17 Humboldtian science

About twenty-five years ago, the American historian of science Susan Faye Cannon began using the term 'Humboldtian science' to characterize a major current in early nineteenth-century natural philosophy, the 'avant-garde', 'the great new thing in professional science in the first half of the nineteenth century'. She used 'Humboldtian' to replace the usual description of the period as 'Baconian', a label which condemned the period to a naive, encyclopaedic empiricism relying entirely on the collection and collation of facts, a fascination with the particular, and a rejection of theory. The vague 'Baconianism' of nineteenth-century scientists, she pointed out, was actually (1) a disciplined practice of observing and measuring a number of physical variables over continental expanses of territory, using the latest advances in instrumentation and attending to all possible sources of error; and (2) a sophisticated conception of the relationship between accurate measurement, sources of error, and mathematical laws. It *was* encyclopaedic, embracing botany, mineralogy, zoology, geology, meteorology, terrestrial magnetism, atmospheric chemistry and tides, and topography, but only insofar as these were capable of numerical expression, arrangement, and comparison. This, Cannon remarked, well describes the enterprise of the Prussian traveller Alexander von Humboldt (1769–1859), and rather than repeat the unhelpful characterization of early nineteenth-century science as 'Baconian', historians would be better off realizing that it is 'Humboldtian'.[1]

The effect of her essay on 'Humboldtian science', published in 1978, was immediate, especially among historians of British and American science, and Humboldtian science quickly found applications in the founding of the British Association for the Advancement of Science (BAAS), the 'Magnetic Crusade', and the professionalization of science in general; it even helped illuminate important aspects of the thought and practice of Charles Darwin, who carried Humboldt's *Personal Narrative of Travels to the Equatorial Regions of the New Continent* (trans. H. M. Williams, 1814–29) with him aboard HMS *Beagle*. The concept clearly 'explained' important aspects of the activities of a broad set of natural philosophers, that had only loosely and uneasily filled the rubric of 'Baconianism', especially the concern for precise measurement and mathematical law.[2]

But while Cannon's invention clarified and deepened our picture of early nineteenth-century science, the label also prematurely 'black-boxed' a complex of concerns and practices, relying on Humboldt's evident stature in the period to define a 'style' or 'complex' and give the package explanatory force. However, the Humboldt which so appealed to Cannon's naturalists was a translated Humboldt, and so a transmuted Humboldt. The evidently useful concept of Humboldtian science requires dismantling; Humboldt needs to be differentiated from the Humboldtians, to expose the illuminating process of translation, the use of Humboldt and his project as a resource in different national and social settings, which the very usefulness of Cannon's concept to historians indicates. To start, I propose to open the black box of Humboldtian science by examining the notion of natural order operative in Humboldt's enterprise.

Born in Berlin in 1769, Alexander von Humboldt began his career as a Prussian mining official in the 1790s, reorganizing the mines and industries of the small, outlying principalities of Ansbach–Bayreuth. He resigned his position in 1797, and after spending two years' searching out instruments, skills, and a boat, Humboldt went to South America in 1799 under the protection of the Spanish king, Charles VII, as part of a planned voyage around the world. Already known for his chemical, geological, and medical investigations, Humboldt returned from the Americas a public hero. He spent the next twenty-two years living and working in Paris, publishing the results of his American travels, which issued in a series of over thirty volumes and exhausted the resources of three publishers by the time the final monograph (on New World grasses) was published in 1834. King Friedrich Wilhelm III of Prussia called Humboldt back to Berlin in 1826 as royal chamberlain, and after a brief expedition to Siberia and the eastern reaches of the Russian steppes in 1829 Humboldt divided the rest of his life between Potsdam and Paris. His intellectual wanderings matched his physical ones. Humboldt's last work, *Kosmos. Entwurf einer physischen Weltbeschreibung* ('Cosmos. Sketch of a Physical Description of the Universe') (5 vols., 1845–62), began its 'physical description' of the universe with the condensation of stars and planets out of nebular clouds and ended with the geography of plants. He was busy with geological stratification when he expired over the preface to the fifth volume in 1859, a few months short of his ninetieth birthday.

By the time he resigned his commission in the mines, Humboldt had committed himself to the pursuit of what he called 'terrestrial physics' (*physique du monde*). He often contrasted the new science with 'descriptive' natural history, as in an 1805 paper read before the Berlin Academy of Sciences:

Until now, little has been achieved by travelling naturalists for . . . terrestrial physics [*Physik der Erde*] (*physique du monde*), because they are almost all concerned exclusively with the descriptive [*naturbeschreibenden*] sciences and collecting, and have neglected to track the great and constant laws of nature manifested in the rapid flux of phenomena, and to trace the reciprocal interaction, the struggle, as it were, of the divided physical forces.

What kinds of phenomena led to 'great and constant laws', manifested the 'interaction of forces', and so attracted the attentions of the terrestrial physicist? Humboldt lists them:

the intensity of magnetism, or the strength of the charge of the globe in different regions and elevations, measured by the oscillations of a magnetised needle; hourly changes of the magnetic meridian; general meteorological phenomena; yearly, monthly and hourly mean decrease in temperature in the upper layers of the atmosphere . . . regular ebb and flood of the aerial ocean, indicated by hourly variations of the barometer . . . the chemical and hygroscopic composition of the atmosphere; the effect of the elevation of the sun and mountainous regions on the electrical charge of the air.[3]

The terrestrial physicist had to carry and care for a remarkable array of precise instruments to measure everything from the passage of time (chronometers) and the angular distances of stars, satellites, and landmarks (telescopes, quadrants, sextants, a repeating circle, a theodolite), the direction and intensity of magnetism (dip needles and magnetic compasses), to the temperature (thermometers), humidity (hygrometers), pressure (barometers), electrical tension (electrometers) and chemical composition (eudiometers) of the atmosphere. Nor would just one of each instrument suffice: chronometers, barometers, eudiometers etc. by different makers or built on different principles should be used together, their errors and constancy compared. In terrestrial physics these instruments now crowded out the specimen cases and collection jars of the voyaging naturalist.

In short, Humboldt's enterprise demanded a new type of naturalist: the naturalist as 'physicist'. In his 1805 *Essai sur la géographie des plantes* (Paris, 1807), the introductory volume to the results of the entire American voyage, Humboldt contrasted the *botaniste nomenclateur*, interested only in the individual structures which distinguish species and genera from one another, with the 'higher, philosophical aims' of the *botaniste physicien*, concerned with the geographical relations of plants to one another and to the geographical variation of other physical parameters. The former concerns were essential, but necessarily preliminary to the latter. Admiration of the ingenuity and variety of the organic structures of an individual or species was to be replaced with admiration for the great laws evidenced in their distribution over the earth. 'We have botanists, we have mineralogists, but we have no *physicists*, of the type demanded by [Francis Bacon's] *Sylva Sylvarum*', he wrote to his banker, explaining his imminent departure for Spanish America in June 1799 by invoking Bacon's exemplary natural history, just as his Humboldtian successors would do. 'My single true purpose is to investigate the confluence and interweaving of all physical forces'.[4] He was pressing the collecting and classifying activities of the field naturalist into the service of terrestrial physics, a master-science, the object of which was the 'mutual interaction of physical forces'.[5]

This new framework for the sciences is nowhere more graphically clear than in Humboldt's *Tableau physique des Andes* ('Physical Profile of the Andes') (Figure 17.1). Complementing his manifesto for a plant geography, with which it was published in 1807, the *Physical Profile* was Humboldt's attempt to summarize the results of his American expedition in a single table, six times the size of the quarto volume within which it was folded. Twenty-one scales framed a schematic portrait of the Andes near the equator, represented by Chimborazo, in present-day Ecuador, then thought to be the highest peak in the world; four of the scales counted elevation in meters and Parisian *toises*, while the other seventeen recorded parameters like the electrical tension and chemical composition of the atmosphere, the nature of rock formations and type of soil, humidity, the refractive power of the air, the intensity of light, the force of gravity, and more, all as they varied with elevation. On the portrait itself were arranged the names of plant species and 'vegetational regions' as they occurred along the flank of the mountain, and for an extra ten francs the hand-coloured edition would illustrate the gradual change in the green of the vegetation and the blue of the sky.

What justified this extraordinary compilation was Humboldt's belief in a 'general equilibrium' of forces:

> The general equilibrium which reigns amongst disturbances and apparent turmoil, is the result of an infinity of mechanical forces and chemical attractions balancing each other out. Even if each series of facts must be considered separately to identify a particular law, the study of nature, which is the greatest problem of general physics [*la physique générale*], requires the congress of all the forms of knowledge which deal with the modifications of matter.[6]

Out of the juxtaposition of so many measurements, 'Nature' itself was supposed to emerge, as a dynamic equilibrium of forces. This equilibrium derived not from a mathematically demonstrable balance of forces, like Laplace's self-regulating world system, but from the sheer number of forces acting simultaneously and varying globally; the lawfulness of Humboldt's 'Nature' was born of 'infinity' and complexity, not of mechanism. The greater the number of forces observed and accurately measured, and the greater the extent of the earth's surface such measurements covered, the more fully would the order of Nature emerge.[7]

'Modern physics', balances, and the history of the earth

Humboldt's insistence on the 'co-operation' or 'equilibrium' born of the 'mutual struggle' of physical forces, which formed the chief object of a 'congress' of all the natural sciences, had two, interrelated sources. The first was a lifelong devotion to a liberal, secular ideal of progress and the progressiveness of history, the constructive 'ebb and flood' of peoples and cultures as well as forces and fluids. The second, which gave the first concrete and practical form, was his encounter with the anti-phlogistic chemistry of Antoine-Laurent Lavoisier and the geognosy of Abraham Gottlob Werner at the Royal Saxon School of Mines in Freiberg, where during the summer and winter of 1791–2 Humboldt prepared himself for his commission in Prussia's Department of Mines.

What so excited Humboldt about Lavoisier's *Traité élémentaire de chimie* (1789), which he read thrice over in 1791, was its analytic 'chain of reasoning': in the very language Lavoisier proposed, one could *see* elementary substances condensing and evaporating as they entered into various combinations, determined by the play of chemical affinities and the temperature of the system, as detected by the precision balance.[8] German debates over the status and existence of Lavoisier's new substances led Humboldt to suggest to G. C. Lichtenberg, Professor of Experimental Physics at Göttingen, that natural science as a whole required a general, metaphysical critique, one that would establish Lavoisier's 'reasoning' – the use of the balance to detect subtle matters which enter into manifold combinations with one another, are fixed and unfixed, in large part due to their greater or lesser admixture with caloric fluid [*Wärmestoff*], or heat – as the general philosophical foundation of physical science. 'In any science unable to reach pure knowledge, we can seek certainty to the extent that its concepts can be constructed. Any science to which quantitative reasoning cannot be applied fluctuates . . . *Ought* a chemistry ever go beyond the ponderable?'[9]

Humboldt eagerly applied the principles of what he saw as 'modern physics' to improving Prussian industry. A new

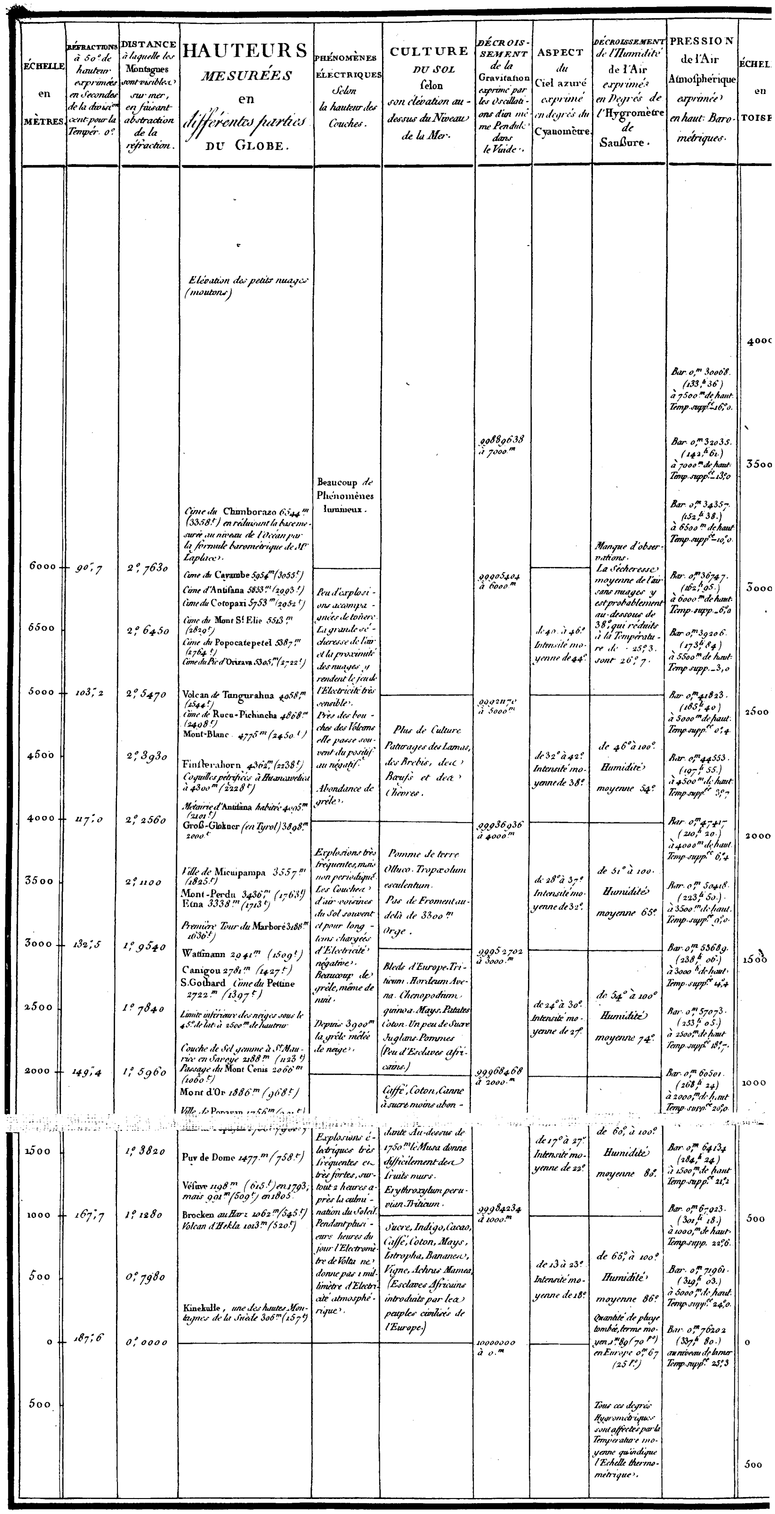

Figure 17.1 Measurements and observations from the 'Physical Profile of the Andes and Surrounding Country' (1807), the engraving intended to accompany Humboldt's 'Essay on the Geography of Plants, with a Physical Profile of the Tropics' (1805). The 'Physical Profile' summarized the results of Humboldt's 1799–1804 expedition from the perspective of a terrestrial physics. The columns, which frame the profile of the Andes, exemplify the collaboration of mathematical theory and precise observation of the widest possible array of physical variables, which characterized Humboldtian science. Humboldt's measurements of atmospheric refraction were corrected by J.-B.-J. Delambre, chief astronomer at the Bureau of Longitudes in Paris; precise elevations were calculated from the barometric measurements of Humboldt and others by Marie Riche de Prony, geometer and engineer at the Paris School of Roads and Bridges, using a formula from Laplace; Humboldt's observations of the hygrometer were converted into humidities by J.-L. Gay-Lussac, a young chemist at the Polytechnic; J.-B. Biot reduced Humboldt's observations of solar intensity to a uniform scale, using a formula from Laplace.

ÉCHELLE en MÈTRES	TEMPÉRATURE de l'Air à diverses hauteurs, exprimée en maximum et minimum du Thermomètre centigrade.	COMPOSITION CHIMIQUE de l'Air atmosphérique.	HAUTEUR de la limite inférieure de la Neige perpétuelle sous différentes latitudes.	ÉCHELLE des Animaux selon la hauteur du sol qu'ils habitent.	DEGRÉS de l'eau bouillante à différentes hauteurs. Thermomètre centigrade.	VUES Géologiques	INTENSITÉ de la Lumière dans l'air à diverses hauteurs en prenant pour unité son intensité dans le Vuide	ÉCHELLE en TOISES.
					Eau bouillante à 77°,0 (61°,6 R) Bar 0m 320.	La nature des Roches paraît en général indépendante des différences de latitude et de hauteur. Mais en ne considérant qu'une petite partie du Globe, on découvre que dans chaque région l'ordre de superposition des roches, l'inclinaison et la direction de leurs couches ont été déterminées par un système de forces particulier. On reconnaît qu'il existe de certaines lois locales selon lesquelles s'élèvent les différentes formations au dessus du niveau de la mer. Les Régions équatoriales présentent à la fois les cimes les plus élevées et les plaines les plus étendues du Globe depuis 0° à 1° 45' et nulle part ailleurs sur la terre, les montagnes excèdent la hauteur de 5850m. Leur abaissement vers les pôles n'est cependant pas très considérable; car sous les 19° les 45° et les 60° de latitude bor on a trouvé des Cimes de 4700m et même de 5500m d'élévation	0,9164	3500t
6500 6000 5500	Régions trop peu fréquentées pour en conaître la Température moyenne, qui cependant y paraît être au-dessous de zéro. A 5403m le Thermomètre monte quelquefois à 17°,8.	La quantité d'oxygène atmosphérique paraît la même dans les hautes régions et dans les plaines.	L'air retiré de l'eau de Neige contient 0,287 d'Oxigène.	Pas d'Etres organisés fixés au Sol. Le Condor des Andes, quelques mouches et Sphinx voltigeant dans les airs, peut-être élevés en ces Régions par les courans ascendans	Eau bouillante à 81°,0 (64°,8 R) Bar 0m 367.	Les Plaines équatoriales au contraire, celles contenues entre la pente orientale des Andes et les côtes du Brésil, sur 700 lieues de long, n'ont pas 70m à 200m de hauteur au-dessus du niveau de l'Océan. Toutes les formations que l'on a découvertes sur le reste du Globe, se trouvent réunies sous l'Equateur. Leur ancienneté relative, qui se manifeste dans l'ordre de leur superposition, y paraît en général la même que dans les Zones tempérées. Les granites, qui servent de base au Gneiss, au Syenite, au Schiste micacé et au Schiste primitif; les formations secondaires, deux de grès, deux de Gypse et trois de Roches calcaires, offrent des exemples frappants de l'identité de structure qui règne dans les parties les plus éloignées du Globe.	0,9047	3000
5000 4500	de -7°,5 à 18°,7 Température moyenne 3,7 (3° R.) Il tombe de la neige jusqu'à 4100m	Mais la proximité des Volcans peut quelquefois, sur les hautes Cimes des Andes, modifier la composition de l'air.	Neige perpét: sous l'Equateur et de 3° lat: bor. à 3° lat australe 4800m (2464t) Pas de variations de 80m. Neige perpétuelle sous les 20° latit bor à 4600m (2361t) minima elle y descend en hiver à 3800m.	Des Vigognes des Guanaco, des Alpaca en bandes nombreuses. Quelques Ours. Condor. Faucons Caprimulgus Plus de poissons dans les lacs.	Eau bouillante à 84°,7 (67°,7R) Bar 0m 418.	La formation problématique des Basaltes, des Amygdaloïdes, des Roches amphiboliques et des Porphyres à base d'obsidienne et de Pierre perlée (Perlstein) se trouve éparse sur la haute crête des Andes, comme elle l'est sur celle des hautes chaines de l'Europe.	0,8922	2500
4000 3500	de 0° à 20° Température moyenne 9° (7°2 R.) Abondance de grêle, même quelquefois de nuit.	La quantité d'hydrogène contenue dans l'air atmosphérique est moindre de deux millièmes. On ne trouve pas plus d'hydrogène a 7000m d'élévation qu'au niveau de la mer.	Neige perpétuelle sous les 35° de latitude à 3500m (1800t) de hauteur. Neige perpétuelle sous les 40° de lat. à 3100m (1600t) de hauteur.	Des Lama devenus sauvages à la pente occidentale du Chimborazo. Le petit Ours à front blanc Grands Cerfs Le petit Lion Quelques Colibri Plus de pulex penetrans	Eau bouillante à 88° (70°,5R) Bar. 0m 474.	Parmi les phénomènes géologiques qui sont particuliers aux Régions équatoriales du nouveau Continent, on doit citer sur tout l'épaisseur des couches et la grande hauteur à laquelle on découvre les formations postérieures au Granite. En Europe le Granite n'est pas couvert par d'autres Roches depuis 3300m à 4700m. Aux Andes on ne le voit pas au-dessus de 3500m.	0,8787	2000
3000 2500	de 1°,2 à 23°,7 Température moyenne 18°,7 (15° R.) Grêle très abondante. Brume fréquente en peu élevée.		Neige perpétuelle sous les 45° de latitude bor à 2500m (1282t) Aux Pyrenées à 2440m En Suisse à 2700m sur les Cones isolés, à 2530m si la cime des Montagnes dépasse 3100m Phénomène peu constant dans les Zones variables.	Viverra mapurito Felis tigrina Grands Cerfs Palamedea bispinosa. Abondance de Canards et de Plongeurs. Beaucoup de poux. (Ped Hum.)	Eau bouillante à 91°,3 (73°,0R) Bar. 0m 536	Les Cimes les plus élevées du Globe sont d'un Porphyre, dans lequel l'Amphibole abonde, qui est dépourvu de Quarz et que quelques Minéralogistes regardent comme produit, d'autres comme altéré par le feu volcanique. Des formations de Grès se trouvent à Huancavelica à 4500m. Le Charbon de terre se découvre près de Huanuco à 4400m de hauteur.	0,8640.	1500
2000 1500	de 12°,5 à 30° Température moyenne 21°,2 (17° R.) Grêle assez rare. Ciel souvent brumeux.	L'air atmosphérique contient 0,210 d'oxygène, 0,787 d'Azote et environ 0,003 d'Acide carbonique.	Sous l'Equateur on voit tomber de la neige à 4100m (2100t) de hauteur	Petits Cerfs (Cervus mexic) Tapir Sus Tayassa Felis pardalis. Quelques Singes Alouates. Troupial (Oriolus) Coluber coccin Pas de Boa, pas de Crocodile, Beaucoup de Chiques (Pul penet)	Eau bouillante à 94°,3 (75°,4 R) Bar 0m 605	Les plaines de Bogota, à 2700m et 2900m sont couvertes de Grès, de Pierres calcaires secondaires, de Gypse et de Sel gemme. Des Coquilles pétrifiées se trouvent aux Andes au-dessus de 4200m (en Europe on ne les a pas vuës au-dessus de 3500m) Le Sol du Royaume de Quito contient à 2500m de hauteur d'énormes ossemens d'Eléphants dont l'espèce paraît détruite.	0,8478.	1000
1000 500	de 18°,5 à 38°,4 Température moyenne 25,3 (20°,2 R.) Pas de Grêle Le Sable souvent à 52°.	Le maximum de ses variations ne paraît pas excéder un millième d'oxygène.	Au Méxique sous le 19° de latitude elle tombe jusqu'à 1800m de hauteur. Neige perpétuelle sous les 75° de latitude bor.	Singes Sapajou et Alouate. Jaguar (Felis onca) Tigre noir Lion (Felis concolor) Cavia capibara. Paresseux. Fourmiller. Cerv. mexic Armadille Aptenodytes. Crax Ampelis Boa. Crocodile Lamentin Elater noctil Mosquito (Oestr Human)	Eau bouillante à 97°,1 (77°,7) Bar 0m 679.	Les Grès de Cuenca ont 1560m d'épaisseur, une formation de Quarz à l'Ouest de Caxamarca en a 2900m. La Cordillère des Andes présente plus de 50 Volcans enflammés dont quelques uns sont éloignés de la mer de 37 a 40 lieues marines et dont les plus élevés et les plus renforcés par les flancs ne vomissent pas de laves coulantes, mais des Pierres ponces, des	0,8309	500
0 500	L'eau de mer à la surface près de l'Equateur hors des courans a 28° mais à la profondeur de 400m la mer est à 7°,6. La Temp. de l'intérieur du Globe paraît sous l'Equat de 22°,3			Dans l'intérieur du Globe de nouvelles espèces de Dermestes qui rongent les plantes souterraines	Eau bouillante à 100° (80 R) Bar 0m 762.	Obsidiennes, des Porphyres et des Basaltes scorifiés, et sur-tout de l'Eau et cette terre carburée, dans laquelle est souvent enveloppé un poisson (le Pimelodus Cyclopum)	0,8123.	0 500

understanding of the role of 'caloric' in evaporation and dissolution enabled Humboldt to classify substances as insulators or conductors, and then reform the construction of salt pans. In the Freiberg *Bergmännisches Journal* ('Miner's Journal'), Humboldt published tables of 'heat-conducting force' for quick, practical reference and published a simplified, Lavoisian account of combustion, 'sufficient for the technician'.[10] Steel production might be rationalized: 'Had the weight [of furnace products] been measured from the beginning of experiments with iron . . . pig iron would have been distinguished from carbonized steel, as amalgam and silver are distinguished, and fewer confusions in iron manufacture would have occurred.'[11]

Humboldt also developed several machines of his own to track the combinations of subtle matters, in effect balances, like his eudiometer, which precisely indicated the evolution and absorption of gases and their more or less intimate combination through the displacement of water. By demonstrating that 'the irritability or tone of the [living] fibre only depends upon *the reciprocal balance between all the elements of the fibre*, azote, hydrogen, carbon, oxygen, sulphur, phosphorus etc.', Humboldt made muscle tissue serve as a chemical balance, its sensitivity varying with the 'irritability' of the fibre.[12] It was in this context that he first staked his claim to a 'terrestrial physics', in a 1796 letter 'on the chemical process of vitality' read before the National Institute in Paris and soon published in the Paris weeklies.[13]

The generality of Lavoisian analysis made it not only the general principle of reform, but the general, rational principle for constructing an earth history. Even before his encounter with Freiberg and Lavoisier, Humboldt had come to the conclusion that the ultimate task of natural philosophy was to develop a history of nature, a secular cosmogony. The speculative cosmology he published in 1799 was advertised as 'an attempt to apply the principles of modern physics to geognosy'. For a long period, everything conduced to raise the temperature at the earth's surface: out of an original gaseous or aqueous solution the primitive rocks began to crystallize, giving up their heat to the surrounding medium, producing evaporation and further crystallization, and so on. Some of this heat went towards developing and expanding the atmosphere, which itself added to the temperature of the earth through its pressure, and the resulting climate made it possible for life to develop everywhere in tropical form and abundance. Eventually, the expansion of the atmosphere and the evolution of heat from crystallization 'reached an equilibrium, towards which they had long striven in vain'. As the atmosphere and the earth cooled, life retreated to the tropics, maintained by the sun's rather than the earth's own warmth. The principles of 'modern physics', Humboldt emphasized, could thereby account for the dramatic change in climate indicated by fossil remains without resorting to extraordinary hypotheses, like the impact of an errant comet or a calamitous shift in the earth's axis. The equilibria of caloric and fluids that grounded the history of the earth were philosophically an extension of the grand celestial equilibrium proved by 'the most profound analysts of our age, La Place and La Grange, [who] have calculated that the changes in the angle of the ecliptic maintain a cycle which never exceeds 1°21′ (as a result of the composite gravity of the planets)'.[14]

Lines, types, and means as forms of equilibrium

The 'general equilibrium' studied by terrestrial physics was just the present-day manifestation of the conflict and equilibrium of forces which generated the history of the planet. That history left its traces, Humboldt thought, in continuous global distributions of heat, magnetism, rock formations, vegetational forms, even the elevation of the earth's surface itself. Humboldt developed and promoted a technique of realizing that physical continuity graphically, with isometric lines. Perhaps the most renowned of these lines is the isothermal line: the annual isotherm connects points at sea-level which experience the same mean annual temperature (Figure 17.2). The sinuous pattern of isothermal lines on the map was the result of the simultaneous action of global causes acting locally.

> Temperature and magnetism are not like those phenomena which, derived from a single cause or a central force, can be freed of the influence of disturbing causes by restricting attention to the mean results of a great number of observations, in which these foreign effects reciprocally counteract and destroy one another. The distribution of heat, like the declination and inclination of the compass needle or the intensity of magnetic force, is essentially conditioned by location, composition of the soil, by the proper ability of the earth's surface to radiate heat.[15]

Isothermal lines therefore preserved local peculiarities within a general regularity, which might one day supply the 'numerical laws' of meteorology. 'It will become clear', Humboldt wrote in a manuscript note, 'that the state of heat is subject to inequalities contained within narrow limits and that, like the planetary system, it "only oscillates around a mean state, from which it never deviates by more than very slight quantities" (Laplace, *Expos.* p. 20).'[16] As in Humboldt's speculative earth history, Laplace's classic demonstration of celestial equilibration, his *Exposition du Système du monde* (1796), supplied a model of the way in which global order emerged from local conflict. *Physique du monde* was Humboldt's version of the *système du monde*.

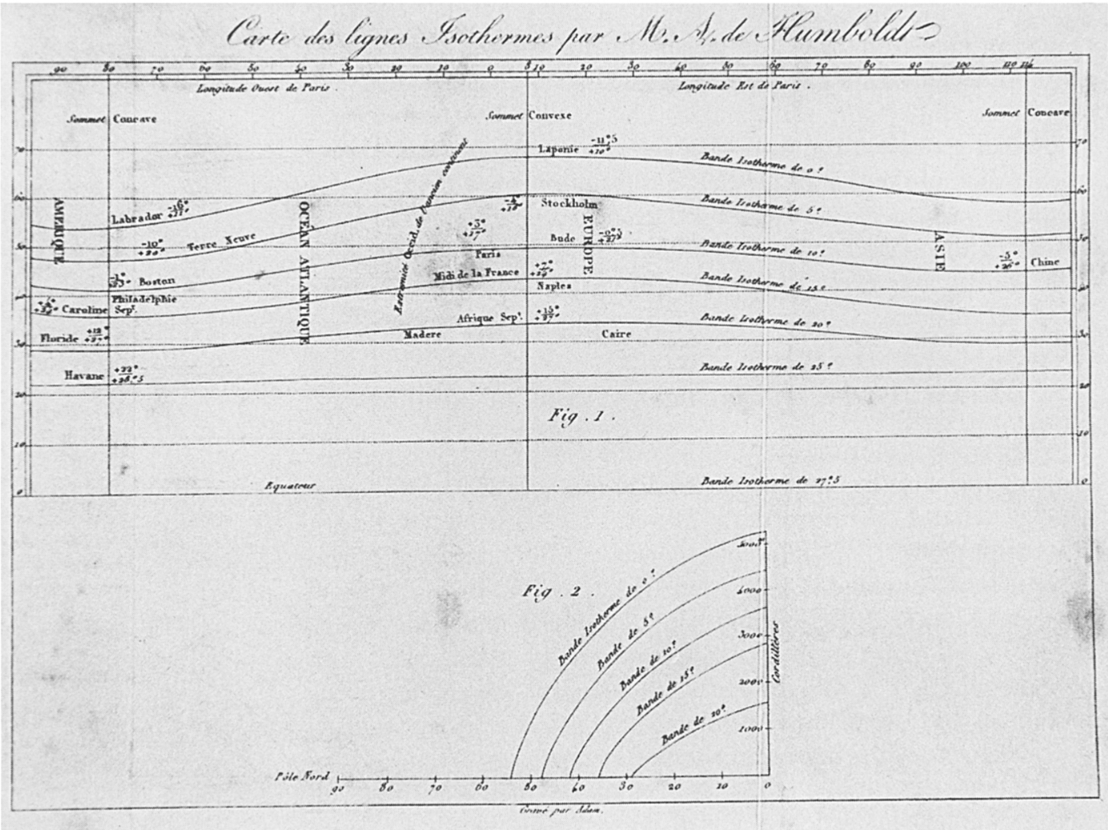

Figure 17.2 'Map of isothermal lines', from *Annales de chimie et de physique*, 5 (1817). On the upper map, lines trace equal annual mean temperatures (isotherms) at the earth's surface, between Asia and the east coast of America; mean winter and summer temperatures for specific locations are placed along the lines, illustrating the variation in annual temperature distributions that can exist along a single isothermal line, and indicating the effect of the shapes of landmasses and coastlines. Despite the variations a lawful and regular sinuosity is observed. The lower graph represents isothermal lines as a function of elevation above sea-level at different latitudes.

The very surface of the earth's crust could be made to yield order in the same fashion. Humboldt promoted the use of barometric surveys (*nivellements barometriques*) and the construction of topographic maps. With these tools the 'physicist' could calculate 'the mean elevation of continents' and draw 'normal surfaces' – horizontal planes that defined, for a given extent of territory, the surface of mean elevation. Using such calculations and surfaces Humboldt showed graphically that mountain chains, for all that their elevated summits attracted 'the common curiosity', actually had little influence on the mean elevation of a large landmass; that rather it is 'those gently undulating plains with alternating slopes' which most determined a territory's normal surface. (Calculations undertaken with the French geologist Elie de Beaumont, for instance, showed that the Pyrenees contributed at most 108 German feet to the mean elevation of France, 816 feet.)[17] Such measurements and maps enabled the terrestrial physicist to reveal natural order in the earth's topography where before only disorder was apparent, perpetuated by the mystifications of geographers who employed the 'hieroglyphic method', representing mountains symbolically and placing little hills around every watershed like 'superstitious Mongolian priests who erect cairns at every parting of the waters'.

We always begin with what most strikes the imagination, and before we realized that climatology required the exact knowledge of mean temperatures, we preferred knowledge of the extremes which heat attains accidentally at several points on the globe. The polyhedral form of the surface of our planet offers striking analogies over vast areas: it is the undulations of the plains and plateaux that principally influence the state of agriculture among a people, the heat and humidity of the air; it is the task of the physicist [*physicien*] to contemplate whatever is constant among the physiognomical traits of each continent.[18]

Before the concepts and techniques of isometric mapping became widespread, and before attention was drawn away from accidental extremes to the mean and the normal, fundamental aspects of the natural and social order were obscured. By revealing analogies and typical physiognomies of climate and landscape, the 'physicist' dispelled the confusion.

The same concept of how order emerged from the conflict of forces and from a mass of data informed Humboldt's plans for a plant geography.

Plant geography can be considered part of terrestrial physics. If the laws which nature has followed in the distribution of vegetable forms are more complicated than they first appeared, we are no less obligated to submit them to exact investigations. We did not stop making maps when we ran up against the sinuousness of rivers and the irregularity of coastlines. The laws of magnetism manifested themselves as soon as we began to trace lines of equal declination and inclination and to compare a great number of observations that at first appeared contradictory. We would be forgetting the path by which the physical sciences were progressively raised to certain results, if we believed that it is not yet time to seek the numerical elements of the geography of plants.[19]

Humboldt had been writing programmes for a plant geography since the early 1790s as a path to a history of nature, and had used the new science ('which exists in name only') to introduce terrestrial physics as a whole (1805), but only in the 'prolegomena' to the botanical results of his American voyage (1817) did he begin to subject plant geography to quantitative, isometric treatment.[20]

By tabulating the fraction of the total number of phanerogamic plant species present in a given climatic and geographical region comprised by the species of each of the seventeen natural families ('groups based on analogy of forms'), lines could be traced that defined 'maxima of concentration' for each family; Humboldt predicted that such lines would approximate the earth's isothermal patterns. In the absence of sufficiently complete catalogues of the flora of specific regions, which recorded not just the names of specimens collected, but their position and elevation and the geology of their habitat – catalogues compiled by *botanistes physiciens* – the order manifest in the distribution of vegetational forms would remain sketchy and provisional. None the less,

> as in all other phenomena of the physical universe, so in the distribution of organic beings: amidst the apparent disorder which seems to result from the influence of a multitude of local causes, the unchanging laws of nature become evident as soon as one surveys an extensive territory, or uses a mass of facts in which the partial disturbances compensate one another.[21]

These were not orders and equilibria that depended on theoretical discoveries or mathematical laws. For Humboldt, nature's lawfulness emerged gradually and progressively from laborious observing, averaging, and mapping over increasingly extended areas. Indeed, for Humboldt, averaging *itself* was the paradigm of lawful behaviour, and mean values were 'the final object, the expression of physical laws; they show us the constant amidst the flux and flight of phenomena'.[22] Isometric lines were a product of averaging and interpolation, connecting well-observed points literally by drawing lines between them on a map. That a continuous line connecting mean values on the earth's surface could be drawn was as little obvious as the very existence of mean values, as Humboldt's own struggles to define and group 'mean daily temperatures' show. Drawing those lines constituted an act of faith in both the physical 'co-operation of forces' and in the emergence of global order out of local averages. The *lines* themselves, which recorded local, physical quantities, rather than mathematical expressions of them, were the principal manifestation of nature's order; Humboldt even offered the editors of the *Dictionnaire des sciences naturelles* an entire article on 'Lines', in an effort to promote terrestrial physics.[23]

Thus lines, and the notion of equilibrium they embodied, prescribed a particular organization and dynamic of science, a particular notion of how terrestrial physics progressed. Order emerged from the landscape, so to speak, in a process of territorial expansion; under the regime of terrestrial physics, natural philosophy progressed with the gradual extension of precise, disciplined measurement, the spread of mean values over an accurate map. The type of enterprise which could establish and track natural equilibria was an organized network of observers, or better, corresponding physical observatories, dispersed over large expanses of the earth's surface, using comparable instruments and standard protocols. In this sense, terrestrial physics was natural history conducted in an observatory.

Mean values and the lines which expressed them guaranteed another kind of order: they gave an exact, physical account of the sensitive layman's intuitions of Nature's constancy, in terms of the 'co-operation of physical forces'. Each mean value is irreducibly historical, local, and characteristic, and yet attached to an identifiable 'type' to which it is bound within fixed limits. Sober, accurate, and global measurement of the proper quantities led to recognition of unity and order, 'analogies' between distant climates, vegetations, topographies, even cultures. Steppes and deserts are analogous phenomena which occur in all climates, on every continent; the fluctuations of isovegetational lines determine a limited number of vegetational types, which vary within strict limits. 'The characteristic traits of nations are like the internal structures of plants, spread across the earth's surface. Everywhere, one sees the stamp of a primitive type, despite the differences produced by the nature of the climate, the soil, and the combination of several accidental causes.'[24] Nature effected this conservation of type, in anthropology and philology as in geognosy, plant geography, and climatology, through mutual compensation. Humboldt demonstrated 'algebraically' that in the Peruvian Andes a stratum of sandstone replaces the stratum of porphyry-schist found in the Italian Alps (according to the principle of the identity of strata or independence of formation); that the relative abundance of genera represented in Arctic flora is replaced by an abundance of species within comparatively few genera at the equator; that along a single isothermal line 'extreme' and 'moderate' climates can be distinguished; 'that the distribution of annual heat between winter and summer follows a definite type [*Typus*] along each isothermal line; that the deviations from the type are confined to certain limits and that they are subject to one and the same law in the zones which cross the concave or convex summits of the isothermal lines'.[25] This may seem to share in the general mania for comparative morphology, a Romantic 'organicism', typified usually by Goethe and Cuvier. In Humboldt's 'physics', however, the conservation of type was not a governing heuristic *principle* but an empirical *result*, a consequence of Nature's regularity that connected the numerical equilibration of physical forces with the aesthetic sensibilities of the 'cultivated individual'.

The progress of civilization and the appeal of Humboldtian science

In the crucial period which saw the emergence of natural science out of natural philosophy, in the first decades of the nineteenth century, Humboldt developed and promoted a comprehensive science (a *physics*), which associated the separate branches of natural philosophy under a dynamic equilibrium model of natural order and developed the concepts and techniques for realizing that order. 'Average' and 'mean' supplied physical–mathematical, organizational, and aesthetic concepts of how order and equilibrium progressively emerged from apparent conflict. Under the aegis of 'general equilibrium', 'terrestrial physics' gave a unified identity to natural philosophy, demonstrated how its parts might be placed in service of global historical progress, and made natural philosophy the privileged custodian and anchor of order.

Humboldt's project attracted a broad spectrum of participants and informants stationed around the world. The lengthy notes to successive editions of his *Ansichten der Natur* ('Views of Nature') (1808, 1826, 1849) and to *Kosmos* (1845–62) record the personal communication of observations from French naval officers, East India Company physicians, Russian provincial administrators, Spanish military commanders, and German diplomats, among others; the Humboldt Nachlaß in Berlin preserves many fragments of those communications, cannibalized by Humboldt and often left without name or date, many of them apparently unsolicited. An admiring Charles Darwin sent observations of atmospheric refraction, excerpted from Captain Fitzroy's logbook, from aboard HMS *Beagle* in 1833.[26] Francis Beaufort, soon to become chief hydrographer to the British Admiralty, expressed himself nobly and typically on the occasion of conveying measurements of horary barometric variations in 1826: 'I dare not flatter myself that these ambulatory observations can be of much service – but the endeavour to contribute to the stock of facts, which you already possess on this interesting subject, should be considered as a public duty by every body – and your acceptance of them will be felt as a personal honor.'[27]

Beaufort's sentiments and the sheer extent of participation in Humboldt's grand equilibrium, especially by colonial officials and bureaucrats, suggest that as a programme for the organization and progress of science, terrestrial physics served Europe's 'civilizing mission'. Humboldt's informants joined Helen Maria Williams, Humboldt's first English translator, in the 'sympathy' aroused by the traveller, 'while he imprints the first step that leads to civilization and all its boundless blessings, along the trackless desert, and, struggling with the savageness of the untamed wilderness, obtains a victory that belongs to mankind.'[28] Contributing to Humboldt's lines was a philanthropic, even heroic act, as frequent retellings and representations of Humboldt's ascent of Chimborazo, barometer in hand, made clear. To extend the reach of mean values was to extend European civilization in its best and most progressive aspect.

In this sense, terrestrial physics had its most direct and visible impact on the former Spanish colonies of South and Central America, where violent struggles for independence between 1808 and 1825 vented previously subterranean social forces, only too apparent to Humboldt during his travels. The forces of intellectual and material commerce that were gradually eroding Madrid's influence in its own colonies were inseparable from the geological forces that had riven the continent with its vast river systems: 'Whoever is master of the Orinoco easily penetrates the provinces of Cumana, Caracas, Barinas, indeed, via the Rio Meta, all the way to Santa Fé de Bogotá. Via this river, ideas can quickly be put into circulation in South America, ideas and goods, and here, where everyone is so hungry for cheap English goods, a muslin blouse makes a revolution as easily as a book in France.'[29] For three decades during the upheavals in Spanish America, from his study in Paris, Humboldt was churning out volume after volume of his account of nature and society in equatorial America. Humboldt's natural philosophical projects both rode and fed the wave of speculative projects that bore European capital and travellers to Spanish America in increasing numbers in the first decades of the century. As Humboldt pointed out to the Spanish colonial administration, and to advocates of Western expansion in the new North American republic, his terrestrial physics provided relatively cheap methods for surveying extensive territories with sufficient accuracy for 'politic' administration, using barometers, chronometers, and thermometers rather than strict and painfully slow geodetic methods.[30] Humboldt's political essays on Mexico and Cuba, meticulous and voluminous compendia of statistics culled from colonial archives and informants, his improved maps, his survey of possible sites for a trans-isthmus canal, attracted the interest of British and French investors, eager to exploit abandoned mines and new markets (markets, Humboldt pointed out to his readers in 1825, which 'have increased to 70 million *piastres* annually'). The Geological Society of London published extracts from Humboldt's *Political Essay on the Kingdom of New Spain* (London, 1811) to encourage mining ventures in Mexico. In turn, Humboldt regarded large, government-sponsored commercial ventures as potential vehicles for his own projects, new expeditions in India and Siberia or a research institute in Mexico.[31]

Figure 17.3 Frontispiece to the *Atlas géographique et physique du Nouveau Continent* (Paris, 1814), engraved by Barthèlemy Roger after a drawing by François Gérard. Mercury, god of commerce, helps the fallen Aztec prince to his feet, while Minerva, goddess of letters, extends an olive branch. The ruins of Mexican culture, the monuments of political upheaval, occupy fore- and background; they are dominated by the most sublime monument of natural upheaval, Chimborazo, the volcanic Andean peak represented on Humboldt's 'Physical profile of the Andes', with its luminous and constant cap of snow. The motto 'Humanitas. Literae. Fruges.' is taken from the *Letters* of Pliny the Younger (book VIII, letter 24), where the gifts of Greece to the civilized nations of Europe are enumerated: 'Liberal Arts, Science, Agriculture'. The plate graces an atlas dedicated to geographic, hydrographic and topographic maps, and hypsometric profiles of large landmasses. Humboldt's terrestrial physics offered America a restoration to law and order, via the forces of commerce and civilization.

But the implication of terrestrial physics in the resurgence of imperial projects in the early nineteenth century went deeper than supplying eager projectors and governments with useful maps and statistics. Mary Louise Pratt, supplying a perspective from the history of travel narrative, with particular attention to the function of natural history in those narratives, has shown recently how the 'co-operation of physical forces' produced by terrestrial physics provided both European and Creole societies with the tools for 'reimagining' America.[32] Humboldt's replacement of the *botaniste nomenclateur* with the *botaniste physicien*, the Linnaean collector with the physical observatory, represents both the disappearance and apotheosis of the naturalist in a Nature constituted by

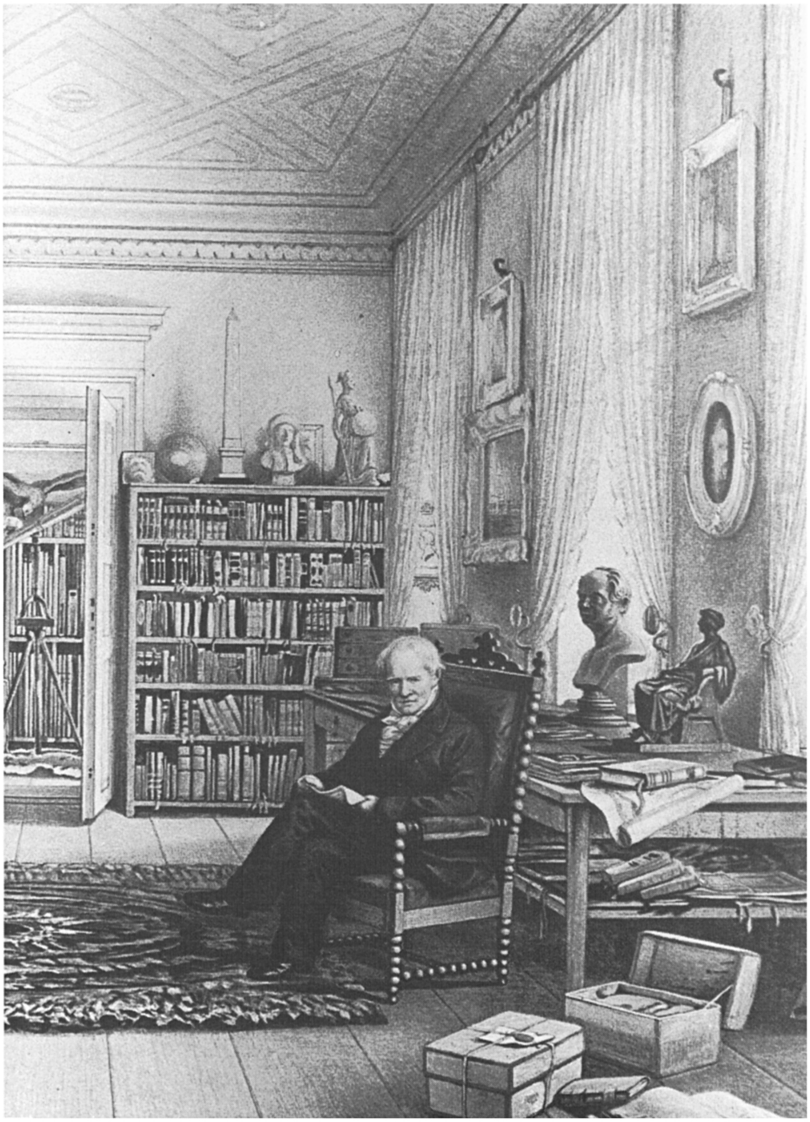

Figure 17.4 Humboldt in his study in Oranienburger Straße, Berlin. Watercolour by Eduard Hildebrandt, 1856; from Douglas Botting, *Humboldt and the Cosmos* (London, 1973), p. 271.

dramatically conflicting forces, which 'deeply impress[es] us with a sense with a sense of her greatness' and 'speak[s] to us forcibly'.[33] Humboldt's own self-presentation in the *Personal Narrative*, and the ideal traveller from whose perspective we enjoy the *Views of Nature*, is the mere 'vestige of a narrative persona', overwhelmed and replaced by forces of nature: '[The traveller] feels at every step that he is . . . in the centre of the torrid zone . . . on a vast continent, where every thing is gigantic, the mountains, the rivers, and the mass of vegetation . . . He can scarcely define the various emotions, which crowd upon his mind; he can scarcely distinguish what most excites his admiration.'[34] The forces themselves supply the narrative and the drama, and the story they tell is one of dynamic balance, equilibrium, and progress, told by the Humboldtian terrestrial physicist and his lines.

Pratt looks at Humboldt's science as a lens through which European and Creole audiences could view America; but it is clear that terrestrial physics was a means not only for reconstructing 'the New World', but for reforming and renovating the Old as well. Humboldt's America provided a mirror in which Europe might see itself, changed. This account of Humboldtian science, focusing on its all-embracing concept of Nature's lawfulness and progressiveness and its practical roots and realization in various mechanical, chemical and graphic 'balancing' techniques, has the advantage of preserving Cannon's emphasis on practice while getting at what others found useful and attractive in it. Thereby, 'Humboldtian science' illuminates the reorganization of knowledge and disciplines in the early nineteenth century that defined the emergence of natural science out of natural philosophy.

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