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## Establishing Commensurability: Intercalation, Global Meaning and the Unity of Science

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*In the face of disunification and incommensurability, how can the scientific community maintain itself and (re-)establish commensurability? According to Peter Galison's investigations of twentieth-century microphysics, commensurability is achieved through local coordination even in the absence of global meaning: The "strength and coherence" of science is due to diverse, yet coordinated action in trading zones between theorists and experimenters, experimenters and instrument builders, etc. Galison's claim is confronted with Georg Christoph Lichtenberg's establishment of commensurability between unitarians and dualists in the eighteenth century dispute about electrical fluids. The contrast of cases suggests an alternative account: Commensurability may be established through the global coordination of local meaning. And where Galison reifies the disunification of science, this account suggests a dynamic interplay between de facto disunification and an intended unity. This interplay is manifested in the pervasive and ongoing practical concern for the conditions of successful communication in a science that is constantly in-the-making.*

### I

In recent years, much of History, Philosophy, even Sociology of Science consisted in attempts to balance two competing historical intuitions:

- Incommensurability arises as a matter of course from the underdetermination of theories by the evidence, *i.e.*, whenever even agreement on the facts allows for disagreements concerning the adoption or abandonment of a theory or research programme. To the extent that each research programme provides evaluative standards which inform judgements concerning its advancement, no research programme provides an internal standard for its abandonment or the surrender of those standards themselves.

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Competing theories, paradigms, or traditions thus prompt divergent courses of action and interpretation in the light of problematic evidence.<sup>1</sup>

- Science as we know it, that peculiar human enterprise which gave rise to a Philosophy of Science in the first place, is characterized by a remarkable ease of consensus-formation. “Normal science” appears to provide communal protocols, procedures, routines for decision-making and the assessment of evidence; it presupposes the commensurability of competing explanatory hypotheses or interpretations of evidence.

Peter Galison reflects on this tension when he registers the need to

make sense of how physicists often experience coherence in physics as a whole even while registering breaks in theory at some times and experiment or instrumentation at others.

On the face of it, his own work on *Image and Logic* traditions in microphysics complicates the task. It confronts the experience of coherence or the “felt continuity” of physics with a disunified array of multiple subcultures, communities of theorists, experimenters, engineers, data analysts. Galison continues:

[I]f, as I argue, the differences between these various subcultures are powerful—if they use concepts in only partially overlapping ways, if they ascribe dissimilar weights to certain forms of demonstrations, if they attend different meetings and even publish in different places—then aren’t we faced with incommensurability multiplied over subcultures as well as over time?<sup>2</sup>

1. Cf. Alfred Nordmann “Comparing Incommensurable Theories: A Textbook Account from 1794,” *Studies in History and Philosophy of Science* 17:2 (1986), 231–246. While that earlier article detailed how Georg Christoph Lichtenberg failed to negotiate the incommensurability of phlogistic and anti-phlogistic chemistries, the present paper shows how he successfully established commensurability between competing theories of electricity.

2. Peter Galison “Introduction: *Image and Logic—A Material Culture of Microphysics*,” *Metascience* 8:3 (1999), 357. In his review of *Image and Logic* Joseph Pitt emphasizes the continuity between Kuhn and Galison. According to Pitt, Galison fills in historical detail for the Kuhnian insight “that as science changes, the meanings of key concepts by which we characterize science also change. [ . . . ] what we count as scientific knowledge has changed, and likewise what counts as a scientific explanation and as an experiment,” cf. *Science, Technology, & Human Values* 24:2 (1999), 296. This continuity renders all the more interesting that Kuhn and Galison disagree on the question of incommensurability.

Despite its emphasis on disunity, *Image and Logic* answers “no” to this question and offers an account of how coherence can arise within a disunified material culture. Galison therefore rejects the positivist intuition that the history of science consists of a succession of discontinuous theories all of which are grounded in a single continuous basis of observation and experiment. He also rejects the opposing view of Kuhn, Feyerabend, and other anti-positivists that nothing persists in the succession of radically different worlds where breaks in theory are attended by simultaneous breaks in observation and experiment. Instead Galison proposes the central metaphor of intercalation where conceptual breaks do not coincide with breaks in instrumentation and where breaks in instrumentation do not coincide with breaks in experiment and observation.<sup>3</sup> Against the positivists Galison does not privilege a reduction basis in experiment and observation, but against the antipositivists his model posits “partially overlapping strands” which explain the physicists’ “felt continuity” of physics as a whole. While it would be wrong to conceive of physics as a static and unified whole, the intercalation of practices establishes linguistic resources sufficient to fend off the threat of incommensurability. According to Galison, incommensurability at the “global” level of theory and theoretical concepts is rendered innocuous by locally shared meaning as established through non-, or pre-, or sub-theoretical pidgin or creole languages:

[B]etween the scientific subcultures of theory and experiment, or even between different traditions of instrument making or different subcultures of theorizing, there can be exchanges (coordinations), worked out in exquisite local detail, without global agreement. Theorists and experimenters, for example, can hammer out an agreement that a particular track configuration found on a nuclear emulsion should be identified with an electron and yet hold irreconcilable views about the properties of the electron, or about philosophical interpretations of quantum field theory, or about the properties of film. [...] At first blush, representing meaning as locally convergent and globally divergent seems paradoxical. On one hand, one might think that meaning could be given sentence by sentence. In this case the global sense of a language would be the arithmetical sum of the meaning given in each of its particular sentences. On the other hand, the holist would say that the meaning of any particular utterance is only given through language in its totality.

3. Peter Galison “History, Philosophy, and the Central Metaphor,” *Science in Context* 2 (1988), 197–212; Peter Galison *Image and Logic*, Chicago: University of Chicago Press (1997), pp. 784–803.

There is a third alternative, namely, that people have and exploit an ability to restrict and alter meanings in such a way as to create local senses of terms that speakers of both “parent” languages recognize as intermediate between the two. The resulting pidgin or creole is neither absolutely dependent on nor absolutely independent of global meanings.<sup>4</sup>

In *Image and Logic* Galison therefore refrains from speaking of two paradigms with incommensurable languages which would require but do resist translation from one into another. Instead, he speaks of two competing traditions with divergent claims on global meaning, with multiple trading zones among and between them. Movement across boundaries does not involve translation but the coordination of action in the trading zones and the concomitant establishment of local languages.<sup>5</sup> Interactions in the trading zones, interactions between theoretical physicists and experimenters, experimenters and instrument makers, lab technicians and engineers, lab directors and funding agencies allow for physics to move beyond the competing image and logic traditions toward a synthesis, a move accompanied by the consolidation of various pidgin languages into creole and finally proper languages for new scientific subfields.<sup>6</sup> Viewed from these trading zones, *i.e.*, from where the action is, “science is disunified,” but that disunity is “patched together through a quilt-work of locally-shared practices.”<sup>7</sup> Indeed, Galison does not regard ‘science’ as a theoretical ideal which prompts action and brings the various traders together. Nor is it subject of negotiation between subcultures, it is not in-the-making. Instead Galison provides a static definition of a dynamically conceived science by reifying the apparent disunity of scientific practices at any given

4. *Image and Logic*, pp. 46f.

5. *Ibid.*, pp. 810 to 840, *e.g.* p. 833 (emphasis in the original): “*The physicists and engineers { . . . } are not engaging in translation as they piece together their microwave circuits, and they are not producing ‘neutral’ observation sentences: they are working out a powerful, locally understood language to coordinate their actions.*” Cf. also p. 664: “Between the standardizing Ansatz of Feynman and the ‘explanatory’ fundamental phenomenology of Buchanan lay vast philosophical differences: global differences in meaning ran riot. That the various practitioners could agree to the local coordinative mission of a ‘shoot-out’ is the sign of the long-sought and often elusive coordination. It was commensurability bought at the price of a vast amount of work.”

6. Cf. Galison, “Introduction” (note 2 above), p. 360, *cf.* also p. 358: “Slowly, painfully the physicists combined their conceptual objects with the algebraic-manipulative strategies of the engineers for circuit design. If the ‘lexical’ structure came from the more powerful physicists, the ‘grammar’ (algebra of combination) came from the engineers. [ . . . ] the Rad Lab pidgin [became] recognizable as a new field: ‘microwave physics.’”

7. *Ibid.*

time: Science is “an intercalated set of subcultures bound together through a complex of hard-won locally shared meanings.”<sup>8</sup>

*Image and Logic* therefore extends a familiar, though somewhat amorphous argument concerning scientific realism and applies it to the problem of incommensurability. If the succession of paradigms invites skepticism regarding the reality of theoretical entities, the relative stability of laboratory practices and experimental phenomena may allow for the “instrumental realism” suggested by Ian Hacking, Davis Baird, Don Ihde, and others. Recognizing that to these laboratory practices correspond linguistic practices, Galison aims to dispel also the specter of incommensurability as a problem that invites skepticism.<sup>9</sup> One might therefore look to *Image and Logic* for a model, if not a theory, of how commensurability is established and how consensus-formation becomes possible.

When representatives of divergent traditions come to an agreement or discover a common practice, they are *somehow* helped by the fact that they “*nonetheless* shared other strata of belief about calculation and laboratory procedure.”<sup>10</sup> It is at the heart of the problem of incommensurability, however, that living together in a shared physical world and having *some* shared beliefs may be insufficient for the resolution of the question at hand, that different paradigms or traditions can integrate shared beliefs in divergent interpretations of the phenomena. Galison does not propose an invisible hand by which commensurability arises magically from encounters in trading zones, as if the coordination of action, a shared world, and some shared beliefs render sustained disagreements about the interpretation of facts impossible. Unlike Andrew Pickering, Galison is also not proposing that the disunity of subcultures and practices makes it impossible to predict how and when commensurability might arise. Instead, he concludes his book with a call to move beyond the metaphor of intercalation, of science producing sturdy cables from numerous flimsy strands: “All metaphors come to an end.” What are the sufficient conditions for the establishment of commensurability, what needs to be done, what sorts of

8. *Image and Logic* (note 3 above), p. 840. Galison’s reification of science as a heterogeneous set of practices issues from his methodological commitment to the “material culture” of microphysics. This commitment appears to preclude the recognition even of materially situated regulative ideas.

9. In his review of *Image and Logic* William McKinney celebrates just this aspect of the book: “I maintain that Galison’s central thesis, that there exists a ‘trading zone’ in the laboratory where theory meets experimental practice in the production of data, offers us a striking alternative to the skepticism of contemporary cultural studies of science.” Cf. “Epistemological Lessons in the Technological Embodiment of Early Microphysics,” *Metascience* 8:3 (1999), 368.

10. *Image and Logic* (note 3 above), p. 841.

beliefs or practices need to be shared, what is incidental and what essential to the functioning of 'normal science'? In order to identify the decisive moves within an amorphous conglomerate of interactions, Galison calls for "a further articulation of 'shared' given by the distinction between local coordination and global meaning."<sup>11</sup> As it turns out, however, such a further articulation may also call into question his distinction between local coordination and global meaning, his characterization of pidgin and creole, the priority of material culture, and his conception of a disunified science.

## II

The following case-study on the establishment of commensurability moves us from the complex world of twentieth-century microphysics to the comparatively tiny community of eighteenth-century experimental physicists embroiled in a theoretical dispute over the nature of electrical charge and the number of electrical fluids.<sup>12</sup> But though it does not involve distinct professionalized subcultures, various levels of practice played together and reinforced one another to form a strong cable of intercalated strands.

On the level of *conceptual practice* the story begins with terminology introduced by Benjamin Franklin. He developed it in the context of his explanation of a simple experiment and later of the Leyden Jar. Three persons, A and B are insulated, C is grounded; A rubs a glass tube, then passes the accumulated charge on to B; as 'measured' by the strength of electrical shocks received, the charge differential between A and B is now greater than that between either of them and the grounded person C; as soon as they touch and shock each other, the charge differential between them dissipates. Franklin's 'unitarian' explanation refers to a single electrical fluid: Before and after the experiment, all three have an equal and balanced amount of electrical fluid; by rubbing the glass tube, A draws some of her electrical fire into the tube and then passes it on to B. At this point, A lacks some of her original electrical fire while B has an over-abundance of it, and grounded C still possesses a balanced fair and equal share of it. By touching each other they restore to themselves the original quantities of the fluid. This is where Franklin's new terminology comes in:

11. *Ibid.*

12. The case-study is somewhat disanalogous to Galison's also in that it directly engages incommensurable interpretations of experimental phenomena and not just divergent traditions from which to judge the instrumental and experimental certification of the real. Cf. Galison's response to Jeff Hughes in his "Author's Reply," *Metascience* 8:3 (1999), 398–400. The term "case study" is to imply "no more than a detailed study of scientific work," cf. *Image and Logic* (note 3 above), pp. 55–59.

Hence have arisen some new terms among us: we say, *B*, (and bodies like circumstanced) is electrised *positively*; *A*, *negatively*. Or rather, *B* is electrised *plus*; *A*, *minus*.<sup>13</sup>

Franklin's unitarianism met opposition among the so-called dualists. While his account explains why two positively or over-abundantly charged bodies can repel each other, the repulsion between two negatively charged bodies appears inexplicable. Assuming two distinct electrical fluids, vitreous and resinous, the dualists reject Franklin's theory and yet find themselves using his terminology, albeit apologetically:

[W]hen a body is said to be positively electrified, it is not simply that it is possessed of a larger share of electric matter than in a natural state; nor, when it is said to be negatively electrified, of a less; but that, in the former case, it is possessed of a larger portion of one of th[e] active powers, and in the latter, of a larger portion of the other; while a body in its natural state remains unelectrified, from an equal ballance of those two powers within it.<sup>14</sup>

[...] I confess it was unlucky that I felt myself obliged to use, in some respect, the same terms that Mr. Franklin and others, who follow his system, make use of, while there is an essential difference in the things meant by them and by me: by the term *positive* and *negative*, they mean, as in algebra, simply *plus* and *minus*: By the same terms I mean two distinct Powers (both of them in reality positive) but acting in contrary Directions, or counteracting one another.<sup>15</sup>

Dualist Robert Symmer thus finds Franklin's terminology inadequate because, like Franklin, he reads 'plus' and 'minus' as 'more' and 'less,' as 'having' and 'lacking,' as 'plenum' and 'vacuum,' *i.e.*, as modifications of a single given substance or state. According to Symmer, a substantial power cannot properly be negative, and certainly not be designated by 'minus.' Though they interpret the terms 'plus' and 'minus' similarly, the conceptualizations of unitarians and dualists are incommensurable in the familiar sense of the term: Both provide explanations for the known phenomena but one considers them deviations from a normal or natural state, while the other does not admit such states at all but sees only the occasional

13. Franklin to Peter Collinson, July 11<sup>th</sup>, 1747, in Raymond Seeger (ed.) *Benjamin Franklin: New World Physicist*, Oxford: Pergamon Press (1973), pp. 74f.

14. Robert Symmer "New Experiments and Observations concerning Electricity," *Philosophical Transactions of the Royal Society* 51 (1759), 371.

15. Symmer on July 10, 1761 (fols. 229–230), quoted after John Heilbron "Robert Symmer and the Two Electricities," *Isis* 67 (1976), 17.

equilibrium of opposing forces. Moreover, unitarians and dualists extend their conceptualization of phenomena to other domains, for example to questions of pleasure and pain, to prudential algebra, to their notions of self and Enlightenment.<sup>16</sup>

At this point enters Georg Christoph Lichtenberg who seeks to establish commensurability between the unitarians and dualists after discovering in 1777 a “New Method for Investigating the Nature and Motion of Electrical Matter,” a method which promised an experimental answer to the contested question concerning the number of electrical fluids. The Lichtenberg dust figures provide a physical trace of discharges, and not only do they make for very pretty and ornate patterns, these patterns are strikingly distinct and neatly inverted for the discharge of ‘positive’ and ‘negative’ electricity. In order to recommend his experimental method as a means to settle the controversy, Lichtenberg sought a terminology which would not prejudice the issue, a convention which “the investigators of this or that school can use without danger of damage or controversy.”<sup>17</sup> A student and friend of the mathematician Abraham Gotthelf Kästner, Lichtenberg was familiar with quite another way of interpreting the algebraic signs for plus and minus. Indeed, Kästner’s criticism of minus as a ‘less than nothing’ and his juxtaposition of a *nihil relativum* and a *nihil absolutum* had inspired Kant’s 1763 *Attempt to Introduce the Concept of Negative Magnitude into Worldly Wisdom*.<sup>18</sup> Lichtenberg can therefore utilize, first of all, Kästner’s and Kant’s conception of ‘positive’ and ‘negative’ as polar opposites. So conceived these terms appear “especially fitting”<sup>19</sup> to the Symmerian conception of two fluids which exert opposite forces that cancel each other out. Lichtenberg also understood that the applicability of one and the same pair of terms to radically different conceptions of electrical fluids testifies to a region of overlapping consensus between unitarians and dualists. Accordingly he suggests that ‘+E’ and ‘-E’ designates the neutral conviction

16. Cf. Alfred Nordmann “From ‘Electricity Minus’ to ‘-E’: Semantic Innovation and the Dissolution of Controversy” (unpublished manuscript), also John Heilbron *Electricity in the 17<sup>th</sup> and 18<sup>th</sup> Centuries*, Berkeley: University of California Press (1979), p. 329 and his “Franklin’s Physics,” *Physics Today* 29 (1976), 33f.

17. Georg Christoph Lichtenberg *Über eine neue Methode, die Natur und die Bewegung der elektrischen Materie zu erforschen* (“Lichtenbergsche Figuren”), ed. Herbert Pupke, Leipzig: Geest and Portig (1956), p. 35, compare 31.

18. Abraham Gotthelf Kästner *Anfangsgründe der Arithmetik, Geometrie, ebenen und sphärischen Trigonometrie und Perspective*, third edition, Göttingen (1774), pp. 62–64. Cf. Immanuel Kant *Versuch den Begriff der negativen Größen in die Weltweisheit einzuführen*, Königsberg (1763), pp. 1f.

19. Letter to Kästner, March or April 1784, in Georg Christoph Lichtenberg *Briefwechsel*, ed. Ulrich Joost and Albrecht Schöne, München: C.H. Beck (1985), vol. II, p. 843.



that there are two electricities or two modifications of a single matter which cancel each other out according to the rules of positive and negative magnitudes. [...] This idea supposes no theory, but no theory can be conceived without this idea; it fits equally with the *Franklinian* conception of a single matter as with the *Symmerian* of two kinds of matter.<sup>20</sup>

Lichtenberg's introduction of a symbolic notation takes Franklin's mathematically derived metaphor literally and bolsters the rise of the quantifying spirit. It provides for two interpretations of the algebraic symbols (excess and privation *vs.* polar opposition) and thus for two qualitative accounts of the phenomena (unitarian *vs.* dualist). What recommends the notation for universal use is that it is open to interpretation, *i.e.*, that no global meaning attaches to it. +E and -E are properly theoretical terms just in that they have an exact use in theoretical discourse but this theoretical use is open to competing physical interpretations.<sup>21</sup> Indeed, while Lichtenberg's terminological innovation was to pave the way for an empirical resolution of the controversy, it ended up dissolving it in quite another way: The shared terminology made it possible to pursue electrical researches without first determining the number of electrical fluids, and since that determination thus proved unnecessary, attempts to do so and

20. *Neue Methode* (note 17 above), pp. 34f. For Lichtenberg's innovation *cf.* Markus Fierz *Die Entwicklung der Elektrizitätslehre als Beispiel der physikalischen Theorienbildung*, Basel: Rektoratsprogramm der Universität Basel (1951), pp. 6ff. and Heilbron *Electricity* (note 16 above), p. 446.

21. For another example of this, *cf.* how Heinrich Hertz established commensurability between various (as Jed Buchwald has shown: incommensurable) systems of electrodynamics: "[T]he representation of the theory in Maxwell's own work, its representation as a limiting case of Helmholtz's theory, and its representation in [my papers]—however different in form—have substantially the same inner significance. This common significance of the different modes of representation (and others can certainly be found) appears to me to be the undying part of Maxwell's work. This, and not Maxwell's peculiar conceptions of methods, would I designate as 'Maxwell's Theory.' To the question, 'What is Maxwell's theory?' I know of no shorter or more definite answer than the following 'Maxwell's theory is Maxwell's system of equations.' [...] The very fact that different modes of representation have essentially the same content, renders the proper understanding of any one of them all the more difficult. Ideas and conceptions that are akin and yet different may be symbolized in the same way in different modes of representation. [...] The mathematical treatment of [Helmholtz's] limiting case leads us to Maxwell's equations. We therefore call this treatment a form of Maxwell's theory. The limiting case is so called also by v. Helmholtz. But in no way must this be taken as meaning that the physical ideas on which it is based are Maxwell's ideas. [...] Considered from a mathematical point of view, [Maxwell's] fourth mode of treatment may be regarded as coinciding completely with [Helmholtz's] third. But from the physical point of view the two differ fundamentally." Heinrich Hertz *Electric Waves*, New York: Dover (1962), pp. 21 and 24f.

even all talk of ‘fluids’ receded after Coulomb’s arrival on the scene.<sup>22</sup> The establishment of notational commensurability thus signals that “when confronted with a choice between a qualitative model deemed intelligible and an exact description lacking clear physical foundations, the leading physicists of the Enlightenment preferred exactness.”<sup>23</sup>

On the level of conceptual practice then, Lichtenberg’s analysis established +E and –E as theoretical terms without global meaning, cutting across Galison’s opposition of local coordination and global meaning. Indeed, Lichtenberg’s symbolism for electrical charge allows for the global coordination of local meaning. In this case, commensurability was established from the (conceptual) top down and not from the (material) bottom up.

Lichtenberg’s conceptual work did not solve the problem of incommensurability on the level of *linguistic practice*. As late as 1784, Lichtenberg notes the difficulty in a letter about the conflict between the unitarian and dualist doctrines:

I really don’t declare for either one; in speaking and writing however, that is when *this* matter is not itself the subject at hand, I am always Francklinian [sic], just as I write *deutsch* though I will gladly admit that one can also write *teutsch* and that the latter might even be preferable.<sup>24</sup>

In the course of speaking and writing one is forced to either employ or refrain from using the plural of the word ‘fluid,’ and this forced choice inevitably implies conceptions of physical significance. As Lichtenberg’s remark indicates, however, his conceptual innovation allows for linguistic practice to be provisional. In speaking and writing he is now aware that propositions about electrical matter interpret not only the phenomena but also the symbolism of +E and –E. While his expressions in the Franklinian mode draw physical significance or meaning from Franklin’s qualitative view, they are no longer grounded in it. This provisional and ungrounded character of linguistic practice opens a wide space of linguistic opportu-

22. Cf. Heilbron *Electricity* (note 16 above), p. 490.

23. Heilbron *Electricity* (note 16 above), p. 500. I am leaving open whether Galison’s twentieth-century subcultures of microphysics might share an exact symbolism and whether their various modes of shop-talk merely articulate its physical significance in sharply different ways. Heilbron suggests a possible continuity when he relates the orientation toward exactness rather than qualitative intelligibility to Dirac’s 1930 statement that “The only object of theoretical physics is to calculate results that can be compared with experiment, and it is quite unnecessary that any satisfactory description of the whole course of the phenomena should be given.”

24. Lichtenberg *Briefwechsel* (note 19 above), pp. 966f.

nity: The symbolism now serves as a pivot which allows speakers to playfully shift back and forth between the various interpretive models. Also, to the extent that it sufficiently coordinates experimental researches, it may render other terms superfluous ('fluid,' 'electrical matter,' 'electrical fire') and allows physicists to background their qualitative questions. It finally invites new linguistic constructions, a hybrid language of sorts:

I conceive more readily how a real +E could draw, bind and hold another equally real -E at a distance than I can picture how a surplus or deficiency could.

Johann Gehler goes on to ask how a "lack can show the same activity that our -E so evidently displays in the phenomena of the electrophore."<sup>25</sup> Gehler's propositions are quite odd and border on the nonsensical in that they presuppose the neutrality and interpretability of +E and -E but would become either tautologous or contradictory just as soon as the symbols receive either a dualist or a unitarian interpretation. Gehler's hybrid language may bear some resemblance to pidgin; but in contrast to the linguistic interactions in Galison's trading zones, Gehler's propositions testify to the liberalization of physical discourse *after* the establishment of commensurability. In any event the contrast between the case studies from the eighteenth and twentieth centuries raises the historiographic issue of how to establish the temporal succession or 'logical' dependencies between such hybrid languages and experienced coherence, felt continuity or relative stability of physics as a whole. As indicated by Karin Knorr-Cetina,<sup>26</sup> it also calls for a more sustained analysis of actual samples of produced text: How 'real,' how stable, how discrete are these hybrid or pidgin languages? Are these languages—as Hertz or Wittgenstein might suggest—the colorful garments which embellish and clothe the skeletal symbolism of a theoretical or logically analyzed language? Do they offer context-specific mnemonic devices, short-hand or stopgap expressions which stand in for a unified and precisely articulated theoretical language that is either extant or intended throughout? Or are they—as Galison suggests—relatively autonomous, "neither absolutely dependent on nor absolutely independent of global meanings"? (And how can textual evidence be used to rule out one or the other of these interpretive possibilities?)

25. From Gehler's *Physikalisches Wörterbuch* (1787) as quoted by Heilbron *Electricity* (note 16 above), p. 446.

26. In her commentary on *Image and Logic* at an author-meets-critic session during the 1998 meeting of the Society for Social Studies of Science.

Intercalated with conceptual and linguistic practices is finally *gestural practice*, a level of non-verbal action coordinated by the paradigm instruments and experiments of Franklin, Symmer, and Lichtenberg.<sup>27</sup>

When Franklin uses ‘plus and minus,’ ‘excess and privation,’ ‘plenum and vacuum,’ he speaks within an experimental culture where electrical fire is concentrated, collected and eventually filled into jars and bottles, a culture which views electrical machines as cousins to the airpump—machines in which phenomena are magnified, normal conditions distorted and then returned to normalcy.

Symmer’s symmetric dualism of opposing forces derives from his paradigm experiment with the “Homely Apparatus of Stockings.”<sup>28</sup> Wearing for some time a pair of black silk socks above a pair of white silk socks, Symmer had noticed that there was a strong and constant attraction between the two socks of the left and the two socks of the right leg, but that the two black socks and two white socks each repelled one another. When he brought the bristling and mutually attracted socks of a given foot together again they ceased to show electricity but

when they are separated [again], and removed of a sufficient distance from each other, their electricity does not appear to have been in the least impaired by the shock they had in meeting. They are again inflated, again attract and repel, and are as ready to rush together as before.<sup>29</sup>

Symmer’s dualism is thus rooted in the physical practice of separating and reuniting black and white socks which he understands as a separation and reunification of the two electrical fluids which coexist in every body.

Lichtenberg’s paradigm instrument is Volta’s *ellectroforo perpetuo*, an electrical machine which is used to build and collect electrical charge and which at the same time exhibits Symmer’s repetitive symmetries. The electrophore consists of a resin cake which can be charged positively or negatively in a variety of ways. A wooden lid, wrapped in tin foil, is placed on the cake and removed and now carries the opposite charge. Once discharged, the lid can be placed on the cake again and, upon removal, will be charged again, and so forth, since the cake retains its charge indefinitely. Now it is clear that the lid placed upon the cake designates a neutral state,

27. I adopt the term ‘gestural’ from Otto Sibum’s discussion of the gestural knowledge implicit in skill and laboratory practice, cf. Otto Sibum “Working Experiments: A History of Gestural Knowledge,” *The Cambridge Review* 116 (1995), 25–37.

28. Symmer on June 19th, 1760 (fols. 182–183), quoted after Heilbron, “Symmer,” (note 15 above), 15.

29. Robert Symmer “New Experiments and Observations concerning Electricity,” *Philosophical Transactions of the Royal Society* 51 (1759), 382.

while its removal creates two opposing poles: Two quantities come into being as the lid is distanced from the cake. Also, as opposed to Symmer's socks, the repeatability of these motions *in perpetuo* creates a precisely working formal system of production. Finally, depending on the size of the electrophore (Lichtenberg built a very large one so as to magnify the phenomena) and the manner of charging of the cake, the produced quantities can be larger or smaller. The instrument thus embodies Franklin's more and less, accumulation and neutralization conjoined to Symmer's symmetrical repetitive actions.<sup>30</sup> One might say, then, that the commensurability between unitarians and dualists was first instantiated in the operation and Lichtenberg's handling of the electrophore.

Galison's metaphor of intercalation is compelling and productive in precisely this way: It allows us to see the isomorphism between conceptual and gestural levels of practice, it invites us to appreciate how material culture implicates habits of action as well as of thought. While Lichtenberg's gestural practice may have causally patterned, prefigured, or reenforced his conceptual work, it was not the case, of course, that everyone who conducted experiments with the electrophore was drawn to combine elements of Franklin's and Symmer's views.<sup>31</sup> For commensurability to arise it is not enough, therefore, to share in an experimental practice. It may be the case, however, that the requisite conceptual work needs to recruit the experimental and linguistic practice of lifting and replacing the lid, of shifting from one mode of speaking to another.<sup>32</sup>

### III

The juxtaposition of case studies from the eighteenth and the twentieth centuries finally questions Galison's conception of a disunified science.

Lichtenberg had to confront the problem of incommensurability in respect to both chemistry and electricity. Believing that critical disputes advance science, he took care to maintain the conditions under which such

30. If the positive or negative charge of the lid is discharged directly into the cake, dust on the cake will produce the star-like Lichtenberg figures. Their patterns are neatly inverted and in today's terminology (which only dates back to 1840 or so) one would say that one figure is the positive (or negative) of the other. This, too, might have disposed Lichtenberg to associate Symmer's symmetry of opposition with Franklin's terminology.

31. Cf. Lichtenberg *Briefwechsel* (note 15 above), pp. 669f.: "I have also had quite a dispute about this with Volta. His French was superior to mine, and yet he admitted in the end: everything can be explained both ways. [ . . . ] Volta said: Oh, Monsieur, one must be unitarian. I said I am neither unitarian nor dualist, and I will remain neither the one nor the other until I will have seen decisive experiments."

32. The metaphor of 'recruitment' comes from Bruno Latour. Like Galison's metaphors, it requires historiographic and philosophical unpacking. Both refer to material culture but do so in decidedly different ways: For Galison, the actor or scientist remains at a Kantian

disputes can occur. In the case of electricity he succeeded by establishing commensurability, in the case of chemistry he failed to overcome the incommensurability of theories and nomenclatures.<sup>33</sup> While he preferred the disunifying power of disputation over premature agreement, he did so because disunity in the field of scientific knowledge signaled untenability, because disagreement is a powerful social incentive to seek out the truth which can justly claim agreement and which will naturally silence dissent.

Galison details the story of the image and logic traditions and also of their fusion in electronic imagery:

[T]he coming together of the two traditions was a halting coordinative effort that frequently ran aground on the technical obstacles. While casting aspersions on the other, each side insistently tried to acquire the virtues of its rival: logic had statistics and experimental control and wanted persuasive detail; image had the virtues of being fine-grained, visible, and inclusive but wanted the force of statistics and control over experimentation.<sup>34</sup>

Galison here presents two traditions united in their view of science, of epistemological virtues and of what is desirable. What is it that makes scientists “want” what the others have if not an idea of a science-in-the-making or knowledge-to-be-achieved? By attending to the ideals of scientists, one may well be able to provide a generic specification of this unifying idea for a presently-disunified science: Science intends a certifiably true (= logic) representation (= image) of the phenomena.<sup>35</sup> This idea of a unified science functions as a regulative ideal, driving conceit or founding myth of science. To expose it as a “mere” myth and to reify instead the present appearance of disunity ignores the Thomas Theorem and the power of self-fulfilling prophecies: “When a situation is defined as real, it is real in its consequences.”<sup>36</sup>

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remove from a robust physical world and human-produced material culture forges interactions between human actors. According to Latour, human and non-human actors create their separation only through material practices and material culture itself is productive rather than the product of human interactions. (This issue was also raised by Karin Knorr-Cetina, note 26 above.)

33. Cf. Nordmann “Incommensurability” (note 1 above).

34. *Image and Logic* (note 3 above), p. 807.

35. Cf. Charles Sanders Peirce on the scientific method of fixing belief as the articulation of the “hypothesis of reality.” The scientific method thus intends reality as that which corresponds to true belief or the final opinion at the end of inquiry.

36. Far from articulating an idealist metaphysics, as a sociological theorem it is inextricably tied to material culture. See Robert K. Merton “The Self-Fulfilling Prophecy (1948)”, in *On Social Structure and Science*, Chicago: University of Chicago Press (1996), pp. 183–201, especially pp. 183f.

On this reading, Peter Galison's investigation develops further a theme which he shares both with positivist and anti-positivist philosophers of science.

Galison begins *Image and Logic* by rejecting Kuhnian incommensurability along with the anti-positivist central metaphor of "block-periodization," *i.e.*, "the historical picture of all-inclusive breaks" between "incommensurable 'ways of life' or paradigms that pass each other like ships in the night."<sup>37</sup> He concludes the book by noting

It is the *disorder* of the scientific community—the laminated, finite, partially independent strata supporting one another; it is the *dis*-unification of science—the intercalation of *different* patterns of argument—that is responsible for its strength and coherence.<sup>38</sup>

It would appear willfully paradoxical to refer the coherence of science to its disunification, were it not for the fact that disunity is productive in science. The threat of disunity provokes an ongoing concern for an intended coherence. Considerable activity is required to gain reassurance that everything is still going well, that the edifice of science is still holding up, that its elements support rather than destabilize each other. While this activity may be piecemeal and local, it is going on everywhere at once: Like spiders, individual scientists cannot survey the web spun by contemporary science in its entirety, but like spiders they can probe from their particular location how tautly the web is spun, whether everything is still hanging together. Galison's idea of a *productive disunity* thus echoes Kuhn's "anti-positivist" interest in incommensurability as a powerful catalyst in the history of science which, in turn, echoes the later Carnap's "positivist" concerns about the heterogeneous reference potential of theoretical terms. For all three, the establishment and maintenance of commensurability, and thus the preconditions of normal science, require the incessant intellectual vigilance and sustained material collaboration of the scientific community.<sup>39</sup>

37. *Image and Logic* (note 3 above), p. 13.

38. *Ibid.*, p. 844.

39. Next to the three brick wall metaphors discussed by Galison and my proposed metaphor of the spider's web, *cf.* also Latour's comparison of scientific facts to frozen fish: Both need to be sustained through a continuity of practice—"the chain of coldness which keeps them fresh may not be interrupted, not even for a moment." *Cf.* in *We Have Never Been Modern*, Cambridge: Harvard University Press (1993), in the section devoted to showing that even large nets are local at all their nodes.