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The Prophet and the Pendulum: Sensational Science and Audiovisual Phantasmagoria Around 1848

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Abstract
During the French Second Republic—the volatile period between the 1848 Revolution and Louis-Napoléon Bonaparte's 1851 coup d'état—two striking performances fired the imaginations of Parisian audiences. The first, in 1849, was a return: after more than a decade, the master of the Parisian grand opera, Giacomo Meyerbeer, launched Le prophète, whose complex instrumentation and astounding visuals—including the unprecedented use of electric lighting—surpassed even his own previous innovations in sound and vision. The second, in 1851, was a debut: the installation of Foucault's pendulum in the Panthéon. The installation marked the first public exposure of one of the most celebrated demonstrations in the history of science. A heavy copper ball suspended from the former cathedral's copula, once set in motion, swung in a plane that slowly traced a circle on the marble floor, demonstrating the rotation of the earth.

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Giacomo Meyerbeer. *Robert le diable,* 1831. The nuns' ballet. Meyerbeer's synesthetic cocktail debuts at the Paris Opera. Bibliothèque Nationale de France.

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JOHN TRESCH

Nothing is more wonderful, nothing more fantastic than actual life.
—E.T.A. Hoffmann, "The Sand-Man" (1816)

The Fantastic and the Positive

During the French Second Republic—the volatile period between the 1848 Revolution and Louis-Napoléon Bonaparte's 1851 coup d'état—two striking performances fired the imaginations of Parisian audiences. The first, in 1849, was a return: after more than a decade, the master of the Parisian grand opera, Giacomo Meyerbeer, launched *Le prophète*, whose complex instrumentation and astounding visuals—including the unprecedented use of electric lighting—surpassed even his own previous innovations in sound and vision. The second, in 1851, was a debut: the installation of Foucault's pendulum in the Panthéon. The installation marked the first public exposure of one of the most celebrated demonstrations in the history of science. A heavy copper ball suspended from the former cathedral's copula, once set in motion, swung in a plane that slowly traced a circle on the marble floor, demonstrating the rotation of the earth.

In terms of their aim and meaning, these performances might seem polar opposites. Opera aficionados have seen *Le prophète* as the nadir of midcentury bad taste, demanding correction by an idealist conception of music. Grand opera in its entirety has been seen as mass-produced phantasmagoria, mechanically produced illusion presaging the commercial deceptions of the society of the spectacle.[1] The pendulum, on the contrary, is celebrated as the ascent of truth and reason over falsity and superstition. A thread connected the two events, however: the technical prowess of Léon Foucault. This experimenter, physicist, and science reporter designed, installed, and operated not only his namesake pendulum but also the self-regulating electric arc lamp that helped make

Le prophète a dazzling success.

These performances align with two important developments from the second quarter of the nineteenth century that likewise staked out opposite epistemic poles. On one hand, Meyerbeer's operas employed elements of the genre of the fantastic—launched by the translations of E.T.A. Hoffmann's tales into French in 1824—and its depictions of wondrous experiences defying the laws of nature. The staging of Foucault's pendulum, on the other hand, resonates with the rise of positivism. Systematically presented by Auguste Comte, who argued for the social importance of popular science and the exemplary status of astronomy, positivism placed its faith only in sensory observations and the relations among them. While the fantastic, seen as a decadent outgrowth of romanticism, explored the imagination and looked backward toward supernatural beliefs, positivism rejected all metaphysics and faith; it fixated on empirical proof and technical progress.

Yet as with the versatile Foucault, these movements, though distant, intersected at various levels. Comte's positivism was part of the efflorescence of utopian socialism whose outlandish visions of progress were repeatedly mocked by Karl Marx as "fantastic."[2] More fundamentally, the positive sciences and the fantastic arts were considered to be linked in a dialectic of doubt and certainty. A review of the 1832 ballet *Le sylphide* enlarged on this point:

> The positive sciences have made too much headway today for one to still concern oneself with those that are purely conjectural. If ever one wanted *reality*, it is assuredly in our century. We even want too much of it, because this pushes men toward general skepticism after which they do not believe what they see and only put stock in what they can grasp. At bottom, they say, this philosophy is as good as any other! And in spite of this, there is a taste, or rather a vogue for the *fantastic*, which, for a start, has also been timely, thanks to recondite *romantic* writings, where, in the process of looking for the *truth*, one puts everything in question, where in running after *that which is*, one encounters, by a singular piece of bad luck, only *that which is not*.[3]

The critic sees positivism and the fantastic as sharing a restless hunger for reality that is bound up with skepticism. Science's desire for certainty puts everything—even the testimony of the eyes—into question. At the same time, romanticism's pursuit of truth in the least likely of places (as in its scenography of remote mountains, exotic lands, imaginary landscapes, and childhood) leads it to the impossible encounters of the fantastic.

The fantastic and the positive traced the same journey in opposite directions. Fantastic tales have been defined by a moment of hesitation in which a protagonist—and the reader—wavers before an event that seems to violate the laws of ordinary reality. To produce this strangeness, however, mastery of the conventional techniques of realism is required; only a well-established, predictable world can be effectively thrown into doubt. This template was closely followed by Hoffmann's French imitators—Théophile Gautier, Alexandre Dumas père, Gérard de Nerval—with scenes in which material objects came to life and ordinary reality was shattered by the intrusion of supernatural, past, or imaginary worlds. This dialectic was enacted across the oeuvre of Balzac, a pioneer of both realist and visionary fiction.[4] Fantastic visual and musical arts produced similar perceptual displacements: familiar images or melodies gradually or suddenly metamorphosed into alien scenes and soundscapes.

In contrast, in the *Course of Positive Philosophy*, Comte contributed to a long-standing narrative in which surprise was the starting point for a movement ending in knowledge. Using the language of biological necessity, Comte described the "fundamental need that our intelligence experiences to know the laws of phenomena":

> To feel how imperious and profound is this need, it is enough to think for an instant of the physiological effects of *astonishment*, and to consider that the most terrible sensation we can experience is that which is produced each time that a phenomenon seems to occur in contradiction to the natural laws that are familiar to us.[5]

Comte's *Course* described the progress of humanity through a series of unexpected phenomena that led to the formulation of natural laws. The system of positive sciences was a fortress against the phenomenological and physiological assault of wonder. Inverting the order traced by the fantastic, in the sciences certainty and predictability followed astonishment.

Both positivism and the fantastic were also deeply invested in reflection upon and manipulation of sensation—or the *aesthetic*, to return to this word's original meaning. Sensation could offer indubitable proof; it could also overwhelm and confound reason. Painters, stage designers, authors, and composers produced distorted perceptions and lifelike hallucinations with new instruments and technical assemblages. At the same time, this was the period in the sciences in which what Gaston Bachelard called *phénoménotechniques* began taking shape as a distinctive mode of knowledge.[6] Physicists and chemists designed apparatuses to produce novel effects that were subsequently brought into theoretical relation;

for example, Augustin Fresnel's lines of diffraction, the interactions between electric and magnetic wires demonstrated by Hans Christian Ørsted and André-Marie Ampère, and François Arago's disk (a spinning copper plate that made a magnetized needle move). The thinking of these physicists was shaped by the program of applied physical science at the École Polytechnique. Comte's thought was similarly shaped. He defined science as the production and artificial arrangement of phenomena: "Whether it is a question of the slightest or the most sublime effects . . . we cannot truly know anything but the diverse mutual connections that belong to [the] realization [of observed phenomena], without ever penetrating the mystery of their production."[7] Through the coordination of regularly observed or produced phenomena, a sufficiently reliable "spectacle" of the world could be assembled.[8]

Most examinations of the scientific and technical underpinnings of nineteenth-century spectacle have focused on the second half of the century, beginning with the Great Exhibit of 1851 in London; they have also concentrated on visual culture.[9] Yet, major components of these spectacles were already well established by the 1840s in Paris, and the most "spectacular" public performances of the period addressed not just the eye but the ear with sound, speech, and music, creating immersive, fully embodied, and shared experiences. These were *audio-visual* phantasmagoria, performances meant to generate thrills and perceptual disorientations by overwhelming a combination of the senses. Unlike the meaning usually attributed to the term *phantasmagoria*, however, the experiences I have in mind did not aim exclusively at sensory deception.[10] Some were presented as entertainment and playful illusion; others, using many of the same techniques, personnel, and spaces, and relying on the same theories of perception, aimed at conveying truths about nature. This essay explores the common ground—technical, social, and epistemological—between these seemingly opposed performances.

In sounding the subterranean links between the positive sciences and fantastic mass spectacle, four features can be discerned. A new technological regime was coming into existence, one founded on the measurement and manipulation of the dynamic force and protean effects of electricity, light, and heat. Simultaneously, epistemological discourses appeared that theorized the contribution of human sense organs and faculties to the experience of both the natural world and artistic creations; the result was a conception of human perception as a form of hallucination. Further, new architectural spaces were built for larger and larger audiences with a concern for maximizing both auditory and visual effects. Finally, these spaces hosted new kinds of collective events, including, notably, both

grand opera and mass-scale performances of popular science. By following the connections among these events, as well as the oscillations of their meanings and valences, we see how novel techniques formed the background for experiences that were by turn, and often simultaneously, wondrous and factual, fantastic and "positive."

Diorama, Panoramic Orchestra, and Opera of Attractions

Although the fantastic arts frequently aimed at the production of illusions and hallucinations, the sciences were never far away. The *Fantasmagoria*—which Étienne-Gaspard Robert (stage name Robertson) displayed in the first decade of the eighteenth century—was staged in Paris in two rooms of an abandoned convent. In the second, darkened room, to the eerie sound of the glass harmonica, wavering images of ghosts and deceased tyrants veered toward and away from the audience. Before this part of the show, however, visitors gathered in a well-lit room stocked with informative displays of electric machines, Leyden jars, and voltaic batteries.[11] Likewise, the mass spectacle of the panorama borrowed from the perspectives of geophysics, the sciences of mountains and weather, and scientists' search for a unifying vantage point. About the panorama, Jacques-Louis David told his students, "Truly, sirs, it is here that you must come to study nature."[12] Just as the *Fantasmagoria* offered both illusion and enlightenment, the panorama was an artifice that evoked and at the same time made observable the mechanics of natural perception.[13]

Louis Daguerre apprenticed with the panorama painter Pierre Prévost before he invented the diorama. More than just a new kind of painting, the diorama was an immersive, hallucinatory experience housed in a specially made building that allowed an audience to gather in a darkened room watching a lighted screen, transparent and opaque at various points, slowly transform itself from night to day, from winter to summer, often accompanied by music and other sound effects. The building itself had moving parts: the viewing platform rotated to bring visitors face to face with two and sometimes three distinct views. The most striking of these were a transformation of a scene in the Alps, complete with yodeling maidens and a live, braying goat, and the midnight mass, in which an empty, day-lit cathedral gradually darkened, grew bright with candles, and filled with worshipers for a mass by Haydn. These uncanny transformations were accomplished through continuous changes in the angle, color, and intensity of lighting, with paint of various degrees of transparency applied to both sides of a silk canvas such that the change in the color and angles of the light brought out different aspects of the image. In a pamphlet published with reports by

Léon Foucault. Self-regulating electric lamp first used to create the photographs in Alfred Donné and Léon Foucault, *Cours de microscopie*, later used for Meyerbeer's *Le prophète*.

the astronomer François Arago and the chemist Joseph Louis Gay-Lussac, Daguerre wrote,

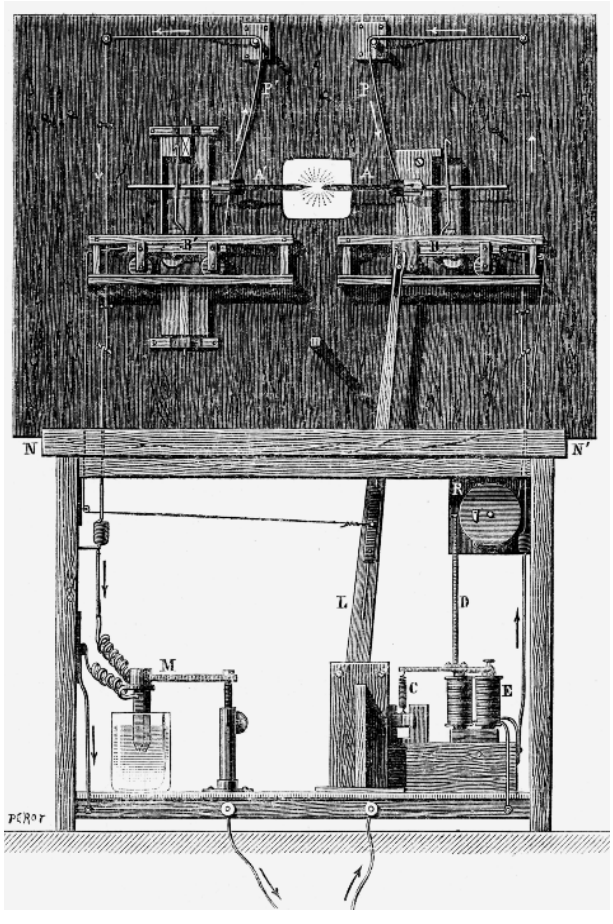
> All of the substances employed by the painter are uncolored; they merely have the property of reflecting such or such ray of light that carries in itself all the colors. The more that these substances are pure, the more they reflect simple colors, but never, however, in an absolute manner, which in any case, is not necessary to bring about the effects of nature.[14]

Presented as an example of up-to-date optical science, the diorama produced an "effect of nature" that lay somewhere between the tableau, the display system, and the eye of the viewer.[15]

The technical production of hallucinations was just as eagerly pursued in music. Hector Berlioz's *Symphonie fantastique*'s nonstandard harmonies, jarring orchestration, and surprising effects were meant to portray—and perhaps reproduce—the effects of opium. First performed in 1830, it exemplified "program music": the work's meaning emerged in a dialogue between the music and a written narrative telling of a jealous lover who witnesses his own decapitation and attends a witches' Sabbath, a passage in which the traditional Dies Irae of the Catholic Mass is transformed into a freakish death march.

The symphony's novel soundscape was made possible by new instruments. Berlioz planned to include octabasses—oversize cellos designed by the instrument maker Jean-Baptiste Vuillaume. Berlioz also worked with Adolphe Sax, whose innovations included the saxophone; improvements on the ophicleide, a prototuba; and other new brasses. These technical innovations increased the range of the orchestra and added unprecedented musical "colors": Berlioz's medium was as much sound quality or "timbre" as it was pitch and rhythm. His *Treatise of Instrumentation* detailed the expressive properties of each instrument of the orchestra—their distinct "personalities," the settings in which their use was appropriate, the emotions and colors they suggested. The treatise presented the orchestra itself as a giant composite instrument.[16] In the fourth section of the *Symphonie fantastique*, "The March to the Scaffold," rather than give distinct lines of melody to a single instrument, Berlioz distributed a single melodic line across a number of instruments. In the age of virtuoso performers such as Niccolò Paganini, Frédéric Chopin, and Franz Liszt, Berlioz presented himself as the virtuoso composer-conductor, playing his orchestra like a kind of giant piano.

Berlioz saw music as a heterogeneous assemblage, *all* of whose aspects had to be controlled: copyists, players, conductor, the decorator, the furnisher, and even



"the architects who construct the rooms."[17] More than any of his contemporaries, Berlioz managed the orchestral *space*:

> The place occupied by the musicians, their disposition on the horizontal plane or on the inclined plane, in an enclosure closed on three sides, or in the very center of a room, with reflectors formed by hard bodies capable of transmitting sound or soft bodies which absorb it and break the vibrations brought nearer or farther from the players, all have a great importance.[18]

To obtain the maximum "acoustic return," his *Requiem* included twice the standard number of wind instruments and a giant chorus. He scaled up the strings, added ten timpanists, and set four groups of brass instruments in the corners of the performance space, thereby "spatializing" the sound so that "the fanfare seems to radiate out from the center of the orchestra."[19] Berlioz's interest in innovations in musical technology was constant and made him susceptible to the industrial religion of the Saint-Simonians in the early 1830s. He composed *The Song of the Railroads* (*Le chant des chemins de fer*), and at the Exposition of 1855 (the "Festival of Industry") he staged his *Te Deum* with over a thousand performers.[20] He also proposed at one point using an electric telegraph to keep players in time. As Alison Winter has suggested in her discussion of depictions of Berlioz and Wagner as dueling mesmerizers, the fantastic phenomena of animal magnetism provided a context for understanding both the power of the conductor—over players and audiences—and the rise of telegraphy, with its implication of invisible command across vast distances.[21] Berlioz's uncanny effects aligned him with the fantastic technique of the diorama, and he staged his symphonies at the gargantuan scale of the panoramas. Heinrich Heine, the poet, critic, and Saint-Simonian sympathizer, compared Berlioz's music to the panoramic landscapes of the painter John Martin. Both conveyed an "antediluvian" impression and possessed

> the same bold feeling for the prodigious, for the excessive, for material immensity. With one, the striking effects of shadow and light, with the other

Giacomo Meyerbeer. *Le prophète*, 1849. Sketch of gigantic stage set, Act IV, Tableau 2. Bibliothèque Nationale de France.

> fiery instrumentation; with one little melody, with the other little color, with both of them at times the absence of beauty and not the slightest naiveté.[22]

Like Martin's giant paintings, Berlioz's orchestra opened perspectives upon the sublime immensity of prehistory, but in an auditory idiom. At the same time it testified to the technical mastery and the demiurgic powers of the industrial age.

Such massive auditory and visual effects were fused in Parisian grand opera, defined in its modern form by Giacomo Meyerbeer's *Robert le diable* of 1831. *Robert* was to grand opera what Michael Jackson's *Thriller* was to MTV: by taking phenomenal technologies to unprecedented heights, it showed subsequent artists what a new audiovisual medium could achieve. The plot of the opera follows the threats to the soul of the half-demon Robert: his father, a demon who has passed himself off as a friend, aims to bring him back to hell, thwarting his virtuous marriage plans and leading him into corruption and the use of evil magic. The interventions of Robert's mother and his innocent fiancée, Alice, as well as heavenly assistance—signaled by Meyerbeer's unprecedented use of a church organ—defeat the demon's plans. The work's critical reception focused on Meyerbeer's sonic and visual innovations, commenting on his new harmonies, instruments, and orchestral combinations as well as his sound effects, including a demon chorus placed beneath the stage and singing eerily through resonating tubes. Hundreds of lavish costumes were on display, as were several stunning set changes employing illusions of depth and color inspired by Daguerre. "The ruins of the third act," wrote *Le Figaro*, "are as perfect in effect and scheme as one of the ingenious Dioramas of M. Daguerre, as the Panorama of M. Langlois; they are of a delicious color; the impression that they produce is completely poetic."[23] For lighting, new gas lamps covered in foil cast unsettling shadows during scenes with Robert's demon father. During a dance of ghosts, resin dust and moss spores thrown over flames produced exploding fireballs. In the most celebrated scene, a ballet set in the graveyard of a convent, fiendish nuns were resurrected and performed a lascivious dance of seduction in skin-colored costumes on a moving platform.

Robert was staged, imitated, and discussed for the next fifteen years. Balzac mentioned it frequently, and his short story "Gambara" contains extended reflections on its innovations. The story tells of a musician, Gambara, who composes a work so transcendent that it can be played only on the gigantic contraption he has built, a *panharmonicon* that reproduces all the sounds of an orchestra, as well as human voices. The machine emits pure cacophony except when drink has lifted Gambara to a rare state of exaltation. The tale concludes with the composer's

pages-long exegesis of Meyerbeer's *Robert*. Though the work depicts a cosmic struggle between good and evil, light and dark, order and chaos, Gambara—who conducts scientific experiments on the connections between sound, light, the ether, life, and thought, much like the protagonist of Balzac's *The Search for the Absolute*—makes clear that the plot's spiritual battle can be grasped only thanks to the detail, expense, and technical care that went into its sets, lighting, instrumental textures, and orchestration. Gambara sees the opera as a kind of Eucharist, in which the carefully controlled use of materials produces a collective experience of the divine. For Balzac, *Robert le diable* showed that contemporary music—like modern science, as suggested by *The Search for the Absolute*, and like his own literary experiments—was unavoidably concerned with the mastery of technologies that, in combination, produced lifelike and even supernatural effects.[24]

To understand the appeal of *Robert* and contemporary works, we need to look beyond the music and the libretti and consider these works as part of what we might call, following film historian Tom Gunning, an "opera of attractions." In discussing the earliest motion pictures, Gunning has written of a "cinema of attractions" focused not on narrative and characterization but on optical tricks, illusions of motion, novelties, and exhibitionism. Early short films were not taking abortive steps toward the conventions of narrative cinema; instead, they aimed to show something unseen, to produce an effect of shock or pleasure, "a unique event, whether fictional or documentary, that is of interest in itself." Aspects of the cinema of attractions continue in modern cinema, but they have gone "underground, both into certain avant-garde practices and as a component of narrative films," as in musicals and effects-heavy blockbusters.[25]

In adapting Gunning's term to performances such as *Robert le diable*, my claim is not that works of Parisian grand opera eschewed traditional narrative or character development; these works *were* judged for their plot and characterizations. Yet neither these traditional dramatic concerns nor the music alone were sufficient sparks for the explosive success of the genre. Audiences flocked to the opera

for its opulent, abundant, and shockingly mobile sights and sounds, seeking surprise, thrills, and gratuitous pleasure. As much as the plot and music, these attractions were the object of its creators' obsessions and the focus of its critical reception.[26] Opera provided audiences—aristocratic and bourgeois—with a "common emotional bond" and a "shared dream." Through the careful manipulation of light and sound within a strictly controlled environment, participants shared a technically produced, multisensory hallucination.[27]

Scientific Light and Magic

These fantastic audiovisual spectacles were improved with the assistance of scientists. Psychologists and epistemologists theorized their effects to better understand the processes of perception. Above all, researchers in physics and physiology helped construct the sensory environment that new spectacles of popular science would also inhabit. Although popular science aimed not at fantastic illusions but scientific truth, the same mechanics of perception—both the external construction of new apparatuses and the understanding of internal processes of those who encountered them—underwrote both kinds of performance.

Scientific investigation of optics and acoustics in this period was extensive, as was inquiry into the relation between ostensibly vibratory phenomena of light and sound. Ernst Chladni had drawn a bow across the edge of plates of metal covered with sand to show how different pitches produced different geometrical figures. He demonstrated these visualizations of sound throughout Europe, launching a field of research pursued in Copenhagen by the *Naturphilosophe* Ørsted, in Berlin by Wilhelm Weber, and in Paris by Félix Savart. All three also conducted research on electricity and magnetism, and Weber was a pioneer in telegraphy. Savart investigated the propagation of sound waves through different media and their effects on solid membranes. He created experiments to study the components of the human voice and constructed an artificial ear to simulate auditory perception and also worked with Vuillaume to design new instruments—including a sharp-edged, trapezoidal violin—that applied his knowledge of acoustics.[28]

Eugène Chevreul, the chemist in charge of dyeing operations at the Gobelins tapestry manufactory in Paris, oversaw comparable collaborations between craft workers and scientists. His book, *The Laws of Contrast of Color*, explored the effects of juxtaposing one color with another both spatially and temporally. He detailed how certain colors melt together into a third at a distance, described how colors near in tone will heighten their difference when seen together, and pro-

vided a rationale of afterimages. A large portion of the book was concerned with practical applications: the effect of colored lights on colors, the effects of size and distance, the means of producing a third color by weaving two others together. Chevreul also considered painting, including "the difference there is between a colored object and the imitation that the painter makes of it, when the spectator chooses another point of view than his own."[29] The work's central message was that color had to be understood as an effect of both technology and perception: a single color might have a completely different appearance depending on its lighting; the other colors displayed before, after, or next to it; and the location of the spectator.

The active role of psychological processes in shaping perceptions was a central theme of the philosopher Maine de Biran, a protophenomenologist who had a decisive impact on thinkers of the 1820s and 30s including Ampère, Victor Cousin, and Félix Ravaisson and later influenced Henri Bergson and Maurice Merleau-Ponty. His *On the Influence of Habit* analyzed the processes by which discrete elements of light and sound (as well as sense givens of taste, smell, and touch) are synthesized through the "internal play" of rapid, barely noticeable organic movements and judgments into recognizable and familiar forms. Discussing sight, he wrote,

> As habit renders judgments, like movements, always more prompt and less noticeable, the activity of the individual ends by transporting itself entirely into the exterior object; color, figure, form, distance, all accumulate on the solid kernel, and melt together in an impression: an indivisible *sensation* which the eye seems to receive *naturally* in opening itself to the light.[30]

Repetition trains us to add our own judgments and motions to exterior objects—in fact to *transport our own activity into them*; we live in a world shaped by our routines of perceiving and judging, most of which escape conscious control. In hearing, likewise, he notes the role of habit and expectation in shaping our perception of melody and harmony: "habit teaches us to distinguish first the successive terms . . . then to reunite them and to perceive clearly many of them together: it thus creates a harmony for the ear."[31] Maine pointed out the internal movements and operations, strengthened through repetition into habits, through which human beings actively construct their experience of the world and all of its parts.[32]

For Maine's interlocutor, the physicist Ampère, the perceiver's active role in perception became the basis for a theory of knowledge. We come to know the world, Ampère argued, through the resistance we encounter in exercising our

will, our muscles, and our senses. The regular relationships between points of resistance can be brought together to discover the physical laws of the external world. As a perfect complement to this epistemology, Ampère later described a new science, "*la Technesthétique*" in his *Essay on the Philosophy of Sciences*. This new field dealt with the "means by which man acts upon the intelligence or the will of his fellows" and the procedures for "recalling ideas, sentiments, passions, etc., and giving birth to new ones in the spectator of an art object, the hearer either of a piece of music or a speech, or, finally, in the reader."[33] While the root *techne* means art or craft in general, at the time that Ampère was writing the modern notion of "technology"—a distinct set of objects and production processes—was taking shape. In *technaesthetics* the calculating, reproducible, and mass-scale aspects of technology were recognized as essential to the arts—the symmetrical match to Ampère's view of perception as a physical, even technical construction of experience.

Thus, the active contribution of human physiology and external sensory technologies were recognized in the romantic era as constitutive of phenomena in both the arts and the sciences. These concerns also underwrote the development of performances of popular science. The quantity of scientific publications rose throughout this period.[34] Science books appeared in new public reading rooms and lending libraries. Newspapers began to report on politically charged debates at the Academy of Sciences about, for instance, animal magnetism and the changeability of species. The physician Alfred Donné wrote a weekly science column that occupied the bottom of the first page of the *Journal des débats*—the same feuilleton in the newspaper of record where serial novels were published to attract readers. In the 1840s Donné transferred the writing of the *feuilleton scientifique* to his assistant, Léon Foucault, whose articles took sides on scientific debates, urged new directions of research, and reported personal experiences. The emerging field of popular science also frequently reached its public in face-to-face settings, including the lecture halls of the Athenée, where Franz Gall spoke on phrenology and Comte preached the social mission of the sciences, and the Centre National des Arts et Métiers (CNAM), where the Association Polytechnique, whose teachers included Arago and Comte, offered public lectures on geometry and mechanics to workers.

Yet popular science of the 1830s and 1840s involved more than publications and speeches. In many of its instances it aimed, like music and the opera, to involve audiences in complete, fully embodied experiences, engaging the imagination and employing both the rhetoric and techniques of wonder.[35] For example, the National Expositions of the Products of Industry—which the English planners

of the Great Exhibit of 1851 sought to imitate and outdo—grew in this time under the guidance of CNAM statistician and engineer Charles Dupin. These displays of manufactured goods and the tools to make them—steam engines, printing presses, lathes, mills, borers, grinders, and scientific and musical instruments—were organized by types of industry, region, and maker, implying a natural order to the products of human art and science. At the same time, these collective festivals of labor, reason, and technology featured oddities from exotic locales, wondrous displays with electricity and light, prodigious machines, and musical performances.[36]

The drive for audiovisual spectacles of popular science was taken up most vividly by Alexander von Humboldt, the Prussian explorer who divided his time between Paris and Berlin, and by the republican astronomer François Arago. Humboldt's works tracked the flow of heat, magnetism, and light across the globe, and his visual tableaux, which displayed qualitative and quantitative features of various *milieux* (what we would now call ecosystems), were works of both art and science. Humboldt frequently quoted Goethe and Schiller on the aesthetic uplift provided by the contemplation of nature. He spoke of his geophysical instruments as "external organs" and as living beings that he coaxed into performing the symphony of the natural world.[37] A musical sensibility marked his works in various ways. For the first meeting of the *Versammlung* of German Investigators of Nature, Humboldt commissioned music by Mendelssohn and led sing-alongs.[38] He befriended both Meyerbeer and Berlioz, whose *Evenings at the Opera* includes a scene of a bored timpanist reading a copy of Humboldt's *Cosmos*. Through Humboldt, Berlioz offered his *Instrumentation Treatise* to the king of Prussia. Humboldt was also an aficionado of the panoramas. In *Cosmos* he wrote of the pedagogical utility of "theatrical illusions":

> In Barker's panorama, by the aid of Prevost and Daguerre, [such illusions] may be converted into a kind of substitute for wanderings in various climates. More may be effected in this way than by any kind of scene painting; and this partly because in a panorama, the spectator, enclosed as in a magic circle and withdrawn from all disturbing realities, may the more readily imagine himself surrounded on all sides by nature in another clime.

Humboldt also suggested that "large panoramic buildings containing a succession of such landscapes" be built in cities and opened to the public as "a powerful means of rendering the sublime grandeur of the creation more widely known and felt."[39] Like the romantic poets and philosophers that he and his linguist brother Wilhelm frequented in Prussia, Humboldt saw science and art as intimately

Foucault's pendulum at the Panthéon. *L'Illustration*, 5 April 1851. Courtesy University of Pennsylvania Rare Books and Manuscripts Library.

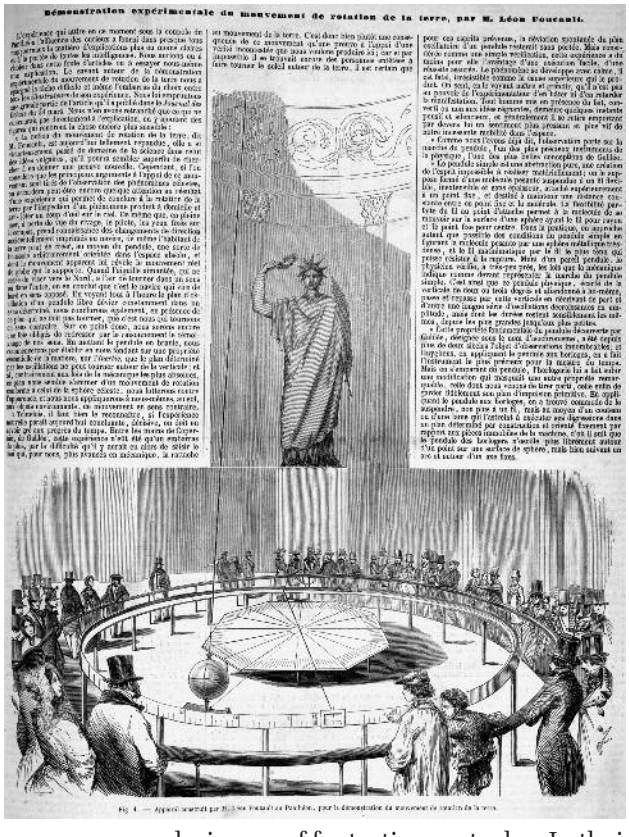
linked. Scientific work should not only instruct the viewer but bring about that transformation of the ordinary into the magical which poets saw as the goal of art. To do so, science would borrow the techniques of romantic spectacle.

Humboldt's friend Arago was director of the Observatory of Paris and "perpetual secretary" of the Academy of Sciences.[40] Arago's science was closely tied to popular audiovisual spectacles. His studies of light and optical instruments led him to secure a lifetime government pension for Daguerre and the estate of Joseph Nicéphore Niépce for their invention, the daguerreotype. In addition Arago assembled a team of scientists who measured the speed of sound by firing a cannon and noting the time at which an observer at a known distance visually signaled that the explosion had been heard. He encouraged science journalism, launched a campaign of participatory astronomy, and gave weekly lectures he called "Popular Astronomy," in a special auditorium he had built next to the observatory with large portraits of astronomical instruments lining the walls. A contemporary described him as an acoustic force at the academy: "His voice burst out like thunder and victorious arguments fell from his lips with a rain of sarcasm and crushing sentences. Often, at the end of one of these storms, there were eight or ten unfortunate academicians blasted by this thundering Jupiter of the Observatory."[41]

"Popular Astronomy" also featured topics central to the wider imaginings of the romantic age: multiple worlds, the technologies and deceptions of vision, the possibilities of animal magnetism. Many poems by Victor Hugo feature visions of outer space with rapid shifts of perspective and scale that echo those of Arago's lectures. Hugo also wrote a prose poem—*The Promontory of Dreams* (*Promontorium somnii*)—about the heavenly bodies he saw through Arago's telescope. Another of Hugo's poems, published in his collection of 1832, *Les feuilles d'automne*, echoed the aesthetic meteorology practiced at the observatory—with its fluid music "oscillating around the world" and its "harps of ether"—and inspired Liszt's influential Symphonic Poem No. 1, *Ce qu'on entend sur la montagne*.[42]

For both Humboldt and Arago, sight and sound, decor and acoustics, performance and sensation were intrinsic to the communication of knowledge. From within the heart of new scientific and technical networks—the global science of Humboldt and the physical, astronomical, and engineering projects for which Arago was the lightning rod—the dream took shape of bringing the sciences to the people, using the same immersive audiovisual techniques and the effects as the performances of the romantic stage.

We now have a firmer grip on the double-stranded rope that entwined the positive and the fantastic in the years before 1848. In one strand, scientists reflected


démonstration expérimentale du mouvement de rotation de la terre, par M. Léon Foucault.

and performed investigations upon the senses and their activity in order to secure the epistemological basis of knowledge. Yet, the more they learned about the sense organs and internal faculties, the more they came to realize how much "natural" perception was the product of the contributions of the observer, a largely self-generated hallucination synthesized from unruly sensations by rapid and habitual movements. The other strand came from the designers of fantastic spectacles. In their quest to produce strikingly realistic illusions and shared hallucinations, they made discoveries about the processes of perception and developed technologies that grew out of and led to discoveries about light, sound, and the natural processes of perception.[43]

In the person of Léon Foucault—author of the *feuilleton scientifique*, assistant to Arago, and publicist extraordinaire—these strands were combined.

"An Influence That Spreads Like Electricity . . . Making Hearts Palpitate"

Born in 1819, Foucault undertook studies of medicine in Paris, where he met the physician Donné. The two collaborated on the first atlas of microscopic daguerreotypes, featuring images of organic structure and bodily fluids.[44] Because of the lengthy exposure time of these early photographs, a challenge was to find a light source as bright as but more constant than the sun. Foucault used an arc lamp in which electrified filaments of carbon were touched together, generating a spark, then pulled apart, resulting in a glowing arc. As the carbon rods burnt down, however, the space between them grew, diminishing the intensity of the lamp. As a solution, Foucault created a self-regulating mechanism to maintain a constant gap: as the rods grew shorter, a system of triggers and springs drew them closer to each other.[45]

This steady, brilliant light made possible the production of remarkably sharp and detailed images. Donné and Foucault's atlas came to the attention of Arago, whose failing eyesight made him keen to find an assistant. He encouraged Foucault and his classmate Hippolyte Fizeau to take the first solar daguerreotype in 1845. He then put them to work on his plan to measure the speed of light, which depended on the unprecedented precision of an experimental setup that included a mirror spinning 800 times per second and powered by a small steam

engine.[46] Reflecting a beam passed through the teeth of diminutive gears over a small space many times, Foucault and Fizeau arrived at the most reliable measure of the speed of light yet. They were also able to show that light traveled faster through air than water, which Arago saw as support for the wave theory of light advanced by his colleague Fresnel. The extremely delicate and regular mechanism of this device also caught the attention of the precision-mad Berlioz, who wrote to Foucault asking for a meeting with the instrumentalist.[47] Foucault was summoned again to the concert hall after the 1848 Revolution.

Among the few successful reforms of the unstable Second Republic was the introduction of universal male suffrage, which backfired on the republicans in power—including Arago, who had become one of the heads of the provisional government—because it gave the presidency to a man whose name was synonymous with order, glory, and repression: Louis-Napoléon Bonaparte, the emperor's chronically conspiring and chronically exiled nephew. Against this background, Meyerbeer opened *Le prophète* in 1849. Its source was the takeover of the city of Münster in 1534 by the Anabaptist Jan van Leyden, who set up a theocracy and enforced collective ownership of wealth before being executed eighteen months later.[48] Meyerbeer's opera was seen to comment on its own moment, the aftermath of a modern uprising that aimed at the redistribution of power and wealth. The increasingly prevalent religious undercurrents of the social reform movements of the 1840s heightened the work's political implications. Indeed, one of its sources may have been an essay on the Münster rebellion by Jules Michelet, who frequently used the rhetoric of prophecy to decry current ills and foresee future improvements.

Meyerbeer's presentation of these events—with a script by Eugène Scribe—did not squarely take sides either for or against the insurgents. It showed its protagonist Jean at first as the dupe of a trio of Anabaptist conspirators who took advantage of his charisma and prophetic dreams, transforming him into a demagogical figurehead. As Jean came to believe their propaganda, however, he ruled despotically. Only confrontations with his devoted mother and soprano girlfriend brought him to contrition. Though Scribe has Jean perish in a fire along with the three Anabaptists, in the end he appears to be redeemed. Meyerbeer, friend of the liberal Humboldt, was read in the 1840s as a champion of social justice. Heine wrote that his music, in which masses of sound prevailed over independent lines of melody, presented the "sound of the masses."[49] The reading of Meyerbeer as musician of the people was again dominant in the 1870s, but in 1849 a number of critics saw the play instead as an indictment of the 1848 Revolution, especially the brutal June Days, allegorizing the Revolution as an uprising by the poor that risked veering into despotism.[50]

What all critics could agree upon, however, was that in the Parisian Opera's ever-escalating arms race of spectacular effects, *Le prophète* had outdone all rivals. The orchestration was as rich, dense, and full of reworked musical allusions and unstable contrasts as Meyerbeer's previous works, including the eerie transposition of liturgical music. Just as remarkable were its visual effects. The flames of hell were "a sublime horror"; "spectators shuddered and all looked behind them to see if the doors were open, if they could escape in time." Fantastic author and critic Théophile Gautier wrote, "Perhaps never has the art of stage decoration been taken farther: it is no longer painting, it is reality itself."[51] At the other end of the thermometer, critics raved about the fourth act's ice skating ballet, an illusion created by putting the chorus on roller skates.

Even more brilliant was the sunrise at the end of the third act: a simulated dawn produced by the self-regulating electric lamp invented and, for the first weeks of the performance, personally operated by Foucault. Having produced the first portrait of the sun drawn with its own light via the daguerreotype, Foucault created, by artificial means, an electric sun as blinding as the original. Its light filled the hall, "inundating the theater with a light so bright that the actors are reduced to shadows, something hitherto unknown on the stage." The scene was described as "a dazzling dawn with a sun, a veritable sun at which no one can look directly."[52] A device created for realist representation—Donné and Foucault's daguerreotype-microscopy atlas—was redeployed to produce a fantastic illusion.

Two years later, Foucault organized another grand spectacle, a further case of precision technology confronting a mass audience with cosmic forces. With Fizeau he had been trying to measure the effect of the ether on the earth's movement. He had observed that a bar held in a lathe, if struck, would vibrate in the same plane, whether or not the "chuck" holding the rod was spinning: the inertia of the vibrating rod was unhampered by any force. He suspected that this effect could be shown to be the same as that of a pendulum swinging in a fixed plane suspended above a rotating surface—for example, the earth. In January 1851, in the basement of his mother's house, he suspended a two-meter pendulum from a bracket he had designed to allow the wire to pivot in all directions. Setting it swinging, he watched as its plane of oscillation slowly shifted in a clockwise direction. This was the first visible demonstration of the earth's rotation.

He reported back to Arago, who gave him access to the much larger Meridian Hall of the observatory, where he repeated the demonstration with a pendulum eleven meters long. Journalists and scientists were invited in February 1851 "to come and watch the rotation of the earth." Word reached President Bonaparte, who had spent much of his time in prison reading up on Saint-Simonianism and

science and conducting electrical experiments. As Foucault wrote, "at lightning speed the President's high influence flashed to the uppermost rungs of the administration," and by mid-March the experiment had been moved to an even grander location, the Panthéon, with a wire sixty-seven meters long. The experiment was opened to the public and received immediate acclaim in the international press.[53]

An interesting aspect of this "experiment" was that it did not prove much. Although Foucault had offered a first "dynamical" or "internal" proof, no scientist in 1851 doubted that the earth rotated.[54] The experiment set loose a storm of mathematical explanations for Foucault's "effect," yet the greatest impact of the experiment came from the fact that it staged a direct, large-scale, and immediate experience of a central article of scientific faith. The Panthéon was an overdetermined choice of setting. Beyond the sheer height of its dome, it was located at one of the highest points in Paris, a stone's throw from the observatory. Its meaning has oscillated since its construction. Built as a church in the eighteenth century, it was transformed into a National Temple during the French Revolution; Napoléon made it a cathedral; in the July Monarchy, it was named a Temple of Glory (and given a new façade by David d'Angers); during the 1848 Revolution some of the bloodiest fighting of the June Days took place on the adjacent Rue Soufflot, and revolutionaries occupied the building; in the Second Republic it was renamed a Temple of Humanity.[55]

The choice of this state-owned temple for the pendulum has been seen as a rejoinder to the papal authorities who forced Galileo to deny the movement of the earth; it was also a continuation of Arago's republican scientific popularization, reaching an audience of many classes (images of the event show workers' caps next to bourgeois top hats). From this perspective, the pendulum appears as a state-sanctioned ritual affirming, after the violence of the revolution, the unity of the new republic under the power of reason—under science and technology. But the experiment was also a coup for Bonaparte, a president criticized equally in 1851 by monarchists and republicans. The performance did nothing to counteract what Arago's brother Étienne called "imperial fetishism." As Foucault explained in 1851 in the *Journal des débats*, "The plane of oscillation of the pendulum is not a material object. It does not belong to the support, or to the table, or to the circle. It belongs to space—to absolute space."[56] This immaterial and absolute space was made visible on such a grand scale only through the intervention of the president, who had written in *Napoleonic Ideas*, "The influence of a great human genius, similar to the influence of divinity, is a fluid that spreads like electricity, elating the imagination, making hearts palpitate, as it touches the soul before it

persuades the mind."[57] Bonaparte, whose empire, created by a coup d'état less than a year after the pendulum was hung, would rely on carefully controlled patriotic spectacle and theater, had every interest in associating his name with Foucault's demonstration of science and technology's power to *produce the absolute*—to harness, centralize, and make visible the order and grandeur of the cosmos.

This experiment did not offer a symphony of blaring saxophones, pounding timpani, sinister demon choruses, or haunting masses of sound. Nor did its audience greet the performance with thunderous applause and cheers—quite the contrary. Foucault described the pendulum's effect:

> The phenomenon develops calmly; it is fatal, irresistible. . . . One feels, in seeing it born and growing, that it is not in the power of the experimenter either to hasten or hinder the manifestation. Any man placed in the presence of this fact remains for some thoughtful and silent moments, and generally he pulls away, carrying with him a more pressing and livelier sentiment of our incessant mobility in space.[58]

If the machinic assemblage of the opera—composer, author, lights, instruments, actors, score, sets, costumes, house, publicity, audience—generated applause, the staging of Foucault's pendulum produced a striking *absence* of sound, a resonant silence. Pascal's words written in response to the shattering of the musical spheres of the heavens come to mind: "The eternal silence of those infinite spaces terrifies me." The pendulum was a wordless poem that justified the works of the universe to man. The experimenter crafted conditions so perfectly that a "manifestation" was produced that "it is not in the power of the experimenter either to hasten or hinder."[59] Human ingenuity opened the door to the more-than-human sublime—greeted, appropriately, with awed silence.

Wonder and the Order of Machines

The exhibition of Foucault's pendulum has been celebrated as "the triumph of science."[60] A similar interpretation seems to guide Umberto Eco in those scenes of his novel *Foucault's Pendulum* set in the Centre National des Arts et Métiers, where the pendulum has long been displayed. The colossal instrument's somber demonstration of the inhuman regularity of the cosmos served Eco as a foil for the delirious fantasies of characters clinging to magical hopes and imaginary conspiracies. Yet Eco's juxtaposition of mechanical common sense and fantastic superstition might be read against the grain of his deflationary fable. Returning the pendulum to its original context—one marked by radical technological meta-

morphoses, arts devoted to collective hallucination, and the rethinking of the importance of religion and fetishism in social life—we can see the pendulum as both a testament to universal law and as a fantastic performance. It possessed both "fairground" and instructive aspects, akin to Robertson's *Fantasmagoria*, the panorama, Daguerre's diorama, and Meyerbeer's opera. Set in a former church, this was also a machine for channeling cosmic forces into inert material objects, a collective sacrament through which an assembled mass was brought to witness transcendent powers. The audiovisual spectacles of the romantic age, whether of mass entertainment or popular science, helped forge a new secular culture that was nevertheless constantly shadowed by religious traditions and the power of fetishism.[61]

As suggested by the series of publications begun in 1851 by the popularizer Louis Figuier, *Les merveilles de la science*, the machines used by scientists were not simply the instruments of rationalization and routinization.[62] With the aid of technology, sublime effects could be produced with regularity. Technology, in its very power to actualize repetitions and stabilize effects, could be an agent of amazement.[63] To mix together two of the slogans with which Max Weber defined modernity—the routinization of charisma and the disenchantment of the world—this period discovered and deployed techniques that brought a *routinization of enchantment*. At the same time, it abounded in the spectacle of the *enchantment of routine*. Technical repetition and the spectacular projection of sublime, clocklike order were the basis of new experiences of wonder.[64]

Just as science's promoters have long given themselves the task of dispelling superstitions and shattering idols, for Karl Marx—living in Paris in the 1840s—criticism meant dispelling the phantasmagoria of ideology in the name of scientific truth.[65] Yet the audiovisual techniques of spectacular illusion were the close kin of the techniques used both to attain and to transmit the "triumphs of science." A similar convergence can be seen today in tools of analysis and projection that move between laboratories, science museums, video games, concert stadiums, and cinemas, and whose skillful and dazzling intensifications of sight and sound are the direct descendants—the avatars, if you will—of romantic-era technaesthetics. This commonality suggests the displacement, if not dissolution, of the line separating scientific truth from collective phantasmagoria. What these two central modes of collective experience in modernity share may be more pivotal than what divides them.

Notes

1. Benjamin and Adorno famously discussed Wagner's opera (the direct inheritor of Meyerbeer's techniques) as phantasmagoria. See Adrian Daub, "Sonic Dreamworlds: Benjamin, Adorno, and the Phantasmagoria of the Opera-House," in *A Companion to the Works of Walter Benjamin*, ed. Rolf G. Goebel (Rochester, NY: Camden House, 2009), 273–294.

2. Karl Marx and Friedrich Engels, *Manifesto of the Communist Party*, in *The Marx-Engels Reader*, ed. Richard Tucker (New York: Norton, 1978), 498.

3. "Académie Royale de Musique. Première representation.—*La Sylphide,* ballet-pantomime en deux actes," *Courrier des Théatres*, 13 March 1832; Joellen A. Meglin discusses this review in "Behind the Veil of Translucence: An Intertextual Reading of the *Ballet Fantastique* in France, 1831–1841: Part One: Ancestors of the Sylphide in the *Conte Fantastique*," *Dance Chronicle* 27, no. 1: 67–129. Meglin mines the dense intertextuality that linked fantastic tales, music, dance, and stage design around 1830, noting the foundational role of *Robert le diable* in the emergence of fantastic spectacle (70, note d).

4. Andrea Goulet, "'Tomber dans le phénomène': Balzac's Optics of Narration," *French Forum* 26, no. 3 (2001): 43–70.

5. *Auguste Comte: Philosophie des sciences*, ed. Juliette Grange (Paris: Gallimard, 1997), 90, emphasis in original.

6. Gaston Bachelard, *Le rationalisme rationnel* (Paris: PUF, 1953).

7. Auguste Comte, *Discours sur l'ensemble du positivisme* (1848), ed. Annie Petit (Paris: Flammarion, 1998), 138.

8. Comte wrote in his *Système de politique positive* that scientific laws "represent the universal order as much as we need to know it" and that "every phenomenon presupposes a spectator." Auguste Comte, *Système de politique positive, ou traité du sociologie instituant la religion de l'humanité* (Paris: L. Mathias, 1851–1854), 4:175, 1:439. See Mary Pickering, *Auguste Comte: An Intellectual Biography*, vol. 3 (Cambridge, UK: Cambridge University Press, 2009), 175–181.

9. Benjamin's studies of the Paris of Baudelaire and the surrealists led a generation of scholars to concentrate on the interval between the Second Empire and the Second World War. See Walter Benjamin, *The Arcades Project*, trans. Howard Eiland and Kevin McLaughlin (Cambridge: Harvard University Press, 1999). For an example of this interpretive trajectory, see Jonathan Crary, *Suspensions of Perception: Attention, Spectacle, and Modern Culture* (Cambridge: MIT Press, 1999). See also Michael Marrinan's refreshing study of the pre-1848 scene in the visual arts, *Romantic Paris: Histories of a Cultural Landscape, 1800–1850* (Palo Alto, CA: Stanford University Press, 2009).

10. Karl Marx, who spoke of the "camera obscura of ideology," used another metaphor from optical technology in his analysis of commodity fetishism: "There is a definite social relation between men themselves which assumes here, for them, the [phantasmagoric] form of a relation between things." Karl Marx, *Capital*, vol. 1, trans. Ben Fowkes (Harmondsworth, UK: Penguin, 1976), 165. Fowkes translates as "fantastic" the German *phantasmagorische*. On this passage, and the dialectics of illusion and demystification implied by "phantasmagoria," see Tom Gunning, "The Long and Short of It: Centuries of Projecting Shadows from Natural Magic to the Avant-Garde," in *The Art of Projection*, ed. Stan Douglas and Christopher Eamon (Ostfildern, Germany: Hatje Cantz

Verlag, 2009), 23–35. See also Jacques Derrida, *Specters of Marx: The State of the Debt, the Work of Mourning, and the New International*, trans. Peggy Kamuf (New York: Routledge, 1994).

11. Robertson's performances are detailed in Gunning, "The Long and Short of It." See also Giuliano Pancaldi, *Volta: Science and Culture in the Age of Enlightenment* (Princeton: Princeton University Press, 2003).

12. David quoted in Patrice Thompson, "Essai d'analyse des conditions du spectacle dans le panorama et le diorama," *Romantisme* 12, no. 38 (1982): 47–64.

13. See Charlotte Bigg, "Staging the Heavens: Astrophysics and Popular Astronomy in the Late Nineteenth Century," in *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture*, ed. David Aubin and Charlotte Bigg (Durham, NC: Duke University Press, 2010), 304–324; Laurent Mannoni, *The Great Art of Light and Shadow: Archaeology of the Cinema* (Chicago: University of Chicago Press, 2000); Stephan Oetterman, *Panorama: History of a Mass Medium* (Cambridge, MA: Zone Books, 1997); and Bernard Comment, *The Painted Panorama* (New York: Harry N. Abrams), 2000.

14. Louis-Jacques-Mandé Daguerre, *Historique et description des procédés du daguerréotype et du diorama* (Paris: Alphonse Giroux, 1839), 78.

15. See Helmut and Alison Gernsheim, *L.J.M. Daguerre: The History of the Diorama and the Daguerreotype* (London: Dover, 1968).

16. Hector Berlioz, *Berlioz's Orchestration Treatise: A Translation and Commentary*, trans. Hugh McDonald (Cambridge, UK: Cambridge University Press, 2002).

17. Hector Berlioz, *The Art of Music and Other Essays (A Travers Chants)*, trans. and ed. Elizabeth Csicsery-Rónay (Bloomington: Indiana University Press, 1998), 182.

18. Berlioz, *Orchestration Treatise*, 319. Berlioz was "one of the first to be seriously pre-occupied with a problem up until then considered as secondary by musicians: the *place* in which his music is interpreted." Jean-Michel Hasler, "A la conquête de l'espace sonore," in *Hector Berlioz*, ed. Christian Wasselin and Pierre-René Serna (Paris: Éditions de l'Herne, 2003), 52. See also Ralph Locke, *Music, Musicians, and Saint-Simonians* (Chicago: Chicago University Press, 1986).

19. Hasler, 56.

20. See Marc Baroli, *Le train dans la littérature française* (Paris: École technique d'imprimerie, 1963), 98–99; and D. Kern Holoman, *Berlioz* (Cambridge: Harvard University Press, 1989).

21. Alison Winter, *Mesmerized! Powers of Mind in Victorian Britain* (Chicago: University of Chicago Press, 2000), 317.

22. Heinrich Heine, *Lutèce*, 25 April 1844, in *Hector Berlioz*, ed. Christian Wasselin and Pierre-René Serna, 358.

23. "Opéra, Robert-le-Diable," *Le Figaro*, 28 November 1831, quoted and translated in Rebecca S. Wilberg, "The *Mise en Scène* at the Paris Opéra—Salle Le Peletier (1821–1873) and the Staging of the First French Grand Opéra: Meyerbeer's *Robert le Diable*" (Ph.D. diss., Brigham Young University, 1990), 299. See M.-H. Coudroy, *La critique parisienne des "grands opéras" de Meyerbeer* (Saarbrücken, Germany: Lucie Galland, 1988). For a discussion of Meyerbeer and Balzac's physio-spiritual machines, see Emily Dolan and John Tresch, "'A Sublime Invasion': Meyerbeer, Balzac, and the Paris Opera Machine," *Opera Quarterly* (forthcoming).

24. Honoré Balzac, "Gambara," trans. Richard Howard, in *The Unknown Masterpiece* (New York: New York Review of Books, 2001).

25. Tom Gunning, "The Cinema of Attractions: Early Film, Its Spectator and the Avant-Garde," in *Early Film*, ed. Thomas Elsaesser and Adam Barker (London: BFI, 1989), 58.

26. Meyerbeer's diaries from the time detail his fears that his musical and visual effects would be scooped by rivals. Critics focused as much on the new harmonies, sound effects, and staging as on plots and music. See *The Diaries of Giacomo Meyerbeer*, 4 vols., ed. and trans. Robert Letellier (Madison, WI: Fairleigh Dickinson University Press, 1999–2004); and Coudroy.

27. Hervé Lacombe, "The 'Machine' and the State," in *The Cambridge Companion to Grand Opera*, ed. Charlton, David (Cambridge, UK: Cambridge University Press, 2003), 21–42.

28. See Myles Jackson, *Harmonious Triads: Physicists, Musicians, and Instrument Makers in Nineteenth-Century Germany* (Cambridge: MIT Press, 2006); Félix Savart, *Mémoire des instruments à chordes et à archet* (Paris: Librairie Encyclopédique de Roret, 1819); Félix Savart, *On the Acoustic Figures Produced by the Vibrations Communicated through the Air to Elastic Membranes* (Edinburgh: Blackwood, 1825); and Félix Savart, "Recherches sur les usages de la membran du tympan et de l'oreille externe," *Journal de physiologie expérimentale* 4 (1824): 183–219.

29. M.E. Chevreul, *De la loi du contraste simultané* (Paris: Pitois-Levrault, 1839), 172. See Françoise Vienot, "Michel-Eugène Chevreul: From Laws and Principles to the Production of Color Plates," *Color Research and Application* 27, no. 1 (2001): 4–14.

30. Maine de Biran, *L'influence de l'habitude sur la faculté de juger* (Paris: Henrichs, 1803), 143.

31. Maine de Biran, 146.

32. Jonathan Crary and Elizabeth Green Musselman argue that, in the domain of vision, perception in all its forms was often presented at this time as a form of hallucination. Jonathan Crary, *Techniques of the Observer: On Vision and Modernity in the Nineteenth Century* (Cambridge: MIT Press, 1990); and Elizabeth Green Musselman, *Nervous Conditions: Science and the Body Politic in Early Industrial Britain* (Albany: SUNY Press, 2006).

33. André-Marie Ampère, *Essai sur la philosophie des sciences, ou Exposition analytique d'une classification naturelle de toutes les connaissances humaines*, vol. 2 (Paris: Bachelier, 1843), 75.

34. On French popular science of this time, see Bernadette Bensaude-Vincent, "Un public pour la science: l'essor de la vulgarisation au XIXe siècle," *Réseaux* 58, "Information scientifique et technique" (1993): 47–66; M. Crosland, "Popular Science and the Arts: Challenges to Cultural Authority in France under the Second Empire," *British Journal for the History of Science* 34 (2001): 301–322; B. Belhoste, "Arago, les journalistes et l'Académie des sciences dans les années 1830," in *La France des années 1830 et l'esprit de réforme*, ed. P. Harismendy (Rennes, France: Presses Universitaires de Rennes, 2006), 253–266; M. Staum, "Physiognomy and Phrenology at the Paris Athenée," *Journal of the History of Ideas* 56 (1995): 443–462; and Theresa Levitt, *The Shadow of Enlightenment: Optical and Political Transparency in France, 1789–1848* (Oxford, UK: Oxford University Press, 2009). See also the special issue of *Romantisme* edited by Bernadette Bensaude-Vincent, "Sciences pour tous," no. 65 (1989).

35. On performances of popular science, see Iwan Rhys Morus, "Seeing and Believing Science," *Isis* 97 (2006): 101–110; and Simon Schaffer, "Natural Philosophy and Public Spectacle in the Eighteenth Century," *History of Science* 21 (1983): 1–43.

36. For a stimulating discussion of the dialectic of wonder and habit, focused in part on the International Expositions, see Tom Gunning, "Re-Newing Old Technologies: Astonishment, Second Nature, and the Uncanny in Technology from the Previous Turn-of-the-Century," in *Rethinking*

Media Change, ed. D. Thorburn and H. Jenkins (Cambridge: MIT Press, 2003); Christine Blondel, "Electrical Instruments in 19th Century France, between Makers and Users," *History and Technology* 13 (1997): 157–182; and Pascal Ory, *Les expositions universelles de Paris: Panorama raisonné, avec des aperçus nouveaux et des illustrations par les meilleurs auteurs* (Paris: Editions Ramsay, 1982).

37. Michael Dettelbach, "Humboldtian Science," in *Cultures of Natural History*, ed. Nicholas Jardine, James Secord, and Emma Spary (Cambridge, UK: Cambridge University Press, 1996), 287–304.

38. See Jackson on connections between musicians, scientists, and instrument makers in the German-speaking countries, with occasional dips into France.

39. Alexander von Humboldt, *Cosmos: Sketch of a Physical Description of the Universe*, vol. 2 (London: Longman, Brown, Green, and Longmans, 1849), 90–91.

40. See Levitt, *The Shadow of Enlightenment*.

41. Maurice Daumas, *Arago, la jeunesse de la science* (Paris: Belin, 1987), 6.

42. Victor Hugo, "Ce qu'on entend sur la montagne," in *Les feuilles d'automne* (Paris: Hauman, 1832), 19–22. On the fantastic and political aspects of Arago's science, see John Tresch, "The Daguerreotype's First Frame: François Arago's Moral Economy of Instruments," *Studies in History and Philosophy of Science* 38 (2007): 445–476.

43. The connections between the sensational projects of romantic-era scientists and artists also frequently had a personal basis. The son of André-Marie Ampère, Jean-Jacques Ampère, a founder of comparative literature, coined the term *fantastic literature* in an 1828 review of Hoffmann's tales. Arago's brother, Étienne, was an art critic, intimate of George Sand, and cowriter on one of Balzac's first publications. Meyerbeer's brother, Wilhelm Beer, was an independent astronomer who built a private observatory in Berlin's Tiergarten and was a friend of Humboldt. Humboldt secured Meyerbeer the position of official composer in Berlin in the 1840s. Ora Avni, "Fantastic Tales," in *A New History of French Literature*, ed. Denis Hollier (Cambridge: Harvard University Press, 1994), 675–676.

44. Alfred Donné and Léon Foucault, *Cours de microscopie: Atlas exécuté d'après nature au microscope-daguerréotype* (Paris: J-B. Baillière, 1845); and William Tobin, *The Life and Science of Léon Foucault: The Man Who Proved the Earth Rotates* (Cambridge, UK: Cambridge University Press, 2003). See discussion in Lorraine Daston and Peter Galison, *Objectivity* (Cambridge, MA: Zone, 2007), 124–140.

45. William Tobin, "Alfred Donné and Léon Foucault: The First Applications of Electricity and Photography to Medical Illustration," *Journal of Visual Communication in Medicine* 29 (2006): 6–13.

46. The device was regulated by an invention originally used to control the flow of air in church organs. David Pantalony, personal communication.

47. See the note reproduced in Tobin, *Life and Science of Léon Foucault*, 130.

48. Van Leyden was a follower of Thomas Müntzer, cited by Friedrich Engels as a precursor of Communism. For discussion, see Antonio Negri and Gabriele Fadini, "Materialism and Theology: A Conversation," *Rethinking Marxism* 20, no. 4 (2008): 665–672.

49. Jane Fulcher, "Meyerbeer and the Music of Society," *The Musical Quarterly* 67, no. 2 (1981): 213–229.

50. See Mark Everist, *Giacomo Meyerbeer and Music Drama in Nineteenth-Century Paris*

(Aldershot, UK: Ashgate Press, 2005).

51. Coudroy, 151.

52. Though the performance was a huge success—ticket lines descended into riots, repeat performances were scheduled throughout Europe, and, for fifty years, it was the most performed opera in the world—criticism was not all positive. Castile-Blaze: "Destined to overexcite imagination, the paraphernalia of the setting is an instrument of destruction, of ruin." *Le prophète* was a further indication of the "decadence of art": "We see our eyes overwhelmed, when instead the play and the music should leave the mind, the heart and the ear in a calm flatness." Coudroy, 158.

53. See Tobin, *Life and Science of Léon Foucault*, 139–172.

54. At the time, the rotation of the earth had been shown only by changes in the relation of the stars. Pierre-Simon Laplace had written that a demonstration of this rotation by a more "direct" means would be welcome. Joseph Bertrand, *Éloge historique de Léon Foucault* (Paris: Institut de France, 1882), 18; and Amir Aczel, *Pendulum: Léon Foucault and the Triumph of Science* (New York: Simon and Schuster, 2003), 40.

55. Mona Ozouf, "Le Panthéon," in *La République*, vol. 1 of *Les lieux de mémoire* (Paris: Gallimard, 1984), 140–166.

56. Étienne Arago quoted in Jacques Arago, *Histoire de Paris, ses révolutions, ses gouvernements et ses événements de 1841 à 1852, comprenant les sept dernières années du règne de Louis-Philippe et les quatre premières de la République*, vol. 2 (Paris: Dion-Lambert, 1853), 372. See Aczel, 148. Foucault is quoted in Aczel, 157.

57. *Les idées Napoléoniennes, par le Prince, Louis-Napoléon Bonaparte* (Paris: Amyot, 1860), 10.

58. Léon Foucault, "Démonstration expérimentale du mouvement de rotation de la terre" (1851), in *Recueil de travaux scientifiques*, vol. 1 (Paris: Gauthier-Villars, 1878), 520.

59. Blaise Pascal, *Pensées*, trans. A.J. Krailsheimer (New York: Penguin, 1995), 66.

60. See Aczel.

61. On reinvestments of fetishism in the postrevolutionary period, notably in Comte's *Religion of Humanity* (whose progeny include Émile Durkheim's collective representations and Claude Levi-Strauss's "floating signifier"), see Pickering, 256–280, 506–507. For a more recent update, see Bruno Latour, *Petite réflexion sur le culte moderne des dieux faitiches* (Paris: Synthélabo, 1996).

62. On Figuier, see Bernadette Bensaude-Vincent, "Un public pour la science."

63. See Gunning, *Re-thinking Media Change*.

64. Lorraine Daston and Katherine Park, in *Wonders and the Order of Nature, 1150–1750* (New York: Zone Books, 1998), analyze the generative role of wonder in natural knowledge during the medieval, early modern, and enlightenment periods, concluding with a wistful lament: wonder has been chased from the serious business of modern scientific world-making. Many recent works suggest that the productive interplay of wonder and natural knowledge has continued into the modern, industrialized age, albeit within different epistemic and sociological constellations. Beyond work on "the technological sublime" (Leo Marx, David Nye) and occult sciences (Richard Noakes, Alex Owen), see also Michael Taussig, *Mimesis and Alterity: A Particular History of the Senses* (London: Routledge, 1993).

65. Karl Marx, "The Fetishism of Commodities and the Secret Thereof," in *Capital: A Critique of Political Economy* (New York: Modern Library, 1906), 81–96.