Alfred Nordmann

From "Electricity Minus" to "-E": Attempts to Introduce the Concept of Negative Magnitude into Worldly Wisdom

I.

In his 1725 *Dissertation on Liberty and Necessity, Pleasure and Pain*, Benjamin Franklin notes that

> since *Pain* naturally and infallibly produces *Pleasure* in proportion to it, every individual Creature must, in any State of *Life*, have an equal Quantity of each.[1]

As with pleasure and pain, so in 1747 with electricity plus and minus:

> We suppose [...] that electrical fire is a common element, of which every one [...] has his equal share.[2]

We start off equal but our common stock can be influenced to deviate from its normal and neutral state, thus producing excess and privation, electricity plus and electricity minus, pleasure and pain in equal proportion to one other. Franklin elaborates this structure by investigating the relationship between the three beings *A*, *B* and *C*:

> Suppose *A*, *B*, and *C*, three distinct Beings; *A* and *B*, animate, capable of *Pleasure* and *Pain*, *C* an inanimate Piece of Matter, insensible of either. *A* receives ten Degrees of *Pain*, which are necessarily succeeded by ten Degrees of *Pleasure*: *B* receives fifteen of *Pain*, and the consequent equal number of *Pleasure*: *C* all the while lies unconcern'd, and, as he has not suffer'd the former, has no right to the latter. What can be more equal and just than this?[3]

In electrical matters, the relationship involves three persons, but just like the inanimate rock C, person C remains grounded and suffers neither excess nor privation:

> *A*, who stands on wax and rubs the tube, collects the electrical fire from himself into the glass; and his communication with the common stock being cut off by the wax, his body is not again immediately supply'd. *B*, who stands on wax likewise, receives the fire which was

[1] FRANKLIN (1930), pp. 21 f.
[2] SEEGER (1973), pp. 74 f.
[3] FRANKLIN (1930).

> collected by the glass from *A*; and his communication from the common stock being likewise cut off, he retains the additional quantity received. To *C*, standing on the floor, both appear to be electrised: for he having only the middle quantity of electrical fire, receives a spark upon approaching *B*, who has an over quantity: but gives one to *A*, who has an under quantity. If *A* and *B* approach to touch each other, the spark is stronger because the difference between them is greater. After such touch there is no spark between either of them and *C*, because the electrical fire in all is reduced to the original equality.[4]

An original equality has to be restored and a balance achieved also in matters of "*Moral* or *Prudential Algebra*", i.e., Franklin's recommended method of decision-making:

> [D]ivide half a Sheet of Paper by a Line into two Columns; writing over the one *Pro*, and over the other *Con*. Then during three or four Days Consideration, I put down under the different Heads short Hints of the different Motives, that at different Times occur to me, *for* or *against* the Measure. When I have thus got them all together in one View, I endeavour to estimate their respective Weights; and where I find two, one on each side, that seem equal, I strike them both out [...] and thus proceeding I find at length where the Ballance lies.[5]

This method of decision-making is designed to help Franklin discover "which is best be done" since "there is every Moment something *best* to be done" that is obscured only by "the various Purposes of Inclinations that alternately prevail", i.e., by a momentary excess of timidity or rashness, hope or fear.[6]

A similar pattern of thought thus unites Franklin's physical interpretation of positive and negative electricity, his metaphysical account of pleasure and pain, and his "algebraic" method of arriving at the best course of action by cancelling out alternately prevailing purposes and inclinations. In all three instances, there is a neutral, just, equalizing and normalizing state, an "original equality" from which there can be only temporary departures, an occasional abundance, an occasional privation. "Communication" with the common element sets this inequality right, and in the case of electricity this happens by means of the electric fire. John Heilbron accordingly describes Franklin's electric fire as "that democratic element forever striving to attach itself to each equally".[7]

> This pervasive pattern of thought gives particular meaning to Franklin's terms: 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*.[8]

In algebraic terms, the neutral, normal, grounded state is implicitly designated as "zero" as a plain nothingness in which nothing is going on. In his early *Attempt to Introduce the Concept of Negative Magnitude into Worldly Wisdom*, Immanuel Kant

[4] SEEGER (1973).
[5] FRANKLIN (1906), V, pp. 437 f.
[6] See FRANKLIN (1930); FRANKLIN (1906), V, pp. 437 f.
[7] HEILBRON (1976), p. 33.
[8] SEEGER (1973).

interpreted this use of the term "zero" in the language of classical metaphysics. In the grounded state of zero, both positive and negative electricity have reverted to the normal level and are thus simply negated. And while an "over quantity" of electric fire or an "under quantity" of electric fire represent states to be known (*cogitabile*) and described (*repraesentabile*), nothing at all is going on or can be described when the quantity is just and normal. The grounded zero is thus the *nihil negativum* or *gar nichts*, it is *irrepraesentabile*. In order to produce this plain and merely negative nothingness, the absence of electrical charge (positive or negative) is considered as a simple negation. Negative charge, then, is "less than nothing", it is an absence or defect, simply designating "not enough: privation".[9] Accordingly, Franklin thinks negative charge in analogy to the physical state of the vacuum:

> [with *A* and *B* standing on wax] we have at the same time a *plenum* of electrical fire, and a *vacuum* of the same fire; and [...] the equilibrium cannot be restored but with a communication [...] though the *plenum* presses violently to expand, and the hungry *vacuum* seems to attract as violently to be filled.[10]

"Positive electricity" thus corresponds to compressed air and simply means "more than enough: excess". It requires free-flowing communication with the grounded common element of stock to re-establish equality, justice and balance. This normal state of equilibrium corresponds to the solid state of the insensible rock at absolute rest. Franklin thus brings the human being "down to an Equality with the Beasts of the Field! with the meanest part of the Creation".[11] By discharging oneself of excess and remedying all privation one will hit rock-bottom and discover a ground or core within oneself: "If there is no such Thing as Free-Will in Creatures, there can be neither Merit nor Demerit in Creatures. [...] And therefore every Creature must be equally esteem'd by the Creator".[12] At this point Franklin's conception of the self joins forces with his political philosophy. Self-mastery grounds the person in common sense and common sentiment and thus becomes a socially significant public spectacle, a spectacle performed, e.g., in Franklin's *Autobiography*.[13] The establishment of a "harmonious order" within contributes to the "happy mediocrity, that so generally prevails throughout these States".[14]

[9] See KANT (1763), pp. 3 f., 9 f., 15 f. Kant's own proposal on how to interpret these algebraic terms will be discussed later. The term "privation" is here used to designate Franklin's negative state. Kant himself reserves "privation" for his proposed zero state which is really an equilibrium of opposites each depriving the other of its effects.

[10] SEEGER (1973).

[11] FRANKLIN (1930).

[12] FRANKLIN (1930), p. 13.

[13] See SEAVEY (1988), pp. 42 f. MARTIN (1961), pp. 10 f. LEVIN (1963), pp. 270 f.

[14] To be sure, the happy mediocrity of the States requires "Truth has fair Play" and that journalistic freedom maintains a just share of "human Felicity" (CONNER (1965), pp. 32 ff., 115 f., *et passim*).

$0 + A$	+	excess, abundance, *repraesentabile*
0, $0 + A - A$, $0 - A + A$	0	grounded in common stock, happy mediocrity, *nihil negativum*, *irrepraesantabile*, normal, nothing at all *(gar nichts*)
$0 – A$	-	privation, lack, *repraesentabile*

Table 1

II.

Two difficulties present themselves to Franklin's construal of electrical phenomena, one conceptual, the other empirical.

The conceptual difficulty arises from a metaphorical rather than strictly mathematical employment of the algebraic terms. In Franklin's experiment subject *A* had collected his fire, passed the spark to *B* and is therefore negatively electrified, say by one unit: -1. Experimental subject *B*, having drawn the fire, is positively electrified by one unit: +1. This agrees with the observation that the shock and spark between *A* and *B* is perhaps exactly twice as intense (two units) as the shock and spark between either one of them and the grounded observer *C* (one unit). However, since the electric fire in *A* and *B* is said to strive only towards the normal state of 0, no more than one unit of electrical fire should pass between *A* and *B* for both of them to reach 0: in other words, though the charge differential is twice as large for *A* and *B* than for *A* and *C* or *B* and *C*, the quantity of electrical fire which has to be transmitted in order to reach the normal state should be the same in all cases.[15] That this conceptual difficulty went apparently unnoticed by Franklin's contemporaries is significant. It signals that his terminology was not taken in a strictly algebraic or quantitative sense.

The second, empirical difficulty is more straightforward and had to be addressed. It concerns the mutual repulsion of negatively charged bodies, a phenomenon unaccounted for by Franklin's theory: why should the mere lack of electrical fire give rise to a very definite repulsive force? Franz Ulrich Aepinus showed in 1759 that, for this and more principled reasons, Franklin's theory had to be amended by the assumption that negatively electrified matter will repel similar matter.[16] Though Franklin's view as appended by Aepinus's assumption is said to have currency even today,[17] there is something obviously awkward and inelegant, if not *ad hoc* about this assumption.

[15] See HEILBRON (1979), p. 329; GLIOZZI (1937), pp. 188 f.
[16] See COHEN (1990), p. 217; PRIESTLEY (1775), pp. 27-36.
[17] See COHEN (1990), p. 10.

III.

This is roughly how things stood when, also in 1759, Robert Symmer published a series of experiments which were to establish

> that the Principle of Electricity consisted of two distinct and counteracting Powers, which produced all the Phaenomena of Electricity; and which might perhaps be a Principle which extended far into the various Operations and Productions of Nature. [The principle] may be found hereafter to account for Magnetism, for Gravity, and [...] may likewise throw a Light upon the Principles of Chemistry, Vegitation, and Animal Life.[18]

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. Bringing 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.[19]

Symmer thus observes the perfectly symmetrical behavior and display of power in the positively and in the negatively charged pair of socks, indicating that there are indeed two distinct and counteracting positive powers at work here.

> When 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.[20]

Symmer thus arrived at a conflicting empirical hypothesis, a hypothesis embellished by his larger postulates about the importance of dualistic principles in Nature. Both fluids are involved in the passing of a jolt or spark, flowing simultaneously in opposite directions such that a greater portion of one power in one body is evened out through an exchange with the greater portion of the other power in another body. As Edmund Whittaker points out:

> The dispute could therefore be settled only by a determination of the actual motion of electricity in discharges; and this was beyond the reach of experiment.[21]

[18] HEILBRON (1976a), p. 14.
[19] SYMMER (1759), p. 382.
[20] *Ibid*., p. 371.
[21] WHITTAKER (1951), p. 59. According to Whittaker, "[t]he chief difference between the rival hypotheses is that, in the two-fluid theory, both the electrical fluids are movable within the substance of a solid conductor; while in the one-fluid theory the actual electric fluid is mobile, but the particles of the conductor are fixed" (WHITTAKER (1951), pp. 58 f.). Priestley also stresses (PRIESTLEY (1775), pp. 19 f., 22 f., 44, *et passim*) that hypotheses concerning the motion of

IV.

Since the problem could not be solved by means of a crucial and decisive experiment, its eventual dissolution issued instead from conceptual clarification and the introduction of a new notation. In a first step toward conceptual clarification, Johann Heinrich Winckler questioned Symmer's cumbersome employment of Franklin's terminology, speaking as if in quotation marks of bodies that "are said to be positively or negatively electrified". Symmer responded as follows:

> 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.[22]

Accordingly, the European scientists who embraced Symmer's dualism revived Dufay's older terminology of "vitreous" and "resinous" electricities and suggested, for example, that one of the electric principles was "phlogiston" and the other "acid".[23]

The next step toward conceptual clarification involved larger developments toward quantification or, as one might call it, the physicalization of mathematics. Franklin's metaphorical use of algebraic terminology was succeeded by attempts to assign appropriate physical meaning to mathematical concepts. These attempts created new questions and conceptual resources which were then exploited in Lichtenberg's terminological innovation.

One document which testifies to the reinterpretation of algebraic terms is Immanuel Kant's *Attempt to Introduce the Concept of Negative Magnitude into Worldly Wisdom* of 1763. Kant suggests that the terms "zero", "minus", and "negative" should be interpreted quite differently than Franklin does. According to Kant, negative magnitudes are positive magnitudes which counteract other positive magnitudes, they are purely relative, namely positive forces which simply work in an arbitrarily defined contrary direction.[24] Instead of adopting Franklin's analogy

electrical fluids do "not admit of the evidence of sense". This was true even for large-scale electrical phenomena. For instance, finding clouds during thunder-storms "most commonly in a negative state of electricity", Franklin is ready to conclude "that, for the most part, in thunder-strokes, 'tis the earth that strikes into the clouds, and not the clouds that strike into the earth" (SEEGER (1973), p. 147). Franklin here heeds Priestley's warning that there are matters only "thought to be [...] evident to the senses" (PRIESTLEY (1775), p. 19).

[22] HEILBRON (1979), p. 17.

[23] From Lichtenberg's point of view, the language of electricity had reverted back from a promising mathematical terminology to the significations of apothecaries: see LICHTENBERG (1956), p. 35.

[24] See KANT (1763), pp. 10 f.

with the vacuum (privation) and compressed air (excess), Kant's *Realrepugnanz* follows the Newtonian theory of motion and matter:[25]

> The real repugnance takes place only in so far as two things as *positive grounds* [Gründe] each suspend the *effects* [Folge] of the other. Take a motive force as a positive ground: then a real *opposition* [Widerstreit] can take place only in so far as another motive force is adjoined and they mutually suspend each others effects.[26]

On this view of a polar opposition between two competing forces, the negative force has real causal efficacy and is not merely a lack or privation. Also, the state designated by "zero" changes significantly in character: it is now a precarious equilibrium of forces (*cogitabile* and *repraesentabile*) and not a mere absence or "nothing at all", it designates a state of *mutual* privation (Kant therefore calls it *nihil privativum*) rather than something purely negative (*nihil negativum*).[27]

> A body at rest is either a mere lack [*defectus*, *absentia*], i.e. a negation of motion in so far as no motive force is present; or it is a privation, in so far as motive force is indeed present but its effect, namely motion, is suspended [*aufgehoben*] by an opposite force.[28]

The latter conception of rest is, of course, the Newtonian conception adopted by Kant. And thus there is nothing lacking in Kant's *nihil privativum*. There is instead a rich interplay of force and matter, an interplay in which the agents happen to deprive each other only of their efficacy, a state of precarious balance in which they neutralized by cancelling each other out.

A (or *-A*)	+	polar opposite of '-', a directional force, *repraesentabile*
A + *-A*, *-A* + *A*	0	precarious equilibrium of forces, *nihil privativum*, *repraesentabile*, rest achieved through struggle, mutual balance and cancellation of effects
-A (or *A*)	-	polar opposite of '+', a directional force, *repraesentabile*

Table 2[29]

[25] See KANT (1955).

[26] KANT (1763), p. 13.

[27] Brian Rotman provides only a beginning in the historical exploration of "zero" as a sign. He does not dwell on the difference (and all that it entails) between *nihil negativum* and *nihil privativum*: see ROTMAN (1987).

[28] KANT (1763), p. 18; see note 9 above concerning Kant's use of "privation".

[29] Kant states explicitly that the expression *'0 - A'* is "in a philosophical sense, impossible; nothing can ever be subtracted from nothing. [...] *A + 0 - A* is still the same as *A - A* and the zero is therefore redundant here. The thought that negative magnitudes *are less than nothing*, which has been derived from this [by treating the *'0 - A'* in isolation], is thus void and senseless" (KANT (1763), pp. 15 f.). Table 1 above contains precisely the objectionable *'0 - A*' with the definition of the negative as less than nothing.

If Franklin's conception of the three states reverberated throughout his body of beliefs, so does Kant's. In his short essay, he begins to outline a conception of pleasure and pain quite opposed to Franklin's, one in which the same stimuli can serve as mutual opposites, as sources of both pleasure and pain. Pleasure is not the relief of pain, but coexists with pain in human experience. And when human reason tries to form some one clear and distinct idea (e.g. in the context of choice), this very effort will shroud and obscure others.[30] And just as the shape or extension of physical bodies results from a precarious equilibrium of attractive (contracting) and repulsive (expansive) forces, just as the human subject (the I) results from the ability of reason to synthesize the resistant testimony of the senses,[31] so the moral character of the human being emerges only from the struggle of two positive forces pulling in opposite directions, the forces of good and evil.[32]

Any "normal" or grounded state thus cannot be compared to the solid foundation of the insensible rock. It is a delicate balance which will easily deteriorate, its perfect symmetry quickly falling into disorder. Knowledge, peace, justice, stability, a perfect constitution, and the *sensus communis* issue from antagonistic polarities,[33] they do not lie dormant as a given common stock in which all beings partake equally by nature.

V.

Kant's interpretation of "positive" and "negative" and the "normal" grounded state expresses Symmer's intuition about the symmetrical opposition of electrical forces.[34] Moreover, on Kant's interpretation, the conceptual puzzle concerning Franklin's experiment vanishes. The intensity of the shock corresponds no longer to the amount of fluid transmitted but to the force-differential involved.

This novel resource was not exploited, however, until Georg Christoph Lichtenberg discovered in 1778 the so-called Lichtenberg figures. A discharge of

[30] See KANT (1763), pp. 49 f, 54 f.

[31] While Hartmut and Gernot Böhme explore the relation between Kant's physical and psychological conceptions of "body" (BÖHME and BÖHME (1985)), Kant's polar conception of the self directly informs his *Critique of Pure Reason*: "The understanding is incapable of intuition, and the senses incapable of thought. Knowledge can arise only from their union. [...] It is plainly necessary that in my knowledge all consciousness belong to one consciousness (consciousness of myself). [...] the standing and persistent I (of pure apperception) makes for the correlate of all our representations" (KANT (1781), pp. 51, 117, 123). The *Critique of Judgement* continues this train of thought by adding "which is why we are given a gift of joy (rather we are relieved of a pressing need), as if it were a fortunate coincidence which furthers our intent, when we do hit upon systematic unity among merely empirical laws" (KANT (1790), p. XXXII).

[32] For a "mathematical proof" of this see KANT (1793), p. 9.

[33] For example, in his *Sketch for a Universal History with Cosmopolitan Intent* Kant praises human unsociability and antagonism for its social and historical value.

[34] To be sure, KANT (1763), pp. 33 f. deals with polarity and electricity without referring to Symmer. Instead, he takes his cue from Aepinus's "unitarian" assumptions (see above, end of § II) which maintain the universality of repulsion between all particles of matter.

electricity into dust can create a pattern not unlike stars or ice-ferns. Moreover, a discharge of negative electricity creates a pattern that looks like the inverted negative of a positive discharge-pattern. Since the stars appeared to represent a visual trace of the discharge, it seemed that here, perhaps, was finally an experimental means to study the various motions of electrical fluids. The Lichtenberg figures held the ultimately unfulfilled promise to settle the controversy between unitarians and dualists experimentally.[35]

In order to recommend his figures to unitarians and dualists alike, 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".[36] To this end Lichtenberg was able to draw on the competing conceptions of negative magnitude. He was, after all, student and friend of the mathematician Abraham Gotthelf Kästner whose criticism of a "less than nothing" and whose juxtaposition of a *nihil relativum* and a *nihil absolutum* had inspired Kant;[37] Lichtenberg was therefore able to recognize, first of all, that under Kästner's and Kant's polar conception of "positive" and "negative", these terms are "especially fitting" to the Symmerian conception of two fluids which exert opposite forces that cancel each other out (from a 1784 letter to Kästner[38] Moreover, he 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. He accordingly suggested that "+E" and "-E" could designate the neutral conviction

> 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.[39]

Lichtenberg thus invited the warring factions to adopt a terminology which provides common ground as long it remains uninterpreted. Upon a traditional interpretation of "positive" and "negative", it expresses Franklin's abundance and privation of just one electrical fluid; upon Kästner's and Kant's interpretation, it expressed the polar opposition of two electrical fluids. On Lichtenberg's views of science, Franklin and Symmer, like all physicists, merely constructed (interpreted) models of reality (*Vorstellungsarten*). His purely formal or mathematical analysis brought out a structural feature shared by these models. Lichtenberg's mathematical symbolism "+*E*" and "-*E*" thus provides an uninterpreted model of the physical

[35] The Lichtenberg figures remained unexplained until well into this century: see PRZIBRAM (1925).
[36] LICHTENBERG (1956), p. 35, see p. 31.
[37] KÄSTNER (1774), pp. 62-4; see KANT (1763), pp. 1 f.
[38] See LICHTENBERG (1985), II, p. 843.
[39] LICHTENBERG (1956), pp. 34 f.

models, it remains open to conflicting physical interpretations. Speaking the language of mathematics, Lichtenberg thinks conflicting physical realities.[40]

After the division between unitarians and dualists had been fortified along terminological and taxonomic lines, after the dualists had taken pains to articulate the revolutionary incommensurability of the two views on electrical fluids, Lichtenberg's ever so slight semantic innovation re-established commensurability.[41] He enabled electrical theorists to bracket and set aside for now the matter of contention. Embracing this opportunity and continuing united on the path towards further quantification, the scientific community soon forgot that original point of contention and progressed without ever returning to the question of one or two electrical fluids.[42]

VI.

Worlds separate the harmonious order of Franklin's original proposal, the polar dynamics of Symmer's and Kant's dualism, and Lichtenberg's negotiated neutrality, his awareness that theories can assign physical meaning to formal models in a variety of ways.

This case study from the history of electricity thus calls for a view of scientific reasoning and the advancement of science which can recognize the resolution of a controversy even where the underlying empirical issue remains open. The material world of the scientist consists of argument, experiment, and nature, all of which serve as plastic resources which have to be molded in the construction of stable phenomena.[43] Employing the technologies of experiment and argument and by collectively negotiating a path of least resistance,[44] scientists create phenomena and stabilize them in a lawlike fashion for public use and scrutiny.[45] The cultural meaning of science thus resides not only in the dynamics of negotiation but also in each particular configuration of its varied material resources. And scientific progress, on these views, does not primarily consist in improving representations of nature, but issues instead from the creation of opportunities and perspectives in the material world of argument, experiment, and nature. An innovative and progressive scientific gambit thus provides access to sets of fruitful problems perhaps even at the

[40] In a somewhat speculative vein, Jean-Claude Schneider links Lichtenberg's '+*E*' to his capacity for thinking in a contradictory manner, entertaining incompatible models in alternating currents: "Lichtenberg does not write in a fragmented manner but thinks through fragments" (SCHNEIDER, (1968), p. 488).

[41] For a case study on Lichtenberg's less successful attempt to do the same for the chemical revolution see NORDMANN (1986), also NORDMANN (1999).

[42] FIERZ (1950/51) and HEILBRON (1979), p. 490.

[43] See PICKERING (1989).

[44] See FEYERABEND (1989).

[45] See HACKING (1983).

cost of leaving some of the old problems unsolved.[46] Accordingly, controversies testify to the cultural richness,[47] resourcefulness, and volatility of science; their resolution need not consist in settling a fact of nature but can result from adjustments to language or experimental technology.

[46] See LAKATOS (1970).
[47] See *Ibid.*

BIBLIOGRAPHY

BÖHME, H. and BÖHME, G. (1985), *Das Andere der Vernunft: Zur Entwicklung von Rationalitätsstrukturen am Beispiel Kants*, Frankfurt, 1985.

COHEN, I.B. (1990), *Benjamin Franklin's Science*, Cambridge, 1990.

CONNER, P.W. (1965), *Poor Richard's Politicks: Benjamin Franklin and His New American Order*, London, 1965.

FEYERABEND, P. (1989), "Realism and the Historicity of Knowledge", *Journal of Philosophy*, 86 (1989), pp. 393-406.

FIERZ, M. (1950-1), *Die Entwicklung der Elektrizitätslehre als Beispiel der physikalischen Theorienbildung*, Basel, 1950-1.

FRANKLIN, B. (1906), *The Writings of Benjamin Franklin*, SMYTH, A.H. ed., New York, 1906.

ID. (1930), *A Dissertation on Liberty and Necessity, Pleasure and Pain*, New York, 1930.

GEIGER, H. and SCHEEL, K. eds. (1925), *Handbuch der Physik*, Berlin, 1925.

GLIOZZI, M. (1937), *L'elettrologia fino al Volta*, Naples, 1937.

GOODING, D. and PINCH, T. eds. (1989), *The Uses of Experiment*, Cambridge, 1989.

HACKING, I. (1983), *Representing and Intervening*, Cambridge, 1983.

HEILBRON, J. (1976), "Franklin's Physic", *Physics Today*, 29:7 (1976), pp. 32-7.

ID. (1976a), "Robert Symmer and the Two Electricities", *Isis*, 29:67 (1976), pp. 7-20.

ID. (1979), *Electricity in the 17th and 18th Centuries: A Study of Early Modern Physics*, Berkeley, 1979.

KANT, I. (1763), *Versuch den Begriff der negativen Größen in die Weltweisheit einzuführen*, Königsberg, 1763.

ID. (1781), *Kritik der reinen Vernunft*, Riga, 1781.

ID. (1790), *Kritik der Urteilskraft*, Berlin, 1790.

ID. (1793), *Die Religion innerhalb der Grenzen der bloßen Vernunft*, Königsberg, 1793.

ID. (1955), *Allgemeine Naturgeschichte und Theorie des Himmels oder Versuch von der Verfassung und dem mechanischen Ursprunge des ganzen Weltgebäudes nach Newtonischen Grundsätzen abgehandelt*, Königsberg, 1955.

KÄSTNER, A.G. (1774), *Anfangsgründe der Arithmetik, Geometrie, ebenen und sphärischen Trigonometrie und Perspective*, Göttingen, 1774[3].

LAKATOS, I. (1970), "Falsification and the Methodology of Scientific Research Programmes", in MUSGRAVE and LAKATOS eds. (1970), pp. 91-196.

LEVIN, D. (1963), "The Autobiography of Benjamin Franklin: The Puritan Experimenter in Life and Art", *Yale Review*, 53 (1963).

LICHTENBERG, G.C. (1956), *Über eine neue Methode, die Natur und die Bewegung der elektrischen Materie zu erforschen ["Lichtenbergsche Figuren"]*, PUPKE, H. ed., Leipzig, 1956.

ID. (1985), *Briefwechsel*, JOOST and SCHÖNE eds., München, 1985.

MARTIN, T. (1961), *The Instructed Vision: Scottish Common Sense Philosophy and the Origins of American Fiction*, Bloomington, 1961.

MUSGRAVE, A. and LAKATOS, I. (eds.), *Criticism and the Growth of Knowledge*, Cambridge, 1970.

NORDMANN, A. (1986), "Comparing Incommensurable Theories: A Textbook Account from 1794", *Studies in History and Philosophy of Science*, 17 (1986), pp. 231-46.

ID. (1999), "Establishing Commensurability: Intercalations, Global Meaning, and the Unity of Science", *Perspective on Science*, 7 (1999), pp. 181-95.

PICKERING, A. (1989), "Living in the Material World: On Realism and Experimental Practice", in GOODING and PINCH eds. (1989), pp. 275-97.

PRIESTLEY, J. (1775), *The History and Present State of Electricity*, London, 1775.

PRZIBRAM, K. (1925), "Die elektrischen Figuren", GEIGER and SCHEEL eds. (1925).

ROTMAN, B. (1987), *Signifying Nothing: The Semiotics of Zero*, New York, 1987.

SCHNEIDER, J.-C. (1968), "Lichtenberg et la Pensée Contradictoire", *La nouvelle Nouvelle Revue Française*, 16 (1968).

SEAVEY, O. (1988), *Becoming Benjamin Franklin: The Autobiography and the Life*, University Park: Pennsylvania State University Press, 1988.

SEEGER, R. ed. (1973), *Benjamin Franklin: New World Physicist*, Oxford, 1973.

SYMMER, R. (1759), "New Experiments and Observations concerning Electricity", *Philosophical Transactions of the Royal Society*, 51 (1759).

WHITTAKER, E. (1951), *A History of the Theories of Aether and Electricity*, revised edition, London, 1951.