they would grow used to it. What he meant was not merely they would get accustomed to turning pages right to left, or even that they would learn a skill like that of astronomers who made observations with *cameras obscura* and had to interpret projected images of the sun inverted by the instrument. Hooke went further, and suggested that if a person wore the glasses from birth so that their retinal image had always been upright, they would see things as inverted should they ever take them *off*.[130] William Molyneux's later criticism of this idea is illustrative. With a variation of Molyneux's 'Problem', he argued that surely someone who had been blind from birth and suddenly given sight, and who was therefore not "prejudiced by custom," would see things the right way up, "as is usual."[131] The difference for Hooke is that he implies that even if we *do* have such an innate, unprejudiced interpretation of visual experience, it can be altered over time. Sensory impressions are always interpreted in the light of impressions from the other senses, and given previous knowledge, to form a coherent picture of the world. "[W]e see by use, that we have an *Idea* of [an object], as if it were erected; and by much use of seeing things inverted, the same *Idea* will be formed as by seeing them erected."[132] Our overall impression of the world is coherent, regardless of the limited or

about how the inverted scene is righted:" Alpers, *The Art of Describing*, 41.

128 Birch, *The History of the Royal Society*, 1757, 3:502.

129 Hooke, "Myopibus Juvamen." For the minutes of the meeting see Birch, *The History of the Royal Society*, 1757, 3:500.

130 Hooke, "Myopibus Juvamen."

131 Molyneux, *Dioptrica Nova*, 212.

132 Hooke, "Myopibus Juvamen," 60. Hooke left it to future self-experimenters to report on the success of his theory. As far as I know no one did, but I am grateful to Maria Kon for telling me about George M. Stratton's experiments in the 1890s on exactly this sort of perceptual apparatus, which apparently bear out Hooke's idea.

potentially conflicting nature of the experiences that make it up. The view is more similar to Berkeley's later radical empiricism than many of Hooke's contemporaries. For instance, Berkeley thought the sight cannot tell us about distance directly, it is only by learning to associate visual ideas with what we have learnt about the size of objects from touch that we can interpret appearances as distant.[133]

Relativity

Everywhere Hooke recommends instrumental aids to vision, he sketches aids for the other senses too, or machines like his hygroscope which reveal unseen nature in a way that gives us no real *visual* idea of the process they measure. Importantly, the representations of the world he created – and thought reformed natural philosophy would later create – were not merely visual but multi-sensory material constructions. The microcosm of the soul, reflecting the macrocosm, was not visual or pictorial but compounded from all of the various impressions one has of the thing 'itself'. The senses each provide different material to build the microcosm, like so many tradesmen working on a building. While I will return to the epistemic aims of natural philosophy in the following chapter, here I will conclude with a little more discussion of the implications of Hooke's understanding of eyesight.

Just as Hooke was sensitive to the worry Cavendish had about *Micrographia* – that objects seem to morph into different things – because he is aware that his images are views through an instrument, he is aware that *every* act of perception is a limited view. Instruments represent not objective but situated, embodied knowledge.[134] Even as the eye was disembodied by the demonstrations of its operation in the new optics of Kepler and Descartes, Hooke's instrument use implies a distinctly *embodied*, causal idea of perception. The instrument itself – the eye or the

133 Berkeley, *A New Theory of Vision*. Compare with Kepler's explanation of distance perception: Kepler, *Optics*, 62–63.

134 See Lorraine Daston's and Peter Galison's recent work on this philosophical issue, particularly their co-authored tome: Daston and Galison, *Objectivity*.

camera – showed off an idealised, uninterpreted, capturing of the light which bounced off objects. But the *use* of the instrument involved adopting that point of view as one's own, the observer taking on the impressions of an organ. Hooke's demonstration of eyesight was, as were the images in *Micrographia*, an exhibition of difference, which emphasised the embodied and limited perspective of ordinary naked sense.

The lesson to be learned from optical instruments was partly about the things seen through them, and partly about the eye which did the looking. Through the microscope Hooke saw that tiny creatures have the same, or equivalent, body parts as larger mammals – eyes, mouths, stomachs, hairy legs. He knew his eye anatomy and his geometrical optics, and consequently he marvelled at the obviously tiny size of "the Picture of an Object that is painted at the bottom of one of those Eyes which by a Microscope we discover in […] small Insects." Hooke had measured the limit of human vision resolution at thirty seconds of a degree.[135] But in an insect, *everything* was proportionately smaller: the optic nerve and the faculty for processing vision. Surely through such small eyes they could "distinguish as many single Parts in those Pictures, as a Man can in a proportionate Picture at the bottom of his Eye."[136] Because every eye operated according to the geometrical optics he displayed in his perspective box, insects saw phenomena that were literally invisible for humans.

In fact, because the material memory was how we experience duration, the lesson was temporal as well as spatial. Time is a puzzle for the empiricist, Hooke notes, if indeed all knowledge comes from the senses.[137] We do not directly perceive time with any of the five external senses, so how do we come to have the impression of its passing? The phenomenon is made visible through instruments – clocks – and the movement of the sun and stars. But what about the other, more innate impression that we have that time is passing, even absent visible phenomena? Hooke's answer is an internal sense. The soul senses time via memory, given the

135 Hooke, "Animadversions on the First Part of the Machina Coelestis," 7.
136 "Lectures of Light," in Hooke, *Posthumous Works*, 135.
137 "Lectures of Light," in ibid., 139.

order of and distance between the ideas therein. The moment experienced as the present is the time at which the idea at the centre of the brain, closest to the soul, is formed. Duration is measured by an awareness of the number of ideas between any two. Time's apparent speed is therefore the speed at which the soul acts on ideas. This Hooke calculates. By the time someone reaches 100 years of age, assuming a solid 8 hours of sleep a night (dreams notwithstanding), and two thirds of the rest of their life discounted for "Infancy, Old Age, Sickness and Inadvertency," they may end up with a repository of one million separate ideas.[138] The numbers, though faintly absurd, give us an insight into Hooke's commitment to the material mind (and more loosely his estimate of his own level of mental activity). They also give us an important insight into how deep the sensitivity to relation and scale that runs through his discussion of perception and ideas goes. Time is a relationship between ideas, and a moment is the time it takes to create a new idea. But ideas are bulky and material, and exist on the scale of a human. Hooke says he could list one hundred instances to make it clear that natural processes happen faster than we can form ideas, and that the "*Phaenomena* thereof proceed only from the length of time there is in the shortest Moment of a Man."[139] But other creatures have different limits:

> I do not at all doubt but that the sensible Moments of Creatures are somewhat proportion'd to their Bulk, and that the less a Creature is, the shorter are its sensible Moments. [...] For when I hear a Fly moving his Wings to and fro so many times, with such Swiftness as to make a Sound, I cannot but imagine, that that Fly must be sensible of and distinguish at least 3 Moments in time that it makes one of those Strokes with his Wings, for that it is able to regulate and guide it self by the Motion of them.[140]

Hooke was quite in agreement with Cavendish that different creatures have different experiences of the world. A fly, he supposes, quite likely experiences as many individual moments

138 "Lectures of Light," in ibid., 143.
139 "Lectures of Light," in ibid., 134.
140 "Lectures of Light," in ibid.

in its short life as a human does in their much longer one – in subjective time it really lives for as long as a human. Phenomena emerge from the action of qualities on senses, but no phenomena can reflect what the world is 'really' like: the complete relativity of perceptions vanishes into infinity. We call the length of time captured by an idea a 'moment,' but "every sensible Moment of time is composed of infinite Instants."[141] To return to the spatial case, Hooke evinces the same insight with the microscope. By this instrument, we can (literally) see "that the least visible Space [...] may be actually distinguished into a thousand sensible Spaces: And could we yet further improve Microscopes, 'tis possible we might distinguish even a thousand more Spaces in every one of those."[142]

What becomes finally clear from Hooke's instrumental approach to eyesight is that there is no possibility of just *seeing* what things are really like. We can and should trust the senses to tell us things relevant to our survival, and if we work carefully, with instruments and reasoning, we can compound ideas to approach a more comprehensive knowledge of the qualities an object has. But observations are always relational: all phenomena, for Hooke, arise from the interaction of the world with a particular size and sensitivity of sense. Considered on its own the world is strictly invisible. Space and time reduce to an insensible infinity. This is apparently the idea that underlies Locke's and Margaret Cavendish's criticisms of the microscope. The instrument conceived – as it popularly was – as a sharper eye that would bring an empirically minded philosopher closer to the nature of things, implied an old connection between sight and knowledge that was unravelling in Hooke's time. In fact, in certain passages of Hooke it is not at all clear that he is in fact a realist about the mechanisms by which he proposes to explain phenomena. His explanation of light, he says, will make the "manner of its Operations mechanically and sensibly intelligible."[143] The local motion that underwrites Hooke's natural philosophy may become, as it was for Huygens, a model of nature valuable for its intelligibility

141 "Lectures of Light," in ibid.
142 "Lectures of Light," in ibid.
143 "Lectures of Light," in ibid., 135.

and imaginative prompt, rather than its objective reality.[144]

The broadest lesson to emerge from Hooke's series of lectures on light, vision, and cognition, is his place in the various epistemological traditions historians have traced back to and through the early modern period. He was an experimenter and a worker and a pioneer of instrument use and craft knowledge. But he was also a rare representative in mid-century England of the epistemological shift that was taking place in Europe generally. Edmund Husserl suggested that with Descartes begins a "new manner of philosophizing which seeks its ultimate foundations in the subjective," yet still claims "an objectively 'true' and metaphysically transcendent validity."[145] This needed a kind of psychological vindication of absolute knowledge unknown to the "ancients." Later, in Locke and Hume, there is a recognition that natural truth, considered absolutely, was out of reach. What happened between was not only a shift in the way the world itself was thought of but consequent rethinking of the relation between people and nature: how the senes and internal faculties functioned, and what could underwrite knowledge as traditionally conceived. Hooke's ambition for optical instruments is part of this shift.

> By the means of Telescopes, there is nothing so far distant but may be represented to our view; and by the help of Microscopes, there is nothing so small, as to escape our inquiry; hence there is a new visible World discovered to the understanding. By this means the Heavens are open'd, and a vast number of new Stars, and new Motions, and new Productions appear in them, to which all the antient Astronomers were utterly Strangers. By this the Earth it self, which lyes so neer us, under our feet, shews quite a new thing to us, and in every little particle of its matter, we now behold almost as great a variety of Creatures, as we were able before to reckon up in the whole Universe it self.[146]

144 See for instance "Lectures of Light," in ibid., 131–135. For Huygens see Dear, *The Intelligibility of Nature*, 25.
145 Husserl, *The Crisis of European Sciences and Transcendental Phenomenology*, pt. 2, 81.
146 Hooke, *Micrographia*, sig. A2r.

Hooke is not only talking about Galilean evidence against the Aristotelian cosmos, or even the more general point that previous philosophers can not possibly have had a complete knowledge of nature. More important, I take it, than the particulars that we can now pay attention to – the new evidence of what the *world* is actually like – is the new evidence of what *we* are like: utterly unfit to proclaim about the nature of things merely from our perspective as medium-sized land mammals. Knowledge was not 'given' or guaranteed by the structure of the eye, but produced by fallible, mediated, very human means. But in the right hands, this was a powerful, optimistic realisation rather than hopelessly sceptical: the mechanism of vision was adjustable and reproduceable. The eye no longer directly received knowledge, it was an instrument of natural history.

Hooke's individual philosopher turns out to be remarkably similar to the ideal of the corporate Royal Society. In the equivalence of one's own visual experience and the engravings in a travel book we can see the importance the Royal Society placed on listening to the accounts of others as well as observing things for themselves. Wilkins wrote that the testimony of others and the direct experience of the senses both gave rise to certain knowledge – different types of certainty appropriate for different sources and subject matters, but still certainty.[147] Hooke's anthropology of limited senses and a material storehouse memory, combined with the imitative capacity of artifice, almost necessitates a collaborative approach to natural philosophy. His ideas on the corporate structure of the enterprise are the topic of the next chapter.

147 Wilkins, *Of the Principles and Duties of Natural Religion*, 5–9.

Chapter 7: Roles and Causes

Method as Performance

After the more philosophical message of the previous chapter, in this chapter I will return to the historical context of Hooke's work, to demonstrate how his instrumental epistemology fitted the institutionalised natural philosophy of the Royal Society. The main focus of this final chapter is not so much on Hooke's works of philosophy themselves but those places in which he deals with more methodological ideas – particularly his *General Scheme*.[1] Many of the epistemic and methodological ideas of the previous chapters find some sort of expression in this, by far Hooke's most thoughtful and detailed presentation of his ideas on the nature of natural philosophy. Like so many other early modern methodological pieces, though, Hooke's is unfinished. He wrote the first two of three projected parts: the 'Present State of Natural Philosophy' and the first half of the 'Method of Building a Solid Philosophy': the "manner of Preparing the Mind, and furnishing it with fit Materials to work on."[2] This is essentially Hooke's recommendations for compiling a natural history. The unwritten third part was then to describe the work of the philosopher: "the Rules and Methods of proceeding or operating with this so collected and qualify'd Supellex (history)."[3] Hooke made great claims about the ease and success of this method, which he called the 'Philosophical Algebra' on the account that, as he said in *Micrographia*, "it is possible to do as much by this method in *Mechanicks*, as by *Algebra* can be perform'd in *Geometry*."[4] Hooke's optimism has meant the incompleteness of the *General Scheme*

1 Full title: *A General Scheme, or Idea of the Present State of Natural Philosophy, and How its Defects may be Remedied by a Methodical Proceeding in the making Experiments and Collecting Observations. Whereby to Compile a Natural History, as the Solid Basis for the Superstructure of True Philosophy*. Included by Waller in Hooke, *Posthumous Works*, 1–70.

2 "General Scheme," in ibid., 7.

3 "General Scheme," in ibid.

4 Hooke, *Micrographia*, sig. D2v.

has been lamented, and a lot of what has been written on it has attempted to reconstruct what Hooke's method of raising axioms with geometrical certainty may have been.[5]

The general agreement is that Hooke meant nothing more than a systematic tabulation of the various possible explanations for a phenomenon, and then eliminating them one by one until only one option remained.[6] It is possible, Pugliese has argued, that this general idea became explictly tied to John Wilkins' artificial language project, which Hooke worked on – and wrote the design for a spring-balanced watch in – later in his career.[7] Rather than the details – and there are many in the intricate close readings of Hooke given by Hesse, Oldroyd, and Pugliese – what I will focus on in this chapter is the general impression one gets of the tasks of history and philosophy. Hooke's label 'Philosophical Algebra' appears to refer to both to compiling histories and raising axioms, and in various places it seems clear which he finds the more important role. It is not hard to see some irony in Hooke's "hope," from *Micrographia*'s preface, that his

> Labours will be no more comparable to the Productions of many other Natural Philosophers, who are now every where busie about greater things; then my little Objects are to be compar'd to the greater and more beautiful Works of Nature, A Flea, a Mite, a Gnat, to an Horse, an Elephant, or a Lyon.[8]

Micrographia exactly placed gnats on the same level as lions. They were as important as large animals, if not more so, in the project of gathering natural knowledge – just as the historian appears to be compared to the philosopher. In Hooke's work it is difficult sometimes to see what is left for the philosopher besides book-keeping after the historian has finished their important

5 Patterson, "Hooke's Gravitation Theory and Its Influence on Newton I: Hooke's Gravitation Theory"; Hesse, "Hooke's Philosophical Algebra"; Hesse, "Hooke's Vibration Theory and the Isochrony of Springs"; Oldroyd, "Robert Hooke's Methodology of Science"; Oldroyd, "Some Writings of Robert Hooke"; Pugliese, "The Scientific Achievement of Robert Hooke: Method and Mechanics," pp. 50-128. See also Michael Hunter's contribution to Bennett et al., *London's Leonardo.* for a brief summary (117-124).

6 See especially Hesse, "Hooke's Philosophical Algebra"; Oldroyd, "Robert Hooke's Methodology of Science."

7 Pugliese, "The Scientific Achievement of Robert Hooke" especially 69ff. For Wilkins' universal character, see Maat, *Philosophical Languages in the Seventeenth Century*; Hequembourg, "The Dream of a Literal World"; Wilkins, *An Essay towards a Real Character and a Philosophical Language*.

8 Hooke, *Micrographia*, sig. G2v.

work.

Accordingly, this chapter follows the current trend in historical scholarship in giving a broadly sociological grounding of much seventeenth century method talk. The changing relationship between humans and nature, and the relations among people in new settings and places of knowledge reshaped the personas and roles of those people involved in philosophy.[9] A guiding assumption for what follows is that paying attention to the context in which methodological works were written allows us to reduce talk of ideal methods to the job or role of the person they describe – usually the author. This is, I think, particularly noticeable in the case of Hooke. Stephen Pumfrey and Michael Hunter in particular have illustrated Hooke's role in defining his ambit within the early Royal Society, and, in compliment, how his reflections on the prosecution of natural philosophy grew from specific tasks.[10] Indeed, this assumption has underwritten much of this thesis thus far, as with the project of drawing insects for the king blossoming into the vindication of collaborative mechanical philosophy that is Micrographia. In what follows I will show how Hooke used his position within the experimental and philosophical community as a stage to present a specific idea not just of the correct method of natural philosophy, but of his own work and abilities. I do not mean that Hooke's General Scheme is entirely a self-serving advertisement; only that it ought to be read as an indication of Hooke's active role in shaping the expectations placed on Curators of the Royal Society and, more broadly, natural historians and philosophers. Hooke learned from his practice performing experiments, and his experience in a collaborative organisation gave him ideas about institutionalising experimental philosophy.

9 See for example Corneanu, *Regimens of the Mind*; Harrison, *The Fall of Man and the Foundations of Science*; Gaukroger, *Francis Bacon and the Transformation of Early-Modern Philosophy*. For Hooke and his milieu more particularly, see Wood, "Methodology and Apologetics"; Shapin, "Who Was Robert Hooke?"; Shapin, *A Social History of Truth*; Shapin, *The Scientific Life*. On method more generally: Schuster and Yeo, *The Politics and Rhetoric of Scientific Method*, especially John Schuster's contribution.

10 Pumfrey, "Ideas Above His Station"; Hunter, *Establishing the New Science*.

It is certainly not enough to call Hooke 'Baconian'.[11] P. B. Wood has written of the "subtle misrespresentation and selective exposition" of details which allowed Thomas Sprat to present a certain view of the new institution in his *History of the Royal Society*.[12] The Fellows of the Royal Society were presented as collaborating on the collection of particular facts, evaluating them, and disentangling them from general theories. The 'Baconianism' they publicly adhered to was one of naïve fact-gathering, and a deliberately random procedure of conducting experiments so as to make raising axioms from them more difficult.[13] This was a disingenuous, or at least selective, reading of Bacon. Wood fingered John Wilkins, a man sensitive to possible criticisms the Royal Society may face, as the force behind Sprat's history. Under his guidance, the picture the Society presented of itself was not strictly accurate, but claimed its method was useful not just for the acquisition of knowledge but for the stability and productiveness of Restoration England. Looking at Hooke's concerns gives us a different angle on the situation. If he was to provide the demonstrations and the gentlemen members the disinterested assent and social credibility, it is likely he not only saw more clearly the corporate structures that facilitated or frustrated his work more clearly than they, but was influential in shaping them. My claim is not that Hooke is interesting because he must have conformed to the methodology of the Royal Society and therefore offers a way to look at it. He is interesting because his methodology was the method that arose from the founding of the institution and the professionalisation of experimental natural philosophy.

There are two main narratives in what follows. First is Hooke's early curatorship and a brief methodological tract he wrote in 1663, and second is his other employment as a Gresham College lecturer and his composition of the General Scheme. As Hooke developed the instruments and epistemology we have seen in previous chapters, and will continue to see here,

11 Though such broad labels have a useful function in larger-scale histories. Recent scholarship has shown it is scarcely enough to call *Bacon* 'Baconian': Jalobeanu, "Bacon's Natural History and the Senecan Natural Histories of Early Modern Europe"; Giglioni, "From the Woods of Experience to the Open Fields of Metaphysics."

12 Wood, "Methodology and Apologetics," 1.

13 Ibid., 7.

he importantly crafted a persona for himself, by emphasising the importance of his work to natural philosophy and, from there, society and England.

Early Employment

Nothing was smooth about the early days of Hooke's employment with the Royal Society. The initial idea for the institution did not involve the paid position of Curator of Experiments that he would come to occupy, and the process of creating one, defining its remit, and sourcing the money to support it was one of constant negotiation. Stephen Pumfrey begins his excellent history of Hooke's curatorship by noting that in 1660 "neither Hooke, nor the Society's founders knew what a curator did."[14] The creation of a paid curatorship was not simply the creation of a job, but also of a new kind of person involved in collaborative philosophical enterprise. The first charter of the Society, from August 1662, had no hint of paid curators.[15] In its first years, the Royal Society worked on a system of 'virtuoso curators' – one Fellow or other would curate, 'take care of', a particular experiment, and three other members, appointed on a rotating basis, would take notes on it and the following debate.[16] The only stable offices were those of President, Treasurer, and Register, this last in charge of recording experiments. The holders of these offices were to change monthly, in the case of the President, and annually in the case of the other two. The only people paid, in this early manifestation, were an amanuensis on a salary of 40s per year, and an operator on £4, both plus incidentals.[17] Curators could be recompensed by the treasurer for the expenses of their experiments but not for their time.[18]

14 Pumfrey, "Ideas Above His Station," 2.

15 The charters are included in *The Record of the Royal Society*, 215ff. They are also available on the Royal Society website. For more on the founding of the Royal Society see Sprat, *The History of the Royal Society*; Webster, *The Great Instauration*; Hunter, *Establishing the New Science*.

16 Pumfrey notes the novelty of the Society's use of the word for this purpose: the *Oxford English Dictionary* references John Evelyn's diary entry about an experiment: Pumfrey, "Ideas Above His Station," 2.

17 Birch, *The History of the Royal Society*, 1756, 1:6–7.

18 Ibid., 1:6.

Most of this changed fairly quickly. As regards Hooke, the details of first year or so are difficult to fill in. He was of course well known to many of the important founders of the Society, and at a meeting on 10 April 1661 the Fellows decided to discuss Hooke's tract on capillary action, which had emerged from his work with Boyle and the air pump.[19] Lisa Jardine has plausibly suggested that he was present to carry out demonstration for them, even though his name does not appear in the record books. In these days he was an invisible operator rather than recognised philosopher.[20] He was in contact with Robert Moray, who in August 1661 reported to Wren the good news that Boyle's assistant would be taking over the task of drawing insects for the king.[21] Through such involvement, Hooke's appetite was whetted.

On 5 November 1662, Hooke volunteered his services more substantially to the Society. Apparently without mentioning the name of Hooke, Moray "proposed a person willing to be employed as a curator by the society."[22] Hooke, at 25, was a practiced experimenter, and confident in his creative and mechanical abilities. His offer was "to furnish [the Society] every day, on which they met, with three or four considerable experiments." Crucially, he would begin the work for free, "expecting no recompence till the society should get stock enabling them to give it." When the proposal was unanimously approved of, Hooke was named, and the Royal Society had a regular, reliable source of experiments. Unpaid by the institution, Hooke was still in the service of Boyle, who received "the thanks of the society for dispensing with [Hooke]," a gesture which no doubt reflects the importance of the arrangement for the Society, and indicates how much they expected of their new curator.[23]

This was important moment for the Society and Hooke both. Pumfrey has suggested that a position in London may have been created for Hooke in part because of the Society's early nervousness. Hooke was the only person capable of operating the air pump successfully, and they

19 Ibid., 1:21.

20 Jardine, *The Curious Life of Robert Hooke*, 94.

21 Wren, *Parentalia*, 211.

22 Birch, *The History of the Royal Society*, 1756, 1:123.

23 Ibid., 1:124. Shapin notes that Hooke continued to refer to himself as Boyle's employee: Shapin, "Who Was Robert Hooke?," 264, footnote 34.

wanted him on hand to perform in front of visitors with the emblematic instrument.[24] He also had the task that would become Micrographia to get on with, and the Fellows soon began to request to see his drawings.[25] That both of these projects were related to winning royal favour might also explain somewhat why Boyle was willing to let his valuable assistant spend so much time away. There were two important effects of the new arrangement: Hooke came to dominate the experimental aspect of the meetings, and the role of curator became enshrined in statute as a paid office.

The Meaning of Experiment

Hooke's name first appears beside an experiment on 19 November 1662, and thereafter with a regularity that implies at least part time residence in London, though he continued to spend time in Oxford.[26] He gradually became the omnipresent experimenter. Pumfrey has charted the declining number of assignments given at the weekly meetings to people other than him: 18 out of 26 in 1663 fell to 17 in 1664, 7 in 1665, 6 in 1666, and 0 in 1667.[27] Typically in these early years, the virtuoso curators were assigned experiments by the Society, and they would have little control over the topics of their investigations. Hooke was not only asked for those delegated by the Society, but also "experiments of his own."[28] Especially after the recess caused by the plague in 1666, Hooke's interests and experiments began to determine the direction of the whole Society's work. Whether this was due more to his enthusiasm for the role or to the other Fellows' willingness to sit back and be entertained by him – or more likely both – he grew to be

24 Hooke wrote to Boyle on 5 June 1663 apologising that he was late returning to Oxford because he had been asked to prepare the air pump the following week: Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 2:81. He was given lodgings at Gresham College later that year to work with the operator setting up devices, and an allowance of 20 shillings a week while he was preparing the royal entertainments: Birch, *The History of the Royal Society*, 1756, 1:315, 340.

25 Pumfrey, "Ideas Above His Station," 26.

26 Birch, *The History of the Royal Society*, 1756, 1:125. When he was away from Boyle for extended periods he would write letters recounting what went on in the meetings, as I mentioned in chapter 3. See Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, especially June and July 1663.

27 Pumfrey, "Ideas Above His Station," 6.

28 Birch, *The History of the Royal Society*, 1756, 1:124.

indispensable. Christopher Wren was not exaggerating when he wrote to Hooke in April 1665: "I know you are full of employment for the Society wch. you all-most wholy preserve together by your constant paines."[29] On 3 June 1663, Hooke was elected Fellow of the Royal Society, his un-gentlemanly status reflected in a waiver of subscription fees.[30] But any suggestion that his Fellowship was reward for his continuing hard work is belied by the details – he clearly was as important to them as they were to him.

Even at this early stage, Hooke recognised that the value of experiments was as a collective endeavour. In a short tract, undated but which R. T. Gunther supposes to have been written in 1663, Hooke outlined the purpose of experiments and the best way to go about them in Royal Society meetings.[31] Hooke is very clear that experiments should not be aimless, but directed at the "confirming or destroying of any preconceived Notion," or at least a part thereof, and he gives a five step plan for how to do this.[32] The Curator should make clear why they are doing the experiment, carefully conduct it, and point out which aspects of it are particularly relevant to "his Theory." Afterwards, the people present should discuss what the trial showed and propose variations on it, and "raise such Axioms and Propositions, as are thereby plainly demonstrated and proved." Then, everything "material and circumstantial in the whole Entertainment of the […] Society" should be recorded and read at the next meeting for further discussion, before the account was signed off by witnesses.[33]

Such tracts, as well as the experimental demonstrations they describe and therefore Hooke's experimental persona, should be read as a performance. I mean this not simply in the entertaining way the Fellows often seemed to hope for, but in the broader sociological sense of achieving meaning by being enacted in a social setting replete with expectations, rules, and rituals.

29 Quoted in Bennett, "Robert Hooke as Mechanic and Natural Philosopher," 33.

30 Birch, *The History of the Royal Society*, 1756, 1:240.

31 Gunther supplies no reason for this dating, though it is lent credibility by its place in Derham's collection immediately after a tract from February 1662/3, and before a letter from Oldenburg dated August 1665. Also notable is the fact that Hooke does not appear to conceive of himself as the only curator, and the role appears to be an abbreviation for "Whosoever...doth rightly make Experiments," rather than an office as such. Hooke, *Philosophical Experiments and Observations*, 26–28; Gunther, *Early Science in Oxford*, 6:111–112.

32 Hooke, *Philosophical Experiments and Observations*, 26.

33 Ibid., 27.

Experimental success or failure was not only a matter of mechanical manipulation of instruments, it was assessed according to a demonstration's adherence to an idealised experimental protocol. That Hooke had ideas about what this ideal was which sometimes differed from those that were followed or argued for by other Fellows has had some important consequences for his career and reputation.

Hooke's short tract echoes much of the general outline of how meetings would run when the Society was founded, as recorded by Birch. But the lack of details of the Society's meeting records themselves shows a different picture.[34] These records are generally tersely written and undetailed. The early Society did not always seem to recognise the importance of comprehensive records of their demonstrations. Relatedly, Michael Cooper and Steven Shapin have both pointed out the excessive expectations placed on Hooke and the other curators, which often took the form of impatience with failed demonstrations.[35] Hooke may have been uniquely able to manipulate the air pump, but the Fellows seemed to want to watch it do what they knew it would. Or, in January 1662/3: "Mr. Hooke made the experiment of condensing air by the pressure of water; but the trial not agreeing with the hypothesis, it was ordered to be repeated at the next meeting."[36] At the same meeting he tried an experiment with falling bodies but was told to practice it in private before showing it to the Society. The Fellows, drunk on instruments, wanted to witness the remarkable and immediate confirmations of hypotheses, not the slow and careful process of limiting ideas, or even the necessary preliminary of determining how a device related to a particular theory. As Ludwik Fleck famously said, and as Hooke's recognition that an experiment can destroy preconceived notions suggests, 'failed' experiments can be as illustrative and important as successes.[37] But it was not just the public face of the Society which was designed to exhibit their successes; their private records were often no less glossy.

34 "[E]verything of importance" should be recorded, debated, and brought back at the next meeting in case anything else had been thought of in the meantime. Birch, *The History of the Royal Society*, 1756, 1:7.

35 Bennett et al., *London's Leonardo*, 15; Shapin, "Who Was Robert Hooke?," 282–285.

36 Birch, *The History of the Royal Society*, 1756, 1:177.

37 Fleck, *The Genesis and Development of a Scientific Fact*.

To take this point further, Hooke has been chastised by historians and his contemporaries alike for the piecemeal and unsystematic nature of a lot of his writing. But as Frédérique Aït-Touati has pointed out, Hooke's ideal mode of philosophical publication was exactly unfinished and sporadic tracts – contributions to a storehouse of knowledge rather than attempts towards comprehensive treatises.[38] The nature of experimental investigation was expressly collaborative: each member of the community would build on the work of the others.[39] In fact, the early modern experimental experience often resulted in detailed first-person reports about, in Peter Dear's words, "how, in one instance, the world had behaved."[40] But whereas Boyle, for instance, marshalled these narratives into sprawling tracts on a single topic, Hooke's works show, as Aït-Touati says, the "refusal of any preconceived order, the voluntary incompleteness of findings, and their variety."[41]

It is important to recognise this difference within the community. Hooke was, if not influential, then at least active in negotiating the meaning and value of experiments in his early days as a curator. The influence of these negotiations on Hooke's life and career are poignant, even a little tragic. They form part of a narrative about professionalisation and class in early modern England, and have been discussed by Shapin and Pumfrey among others.[42] During the early years of the Society, with Hooke as curator, it was Oldenburg's task to maintain the records of meetings. The resentment Hooke had for Oldenburg is famous – following the latter's support of Huygens over Hooke as the inventor of the spring-balance watch it was Hooke's interpretation that the Secretary had deliberately left details out of the Journal Book to hide Hooke's invention.[43] It must also have been frustrating for him to say the least when in August

38 Aït-Touati, "'The Spirit of Invention,'" 112ff; see also Hunter's contribution to Bennett et al., *London's Leonardo*, especially the section "The Reluctant Author."

39 Aït-Touati, "'The Spirit of Invention,'" 113; see also Hooke's own words in his preface to *Micrographia*.

40 Dear, "Totius in Verba," 152.

41 Aït-Touati, "'The Spirit of Invention,'" 112.

42 Shapin, "Who Was Robert Hooke?"; Pumfrey, "Ideas Above His Station." For a broader context, see also the likes of Hill, *The World Turned Upside Down*; Thompson, *The Making of the English Working Class*.

43 An interpretation apparently borne out by an entry (or lack-thereof) in Oldenburg's draft minutes for the meeting of 23 June 1670. Oldenburg had left room for Hooke to pencil in a description of his watch, and the latter had done so. Oldenburg then apparently began to ink over Hooke's words, before stopping and deleting the entry. There is no mention of the demonstration in the Royal Society Journal Book. See Adams and Jardine,

1679 the Council ordered Hooke to "print a relation of all experiments, observations, and relations made and brought to the Society by himself since his first coming into it."[44] But by then Hooke was not blameless. At this time he was Secretary, and the task of keeping records was his responsibility, as well as printing the *Philosophical Transactions* and maintaining the Society's correspondence. His neglect of these jobs saw him shunted out of office and back to the role solely of curator. There, he fell foul of the 'Williamson Orders,' new regulations, named for the new president of the Society Joseph Williamson, which made curators more responsible for the recording of their own experiments, and which Hooke himself likely helped to draw up and instigate.[45] Hooke's outrage at Oldenburg and frustration when his discoveries were not properly recorded gave way in later life to resignation and snide remarks that the Society was wasting their money asking him to demonstrate things he did years ago.[46] As Dear notes, the institution "in reality failed even to act as a successful coordinator of the projects of individuals."[47]

Relatedly, these are the sorts of contextual standards we as historians need to pay attention to in discussing the work of a character like Hooke. Evaluating his work against the criteria of his peers ignores the extent to which Hooke succeeded in prosecuting his *own* design, and the Royal Society failed to institutionalise experimental philosophy according to *him*. His idea of the value of experimental philosophy was intimately concerned with experiments as public 'trials', in a literal sense. Their results need not be expected or obvious, the value of public demonstration was rather a crowdsourcing of opinion and insight. Rather than only share the completed and determinate results of people's experience, Hooke thought the messy beginnings of experiment ought to be distributed. Hooke was conscious of (and sometimes complicit in) the

"The Return of the Hooke Folio"; Hooke, "Hooke Folio"; Hall, *Henry Oldenburg: Shaping the Royal Society*.

44 Birch, *The History of the Royal Society*, 1757, 3:501.

45 Pumfrey, "Ideas Above His Station," 8; Hunter, *Establishing the New Science*, chap. 6. While his minutes as Secretary begin well, within months they deteriorate and become full of gaps and promisory notes, and he completely neglected the Record Book for the first three years of his Secretaryship. See Adams and Jardine, "The Return of the Hooke Folio."

46 For example, in a lecture given on 24 May 1699, Hooke refers to the Society's request for an investigation into the effect of atmospheric refraction on astronomical observations, which he had discussed in Observation 58 of *Micrographia* and lectured on in the 1660s. The lecture is preserved as Royal Society Classified Papers 20/93: Hooke, "Of the Refraction of the Atmosphere."

47 Dear, "Totius in Verba," 147.

shortcomings in the Society's supposedly collaborative and gradual approach to natural philosophy almost from their founding.

Professional Natural Philosophy

The other important effect of Hooke's sustained curatorship was the eventual creation of the office of 'curator'. The second charter of the Royal Society, which listed 'curator' among the offices of the Society, was drawn up in April 1663, five months after the Fellows invited Hooke to "sit amongst them."[48] Statutes were likewise created for "Curators by Office", predicting that curators would become full-time employees of the Society, but still allowing for occasional payments to people who were engaged with other positions.[49]

It was a while before anything came of this, and the source of Hooke's money was a continuing problem. Around this time the council were growing concerned about the Society's subscription fees. In May 1663 President Brouncker ordered all the Fellows to "pay their whole arrears unto this day."[50] The concern was well founded – the members paid their fees so rarely that the Society was almost £1,500 in arrears ten years after its founding.[51] That Hooke was exempt from subscription fees perhaps recognised the importance of his work for the Society, but in reality he was not the only one to escape paying. That "the farr greater Number [of Fellows were] Gentlemen, free, and unconfin'd" may have made the Royal Society a model of early modern credibility and trust, but lacking royal patronage and reliant on these gentlemen for money, they failed as an institution to provide for their one really necessary member.[52]

48 Birch, *The History of the Royal Society*, 1756, 1:124.
49 Pumfrey, "Ideas Above His Station," 6, footnote 18. For the statutes see *The Record of the Royal Society*, 287ff.
50 Birch, *The History of the Royal Society*, 1756, 1:237.
51 Bennett et al., *London's Leonardo*, 8.
52 Sprat, *The History of the Royal Society*, 67. Boyle, by way of comparison, was the son of the first Earl of Cork, his father made rich through aggressive land grabs in Ireland. Since the mid-1630s Boyle had received at least £2,000 of his father's rents, and his fortune only grew as he inherited more estates. Sir Robert Moray was the son of a Scottish laird, a Privy Councillor and Lord of Session. Such titles can be found throughout the founding members of the Royal Society. See Shapin, *A Social History of Truth*, chap. 4, for a brief history of Boyle's lineage and its influence on his subsequent philosophical persona. A more comprehensive view of Boyle Senior can be found in Canny, *The Upstart Earl*.

I do not mean to rehash the idea of Hooke as a philosophical servant, excluded from the world of those around him.[53] The point is rather that despite the decision that he ought to be rewarded by the Society for his work, institutionalisation of Hooke's role never really happened. This was not a problem unique to Hooke – Michael Hunter has written of Nehemiah Grew's similar situation reliant on a member of the Royal Society rather than the organisation itself. In 1672 John Wilkins canvassed the Fellows for donations to pay Grew, a practicing physician in Coventry, to move to London and continue his research into plant anatomy. The Society agreed on a salary £50, with Wilkins in charge of collecting subscriptions.[54] Grew moved to London, but just a few months later Wilkins died, and Grew never received even one full year's salary.[55] Grew's subsequent letter to Oldenburg emphasises his disappointment and the uncertainty he felt about being able to continue in London without the influence of Wilkins, and sure enough he soon moved back to Coventry to resume his practice.[56] Richard Lower seems to have rejected the Society's request that he become anatomical curator in 1667 for much the same reasons – he could earn a much better living as a practicing physician than as a curator.[57] Eventually it was Hooke who managed to secure Grew employment back in London by recommending him as deputy to Jonathan Goddard, Professor of Physic at Gresham College. Once established there at the end of 1673, Grew found means to stay in the capital to become joint Secretary for the Royal Society with Hooke in 1677.

Hooke's role is interesting in both of these other situations. 1667 was a busy time for Hooke with work for the Society and as a Surveyor for the City of London in the aftermath of the Great Fire.[58] His curatorial services were flagging, particularly in the area of anatomy, where he was increasingly unhappy at requests to vivisect dogs. He performed such a vivisection in

53 For the original argument, see Shapin, "Who Was Robert Hooke?" And for an important response, see Feingold, "Robert Hooke: Gentleman of Science." For more on Hooke's inclusive world see Iliffe, "Material Doubts."

54 Hunter, *Establishing the New Science*, 264. The agreement is noted in Birch, *The History of the Royal Society*, 1757, 3:47.

55 Hunter, *Establishing the New Science*, 266.

56 The letter is reproduced in ibid., 266–268.

57 Bennett et al., *London's Leonardo*, 16–17.

58 For more on Hooke's rebuilding work, see Cooper, *"A More Beautiful City."*

1664, cutting open the chest and keeping the dog alive with bellows, but found the cruelty too much and resolved never to do it again.[59] In 1667, Society interest in the experiment renewed, and Hooke quickly pointed to his "friend" who had done many such experiments – perhaps Lower. Throughout the second half of the year Hooke and Lower were asked to follow up on different aspects of dissection, and Lower performed various experiments about circulation in dogs and transfusing blood from a sheep to a human.[60] Hooke meanwhile claimed vaguely to be working on a "contrivance" with which to perform his experiments, and apparently tried to let the matter drop. When pressed, he repeatedly promised to bring something to the next meeting, his usual ingenuity apparently not serving him very well on a matter he found distasteful.[61] What is interesting is Hooke's response to requests to do something he did not want to do. He seemed unable to perform the experiment, but equally unable to outright refuse the Society's orders. In September, perhaps predicting the flurry of requests to come, Hooke had written to Boyle saying, "I hope I shall prevail upon Dr. *Lower*, and for him, so as to get him anatomical curator to the Society," not least because of his "most dextrous hand in dissecting."[62] Whether directly influenced by Hooke or, perhaps indirectly by the contrast between Lower's success and Hooke's reticence, the Society did decide that Wilkins should talk to Lower about becoming an anatomical curator.[63] He did so, but Lower also said he was too busy with his physician's practice.[64] Hooke was specialising. He never seems to have considered the position of Curator to have been unique – performing experiments was the bread and butter of natural philosophy, and as such was far

59 Birch, *The History of the Royal Society*, 1756, 1:482; Hooke to Boyle, 10 November 1664: Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 2:399.

60 Birch, *The History of the Royal Society*, 1756, 2:181–216. Lower seems to have been happy to perform the experiments. Sometimes he was assisted by Edmund King, who seems almost to have relished them, helping Lower with no (noted official) bidding and in July providing the Society with accounts of seven gruesome experiments he had performed apparently on his own initiative. Ibid., 2:189–192.

61 Birch, *The History of the Royal Society*, 1756, 2:209, 216, 227. The lecture included as an Appendix to this thesis is interesting in this regard: Hooke touchingly claims it is one of the microscope's great benefits that they leave the subject intact through investigation.

62 Hooke to Boyle, 5 September 1667. In Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 3:332.

63 Birch, *The History of the Royal Society*, 1756, 2:206.

64 Ibid., 2:212.

more than the work of any one person.[65]

The salary difficulties Grew faced in the 1670s give Hooke's experiences a decade earlier a fatalistic air. In July 1664 the Society had agreed on a yearly £80 salary for Hooke as curator, but it was not obvious where this would come from.[66] He received his first payments from the Royal Society, totalling £50, only two years later, in November 1666. At the time, the Society was £678 5s. in arrears.[67] When Hooke recommended Gresham College to Grew he was a professor and resident there, and was all too familiar with the possibilities for additional income the College provided.

The Royal Society had been eager for Hooke to secure an appointment at Gresham. They met there, and a professorship would not only give their curator convenient lodgings, but a salary at a time when they could not afford to pay him. In May 1664 Hooke applied for the position of Professor of Geometry, recently vacated by Isaac Barrow, but lost out to Arthur Dacres.[68] Another opportunity existed though, and the Society were determined not to let it get away. Sir John Cutler – a wealthy member of the Grocers' Company, slightly self-serving benefactor of various civic institutions, and acquaintance of Fellow John Graunt – had apparently promised to inaugurate for Hooke a £50 per annum lectureship on "the histories of trades" at Gresham.[69] Hooke wrote to Boyle in October 1664 to relay the good news that he had moved into Gresham College in the summer, and that Cutler had "not only kept his word, but been better than it," sending half a year's salary in advance. But he also found himself "engaged in a very great design, which I fear I shall find a very hard, difficult, and tedious task, and that is,

65 It is worth noting also Hooke's introduction of Denis Papin to the Society in 1679. Papin was offered scribal work by the Society, but proved an ingenious mechanic and was quickly promoted to curator. See Pumfrey, "Ideas Above His Station", footnote 30; Birch, *The History of the Royal Society*, 1757, 3:486, 491–504; Birch, *The History of the Royal Society*, 1757, 4:277.

66 Birch, *The History of the Royal Society*, 1756, 1:453.

67 Royal Society Account Books I, cited in Bennett et al., *London's Leonardo*, footnote 38.

68 Gunther, *Early Science in Oxford*, 6:179, footnote; Pugliese, "The Scientific Achievement of Robert Hooke," 2–4. Both cite for their information regarding Hooke's bid for the Geometry chair John Ward's *Memoires relating to Gresham College*, preserved in a manuscript (Book I, British Library Additional Manuscript 6195).

69 See Hunter, *Establishing the New Science*., pp. 283-288 for some background on Cutler and suggestion of his reasons for endowment, as well as more on the following story about Hooke's employment.

the compiling a history of trades and manufactures."[70]

The Society's aforementioned resolution, in July 1664, to pay Hooke an £80 salary had an important caveat. The amount was to be kept secret until Hooke was secure in his Cutlerian lectureship. It was the Society's aim that £50 would come from Cutler, and only £30 from Fellows' subscriptions.[71] Hooke was apparently happy with the arrangement, but the merger of incomes implied a merger of positions.[72] The Society wanted Cutler's money to support the work Hooke did for *them*, not him. When the lectureship was announced before the full Society on 9 November 1664, a delegation was sent to get Cutler's word that he was "willing to refer it to the president, council, and fellows of the Royal Society of London [...] to direct and appoint the said Mr. Hooke how many lectures he shall read, and when, and upon what subjects; or what kind of inquiries, by way of experiment, he shall be engaged to prosecute."[73] With an insidious semicolon, the Royal Society were explicitly conflating Cutler's endowment with Hooke's curatorship, rather than seeing it as payment for a separate position. As they thanked had Boyle for lending them Hooke's services, so they thanked Cutler for paying "Mr. Hooke *50l. per annum*. for such employment, as the Royal Society should put him upon."[74]

This, it would become clear, was a subversion of Cutler's intentions. Though Cutler's reasons for founding the lectureship are not very clear, it seems it was intended for public education about trade practices. Likely the Society thought his patronage was a gesture for the benefit of his own reputation, and that he would be as hands off as the Gresham Trustees, who

70 Hooke to Boyle, 6 October 1664. In Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 2:342–344. Cutler could well have had a hand in Hooke's failed application to the Geometry Professorship. In later litigation hearings between Cutler and Hooke, Hooke mentioned running into his benefactor in a public house just after the failed application and mentioning his disappointment "by the deportment of some of the Electors to whome or one of them [Cutler] had some relation" (an extended quote from the hearing is given in Hunter, *Establishing the New Science*, 287.) Cooper suggests the most likely explanation for Hooke's failure is "a conspiracy between Cutler, Foote [Samuel, Cutler's brother-in-law, who was on the election committee], and the Bateman brothers [likewise] to save Hooke for Cutler's sponsorship" (Bennett et al., *London's Leonardo*, 24.)

71 Birch, *The History of the Royal Society*, 1756, 1:453.

72 When the hitherto secret details of the Office of Curator were made public and Hooke was proposed by Wilkins for the position on 23 November 1664, the salary was set at £30 per year. Hooke was recorded to be happy with the lowered rate given the "fifty pounds a year, upon the account of reading lectures of experimental philosophy" that he was to receive from Cutler. Ibid., 1:490, 496.

73 Ibid., 1:484.

74 Ibid., 1:479.

dealt with weary resignation with the routine chaos that was the College.[75] After March 1665, when Hooke petitioned for his application for the Geometry post to be re-examined and was duly elected to that position as well he had little difficulty discussing a wide variety of things in those lectures.[76] The many times that a Fellow reported to the Society that Cutler was leaving the ambit of the lectures to the Society also might indicate that they were quite deliberate about subverting the public philosophy of the College to their own ends.[77] When the Council debated the number and topic of the lectures, the latter was settled on "the *History of Nature and Art*."[78] They were to be given in the same room as and immediately preceding Society meetings, indicating the two offices were intended to be connected, and the lectures of interest to and attended by Fellows.[79]

Where the Society saw a way to maintain their Curator, Cutler saw his money being used for something he did not want to pay for. Cutler's patronage gave Hooke means, but it also resulted in litigation over salary and commitments which was only resolved on Hooke's 61st birthday. On 18 July 1696, Cutler's estate was ordered to pay arrears, having withheld his salary, and Hooke was overwhelmed. "I was Born this Day of July 1635. and God has given me a new Birth, may I never forget his Mercies to me; whilst he gives me Breath may I praise him."[80] Hooke's diary was not usually so emotive; receiving his settlement clearly meant a lot to Hooke,

75 Michael Cooper relates the state of the College following a report in 1676: "Only two professors (one was John Mapletoft, Professor of Physic, the other was Hooke) were resident in the College; the rest, having let their lodgings, were either living at ease in the country or overseas, or pursuing their careers in other places. Thomas Baines, Professor of Music, had let his lodgings and stable to Elias Harvey. Sir Andrew King rented the stable of Walter Pope, the Professor of Astronomy, but lodged in the College's public rooms. Walter Pope's lodgings were either empty or let to Mr Barfoot (it could not be ascertained which). A Mr Crispe, who rented the lodgings of Roger Meredith, Professor of Law, had converted the stable and hay room into a hall and kitchen and made a door and steps out into Broad Street" (Bennett et al., *London's Leonardo*, 25). Ten years later the Trustees found "the same in great disorder" (ibid.).

76 Cf. his 'Lectures of Light.' See Pugliese, "The Scientific Achievement of Robert Hooke," 2–4, for more on the situation.

77 Wilkins related to the Society that Cutler had told him he was resolute in paying Hooke his salary for doing whatever work the Society required of him, and William Petty reported that Cutler had "intimated" the management of the position should be left to the Society. Birch, *The History of the Royal Society*, 1756, 1:479, 499, 503.

78 Ibid., 1:499, 503.

79 Hunter, *Establishing the New Science*, 292; Bennett et al., *London's Leonardo*, 24.

80 "The Life of Dr. Robert Hooke," in Hooke, *Posthumous Works*, xxv. Hooke's actually wrote "D O M S H L G I S S," which Waller then expanded: "*Deo Opt. Max. summus Honor, Gloria in secula seculарum, Amen*."

more than simply the money involved. Moved to think of a higher power and his own humanity, Hooke's words have a sense of closure and fulfilment. Cooper has suggested he saw the decision as a vindication of his life as a natural philosopher, and as someone defined by his status as reliant employee rather than free, unconfin'd gentleman, this seems a likely suggestion.[81] Towards the end of his life his lectures are peppered with frustrated asides – the Royal Society repeat experiments again and again, people do not record or share their observations, knowledge is kept in closed communities. His reaction to the settlement evokes a sense of just treatment by a power greater than those whose mercy he was immediately at, and who regularly frustrated him.

Pumfrey has equated Hooke's position to a professional career such as a government official, teacher, or land steward. These careers potentially rewarded intellectual and physical labour with elevated social status. Generally beginning with a low status and low salary, and often a patron, the possibility of becoming 'pseudo-gentry' beckoned.[82] But the difference for Hooke was the ascent was unestablished and insecure. A patron rewards their client for things the patron wants, but a professional receives a salary for fulfilling a *role*. There was no precedent for Hooke's role, and he worked to establish it. Arrangements like the one between the Society and Cutler, which Hooke had no say in, represented a failure to do this and stabilise his position as *their* employee, working for the institution and rewarded by them for his labour.

Out of all of this payroll confusion came the *General Scheme*. It is likely the result of Moray suggesting in February 1664/5 that "Mr. Hooke's lecture might be perfected and printed."[83] Which lecture Moray means is not entirely clear,[84] but there is significant overlap between the *General Scheme* and a lecture Hooke gave sometime after the lectureship was

81 Bennett et al., *London's Leonardo*, 21.
82 Pumfrey, "Ideas Above His Station," 11; see also Stewart, *The Rise of Public Science*.
83 Birch, *The History of the Royal Society*, 1756, 2:16.
84 In general it is difficult to pinpoint which of Hooke's lectures belong where, but Pugliese and Hunter have both worked to identify some: Pugliese, "The Scientific Achievement of Robert Hooke," 11ff; Hunter, *Establishing the New Science*, 299–301.

inaugurated in October 1664[85] and March 1665.[86] In both the *General Scheme* and this lecture, Hooke lists the same attributes required of the natural historian, and uses the same examples to illustrate how discoveries about one thing can lead to discoveries about others. There is a passage which appears almost verbatim in both and that has been added later to the lecture manuscript, written on a separate sheet and attached. This at least indicates that Hooke returned to the lecture to edit it after he had completed it, though whether before or after he delivered it is unclear.[87]

Hesse has dated the *General Scheme* to 1666; Wood to 1665; and Pugliese and – following him – Hunter, to 1668.[88] The disagreement comes from a confusion of publications in the *Philosophical Transactions*, and there is good reason to prefer Hesse's original dating.[89] This date is

85 Hooke's first Cutlerian lecture is probably the first part of the manuscript Royal Society Classified Papers 20/50(b). This is a straightforward acknowledgement of Cutler for "promoting of Soe Excellent and Usefull a Designe as the Compiling of A Philosophicall history." (fol. 110, reproduced in Hunter, *Establishing the New Science*, 337.) Writing to Boyle on 6 October 1664, Hooke mentioned he is so busy that "[t]he most I think I shall be able to do in this business this term [...] will be only to make a short speech, both in praise of Sir *John*, my noble patron, and of the excellency and usefulness of the design it self, and of what method and course I shall take in it" (see Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 2:344.)

86 The lecture is preserved as Royal Society Classified Papers 20/50(a), and has been reproduced by David Oldroyd: Oldroyd, "Some Writings of Robert Hooke." It seems to immediately precede a lecture Hooke gave about comets Hooke was ordered to publish in March. Birch, *The History of the Royal Society*, 1756, 2:19. This lecture is preserved as London Metropolitan Archive CLC/495/MS01757, 11, formerly London Guildhall Library Ms. 1757, 11.

87 Compare: Hooke, *Posthumous Works*, 29; Oldroyd, "Some Writings of Robert Hooke," 154.

88 Hesse, "Hooke's Philosophical Algebra," 68, footnote 3; Wood, "Methodology and Apologetics," 24; Pugliese, "The Scientific Achievement of Robert Hooke," 9–10; Hunter, *Establishing the New Science*, 299, footnote 70.

89 She and Pugliese both point to the same internal evidence – Hooke mentions his discovery "about two Years since" of the "Motion of [Jupiter] about its own Axis, by means of a somewhat darker spot in the Body of it" (*Posthumous Works*, 15). Hesse gives the correct date of this discovery – 9 May 1664 – but gives the reference for a *different* observation, published in the *Philosophical Transactions* on 2 July 1666 (1665-1666, 1:245). This observation, also by Hooke, and also of Jupiter, was made on 26 June 1666. Pugliese takes this later date to be the one Hooke mentions in the *General Scheme*, and therefore dates the text to 1668, two years later. The missing publication, of the May 1664 observation, was in fact published in the *Philosophical Transactions* on 6 March 1665 as 'A Spot in one of the Belts of Jupiter' (1665-1666, 1:3). A third monograph in the *Transactions* settles the matter. This article, published between the two others, reports that in addition to the shadows of the moons passing over Jupiter, "there hath been observed, by Mr. *Hook* first (as is mentioned in *Numb.* 1. of these *Transact.*) and since by M. *Cassini*, a permanent Spot in the Disque of *Jupiter*; by the help whereof, they have been able to observe, not onely that *Jupiter* turns upon his own Axis, but also the Time of such conversion; which he estimates to be, 9 hours and 56 minutes" (*Philosophical Transactions* 1665-1666, 1:143). The key is the addition of the discovery of the *period* of revolution – "not onely" the revolution itself. The discovery simply that Jupiter rotates was surely that of 9 May 1664, when Hooke observed a spot on its surface and "observing it from time to time, he found, that within 2 hours after, the said Spot had moved from East to West, about half the length of the Diameter of *Jupiter*" (*Philosophical Transactions* 1665-1666, 1:3). The observations are easily conflated, but the discovery Hooke references is surely the one from 1664. Two years after that, in 1666, he wrote the *General Scheme*.

In fact, Hooke also includes a mention of the issue in his later *Lectiones Cutlerianae*, in a small editorial aside: "The Revolution of the body of [Jupiter] upon its *Axis* I first discovered in *May* 1664, and published in the first Transaction, which was a considerable time before it was discovered by Monsieur *Cassini*; but we are obliged to him for the perfecting the Theory, as we are also for many other rare Discoveries and excellent improvements in Astronomy" (Hooke, "Microscopium," 78).

given further credibility by a letter from Oldenburg to Boyle on 27 January 1666 referencing what sounds like Hooke's methodological tract: "Mr Hook has also ready (having shewed it to me and others) a Method for writing a Naturall History, which, I think, cutts out work enough for all Naturalists in the World; and intends as I heare, to print it ere long."[90] No other methodological work by Hooke (except the Preface to the already published *Micrographia*) was intended for print. Furthermore, what sounds like a criticism from Oldenburg was of course the point of the *General Scheme*: a description of the work of naturalists, which Hooke himself admitted seemed "infinite and impossible to be completed."[91]

If this is correct it would provide a neat efficient cause for the *General Scheme*, but perhaps the details are not so important. Either way it certainly overlaps considerably with the content of early Cutlerian lectures, and is thus strongly related to his employment, his role in the Society, and in London's philosophical community.[92] The *General Scheme* is not simply an unfinished and unpublished tract which details Hooke's personal ideas about the proper method of natural philosophy. When Hooke stood in front of his audience of Fellows and the London public and delivered it, he was making a public proposal about the roles and structures of knowledge creation which were in the process of being negotiated and institutionalised, and in which Hooke himself was implicated and invested. It was a performance which, alongside his experimental demonstrations, shaped his role and persona in the experimental project.

90 Oldenburg to Boyle, 27 January 1666. In Hunter, Clericuzio, and Principe, *The Correspondence of Robert Boyle*, 2001, 3:46.

91 "General Scheme," in Hooke, *Posthumous Works*, 28.

92 That Hooke was a long time in thinking about the issues in the *General Scheme* is evident from a mention in *Micrographia*'s preface, written in 1664, that he might "in another Discourse […] attempt to propose some Considerations of the manner of compiling a Natural and Artificial History, and of so ranging and registring its Particulars into Philosophical Tables, as may make them most useful for the raising of *Axioms* and *Theories*." Hooke, *Micrographia*, sig. B1v.

Hooke's Histories

With the opening lines of the lecture, Hooke let his audience know, in no uncertain terms, the importance of experiments and observations.

> Philosophy, though of almost as great an age as the world, is yet as much in its infancy as ever[.] [I]t grows not but as the antient Mythologists fained Cupid it is for ever childish, and never has arrived to a manly perfection and activity. Its stature is Dwarfish, its constitution very tender, its power and strength exceeding weak, its growth scarce sensible, if at all, its command, nothing or insignificant. Soe that it seems rather monstrous and deformed than Naturall & be[a]utifull. The reason of all w^{ch} seems to have been because it has not had convenient food administred; that w^{ch} is the staff of its life has not been sufficiently supplyed. Naturall and Experimentall history has been but very thinly gathered and less of it has been applied to the raising and Increase of Naturall Philosophy, and therefore soe long as the materiall cause is wanting noe wonder if the efficient can performe no thing.[93]

It was the historian's job to provide, in a very literal sense, material for the philosopher. Guido Giglioni has recently written of Bacon that "the solipsistic and idealistic assumption that the thinking activity can do without matter is very distant from Bacon's philosophy."[94] So too in Hooke philosophy feeds off matter rather than discourse. The matter of observational records: experiments registered in a certain way, in certain language, with certain details, and available for a community to use. As we shall see, and is intimated in the quote above, the task of nourishing philosophy was far from a straightfoward or menial task. Because the history "we find in Aristotle, Pliny, and others...is so uncertain and superficial,"[95] all that has resulted is a dwarfish, childlike philosophy. Pliny filled his Natural History with wonders and monsters, tales of strange things from strange lands beyond the Roman Empire, and the philosophy that has fed on it itself

93 Oldroyd, "Some Writings of Robert Hooke," 151. In what follows I will use Oldroyd's transcription of the lecture in Classified Papers 20/50(a). I follow his editorial decisions, but leave out his marks indicating uncertain words.

94 Giglioni, "From the Woods of Experience to the Open Fields of Metaphysics," 261.

95 "General Scheme," in Hooke, *Posthumous Works*, 3.

turned monstrous and deformed. A "Naturall & beautifull" philosophy needs to be built from the right materials. As Hooke shows in Micrographia, natural beauty is found everywhere: small hairs on a fly's wings resemble Persian carpets; moss is as beautiful as any flower; even frozen urine reveals a "very regular and curious Figure."[96] His point was not just to pay attention to everything in nature, but to pay attention to the right details of everything. "[T]here must be Judgment in the Historian to discern what will be material and useful" to philosophy.[97] There is no need for such judgement or discernment for the philosopher. This is something Hooke emphasised throughout his career, in his preface to Robert Knox's report on Ceylon, for instance, and as he wrote in Micrographia: "the storing up of all (particulars) [...] will only tend to darkness and confusion. We must not therefore esteem the riches of our Philosophical treasure by the number only, but chiefly by the weight."[98]

History is "material" to philosophy, and the right kind of observations have more "weight" – they provide more material to be turned into knowledge. The primacy of such observation is clear from the self-conscious opening of *Micrographia*, Hooke's microscopical enactments of Euclid's first three axioms: the point of a needle, the line of a razor's edge, and the plane of linen cloth. Though the naked eye "cannot distinguish any parts of" the point of a needle, under the microscope it is revealed as complex and ragged.[99] The point exists in the world as a material object, at the end of a needle, or printed and labelled in geometry textbooks. And, Hooke shows us, it never lives up to the mathematical ideal of an insensible, unextended object. Imaginative assumptions about the undivided point are not physically true. This is not merely wordplay. The philosopher should not use imaginings and stipulations to construct their philosophy, but materials, and it was exactly the materiality of the point which was in question. What the point *was* influences its meaning in later theorems. Michael Barany sees in Hooke the final step in a transition in the meaning of the Euclidean point: from being the foundation of

96 Hooke, *Micrographia*, 174, 131, 91.
97 "General Scheme," in Hooke, *Posthumous Works*, 19., p. 19.
98 Hooke, *Micrographia* sig. A2r; see also Knox, *An Historical Relation of the Island Ceylon*, sig. A2r.
99 Hooke, *Micrographia*, 2.

exact knowledge in the sixteenth century, it became the source of the *problem* of exact knowledge in the seventeenth. Early modern English versions of Euclid defined the point in different ways, as the endpoint of a line or as the thing which combines infinitely to generate lines, dependent on the author's interest in practical or theoretical geometry.[100] Which should take precedence? For Hooke, all definitions must be grounded in observation. As he says elsewhere, "we are noe farther certaine of the truth of this proposition, that one & two are three, than that in all the sensations we have yet had, we have found it so."[101] Not even mathematical axioms are innate, but may "extend soe far only, as to things which fall under the power of our senses."[102] The point, in *Micrographia*, is more heuristic: the geometer serves as a model for the natural philosopher. "How much therefore can be built upon demonstrations made onely by the productions of the Ruler and Compasses, he will be better able to consider that shall but view those *points* and *lines* with a *Microscope*."[103] Before certain knowledge comes a thorough understanding of the materials that construct it.

Two heavily related issues come out of this general picture: first is Hooke's description of the jobs of the historian and the philosopher, and secondly the persona which he attaches to the historian.

History and Philosophy

Compiling a natural history begins with identifying the subject matter to be explored. This could be anything:

> [T]here is no Body or Operation in the Universe, at least if it can be any way brought to our Knowledge, that is not some way or other to be taken notice of in this Great Work, the most

100 Barany, "That Small and Unsensible Shape."
101 From a lecture transcribed in Oldroyd, "Some 'Philosophicall Scribbles' Attributed to Robert Hooke," 19.
102 Ibid., 20.
103 Hooke, *Micrographia*, 2.

precious are here not more considerable, nor perhaps so much as the most trivial and vile.[104]

Hooke, like the empiricist not the idealist, the practical man not like the metaphysician, divided the world into "heads of enquiry" not "according to the Nature of the things themselves, [but] according to their Appearance or Respect to us."[105] The first division is between art and nature, followed by headings within each. Natural subjects range from "Comets and Blazing Stars" down through the atmosphere and weather phenomena, the magnitude and figure of the earth, seas, lakes, ponds, mountains, vales, and plains, all the way to mushrooms, mosses, ground animals and worms (see Figure 7.1).[106] This, Hooke suggests, will be sufficient at least for the "first Book of Entries". More detail will come with more work.

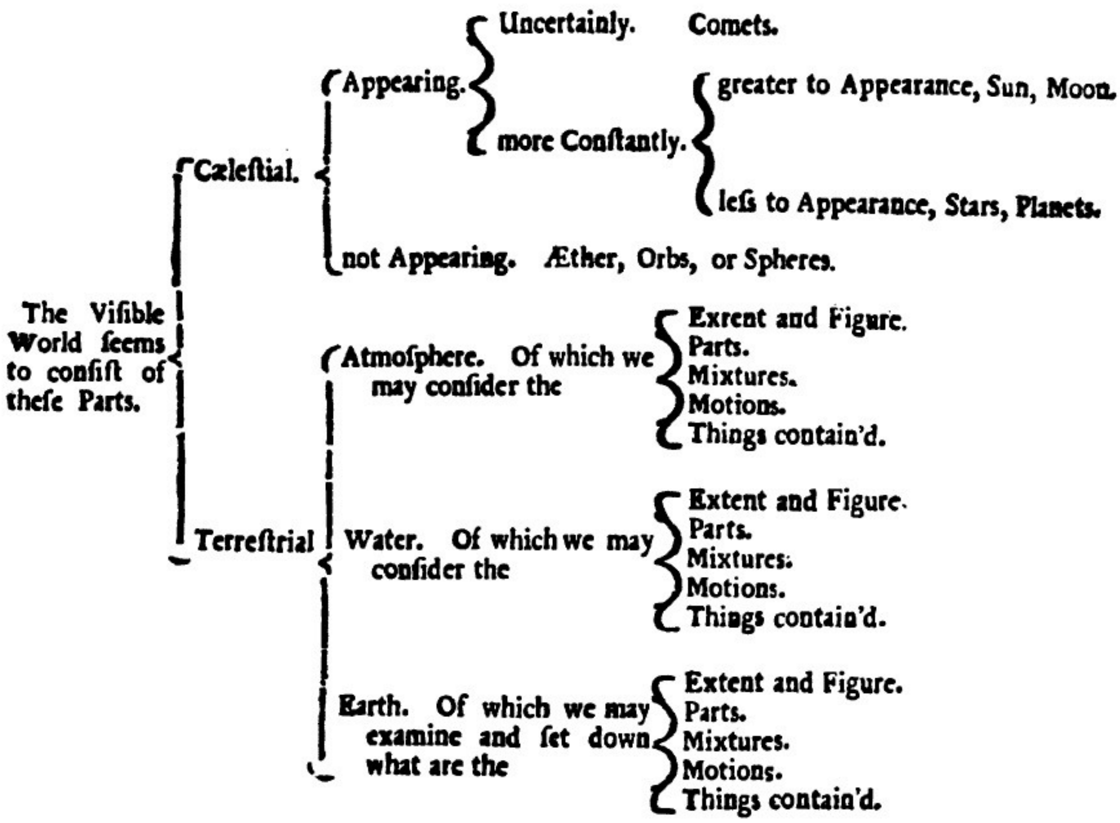

Figure 7.1: Hooke's divisions of natural history. *Posthumous Works*, 22.

104 "General Scheme," in Hooke, *Posthumous Works*, 21.
105 "General Scheme," in ibid.
106 "General Scheme," in ibid., 22–23.

As noted above, all kinds of bodies might be equal, but not all information about them is. The history of each subject should only contain relevant, useful facts. The first thing to do, then is:

> to consider what information or proprietys are wanting to make A full and perfect discovery of its nature, And in Order hereunto to propound to one[']s self & set downe in writing as many quaerys as can be thought of, the solving of which would give one a perfect knowledge of y^e^ Nature of y^e^ body that is to be examined.[107]

The experimenter should draw up a list of particular queries about their subject, and set about answering them with three techniques, each of which gives us different information about a subject:

> I. By the Help of the Naked Senses.
> II. By the Senses assisted with Instruments, and arm'd with Engines.
> III. By Induction, or comparing collected Observations, by the two preceding Helps, and ratiocinating from them.[108]

In this, Hooke differs from Bacon. Bacon "set little store by the immediate and peculiar perception of the sense," and went as far as claiming that "the sense judges only the experiment whereas the experiment judges the thing."[109] As I have discussed in the previous chapters, for Hooke, investigating a subject was not about getting the one true view of a thing but about comparing and blending the various impressions that come from various senses and instruments. Though I wish to avoid understanding Hooke only in relation to Bacon, some further points of comparison will be illustrative.

107 Oldroyd, "Some Writings of Robert Hooke," 153.
108 "General Scheme," in Hooke, *Posthumous Works*, 35.
109 *The Plan of the Work*, in Bacon, *The Oxford Francis Bacon*, 11:35.

Bacon associated different sorts of knowledge with different metaphorical places: the woods (*silva*) of experience, the open fields of axioms, and the level ground where we descend from the axioms to produce works.[110] Emerging from the woods, shifting from particulars to universal statements, is the beginning of philosophy. This extended metaphor points to an important but subtle difference between Hooke and Bacon. Bacon recognised that "long and agitated lingering on experience and matter" may give an impression – like Oldenburg's impression of the work described by Hooke in the *General Scheme* – that the work to be done is impossibly complex, and "casts [the mind] into the blackest hell of confusion and distress."[111] The final goal of natural enquiry might be to cross the fields and improve the human condition with works, but the path there is not easily come across and can be daunting. According to Bacon, there is significant therapeutic and heuristic value to spending time lost in the woods of experience, encountering the world in a pre-lingual, pre-knowledge way. Such dense, constant confrontation with the materials of the world remind one "how great is the gulf between the *Idols* of the human mind and the *Ideas* of the divine," and thus that truth about nature cannot be invented by humans.[112] Natural particulars are far fewer in number than the convolutions and repetitions of human discourse. The edge of the forest is always nearby.

While wandering around the *silva*, the investigator should keep an eye out for particularly enlightening instances which will lead them out of experience and to axioms. His famous *instantia crucis*, Instances of the Fingerpost, borrow their name from signposts by the side of roads, guiding travellers toward their destination in "a case of the parting of the roads."[113] By following the right signs, the observant experimenter will be led from mere phenomena to knowledge of the underlying causes behind their experiences. In fact, given his geographic talk of knowledge, many of Bacon's metaphors are of similar progression – travel beyond the pillars of ancient learning, the gradual ascent up the pyramid of knowledge, out of the woods and into

110 Giglioni, "From the Woods of Experience to the Open Fields of Metaphysics."
111 *Novum Organum,* book 1, aphorism 124. In Bacon, *The Oxford Francis Bacon*, 11:187.
112 *Novum Organum*, book 1, aphorism 124. In Ibid.
113 *Novum Organum*, book 2, aphorism 36. In Ibid., 11:320.

the clear. For him, knowledge is a specific type of thing which happens *after* experience.

Hooke, by contrast, speaks of circulation and of landmarks. Linear analogies are replaced by multi-dimensional ones.

> [I]n *Physical* Enquiries, we must endevour to follow Nature in the more *plain* and *easie* ways she treads in the most *simple* and *uncompounded bodies*, to trace her steps, and be acquainted with her manner of walking there, before we venture our selves into the multitude of *meanders* she has in *bodies of a more complicated* nature; lest, being unable to distinguish and judge of our way, we quickly lose both *Nature* our Guide, and *our selves* too, and are left to wander in the *labyrinth* of groundless opinions; wanting both *judgment*, that *light*, and *experience*, that *clew*, which should direct our proceedings.[114]

This passage, from the beginning of *Micrographia*, is clear on the importance of the microscope – we ought not start our histories with comets and stars. These elusive things require 'meandering' investigation, using both judgment and experience together. There is a constant interplay between observation and more abstract knowledge. Inquiry is made strong by circulating through the senses, memory, and reason "as the body of man is by the *circulation* of the blood through the several parts of the body."[115] By observing carefully with the unaided senses, we gain a certain familiarity with the world; moving through the wood of experience, we begin to follow Nature "closer and closer at the heels," so that we see "where she begins to make a Deflexion out of her common Road."[116] When this happens we switch methods, and use instruments and experiments to find her again. For instance, from plain observation it is obvious that bodies generally expand when heated. But water expands when it freezes too – the common road has been abandoned and "[w]e are at a loss to find what way Nature should take with two quite contrary Agents, to bring forth the same Effect."[117] At this point, conjecture and

114 Hooke, *Micrographia*, 1.
115 Hooke, *Micrographia*, sig. B2r.
116 "General Scheme," in Hooke, *Posthumous Works*, 34–35.
117 "General Scheme," in ibid., 35.

experiment are necessary. Perhaps ice is always full of minute, invisible air bubbles, and so takes up more space? When Hooke observed ice with his microscope he found this was not the case. With no immediate explanation for all instances of expansion, he instead enlisted the memory, and "set up a rest" – marked the place where the investigation had halted, and waited for a new experiment to suggest itself.[118]

Relatedly, as I mentioned in Chapter 3, Hooke emphasised much more than Bacon did that those experiments in which "Nature is as 'twere put to Shifts and forc'd to confess" will be rare, and inquiry is really a gradual process of gaining familiarity with nature.[119] The microscope – the new optics generally, as we saw in the previous chapter – showed that through our gross senses we perceive the world as various constantly shifting qualities. Hooke gives a list of these "prime sensible qualities":

1. Light and Darkness.
2. Transparency and Opacousness.
3. Colours, commonly distinguisht into real and appearing.
4. Sounds, Musical and Harmonious.
5. Tastes.
6. Smells.
7. Heat and Cold.
8. Gravity and Levity.
9. Density and Expansion.
10. Flexibility and Stiffness.
11. Maleabiilty and Brittleness.[120]

Moving beyond these appearances to find out the properties of a body which are the causes of such sensory qualities is the aim. For Hooke this meant constantly shifting between

118 "General Scheme," in ibid.
119 "General Scheme," in ibid., 34.
120 "General Scheme," in ibid., 23–24.

different experiments and subjects, not concentrating on only one thing at a time. "[F]inding out the Cause of Fluidity, Heat, Gravity, Brittleness, *&c.* in one Body, will much facilitate the Inquiry after the like Properties in any other Body."[121] Experiments give knowledge, but are possible only *with* knowledge. The two are interdependent, and often inquiry will stop, as with the expansion of ice, until new knowledge opens another avenue to pursue. More than anything else, what underwrites Hooke's recommendation to the natural historian is the idea of 'imperfect knowledge'.

> For it cannot be expected, that any one should be alike able to make Queries of those things in which he has not been much, if at all conversant; as one that has had the Opportunity of acquainting himself more particularly with the Nature of it, and has imbib'd in (though he knows not how) a great deal of imperfect Knowledge of the Proprieties of it.[122]

As so often in Hooke's own writing, another example illustrates this point best. On discovering that cork is light because it is being riddled with pores which trap air, Hooke supposed the same to be true of all wood. He looked at "Wood both green and dry" through his microscope, and could not immediately discover any pores. But his 'imperfect knowledge' informed his practice, and he conjectured that perhaps they were hidden somehow, maybe under a layer of sap. By heating the wood to evaporate the sap, he discovered he was correct.[123] "[T]rying the Experiment over and over again, I found the same Propriety was not only to be found in one or two other kinds of Wood, but was common to all sorts of Vegetables that I was able to charr."[124] Hooke emphasises the power not of direct investigation but of analogical thought, which was guaranteed to be effective because underneath nature's dizzying superficial diversity, "there seems to be multitudes of proprietys or natures which are common to a great

121 "General Scheme," in ibid., 29.
122 "General Scheme," in ibid., 27.
123 Oldroyd, "Some Writings of Robert Hooke," 153–154; "General Scheme," in Hooke, *Posthumous Works*, 28–29.
124 "General Scheme," in Hooke, *Posthumous Works*, 29.

number of bodys."[125] The 'nature' of a body here means something like 'riddled with holes.' Knowing this cause of levity gives imperfect knowledge about objects that appear light, suggesting queries about them. Knowledge about one thing leaks into those nearby. In a sense, Hooke was refining Bacon's famous tables of presences and absences. Where Bacon suggested a direct course, from an exhaustive itemisation of objects with a particular quality to knowledge of that quality, Hooke's method meanders. Enquiry begins with a body, moves to qualities, and from there back to other bodies, and round to the quality again. As we saw in Chapter 3, his *experimentum crucis* against Descartes' theory of colours was carefully crafted and interpreted given the imperfect knowledge he was developing about light, lenses, and mica.

The comparison between the two men's methods is stylised. As well as Bacon's tables and his prerogative instances, he suggested eight more methods of investigation, though never completed them in as much detail.[126] Furthermore, Dana Jalobeanu has recently pointed out a distinction in Bacon's writing between two types of natural history, one which he prescribed in his methodological writings, and one which he actually wrote, particularly *Historia ventorum*, *Historia densi et rari*, and *Historia vitae et mortis*. The former, which Jalobeanu calls 'mother histories', "[picture] natural history as resulting from an essentially collaborative enterprise sketched on a cosmographical scale, and comprising narrative histories of bodies."[127] The latter, in contrast, are "middle histories," much more like Hooke's, and largely concerned with virtues, qualities, and appetites of matter – "a more sophisticated natural history, a sort of 'middle term' between natural history and philosophy."[128]

Still, if we continue to press on this distinction between history and philosophy, an important difference appears in the way the concept of 'knowledge' appears and is used in the two men's schemes. The point becomes, unsurprisingly, less abstractly methodological and reduces more to the roles of the people involved in their methods.

125 Oldroyd, "Some Writings of Robert Hooke," 153.
126 *Novum Organum*, book 2, aphorism 21. In Bacon, *The Oxford Francis Bacon*, 11:273.
127 Jalobeanu, "Bacon's Natural History and the Senecan Natural Histories of Early Modern Europe," 227.
128 Ibid.

Bacon, following the Aristotelian tradition before him, distinguished between *historiae* as descriptive accounts of phenomena, and *philosophia* as explanations dealing in causes.[129] He emphasised the importance of natural historical knowledge for attaining philosophical knowledge, and likely *over*emphasised the novelty of this view, but knowledge proper was the work of philosophy. “Natural History describeth the *variety of things*;” he wrote in *The Advancement of Learning*, “Physic, the causes, but *variable or respective causes;* and Metaphysic, the *fixed and constant causes*.”[130] Bacon's middle histories, as a step towards philosophy, included multiple possible causal explanations of phenomena. The benefit was largely heuristic, as he made clear in *The Plan of the Work*:

> I quite often adjoin my own observations, which are like the first gestures, nods, or glances of history towards philosophy, to give men some guarantee that they will not forever be tossed on the waves of history, and to make everything readier for when we come to the work of the intellect.[131]

One can climb a tree in the forest and look to the horizon. But the open fields are a different place. For Bacon, experience (*experimentum*) was pre-lingual, before the “work of the intellect.” To explain a phenemenon was to generalise from a particular instance to a universal causal story.[132] This, properly, was 'knowledge.' Hooke, on the other hand, emphasised the continuity of methods of investigation, and the cognitive work involved in experience itself. Causes and abstract knowledge – prestigious notions which carried a certain social cachet – were necessary to the work of the historian. Wandering in the wood of experience was a thoughtful task, and involved knowledge of causes.

129 For more on the meaning of 'historia' in the Renaissance, see Pomata and Siraisi, *Historia*.
130 Bacon, *The Works of Francis Bacon*, 1858, 6:218.
131 Bacon, *The Oxford Francis Bacon*, 11:41. See also Rees, “An Unpublished Manuscript by Francis Bacon”; Giglioni, “Mastering the Appetites of Matter”; Garber, “Merchants of Light and Mystery Men.”
132 See Gaukroger, *Francis Bacon and the Transformation of Early-Modern Philosophy*, 149.

Induction does not take Hooke out of the woods of experience, it leads him deeper into it. By "putting several Observations and Informations together, and collecting from them, and by reasoning and deducing from them" we can investigate "Effects produced at a greater Distance, and more remote from immediately affecting the Sense."[133] Natural history divided the world into topics according to their relation to people, and things that were close at hand could give an historian insight into things further away. There is more to stars than their appearance as small bright dots, but "we cannot go to the Sun, nor fetch Fire so far distant from us."[134] Instead, we can bring "our Inquiry into Subjects much nearer to us." When we have found out "what the efficient Cause of Fire and Light are, we shall by Analogy easily find out what is also the Cause of the Light in the Sun."[135]

Going 'beyond' experience like this helps to overcome sensory limits, but the limited memory is no less important in necessitating induction. As Nick Wilding has pointed out, by conceiving of the memory as a physical organ, Hooke "invokes the same logic of supplementary arts that potentially characterize other postlapsarian senses."[136] It is too imperfect to rely on, and in any case cannot be shared. There is a serious question of how knowledge should be registered. In Chapter 4 we saw the value Hooke placed on pictures as records of details that could not be "fully and sensibly exprest by Verbal Description."[137] That is all very well for ants or razors, but not everything lends itself to illustration. How is the historian to record their observations on the spring of the air? Even pragmatically speaking, the job of the experimenter must involve some form of generalisation or explanation.

> If the Natural Historian proceeds no further in his Examination (than observation), his Information will be very imperfect, and he that shall afterwards come to make use of it will find himself necessitated almost to begin the whole Inquiry anew, to make over again all those

133 "General Scheme," in Hooke, *Posthumous Works*, 42.
134 "Lectures of Light," in ibid., 93.
135 "Lectures of Light," in ibid., 100.
136 Wilding, "Graphic Technologies," 125.
137 "General Scheme," in Hooke, *Posthumous Works*, 64.

> Experiments and Observations that he finds Registred, and to intermingle divers others to the end that he may find out that which ought to have been ready prepared to his hands; and in Truth, without prosecuting this third way (of answering queries, that is, by induction – see above) 'tis not possible to make Experiments with any Judgment, that is, to know which Experiment is more or less significant, or of greater or less Concernment as to the Discovery of the Proprieties sought, for most Experiments are like single Letters which seldom signify but when they are joyn'd and compounded in Syllables and Words.[138]

As writers like Michael Polanyi and Andrew Pickering have more recently illustrated, communicating the tacit knowledge involved in the messy beginnings of inquiry is problematic.[139] One solution that Hooke gives is to reach a level of abstraction that can be adequately expressed linguistically. Another solution is implicit in his model of memory we saw in the previous chapter: build it.[140] It is interesting that while Hooke uses the term "imagine" throughout *Micrographia* to mean something like the the limits of what is possible to think, the faculty of Imagination does not feature at all in his model of the mind 15 years later. He speaks instead of the memory as the "repository" of ideas. The omission speaks to two concerns. The first is that Hooke was distancing himself from the possibility that sensory knowledge is dangerously unreliable because indistinguishable from the fantastical productions of the mind itself.[141] The second, more pertinent to my discussion here, returns us to the comparison with the purely visual memory of Alpers' northern artists. "Repository" has a very particular resonance when used by the Curator of the Royal Society. Hooke had been given charge of the Society's Repository in 1663, a museum which Thomas Sprat tells us was to be "a General Collection of all the Effects

138 "General Scheme," in ibid., 42.
139 Polanyi, *Personal Knowledge*; Pickering, *The Mangle of Practice*.
140 It should be noted that Antonio Perez-Ramos found this idea of knowledge in Bacon too. The point of my comparison between him and Hooke was not so much to express difference as to bring out Hooke's ideas. A comparison more *a propos* of this task is perhaps between Hooke and 'Baconianism,' where the latter is something directed to contemplative truth, of which works are symptoms. See Pérez-Ramos, *Francis Bacon's Idea of Science*.
141 I am grateful to Megan Baumhammer for many conversations about this topic. See her "Optical Instruments and the Early Modern Imagination." See also the final chapter of Gal and Chen-Morris, *Baroque Science*.

of *Arts*, and the Common, or Monstrous *Works* of *Nature*."[142] Appearances were certainly important in such a marvellous collection, but so were the performances and processes of artifice.[143] One could know the form of a thing, or a *thing* could know a natural process by replicating it artificially. Instruments articulate knowledge.[144] This, of course, was the implicit power of Hooke's artificial eye demonstrations. To explain a process in nature could therefore simply be to design and build a machine that would recreate that process. Jim Bennett and Ofer Gal have separately discussed the two sides of interchangability of theory and material in Hooke. Hooke treats his instruments and demonstrations as explanations of phenomena,[145] and he deploys and manipulates ideas as he would material tools.[146] Theory and equipment are inseparable, and parts of both are dropped, swapped, or replaced as the need arises. As a model for the individual memory, the strong implication of the repository is that some knowledge is not expressed in images or in words, but in action.

These issues confound a neat division between experience and knowledge. There is no dividing line between compiling a natural history that is useful for discovering causes, and using it to do that. There *can* be no difference between empirical investigation and philosophical learning – succesful experimentation requires knowledge even as it creates it.[147] Causal explanations are not just the aim of inquiry but part of the process, materials to be used to complete natural history.

There is certainly the possibility of theorising beyond the end of Hooke's histories, but he is generally dismissive of this type of thought. He typifies the broader meaning of mechanical philosophy that Jim Bennett has identified, rather than a narrower one focused more particularly

142 Sprat, *The History of the Royal Society*, 251. For more on the Society's repository see "Between Cabinet of Curiosities and Research Collection," in Hunter, *Establishing the New Science*.

143 For the Kunst- und Wunderkammer for concepts of nature and natural knowledge, see Bredekamp, *The Lure of Antiquity*.

144 See Baird, *Thing Knowledge*.

145 Bennett, "Robert Hooke as Mechanic and Natural Philosopher."

146 Gal, *Meanest Foundations and Nobler Superstructures*, 43–41.

147 Paul Feyerabend could have been writing about Hooke when he said that "experience arises *together* with theoretical assumptions *not* before them." Feyerabend, *Against Method*, 168. His objection, topical to the career of Robert Hooke, was that the distinction between theory and observation is irrelevant to the running of science.

on matter theory.[148] Bennett is exactly describing Hooke when he writes of the mechanical philosophers, "[t]heir working conceptual categories were mathematically-characterized matter and its mechanical operations, and beyond this the ontological status ascribed to material entities, derived from metaphysical argument, were niceties that had little effect in practice."[149]

For an example, let us return to his investigation of light. Hooke concludes, by looking at a variety of luminous objects, that there is one "Principal Cause of all, which is in almost each of them conceal'd under a differing covering."[150] This cause is "a very short vibrating motion," as he registered in *Micrographia*. Later, in his *Lectures of Light*, Hooke dismisses the idea of Ismaël Bullialdus (1605-1694) that light is a kind of 'middle' substance, between corporeal and incorporeal. Hooke does not understand it, and he does not need to. Light results from motion, so for it to travel it must do so through a substance that transmits it. But "there is no need of supposing any other Substance, but Corporeal, or Body; and that, so and so qualified; that is, perfectly Fluid, and perfectly Dense, and so Receptive and Communicative, of all manner of Motion."[151] His conclusion is restricted to what was can intelligibly think. "I know not what can be farther added, that is more known or more Intelligible than that it is [… a] Substance, or a something; that is infinitely fluid, or at least, indefinitely; if that be more conceivable."[152] What exists is a wonderfully nondescript 'something', and it must only be 'indefinitely' fluid: only as far as we can tell is it "free from cohesion [and] susceptible to any kind of Motion."[153] We saw in Chapter 3 that Hooke certainly had ideas about the nature of light beyond the relations between phenomena that Newton wanted to establish. However, even that ended with ambiguity about how wedded to the intricacies of the mechanism he was beyond the requirement that an explanation of refraction must involve some kind of consistent and predictable alteration of

148 Cf. Henry Power – see Chapter 4. For this element of Bacon's thought, see Giglioni, "Mastering the Appetites of Matter"; Gaukroger, *Emergence of a Scientific Culture*; Rees, "An Unpublished Manuscript by Francis Bacon."
149 Bennett, "The Mechanics' Philosophy and the Mechanical Philosophy," 24.
150 "General Scheme," in Hooke, *Posthumous Works*, 51.
151 "Lectures of Light," in ibid., 115.
152 "Lectures of Light," in ibid.
153 "Lectures of Light," in ibid.

light. Here, as in the previous chapter, what is important is that a model, either material or metaphysical, be both intelligible and consistent with experience. Such metaphysical postulates turn into imaginative aids, to assist further inquiry by suggesting more queries to be answered. Localised conjecture is necessary to make experiments.

If theories and works are equivalent in one sense, it is clear which Hooke valued more. The final promise of his method was industry. As he wrote in *Micrographia*, by his method "*Talking* and *contention of Arguments*" will dissolve into "*labours*," and "universal metaphysical natures" will "vanish, and give place to solid Histories, Experiments and Works."[154]

Writing His Own Job Description

Hooke's reconceptualisation of knowledge as something more bodily and processual effected the persona of the person involved with it. At the turn of the century, Bacon worried that people would find the observations collected in his *Sylva Sylvarum* "vulgar and trivial, mean and sordid, curious and fruitless."[155] He answered humanists critical of natural philosophy that empirical investigation of the world would lead to the kind of "peace and tranquility of abstract wisdom" which they respected as noble for a philosopher.[156] Interestingly, though he thought they were important, collecting observations was not a job Bacon imagined for himself. The Lord Chancellor spoke "complainingly" to his anmanuensis William Rawley of the task. Bacon felt he deserved to be a philosopher, an architect planning the edifice of natural philosophy. Instead, he was "forced to be a workman, and a labourer; and to dig the clay, and burn the brick; and [...] gather the straw and stubble."[157] A resigned claim that it is honourable enough to observe God's works was his little compensation. Hooke, on the other hand, recommended experiment and observation themselves to "the *Gentlemen* of our Nation, whose *leisure* makes them fit to *undertake*,

154 Hooke, *Micrographia*, sig. B2r.
155 Bacon, *The Works of Francis Bacon*, 1858, 4:155–156.
156 *Novum Organum*, book 2, aphorism 124. In Bacon, *The Oxford Francis Bacon*, 11:187.
157 Bacon, *The Works of Francis Bacon*, 1858, 4:156.

and the *plenty* of their fortunes to *accomplish*, extraordinary things," and promised as reward not only a "high *rapture* and *delight* of the mind," but the "*material* and *sensible* Pleasure" of investigation.[158] With the elevation of the historian to a crafter of knowledge, it is difficult to see what Hooke thinks is left for the philosopher. If Bacon was clear about the importance of natural history, Hooke emphasised the worthiness of the occupation, and the importance of the natural historian himself.

The natural historian is of course Hooke. If he was an active force in redescribing natural history as genuine knowledge, and experimenters as producers of that knowledge, he certainly had an interest in doing so. When he wrote of the many "Accomplishments requisite for a Natural Historian" to ensure they could fulfil the demands of their important task, they were attributes he himself possessed.[159] At first he volunteered his services to the Society, but by the mid 1660s he was redefining his role, and presented himself as a model Curator.

The natural historian, he stood in Gresham College and explained, must be knowledgable about both current theory and practice. The hypotheses of existing philosophies are as important to guide experiments as trade techniques, mechanics, and mathematics are to carry them out. This knowledge should be handled with care. Part of the importance of knowing different philosophies was, as Boyle also held, that the mind does not get overly attached to any particular one. Though the natural historian ought to be literate, so as to be able to read existing philosophical works and keep abreast of current research, skill in writing is not very important. They should record the results of their experiments plainly and ingenuously, without rhetorical or poetic flourishes. Draughtsmanship, on the other hand, is very important, both to design instruments and experiments, and to record results more exactly and failthfully than can ever be done in words.[160]

158 Hooke, *Micrographia*, sig. D2r.
159 "General Scheme," in Hooke, *Posthumous Works*, 19.
160 "General Scheme," in ibid., 19–21.

This is a pretty good self-portrait. Hooke was widely read in philosophy, conversant with trade practice, his skill with instruments was unequalled in the early Royal Society, and he could certainly draw.[161] It is interesting that Hooke furnishes the requirements for the natural historian with a sustained allusion to Christopher Columbus. The historian should, for example, take heart from experimental results, "as *Columbus* did from the decreasing Depth of the Sea, the Drift of Weeds on the Surface of the Water, and the White Clouds that appear'd near the Horizon, and the like[,] to incourage and direct him in his Course."[162]

Hooke does not explicitly make much of the analogy, but the resonance is clear.[163] The famous frontispiece to Bacon's *Novum Organum* depicts two ships sailing between two columns – Columbus travelling beyond the Pillars of Hercules at the mouth of the Mediterranean. In Renaissance tradition the Pillars bore the inscription '*non plus ultra*' to caution travellers of the empty beyond, and had to Bacon come to represent the misleading constraint of ancient authority. The inscription had been proven wrong, and knowledge had progressed through literal movement to a new place. The scholastics never strayed far, preferring to move in circles around their libraries and studies, as their knowledge did in their repetitive disputes. It was explorers who were advancing knowledge. Bacon's frontispiece was probably a deliberate copy of that of an earlier Spanish work on navigation, the *Regimiento de navegación* of Andrés García de Céspedes (1606), just as Joseph Glavill's defense of the Royal Society *Plus Ultra* shared its title with the motto of Habsburg Spain. The Spanish crossing of the Atlantic represented the advance of knowledge, both in terms of the technical success of the voyage, and the discovery New World novelties.[164]

Bacon had also compared himself to Columbus, laying out "just as *Columbus* did before his epic voyage across the Atlantic," the reasons why he thought his ambitious project was possible. "[R]easons which, though rejected at first, were afterwards vindicated by his experiment,

161 As well as the obvious evidence in *Micrographia*, see also Hunter, "Hooke's Figurations."
162 "General Scheme," in Hooke, *Posthumous Works*, 20.
163 See also Hunter, *Wicked Intelligence*, 50.
164 For more on spatial discovery as analogy for philosophical, see Grafton, *New Worlds, Ancient Texts*.

and were the origin and cause of events of vast consequence."[165] By the seventeenth century Columbus had been reimagined, as Anthony Grafton has noted, from the "equivocal figure that his own writing reveals him to be," into a "prototypical hero-explorer."[166] Hooke was tapping into a rich analogy to flesh out his curatorial persona, for which there was no precedent in Restoration England. In analogy, Hooke could step away from the literal situation and describe the optimistic possibilities for this role. By drawing on the the established and praiseworthy attributes of the explorer, he was able to imply the same things about the natural historian. The explorer was a model of progress, impartial discovery, and the possibility of a successful collaboration of materials, men and money. The historian takes the tiller of natural philosophy – it may not be his boat but his importance is undeniable.

When he stood in front of the Fellows of the Royal Society and the London public and told them about the "Methodical Proceeding in the making Experiments and collecting Observations whereby to Compile a Natural History, as the Solid Basis for the Superstructure of True Philosophy," Hooke was crafting himself as an experimenter. While the Society could emphasise their respected, gentlemanly make up for the benefit of outsiders, what about the natural historian *within* the Society? Trust was crucial, in both directions. The Society needed to be able to trust the results of his experiments and demonstrations, and also that he would convert their institutional resources into luciferous experiments in the first place. And he would be reliant on their judgement and discourse as guides, and their money for income. Both aspects were contentious. The role was rewarded by the confused situation of patronage and employment I outlined earlier – a situation it is not difficult to read as 'no one really knew what was going on.' What would count as success in this role? What was the meaning of experiment? It was a formative stage in his both Hooke's career and profession of the experimental philosopher. Indeed, though the institutional structure changed after Hooke's death when Isaac

165 *Novum Organum*, book 1, aphorism 92. In Bacon, *The Oxford Francis Bacon*, 11:151.
166 Grafton, *New Worlds, Ancient Texts*, 64, caption of Figure 2.2.

Newton became President of the Royal Society, later curators like Denis Papin and John Theophilus Desaguliers in no small way had their roles shaped by expectations and precedents set by Hooke.

As a final comment, later in his career Hooke acted much more like a collector and systematiser of histories than a historian himself. He became Secretary of the Royal Society and replaced Oldenburg's *Philosophical Transactions* with his own *Philosophical Collections*, and he wrote to correspondents, most famously Isaac Newton.[167] He recognised the importance of Moses Pitt's *English Atlas* and strove to secure Royal Society sponsorshop for it, and wrote of the importance of the travel books published by Samuel Purchas and Richard Hakluyt.[168] He began to enact what was implied by prescribing his role earlier: that in looking at the job from the outside he transcended it.[169] Hooke was a super-historian, the captain of the ship.

167 See Gal, *Meanest Foundations and Nobler Superstructures*; Nauenberg, “Robert Hooke’s Seminal Contribution to Orbital Dynamics”; Gal, “Hooke’s Programme: Final Thoughts.”

168 See Johns, *The Nature of the Book*, 451–453 for Hooke’s role in Pitt’s work; his preface to Knox, *An Historical Relation of the Island Ceylon* for his approval of Purchas and Hakluyt.

169 Stephen Gaukroger has made a similar point about Francis Bacon's *New Atlantis*: Gaukroger, *Francis Bacon and the Transformation of Early-Modern Philosophy*, 130–131.

Conclusion

Hooke shaped the meaning of experiment and instrument use in natural philosophy. The epistemic insight behind his contrived experiences was that even the everyday experience of humans in the world was fundamentally arbitrary. The senses were not conduits to the essences of bodies but limited instruments. "The power of distinguishing by the naked eye is that which bounds and limits all the other niceness," he wrote in his critique of Hevelius' astronomy, "and whatever part is more curious then that can equalize, is of no significancy."[1] To escape this limited view of our animal bodies required a certain kind of experimentalism, not one aimed at interrogating nature directly but one that would move nature into the view of the human. Whether he was monitoring the height of a mercury column in an air pump in front of Margaret Cavendish, or smiling at an engraving in a traveller's report from the New World, the job of the natural philosopher was to make the insensible sensible. It was an act of translation, a movement through different perspectives that would follow nature along her meandering path. The great promise of collaborative instrument-based philosophy was that instruments could be copied and information shared, and the woods of experience might be explored more quickly.

Hooke's microscope exemplifies his approach. His use of this instrument went far beyond peering through a lens: it involved constructing his own novel instruments, and machines for making those instruments. His ability to produce clear views of his subjects extended even to the old natural magician's skill in manipulating light itself, knowledge which he set down as a hypothesis about its nature. Although the tiny cells and mouths he saw through his lenses were remarkable revelations, there was more to enlarged vision than information about cork or lice.

1 Hooke, "Animadversions on the First Part of the Machina Coelestis," 4.

This approach was the foundation of certain and comprehensive natural knowledge.

The knowledge he sought was of how nature produced phenomena – not only those those that *we* perceive, but also those that we miss, that other creatures see or that the small machines of nature react to. Preliminarily, this knowledge might take the form of descriptions or pictures of things from beyond the senses. But the grander aim of philosophy was to understand how to recreate natural processes in the workshop: to express knowledge through words and instruments. Works would redescribe the relation of humans and nature, thus fulfilling "great prerogative of Mankind."[2] We were not only meant to contemplate, but reclaim that ease with which the first humans had lived amongst nature. Hooke's apparently inexhaustible ingenuity and his broad scholarly learning; all the techniques and theories and stories he read in books and heard in the coffee houses, workshops, and colleges of Restoration London; were funnelled into the task of making the human perspective of nature unnecessary – precisely because it was human nature to do so. It was an important conceptual move: the creation of an evenly illuminated world, not viewed from the point of view of humans, but made understandable for humans.

2 Hooke, *Micrographia*, sig. A1r.

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Appendix: "The Uses and advantage of Microscopes"

The following is a transcription of a manuscript kept in the Royal Society Archives, Classified Papers 20/84. It was a lecture delivered by Hooke at a meeting of the Royal Society on 29 November 1693. The first half is praise for the microscope, and the second is a review of the then recently published *Micrographia curiosa* of Filippo Bonanni.

The manuscript has been heavily edited by another hand. Likely it was prepared for publication by one of Hooke's posthumous editors, Richard Waller or William Derham, though it appears in neither of their volumes of his works. Derham did include a tract entitled 'Mr. Waller's Observations upon Dr. Hook's Discourses, concerning Telescopes and Microscopes,' which, despite the differences in the title, is obviously Waller's notes on the lecture below.[1] It is heavily truncated and focuses mostly on Hooke's opinions of Bonanni, missing, I think, a good deal of the interest of Hooke's lecture.

My guess, based on the editorial marks on this and other manuscripts, is that Derham picked over the manuscript to prepare it for publication, but found Waller's observations on the lecture and published them instead.

What follows is a semi-diplomatic transcription. I have silently followed any corrections Hooke himself made, but have indicated those made in the second pen. Derham's/Waller's changes are marked with <chevrons>, and those words he deleted or replaced are footnoted. Uncertain words are marked [thus?]. The second pen has has underlined several words and passages. I take this to instruct the printers to italicise these words and I have followed this instruction, so all italics are Derham's/Waller's. All parentheses are Hooke's. The large paragraph on ff. 2-3 in {braces} is entirely crossed out by the second pen in the manuscript.

1 Hooke, *Philosophical Experiments and Observations*, 270.

[f. 1]

<The uses and advantage of Microscopes>

<Read before the Royall Society Nov. 29. 1693.>

Among the various methods of inquiring into the Latent and innermost Structure and composition of Bodys, that by the help of *Microscopes* has not been the least significant, but when we consider the nature of the informations it has and may yet afford, it may possibly appear to Deserve to be ranked even among the most Considerable, and that upon this account that it doth immediately inform the <sight>[2] of the true and naturall construction of the minuter and otherways wholy insensible constituent parts of bodys, discovering their forms & shapes and how they serve to make up the more gross & Sensible parts both by their texture and motions, which carryes the Inquirer soe much farther into the Latent and internall mechanism of Bodys, whilst they are yet intire and undisturbed in their Naturall State whereas the other ways of Examining of the Nature of Bodys, (as by fire or chymistry) the naturall constitution of the bodys to be examined is wholy vitiated and Destroyed, and torne all to pieces, and scarce soe much Left Intire as may Deserve the name of the [ruines?] of it, but ought Rather to be called the Rubbish and Corruption thereof, for that noe one part of the [construct?/compleat?] is Left Intire but every part is as it were ground to Dust and attomes by the Action of the fire or menstruum and not only soe but even those attoms of Dust are blended & compounded by other heterogeneous substances insinuated and mingled with them, that are properly parts of the Fire or *Menstruum* that Dissolved them. Now as this method of Dissecting and anatomising a body is a much more probable and <has> Experimentally proved a

2 Replaced: 'sense'

more effectuall way to Discover the construction make and use of the Constituent parts of animated bodys and the uses to which they are subservient, and as living Dissection, or inspections and Experiments & observations made whilst nature is yet acting, are more informing than by Destroying the Life of the animated body & beating it all to a mash in a morter with water or any other substance & then examining of the *Composition*: Soe the Discoverys to be made by the *microscope* are upon both those accounts to be preferrd before those other that I have named, for that <in> a multitude of such kind of observations as are to be made by the *Microscope* you may not only Discover the texture and fabricks of the parts by Dissecting or anatomising them, but you may with pleasure & admiration behold the wonderfull construction, motions, operations & uses of the parts whilst Nature is still & at peace undisturbed, and working in its Direct and Naturall course, without any such Dissecting and without any Dislocation of Parts or any alteration or Disturbing of the motions, or <the> effects thereof. This is a Prospect that is wholy due to the *microscope*, and is hardly to be found in all the visible *phenomena* to the Naked Eye, for that the texture and constitution of most animate bodys <as to the parts>[3] thereof that are visible, to the naked eye are of Bulk enough to make [f. 2] them opaque or not of transparency enough to Discover the internall make and motions thereof through them, whereas there are thousands of Objects that by the *microscope* may be found whose Skin, Rind or inclosing teguments <[4]> are Soe transparent as to admitt a free prospect for the sight to Discover through them the fabrick, figure, texture, <&> motion <[5]> thereof: for As most of the parts of animated bodys are *in minimis* transparent enough to permit a free passage for the light free enough to Discover pretty cleerly the differring shapes and lineaments of

3 Replaced: 'is but the part'
4 Deleted: illegible word.
5 Deleted: 'and effect'

the parts behind them, and the variety of the Refraction & reflection of Differing parts is sufficient to make a Sensible difference in that appearance where too many of them are not Confounded & blended together as in those Smaller fabricks of animalls & vegetables, visible only by the assistance of the microscope. Soe in most others that are Discoverable by the bare eye, there is soe great a masse of such transparent <particles>[6] joyned together that those varietys of Refractions and Reflections <[7]> blended all together doe confound each other & by that means they are made big enough to be visible to the Eye they appear opaque and as it were in a fogg or cloude. Of these kinds of Discoverys I have given Severall Specimens in my *Micrography*, as in the Gnat, Mite, Louse, and some others, but had not then oportunity of instancing or Relating all the Severall observations I had made, my Designe in that being rather to Show in what variety of Subjects <[8]> Discoverys might be advantagiously made by ye help of microscopes, & other <optical glasses>,[9] by exhibiting some one or other instance thereof, then to persist in prosecuting any one Species of all those varietys. That designe indeed as it would Require much time and Labour, soe if it were well performed would not want its benefit for the explaining the progresses and operations of Nature and would prove as instructive a piece of Naturall history as any yet extant, and possibly for some uses much more than any other that has yet been published as to exhibit the Structure fabrick and Contexture of animated bodies. for that most of the History we have either of Plants or animalls give us only a superficiall and outward Description of their visible shapes and of the more grosse appearances of them, But tell us not the inwards Fabrick operations vertues & uses of their parts, And even there where anatomy has been applied for that Purpose, we are gone noe farther then to the forme & make of

6 Replaced: 'parts'
7 Deleted: 'are'
8 Deleted: 'the'
9 Replaced: scarcely legible, perhaps 'optick glasses'

the greater constituent parts such as are big enough to be visible to the Eye & tractable to the hand, But all the organs that are Lesse then such a Bulk they remain in their Primitive Obscurity and are only the Objects of Conjecture and imagination. {Now how wide such conjectures to [be probably?] from the truth of the thing under consideration may be conceived from this Similitude. If to a wild Indian that had never heard of or seen clock watch or wheel one should Describe or shew him a watch inclosed in a Leather case of the bignesse and shape of a small [turnep?] and tell him that this did keep a certain account of the time and did divide all the time from noon to noon into 24 equall parts or hours and at every hours end tell by soe many distinct sounds which hour it then was, he would certainly conclude that there was some very cunning creature included [inside a?] box. If then you should open the lid of [f. 3] the case and shew him the face of the watch and shew him the Diall plate where he might see the Diall Ring and the hand pointing to the Divisions of the Day, he would then understand somewhat more of what the effects of the watch then what by seeing only the out case & hearing the noyse of the strokes on the Bell he did conceive, but still he would be apt to think some living thing was kept within the yet unopened part, for that he could hitherto see noe more then the Diall face and moving hand and hear the Pulse or beating of the Ballance and at the hours end the noyse & strokes of the clock part. Tis easy to conclud that his conjectures concerning the fabrick of the watch would be differing enough from what they realy were, if the watch should further be opend to him to see the wheels move & the Ballance beat and all the make of them as they are to be seen when the watch is opend he would still be at a Losse what twas that made these move, and would think that the spirit of the watch was either in the wheels or in the Barrell of y^e^ spring. And soe as he could farther & farther Discover the conceald parts he would more truly be informed of its excellent contrivances.}

Now how far such kinds of Discoverys may be made into the curious fabricks of plants and animalls tis not for me to Determine but it seems very probable that the Microscopes will show us many essentiall and constituent parts of which we had before noe imagination, some *specimens* of this kind I have formerly shewn, and Mr. Leuwenho<oek> has since prosecuted the Inquiry and made Divers considerable additions . Some others also have indeavourd to Doe somewt that way as *Cherubine* at *Paris* and *Grundelius* in *Germany* but have made but Little progresse either for the Improvement of *microscopes* or for New discoverys by the help of them.

That which Revived this Discourse [at Present?] is a new treatise Published in Latin by *Sigr Bonani*[10] the same that Published a book of the Descriptions of the shells of Fishes: He calleth it *Micrographia Curiosa sive Rerum Minutissimarum Observationes qua ope microscopia Recognita et Expressa Describuntur.*[11] Wherein he indeavours to Revive the practise of it in *Italy* shewing it to be very useful for the Convincing of *Atheists* and to bring them to the Acknowledgement of *God* by contemplating the Wonderful works of his providence. But at the same time indeavours through his whole Discourse to prove Spontaneous Generation, which seems to have a contrary tendency. He seems to have perused most of the authours who have written any thing considerable concerning *microscopes* and Microscopicall Observations, and upon the whole has given the Result of his own Sentiments, first concerning the instrument it self Describing which kind he doth most approve of & which he made use of for his own observations. and therein he Describes which way he thinks best for grinding of Glasses to a true figure which he Delivers in a Cypher & enigmatically in 3 Directions or Rules which I have Decyphered read thus. The tools are to be made of Brasse or tin to grinde the glasses of their true formes, which

10 Filippo Bonanni, 1638-1725.

11 *Micrographia Curiosa, or: observations of minute things recognised and described with the help of the microscope* (1691).

tools or Dishes must be <of> a Due form to procure which he says care must be had *ut non volve ampla Sint sed Lentis faciendae ita commensurentur, ut Lens fere triplicem diametri partionem occupet*. That is the dish must be 3ce the Diameter of the glasse. Next the glasse must be ground to its figure in a tool or Dish of a Little bigger Sphere then perfected in the Lesser, which is thus performed. *Utra manu simul concurrente ita ut radente vitro scutellam [&?] ducurrat, Leva autem Scutellam is vitro adaptet, altera obsecundante alteri*. Both hands must be imployed the <right>[12] to hold the glasse and move it in the Dish and the Other hand to adapt the Dish to the glass and soe both to Move them true one in the other. When by this means it be ground to its true figure [f. 4] then it remains only to be polished and of all the ways for doing this he preferrs that by paper stuck fast with glue in the tool or dish in which it was last ground & by spreading upon that paper the fine powder of tripoly, and thereon to work the glasse till it has acquird a Due polish. Which you may the better perform, *Si instrumento tornatili utaris quod beneficio Rota majoris velociter circum & satur*. That is if ye tool or Dish be fixt to a mandrill and that be made to run Swift Round by a larger either foot or hand wheel. Both which ways I have seen commonly made use of here for <[13]> above 35 years since. And also a better way which is by a reciprocating motion: both which ways our workmen here very well know and commonly practise yet I am apt to think the Last polish from the Bare tool without the Paper to be the more exact, at least by Severall tryalls I have soe found it for object glasses. But for the eye glasses I judge <[14]> the Polish by tripoly or paper as he prescribes to be <sufficiently exact.>

The microscope he prescribes has too much apparatus and clutter and yet is wanting of many accommodations for examining or as it were handling & turning the Object

12 Replaced: 'left'
13 Deleted: 'much'
14 Deleted: 'sufficiently exact'

into all postures & for all lights, and therefore I shall not spend time in the Description of it. Nor shall I repeat here the names of the multitude of all the authors which he has mentioned who have been spoken of this way of making microscopes or the Descriptions of Some kinds of them: but in short to note that each of them is referrable either to the simple or the Compounded form, the Simple is by one glasse only but the compound by 2, 3, 4, 5 or more glasses, but still the more the worse, however he thinks every kind some ways or other usefull: concerning that of *Griendelius* published in 1687[15] which that author would have the world so believe that it exceeded all that had been ever made in England France Italy or Holland, this author upon explaining it is quite of a contrary opinion and thinks it much inferior to them which I also was before Sufficiently Satisfied of when I Read the Said *Griendelius* his Description of it. But this Authour seems Most to approve that which I have Described in my micrography. *Omnes fere expertum esse sine fuco Mendacis affirmato: nec ulla plene satisfactum Singula enim vitio aliquo laborabant nullam abunde commodam [iuvari?] ad observationes, [profectionis?] si oculo attente respeciente, manu delineare vellet quicquid observabatur. Inter omnes utiliorem modum existimavi quo suas observationes fecit A Hookius &c.* however he has made some additions to it for the fixing it more steadily to observe the object whilst it is in drawing which I conceive may be too troublesome & yet not sufficient for all purposes.

The instances he has mentioned to have observed are [many?] taken out of other authours upon which he has added his own remarks. But he excuseth his inability for Delineating them soe well as he could see them however he has copyed Severall of those I have Described in my micrography & some also out of others those of mine are the gnat worm in both formes, the foot of the fly and the wing as also the eyes the sting of the bee, the louse and the flea, the stinging points of nettles and the

15 Grindelius, *Micrographia nova*

scales of fishes. and he has both to those and all his other added his own animadversion among which there are severall very curious. But it would be too Long to mention them at this time, and much more to adde my objections to some of them, which I may have a more proper occasion to doe in an other Discourse: I shall at present only shew the figure of the stings or thornes of the prickly pare or indian figge which I mentioned before 3 weeks since when the plant itself was here produced. The Brown tufts on that prickly Pare I found to consist of a great number of very Small & Sharp pointed thorns or needles being abundantly Smaller then the finest needells I ever saw. These thornes being soe very small soe sharp and yet soe stiffe do easily peirce the Skin of whoever toucheth them, and which makes them the more troublesome they being all over barbed with thornes like a bramble almost or a bee's sting they stick to the flesh & cannot be easily gott out when they are once enterd.

Figure A1: The thorn of a prickly pear. From Hooke, *Philosophical Experiments and Observations*, 272. Derham notes that Hooke "gives a Microscopical Figure" which may well be this, but it is no longer with the lecture manuscript.