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The daguerreotype's first frame: François Arago's moral economy of instruments

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Abstract

This paper examines the meanings of the daguerreotype for the astronomer and physicist who introduced it to the world, François Arago. The regime of knowledge production which held sway at the birth of photography implied an alternative view of the moral and political implications of machines from that usually suggested by discussions of 'mechanization'. Instead of celebrating detachment, instantaneity, transparency and abstraction, Arago understood instruments and human citizens as dynamic mediators which necessarily modify the forces they transmit. His moral economy of instruments also implied specific aesthetic and political commitments. Arago's republican convictions and expressive personal style, as well as his identification with revolutionary scientist–statesmen including Lazare Carnot and Condorcet, present a strong contrast with the imperial science of Laplace and the image of disengaged, impersonal 'mechanism' often associated with the physical science of this time.

Keywords: Daguerreotype; Photography; François Arago; Romanticism; Mechanism; Pierre-Simon Laplace

1. Machines and mobs, balloons and birds

Few concepts are as central to the history of modern science as 'mechanism' and 'machine', though the signification of these terms has varied widely. In the enlightenment, the clock, the balance, and the lever were symbols of cosmic harmony; as embodiments of the mathematically ordered universe of points and forces, they were celebrated for their

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exactitude, predictability, and uniformity. Despite this reverence for the clockwork universe, however, machines could also be viewed with suspicion. Because 'machine' often meant any device that passively and regularly transmitted an external force, a person acting without feeling, inspiration or free will was dismissively said to perform 'mechanically'; despotic governments were said to demand 'mechanical' obedience of their subjects. The very 'inhumanity' which made machines the model for disciplined conduct and the well-governed state—uniformity, efficiency, lack of emotion—also made them targets of fear and hostility.[1]

This ambivalence is reflected in critical responses toward mechanical techniques of representation including, significantly, photography. Photography's 'inhuman' traits have called forth its greatest accolades: its scientific uses have been championed as a giant step in the 'mechanization' of observation and representation.[2] More recently, photography has been presented as part of a major shift in the history of objectivity, away from scientific norms of aesthetic judgment or personal interpretation in favor of 'mechanical objectivity', which sought methods of depicting phenomena that minimized human intervention. According to Daston and Galison, this change in scientific practice paralleled the rise of a moral connotation of objectivity which stressed observers' restraint and the suppression of individuality.[3] Mid-nineteenth century objectivity had

> everything to do with a machine ideal: the machine as a neutral and transparent operator that would serve as instrument of registration without intervention *and* as an ideal for the moral discipline of the scientists themselves. Objectivity was that which remained when the earlier values of the subjective, interpretive, and artistic were banished.[4]

This 'machine ideal' of mechanical objectivity seems rooted in the concept of an *ideal machine*—a neutral, transparent and quasi-abstract instrument, a standardized part in a uniform chain of causality, a frictionless cog passively transmitting an external impulse. This ideal encouraged an image of the researcher as an emotionless, non-intervening, and passive receptor. According to this analysis, photography—including its first widely successful version, the daguerreotype—was the 'essence and emblem' of mechanical objectivity. Considerable strength has been lent to this reading of early photography by the fact that the daguerreotype, one of the earliest successful forms of photography, had for its scientific midwives Gay-Lussac and Arago, the protégés of the Newtonian astronomer Laplace. Laplace's life and work were often presented as the embodiment of the most salient qualities of the enlightenment's 'ideal machine'. Following this chain of associations, Laplacean science was reductively mechanical; the daguerreotype was introduced by Laplaceans; therefore, the first scientific understandings of photography must recapitulate the reductive ideals of Laplacean mechanism.

If the inhuman machine played a starring role in Newtonian physics and engineering diagrams, it also owed much to 'romantic' polemics against mechanical science.[5] For poets and philosophers from Schelling and Coleridge to de Stael, the machine was an enemy:

[1] See Giedion (1948), Mumford (1963), Foucault (1979), Mayr (1986), Schaffer (1999), Hughes (2004).
[2] See Conrady (1923), Hoskin (1997), Thomas & Braun (1997).
[3] Daston & Galison (1992).
[4] Galison (1998), p. 332.
[5] Schlanger (1971).

reductive, unfeeling, impersonal, and determined where the organism was holistic, sensitive, irreducible, and free. Such critiques anticipated an aesthetic reaction against photography, so that by 1859 Charles Baudelaire could draw on a common association among photography, realist painting, and mass industry to redefine the relations of art and technology. According to Baudelaire, unlike the *imaginative* artist, who says: '"I want to illuminate things with my spirit and project its reflection upon other spirits"', the *realist* or *positivist* says, '"I want to represent things as they are, or rather, how they would be, if I did not exist"', aiming to represent 'the universe without man'. He concluded, 'If photography is allowed to assist art in a few of its functions, it will have soon supplanted or corrupted it entirely, thanks to the natural ally that it will find in the idiocy of the mob [*la multitude*]'.[6] It would be an error to allow a mechanical procedure to take on the active role deserved by noble, imaginative, and creative art; like the unruly *demos*, its 'natural ally', industry must be limited to its proper role as passive servant. Baudelaire's intuition that mechanically produced images are antithetical to full humanity has often reappeared in worries over the deceptive visual rhetoric of realism, the alienation and reductive 'enframing' of photography, its destruction of the aura of the artwork, and its use by colonial and metropolitan governments to police suspect populations.[7] Yet despite the clash between 'humanist' critics of the machine and those who championed mechanical progress, a tacit collusion can be observed: for both, photography and other techniques of mechanical imagery seek Baudelaire's 'universe without man', images of the natural world made without human intervention.[8] This conceptual frame of machines as inhumanly efficient and detached reinforces an image of science as impersonal, unfeeling, and automatic, fortifying the autonomy of scientific professions by making technological expertise a further bar to entry.

But quite different conceptions of the machine are possible. The 'mechanistic' eighteenth century materialist physiology of Diderot and La Mettrie, for example, had investigated processes which later were seen as distinctly vital, organic, and thus *non-mechanical*: growth, digestion, adaptation, reproduction, and even thought.[9] More pertinently, the steam engine replaced the clock, lever, and balance as the cosmic symbol of the early nineteenth century. With its motive force within it, the steam engine was seen as a universal converter, a transformative node in a universe of protean energy.[10]

By pointing out diverse and neglected affiliations of the daguerreotype, one aim of this paper is to weaken the perception of an umbilical link between the birth of photography the Newtonian 'ideal machine'. I focus on the life and works of François Arago, the astronomer who publicly introduced the daguerreotype and used his scientific and political clout to reward its inventors (Fig. 1). Arago framed this new technology within an alternative vision of the machine, endowing it with moral and political meanings that

[6] 'Le gouvernement de l'imagination', in Baudelaire (1990), p. 625. All translations are my own unless otherwise indicated.

[7] Barthes (1981), McClintock (1994), Tagg (1988), Heidegger, (1977), and Benjamin (1986).

[8] Galison & Jones (1998).

[9] Similar conceptions continued in the life sciences in Lamarck, Geoffroy Saint-Hilaire and Milne-Edwards, who elaborated this vital materialism with conceptual resources from chemistry and industry. For a discussion of enlightenment physics which runs counter to classic accounts focusing on uniformity and depersonalization by concentrating on emotional and perceptual 'sensibility', see Riskin (2002).

[10] Serres (1982).

Fig. 1. Portrait of Arago © Observatoire de Paris.

surpassed the 'neutral and transparent operator' of mechanical objectivity and the Laplacean regime.

Relatively unknown today, Arago was one of the preeminent scientists of the nineteenth century. Because of his close connections with Laplace and the Ecole Polytechnique, we might expect him to display a cold and analytic demeanor in tune with scientific and military ideals.[11] Consider, however, this anecdote from the visionary romantic Victor Hugo:

[11] Porter (1991), Weiss (1982), Shinn (1980).

> One evening I was walking in the Allée de l'Observatoire with that great pioneer thinker, Arago. It was summer. A balloon that had ascended from the Champ de Mars passed over our heads in the clouds. Its rotundity, gilded by the setting sun, was majestic. I said to Arago: 'There floats the egg waiting for the bird; but the bird is within it and it will emerge.' Arago took both my hands in his and, fixing me with his luminous eyes, exclaimed: 'And on that day, Geo will be called Demos!' A profound remark. The whole world will be a democracy.[12]

A profound remark, perhaps; a strange one, certainly. The sight of what the Montgolfiers called an 'aerostatic machine' provokes a prophecy of global democracy and the emancipation of the masses illuminated with mesmerizing verve and passion—traits difficult to square with the emotionless discipline usually associated with polytechnician scientists. By presenting the epistemological commitments, moral values, and political engagements which made such scenes possible, this paper places Arago's introduction of photography within a coherent scientific and political project which implied a new view of the machine and of the relations between humans and nature.[13]

Although industrialization in France had not yet reached English levels, in the 1830s and 40s the 'industrial revolution' was perceived as unstoppable. Changes in production had already brought social changes, including the impoverishment of many Paris's new inhabitants and demands from the newly self-conscious working class for a more equal distribution of wealth and power. Like his socialist contemporaries, Arago perceived the potential harms of mass industry. But he did *not* position machines as the antithesis of human spontaneity and freedom. In contradiction to a familiar polarity in the historiography of ideas, Arago and many of his contemporaries joined a fascination with mechanical sciences and new machines to the attitudes and aspirations we associate with romanticism—a longing for a union of mind and nature, a celebration of the individual and the emotional, a rejection of convention. Though these juxtapositions at times resulted in paradox, such mixtures were embraced as a step beyond both retrograde faith in tradition and the enlightenment's narrow faith in dispassionate reason. The daguerreotype was a *romantic machine*.

This paper explores the contrast Arago developed between himself and Laplace, his alternative identification with savants of the revolutionary era, Condorcet and Carnot, and his promotion of the scientific ideals and methods of Alexander von Humboldt. Public speeches in which he combined the roles of scientist and statesman provide equally important background for his introduction of the daguerreotype. As the conclusion will bring out, the study of the daguerreotype, its cultural resonances, and the commitments of its chief promoter shed light on the fantastic undercurrents of the early industrial age.

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[12] Hugo, letter of January 1864, in Gosling (1976), p. 16. Works on Arago consulted include: Audiganne (1857), Daumas (1943), Cawood (1985), Grison (1989), Sarda (2002), Hahn (1970–1990).

[13] For more on this symbolically charged intersection, see Aubin (2003). On balloons and engineering, see Gillispie (1983); on Hugo and technology, Charles (1997).

2. Arago as anti-Laplace

At the hour of its imperial ascension, the most salient characteristics of the enlightenment machine were epitomized by Pierre–Simon Laplace.[14] One of the most powerful figures in French science, he sought to apply the Newtonian regularity of the heavens to the innermost recesses of matter, and played a key role in 'mechanizing' the practices of science, engineering, war, and the administration of the modern state. Under the Empire, the physical and mathematical sciences were so highly prized that Napoleon had himself elected to the Académie des Sciences; the *philosophes*' emphasis on reason, number, and uniformity were imposed across Europe through the Continental System's axiomatic, centralized bureaucracy. Laplace's *Mécanique Célèste* deified the clockwork cosmos without help from God. Just as his colleague Lagrange had claimed that mathematics was complete, Laplace was seen to have perfected Newton's system of the heavens. He also worked as a dutiful instrument of the state, creating a uniform system of measures and establishing national standards in the teaching of mathematics and engineering. Various pedagogical and institutional means assured his scientific status: as teacher and administrator he selected candidates, set topics for prize competitions, and served as patron for the highly influential 'Society of Arceuil' at his neighbor Bertollet's home. His students combined virtuosic mathematics, precise experimental machinery, and practical applications, laying the technological infrastructure for wide-scale industrialization and imperial expansion.[15]

As a member of the Soceity of Arceuil and outstanding student of the Ecole Polytechnique, François Arago benefited heavily from Laplace's patronage in his early career. Yet after Napoleon's fall, he led the charge to dismantle Laplace's scientific empire. Arago developed a strong contrast between himself and the Marquis which amounted to a major shift in what Lorraine Daston has called 'the moral economy of science': a 'web of affect-saturated values that stand and function in well-defined relationship to one another'.[16] Robert Fox has demonstrated the theoretical stakes of this opposition, which held just as strongly at the level of personality, political conviction, methodological commitments, and the image of science. In his memoirs, Arago recalls dining at Laplace's home as a student:

> My mind and heart were highly disposed to admire everything, to respect everything, at the home of the man who had discovered the cause of the secular equation of the moon ... But what then was my disenchantment when, one day, I heard Madame de Laplace approach her husband and say to him, 'Would you entrust me with the key to the sugar?'[17]

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[14] The homogeneity of 'Laplacean physics' and the starkness of the opposition between faithful Laplaceans and renegades like Arago, Fresnel, Ampère, and Fourier can appear somewhat overstated when we examine Laplace's own scientific and political positions closely; nevertheless, the historical record shows a concerted effort on the part of at least Arago to create the image of a unified Laplacean program, a rhetorical strategy that put his own ambitions into sharper relief. A schematic evocation of science in the Laplacean and Lagrangean mold, highly useful for illustrative purposes, can be found in the discussion of 'royal science' versus the 'nomadic science' of Monge and other engineers in Deleuze & Guattari (1987), pp. 351–423.

[15] See Crosland (1967), Fox (1976), Hahn (2005).

[16] Daston (1995), p. 4.

[17] 'Voulez-vous me confier la clef du sucre?'; Arago (1854–1862f), p. 58.

Reminding us of the embargo which isolated France's sugar colonies, Arago stirs a *soupçon* of accusation into this anecdote, presenting his mentor as at worst a slave master and at best a petty domestic tyrant who keeps sweetness under lock and key from his wife. Arago's appalled depiction of a lack of warmth and generosity was part of a broader and often disparaging characterization in which personal traits spilled over into scientific commitments. In a biographical sketch from the 1840s, he praised Laplace for demonstrating how much 'an observant geometer who, from the moment of his birth, never left his work cabinet, who never saw the sky except through the narrow opening running from north to south in which the principal astronomical instruments move in the vertical plane' might discover. Such a stationary observer could learn that 'his humble and narrow dwelling was part of a flattened, ellipsoidal globe ... he would have found as well, still without moving, his true distance from the sun'.[18] Yet this is backhanded praise. Though Arago acknowledged Laplace's achievement and presented equations from the *Mécanique Célèste* in the opening lectures of his *Popular astronomy*, throughout his career he distanced himself from the image of the astronomer fixed in the observatory analyzing a limited quantity of observations.

Arago depicted Laplace's approach to knowledge—and to sugar—as ruled by rarity, enclosure, and arbitrary authority. In hindsight he judged Laplace's coterie in the Society of Arceuil as both deficient and excessive, noting that 'preconceived ideas, to which the best minds succumb more easily in a group which is, so to speak, intimate, than before a larger public, could result in stifling the spontaneity of genius and restrain research to a conventional level'; the group mentality of Arceuil inhibited spontaneous genius and promoted obedience to expectations and conventions. Yet 'on the other hand, desire to give evidence of ability in the presence of the most celebrated men of science of their age, might surely lead enthusiasts into speculative theories'. The enlightenment watchword of *enthusiasm*, usually a stick with which to beat the superstitious, is here redirected against an overzealous rationality. Laplace's goal of universally applying Newtonian conceptions and methods is portrayed as a dangerous temptation to impose *arbitrarily* preconceived theories upon nature.[19] In hindsight, Laplace's system of science appears moribund: a closed machine turning endlessly in circles.

In the first decades of the nineteenth century, Arago used Laplace's own methods for securing control over the sciences against him. Taking over a number of powerful positions—director of the Bureau of Latitudes, Director of the Observatory, and eventually Perpetual Secretary of the Academy of Sciences, which made him editor of its *Comptes Rendus*—he redirected research, controlled publications, and promoted candidates. From these institutional strongholds, he delivered a jolt of romanticism to precision physics, taking inspiration from the personal and scientific example of the explorer and natural historian Alexander von Humboldt, his close friend and fellow member of the Society of Arceuil. Humboldt's sensitive, instrumentally mediated cosmopolitanism was reflected in Arago's charismatic scientific persona and in his turn to a model of astronomy and global science shaped by the experience of working in the field.

Arago implied that Laplace ignored the aesthetic and affective aspects of natural knowledge; by making positional astronomy the model for all sciences, he effaced the unique and

[18] Arago (1854–1862b), p. 485.

[19] Arago (1854–1862h), Vol. 3, pp. 33–44, quoted in Crosland (1967), p. 427.

irreducible experience of observation in unalterable mechanical laws. Conversely, aesthetic concerns were central to Humboldt's cosmological science: evocative language and imagery inculcated an emotional and intellectual sensibility which would improve and liberate his readers.[20] The personal accounts and evocative descriptions of exploration, observation, and discovery in Arago's public lectures also restored this aesthetic dimension. Like Humboldt's *Cosmos*, Arago's lectures on *Popular astronomy* were full of evocative rhetorical flourishes and colorful, sensuous descriptions aimed at engaging the listener's imagination: one chapter, for example, inquires about the habitability of comets, while others relate anecdotes from Greek mythology, dramatic narratives from the history of science, and his own experiences. His early scientific reputation was as a heroic adventurer; his picaresque *Histoire de ma jeunesse* recounts his near-death encounters while measuring the meridian through France.[21]

His writings as Perpetual Secretary and Deputy likewise testify to a poetic sensibility. In *Discours sur la réforme éléctoral* he quotes Goethe as an authority on the proper use of number in political decision making; an epigram from Byron adds color to his 'Eloge d'Ampère'. In that essay he cites verses composed by Ampère which could 'figure in the debate, if it was renewed' over whether or not scientific studies 'dry out' the intellect. Further, though he hints that Ampère's energies might have been put to better use than in his extensive metaphysical studies, the latter's work on electromagnetism also proves that poetry and a '*romanesque*' imagination do not prevent scientific achievement.[22] In his funeral éloge of his fellow deputy, Eusèbe Salverte, reprinted as the preface to the latter's history of the occult sciences, he made a special point of arguing against his detractors: 'Yes, *messieurs*, he had a warm heart'.[23]

For Arago, a *coeur chaud*, the quality that Laplace lacked, was *de rigeur*. His public actions conform to this standard; professions of strong feeling are a constant leitmotif of his scientific and political writings. He justifies his discourse on the daguerreotype by saying, 'we are forced to share our convictions with you because they are lively and sincere'; elsewhere, out of his 'intimate conviction' of 'the great, the majestic figure of Condorcet', he combats the philosopher's detractors 'with visor raised' (p. iii). Such linguistic forms and gestures typify the *homme de sentiment* and the 'expressive' romantic subject[24]. Yet against assumptions about romanticism as individualist, subjectivist, and escapist,

[20] See Dettelbach (1996) and Tresch (Forthcoming). Humboldt's moral conception of instruments was closely linked to Schiller's adaptation of the moral philosophy of Kant. Taking morality out of the realm of the ideal, Schiller located it in communal and physical activity, through which freedom is bestowed upon others and returned in a cosmic circuit of exchange. In the *Aesthetic education of mankind*, this role of moralizing mediator is played by fine art; in Humboldt's science, by instruments.

[21] Arago's prolixity and penchant for colorful digressions compelled his English translators to warn that 'The attentive reader, while pursuing with deep interest some of the more argumentative parts of the work, may, probably, sometimes be induced to think that his instructor has entered more into details than he need have done to establish the correctness of his position; but it will invariably be found that these excursive episodes terminate in some useful result'. They attribute this verbosity to the demands of explaining science to a wide, uninformed audience. This may be the case, but such 'excursive episodes' also occurred in Arago's reports to the Academy *intra muros*, showing how his conception of the proper style of science exceeded the standards of 'correctness' and 'utility' promoted by most of his English equivalents (Arago, Grant, & Smyth, 1855, p. v).

[22] Arago (1854–1862e), pp. 11, 102.

[23] Arago (1843), p. xv.

[24] Taylor (1989).

Arago, the 'Jupiter of the Observatory', applied these conventions of unconventionality within projects marked by patriotism, mathematics, and machines.

The opposition between Arago and Laplace grew more marked and took on a fundamentally political dimension after the Revolution of 1830, in which Arago played a central role thanks to his connections in radical republican circles. After the fall of the empire, the Ecole Polytechnique became a hotbed of republican sentiment; his brother Etienne, the playwright and *carbonaro*, was a collaborator of Balzac and George Sand and a public spokesman and private conspirator for the revolution. Furthermore, revolutionary-era ideals of freedom and equality, translated into German romantic philosophy, came back to him through his contact with Humboldt. He also deepened his connection to the revolution through his role as historian of science; retrieving the examples of his predecessors, he invented a new tradition of enlightenment.

3. Rehabilitating revolutionary representation: Carnot and Condorcet

While Laplace served as a faithful Senator under Napoleon, from 1830 Arago was a Deputy for the opposition. From his institutional strongholds he sought to replace Laplace's imperial control over scientific knowledge with a 'republican' drive to make science available to the widest audience possible. He gave lectures on *Popular astronomy* at the observatory to a crowd that included romantic notables like Balzac and Georges Sand. Along with other members of the Association Polytechnique, he gave lectures to workers and artisans on the mechanical principles of their trades.[25] Further, he reshaped the representation of science in the press: he took over the editorship of various journals as editor and changed the format of the reports of the Academy of Science to make them more accessible. He also opened the Academy's gallery to reporters and the public, encouraging newspapers to publish a weekly account of its scientific debates—the '*feuilleton scientifique*' which occupied the same space as the weekly installments of romantic novels at the bottom of page one. These politically loaded and controversial changes were all aimed at increasing public participation and 'transparency' in the conduct of science.[26]

As Perpetual Secretary, Arago was tasked with writing memorial *éloges* for departed scientists.[27] In these speeches he often revisited the French Revolution, whose meaning and implications were hotly debated in the 1830s and 40s.[28] Was the revolution's vision of a transformed, egalitarian, democratic society the true and inevitable direction of history, just waiting for the proper moment to be reawakened? Or was the revolution a cannibalistic, fratricidal monster which could at last be laid safely to rest? In his *éloges*, Arago strongly identified himself with revolutionary scientists and statesmen, including, notably, Condorcet and Carnot. These departed heroes were of the same generation as Laplace, but

[25] See Grattan-Guinness (1984).
[26] Levitt (2003). On reactions to these changes, along with analysis of the anti-Arago polemic by Guillermo Libri, see Fox (1976) and Tobin (2003).
[27] One could revisit Dorinda Outram's arguments along these lines to contrast the commitments of Arago's polity of science with those of Cuvier, against whom he supported Geoffroy de Saint-Hilaire in the debates of 1830. See Outram (1984).
[28] See Tocqueville (1955), Michelet (1847), and Furet (1981), especially pp. 132–163 on de Tocqueville and Guizot.

in Arago's reconstruction, their theories of *representation* and *agency* contributed to a very different image of the machine as a metaphor for knowledge and politics.

In the 1830s, Arago edited Condorcet's collected works. Condorcet had been demonized by reactionary writers of the Restoration who blamed him for the Terror and for ruthlessly advocating egalitarian uniformity. The vision in his *Outline of the progress of the human mind* of a rational government was portrayed as a delirious vision of an arid machine whose standardized human parts work miraculously in concert. Instead, Arago took pains to show Condorcet's main preoccupation as the protection of personal freedom and individuality in an orderly but developing society. Condorcet's great concern, he showed, was to create a system of representation which would ensure that all decisions benefited society as a whole. His work on probabilities aimed at determining the size of the majority needed to ensure that a law really represented general welfare. He likewise developed a detailed plan for the conduct of local assemblies and the way in which their delegates and recommendations would reach the national level; he drew up detailed parliamentary and deliberative procedures at all levels, insisting that all laws must be susceptible to debate and amendment; instead of seeing popular resistance as external to government, he factored dissent into his system. Further, he saw that if all citizens were to participate in legislation, they must be educated; accordingly he put forth a plan for state-funded schools.[29]

As Arago's anecdotes from the life of this 'enraged sheep' or 'frozen volcano' related, Condorcet's conception of citizenship depended on affection and empathy, on an intersubjective identification with all other members of society. Neither the automatic obedience demanded by a despot, nor the transparent, immediate realization of the wills of each member of the society would allow the true nature and needs of the nation to be realized. Representation, for Condorcet, was more complex, more opaque, and more emotionally involving than was implied by most models of government as a simple machine. His probabilistic science and modifiable rules of government were designed to adapt to and incorporate the inevitable resistance brought by distinct individuals working toward consensus.

Arago also sought to rehabilitate the revolutionary-era reputation of the military engineer Lazare Carnot. Though he had been a member of the notorious Committee of Public Safety, Carnot was presented in Arago's obituary as an exemplary statesman and scientist who did everything in his power to keep Robespierre in check. An important aspect of Carnot's legacy was his reflection on *how forces are conveyed*. For both social and physical forces, this reflection went beyond the simple image of the lever or balance. Carnot was celebrated as the 'organizer of victories' for his role in constructing the revolutionary-era war machine.[30] French victories prompted Von Clausewitz's famous treatise *On war* (1820), which argued that a flawless transmission and enactment of orders could occur only in an 'absolute', ideal concept of war. In reality, there is always a potential gap between a plan and its execution; Clausewitz named it *friction*. Decades earlier, at the height of the Revolutionary wars, Carnot had already recognized this gap. Yet in a republican army, it was not an obstacle but an accelerator: into this gap of free will and consent, individuals introduced the lubricant of *patriotic enthusiasm*. His 'Discourse against passive obedience', declaimed in the Legislative Assembly in 1792, argued for soldiers' right to dis-

[29] See Condorcet's *The nature and purpose of public instruction* (1791), translated in Condorcet (1976), pp. 105–142.

[30] See Gillispie (1971), p. 13 on forming the army; p. 19 on the role of representative-on-mission.

obey unjust orders. There is no automatic assent in the best disciplined armies, he urged; a soldier is *free* in choosing to obey orders that agree with reason and the interest of the nation. In fact, the use of reason allows for a distinction between free and slavish soldiers:

> It is said that soldiers have given up their liberty—that they must not be thought of as citizens. Yet the constitution answers, in my view, that liberty is inalienable and unprescribable; one may well engage to take up arms for the execution of the law, to do such and such military maneuver; but one cannot engage to put oneself so fully under the orders of one's superior as to be required to kill one's neighbor at the superior's command... They will add that there is no middle ground between the passive obedience of the soldier and the indiscipline which wipes out armies; [yet] this middle ground is precisely that which distinguishes man from the beast of burden. It is reasoned obedience. Yes, an army which obeys by reason will always defeat an army which acts like a machine [*machinalement*], because the free soldier is better than the slave (*Applause*).[31]

The victorious army is made of citizen-soldiers, enlightened humans who are 'more than a machine', as Kant put it in 'What is enlightenment?'; they freely obey the reasonable commands of the popular will.[32]

Although Carnot's quote distinguishes the reasoned obedience of the soldier from the '*machinale*' subservience of the slave, a strong parallel may be identified with his physics of moving bodies. His *Theory of machines in general* considered the functioning of real machines—a significant break from the mechanics of Laplace and Lagrange, whose equations ignored the influence of resistance and friction. This founding text of thermodynamics analyzed the loss of 'moment-of-activity' (or *work*) due to shocks or violent shakes. Friction and deviation were again central terms. Of course, there is a difference between the citizen-soldier's friction and that of a machine: for an industrial machine, maximizing efficiency means *reducing* friction, while an army which tried to suppress the beneficial friction introduced by the free soldier would be morally reprehensible and militarily ineffective. The point at issue, however, is that in both cases Carnot eschews the idealized conception of a social or physical machine as a device for the unmodified, transparent transmission of force. Both the citizen-soldier and a real as opposed to an 'absolute' machine necessarily modify the expression of their initiating impulse.

According Arago's recasting, Condorcet showed the gap between the wishes of any individual and the best law for society, providing rules and procedures for crossing that space. Likewise, Carnot showed that in machines and in armies, there is a significant disjuncture between the initial cause and its effect—whether narrowed by enthusiasm or widened by friction. In both cases, the conceptual frame underlying Laplace's universe—with nature and society as frictionless, transparent, passively obedient machines—fell short. A different machine—new, but bearing a distinguished pedigree of enlightenment and revolution—took shape in Aragos's éloges and his scientific practice.

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[31] Carnot (1984–1985a), pp. 100–101, spoken in the Legislative Assembly, 19 April 1792. For a discussion of Carnot's 'art of war', see Carnot (1984–1985b), Vol. 1, p. 155.

[32] Note the transitivity in Republican discourse between soldier and citizen—Carnot declared that 'tout citoyen est soldat'—and between citizen and representative, since all are equally constitutive members of the *res publica*.

4. A Humboldtian science of the heavens

Arago's science made common cause with the sciences of the field: it stressed openness, the multiplication and juxtaposition of observations, and the impact of the specific setting of the observation. This shift in astronomical emphasis occurred in the context of several revolutions in terrestrial physics. Laplacian physics sought to extend Newtonian approaches to the weightless (imponderable) phenomena of heat, light, electricity and magnetism, explaining them on the basis of attractive and repulsive forces working between molecules. 'General Arago' coordinated a successful multi-front attack on Laplace's program: these successful challenges included Fourier's study of the propagation of heat, Ampere's investigation of electromagnetism, and Fresnel's wave theory of light.[33] In each case, the emphasis shifted from substances to processes; experimental apparatus produced effects and traced the movement of phenomena across a *milieu*, with a theoretical agnosticism about the nature of the underlying substances. Further, while Laplace and Lagrange avoided diagrams and geometric solutions, Arago and his allies were closely linked to the rival methods of Gaspard Monge, whose courses in descriptive geometry at the Ecole Polytechnique inspired a generation of research in fluid dynamics, topography, and practical engineering.[34]

The primal scene of Mongean engineers was Napoleon's expedition to Egypt. Arago took further inspiration from another famous voyager, Alexander von Humboldt. Humboldt's science of the interactions among geophysical phenomena within a local ecosystem, or *milieu*, and across the globe, offered an alternative cosmological horizon for both terrestrial and celestial physics. With his varied arsenal of geophysical instruments, Humboldt assembled copious data concerning light, temperature, air pressure, and magnetic declination and inclination which he then combined into synoptic *tableaux* depicting the cosmos as 'a general equilibrium which reigns among disturbances and apparent turmoil'. He presented this work in evocative language and imagery aimed at educating and elevating the sensibilities of the masses.[35]

In the Observatory of Paris, Arago developed a *Humboldtian science of the heavens*: the astronomical wing of Humboldt's geophysical field research.[36] Laplace's reports of his findings were largely mute about the role of specific apparatus, but Arago's *Astronomie populaire* abounded in descriptions, images, and analyses of the functioning of new scientific devices. For Arago, like Humboldt, the play of instruments was part of the scientific drama. He celebrated the mechanical inventiveness of scientists and their artisan assis-

[33] See Kuhn (1977) and Frankel (1976) on the emergence of *la physique experimentale*.

[34] I suggest that physics immediately after Laplace may be understood not as a story of disintegration and decline (as much of the historiography has suggested), but as a network of technical practices, personal liaisons and shared enmities, and a loosely joined if not uniform conceptual horizon. Shared commitments of this anti-Laplacean synthesis include an emphasis on the public visibility of instruments; a preference for geometrical over mathematical methods; a 'positivist' view of science as a pluralist ordering of naturally and artificially produced phenomena; and a 'fluid imaginary' associated variously with a search for a single unified substance, fluid theories of the nutritive interaction between organism and environment (*milieu*), and popular theories of animal magnetism. For previous accounts see Fox (1976); Ben-David & Freudenthal (1991); on the history of the thesis of decline, see Dorriës (1997).

[35] For a comprehensive overview, see Dettelbach (1996).

[36] See the abundant scientific and personal references to Arago in Humboldt's *Cosmos* (Humbolt, 1997).

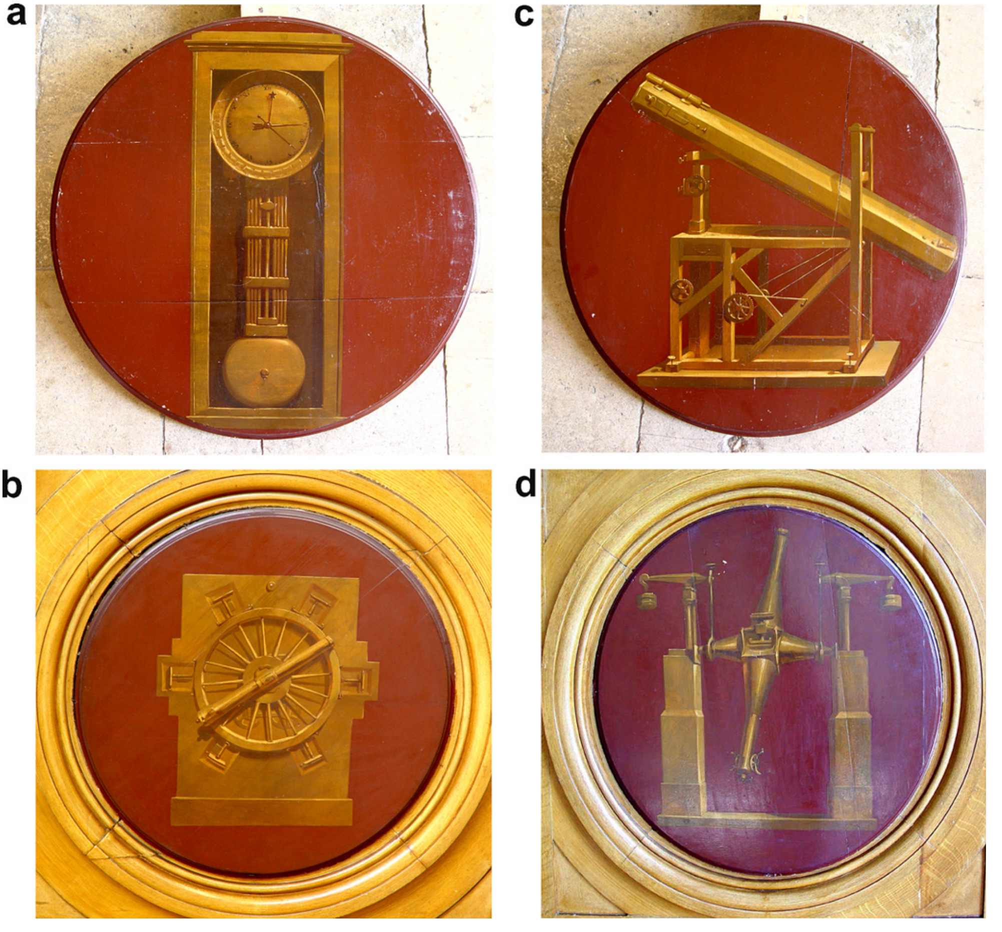


Fig. 2. Medallions of instruments on wall of auditorium for *Popular astronomy* © Observatoire de Paris.

tants, whose contributions he publicly acknowledged. The walls of the new public lecture hall built for his popular lectures was lined with totemic medallions of astronomical instruments (Fig. 2).

Unlike Laplace, Arago presented science as an open-ended exploration and dialogue. In his discussions of scientific findings he noted the difficulty of getting to know the properties of apparatus. He devised instruments to measure light and color intensity as a means of ascertaining the physical makeup of celestial bodies—the sun's gaseousness, the origin of moonlight, the physical nature of comets and planets. In ingenious experimental setups and instruments, discrete techniques were combined and redirected to fix on new phenomena, as in his cyano-polarimeter, a hybrid of telescope, polarimeter, and a device he invented to register the degree of blue in the sky (Fig. 3). Each representative of a specific range of phenomena mingled and cooperated with others in Arago's observatory, whose roof was crowded with apparatus for meteorological and atmospheric measures. Under Arago, the Observatory became a Humboldtian outpost in the center of the metropolis,

Fig. 3. Arago's cyano-polarimeter, built by Soleil © Collection École Polytechnique.

a crucial node in the global network that tied together a cosmic republic of observers, instruments, and the natural world[37] (Figs. 4 and 5).

Again and again the object of Arago's study was the *space between* the object observed and the observer, investigating the 'nature ... of the milieu crossed'.[38] This interest can be found in his early studies with Biot on the effect of different gases on the transmission of light, through to his later explanation of the scintillation of stars by their transmission through atmospheric layers of varying temperatures and humidities. To study these *milieux*, one needed to interrupt, divert or capture light with a regular 'interference'. For Arago, instruments were *media* which structured the *milieu* between the object studied and the observer in accountable ways.

[37] Aubin (2003); on the republican daydreams of Arago's assistants, see Levitt (Forthcoming).

[38] Arago (1854–1862d), p. 36.

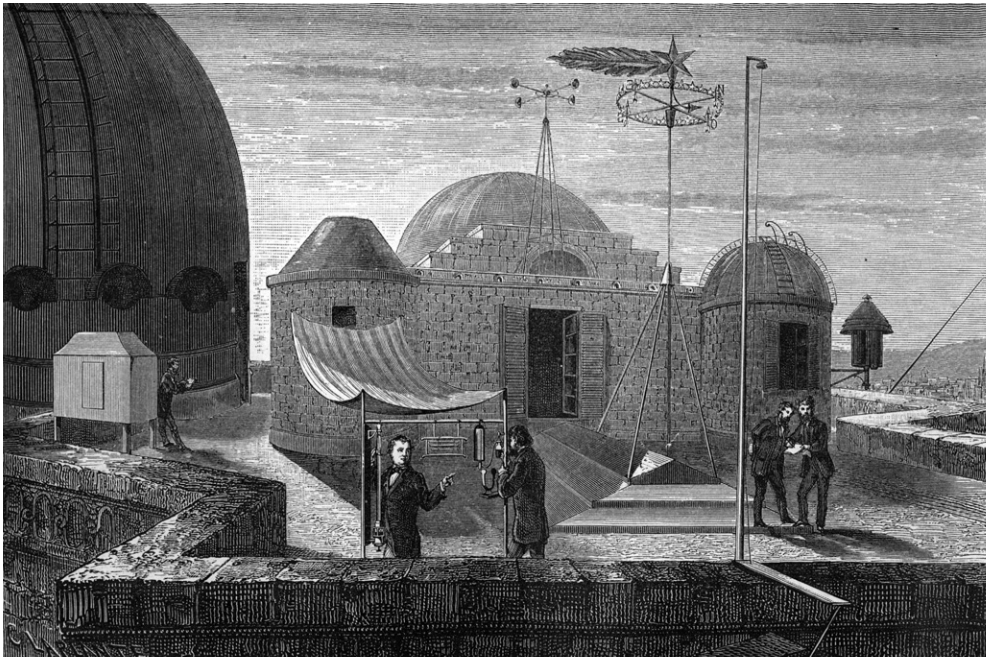
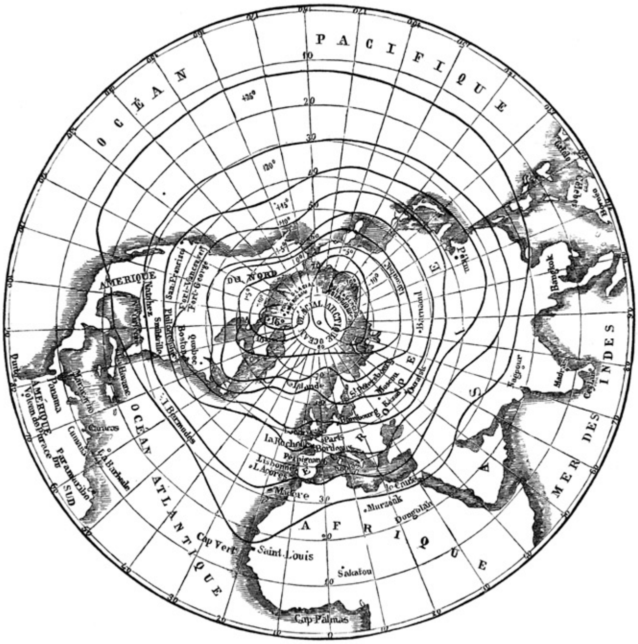


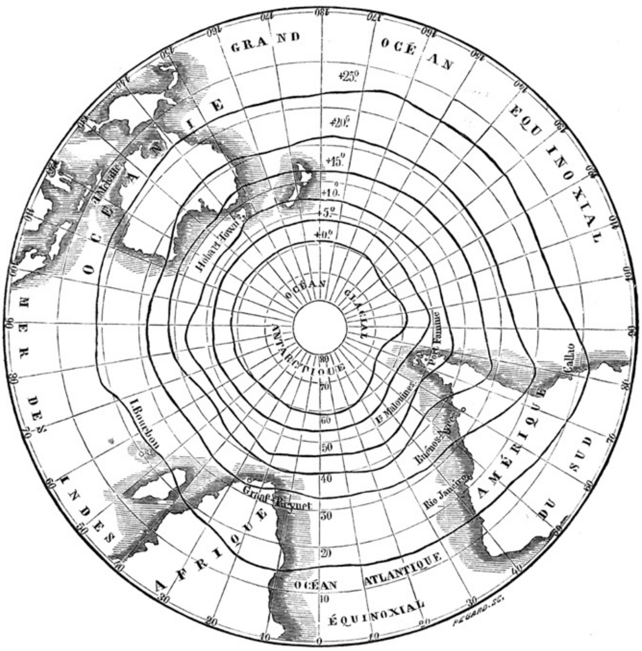
Fig. 4. Meteorological instruments on rooftop of Observatory of Paris © Observatoire de Paris.

According to the image Arago built up in his writings, Laplace presented the universe as a balanced system unslowed by resistance or friction; likewise, heavenly bodies could be known as points of light, observed by an abstracted eye in the astronomer's cabinet using obedient, unproblematically 'transparent' instruments. To the contrary, Arago had no illusions about an 'unmediated' vision. The human eye, like other optical devices, was an instrument with specific sensitivities and limitations: he referred to a variation on the daguerreotype as an 'artificial eye', and stated elsewhere that 'the eye may be treated as a lens having for its "focus" a screen of nerves named the *retina*'.[39] Like in Carnot's reflections on the transmission of forces, Arago made it clear that *something happens* at the interface between the object and the observer. He presented his instruments as specific modes of mediation and interference, which introduced *friction* and thus, in many respects, a *deformation* between the observer and the natural world. Yet just as the enthusiasm of the citizen-soldier in no way detracted from his zeal and ability to defend the nation, the deviation introduced by the instrument was not a hindrance to knowledge, but rather its necessary condition. Arago set his model of scientific sociability against the image of a closed echo-chamber of frictionlessly obeyed commands. His reign at the Observatory and over French science was marked by emotion, spontaneity, dialogue, and openness—qualities possessed by both humans and machines.

[39] Arago in Daguerre, Arago, Gay-Lussac, & Niépce, (1839), p. 43.



Lignes isothermes de l'hémisphère boréal, d'après la projection stéréographique.



Lignes isothermes de l'hémisphère austral, d'après la projection stéréographique.

Fig. 5. Global map of Humboldt's isothermal lines by Arago © Observatoire de Paris.

5. Instruments of the general will: Arago on workers and machines

Enlightenment era comparisons between human and machine could raise a fearsome specter of autocratic state control over individual bodies and minds.[40] Yet the concept of the machine with which Arago identified was not the Newtonian clock or balance. Instead, like Carnot's citizen-soldier or engine, or Humboldt's flexible and gregarious instruments, Arago's machines could combine disciplined regularity with spontaneity and freedom. He suggests just such an identification in his *Éloge de Carnot* as an example of the 'analogy that can almost always be pointed out between scientific theories and the rules of conduct of their authors'. In conversation he asked the retired statesman how he had maintained a steady course through the violent upheavals of the revolution; Carnot answered that he simply kept in mind his own theory of machines, which demonstrated that a sudden change of speed causes a greater loss of momentum than a gradual one.[41] In his own role as statesman, in a speech to the Chamber of Deputies in May of 1840, 'On electoral reform', Arago deployed a strikingly similar argument: gradual measures of reform were needed to avoid an uprising and to ensure a progress that would be 'constant, regular, without shakes, without violence'—precisely the language used to describe an engine whose speed changed incrementally and with maximum efficiency.

Steam engines, which underwent an explosive process of conversion in calculable and predictable form, were much more than a metaphorical resource for Arago. His interest in scientific instruments and was directly continuous with industrial applications of science: there was no difference in kind between an 'instrument', 'tool', or 'machine': he wrote, such a distinction is puerile: [it would be] impossible to say with precision where the tool ends and the machine begins'.[42] With Dulong and Petit he studied steam engines' pressure limits to establish safety standards and made himself one of the leading public advocates on the question of the proper role and social impact of steam technology. Taking the political stage in the late 1820s and the revolution of 1830, he updated revolutionary rhetoric concerned with *the people* to make his primary focus *the workers*.[43] Once elected as a Deputy, Arago spoke on behalf of this newly visible class; he advocated universal male suffrage and campaigned against slavery in the colonies and against the death penalty. In recognition of these stances, Arago was installed as one of the heads of the Provisional Government installed after the workers' revolution of 1848.

The central section of his much-reprinted biography of James Watt from 1834 was 'Machines considered in their relations with the well-being of the working classes'. He combats 'the opinion that machines are harmful to the workers' as 'an old prejudice without any current value, a true phantom' (p. 431). Against those who think that new machines take away the livelihood of workers, he cites contemporary political economy's arguments that because of the 'insatiable desire for well-being that nature has placed in the heart of men' (p. 443), increases in productivity and the subsequent lowering of prices result in a demand for more and more varied machine-produced goods. In printing and

[40] Cf. Foucault (1979), Schaffer (1999).
[41] Arago (1854–1862c). Arago's analogy anticipates Durkheim and Mauss's isomorphism between taxonomy and social structure in *Primitive classification*.
[42] Arago (1854–1862g), p. 438.
[43] During the Restoration and July Monarchy, claims of the importance of the Third Estate, inaugurated during the Revolution, were adapted into arguments in support of the new industrial working class (see Sewell, 1980).

cotton, labor-saving devices led to the vast expansion of their markets, resulting in a net increase in the number of workers employed and an improvement in their quality of life. Throughout the speech he bewails the British government for denying the epochal inventor Watt his rightful honors and recompense. His conclusion offers a starry-eyed vision of the benefits of steam: 'A time will come when the science of destruction will bow down before the arts of peace'; steam engines will let humans 'penetrate into the entrails of the earth', hollowing out 'spacious galleries and clearing them, in a few minutes, of the immense volumes that flooded them'. Railroads will connect distant regions; steamboats will cross the seas; all branches of each domain of production will be joined under a single roof. Even the 'steppes of Europe' will be covered with 'elegant habitations'; 'the population, well fed, well dressed, well heated, will quickly grow'. Echoing the obsession of his Saint-Simonian allies, Arago presents a utopia of *communication* and *circulation* where technological advances hasten the flow of goods and people across the territory's reticulated networks, drawing forth nature's wealth and renewing the earth itself.[44]

A line can be drawn connecting this speech to his discourse on the daguerreotype of 1839 and 'On electoral reform' of 1840: each incorporates the science of machines and support for inventors into a political program for improvement of the lot of workers. 'On Electoral Reform' warns about the political threat posed by the miserable conditions of the poor. The cause of their 'cruel sufferings' is mechanical industry's domination by a *très-petit* number of capitalists. He denounces his fellow deputies for tolerating these egoists; the 'monopoly Chamber', as it has been called, has 'duped and blinded the people'.[45] To defuse this explosive situation, Arago argues for giving the people a say in government by expanding the highly limited, plutocratic electorate to include all males. As proof of workers' merit, he lists their contributions to the common weal: Benjamin Franklin, the 'son of a poor artisan', invented the lightning rod 'which preserves and protects national edifices'; the looms of Lyon, steam engines, and the clocks and spyglasses used by sailors were all inventions from the 'class of artisans'.[46]

In this inventory, most striking is Arago's insistence on the epistemological contribution of worker-inventors: the *doing* and *making* of the laborer is also a *knowing*. As mentioned earlier, Arago drew attention to experimental apparatus and showed the interdependence between theory and the instruments which tested, shaped, and embodied it. Harmonizing his political and scientific commitments, we might call Arago's epistemology a *labor theory of knowledge*. In the first half of the nineteenth century the stigma formerly attached to physical labor was lifted; as part of the growing self-consciousness of the working class, artisanal work now appeared virtuous.[47] The term *travail* (either work or labor), is a key to the conceptual underpinnings of Arago's projects: he made himself a point of intersection between 'practice' and 'labor' as key elements of epistemology, the

[44] On p. 433, speaking of England's system of canals and railroads linking the entire nation for the rapid movement of goods, he exclaims: 'Voilà donc l'utopie des nouveaux économistes réalisée'.

[45] See Heurtin (1999), on 'le peuple toujours malheurese' as a recurrent topos in the rhetoric of the Chamber of Deputies of this period.

[46] In this speech, Arago may well be recalling his report on the daguerreotype: he had commented to Humboldt that he could see on one of Daguerre's first plates something he had never perceived with the naked eye: a lightning rod on the Louvre. The reference to Franklin—associated not only with artisanship but with the proper 'sensibility' to dynamic nature, also links Arago to a non-Laplacean enlightenment; see the starring role of Poor Richard in Riskin (2002).

[47] See Rabinbach (1990), Rancière (1989), Sewell (1980), Vatin (1993).

concept of 'work' as the central object of early thermodynamics, and 'labor' as a burning issue on the political agenda.

Arago's political speeches describe and demonstrate the ways in which his ideal citizen and statesman shares the virtues of the ideal scientific instrument or machine. As we saw above, his instruments were 'autonomous' in a quite specific sense: they were *disciplined* and *interconnected* but at the same time *spontaneous*, *active*, and *free*. His own conduct exemplified these values. As a deputy, Arago stood in an intermediary position: responsive to the interests of those who elected him, while acting in accordance with the demands of parliamentary procedure. Yet he was not a passive channel for these disparate demands. As seen by his often explosive performances in the chamber and in public meetings, fulfillment of his duty did not mean the suppression of his individuality, emotion, or personality. He presented the image of the obedient but enthusiastic citizen-soldier in a key of romantic individualism. As a dissenting deputy, he played the role of a 'useful interference', a notion he developed in his study of the polarization of light: he captured the ordinary course of government and redirected it in a constructive way.[48]

6. 'The dream has been realized'

The threads of Arago's commitments concerning science, machines, representation, and politics all weave together to form the background for the text for which he is now best known, his introduction of the daguerreotype in July 1839. Interest in photosensitive materials had been growing in preceding years, since experiments by Erasmus Darwin in England, continued by John Herschell and William Henry Fox Talbot. Despite the success of Daguerre and Niepce in discovering a process by which to fix the images in the *camera obscura*, they sought in vain for a purchaser until Arago agreed to promote the technique and to secure for the inventors a lifetime salary in exchange for making it available to the public. After a long campaign of tantalizing leaks to the press, Arago at last announced the discovery to the world in the Chamber of Deputies to great fanfare. The text of his speech was immediately reprinted along with a copy of the law granting the lifetime salary to the inventors, a briefer report by Gay-Lussac, technical drawings, and instructions for use. Arago's speech has become a classic reference in the history of photography.

The aesthetic, moral, and political contexts we have discussed are indexed throughout Arago's presentation. Arago explains technical details: a silver-coated plate, made light-sensitive by an iodine treatment is placed at the back of a camera obscura and exposed to light passing through a lens for up to an hour. Exposure to a mercury vapour develops an image on the plate, and a salt water solution fixes it. The resulting images appearing on this reflective background were visible only from certain angles and distances, giving them a spectral and ghostlike quality.[49] But as suggested by the images which Daguerre originally offered Arago (a satyr and nymph by a fountain, an image of Eve and Venus, and

[48] On the political and aesthetic implications of the dialectic between individual and collective in French Romanticism, see Sharp (2004) and Breckman (2005).

[49] Paper and digital reproductions of daguerreotypes thus fail to render their actual impact; they must be seen in person. A recent exposition at the Musée d'Orsay and the Metropolitain Museum of Art made it possible to come face to face with the daguerreotype's crystalline eeriness in an unprecedent collection of early plates. See Bajac et al. (2003).

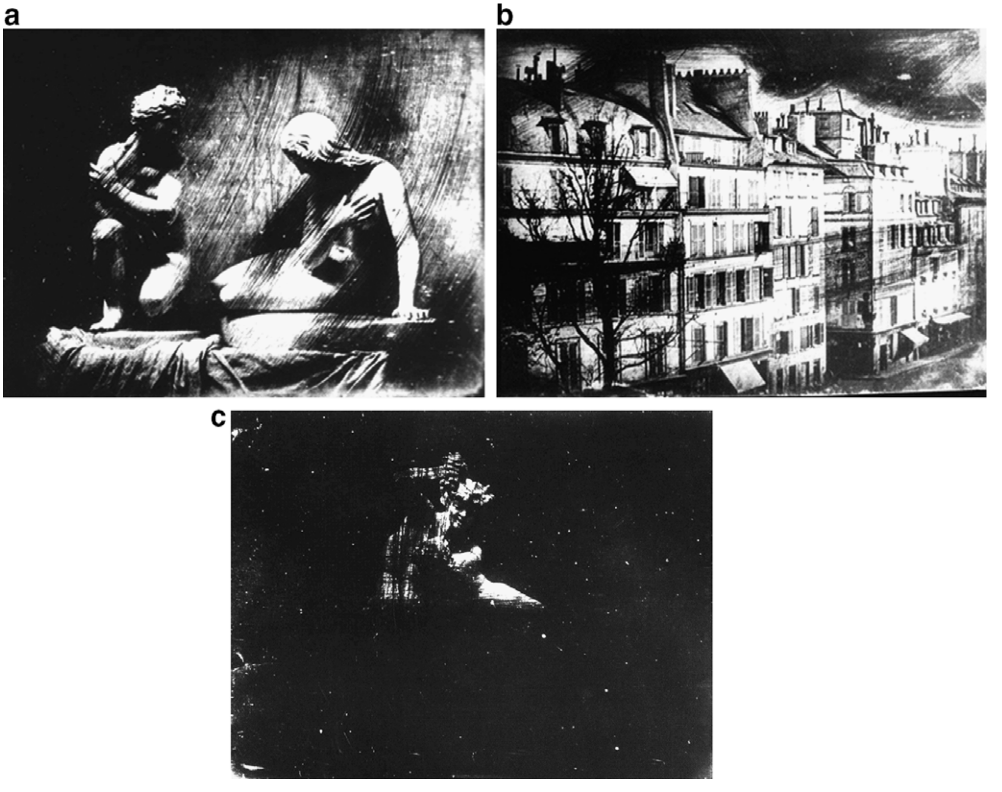


Fig. 6. Triptych offered to François Arago, by Louis Jacques Mandé Daguerre, Collection du Musée des Beaux-Arts Hyacinthe Rigaud Perpignan, photo Ville de Perpignan.

between them a view from the artist's atelier—a series which juxtaposes classical, Christian, and contemporary figures of creation), the daguerreotype was immediately recognized as more than a technical object (Fig. 6). Accordingly, his speech is much more than a technical report.

By setting the speech in the Chamber of Deputies, not the more exclusive setting of the Academy of Sciences, Arago is consecrating the daguerreotype in a ritual of the state conducted, he says, only 'in the name of national glory' and for achievements which occupy a 'very elevated region'.[50] He makes the discovery the final chapter of a history which begins with 'the Neapolitan physicist [*physicien*], *Jean-Baptiste Porta*'; Arago presents Renaissance magician Della Porta as a founding figure of his own profession, *physicien*. He discusses discoveries concerning metals and chemicals made by early alchemists—many of whom considered metals living substances—and the explorations of silver chloride conducted by the romantic chemist Humphry Davy. Della Porta and others, he says, dreamed of finding a way for the lines that the camera obscura drew on a wall to be fixed by themselves, 'a dream that was destined to find its place among the extravagant conceptions of a

[50] Arago in Daguerre, Arago, Gay-Lussac, & Niépce (1839), p. 20.

Wilkins or of a Cyrano de Bergerac'. With the daguerreotype, in the age of mechanical science, 'the dream has been realized'.

Having shown the technique's history and its novelty, he moves to its utility, suggesting it for use in inventorying monuments of France, noting with regret that it was not available for Napoleon's survey in Egypt. Recall that Egypt was an important topos for thinking about nature, language, and knowledge throughout the eighteenth century; it was often suggested that hieroglyphics might contain the secrets of the Pharaoh's magicians, such as their power to endow inanimate objects with life.[51] Egyptomania was renewed with Napoleon's expedition, the primal scene for Monge's surveyors and engineers. The daguerreotype is thus set within the strangely complementary projects of an illuminist decoding of nature, imperial expansion, and the mapping of the national territory. The device, Arago notes, can preserve certain 'nearly mathematical' relations, useful for drafts or for surveying; the dimensions of the plate, for instance, were assumed to be proportionate to the actual sizes of objects represented.[52] Yet these elements of 'immutability' constantly vie with subjective, affective, or physiognomical impressions. In Arago's speech the daguerreotype's *photochemical effect* merges with its theatrical, dramatic, *aesthetic effect* on the viewer.

For Arago, the daguerreotype's aptitude for utilitarian functions did not diminish its aesthetic power. He quotes the testimony of the academic painter, Paul Delaroche, to allay the fears of those who see the technique as a threat to artists and engravers. Instead, 'the admirable discovery of M. Daguerre is an immense service rendered to the arts' (p. 20) as it provides them more exact models. Delaroche emphasizes that 'the correctness of the lines, the precision of the forms is as complete as possible in the plates [*dessins*] of M. Daguerre, and we see in them at the same time a large, energetic model, and an ensemble as rich in tone as in effect'. In what could be read as a combination of classicism and romanticism—two styles Delaroche reconciled in his own painting—he sees the geometrical precision of the image not as inhuman and affectless, but rather as the basis for its dynamic and aesthetic impact. Similarly, recent critics have shown how formal aspects of daguerreotypes were continuous with the ambitions of romantic painting: to capture a meaning-rich experience of nature based on meticulous observation of natural scenes.[53]

At last Arago concentrates on specifically scientific uses. In photometry, daguerreotypic effects allow for the measurement of relative intensities of light: instead of comparing, with difficulty, the brightness of a star against an imperfect artificial light, the physicist now 'will compare lights by their effects'. As was the case in many fields of physics at this time, the research process is presented as an encounter staged with instrumental apparatus, generating artificial phenomena whose relations can then be analyzed: experiment as production of effects.[54] Furthermore, in photometry the daguerreotype must combine with another set of tools to measure its development times and brightness; the new instrument

[51] See Assmann (1997), including discussion of Humboldt's frontispiece of Isis; on metals, mummies, and automata, see the fascinating Nelson (2001).

[52] He anticipates using daguerreotypes as part of descriptive geometry 'to scale up to the exact dimensions of the highest and most inaccessible parts of edifices' (Arago in Daguerre, Arago, Gay-Lussac, & Niépce, 1839, p. 20).

[53] Nochlin (1971), Galassi (1981), Rosen & Zerner (1984), Recht (1989).

[54] Bachelard's theory of 'phénomènotechniques' as the production of effects arises principally from his studies of immediately post-Laplacean electricity and chemistry; he argues that the chemistry of this time created an 'artificial nature', finding support in Comte's view of science as an artificial system of links established among phenomena. On Comte, see Bachelard (1927).

does not stand alone, but is immediately understood as an element in the integrated apparatus of the observatory. Other scientific uses Arago suggests are set firmly among the Humboldtian field sciences: topographical surveys and a map of the moon. Another application entirely bypasses the image's content. Noting that the plates develop at different rates depending on the time of day and the location, he suggests that:

> the meteorologist would have one more element to include in his *tableaux*, and to the former observations of the state of the thermometer, the barometer, the hygrometer and of the transparency of the air, he will have to add an element that the other instruments do not grasp, and he will have to take account of a particular absorption, which cannot be without influence on many other phenomena, even on those touching on physiology and medicine.[55]

Here he is not interested in the object depicted on the silver plate, but rather in what the process of its development tells about the invisible atmospheric phenomena that make it appear. Rather than reproducing what the perfect, unbiased human eye would see, the daguerreotype registers *invisible* phenomena by keeping track of the time it takes to unfold *as a process*.[56] This dimension of the instrument's sensitivity is *not* inscribed in the image itself, but is indexed by the time it takes to develop. In short, the daguerreotype was presented by its first public supporter as another member of the family of Humboldtian geophysical instruments—another temperamental, site-specific, and networked tool for registering a specific range of phenomena and mapping cosmic milieux.

7. Reflections on transparency and reciprocity

Arago's quickly reprinted and much cited discourse invites a more detailed reflection on his sense of the epistemology of the daguerreotype and on the place he assigned it in science and society. Above we noted that Arago's instrumental regime foregrounded the technical, laborious, and transformative aspects of scientific research; this 'labor theory of knowledge' contrasts with the tendency in public representations of science to hide or minimize labor and artifice so that experimental facts appear to speak as the unmodified voice of nature.[57] Arago's emphasis on process and transformation also applied to the daguerreotype, which was for him a peculiarly dense, active, and idiosyncratic mediation between natural objects and human viewers. Recent writings on early photography have, however, stressed its putative *transparency*. In an admirable study, Theresa Levitt argues that Arago in 1839 took the daguerreotype as 'an unproblematic representation of the

[55] For scientific background, see Barger & White (1991), especially p. 27. See also comments on Arago's speech by Walter Benjamin (1955), p. 17. Above all, see McCauley (1991) which, if discovered earlier, would have spared me considerable effort.

[56] Levitt (2003) quotes very similar lines from Biot, who used exposures on paper to explore the action of 'invisible radiation'. But whether Arago is borrowing from his rival Biot or, instead, continuing Humboldtian field science's patient analysis and mapping of atmospheres (or *milieux*), the quote shows that Arago appreciated the daguerreotype in part as *an inscription of the invisible*. For a thought-provoking discussion of photography and cinematography as an inscription of a dimension of reality otherwise inaccessible to humans (and not as the fixation of the viewpoint of an ideally non-intervening human observer), see Snyder (1998). Thanks to Joel Snyder and to Theresa Levitt, whose insightful articles and conversations have been very helpful.

[57] On the *invisibility* of scientific labor, see Shapin (1989); on its *visibility* in the public representations of Arago, see Blondel (1997).

thing it depicted', an image which 'could easily be used to stand in for the world' (p. 457). In this analysis Arago's daguerreotype conforms to Daston and Galison's notion of mechanical objectivity as a 'neutral, transparent operator' free of human intervention.

When speaking of a technique which presents images of natural objects, two distinct, though frequently combined notions of 'transparency' may be implied. First is the notion that the technique produces a faithful, unmodified visual image of the objects of the world. One frequent claim about photography is that the image of nature it produces is in principle verifiable by simple comparison with the object as we see it with unaided eyes. Yet such resemblance is necessarily incomplete in any photograph, and strikingly so in daguerreotypes. Colors are altered, movement is lost, a landscape is reduced to a few square centimeters; *truly perfect* imitation of the world would be indistinguishable from the world. Though obvious, the point bears mentioning as the fascination for daguerreotypes in the 1840s derived in part from their *difference* from the objects they represented—between a three dimensional, full color, immersive setting and a static, reflective, two-dimensional image. Even if certain proportions were maintained, the image was in fundamental ways a deformation, not a 'transparent' reproduction of the world. Similarly, in a footnote to the printed discourse, Arago offers hypotheses on its mode of action: what occurs is not transparency but *transmutation*.[58] To describe the operation he repeatedly uses language of activity, vitality, and transformation, speaking of 'the action of light', 'penetration', and a 'sensing substance': 'the most feeble rays of light modify the substance of the Daguerreotype'. During development, the 'operator' of the technique can see 'the mercury vapor, like the most extremely delicate pincer, mark each part of the plaque with the appropriate tone'. Far from passive transmission of visible properties, Arago describes an *active modification*. The idea of transparency as visual resemblance is further undermined by Arago's reference above to the 'peculiar absorption', where the relevant observation was the *time taken for exposure*, not the image developed. As with the photometric observations of Foucault and Fizeau, this 'daguerreotypic effect' is indifferent to mimetic representation; it is a photochemical process whose interesting feature is its *duration*.[59]

Alternatively, *transparency* can mean that a technique or instrument's use has become so much a part of social convention that any disputes about it have reached 'closure'; it has been 'black-boxed', with its mode of action taken for granted: 'Closure makes instruments into what are seen as uncontestable transmitters of messages from nature, that is, it makes them "transparent"'.[60] As long as outputs follow inputs in a regular way, unresolved questions about the details of an instrument's operation may be ignored. In this sense, the process of fixing the images in the *camera obscura* was indeed a black box. According to Arago, this 'mysterious' process displays 'many curious phenomena' (p. 18); his hypotheses about the interaction between the dynamic forces of iodine, silver, mercury and light are so many submolecular fantastic symphonies. He concludes that 'we will

[58] Arago in Daguerre, Arago, Gay-Lussac, & Niépce (1839), pp. 7, 17. Though not actually spoken by Arago in the Chamber, this footnote was prominent in the published text, which for most was the primary site of reception: Daguerre immediately had Arago's discourse printed up along with instructions on the process, a testimonial by Gay Lussac, and his business address, as Daguerre, Arago, Gay-Lussac, & Niépce (1839).

[59] As Levitt shows, in Foucault and Fizeau's experiments, the intensity of a given light source was established not by the brightness of the image produced, but by the *time it took to develop* to a standard degree. See Levitt (2003), p. 470.

[60] Schaffer (1989), p. 70, referencing Pinch (1986), pp. 212–214.

make perhaps thousands of beautiful drawings with the daguerreotype before its mode of action will have been completely analysed'. However, the daguerreotype was definitely *not* a black box, if by that we mean a rapid, automatic, and completely predictable passage from input to output. Many steps were required before photography was seen as a reliable, automatic technique in astronomy, before stars could 'register themselves'.[61] In 1839, the time for development was still thirty to forty-five minutes, varying widely according to atmospheric conditions. Though Arago noted the ease of the process, he was immediately rebuked in reviews in the *Journal des Débats*, which asserted a much steeper learning curve.[62] Moreover, Arago deliberately downplayed the possibility of making portraits, the most hotly anticipated use, because of the difficulty of getting subjects to sit immobile for six to twelve minutes in bright sunlight. Finally, mass reproduction was out of the question due to the 'delicacy' of the process: it would be impossible, he said, to use the silver plates themselves as stamps for lithography, as the rolling press would destroy them. 'But', he wondered, 'would anyone imagine giving a strong pull on a band of lace, or of scrubbing the wings of a butterfly?' (p. 22). Rather than emphasize the rigid repeatability of the process or the sturdiness of its product, he compared the daguerreotype to lace and butterfly wings, the most fragile of artisanal and natural creations.

The daguerreotype fused the aesthetic and the cognitive, the fleeting and the fixed. Like the citizen who is at once autonomous and completely dependent on the nation, the unique properties of the daguerreotype allowed it to participate in an existing network of instruments and researchers, and, at a higher level, in the 'moral economy' that Arago worked to establish in French science after Laplace. Much writing about nineteenth-century science has focused on strategies of professionalization and exclusion.[63] From such a perspective, scientists' growing reliance on technology is another strategy for disqualifying and keeping the public out of the halls of science; the *epistemic* detachment emphasized in nineteenth-century objectivity can be understood as contributing to science's *social* detachment as well.[64] The moral economy established by Arago, however, circulated within a much broader social space than laboratories, universities, and qualified audiences. The term 'moral economy', recently retrieved in history of science by Robert Kohler and Lorraine Daston, was coined by Marxist historian E. P. Thompson, for whom it meant the assumed obligation of the wealthy to guarantee the basic subsistence of the poor; as in Arago's argument in 'Electoral reform', violation of this tacit agreement justifies revolt.[65]

In his *Essay on the gift*, Marcel Mauss argued that *all* economies are moral economies: that material exchanges are a vessel for the redistribution of status and esteem and a

[61] Rothermel (1993), Schaffer (1995), Pang (1997).

[62] See 'Le daguerrotype' (sic), article of Alfred Donné of 1839, in Bajac et al. (2003), p. 386: 'Cette parole de m. Arago a dû rassurer bien du monde; mais il nous a néanmoins paru curieux de nous rendre compte par nous-mêmes de difficultés du Daguerrotype en nous mettant de suite à l'oeuvre et en suivant de point en point les renseignements si bien décrits par M. le secrétaire de l'Académie ... Les premières expériences ont donné un résultat à peu près nul'.

[63] See for example, Yeo (1993), Gieryn (1999).

[64] Daston (1995) suggests that such detachment is a general tendency of modern science. Scientific boundaries are permeable to social values, but we should expect primarily a 'one-way' communication: 'although moral economies in science draw routinely and liberally upon the values and affects of ambient culture, the reworking that results usually becomes the peculiar property of science'.

[65] Kohler (1994), Daston (1995), Thompson (1971).

means of structuring social relations.[66] Arago's presentation of the daguerreotype was an overdetermined move along Maussian lines. It manifested a complex system of reciprocal relations—at once symbolic and material—linking inventor, science, government, and people. In sponsoring the pension for Niepce and Daguerre, Arago, the broker of this exchange, guaranteed a recompense and gave lasting credit to Daguerre by immortalizing his name. Similarly, in exposing the device to a much broader public, he acknowledged the debt of an intellectual elite toward the productive labor of the rest of society—a debt he also repaid with his promotion of electoral reform and his popular lectures and lessons on mechanics for workers, which gave the people access to intellectual and political capital to improve their condition. Finally, by ensuring the priority of Daguerre and Niepce and recognizing the invention as *French*, Arago's intervention became a patriotic act of republican piety, a gift for the glory of the nation.

The introduction of photography has been associated with Laplacean mechanism in physical theory, scientific discipline, and research style; it has been inscribed within a drive for automatic, rigidly repeatable, aesthetically neutral and transparent modes of representation which avoid the passions and variability of humans; finally, it has been seen as a prop for patrolling the border between professional scientists and other knowledge-makers and audiences. Examples from later in the century can be gathered to support all of these readings. However, a different set of possibilities can be disclosed in the daguerreotype and other new machines of this period. Arago introduced photography to the world as a dynamic, aesthetic, and mysterious process; he wove it together with diverse practices for grasping cosmic milieux, and integrated it into political projects reconciling individuality and the needs of the collective, where science served the aim of social renewal.

8. Technologies of transmutation

We may conclude by setting Arago's act of framing within the broader historical frame of French culture and politics leading up to 1848. Arago's emphasis on the mystery involved in the photographic process—heightened in later popular writings—suggests a kinship between its reception and the metaphysical excitement generated by the experiments devised by Oersted, Ampère, and Arago demonstrating the convertibility of electricity into magnetism.[67] Similar commotion met the arrival of railroads and other technologies based on the conversion of fire into motion through the mercurial medium of steam. Much of the fascination for these romantic machines lay in their status as a *processes*, as a technologies of time.[68]

The daguerreotype, the precision instruments of geophysics, and the steam engine, I suggest, participate in a widespread *fluid imaginary* which flowed across disciplinary boundaries in the 1820s, 30s and 40s. This reservoir of ideas and images implied the

[66] Mauss (1990). Studies of early modern science have made use of Maussian analyses of gift exchange (see Biagioli (1993), Smith (1994)), but historians of science have rarely addressed similar processes in the 'rationalized' sciences, states, and public cultures of the nineteenth century and twentieth centuries. See however Latour (1999), Chapter 3.

[67] Krauss (1978); see also Gunning (1995).

[68] Daguerre had earlier set scenery into motion with his *Diorama*, where day changed to night and summer to winter. Niepce also had a history of interest in technologies of motion and conversion: in 1811 Lazare Carnot reported to the Academy of Sciences on an engine which gathered its energy from the heat differential between itself and cold air, invented by none other than Niepecore Niepce and his brother, as noted in Gillispie (1971).

possibility of connecting light, heat, electricity, magnetism, and at times thought and vital force into a single framework or principle. Such themes arose not only in physics—in the measurement of imponderables and the sciences of the *milieu*—but also in reflection on 'social forces' as in Comte's sociology, in post-Lamarckian natural history's vitalism and transformism, in the fantastic literature, and in popular discourses on magic and mesmerism.[69] Without endorsing all possible connections among these fluids, Arago deliberately kept such interpretive channels open. Just as he had called Della Porta a *physicien*, Arago's allusion to 'myriad new worlds' recalls pantheist strands of Renaissance cosmology, which promised the transmutation and conversion of a universal principle through secret techniques and technologies. Steam engines and electromagnetic or chemical apparatus were imaginatively understood as just such conversion technologies; the daguerreotype was one of the brightest stars in this periodically recurring constellation. On Arago's flirtation with radical, pantheist, natural magic implications of 'multiple worlds', see Crowe (1986). For a provocative philosophical consideration of photography as a technology, see Maynard (1997).

A new cosmological attitude took shape in Paris at the start of industrial modernity, grounded on the fertile notion that nature can be remade by human technologies, concepts, and actions. To make sense of this change, precedents were found in the past: fantastic literature abounded with tales of alchemy and natural magic which directly and indirectly referenced contemporary science and technologies. Balzac's *Quest for the absolute*, for example, was a Faustian tale of a chemist in the early 1800s mocked as an 'alchemist' when he meets his tragic end; a model for the protagonist may have been Ampère or Arago himself, who often hosted the author of *The human comedy* at the Observatory. Similarly, in the 1830s, sculptor Dantan Jeune caricatured Arago as a sorcerer, holding telescope and compass in place of magic wand, perched on his observatory castle tower, commanding a globe crisscrossed by railroads and illuminated by the lighthouse lenses he helped Fresnel invent (Fig. 7). In such images, modern mastery over the secrets of nature, exemplified by France's leading scientist, was depicted as a return to the claims of Renaissance natural magic.[70] At its introduction, the daguerreotype was received as another such spiritual technology: Balzac and Gérard de Nerval (fantastic novelist, poet, and translator of *Faust*) were reluctant to have their portraits taken by daguerreotype, out of fear that the image would capture the outer ethereal layer of their spirit.[71] Arago did not always discourage such *rapprochements* between science and magic. He included discussions of astrology and multiple worlds in his *Popular astronomy*. Though apparently satisfied with the report of the Commission on mesmerism of 1784, Arago undertook his own investigation of the new claims of mesmeric clairvoyance in the 1820s and 30s, declaring that 'somnambulism must not be rejected a priori, especially by those who have kept up to date with the most recent advances in the physical sciences' and urging continued investigation of animal magnetism.[72] At this time, the line between fluids proper to *physiciens*

[69] His alignment with Geoffroy Saint-Hilaire against Cuvier in the famous debates of 1830 traces a major fault-line in post-revolutionary French science: the opposition between the naturalists matches that between the astronomers. See Appel (1987).

[70] On Renaissance technology as magic, see Eamon (1983); on the Romantic reappropriation of this view, see Charles (1997).

[71] See Krauss (1978), Gunning (1995).

[72] Arago (1854–1862a), p. 315.

Fig. 7. Statue of François Arago by Dantan Jeune © Musée Carnavalet.

and those which were mere phantasmagoric illusions was up for grabs. While pursuing techniques of precision and mechanical analysis and in certain respects remaining committed Newtonians, Arago and many of his contemporaries nevertheless put mechanism and machines to work towards higher, even transcendental goals of cosmic unity and transformation. It is possible to perceive the same hope for a fulfillment of a magical past in the quote from Victor Hugo at the start of this article, which assimilated the hot air balloon and democratic revolution to a transmuted 'cosmic egg', a symbol whose alchemical resonances are hard to miss when read alongside Hugo's reveries about his visits to Arago's Observatory.[73]

The sciences and technologies of the early industrial age were often seen not as enemies and vanquishers of magic and alchemy, but as their fulfillment. Yet against common views of 'romantic science', the utopian valorization of poetry, aesthetics, emotion and individuality was not a dead end or historical curiosity, not a minor detour in the unstoppable progress of rationality; closer study reveals the diverse and lasting impact of romantic assumptions and attitudes on mainstream science and society. We might say that science offered techniques of manipulation of nature's hidden powers so successful that they no longer needed to be kept secret: to mangle two concepts of Max Weber, this period witnessed a *routinization of enchantment*. In its fascination with the uncanny aspects of machines and mechanical procedures we may note a complementary *enchantment of routine*.

At the beginning of industrial modernity, scientists and engineers, politicians and artists gave increasingly emotive, aesthetic, and utopian turns to rational and technological projects. They developed new machines to frame, organize, and make use of natural forces in order to harmonize and remake the social and natural worlds. One such instrument was the daguerreotype, which balanced delicately among diverse segments of society, the range of geophysical instruments, and between humans and the shimmering phenomenal surface of nature. In its first frame, it offered an image—precisely scaled down, yet singular, flexible, and autonomous—of its presenter and its world.

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[73] Hugo (1993).

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