What Can Local Circulation Explain?

The Case of Helmholtz's Frog-Drawing-Machine in Berlin

By M. Norton Wise[*]

"Circulation" seems to have replaced "travel" as a favored concept in history and social studies of science and to have taken on new significance. Formerly, circulation referred primarily to diffusion or spread, such as the diffusion of knowledge through the republic of letters or of paper-making from China to Europe. Circulation now often highlights exchange: exchange of people, materials, instru-

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ments, and practices between laboratories in a network. In this sense, exchange helps to explain how standards become established for precision measurements.[1] Circulation can also draw attention to the role of a particular location or country as a center of circulation within a larger network. For this purpose in 2005 the Dutch and Belgian History of Science Societies chose circulation as a subject that could serve to integrate, or at least interrelate, their diverse interests in the role that the low countries have played in the history of science and that they continue to play in the European Community.[2] I would like to suggest here another function for circulation, in cultural history of science, especially the intensely local studies currently being produced. For that purpose I will develop an example drawn from a book manuscript on *Bourgeois Berlin and Laboratory Science*. I hope to show how circulation helps us to understand that the resources available to Hermann Helmholtz and his friends in the Berlin Physical Society in the late 1840s were cultural resources. The story will culminate in Helmholtz's early work on muscle and nerve physiology, as illustrated by his frog-drawing-machine (figure 20 below). The focus will be on the status of the line and the curve as they circulated among the representatives of neoclassical aesthetics, industrial promo-

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[1] Joseph O'Connell "Metrology: The Creation of Universality by the Circulation of Pariculars", *Social Studies of Science*, 1993, *23:*129-173; Simon Schaffer, "Accurate Measurement is an English Science", in *The Values of Precision*, ed. M. Norton Wise, (Princeton: Princeton University Press, 1995), pp. 135-172.

[2] Conference organized by Lissa Roberts and Bert Theunisson on "The Circulation of Knowledge and Practices: The Low Countries as an Historical Laboratory," Woudschoten, 27-28 May 2005.

tion, military modernization, and science education in Berlin in the 1830s and 40s.

Figure 1. Franz Krueger, Parade auf dem Opernplatz (Berlin), 1824-1830.

Consider the painting in figure 1 of “Eine Parade,” by Franz Krueger, one of the exponents of what may be called Berlin Realism, referring here to Krueger’s portraiture of people, horses, and buildings. The painting depicts a parade of heavy cavalry down *Unter den Linden* in 1824, celebrating their honorary commander, Archduke Nicholas (Tsar Nicholas I from 1826) and his wife Charlotte, daughter of the Prussian King, Friedrich Wilhelm III. The cavalry is passing before the King with his military high command in the left background. But the real subject of the painting lies instead in the right foreground, where a crowd of citizens is gathered (figure 2). Here Krueger has done much of my work for me. He has assembled a who's who of bourgeois culture, including a number of the people who will play leading roles in my story, and set them in interrelation.[3]

Figure 2. Well-placed citizens of Berlin.

Behind the coiffed woman in white in the right front (the actress Caroline Bauer), recognizable in figure 3, are Gottfried Schadow (balding and hatless), head of the Academy of Art; Carl Friedrich Schinkel (right of Schadow),

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[3] Renate Franke, *Berlin vom König aus zum Schusterjungen: Franz Krügers "Paraden" Bilder preußischen Selbstverständnisses* (Frankfurt am Main: Peter Lang, 1984), makes a convincing argument for seeing Krüger's parade pictures as bourgeois self-representations and includes identification keys for many individuals, with discussion pp. 128-144.

the architect who designed the neo-classical guardhouse (Neue Wache) behind the crowd; and Christian Daniel Rauch (right of Schinkel, tall, in top hat), who sculpted the statue standing in front of the guardhouse of General Scharnhorst, hero of the War of Independence from Napoleonic France, 1813-15. This closely connected group, along with other artists in the painting, like Krueger himself, repre-sents the reforming ideals of Berlin art, which aimed to guide the populace in achieving the aesthetic and moral status of citizens in a modern state, a new democratic Athens.

Figure 3. Schadow, Schinkel, and Rauch.

Another group, who will appear importantly below, stands behind the brown and white horses in the left front, detailed in figure 4. They include Alexander von Humboldt (in tophat on the left), who had only returned to Berlin in 1827 after 20 years in Paris, where he published the many volumes documenting his expedition to South America and Mexico; Gaspare Spontini (right, tall, in tophat), composer and director of popular operas, sometimes with Humboldtian tropical scenery designed by Schinkel; and P.C.W. Beuth (rear, in red-banded cap), leader of the industrialization movement of the Prussian government and intimate friend of

Schinkel, who in turn was a longtime friend of the Humboldt family. Krueger here seems to want to capture a new constellation of cultural forces in Berlin in the late twenties.

The celebrated Humboldt, whom Krueger has imported here although he was not yet in Berlin for the 1824 parade, had won popular acclaim with his famous Kosmos lectures in 1827-28. He embodied the excitement of foreign landscapes and peoples along with an anticipated rejuvenation of all fields of natural science. Spontini reinforced the exotic Humboldtian image with operatic dramas. Meanwhile, Beuth stood at the center of the science-technology nexus as the leader of Prussia's drive to industrialize and as founder of new industrial institutions: the Technical Institute (*Gewerbeinstitut*) and the Society for the Advancement of Industry (*Verein zur Beförderung des Gewerbefleisses*). In these efforts he worked closely with Schinkel, as also in the reformed School of Architecture and Civil Engineering (*Bauschule*). Helmholtz and the ambitious young scientific modernizers who formed his immediate group of friends during his medical education in Berlin belonged to the next generation. They acquired their cultural identities within this milieu of material and social progress guided by neo-classical aesthetics and they sought to

Figure 4. Humboldt, Beuth, and Spontinni.

bring those ideals into the sciences when they established the Berlin Physical Society in 1845.[4] Like many of his peers, Helmholtz maintained a deep engagement with music and art throughout his life. As is well known, he was an accomplished pianist, but his drawing skills were also impressive, following five years of instruction in the Potsdam Gymnasium where his father was subrector (third in line).[5] The "godfather" of the Physical Society was Gustav Magnus,[6] whose brother Eduard was the most successful portrait painter in Berlin. Eduard maintained close ties with the already well-known painter Adolph Menzel, with whom Helmholtz would soon come in contact through his marriage to Olga von Velten. She was the niece of Helmholtz's superior while serving as a military doctor in Potsdam, Wilhelm Puhlmann, founder of the Potsdam Society of Art and a close friend of Menzel. These tight circles of relations begin to suggest why circulation captures something critically important to local culture. The circles extend easily through Helmholtz's closest friends in the Physical Society. Ernst Brücke's father, two uncles, and a stepbrother were Berlin artists and he himself remained active in the arts throughout his life. Emil du Bois-

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[4] On the founding of the Society see Wolfgang Schreier and Martin Franke, with the assistance of Annett Fiedler, "Geschichte der Physikalischen Gesellschaft zu Berlin," in *Festschrift: 150 Jahre Deutsche Physikalische Gesellschaft*, ed. Theo Mayer-Kuckuk, special issue of *Physikalische Blätter*, 1995, 51, F-9 — F-59.

[5] This assumes he followed the usual course of instruction. See "Der Jahresberich", by Director Dr. Rigler, in *Zu der öffentlichen Prüfung der Zöglinge des hiesigen Königlichen Gymnasiums den 21sten und 22sten März laden ganz ergebenst ein Director und Lehrercollegium* (Potsdam: Decker'schen Geheimen Oberhofbuchdruckerei-Etablissement, 1837), pp. 45-58, on 53.

[6] Dieter Hoffmann, ed., *Gustav Magnus und sein Haus* (Stuttgart: Verlag für Geschichte der Naturwissenschaften und der Technik, 1995).

Reymond always regretted that he had not taken up a career in art, like his aunt, his grandmother, and his renowned great grandfather Daniel Chodowiecki.[7] Given these relations with artists, it will be useful to begin exploring circulation with respect to drawing in art and the perceived significance of the line or curve.

Dürer Renaissance

Complementing Humboldt's *Kosmos* lectures at the *Singakademie* in the spring of 1828 was Spontini's romantic opera *Nurmahal*, with sets by Schinkel featuring exotic tropical vegetation inspired by Humboldt's *Vues des Cordillieres*. But another event marked the aesthetic character of Berlin art. On the 18th of April 1828, the 300th anniversary of Dürer's death, a great commemoration was held in Berlin, as well as in Dürer's native city of Nürnberg. The iconic status that Goethe was already acquiring by that date for German culture is well known; less familiar may be the fact that Dürer

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[7] For perceptive discussions see Sven Dierig, "Apollo's Tragedy: Laboratory Science between Calssicism and Industrial Modernism," in *Science as Cultural Practice,* eds. Moritz Epple and Claus Zittel (Berlin: Academie Verlag, 2007), and *Wissenschaft in der Maschinenstadt: Emil du Bois-Reymond und seine Laboratorien in Berlin* (Göttingen: Wallstein, 2006), pp. 10-16, 122-144 and *passim*; Timothy Lenoir, "The Politics of Vision: Optics, Painting, and Ideology in Germany, 1845-95", in *Instituting Science: The Cultural Production of Scientific Disciplines,* ed. Timothy Lenoir (Stanford; Stanford Univ. Press, 1997), pp. 131-178; and Gary Hatfield, "Helmholtz and Classicism: The Science of Aesthetics and the Aesthetics of Science", in *Hermann Helmholtz and the Foundations of Nineteenth-Century Science*, ed. David Cahan (Berkeley and Los Angeles: Univ. California Pr., 1993), pp. 522-558. Ernst Theodor Brücke, *Ernst Brücke* (Vienna; Springer, 1928), pp. 2-4, 137. Ernst Brücke, *Schönheit und Fehler der menschlichen Gestalt* (Wien & Leipzig; Braumüller, 1892). Emil du Bois-Reymond, "Naturwissenschaft und bildende Kunst", in *Reden von Emil du Bois-Reymond,* ed. Estelle du Bois-Reymond (Leipzig; Veit, 1912), vol. 2, pp. 390-425.

had become the personification of Germanness at a time when the Germans had discovered the gothic as their own, a wellspring of their unifying national character even though political unity eluded them. Dürer *was* the gothic, incorporating the romantic, the rational, and the Christian in one figure. This theme appears in an altar wall designed by Schinkel that graced the auditorium of the *Singakademie* in Berlin for the celebration there (figure 5).[8]

Dürer's larger-than-life statue, modeled after the most famous of his christomorph self-portraits, stands in the middle beneath a large painting of the ascent of Christ into heaven. The seated female figures to his right and left recall his work in the areas of "linear perspective", "painting", "sculpture", and "military architecture", the interrelation of which thematizes the present chapter. Importantly also, Schinkel had no difficulty incorporating the gothic Dürer into his own modernizing neo-classical statuary and frame, for he himself had recently made that transition in his architecture following the War of Independence (1813-15).[9] Schinkel's neo-classicism looked forward, toward an age of technology and industry, and it brought aspects of the Dürer renaissance with it.

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[8] Jan Bialostocki, *Dürer and his Critics, 1500-1971: Chapters in the History of Ideas Including a Collection of Texts* (Baden-Baden: V. Koerner, 1986), pp. 121-123; Matthias Mende and Inge Hebecker (eds), *Das Dürer Stammbuch von 1828* (Nürnberg; Carl, 1973), pp. 113-115.

[9] The literature on Schinkel is immense but a cogent interpretion is Barry Bergdoll, *Karl Friedrich Schinkel, An Architecture for Prussia* (New York: Rizzoli, 1994).

Figure 5. Karl Friedrich Schinkel, Dürer altar, 1828.

One such aspect was what Berlin artists admired as Dürer's realism, which provided a point of reference for their own realist tradition. That tradition has often been referred back to du Bois's great-grandfather Chodowiecki, whose woodcuts recall Dürer's. Another canonical reference is a sharp critique from Goethe in 1800, who complained that Berlin artists had lost sight of the universal ideals of classical Greece and become mired in provincialism, both historically and geographically: “In Berlin . . . naturalism seems to be at home with the demand for realism and utility and generally to manifest the prosaic Zeitgeist. Poetry is suppressed by history, character and the Ideal by portraiture, . . . and the universally human by nationalism”. In response, Gottfried Schadow, sculptor, painter, and soon to be director of the Academy of Art, called on the memory of Chodowiecki and Dürer in defense of a naturalism that mirrored real people with real emotions living in particular locations. In Berlin, he said, “one gives priority to those artworks that truly and honestly depict an existing model; every work of art is treated here as a portrait, a reflection of nature [*Konterfei*]”. A representative example is his famous double sculpture of the two princesses (*Prinzessinnen von Preussen*, 1795-97), the future Queen Luise and her sister Fredericke. Regarded as an epitome for German neo-classicism, it presents their teenage beauty in lifelike individual portraits, expressed through the pure lines of universalizing classical purity. The universal lies within the particular, he insisted, and not the particular within the universal.[10]

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[10] Johann Wolfgang Goethe, “Flüchtige Uebersicht über die Kunst in Deutschland”, *Propyläen,* 1800, *3*, repr. (Stuttgart; Cotta, 1965), 1065; Johann Gottfried Schadow, “Ueber einige in den Propyläen abgedruckte Sätze Goethes . . . (1801)”, *Gottfried Schadow: Aufsätze und Briefe*, ed. Julius Friedländer (Stuttgart; Ebner & Seubert, 1890), pp. 45-55; both in *Kunsttheorie und Kunstgeschichte des 19. Jahrhunderts in Deutschland: Texte und Dokumente*, Vol. 1: *Kunsttheorie und Malerei; Kunstwissenschaft,* eds. Werner Busch and Wolfgang Beyrodt (Stuttgart; Reclam, 1982), pp. 91-100. Schadow’s sculptures are depicted and described in *Nationalgalerie Berlin: Das XIX. Jahrhundert: Katalogue der ausgestellten Werke* (Berlin; E.A. Seemann, 2001), pp. 359-363: *Prinzessinnen Luise u. Fredericke von Preussen*, 1795-97, Inv.-Nr. B II 34.

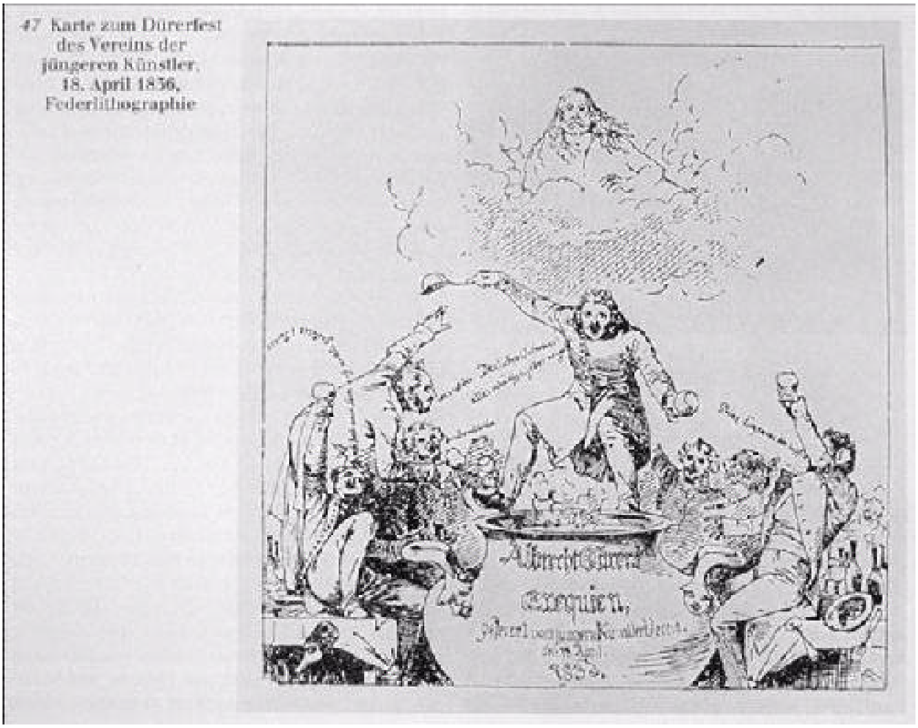
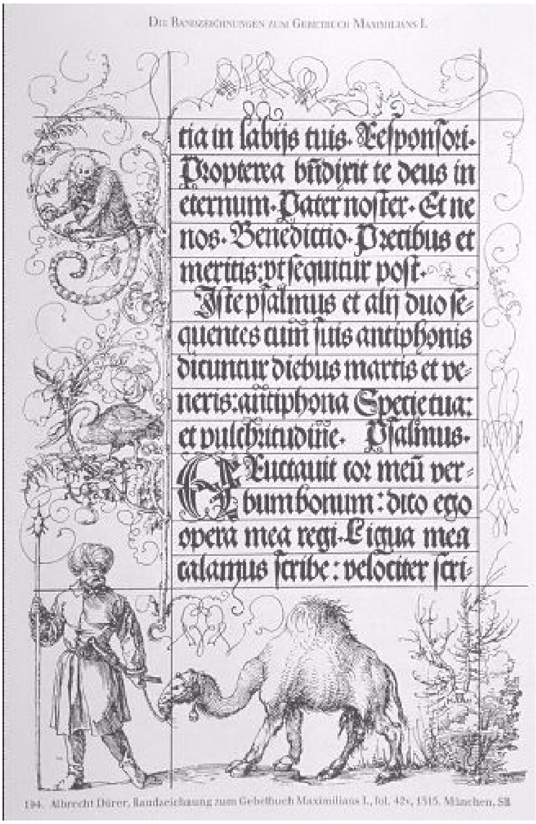


Figure 6. Adolph Menzel, Dürerfest, Union of Younger Artists, 1836

It was Schadow who organized the Dürer celebration in 1828. By that time he had himself become the representative of established academic art. A rather rebellious younger generation had emerged with full self-consciousness, having organized themselves in 1825 into the Union of Younger Artists. But even in their desire for greater freedom, they maintained Schadow's realist principles along with his pursuit of a truly national art, though with less reverence. Dürer remained their spiritual referent and the focus of a raucous yearly party (figure 6). Adolph Menzel joined them in 1834. This invitation card for the Dürerfest of 1836 is one of a series he produced from 1834 to 1837. Godfather Dürer frowns benevolently down from the clouds on his drunken disciples.



Die Randzeichnungen zum Gebetbuch Maximilians I.

tia in labijs tuis. Reſponſori.
Propterea bñdixit te deus in
eternum. Pater noſter. Et ne
nos. Benedictio. Precibus et
meritis: vt ſequitur poſt.
Iſte pſalmus et alij duo ſe-
quentes cū ſuis antiphonis
dicuntur diebus martis et ve-
neris: añtiphona Specie tua:
et pulchritudiñe. Pſalmus.
Eructauit cor meū ver-
bum bonum: dico ego
opera mea regi. Lingua mea
calamus ſcribe: velociter ſcri-

194. Albrecht Dürer, Randzeichnung zum Gebetbuch Maximilians I., fol. 42v, 1515. München, SB

Figure 7. Albrecht Dürer, Prayerbook, 1808.

It is Dürer's line that interests me here. It had become widely available through his famous illustrations for the Prayerbook of Emperor Maximillian I. A lithographic reproduction appeared in 1808 with regular republications afterwards.[11] Dürer's drawings in the margins, exemplified in figure 7, were the focus of attention. The lines of the gothic images metamorphose from one form to another and thence into snorkel-like lines and intricate arabesques. The style found numerous imitators in the 19th century, especially following the 1828 celebrations.[12] Another of Menzel's invitation cards for the annual Dürerfest of the Union of Younger Artists in 1837 gives a

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[11] Gebetbuch pub. Info, with lithographic editions of 19th C.

[12] E.g., Eugen Neureuther, *Randzeichnungen zu Goethes Balladen und Romanzen: Baierische Gebirgslieder* (1829-1839; 1855), facsimile of 2nd ed. (Unterschneidheim; Alfons Uhl, 1977). Werner Busch, *Die notwendige Arabeske: Wirklichkeitsaneignnung und Stilisierung in der deutschen Kunst des 19. Jahrhunderts* (Berlin; Mann, 1985), gives a thorough discussion of the arabesque genre, taken in its broadest sense to characterize an era of complexly interwoven modes of literary as well as graphic representation.

typical example (figure 8), here depicting Dürer's funeral with his long-time friend Peuckheimer giving a farewell blessing. Notice how Menzel's line moves smoothly between the plant forms, the written message, and the arabesque at the bottom, which symbollically ties the whole together.

Figure 8. Adolph Menzel, Dürerfest, 1837

A more elaborate example is the certificate of membership of the Berlin Physical Society (figure 9), which Du Bois-Reymond drew in 1845, organized by the line that metamorphoses from form to form: from the tree with its society of experimenting youth to the arabesque at bottom center, to the writing of Du Bois's name, "Emil Bois" at bottom center, to the name of the engraver, H. R. Heidel at bottom right, who would become an associate member of the Society.[13]

Apparently Du Bois conceived his iconography and employed his own line within

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[13] Hermann Rudolf Heidel (1811 – 1865), sculptor and draftsman, later a member of the Berlin Physical Society. I thank Gerhard Rupp for information on Heidel.

what had become a popular genre in the Dürer revival, carrying considerable symbolic significance for hopes of rejuvenation of the German nation. It may be indicative of a more direct parallel between Menzel's and Du Bois's images that in 1841 Du Bois founded a similarly progressive group calling itself the Union of Younger Natural Scientists (*Jüngere Naturforscherverein*), whose members would form a nucleus for the Physical Society four years later.[14] Like the Younger Artists and the Younger Natural Scientists, the Physical Society presented itself as a vanguard for this movement into the future. I will return to their means of achieving it below.

Die phyſikaliſche Geſellſchaft
zu Berlin
erwählte in ihrer Sitzung vom 14ten Januar
Herrn
Dr. Emil du Bois-Reymond
zu ihrem
ordentlichen Mitgliede.
Berlin, den 14ten Januar 1845
der zeitige Vorsitzende
der zeitige Schriftführer

Figure 9. Certificate of membership, Berlin Physical Society

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[14] Estelle du Bois Reymond, *Jugendbriefe von Emil du Bois-Reymond an Eduard Hallmann* (Berlin; Reimer, 1918), 29 March 1841, p. 86. Finckelstein, *Emil du Bois-Reymond*, p. 213. Ingo Schwarz und Klaus Wenig, eds., *Briefwechsel zwischen Alexander von Humboldt und Emil du Bois-Reymond* (Berlin; Akademie Verlag, 1997), p. 36.

But I want to pursue more deeply the function of Dürer’s line. Friedrich Teja-Bach has given an illuminating analysis. He shows the lines and arabesques to be integral to Dürer’s theory and practice of drawing. They interpret, so to speak, the naturalistic images of the drawings. Compare in figure 7 the arabesque in the top border with the camel at the bottom. As can be seen by superposition (figure 10), the arabesque provides a kind of paraphrase or epitome of the camel. It consists of a line which gives the basic shape of the camel and then returns to play rhythmically on its own forms in a suggestion of the organic unity of the actual animal and perhaps its rythmic movement.[15]

This example suggests that Dürer’s arabesque provides an abstract essence of naturalistic objects and processes. That is, the abstract line represents an ideal form, in the sense of a Platonic idea. That Dürer intended this Platonic reading seems to be unproblematic among art historians. It attains more depth through Teja-Bach’s discussion of how Dürer treated his line as a form of writing.[16] While the pictures continue the text allegorically, the snorkel-lines and arabesques write out the pictures in an ideal symbolic form.

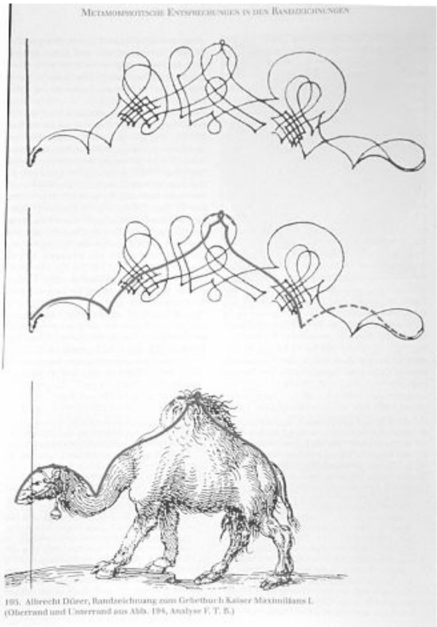

Figure 10. Analysis of Durer's arabesque and camel by Friedrich Teja-Bach.

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[15] Friedrich Teja-Bach, *Struktur und Erscheinung: Untersuchungen zu Dürers graphischer Kunst* (Berlin; Gebrüder Mann, 1996), pp. 165-193; camel, p. 172-173, 177.

[16] Ibid., pp. 282-297.

A similar relation between object, arabesque, and writing is apparent in the drawings of DuBois and Menzel above (figures 7 and 8). The effectiveness of these depictions, however, seems to have depended on other, much more widespread, expressions of the relation between objects and curves. Consider a depiction of "The Origin of Drawing" (figure 11) done in the 1830s by a Professor at the Academy of Art, Johann Erdmann Hummel, who taught architecture, projection, and optics. Hummel's picture continues an origin myth, also often labelled „the origin of painting", which goes back to Pliny the Elder and continued as a literary tradition into the modern period. But it came to be widely represented in drawings and paintings only from about 1770, in close association with neo-classical ideals, as well as with the popular art of the silhouette and Johann Caspar Lavater's *Physiognomische Fragmente*, illustrated by Chodowiecki.[17] At least six of these allegorical depictions were produced by a lineage of Berlin artists: Christian Bernhard Rode (1790), Schadow (1804), Franz Ludwig Catel (1806), Schinkel (1830), Hummel (1830s), and Wilhelm Eduard Daege (1834).[18] As the story goes, a Corinthian maid named Dibutades, whose young lover had to depart on a long journey the following day, was

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[17] Robert Rosenblum, "The Origin of Painting: A Problem in the Iconography of Romantic Classicism", *Art Bulletin,* 1957, *39*:279-290, discusses both linearity and silhouettes. Frances Muecke, "'Taught by Love': The Origin of Painting Again", *Art Bulletin,* 1999, *81*:297-302. I thank Claudia Swan for discussion and references.

[18] Hans Wille, "Die Erfindung der Zeichenkunst", in *Beiträge zur Kunstgeschichte: Eine Festgabe für H. R. Rosemann*, ed. Ernst Guldan (Munich; Deutscher Kunstverlag, 1960), pp. 279-300, who shows a different version of Hummel's drawing, dated 1834, and does not mention Daege. *K. F. Schinkel: Architektur, Malerei, Kunstgewerbe* (Berlin, 1981), catalogue no. 207a, p. 267. Wilhelm Eduard Daege in *Nationalgalerie Berlin*, Inv.-Nr. A I 216.

inspired to outline his shadow on the wall in order to keep his image clearly before her during his absence. Thus drawing and painting originated in love. Her father Butades, being a potter, filled the silhouette with clay and fired it in his kiln, producing a permanent image.

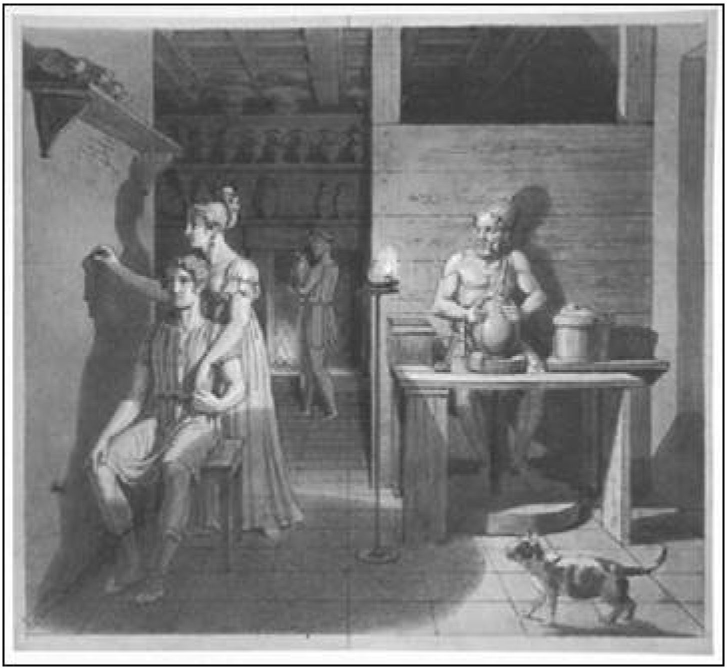

Figure 11. Johann Erdmann Hummel, Origin of Drawing, 1835.

In the neo-classical aesthetics of the late Enlightenment and Romanticism the story had particular relevance because it gave such prominence to the firmly drawn line, as opposed to color, as the foundation of art. This emphasis was appropiately figured in all of the „origin“ drawings and paintings as the line of the silhouette obtained by linear projection. Sharp outlines and smooth surfaces, symbolized definiteness, unity, and above all, rationality.

Hummel’s rendering, while maintaining the ideals of neo-classicism, transforms both the story of Dibutades and the genre of depictions based on it. Normally the potter Butades did not actually appear at all. And if he had, he would have been producing a flat clay model of the silhouette of Dibutades’ lover. Here his role is both prominent and differrent. He is engaged in his everyday work of producing large numbers of vases, all with the same classical form, which we see his assistant arranging on drying racks in the background. The origin of drawing is now manifested in the potter’s sharp-eyed concentration on the relation of his daughter’s drawing hand to his own shaping hand, the relation of the artist to the craftsman. Just as Dibutades’ line captures the visual essence of her lover, so a similar line becomes the materialized essence of Butades’ vase, whose classical silhouette he shapes in the clay as it rotates on the potter's wheel.

Hummel thus closely juxtaposes the work of art with craft manufacture and connects them through the classical line. His metaphorical picture also seems to depict his teaching of projective drawing at the Academy of Art, where he promoted the training of the mind through the hand and eye. A grasp of the basic principles of geometrical projection acquired through „numerous examples and drawings“ lay behind the capacity to render correctly, as though by second nature, the realistic effects of light and shadow. “Through industrious exercise”, he said, “the mind as well as the eye becomes practiced in correctly conceiving the appearances in nature and in making the laws on which they rest more intuitively apparent [*anschaulicher*]".[19] This view of *anschaulich* representation of laws as curves begins to get to the heart of the present paper.

To see Hummel's conception of the potter's curve in relation to practical use, one need only look at drawings that Schinkel and Beuth published as *Prototypes for Manufacturers and Craftsmen* for students at Beuth's *Gewerbe-Institut* (figure 12). The collection constituted a kind of canon of aesthetic forms, all classical, for the consumer goods of bourgeois life: tableware, wallpaper, fences, furniture, and architectural ornamentation. It formed part of a widespread attempt to elevate public taste and civic virtue through the artistic quality of the material environment within which the citzens of a modern state would live their lives. As shown for the elegantly simple vases, the *Prototypes* made quite explicit the sought-after relation between ideal curves and manufactured

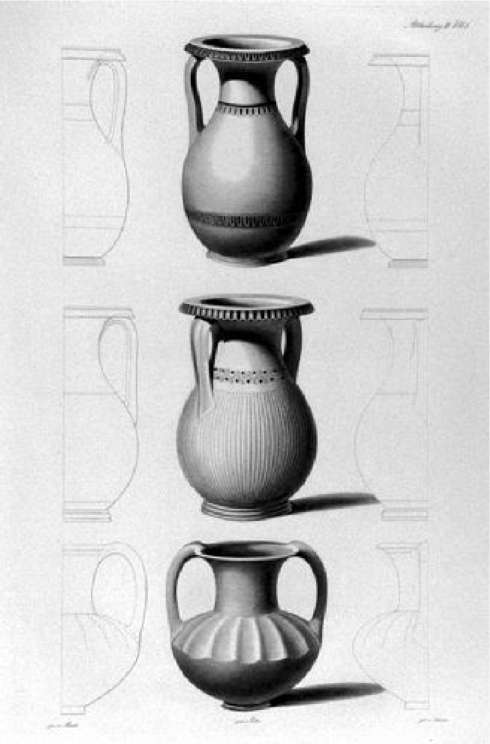

Figure 12. P. C. W Beuth & K. F. Schinkel (eds), Prototypes for Manufacturers and Craftsmen, 1821

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[19] Johann Erdmann Hummel, *Die freie Perspektive erläutert durch praktische Ausgaben and Beispiele, hauptsächlich für Maler und Architekten*, 2 vols. (1823; 1825), 2nd ed. (Berlin; Herbig, 1833), *vol. 1*, pp. vii-viii. See also, Hummel, *Geometrisch-praktische Construction der Schatten für Architekten und andere zeichnende Künstler* (Berlin; Herbig, 1842).

objects.[20] The collection as a whole emphasizes not only the smoothly flowing lines but also the familiar harmonic and periodic curves employed for cornices, decorative borders, fences, and wallpaper.

Importantly, Schinkel and Beuth make no distinction in their Prototypes between craft and machine manufacture, even though Beuth served as the most prominent promoter of industrial machinery in Prussia.[21] Indeed, with few exceptions, manufacture remained craft work, even when carried out with machines. More generally, the age of machine manufacture had not yet come to be seen as a tasteless era of „mechanical reproduction“ but rather as an era in which a broader cross-section of society could share in the great neohumanist project of personal self-realization (*Bildung*) and cultivation through the universal forms of classical art and architecture.

The project did not stop with students at the *Gewerbeinstitut* and *Bau-Akademie* but extended directly to Industry itself through such organizations as Beuth's Union for the Advancement of Industry (*Verein zur Beförderung des*

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[20] Technische Deputation für Gewerbe [P. C. W. Beuth and K. F. Schinkel] (eds.), *Vorbilder für Fabrikanten und Handwerker*, (Berlin, 1821). Conrad Matschoss, *Preußens Gewerbeförderung und ihre grossen Männer, dargestellt im Rahmen der Geschichte des Vereins zur Beförderung des Gewerbefleißes 1821 – 1921* (Berlin; Verein Deutscher Ingenieure, 1921), gives extensive discussion of Beuth's activities in promoting industry. See also Matschoss, "Geschichte der Königlich Technischen Deputation für Gewerbe. Zur Erinnerung an das 100 jährige Bestehen. 1811-1911," *Beiträge zur Geschichte der Technik und Industrie. Jahrbuch des Vereines deutscher Ingenieure*, 1911, *3*:239-275, esp. 239-250.

[21] Dierig, "Apollo's Tragedy", (cit. n. 7). The students trained in the crafts at the Gewerbe-Institut, with courses in drawing, modeling, and the natural sciences, fit more nearly the model of Halske than of traditional craftsmen. They were groomed to play an entrepreneurial role.

Gewerbefleisses), the pendent to the *Gewerbeinstitut*. Its membership placed craftsmen and entrepreneurs alongside professors, artists, and state administrators. Specifically, while Schadow, Schinkel, and Rauch all participated on the administrative committee for Architecture and Fine Art, Hummel's brother Caspar, a mechanic and founder of a machine factory in Berlin, served with other shopowners, professors, and state administrators on the corresponding committee for Mechanics and Mathematics.[22]

Geometrical Realism

Having observed some of the ways in which curves were seen to capture essences in both theoretical and practical terms, I want to return to Hummel's "Origin of Drawing" (figure 11) to raise a closely related subject, to which Dürer's name had been attached since the 16th century: geometrical drawing and perspective, but in the new 19th century form of projective geometry. It will be apparent that Hummel places the origin of the classically curved but otherwise arbitrary lines of drawing within a highly mathematized space, ruled by linear perspective and by the linear projection of shadows cast by the oil lamp of enlightening antiquity. As professor of architecture, projection, and optics at the Academy of Art, Hummel specialized in producing such constructions in ever

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[22] *Verhandlungen des Vereins zur Beförderung des Gewerbefleisses* (1822), 13.

more intricate detail, using multiple lighting sources, multiple mirrors, and multiple perspective.

Hummel received high praise from the critics for the extraordinary optical effects that he was able to incorporate in a fully natural manner. For this period, artistic sensibilities in Berlin cohered rather well with geometrical precision in drawing. Architectural realism in painting, for example, characterized not only the works of Schinkel but of well-known painters like Franz Krüger and Eduard Gaertner. Gaertner's "Klosterstrasse" (figure 13), almost photographic in detail, appeared in an engraved version for a great collection in Nürnberg, contributed by artists from all over Germany to honor Dürer.[23] With its depiction of Beuth, Schinkel, Gaertner, Krüger, and Rauch in the street in front of the *Gewerbeinstitut*, it suggests how closely related were the fine and manual arts in Berlin. One specific vehicle for this (partial) convergence in technique was the teaching of projective geometry — Hummel's subject — to students of art, engineering, and technology alike, from the *Kunstakademie*, to the *Bauschule*, to the military schools.

The subject came to Berlin largely as an import from France during and after Napoleon's occupation and followed the mathematical theory and practices of the engineers, Monge, Dupin, and Poncelet (though Hummel preferred the techniques of the earlier Berlin mathematician, Johann

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[23] Eduard Gaertner, *Klosterstraße*, engraving, 1830, in Mende and Hebecker, *Dürer Stammbuch von 1828*, (cit. N. 8), p. 152. The Stammbuch continued to grow for several years after 1828.

Heinrich Lambert).[24] At the technical schools, both civilian and military, projective geometry provided part of the foundation for subsequent courses in mathematics and mechanics, as well as drawing.

Figure 13. Eduard Gaertner, Klosterstrasse, Berlin, 1830

A good example comes from Du Bois Reymond's closest friend during his youth, Anton Hallman. Figures 14a,b suggest the transition from student exercises in projective

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[24] Lorraine Daston, "The Physicalist Tradition in Early Nineteenth Century French Geometry", *Stud. Hist. Phil. Sci.*, 1986, *17* :269-295, offers a good introduction to the subject. Ken Alder, "Making Things the Same: Representation, Tolerance and the End of the *Ancien Régime* in France," *Social Studies of Science*, 1998:*28*, 499-545, places projective geometry among a differentiated set of attempts to attain a perspectival representation, or mechanical objectivity, pp. 513-518. This reading would be too mechanical for the Berlin artists, architects, and engineers discussed here.

geometry to a fully realized artist's drawing in the architectural realist style of a Krüger or Gaertner. Interestingly, Hallman learned his projective geometry at the *Artillerieschule* in Hannover.[25]

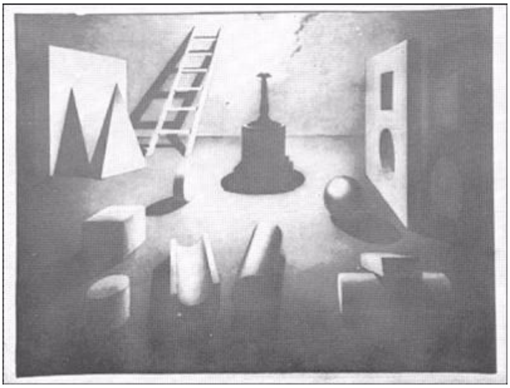

Figure 14a. Anton Hallmann, studies of projective geometry

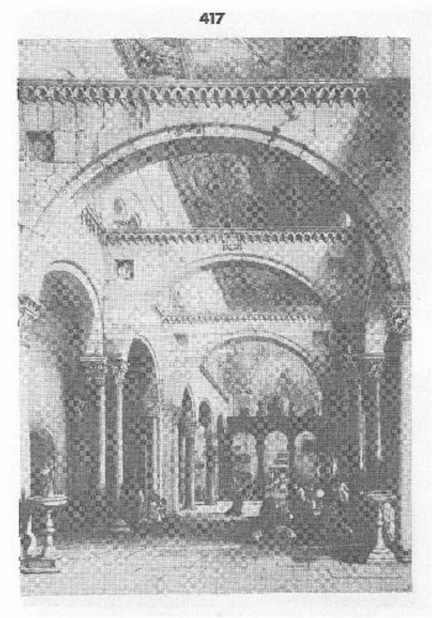

Figure 14b. Anton Hallmann, studies of projective geometry

Werner Siemens provides another marker for this movement in his study of projective geometry with Captain Meno Burg at the Artillery and Engineering School in Berlin,

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[25] Sabine Fehlemann, *Der Maler-Architekt Anton Hallmann, 1812-1845. Leben und Werk mit einem Oeuvre-Verzeichnis* (Diss., Munich, 1974). Dierig, "Apollo's Tragedy", (cit. n. 7), and Sven Dierig and Thomas Schnalke, *Apoll im Labor: Bildung, Experiment, mechanische Schönheit,* exhibition catalog (Berlin: Berliner Medizinhistorisches Museums der Charité, 2005), pp. 39-64.

which he attended from 1835 to 1838. Like Hummel at the *Kunstakademie*, Burg presented projective geometry as the vehicle for learning to produce correct representations according to "mathematical laws". Again like Hummel, Burg couched this mathematical ideal in the all-important language of neo-humanist *Bildung* — self-realization, creative action, reaching the inner form of things — all expressed through the properly expressive line:

> The draftsman must create out of himself . . . and, in using the forms and measures that have been given to him, become capable of allowing the picture, in its outlines and in its inner forms, gradually to emerge in lines.[26]

Burg's students at the Artillery and Engineering School, like Hummel's at the Academy of Art, could reach beyond mechanical reproduction to an authentic creative work only through extensive theoretical and practical exercise with the mathematical laws of projection, until these laws became expressions of the self, even in a drawing by Lieutenant Siemens of a cannon being placed on a wall, shown at the annual exhibition of the Academy of Art in 1838 with the title "Part of a wall with a windlass and 12 pound cannon."[27] Here was an aesthetics for a particular time and place. What may look today like „mechanical drawing“ was in

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[26] M. Burg, *Geschichte meines Dienstlebens* (1847), 3rd ed. (Leipzig: Kaufmann, 1916), pp. 71-75, paraphrasing his original memorandum of 1816. On Burg and his geometrical drawing, see also, Kathryn Olesko, *Precision in German Society, 1648-1989* (in preparation), ch. 6, “Aesthetic Precision”.

[27] Siemens’ drawing is listed in Helmut Börsch-Supan, ed., *Die Kataloge der Berliner Akademie-Ausstellungen 1786-1850*, 2 vols. & *Registerband* (Berlin: Bruno Hessling, 1971), 1838, no. 908.

the eyes of the Berlin drawing instructors a path toward attaining *Bildung* and an aesthetics for the modern world.

Had Werner Siemens had the financial means to study at the School of Civil Engineering and Architecture (*Bauschule*), as he had wished, he might have learned his projective geometry from none other than the precocious young mathematician Gustav Lejeune Dirichlet, already a member of the Academy of Sciences and associate professor at the University, although his primary teaching duties were at the War College (*Kriegschule*), where he included projecttive geometry in the first year of a three year sequence. Dirichlet also taught projective geometry for the *Bauschule*, with classes meeting at the *Gewerbeinstitut*, in 1835. Earlier, the instructor was another university professor, Martin Ohm, a serious mathematician himself and brother of Georg Simon Ohm of Ohm's-law fame.[28] That such high-powered analysts were teaching projective geometry to architects and civil engineers, military officers, and future technological entrepreneurs speaks once again to the perceived centrality of the subject and to its role as a medium of exchange — both aesthetically and practically — circulating through the fine arts, modern industry, and the mathematical sciences in a culture obsessed with neo-humanist and neo-classical ideals.

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[28] E. Lampe, "Dirichlet als Lehrer der Allgemeinen Kriegsschule", *Naturwissenschaftliche Rundschau*, 1906, *2:*482-485. Eduard Dobbert and Alfred G. Meyer, *Chronik der königlichen technischen Hochschule zu Berlin: 1799-1899* (Berlin: Wilhelm Ernst & Sohn, 1899), pp. 43, 48.

The Mathematics of Curves

The widespread teaching of projective geometry begins to suggest why the progressive young men of the Berlin Physical Society might have been particularly interested in the role of curves in the sciences. But it does not yet suggest how they learned to connect the irregular curves of nature's reality with the highly *regular* idealized forms of geometry. It was a longstanding problem. Dürer himself had worked on it with little success. Without going into the long history of the problem, it will be useful here to describe briefly the new approach followed by Dirichlet and Ohm.

While Dirichlet was teaching at the military and technical schools, as well as the University, he was also developing the methods of mathematical analysis that initially won him his fame. Most important for physical scientists was a rigorous proof, first presented in 1829, of the generality of the recent discovery by the French engineer and mathematician Joseph Fourier that many mathematical functions could be represented as an infinite sum of sine and cosine functions, or „Fourier series“, of which the harmonic vibrations of a violin string are a familiar example.[29]

Fourier used such series primarily to solve problems in heat conduction, published in 1822 as the *Analytical Theory of Heat*. Dirichlet studied in Paris from 1822-26, where Fourier became his mentor, and when he arrived in Berlin in

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[29] G. Lejeune Dirichlet, “Sur la convergence des séries trigonométriques qui servent a représenter une fonction arbitraire entre des limites données”, Crelle’s *Journal für die reine und angewardte Mathematik, 4* (1829), 157-169, in *G. Lejeune Dirichlet’s Werke* , 2 vols (Berlin; Reimer, 1889 & 1897), Vol.*1*: 118-132.

1828 he continued work on Fourier series. Without entering on the technical treatment, it is correct to say that Dirichlet established the validity of the Fourier series representation for a very broad class of functions of interest in the physical world, so broad that they exceeded the confines of functions that could be expressed in algebraic form. Throughout the great flowering of analytic mathematics, from D'Alembert and Euler through Lagrange and even Cauchy in Dirichlet's own time, the generality of mathematical analysis and its use in analyzing physical problems continued to run up against the view that a valid function ought to obey an algebraic law. For this and related reasons, Fourier analysis continued under a mathematical cloud even after its use in physics had begun to spread.[30]

In 1837 the Berlin physicist Heinrich Wilhelm Dove inaugurated the annual review *Repertorium der Physik*. Although the review would deal primarily with experimental physics, as did Dove himself, he had invited Dirichlet to join the editorial consortium as the representative for mathematical physics. For the first volume, Dirichlet chose to present his most important results on Fourier series, since, as he put it, „The peculiar series, which represent functions in a definite interval and which are entirely without law or follow entirely different laws in different parts of this interval, have found . . . numerous applications in the analytical treatment

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[30] Ivor Grattan-Guinness, *The development of the foundations of mathematical analysis from Euler to Riemann*, (Cambridge; MIT, 1970).

of physical problems.”[31] Through the *Repertorium* Dirichlet reached a very broad audience of experimental as well as mathematical physicists with his message, which deserves reiteration in terms of curves.

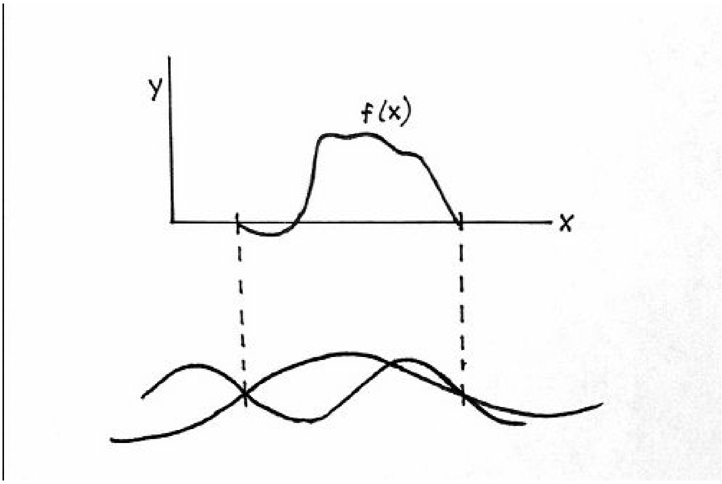

Figure 15. G. Lejeune Dirichlet, Function as curve (top) and harmonic analysis (down), 1837

He argued, first of all (figure 15 – top), that a mathematical function — more specifically, a single-valued function, whether continuous or discontinuous — need conform to no algebraic expression at all, no law, as he put it, but could be defined geometrically, as any freely-drawn curve: “This definition ascribes to the individual parts of the curve no general law; one can think of it as compounded of the most diverse parts or as drawn entirely without law.”[32] For

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[31] G. Lejeune Dirichlet, “Ueber die Darstellung ganz willkührlicher Funktionen durch Sinus- und Cosinusreihen”, *Repertorium der Physik*, 1837, *1*:152-174, on p. 152.

[32] Ibid., p. 153.

physicists, this meant that if any such curve could be obtained empirically, say as data from an experiment, it constituted a valid mathematical function (e.g., displacement of an elastic string, temperature distribution in a bar). Secondly (figure 15 – down), such curves could be analyzed mathematically by representing them as Fourier series, as sums of simple waves with different wavelengths and amplitudes. Thereby, the most non-lawlike looking curve could be analyzed into the simplest of harmonic laws, often taken to represent the underlying rhythms of nature.

It is difficult to overemphasize the importance of this result for the history of physics at the time. In a most lucid and accessible way, it turned a whole range of purely experimental physics into mathematical physics through the curve, at least in principle. So enthusiastic was Bernhard Riemann, who studied with Dirichlet in Berlin from1847 to 1849 and wrote his *Habilitationschrift* of 1854 on Fourier analysis, that he claimed Dirichlet's results covered „all cases in nature . . . for however great our uncertainty concerning how the forces and conditions of matter change in space and time in the realm of the infinitely small, we can nevertheless safely assume that the funtions to which Dirichlet's investigations do not reach, do not occur in nature."[33]

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[33] Bernhard Riemann, "Ueber die Darstellbarkeit einer Function durch eine trigonometrische Reihe" (Habilitationschrift, 1854), *Abhandlungen der Königlichen Gesellschaft der Wissenschaften zu Göttingen, 13* (1854), in *Bernhard Riemann: Gesammelte mathematische Werke,* eds. Heinrich Weber u. Richard Dedikind (eds), reedited by Raghavan Narasimhan (Berlin; Springer, 1990), pp. 227-264, on p. 237; also quoted in H. Koch, "Gustav Peter Lejeune Dirichlet", in *Mathematics in Berlin,* eds. H. G. W. Begehr, *et. al.*, Berlin; Birkhauser, 1998), pp. 33-48, on p. 37.

A second person who brought Fourier analysis to the attention of a broad audience in Berlin was Georg Simon Ohm, who had actually taught Dirichlet as a Gymnasium student in Cologne. Ohm moved to Berlin in 1826 to complete his now classic book on the electric circuit and then took up a part-time position at the War College for five years, where Dirichlet was also teaching. Ohm is known today largely for Ohm's law, which says that the current I through any section of a circuit is proportional to the electrical tension E (potential difference) across the section divided by its resistance R, or $I = E/R$. Ohm himself expressed a more general time-dependent relation for the electric potential at any point, closely resembling Fourier's differential equation for the temperature in a bar conducting heat. Drawing on this analogy with heat conduction, Ohm solved the equation for electric potential with a Fourier series. Although Ohm himself supplied no illustrations of curves, his results showed once again the great power of the harmonic decomposition as an expression of physical processes.[34]

I will not pursue further either Fourier analysis or Ohm's work except to note that in the 1840's the members of the Berlin Physical Society would adopt Ohm, whose work had been only slowly recognized, as one of their heroes in the cause of rigorous experimental and mathematical science. His analysis of the physics of hearing, based on the assumeption that the ear behaves essentially like a Fourier analyzer, so that we hear only the harmonic components of any com-

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[34] Georg Simon Ohm, *Die galvanische Kette, mathematisch bearbeitet* (Berlin: Riemann, 1827), reprint with commentary by Lothar Dunsch (Berlin: Verlag der Wissenschaften, 1989), pp. 170-176.

plex sound wave, stimulated a long-standing debate over combination tones, including Helmholtz's well-known work from the mid-fifties on combination tones and on the sensations of tone.[35] Fourier analysis had by then become a pervasive tool of mathematical physics.

Return now to Dove, who had published Dirichlet's review article in his *Repertorium*. In the 1830s and 40s Dove was omnipresent in Berlin education. In addition to teaching physics at the University, where du Bois-Reymond attended his lectures, Dove taught at various times at the *Friedrich-Wilhelms-Institut* for army doctors, where he was among Helmholtz's teachers, the *Kriegschule* (where he lived with his family), the *Artillerie*- und *Ingenieur-Schule*, and at one or more *Gymnasia*, including the *Friedrich-Wilhelms-Gymnasium*, where his geometry course included exercises in geometrical drawing.[36] He was also one of the pioneers in Berlin of the use of curves to represent physical laws,

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[35] R. Steven Turner, "The Ohm-Seebeck Dispute, Hermann von Helmholtz, and the Origins of Physiological Acoustics", *British Journal for the History of Science*, 1977, *10*:1-24. Myles Jackson, *Harmonious Triads: Physicists, Musicians, and Instrument Makers in Nineteenth-Century Germany* (Cambridge, MA: MIT Press, 2006), ch. 6. Georg Simon Ohm, "Ueber die Definition des Tones, nebst daran geknüpfter Theorie der Sirene und ähnlicher tonbildender Vorrichtungen", *Annalen der Physik und Chemie*, 1843, *59*:513-65; and "Noch ein Paar Worte über die Definition des Tones", *Annalen der Physik und Chemie*, 1844, *62*:1-18; both in *Gesammelte Abhandlungen von Georg Simon Ohm*, ed. E. Lommel, (Leipzig, 1892), 587-633, 634-649. Hermann von Helmholtz, "Ueber Combinationstöne," *Annalen der Physik und Chemie*, 1856, *99*:497-540; in *Wissenschaftliche Abhandlungen von Hermann Helmholtz*, 3 vols (Leipzig: Barth, 1882), Vol. I: 263-302.

[36] Hans Neumann, *Heinrich Wilhelm Dove: Eine Naturforscher-Biographie* (Liegnitz; Krumbhaar, 1925), pp. 13-14. Gymnasium courses in *Programmschrift, Königlichen Friedrich-Wilhelms-Gymnasium* (Berlin, 1838), pp. 53-60.

especially laws that seemed to defy mathematical expression. This work connected his interests directly to Dirichlet's.

Already in his first publication as a newly habilitated *Privatdocent* in Berlin, „Meteorological Investigations of the Wind" (1827), Dove sought to show that the direction of the wind, which appeared to change so arbitrarily „that people had given up trying to discover anything lawlike in it," actually obeyed a regular law that could be revealed by barometric observations. On the basis of published measurements taken over 10 years in Paris, he succeeded in representing the average yearly barometric pressure (and temperature and humidity) as a periodic function $b(x)$ of the direction of the wind x, from 0° to 360° around the compass,[37]

$$b(x) = a - c \sin(x + a),$$

where a and c are constants and a is a phase angle. Although Dove did not publish the curves for his laws, he suggested that the reader should construct them from his tables to actually see the cycles of pressure, temperature, and humidity as the wind moved around the compass.[38] It will be apparent why Dove would have been interested in publishing Dirichlet's proof of the validity of Fourier analysis of empirical curves.

These examples from Dirichlet, Ohm, and Dove, and the importance they took on for the members of the Berlin Physical Society, might be thought of simply in terms of the

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[37] Heinrich Wilhelm Dove, "Einige meteorologische Untersuchungen über den Wind", *Annalen der Physik und Chemie,* 1827, *11*:545-590, on 545, 550. Revised version in H.W. Dove, *Meteorologische Untersuchungen* (Berlin; Sander'schen Buchhandlung, 1837), pp. 97-120.

[38] Dove, "Einige meteorologische Untersuchungen", pp. 585, 590.

practical utility of harmonic decomposition of processes occurring in nature. But when correlated with the related practices in projective geometry and neo-classical art, they suggest again that the anschaulich representation of laws in terms of lines and curves had rather broad circulation in Berlin culture.

Alexander von Humboldt: Patron of the Curve

If by 1840 Dove and Dirichlet represented the pinnacle of current practice in the physical and mathematical use of curves, there stood behind them, both intellectually and politically, a patron of enormous prestige, Alexander von Humboldt. As noted previously, Humboldt had returned to his native Berlin in 1827 after twenty years in Paris, where he published the grand volumes that contain the scientific account of his travels in South America and Mexico with Aimé Bonpland from 1799 to 1803. A favorite of King Friedrich Wilhelm III, Humboldt had officially held the title of Chamberlain since 1805 and returned to Berlin at the king's insistence to take up his duties, with an enhanced salary of 5000 thaler. He returned like a modern Columbus. His lectures at the University and at the *Singakademie* in 1827-28 — overlapping with the Dürerfest, also at the *Singakademie* — made him a sensation in Berlin society and laid the foundation for perhaps the most popular scientific book of the 19th century, his five-volume *Kosmos* (1845-1862).[39]

Not so well known is that images of lush tropical landscapes from his Vues des *Cordillieres* (1810) and of mysterious peoples associated with them had already become familiar to Berlin opera-goers in the scenery that Schinkel designed for Goethe's *Magic Flute* (1816) and for a series of other operas: Handel's *Athalia* (1817), Spontini's *Fernand Cortez* (1818), Rossini's *Armida* (1820) and especially Spontini's *Nurmahal*, which complemented Humboldt's popular lectures of 1828.[40] Images of exotic lands and peoples thus surrounded Humboldt's popular persona as he went about establishing his scientific presence. The famous lectures at the *Singakademie* were followed by an epochal meeting in Berlin of the Union of German Scientists and Doctors (*Verein deutscher Naturforscher und Ärzte*), which Humboldt organized with his longtime friend, the professor of zoology Heinrich Lichtenstein. Since they aimed to instill a new sense of pride and confidence among German scientists, staging was important. With Schinkel's help, he employed some of the same sort of operatic scenery that already carried his

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[39] Publication details in Hanno Beck, ed., "Zu dieser Ausgabe des *Kosmos*," in Alexander von Humboldt, "*Kosmos": Entwurf einer physischen Weltbeschreibung*, vol 7(2) of *Alexander von Humboldt: Studienausgabe,* ed. Hanno Beck (Darmstadt: Wissenschaftliche Buchgesellschaft, 1993), p. 355.

[40] Humboldt, *Vues des cordillières,* e.g, plates 31, 33, 41-42, 63. Ulrike Harten, ed., *Die Bühnenentwürfe*, vol. 17 of *Karl Friedrich Schinkel, Lebenswerk*, eds. Helmut Börsch-Supan u. Gottfried Riemann (Munich & Berlin: Deutscher Kunstverlag, 2000), pp. 132-135, 228, 233-35, 237, 266, 271, 274, 340. Friedrich Muthmann, *Alexander von Humboldt und sein Naturbild im Spiegel der Goethezeit* (Zürich; Artemis, 1955), pp. 91-102. See also M. Norton Wise and Elaine M. Wise, "Staging an Empire", in *Things that Talk,* ed. Lorraine Daston (Cambridge; Zone Books, 2003), pp. 100-145, esp. 137-144.

popular image. For a celebratory evening session, held in one of Schinkel's greatest buildings, the *Schauspielhaus*, with Humboldt himself as the featured speaker and with King Friedrich Wilhelm III in attendance, Schinkel adapted his earlier Queen-of-the-Night scene from The Magic Flute for a backdrop. Like stars in the heavens above Zoroaster's temple, the names of famous Germanic scientists shined down on their earthly heirs. Music too enhanced the unifying spirit of the evening, including a choral piece composed at Humboldt's request by the precocious young Felix Mendelssohn-Bartholdy, one of the talented family of Abraham Mendelssohn-Bartholdy, at whose home Humboldt was a welcome guest.[41]

As the cultural life of the city shaded seamlessly into the life of science, Humboldt went about promoting the first-class research structures that he envisaged for Berlin, drawing heavily on his personal relationship with the King, with several of his Ministers, and with numerous friends throughout Berlin society.[42] He recruited young talent where-

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[41] A. v. Humboldt and H. Lichtenstein, *Amtlicher Bericht über die Versammlung deutscher Naturforscher und Ärzte zu Berlin im September 1828* (Berlin; Trautwein, 1829), 19 (schematic order of names for the backdrop). Paul Ortwin Rave, *Karl Friedrich Schinkel. Berlin, dritter Teil: Bauten für Wissenschaft, Verwaltung, Heer, Wohnbau und Denkmäler* (Berlin; Deutscher Kunstverlag, 1962), 363 (drawing of the hall with backdrop in the *Schauspielhaus*). See also Myles W. Jackson, "Harmonious Investigators of Nature: Music and the Persona of the German *Naturforscher* in the Nineteenth Century", *Science in Context*, 2003, *16*:121-145, who gives a fascinating account of the role of music among the *Naturforscher*, especially at the Berlin meeting, and whom I thank for very helpful discussions. We differ on whether the Schinkel backdrop was at the *Singakademie* or the *Schauspielhaus*.

[42] Humboldt's promotional efforts are best captured in the collections of his letters published by the Akademie der Wissenschaften, e.g., Kurt-R. Biermann, ed., *Alexander von Humboldt. Vier Jahrzehnte*

ver he saw it, including the newly arrived Dirichlet and Dove. Almost immediately he set up a magnetic observatory to extend earlier work from 1806-7, recording hourly and daily variations in the direction of the earth's magnetic field. For the purpose, Abraham Mendelssohn-Bartholdy offered the large garden of the family home, while the ubiquitous Schinkel contributed the design for a small iron-free observing house. Around this small observatory, linked through Humboldt's promotional activities into an international network of similar sites taking corresponding observations, the charismatic organizer attracted the young physicists and mathematicians of Berlin: Dirichlet, Dove, Magnus, Encke, and Poggendorf, among others. It was Dove who proudly took charge of publishing their results of 1829-30, represented graphically in sixteen plates of curves of magnetic declination, comparing the Berlin observations with simultaneous readings from the string of observatories from South America to Russia.[43]

Humboldt's own use of curves was already well-established. Famous are his „physiognomic" projections of landscapes in South America and Mexico. In their simplest form they were vertical cuts, yielding a silhouette of rising and falling elevations over mountains, plateaus, and valleys,

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Wissenschaftsförderung. Briefe an das preußische Kultusministerium, 1818-1859 (Berlin; Akademie-Verlag, 1985).

[43] Alexander von Humboldt, "Ueber die Mittel, die Ergründung einiger Phänomene des tellurischen Magnetismus zu erleichtern", *Annalen der Physik und Chemie,* 1829, *91*:319-336, on p. 333. H. W. Dove, with a forward by A. v. Humboldt, "Korespondierende Beobachtungen über die regelmässigen stündlichen Veränderungen und über die Perturbationen der magnetischen Abweichung im mittl. und östl. Europa" *Annalen der Physik und Chemie*, 1830, *19*:357-391. H. W. Dove, *Gedächtnissrede auf Alexander von Humboldt* (Berlin; F. Dümmler, 1869), pp. 22-23.

from which much could be read about the character of the landscape and the culture that inhabited it.[44] In the more elaborate form of the „physiognomy of plants“ Humboldt inscribed characteristic species on his vertical projections as well as on the more usual surface projections, yielding changing zones of vegetation with changing elevation, latitude, and longitude. Through physiognomy, he sought not a botanist's taxonomic classification of the vegetation but rather "that through which its mass individualizes the total impresssion of a region."[45] From this painterly analysis he identified eighteen main forms of plants characteristic of different climate zones, from the tropics to northern latitudes and from sea level to the tops of mountains.

Importantly for the present discussion, and as Michael Dettelbach has persuasively argued, Humboldt's aesthetically inspired physiognomy of plant zones cannot be split off from his equal emphasis on precision measurement of physical quantities: temperature, pressure, altitude, and magnetic parameters. In fact, for Humboldt, quantitative mapping was precisely what would reveal the qualitative landscape. This passage between quantitative and qualitative is particularly

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[44] On Humboldt's physiognomic vision see Michael Dettelbach, "The Face of Nature: Precise Measurement, Mapping, and Sensibility in the Work of Alexander von Humboldt," *Studies in History and Philosophy of Biological and Biomedical Sciences*, 1999, *30*:473-504.

[45] Alexander von Humboldt, *Ideen zu einer Physiognomik der Gewächse* (1806), republished (with extensive notes) in Humboldt's *Ansichten der Natur*, 3rd ed. (1849), reprinted in Beck, *Studienausgabe*, vol. 5: *Ansichten der Natur* (1987), (cit. n. 40), p. 184. Humboldt's physiognomic perspective attained its most extensive form in A. v. Humboldt and A. Bonpland, *Ideen zu einer Geographie der Pflanzen nebst einem Naturgemälde der Tropenländer* (1805-1807), in Beck, *Studienausgabe*, vol. 1: *Schriften zur Geographie der Pflanzen* (1989), (cit. n. 40), 43-161.

apparent in the curves with which he attempted rigorously to define the distribution of climatic zones over the surface of the earth. His pathbreaking „isothermal lines“ of 1817 were curves of constant annual mean temperature mapped over the northern hemisphere for both surface position and mountain elevation (figure 16).[46] For Humboldt the isothermal lines continued to express the physiognomy of nature, a concept that included both art and science, somewhat like projective geometry.

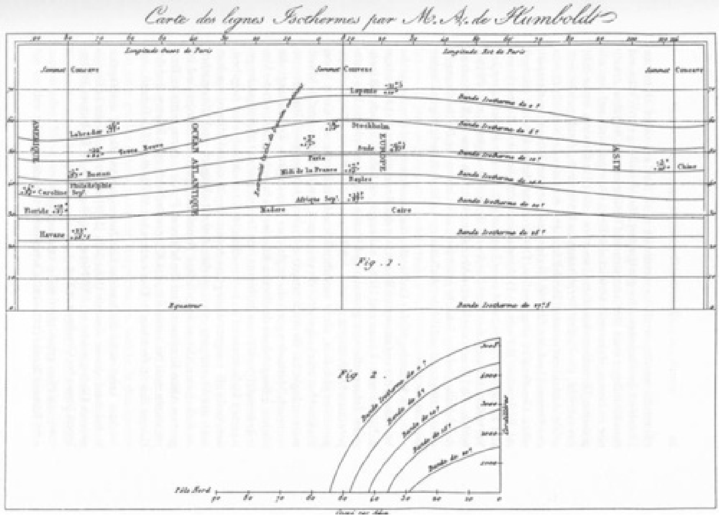

Figure 16. Alexander von Humboldt, Isothermal Lines, 1817.

By the time he arrived in Berlin, Humboldt envisaged a much broader program to incorporate variations over time

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[46] Dettelbach, "The Face of Nature," pp. 473-487. A. von Humboldt, "Des lignes isotherme et de la distribution de la chaleur sur le globe", *Mémoires de physique et de chimie de la Société d' Arcueil*, 1817, *3*:462-602; strangely, the chart appeared only in a separate publication (Paris: Perronneau, 1817); German in Beck, *Studienausgabe*, vol. 6: *Schriften zur physikalischen Geographie* (1989), pp. 18-97, chart on 19.

into the curves of nature, as in the variations of magnetic lines, and to extend his method to a whole range of meteorological measurements. The time had come to discover whether „the pressure of the atmosphere, the quantities of rain falling from the air, the relative frequency of prevailing winds, and the direction of isothermal lines, like the distribution of magnetism over the earth, are subject to secular variations“.[47] This is the program that Dove made into his life's work, adapting Humboldt's method of curves to reveal the laws of meteorology. Indeed, Dove's description of the relation of average barometric pressure to the direction of the wind was inspired in part by Humboldt's isothermal lines and by his extensive observations on climate. Dove had just completed his *Habilitationsschrift* on the distribution of heat over the earth, the distribution that Humboldt had depicted with his isothermal lines.[48]

The isothermal lines inevitably recall also Humboldt's personal acquaintance with Joseph Fourier in the Paris Academy of Sciences and with his *Analytical Theory of Heat* of 1822. On the basis of calculations dependent on the mathematical theory of the diffusion and radiation of heat, Fourier had become a leading proponent of the view that the earth was a cooling body, most likely having been formed originally as a molten mass. That view, which informed all of Humboldt's work in physical geography, had major impli-

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[47] Humboldt, "Ueber die Mittel . . . tellurischen Magnetismus", 319.

[48] H. W. Dove, "Einige meteorologische Untersuchungen", 578. *Idem*, *De barometri mutationibus*, Dissertation, Berlin, 1826; *De distributione caloris per tellurem*, Habilitations-Schrift, Königsberg, 1826 (not published).

cations for the isothermal lines at the surface of the earth as well as for the internal temperatures that Humboldt and others had measured deep in mines and in the water issuing from springs. He looked forward in 1817 to the „beautiful analytical work with which Fourier will soon enrich general physics“.[49]

Humboldt knew Fourier well by the time the young Dirichlet joined Fourier’s circle in 1825. And it was at Fourier’s instigation that Humboldt arranged for Dirichlet to obtain his appointments in Prussia, first at the University of Breslau in 1827 and then from 1828 successively at the *Kriegschule*, the University, and the Academy of Sciences in Berlin. Humboldt’s loyal friendship smoothed Dirichlet’s entire career, including even his marriage in 1832 to Rebecca Mendelssohn-Bartholdy (daughter of Abraham), after Humboldt introducted him to the family.[50]

1828 was a great year for curves. As though in a stellar conjunction, the revived Dürer, Humboldt, Dirichlet, and Dove arrived together in Berlin. In their different ways, they all treated the curve as revealing the essence of nature’s forms and processes, and in this they joined an already flourishing culture represented by people like Schinkel, Beuth, and Hummel. It is this culture and the technical practices circulating through it that supplied the inspiration and the

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[49] Humboldt, “Des lignes isotherme”, p. 94.

[50] Kurt-R. Biermann, ed., *Briefwechsel zwischen Alexander von Humboldt und Peter Gustav Lejeune Dirichlet* (Berlin; Akademie-Verlag, 1982), see the Introduction and early letters from 1825. *Idem*, *Johann Peter Gustav Lejeune Dirichlet, Dokumente für sein Leben und Wirken* (Berlin; Akademie-Verlag, 1959), p. 12. E. E. Kummer, “Gedächtnissrede auf Gustav Peter Lejeune Dirichlet”, in *G. Jejeune Dirichlet’s Werke*, 2 vols (Berlin; Reimer, 1897), pp. 310-344, esp. 314-324.

resources available to the members of Berlin Physical Society for their own curve-drawing activities.

Laws as Curves in the Berlin Physical Society

In people like Du Bois-Reymond and Helmholtz we see how the Humboldt-Dove-Dirichlet nexus of curve production became a part of the scientific literacy of a new generation that sought to make physical science the basis of all natural science, using curves to capture the lawlike character of apparently non-lawlike phenomena in nature. We see too how crucial was Dove's role both as a ubiquitous teacher in the Berlin educational network and as editor of the *Repertorium der Physik*. Dove taught physics to Du Bois at the University and to Helmholtz at the Friedrich Wilhelm's Institute for military doctors. And while he no doubt exposed them to the virtues of graphic representation, he also brought to their attention the latest works on electricity by Ohm and by Faraday, whose lines of electric and magnetic force were already capturing attention. Du Bois carried both the electricity and the lines into physiology in the early 40s, when he began to study the electrical stimulation of nerves and muscles, culminating in his *Untersuchungen über thierische Electricität* of 1848-49. His usual source of experimental material was the frog.

Figure 17 depicts his first major discovery, the law of the frog current. The diagram shows a rectangular section of freshly prepared muscle, with fibres running longitudinally, and a curve of current strength, which surrounds the rectangle. This curve of current (e.g., the top left portion) results from placing two electrodes a short distance apart and moving them in steps between the *x*'s along the longitudinal surface and down the cross-section. Du Bois-Reymond's sensitive galvanometer showed that a current will always flow between the electrodes in the direction of the arrow around the corners, with a strength increasing to the corner (5) and then decreasing to the mid-point on the cross section (7). The ordinates of the curve are the dashed lines parallel to the bisecting line of the corner. No current flows with the electrodes placed symmetrically on two sides of the mid-points at I and 7. This inventive if complicated representation, with the curve superposed on the muscle section and showing all of the symmetries of the phenomenon, suggests Du Bois-Reymond's fascination with laws as curves.[51]

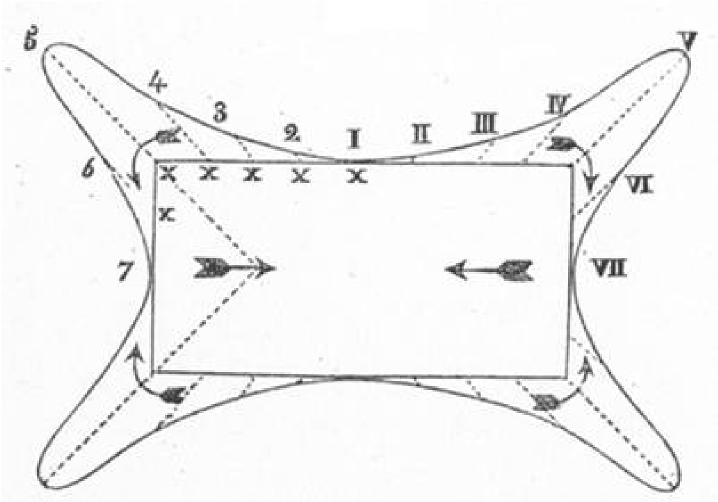

Figure 17. Emil Du Bois-Reymond, Muscle-current diagram, 1848-49

Frogs, however, were not his only experimental animal. In figure 18 he has drawn himself with the youthful beauty of a Greek athlete. He is measuring the current that passes over his body when his right bicep is strongly

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[51] Emil du Bois-Reymond, *Untersuchungen über thierische Electricität* , 2 vols (Berlin: Reimer, 1848-49), vol. 1.

contracted and the left remains relaxed. Du Bois-Reymond's ability consistently to produce deflections of his galvanometer actually resulted from a highly skilled performance, mastered only after extensive practice in controlling his own body. As Sven Dierig has emphasized, this bodily control as experimenter mirrors Du Bois's bodily control as a gymnast, attained through many years of exercise on the bar, beam, and horse.[52]

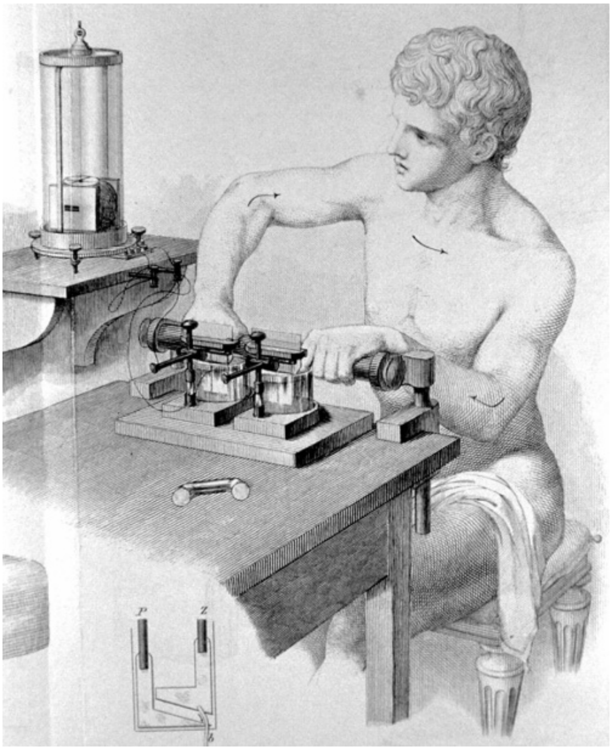

Figure 18. Emil Du Bois-Reymond as experimenting Apollo, 1848-49.

Dierig suggests that in his classical self-representation, Du Bois intended to portray himself as an Apollonian figure. Within the pervasive neo-humanist value structure of the *Bildungsburgertum*, Apollo epitomized manly beauty and the virtues of athletic excercise, particularly gymnastics, as a component of *Bildung*. This interpretation of Du Bois's self-image is thoroughly consistent also with the idealist conception of beauty that his closest collaborator in founding the Physical Society, Ernst Brücke, held throughout his life,

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[52] Dierig, "Apollo's Tragedy," (cit. n. 7). Du Bois-Reymond, *Thierische Elektricität*, vol. 2, pp. 276-288.

reflecting the neo-classical aesthetics that he had learned from his artist father and uncles and that he recognized in the smoothly muscled bodies of trained gymnasts and acrobats.[53]

As the values attached to instruments and aesthetics circulated among the members of the Physical Society, their attempts to represent laws as curves aimed less at employing the disciplined self as a recording instrument than at developing the skills to use mechanical and electrical instruments that would draw the curves directly, thus „self-recording“ or „self-registering“ instruments. These instruments were aids in the effort to reveal the essences of nature in the form of curves. They sought ideal forms, not photographic realism and not the confused and contingent appearances of particular events.[54] Du Bois, Brücke, and Helmholtz all maintained the classicizing aethetics of their youth throughout their lives. Although this simultaneous commitment to mechanics and aesthetics could be developed at length for several members of the Physical Society, I will indicate briefly only how it played out for Helmholtz.

Important sources in mechanics for the proliferation of self-recording instruments in the 1830s and 40s were the dynamometers and indicators developed by engineers to record the work being done by any working machine, whe-

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[53] E. T. Brücke, *Ernst Brücke*, pp.139-146.

[54] For this reason, the term "mechanical objectivity" employed for atlas makers of the 19th century by Lorraine Daston and Peter Galison, "The Image of Objectivity", *Representations*, 1992, *40*:81-128, does not seem appropriate to the aims of the Physical Society. More generally, while they make a very persuasive case for the atlases, which belong to the tradition of natural history, I am skeptical about its extension to natural philosophy, primarily because of the strongly idealizing practices of both mathematical and experimental physics.

ther powered by muscle, wind, water, or steam. The indicator for a steam engine, because it responded to the pressure inside the cylinder, was sometimes said to take its pulse, like a stethoscope.[55] Figure 19a shows how an indicator from the 1840s was screwed into the top of the cylinder of a steam engine.[56] The string attached to the connecting mechanism of the engine's main beam produces one revolution of the recording cylinder of the indicator (figure 19b) for each cycle of the engine's piston, while a stylus rises and falls with the pressure in the cylinder. Although originally invented (in a much simpler form) by James Watt and his master mechanic John Southern in 1796, the indicator remained almost unknown until the 1820s and received rapid development only in the 1830s and 40s, when various versions of the rotating drum were introduced.[57] Since the recording drum rotates with the motion of the piston, and thus in proportion to the volume of the cylinder, while the stylus records the rise and fall of pressure in the cylinder, the indicator effectively traces a curve of pressure vs. volume. Consequently, the area enclosed by the resulting „indicator diagram" (figure 19c)

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[55] Thomas John Main and Thomas Brown, *The Indicator and Dynamometer, with their Practical Applications* (London; Hebert, 1847), p. 5.

[56] Joseph Hopkinson, *The Working of the Steam Engine Explained by the Use of the Indicator: With a Description of that Instrument and Instructions How to Use It* (London; Simpkin, Marshall, & Co., 1854), title page.

[57] H. W. Dickinson and Rhys Jenkins, *James Watt and the Steam Engine* (1927), reprint (Derbyshire; Moorland, 1981), pp. 228-233. R. L. Hills and A. J. Pacey, "The Measurement of Power in Early Steam-driven Textile Mills", *Technology and Culture*, 1972, *13*:25-43. Indicators were described in Berlin for Beuth's Gewerbefleiss-Verein in *Verhandlungen*, (1830), 72, 228. For the Physical Society, Werner Siemens provided an obvious source.

measures the work done by the engine in one cycle: i.e., the integral of pressure times change of volume over one revolution.

Helmholtz was familiar with the use of these diagrams for steam engines by mechanics and with their transformation into the idealized Carnot diagrams for generalized heat engines by mathematical engineers and physicists. He was equally familiar with the physiological instruments derived from them,[58] especially the "kymograph" invented by his friend Carl Ludwig in 1847, which produced a graphical recording of blood pressure or respiration. The instrument of present interest, however, is the frog-drawing-machine (*Froschzeichenmaschine*, or myograph) of figure 20, which Helmholtz developed between 1848 and 1852.[59]

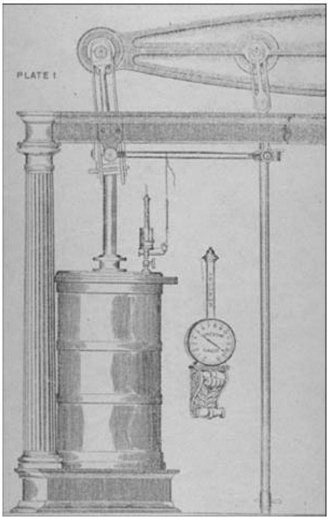

Figure 19a. Joseph Hopkinson, The Working of the Steam Engine Explained

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[58] Soraya de Chadarevian, "Graphical Method and Discipline: Self-Recording Instruments in Nineteenth-Century Physiology," *Studies in History and Philosophy of Science*, 1993, *24*:267-291; and "Die 'Methode der Kurven' in der Physiologie zwischen 1850 und 1900," in *Die Experimentalisierung des Lebens: Experimentalsysteme in den biologischen Wissenschaften 1850/1950,* eds. Hans-Jorg Rheinberger und Michael Hagner (Berlin : Akademie Verlag, 1993), pp. 28-49.

[59] I give a reinterpretation of this work, focusing on its relation to Helmholtz's conservation principle and his aesthetics, in *Bourgeois Berlin and Laboratory Science* (in preparation), ch. 8, "Ein Schauspiel für Götter." This account builds on the papers of Olesko and Holmes cited below. The main primary sources are Hermann Helmholtz, "Messungen über den zeitlichen Verlauf der Zuckung animalischer Muskeln und die Fortpflanzungsgeschwindigkeit der Reizung in den Nerven" (1850); "Messungen über die Fortpflanzungsgeschwindigkeit der Reizung in den Nerven. Zweite Reihe," (1852); "Ueber die Methoden, kleinste Zeittheile zu messen, und ihre Anwendung für physiologische Zwecke (1850), all in Wissenschaftliche Abhandlungen, 3 vols (Leipzig; Barth, 1882-95), vol. 2: 764-843; 844-861; 862-880.

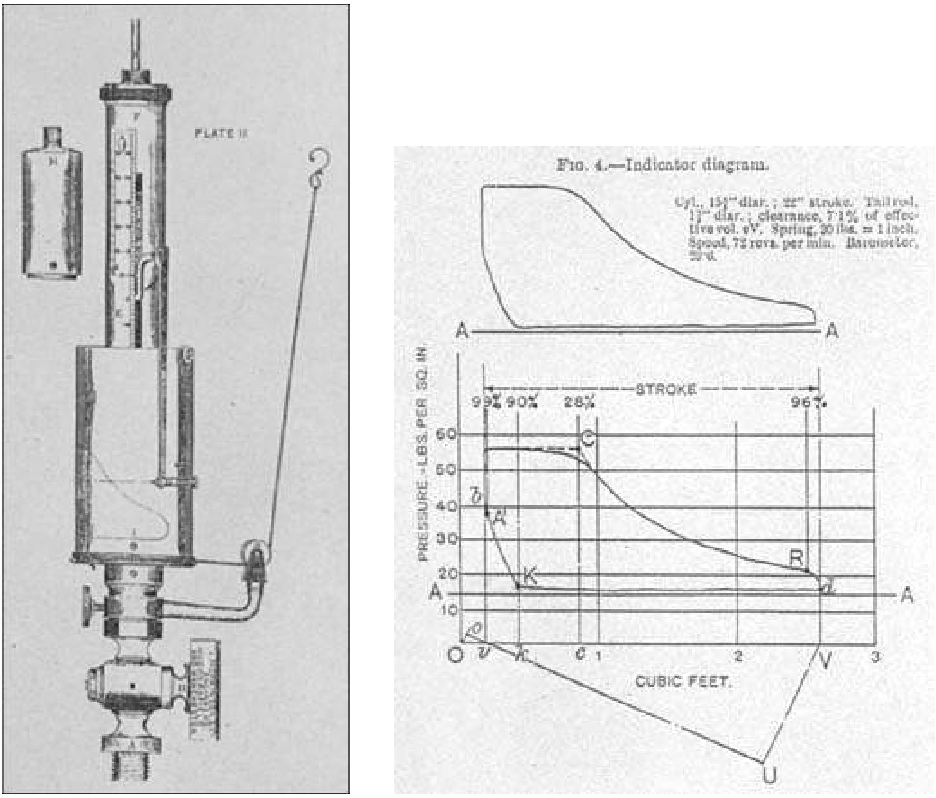

Figure 19b and 19c. Recording cylinder and indicator diagram, 1854.

According to Ludwig, both his own and Helmholtz's instruments derived directly from the indicator. Helmholtz's device treats the contracting and relaxing frog muscle quite literally like an engine burning fuel to produce work. The frog muscle (not shown) pulls on the hook at top center in the main drawing. When contracting, it lifts a frame (top view on the right) which carries a stylus on its left end. The stylus draws a curve on the rotating drum to the left of one cycle of contraction and extension of the muscle, like an indicator curve, but here representing at any point the net work that has been done by the muscle.[60] The conical pendulum on the bottom left, originally intended as a regulator of rotational speed, may well have derived from a differential governor for steam engines developed by Siemens. Finally, the timing scheme for triggering the electrical stimulus to the frog's nerve at a definite point in the drum's rotation (detailed at bottom left), was adapted from a precision technique that Siemens had developed for measuring the muzzle velocity of cannon balls and which Du Bois, at one of the first meetings of the Physical Society in 1845, suggested might be adapted for muscle contraction. In realizing this idea, Helmholtz obtained a fairly precise measure of the temporal process of muscle contraction following a stimulus.[61]

Helmholtz's results for what he called the curve of *Energie* of the frog muscle, appear on the right. The curves write out the muscle's action in the language of engines. His Fig.'s 5 and 6 show results for fresh and slightly tired muscles while Fig.'s 4 and 7 are controls, for tiredness and irritability.

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[60] Carl Ludwig, *Physiologie des Menschens*, 2 vols (Heidelberg: Winter, 1852), vol. 1: 333. Robert M. Brain and M. Norton Wise, "Muscles and Engines: Indicator Diagrams in Helmholtz's Physiology," in *Universalgenie Helmholtz: Ruckblick nach 100 Jahren*, ed. Lorenz Krüger (Berlin: Akademie Verlag, 1994), pp. 124-145; reprinted in Mario Biagioli, ed., *The Science Studies Reader* (New York: Routledge, 1999), pp. 51-66.

[61] Werner Siemens, "Beschreibung des Differenz-Regulators der Gebrüder Werner und Wilhelm Siemens," *Dingler's polytechnisches Journal*, 1845, *98*:81, in *Wissenschaftliche und technische Arbeiten von Werner Siemens*, 2 vols (Berlin: Springer, 1891), pp. 2-11. Siemens, "Anwendug des elektrischen Funkens zur Geschwindigkeitsmessung," *Poggendorff's Annalen der Physik und Chemie*, 1845, *66*:435-445; in Siemens, *Wiss. u. Tech. Arbeiten*, 8-14. Siemens, "Ueber Geschwindigkeitsmessung," *Fortschritte der Physik im Jahre 1845*, 1847, *1*:46-72. "Protcoll der Physikalischen Gesellschaft zu Berlin: 1845," Archiv der Deutschen Physikalischen Gesellschaft, Nr. 10001, 7 March 1845.

Fig. 4 may be taken as the iconic result. Its two curves demonstrate two things in a perspicuous manner.[62] First, the muscle only develops its *Energie* over time (about 0.15 seconds to raise the weight to maximum height).

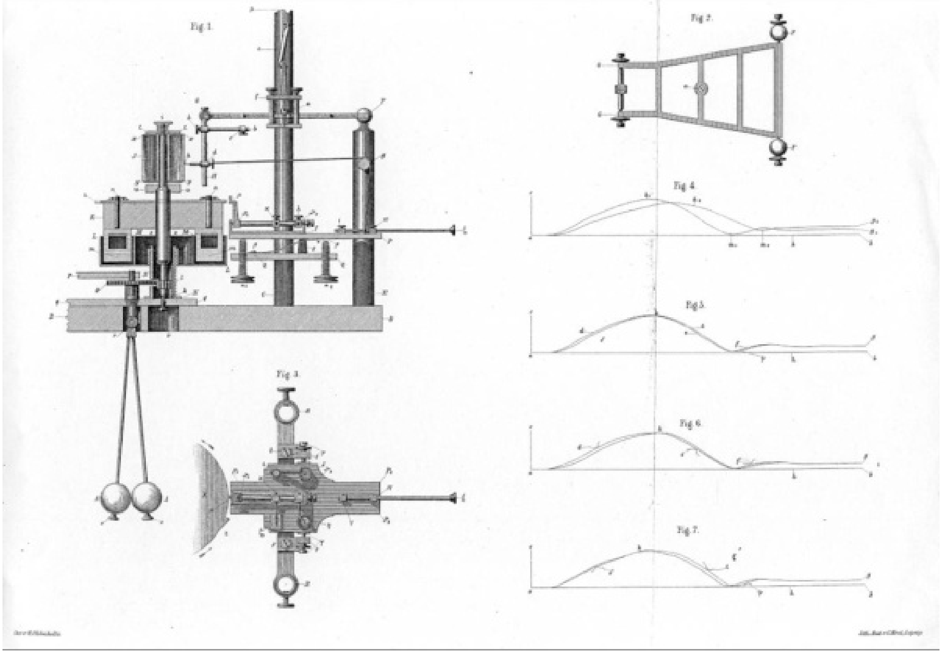

Figure 20. Helmholtz's frog-drawing machine (myograph).

This was a surprising result for physiologists when Helmholtz first announced it in 1850, although he fully expected it on the assumption that the *Energie* resulted from purely physical-chemical processes going on in the muscle.

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[62] Helmholtz, "Messungen über Fortpflanzungsgeschwindigkeit," W.A., plate II. A nice analysis focusing on „qualitative precision" is Frederic L. Holmes and Kathryn M. Olesko, "The Images of Precision: Helmholtz and the Graphical Method in Physiology," in *The Values of Precision,* ed. M. Norton Wise (Princeton: Princeton University Press, 1995), pp. 198-221.

The result served to confirm the thesis of conservation of force that he had developed at length in his (not yet) classic paper of 1847, *Ueber die Erhaltung der Kraft*. Secondly, the observeable delay time suggested to Helmholtz that he might actually measure the time it took for a stimulus to reach the muscle when propagated along the nerve. The two curves of Fig. 4 depict Helmholtz's famous demonstration that the nerve impulse requires time for propagation. They are displaced relative to one another because they are stimulated from different points on the nerve. Dividing the distance between the stimulation points by the time represented by the displacement, shows that the nerve impulse travels at the relatively slow speed of 27 meters per second, less than 1/10th the speed of sound in air, again confirming the assumption of ordinary physical processes.

So far we have seen only Helmholtz's mechanics. But he had had five years of training in drawing at the Potsdam Gymnasium and when he began his work on the *Froschzeichenmaschine* in 1848 he had just taken up a position at the Academy of Art in Berlin teaching anatomy to art students, a position in which Brücke had preceded him and Du Bois-Reymond would follow. The relation between these two activities can be symbolized by the fact that he made the drawing of the machine himself, entering *Gez. v. H. Helmholtz* (drawn by H. Helmholtz) on the lower left, in the manner of artists, with the lithographer on the bottom right. More deeply, his aesthetic values can be seen in his usage of Form, in both contexts. In his *Probevortrag* for the Academy of Art, his conception of Form appears in the adjectives he regularly associates with the term — *lebendig*; ideal; *harmo-*

nisch; *geistig* — and with the artist's capacity to express it — *Anschauung der Form*; *künstlerischen Schönheitssinn*; *künstlerischen Geist*. Unlike the closely related term *Gestalt*, Form refers in Helmholtz's usage not to the particular shape that a muscle may have on a specific body but to its type and especially to its Idea. The artist must be able to perceive this Form in an immediate, intuitive, and lively *Anschauung*. Training in anatomy is crucial to recognizing the Form and its causes and to differentiating essential from non-essential features of a particular shape (*Gestalt*), although it can never replace the *künstlerische Geist*.

> It is a means which facilitates for the artist his spiritual victory over the ever-changing variety of his earthly object, the human Form, which should sharpen his view of the essential in the *Gestalt*, which should equally make transparent to him the entire *Gestalt*. . . . But art, I would like to say, begins only beyond anatomy. The artistic spirit reveals itself first in the wise application of the Forms whose interconnection and elementary features anatomy has taught; it reveals itself in the differentiating characteristic of the *Gestalt*.[63]

Thus it is through the realization of the Form that an artist produces the beauty of a particular *Gestalt*. And just because it is the *Form* and not the *Gestalt* that is of primary interest, the artist's task is not to copy nature but to capture ideal beauty, to awaken in the viewer "*das Gefühl harmonischer und lebendiger Schönheit*."

> The artist should never attempt to imitate in the truest possible way, because his model is always only a person grown up in earthly imperfection, never corresponding to

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[63] Hermann Helmholtz, "Probevortrag," in Leo Koenigsberger, *Hermann von Helmholtz*, 3 vols (Braunschweig: Vieweg, 1902-1903), Vol. I: 95-105, on 102-105.

> the Ideal; rather, he should modify the individual Gestalt until it is the perfected impression of its spiritual content.[64]

To reveal the *Ideal* of the curve of *Energie* as opposed to any individual *Gestalt*, was precisely Helmholtz's aim in his four years of work on the frog-drawing-machine. His entire argument, in fact, rested on establishing this *Form* as a constant of the natural process of contraction. For example, the measurement of propagation speed from his Fig. 4, as he fully elaborated, depends on the two curves being congruent throughout their length, so that the displacement is uniform throughout and therefore dependent only on propagation time, not on such contingencies as state of tiredness or intensity of stimulation.[65]

The frog-drawing-machine represents the pinnacle of self-recording instruments in the early days of the Berlin Physical Society. But it was only one of a considerable number of curve-producing techniques and instruments that the members of the Society developed in the 1840s, the conditions for which I have attempted to draw out of the artistic, scientific, and industrial life of the city. Indeed, their work as a whole should be seen as a subset of many forms of curve production in Berlin.

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[64] Helmholtz, "Probevortrag," 101.

[65] Helmholtz, "Messungen über den Zeitlichen Verlauf"; usages of *Gestalt* and *Form* appear at 768, 770, 791-794, 820. Kathryn M Olesko and Frederic L. Holmes, *Experiment, Quantification, and Discovery: Helmholtz's Early Physiological Researches, 1843-1850*," in *Hermann von Helmholtz and the Foundations of Nineteenth-Century Science*, ed. David Cahan, (Berkeley: University of California Press, 1993), pp. 50-109, analyze especially Helmholtz's accounting procedures using the method of least squares.

Conclusion

Return now to Du Bois's certificate of membership, and particularly to the lush tropical tree (figure 21) on which the modernizing scientists perform their feats. It is a tree of knowledge, to whose fruiting and flowering higher branches one of the heroes of enlightenment has tied the banner of the Physical Society. Unlike the pudgy cherubs or Putti familiar in many other such fanciful images at the time, the analogous figures here are athletic youths. They conspicuously employ physical instruments to carry out analytic experiments in the various „branches“ of physics, which the group had begun to review in its new journal, *Progress in Physics* (*Fortschritte der Physik*). From his perch in the higher branches, a young astronomer aims his telescope to reveal the line of epicyclic motions of a comet, now tied to the tree of knowledge, while a symbolic Newton with a large prism similarly analyzes the spectrum of sunlight, symbolized as an arabesque of harmonic loops, reminiscent of both Dürer and Fourier. A new Galileo on the right demonstrates the law of falling bodies, showing that the distance increases with the square of the time. The gymnast on the left, surely representing Du Bois himself, performs his exercises on an electromagnet. His neighbor attempts to fathom the watery depths with a perfectly straight plumbline, unaware that the deceitful nymphs below are busy making a tangle of it. Of the performers at the base of the tree, one investigates the lines of Chladni figures (produced by bowing a metal plate covered with dust)[66], another carries out a geometrical analysis, a third draws electrical sparks from a Leyden jar, and a fourth tests the laws of hydrodynamics with a curiously phallic pump. The prominence in this scene of physical instruments and of curves is everywhere apparent.

Equally apparent, the curves are conceived as inscribed by the instruments, which read out the ideal forms of nature. The heroes themselves, in their classical beauty, seem to play much the same role as Du Bois's Apollonian experimenter. If so, their activities should be seen as disciplined performances on their instruments of analysis to reveal nature's true Forms. Thus Du Bois's iconography states my central theme, that curves, especially harmonic or rhythmic curves, conceived as representing the essence of natural objects and processes, played an extraordinarily important role in the view of knowledge held by the members of the Physical Society, a view that carried across the boundaries of art, science, and technology. As Du Bois himself expressed it in the introduction to his *Animal Electricity*,

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[66] On Chladni's figures and their fundamental significance for music and science, see Jackson, *Harmonious Triads*, (cit. n. 36), especially ch. 2.

even though one could only rarely obtain knowledge of cause-effect relations in a mathematically expressible form, ”The dependence of the effect on each circumstance presents itself in the form of a curve . . . whose exact law remains . . . unknown, but whose general character one will in most cases be able to trace."[67] This is a view of the relation between laws and curves that Hummel, Burg, Humboldt, Dirichlet, and Dove had all expressed in their own ways and that Helmholtz realized with his frog-drawing-machine. It carries Dürer's Platonism into the 19th century, but with the crucial addition of Fourier analysis, precision instruments, and graphical representation, which seemed finally to provide the tools to put Dürer's idealist vision of knowledge into a realist form.

Looking once again at Du Bois's allegory, if we follow the vertical display downward, we leave the light of day and the scenes of rational analysis above ground and move under ground, where the roots of the tree of knowledge lie buried in the mythological past. This underworld recalls Du Bois’s well-known polemic, immediately following his extended discussion of mathematical-physical methods and the use of curves, launched against the dark and vitalistic notion of a *Lebenskraft*, which he ascribed to the speculative romanticism of contemporary physiologists and to their ignorance of physical methods.[68] Here Mephistopheles steps out of the flames of hell to observe the searching figure in the cave, from Plato's Republic, who with book in hand is vainly attempting to decipher dim shadows on the wall, imprisoned in his own

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[67] Du Bois-Reymond, *Thierische Elektricität*, vol. 1: 26-27.

[68] Ibid., pp.xxxiv-xl.

imaginings. Apparently he lacks the instruments of enlightenment that the new physicists regard as necessary for ascending the Platonic scale from the visible to the intelligible. Outside, bearded giants with torch and urn evoke the powers of fire and water while plucking grapes to share with another of the voluptuous water nymphs.

Finally, as the roots of knowledge descend to their primordial source in the world of the nymphs, the aesclepius, ancient symbol of medical art, entwines itself on a root. The serpent is ironically juxtaposed with the lowly frog, whose muscles and nerves provided the primary material for the new electro-physiology of Du Bois and Helmholtz. Down in this watery romantic domain, the rationalized curves of nature — cometary trajectory, spectrum of sunlight, Chladni figures, geometrical diagram, and the pronounced black plumb line — become an inaccessible tangle. If Du Bois's athletic heroes feel the attractions of the vital force, their machines of objectivity elevate them beyond its seductive grasp.

For interpreting the cultural location of Du Bois's playful but intense promontory of science, its horizontally arrayed background is significant. The lush tropical growth emerges out of scenes of both classical purity and industrial progress. From a galley nearly lost in the distance on the left, classicism proceeds through the Egyptian obelisks, sphinx, and pyramid, to the Parthenon of Athens, and up to an 18th century scene of academic learning, with a professor in wig and frock coat lecturing to the passively assembled students outside his temple. Only in the present of the mid-19th century do the students themselves, freed from temples and priests, take over the task of making knowledge through experimental research. From the right, their new mode of action has emerged from the era of sailing ships and stands before those newly domesticated powers of Neptune and Vulcan, the steamship and the railroad, which appear on the Bay of Naples before a gently smoking Vesuvius.

The background panorama thus carries forward to the viewer dual ideals of knowledge-making, or *Wissenschaft* — namely, classical learning and material progress — which were continually circulating through the culture in which the members of the Berlin Physical Society formed their identities. Du Bois's imagery, in brief, places the young heroes wielding their implements of progress at the juncture of a vertical history leading upwards from mythology to truth and a horizontal history projecting forwards both from classical education on the left and from industrial drive on the right, uniting those forces in the movement to the future. That movement is carried by the instruments that draw the curves of nature’s laws.