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Organon 11, 251-269

1975

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OERSTED'S LAW OF OSCILLATION IN THE DEVELOPMENT OF SCIENCE

The purpose of the present article is to analyze the thinking of two scientists in Denmark who participated in respective revolutions of science. These were Hans Christian Oersted and Ludvig August Colding, a protégé of the former. In addition to precipitating a great revolution in physics, Oersted propounded a unique philosophical law during a lecture course conducted at the University of Copenhagen as early as 1805–1806. He called it the "law of oscillation in the development of science," which will be discussed below [1].

Oersted is known primarily for his crucial experiment, in 1820, demonstrating that a compass needle placed over a conducting wire moves to a position at right angles to the wire when it carries an electric current. This discovery precipitated the revolution involving the far-reaching study of electromagnetism and transformed 19th century science as drastically as the steam engine had transformed 18th century technology. Oersted is equally known among historians of science as an exponent of *Naturphilosophie*, but not quite correctly so because he was also a critic of this philosophy and advanced to an independent position of his own.

With respect to the revolution of electromagnetic conversions, French and British scientists rapidly capitalized on Oersted's discovery of electromagnetism. Within a week, André M. Ampère, inspired by the announcement of this discovery at the Académie Royale des Sciences of France, quickly proposed the right-hand screw rule in which the thumb indicates the direction of deflection of the magnet's north pole. Parallel wires were caused to attract or repel by this means. Similarly, Arago, working at the Paris Laboratory, soon afterward discovered that a copper wire carrying a current exhibited the properties of an iron magnet and that unmagnet-

[1] Hans Christian Oersted, *Soul in Nature* (translated by Leonora and Joanna B. Horner), London, 1966. References used here come from a chapter titled "Observations on the History of Chemistry" originally published by the Scandinavian Society, 1809 and in *Gehlen's J. f. Chemistry and Physic*, Vol. 3, Berlin, 1807 (in German). Also reprinted almost verbatim in London, 1852.

ized iron could be transformed into a magnet by an electric current. Moreover, Ampère's rule stimulated a new concept related to lines of force around a magnet, one that further stimulated Faraday's researches and development of a philosophic concept of extension of these forces throughout the universe, a view that ultimately inspired Maxwell. The discovery by Faraday (and independently by Joseph Henry) of electrical induction was followed by the former's invention of the electric generator in 1831 which Isaac Asimov characterized as "probably the greatest single electrical discovery in history." Meanwhile, William Sturgeon invented the first electromagnet, which was capable of lifting many times its weight when the current in a wire, wrapped around a horse-shoe core, was turned on. This invention was later improved by Joseph Henry. Finally, the discoveries of Jean B. Biot and Nicolas Savart were likewise stimulated by Oersted's discovery.

The intensive flurry of experimental success dealing with electromagnetic conversions certainly meets the requirements of a revolutionary outlook in science. Nevertheless, it is ironic that some of the French scientists like Ampère and Biot, who were eager to capitalize on Oersted's discovery of unified electromagnetism, had previously supported the current belief that electricity and magnetism were two different fluids or principles. The contrast in the prevailing French, German, and English theories of two fluids was cited by Robert C. Stauffer as follows:

> In the decades immediately preceding Oersted's discovery, which was made in the spring of 1820, scientists were far from agreement as to existence of any physical relation between electricity and magnetism. In 1802, Ampère had announced that he would 'demonstrate' that the electrical and magnetic phenomena are due to two different fluids which act independetly of each other. (François Arago, *Oeuvres complètes,* II, Paris, 1854, p. 50). In 1807, Thomas Young in his *Lectures on Natural Philosophy* (London, 1807, I, p. 694) had held that 'there is no reason to imagine any immediate connection between magnetism and electricity.' In 1818 John Bostock remarked in regard to galvanism that 'although it may be somewhat hazardous to form predictions respecting the progress of science... it does not appear that we are at the present in the way of making any important additions to our knowledge of its effects' (*An Account of the History and Present State of Galvanism,* London, 1818, pp. 101–102. In this book, Bostock revised and amplified his article in the *Edinburgh Encyclopaedia).* In 1819, David Brewster published volume XIII of his Edinburgh Encyclopedia. Here J. B. Biot, at the end of his article on magnetism, after stating that 'there exists the most complete, the most perfect, and the most intimate analogy between the laws of the two magnetic principles and those of the two electrical principles', concluded in regard to the magnetic principles that 'the independence which exists between their actions does not allow us to suppose them to be of the same nature as electricity' (p. 277) [2].

[2] Robert C. Stauffer, "Speculation and Experiment in the Background of Oersted's Discovery of Electromagnetism." *Isis,* Vol. 48, p. 43.

Stauffer then contrasts the experimentation (which misguided the French and English) to the philosophical approach (which served to guide the Germans). In this instance, philosophy was a better guide to Oersted than empiricism. Stauffer continues as follows:

> In Germany, *Naturphilosophie* [also called Nature Philosophy] still appeared in association with the opposite views, such as those which Julius von Yelin set forth in a public address to the Bavarian Academy of Sciences in 1818. There Yelin said, 'I speak of magnetism and electricity as identical yet individualized fundamental forces of nature' (*Ueber Magnetismus und Electricität als identische und urkrafte,* Munich, 1818, pp. 20–21). And in Denmark, 'Oersted was searching for the connection between those two great forces of nature. His previous writings bear witness to this, and I, who associated with him daily in the years 1818 and 1819, can state from my own experience that the thought of discovering this still mysterious connection constantly filled his mind,' Johan Georg Forchammer recalled in a commemorative address. (*Hans Christian Oersted, Et Mindeskrift, laest i det Kongelige danske Videnskabernes Selskabs Mode dne 7 de November 1851* (Copenhagen, 1852), p. 13; also *Oersted's Leben Denkschriften von Hauch und Forchhammer,* p. 101) [3].

Stauffer comments, however, that we should "consider the following statement written to his wife in 1823 [on] Oersted's own position in regard to general differences between the approach to science in German and in France" and quotes from the letter as follows:

> If in Germany I am often tempted to protest against Nature Philosophy when I see how it is misapplied, in France I feel so much the more called upon to defend it, or rather I feel a fundamental difference in scientific thought which I should not have imagined to be so great if I had not so often felt its vital presence [4].

Thus as early as 1823, Oersted was definitely conscious of a sense of isolation with respect to both the German and the French-English interpretation of modern science. The Germans were attempting to fit scientific discoveries to an *a priori* philosophy; the French-English, to an empirical interpretation. Stauffer comments further:

> Soon after, with the rise of the generation of Liebig and Schleiden, the reaction of German scientists against *Naturphilosophie* was to become general [5].

Fortunately, Oersted was quite specific about his own method. During the winter course at the University of Copenhagen in 1805–1806, he explained the details about his law of oscillation. He stated that the human mind naturally divides basic ideas into two distinct models of which each dominates in turn. He called these, respectively the c r e a t i o n and

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[3] *Ibid.*, pp. 43, 44.

[4] *Ibid.*, 44 (footnote 59).

[5] *Ibid.*

the formation[6]. It appears that the "creative" idea emanates from the subconscious mind in a rather amorphous state, one not clearly defined. The incorporation of an opposing idea, on the other hand, into a well defined entity represents the "formative" idea, that gradually emerges from careful and precise experimental data. Oersted's idea appears to be a variation on the dialectic, in which the synthesis becomes functional as the "formation" becomes more precisely defined. And when the "creation" and the "formation" attain an antithetical position, it appears from Oersted's examples that the "creation" and "formation" may be interchanged. That is, the former entity is made more and more precise until the latter commences to become relatively less precise. In lieu of three elements in the dialectic — the thesis, antithesis, and the synthesis — Oersted's concept, the law of oscillation, utilizes only two of them while the synthesis appears to emerge implicitly with precision of the experimental data. As stated above, when the formation element loses its pristine clarity and the "creation" element gains clarity, their roles may be reversed in a kind of functional synthesis. The three examples discussed below will illustrate Oersted's method of explanation.

The first of these dealt with alchemy in which the creative idea was the belief in the association between the seven metals and heavenly bodies of antiquity. Indeed, the days of the week were named in honor of this fancied association. Oersted commented on the positive results (the formation) derived from a "feeble anticipation of truth" (the creation) as follows:

> Amidst the errors of alchemy, the one which appeared most strongly was that metals bore an analogy with planets. It would be folly to deny that this idea led to opinions and labours utterly opposed to nature; but yet it is not impossible that it contained a feeble anticipation of truth...Yet... we will not conceal from ourselves that we do not lay much weight on this supposed possibility.
>
> But... that former period has been beneficial to science... for instance, mineral acids, as well as the commencement of our knowledge of alkalinity. The so-called oxidation of the metals and the different modes by which it is usually treated, were likewise discovered by the chemists of that period. They even contributed something to the chemical knowledge of the atmosphere since they showed that there exist some kinds of gas different from those which surround our earth [7].

The vaguely elucidated "creation" in alchemy was the supposed association between planets and metals. The "formation" was the concomitant idea of an oxidation-potential series (in terms of the degree of stability of seven metals) that was roughly correlated with the time of rev-

[6] Oersted, *op. cit.*, pp. 320 ff. He refers here specifically to the "Law of oscillation in the development of science" with the human mind dividing in two directions: to create and to form, which dominate in turn.

[7] Oersted, *op. cit.*, p. 308.

olution of the respective heavenly bodies around the Earth. For instance, gold is the most stable metal of the seven; the sun "revolves" fastest around the Earth (daily in the geocentric system); the moon (second fastest) in a lunar month. Thus, gold was associated with the sun, and the moon with silver (second most stable metal of the seven). Hence the expressions still used: the golden sun and the silvery moon. The same symbol (a circle with a dot in the center) was used for the sun in alchemy and in astronomy. A crescent was the symbol utilized for both the moon and silver, and similarly with the other five planets and metals which were arranged in comparable pairs. The slowest planet of antiquity with respect to time of revolution as observed from the Eearth is Saturn and it is associated in alchemy with lead, and, in literature. Indeed, the word leaden is defined as sluggish. Hence the vulgar expression: Take the lead out.

Modern chemistry has made careful and accurate measurements of the stability of the chemical elements including the seven metals of antiquity. These measurements are the so-called oxidation-reduction potentials which are given in the following table selected from the *Handbook of Chemistry and Physics.*

Reaction in Symbols	Electron (s)	E_0 (Voltage)	Name of Metal	Planet	Day of the Week
$Au = Au^{+} + 1$	"	−1.5	Gold	Sun	Sunday
$Ag = Ag + 1$	"	−0.799	Silver	Moon	Monday
$2Hg = Hg_2^{++} + 2$	"	−0.798	Mercury	Mercury ...	Wednesday (Mercredi in French)
$Cu = Cu^{++} + 2$	"	−0.344	Copper	Venus	Friday (Vendredi in French)
$Pb = Pb^{++} + 2$	"	+0.12	Lead	Saturn	Saturday
$Sn = Sn^{++} + 2$	"	+0.13	Tin	Jupiter	(Thor) Thursday (Norse myth)
$Fe = Fe^{++} + 2$	"	+0.44	Iron	Mars	Tuesday (Mardi in French)

The order of the days in the week is a measure of the accuracy of this statistical correlation. Sunday, Monday, Wednesday, Friday and Saturday are in proper order; Tuesday and Thursday, corresponding to Mars and Iron, and Thor and Tin, are not. The latter two metals, however, are very active chemically and were confused with other metals. For instance, iron was confused with electron, a silvery alloy of gold and silver, a consideration accounting for the ancient positions of both iron and tin in the oxidation-potential series. Moreover, tin's chemistry is very complex because of its chemical activity as a good reducing agent and the reactions of tin were not understood until modern times in view of its amphoteric nature. The compounds of iron, like those of tin, occur in two ionic forms and in addition display a bewildering array of colors in both simple and complex forms. Thus, the inability of the ancients to place correctly iron and tin in their oxidation-reduction series proves the rule and significance of the correlation outlined above.

It appears, however, that, despite the surprising correlation between the orbital period of the planets and the chemical stability of the metals, no-cause-and-effect relationship exists. What Oersted's calls "a feeble anticipation of the truth" on which "we do not lay much weight" still prevails in modern science. Nevertheless, it is true that this working hypothesis of the alchemists was the initial stimulus for the modern oxidation-reduction potential tables such as those developed by Latimer to a high degree of accuracy with compounds numbering into the hundreds. Thus the original "creation" noted by Oersted had served its purpose, as the "formation" laid the groundwork for another chemical problem, the nature of combustion, which we shall now explore in the next oscillation propounded by him in this aspect of the history of science. Before leaving the present topic, however, it is worth-while noting that modern astrologists appear to be clinging to "the feeble anticipation of the truth" characterized by the investigations of the ancient alchemists. The anti-astrologists, on the other hand, are apt to dismiss the role of alchemy in the past as insignificant in the understanding of modern science.

In his second exposition of his law of oscillation, Oersted cited the phlogiston theory. He stated that combustion and reduction are two antagonistic chemical processes. The problem of reduction of ores to metals had already been solved by the alchemists and utilized in the mining industry, but the lack of information about combustion led to a serious difficulty. Utilizing his theory, he interpreted the "phlogiston," originally propounded by Stahl, as "the unknown basis of combustion" [8], That is, phlogiston became the "creation" and reduction became the "formation." Once the idea of mutual influence between heavenly bodies and metals had been rejected as erroneous, and a rudimentary solution of the nature of stability in metals was established, it was natural to seek the cause of this stability on the Earth. As stated above, the new cause proposed was phlogiston. To quote Oersted:

> The thought that combustion was the central point of all chemical effects, betrayed an usually profound view into nature; for to embrace such a thought it was not sufficient to regard with attention the origin of fire and the brilliance of flame, it was necessary to perceive that nature often produces effects similar to combustion by other means than fire, and to discover that there was, nevertheless, one force in common in all these apparently different effects. It requires a very discriminating spirit to discover combustion where no flame, frequently not even warmth, proclaims its existence. And to distinguish combustion even in the midst of a fluid body, or, what is still more, to discover a decided similarity between the breath and flame, demands indeed a preparation of centuries.

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[8] Oersted, *op. cit.*, p. 310.

After such a great and yet deeply penetrating view, it was first possible to arrange bodies in a series according to their combustibility, for it was known in what combustibility consisted. By means of this series, the natural law was determined that the more combustible, when in a state of combustion, can restore the less combustible to its first condition. It was also perceived that a body lost its combustibility in the same degree that it was burnt; and thus that great law was determined, which is as widely comprehensive as simple to understand, that combustion and reduction are two antagonistic processes which pervade the whole of nature. Such great ideas, the fruit produced by the efforts of a century, are comprised in these few words [9].

We note that in this dichotomy, we have both a thesis (combustion) and an antithesis (reduction), but no synthesis. The latter was implied by the correction made in the "creation": In lieu of a solar, lunar, and supralunar influence in chemistry, we are given a sublunar influence. For Stahl conceived of phlogiston as a substance in the terrestial atmosphere. Indeed, even suggested that it was lightning.

The third example given by Oersted involved the discovery of oxygen by Priestley and the introduction of the anti-phlogistic theory by Lavoisier with oxygen at the pivot. The link between Priestley and Lavoisier was Cavendish, the discoverer of hydrogen, who insisted on interpreting his results in terms of the phlogiston theory in 1766 and 1784. As early as 1670, Boyle had noted that "a flammable gas was envolved when certain metals like iron were treated with acids, but it was Cavendish who collected the gas and subjected it to systematic study. His findings were read before the Royal Society in the first of a series of papers on *Factitious Airs*...". In 1766, Cavendish stated in his paper:

It seems likely from hence that either of the above-mentioned metallic substances [zinc, iron, tin] are dissolved in spirit of salt, or the diluted vitriolic acid, their phlogiston flies off, without having its nature changed by the acid, and forms the inflammable air... [10]

Aaron J. Ihde, a modern historian of chemistry, describes the sequel as follows:

The suggestion that 'inflammable air' was phlogiston was quickly adopted by Scheele, Kirwan, and others... In 1783 Cavendish published results of experiments which proved that water was formed when 'inflammable air" (H_2) was burned in Priestley's dephlogisticated air (O_2)... [11]

With respect to further developments announced by Cavendish, we quote again from Ihde:

The 1784 paper [of Cavendish] is important because it showed the quantitative combination of oxygen and hydrogen. Cavendish reported that when

[9] Oersted, *op. cit.*, pp. 308, 309.

[10] Aaron J. Ihde, *The Development of Modern Chemistry*, New York, 1964, p. 40.

[11] *Ibid.*

two measures of 'inflammable air' and five measures of common air were exploded, no 'inflammable air" remained, and the decrease in volume of the common air amounted to one fifth; a colorless liquid remained in the vessel... [12]

The colorless liquid was, of course, water which was formed from the combustion of hydrogen and oxygen, but Cavendish preferred to explain his results on the basis of phlogiston, as explained above by Ihde.

In 1783, Lavoisier reported to the Académie des Sciences in Paris on a joint paper with Laplace in a paper titled "On the Nature of Water and on Experiments that Appear to Prove this Substance is not Properly Speaking an Element, but can be Decomposed and Recombined." Ihde comments that "Lavoisier showed his superior theoretical mind by fitting the new facts into his own philosophical system at a time when other chemists were attempting to explain the formation of water by reference to the phlogiston theory" [13].

Oersted made the following comment about the development culminating with Lavoisier:

You easily perceive that the antiphlogistic system, in spite of its name, is still a continuation of the phlogistic. That they are opposed...proves nothing to the contrary for you have seen yourselves that it was only in one point, and not in all. We therefore easily make the transition from one to the other [14].

The following table provides the sequence of the oscillations:

Creation	**Formation**
Phlogiston	Reduction
Anti-phlogiston	Oxidation
Electrons	Reduction

Thus in this progressive development, we note that the chemical influence emanated in theory successively: firstly, from the sun, moon and planets; then the sublunar regions with phlogiston; oxygen in the atmosphere; from hydrogen in water; and finally from subatomic electrons. Note that the accuracy is progressive in the Creation column which culminates in the modern system in the loss of electrons (negatively charged) and a gain in valence of the substance oxidized, and *vice versa* for the substance concurrently being reduced. (Apart from these generalities the table above illustrates not only the accuracy, but also the oscillation cited by Oersted for his law propounded in 1805–1806.) Formation, on the other hand, remains specific in function during oscillations, but increasingly informative.

Oersted sums up his principle with the following comments:

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[12] Ihde, *op. cit.*, p 71.
[13] Ihde, *op. cit.*, pp. 71, 72.
[14] Oersted, *op. cit.*, p. 311.

> It cannot have escaped your attention, in all these considerations, that the point of view for all natural events is certainly changed, but yet that the connexion which had at one time been found between great series of natural events, will not be destroyed in order to form a new one. [Unlike the case in the Hegelian Dialectic]

Referring to the continuity in successive theories, he states, in italics, with reference to "the necessity of a higher law": "*That there is a true course of development in the theories which have followed one another, and which have been successively solved*" [15].

Oersted then continues:

> The most difficult task in our undertaking, namely to exhibit an internal truth in the variery of contradictions which are offered by the history of science to the unpractised eye, is now, I hope carried out as far as our limited time permits...
>
> Science has gradually gained, not merely by theory having attained a greater perfection, but also with respect to the extent which it embraces. In the middle ages, no other chemistry was known than that of the metals, and this is very natural because these bodies, after they have undergone the most various changes in their aspects, most easily resume their previous form, so that we first receive from them a connected experience...
>
> The antiphlogistic theory...was the first to accept the doctrine of gases as one of its fundamental constituents. The new theory which we might name the dynamic enlarges...the extent of chemistry far beyond its former limits. Electricity, magnetism, and galvanism now also belong to chemistry, as it appears that the very same fundamental forces, which produce this effect, produce chemical effects in another form [16].

We shall now illustrate how Colding, a student of Oersted, utilized the law of oscillation in his own work. The importance of Colding is underlined by the recent publication of all his scientific papers by P. F. Dahl, physicist af Brookhaven National Laboratory, major center for atomic energy research. The publication was titled, *Ludvig Colding and the Conservation of Energy Principle*, one of a series of reprints under the editorship of Harry Woolf. A little earlier Kuhn had called attention to the importance of Colding as being one of the four major discoverers of the hypothesis of energy conservation during the period of 1842 and 1847. These were:

> Mayer, Joule, Colding, and Helmholtz — all but the last working in complete ignorance of the others. The coincidence is conspicious, yet these four announcements are unique only in combining generality of formulation with concrete quantitative applications [17].

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[15] Oersted, *op. cit.*, p. 313.

[16] Oersted, *op. cit.*, pp. 313, 314.

[17] Thomas S. Kuhn, "Energy Conservation as an Example of Simultaneous Discovery", [in]: *Critical Problems in the History of Science* (Edited by Marshall Clagett), Madison, 1959, p. 321.

These four were unique because their approach involved not only the generality of formulation in a metaphysical sense but the "concrete quantitative applications" in terms of conversion equivalents as between heat and work, and the like. In addition to this quartet, there were two others who demonstrated either the former or the latter characteristic. For instance, Sadi Carnot, Séguin, Holtzmann, and Hirn computed conversion equivalents, but omitted the generality of formulation. Conversely, the third quartet, Mohr, Grove, Faraday, and Liebig included the latter, but not the former [18].

I shall discuss the dual approach of the first group, particularly that of Colding in the present context and refer only incidentally to the others at this time. Kuhn comments in his usual and objective way on the interplay in the case of Colding and Mohr who utilized both a metaphysical idea and the connexions in their approach to an understanding of the law of conservation of energy. As stated above, Mohr did not evaluate a "concrete quantitative application" in numerical terms, whereas Colding did. To quote Kuhn:

> Mohr and Colding started with a metaphysical idea and transformed it by application to the network of conversion process. In short, just because the new nineteenth-century discoveries formed a network of 'connexions' between previously distinct parts of science, they could be grasped either individually or whole in a large variety of ways and still lead to the same ultimate result. That, I think, explains why they could enter the pioneers' research in so many different ways. More important, it explains why the researches of the pioneers, despite the variety of their starting points, ultimately converged to a common outcome. What Mrs. Sommerville had called the new 'connexions' between the sciences often proved to be the links that joined disparate approaches and enunciations into a single discovery [19].

Thus, we find Colding following Oersted's example in utilizing the law of oscillation as a means of accounting for the development of the law of conservation of energy. At this point it is clear that we have two factors that are "grasped together," to use Kuhn's expression. Indeed, Kuhn considers them equally grasped in his comment as follows:

> Colding was a protégé of Oersted whose chief renown derived from his discovery of electromagnetic conversions. On the other hand, most of the conversion processes cited by Colding date from the eighteenth century. In Colding's case, I suspect a prior tie between conversion processes and metaphysics ...Very probably neither can be viewed as either logically or psychologically fundamental in the development of his thought [20].

From this, we can readily perceive the "creation" (conservation) as metaphysical and the "formation" as the carefully evaluated conversion-equi-

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[18] *Ibid.*

[19] Kuhn, *op. cit.*, pp. 325, 326.

[20] Kuhn, *op. cit.*, footnote 32, pp. 346, 347.

valents. The influence of Oersted on Colding is quite apparent in this respect. Hiebert emphasizes the comprehensive nature of the metaphysical law:

> ...A number of newly discovered physical facts connected with electricity, chemistry, heat and light, and the quantitative observation of their interconversions, led scientists to suspect that seemingly disparate research efforts might converge in some manner, or at least, that certain of these facts provided physical examples of earlier intuitions of the conservation of a metaphysical force..." [21]
>
> "...Success of the conservation theory in chemistry, as elsewhere in electricity, magnetism and optics, led late nineteenth-century and early twentieth-century scientists to contend with some right that 'energy' being the one aspect of matter conserved in all of nature's manifestations, was the key concept which would provide a new unity for all the physical sciences. In fact we know that energetic notions were incorporated into economics, sociology, religion, etc. [22]

Hiebert adds that the outstanding philosophers of science expressed a similar sentiment in their writings from 1872 to 1910, in which they evaluated the "conservation of energy as a unifying principle in nineteenth-century science." He regarded this group — Mach, Duhem, Enriques, Poincaré, Meyerson, and Cassirer — as scientists, philosophers, and historians, each of whom "has a claim to all three of those titles" [23].

At this point it is important to state that Colding had very little influence in the establishment of the law of conservation of energy. He had presented a paper on this law in 1843 before the Royal Society of Science in Copenhagen entitled Theses concerning Force (*Nogle Soetninger om Kroefterne*) but it was belatedly published in 1856 by the Danish Academy. It was not translated from Danish until 1913 (into IDO, a simplified Esperanto), and then published the same year in volume 1 of *Isis* together with a review by Sarton and a preface by Ostwald. In the interim, Colding was given an opportunity of publishing his views "On the History of the Principle of the Conservation of Energy" in the *Philosophical Magazine*, in English, in 1861 and 1864. By this time, however, the die had been cast in the form of Helmholtz's successful, empirical version of the subject which has been brilliantly expressed by Gillispie as follows:

> Historically at least, growing appreciation of the first law and its scope owed much to the urbanity and economy of Helmholtz's beautiful memoir of 1847, *On the Conservation of Force.* His was perhaps the most gracious personality of nineteenth-century science... Instead of beginning with heat, or force in general, he went back to classical eighteen-century dynamics, started with its fundamental principle, the conservation of *vis viva,* and assimilated heat to that by applying conventional analytical mechanics to problems of energy. For though not a creative mathematicians, he was gifted with

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[21] Erwin Hiebert, "Commentary on Kuhn...", *Critical Problems, op. cit.*, p. 392.
[22] Hiebert, *op. cit.*, p. 400.
[23] *Ibid.*

a powerful mathematical grasp... And he couched his discussion in the most sophisticated language known to physics... the graceful, taut, and lissome differential equations of classical dynamics [24].

Gillispie's analysis continues with the resolution of a metaphysical idea:

It is meaningless... to ask who discovered the conservation of energy? No one did. Helmholtz's was a more difficult achievement. He expressed what everyone was vaguely assuming. And the decisive element in his success was that he alone began, not with heat or force (the unknown), but with motion (the known). Motion is the one instance of regular, lawful change of which matter *per se* is capable. The most general principle of dynamics is conservation of *vis viva.* The problem, as Helmholtz saw it, was to extend the laws governing spatial rearrangements to the parallel domain of forces... Thus Helmholtz prepared dynamics to serve his purpose by first importing into it the analytical device which Carnot had fashioned of the concept of the reversibility in a conservative situation. By the same token, moreover, he liberated the argument from its dependence on the caloric theory if heat, and clothed it instead in the strong authority of classical mechanics... Now it follows from the axiom that work consumed in going backwards equals that created by the initial process, regardless of what means are employed, what routes are followed by the particles, or what the velocity is in either direction. If it were not so, one could choose one route, say in preference to another, in order to profit from the difference. Thus could one create perpetual motion, the inadmissible. The mathematical expression which excludes that impossibility is simply the conservation of *vis viva,* and since we knew this result in principle all the time, what we have won is confidence in the argument [25].

Gillispie then demonstrated how Helmholtz proceeded to the next step; namely, equating "the work expended by a free falling body with the *vis viva* acquired," and then to additional concepts such as work, potential energy, kinetic energy, all of which is offered (without historical explanation) in a freshman course of mechanics. In Kuhn's *Formation* conversion equivalents were treated in general fashion; in Gillispie's analysis the equivalents were clustered around exchanges with *vis viva.* Both Kuhn and Gillispie agreed on the metaphysical implications. All these data were known to Colding when he wrote his observations and contributions "On the History of the Principle of the Conservation of Energy" for the *Philosophical Magazine* in 1861 and 1864. But Colding pursued an independent path of his own, one that was original to him and has far more significance today than it did a century ago.

Kuhn, Gillispie, Hiebert and I, like many others, are greatly indebted to the late Alexandre Koyré whom we all regard as "the master of us all," as publicly stated [26]. In Colding's work I am not tracing the path of

[24] Charles Coulston Gillispie, *The Edge of Objectivity,* Princeton, 1960, pp. 382–384.

[25] Gillispie, *op. cit.,* pp. 385–386.

[26] Gillispie, *op. cit.,* p. 523. Professors Marshall Clagett and I. Bernard Cohen (and I) "have dedicated their own major works to Alexandre Koyré of the Ecole pratique des hautes études, Sorbonne, and the Institute of Advanced Study, Princeton". Gillispie adds that he owes more to Koyré professionally than to anyone else.

successful science as my colleagues have done above, but rather a dead end of science that is only now coming to life. Koyré always advocated both techniques.

It was in 1864 that Colding summed up his views in English in the *Philosophical Magazine* and reviewed the nature of the development of his ideas and experiments. Here he cited the metaphysical source of the powers of nature and of "the forces [which] ought to be regarded as absolutely imperishable." He stated:

> It was in accordance with this idea that I twenty years ago presented to the Royal Society, here in Copenhagen, a treatise in which I explained my idea that force is imperishable and immortal; and therefore, when and wherever force seems to vanish in performing certain mechanical, chemical, or other work the force then merely undergoes a transformation and reappears in a new form, but of the original amount of the force.
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> In the year 1843 this idea, which completely constitutes the new principle of the perpetuity of energy, was distinctly given by me, the idea itself having been clear to my own mind nearly four years before, when it arose at once in my mind by studying D'Alembert's celebrated and successful enunciation of the principle of active and lost forces... [27]

The reference to d'Alembert's principle is essentially one of equilibrium between an original external vector and a reversed effective vector during constraint, usually during a change of direction. This is an idealized principle which grew out of the theory of the compound pendulum. In the latter case it was imagined that a pie-shaped hard body, affixed at the apex, was composed of a series of simple pendula under necessary constraint. Consequently, stresses were set up within the compound pendulum which were transferred instantaneously without loss throughout the hard body. While this principle was very useful, it supposed that there would be no rupture of the bodies under constraint. In the obvious case, a large enough swinging pendulum of this type would break. While Newton's atoms were held to be infinitely hard, only Deity could have made them so. Colding followed a similar track by idealizing force to be "imperishable and immortal." Other cases of idealized concepts are Newton's third law of action and reaction and the law of inertia governing the path of a body in motion, without constraint, forever. Colding continued his explanation as follows:

> In my first treatise, of 1843, the title of which is 'Theses concerning Force'... I went on to call attention to several old experiments made previously to my life, the first of which was Dulong's celebrated discovery respecting the heat disengaged or absorbed during the compression or expansion of a great number of different airs and gases... how perfectly these experiments proved the truth of the said principle for bodies of that kind. After... confirmation of the principle by elastic fluids, I tried to show that the experiments of M. Oersted on the compressibility of non-elastic fluids and the heat disengaged thereby

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[27] M. A. Colding, "History of the Principle of the Conservation of Energy", *Philosophical Magazine,* London, 1864, Vol. 27, p. 58.

were in perfect accordance with my new principle; and after... this... to show that the heat disengaged on the compression of solid bodies also was proportionate to the quantity of mechanical energy expended; and from the experiments of Berthollet [which measured the heat generated by compression of metals] and of Lagerhjelm [heat released from ruptured rods] ...I found that here also everything spoke in favor of this principle [28].

In addition, Colding performed some 200 experiments on generating heat by friction of brass rods with others made of zinc, lead, iron, brass, wood, and woolen cloth under various pressures and velocities. The results showed that 350 kg-m raised the temperature of one kg of water 1°C. Mayer's ratio, he added, was 365 to 1 [29].

As for his views on heat Colding propounded an extended hypothesis:

We need not look upon heat as distinct force, but rather as a living force [*vis viva*], whose strength depends on the attractive and repelling forces responsible for the motion of the material particles and partly on the quantity of activity which may be supplied to the body in one or more ways either in the form of mechanical activity, or in other ways [30].

This quotation was included in a memoir which Colding submitted to the French Academy of Sciences in an open contest. He did not receive the prize although he was given an honorable mention. The committee of examiners found that "l'auteur expose les idées généralement admises sur les relations entre le travail mécanique et la chaleur, dont la cause consisterait dans les mouvements vibratoires des molécules des corps." They continued as follows:

Appliquant ensuite les équations générales de la Dynamique... il [l'auteur] arrive aux relations connues et données par les auteurs qui y sont parvenus par une voie plus simple. Il obtient une equation nouvelle entre les variations de la pression et de la force vive interieure dans une masse fluide, relation douteuse et dont l'exactitude n'est confirmé a posteriori par aucun fait bien certain. Il combat, chemin faisant, une hypothèse de MM. Krönig et Clausius sur la constitution intime des gaz. Les calculs par lesquelles cetter hypothèse est combattue dans le Mémoire n° 3 n'en demonstrent pas la fausseté [31].

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[28] Colding, *op. cit.*, pp. 58, 59.

[29] *Ibid*, p. 59.

[30] P. F. Dahl (Physicist, Brookhaven National Laboratory, Editor — Harry Woolf; Editor-in-Chief, Willis K. Shepard Professor of the History of Science, The Johns Hopkins University) *Ludvig Colding and the Conservation of Energy Principle, Experimental and Philosophical Contributions,* The Sources of Science No. 104, Johnson Reprint Corporation, New York, 1972, page 133. The quotation is from Paper VI titled "Unified Presentation of the Forces of Nature with Application to the Mechanical Theory of Heat", a paper that was submitted in a prize contest offered by the French Academy for the year 1864 by Colding anonymously in 1863. The decision by the judges was rendered without knowledge of the authorship. Colding's paper was analyzed as No. 3 (of four participants) and received honorable mention. The decisions on the contest were published in *Comptes Rendus*, Vol. 62, 1866, pp. 499–501.

[31] *Comptes Rendus, op. cit.*, pp. 499, 500.

The difference of opinion stems from the problem of the "attracting and repelling forces" cited above by Colding in his memoir. Visualizing the aim of these forces from an idealistic point of view, he wanted to include them as a part of his metaphysical vision of nature. For Krönig and Clausius, on the other hand, who were more concerned about getting practical results with relative ease, the inclusion of these forces between molecules was troublesome and unnecessary for all practical purposes. Indeed to this day such gravitational forces have not been measured.

The emphasis on empirical results and measurement, however, takes its toll in diminishing comprehension and understanding of science by nonscientists. When these assets are sacrificed, the people tend to turn to pat formulas such as those generally illustrated by astrological productions. Success of the latter merely compounds the general ignorance.

By translating the Latin expression — *vis viva* — into the English "living force", Colding accentuated the nature of his departure from empirical science, a discipline which discarded the expression from the Latin too, but adopted the Greek expression — kinetic energy — instead. His aim was to fit the basic forces of attraction and repulsion into a universal law of nature namely "that the forces are imperishable." Dissatisfaction with the empirical school prompted him to present his "favorite idea on the relationship between the forces of nature and the spiritual life." Citing Oersted's *The Soul in Nature,* as a worthy example to follow, he proceeded to explain his theory in Paper V as outlined below.

The forces of nature are responsible for maintaining bodies in their original state, which is a restatement of the conservation of mass. Although it is clear that forces exist and survive as unique entities when bodies change and "when the whole plant and animal world comes to an end," their essence and nature are incomprehensible, thus stressing the metaphysical nature of the law of conservation of force. He does believe, as well, that "the forces are free and independent entities...able to detach themselves from matter and traverse the universe with the speed of light" — certainly at least a prediction of the release of atomic energy. He cited the development of the electric telegraph as an instance of the unbelievable speed with which electric force can travel with the speed of light. "The forces of nature, far from being permanently bound to matter, traverse the universe without cessation." Colding extended the term "living force" to include all "mechanical activity, heat and light, and electric, galvanic, electromagnetic or magnetoelectric current," etc., under the rubric of living force, a term that he finds fortunate "insofar as it implies the concept of a transitional form between two quite different independent states, and thus points to a higher life.." [32]

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[32] P. F. Dahl, *op. cit.*, pp. 120 ff.

A current article by Bloembergen on lasers describes the specific characteristics of modern particles having mutually attractive and repulsive forces, respectively, and which traverse the universe.

> Physics knows two different forms of identity which are displayed by photons and electrons. Particles such as photons that tend to flock together are called b o s o n s. All photons in the laser beam are indistinguishable; they have the same wave vector, energy, and polarization. If two photons are interchanged or permuted, their joint wave function remains the same. Electrons are also indistinguishable, but they tend to stay apart, even if the repulsive effect of their charges is neutralized. Such particles are called f e r m i o n s. The wave function of a system of electrons changes its sign when two electrons are interchanged or permuted. Electron orbitals resist overlap, thus providing the reason why it is difficult to compress any solid material. We cannot put two objects in the same place! This is formulated precisely in the famous Pauli exclusion principle which states that no two electrons can occupy the same quantum state. The exclusion principle, the basis for the periodic system of elements, is fundamental to chemistry.
>
> Quantum mechanics, or wave mechanics, leads naturally therefore to these two opposite types, bosons and fermions. It is remarkable that this fact has not captured the imagination of philosophers and a broader public outside the sciences. This is in marked contrast to the concept of duality and complementarity, which has received wide attention among nonphysicists, as has the concept of relativity [33].

Among the applications of a laser (light amplification by stimulated emission of radiation) are the transmission of signals (over short distances or to the moon and back), measuring time (accurate to one second in 30,000 years), measuring distances (in mines, tunnels, seismic motion), creating high temperatures (any material known, to a hot gas almost instantaneously), in surgery (all cuts, bloodless). Bloembergen cites other sources of lasers such as the noble gases, metallic vapors; compounds such as water, the carbon oxides, rare-earth ions. Furthermore:

> The ruby laser, dating from 1960 was actually the first man-made laser. Long before that, however, lasers utilizing water molecules and hydroxyl radicals were operating in interstellar space. These celestial lasers were discovered after the construction of lasers in the laboratory, but since they are thousands of light years away, they were there first [34].

With reference to Oersted's law of oscillation, we ascertain that when Colding was postulating the existence of forces detached from matter, he was indulging in a metaphysical "Creation." Yet he was doing more than this. He was attempting to fit forces like electromagnetic waves into a "Formation". He accepted the nebular hypothesis, suggested by Kant and later developed by Laplace, which proposed "an immense

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[33] Nicolaas Bloembergen (Professor of Applied Physics and Rumford Professor of Physics at Harvard University), "Lasers: A Renaissance in Optics Research", *American Scientist* January–February 1975, pp. 19, 20.

[34] *Ibid.*, p. 19.

sphere of condensation, possessing rotation about an axis, and held together by mutual attraction according to the well-known Newtonian law." Colding added to this hypothesis the proposal that "the contraction of these universal globes could not take place, however, without the liberation of a living force equivalent to the contraction." This living force so released, he explained, — in the form of heat and electricity — then combined with the matter to form the chemical elements. (All of which was preparatory for nourishing "the organic and spiritual life which would evolve in the course of time.") With further contractions and cooling of the Earth, the pressure would have increased sufficiently to generate the chemical transformations into minerals, which in turn were followed by plant and animal life on earth in the evolutionary process during which Man finally appeared. Colding then proposed the following thesis to be investigated: "The human intellect is a new and refined form of releasing the forces of nature" [35]. Modern scientists would prefer to insert the world "releasing" in the previous sentence, as indicated, because the intellect acts like a key that opens Pandora's box.

It seems that Colding had a partial conception of r e s t - m a s s e n e r g y, which was defined by Einstein as the product of the mass of annihilated matter by the square of the velocity of released light ($E = mc^2$). While Colding did not visualize the destruction of matter as a necessary prelude to the release of energy from matter, it is clear that he considered the released forces as independent.

There is another perplexing problem: what of the attractive and repulsive forces? In Bloembergen's article on lasers as cited above, the electrons were mutually repulsive. While one would expect unlike charged particles of electricity to attract and like ones repel, it is rather astounding to note the author's comment that the negatively charged electrons "tend to stay apart, even if the repulsive effect to their charges is neutralized." This experimental observation also suggests that these electrons and photons are moving so rapidly that they are tracing paths in curved space, as defined in the theory of relativity. That is the Coulomb forces operating on the very fast electrons have insufficient time to show any appreciable effect of attraction. It follows too that these Coulomb forces acting on charged particles require a finite time to act, and are not instantaneously operative. In the days of Coulomb, this consideration was irrevelant.

From his belief in the law of the conservation of energy and that of identification of mental activity with living force Colding concludes:

> Consequently, intellectual activity can no more undergo destruction than can living forces. Every true idea we are capable of conceiving is a glance into the infinite abyss out of which the forces ascended; a glance into the

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[35] O. F. Dahl, *op. cit.* Paper V, pp. 122, 123.

> basic nature of the forces; a revelation of the Divine itself; yes, a pledge to the immortality of the human soul. But in all our actions and labor we must not forget the law of nature which states that only that which is in accord with the soul in nature can persevere, while everything which offers resistance is perishable and must sooner or later be destroyed [36].

We can now proceed to formulate a further application of Oersted's law of oscillation. The "Creation" which outlines the metaphysical idea poses the concept that forces detached from matter have uniquely spiritual origin. In evaluating this concept, we should differentiate between the so-called forces of attraction and repulsion that were rampant in 18th and 19th century science and said to be acting at a distance, as against the same forces which appear to be integrated in the particles, themselves. The first group have been used to explain the action of gravitational attraction. While Newton utilized this interpretation, he was careful to emphasize that "an Agent" was responsible for gravitation.

To quote from Newton's third letter to Bishop Bentley:

> That Gravity should be innate, inherent and essential to Matter, so that one body may act upon another at a Distance thro' a Vacuum, without the Mediation of anything else, by and through which their Action and Force may be conveyed from one to another, is to me so great an Absurdity, that I believe no Man who has in philosophical Matters a competent Faculty of thinking, can ever fall into it. Gravity must be caused by an Agent acting constantly according to certain Laws; but whether this Agent be material or immaterial, I have left to the Consideration of my Readers [37].

Thackray in his monograph *Atoms and Powers* traced the carry-over of this view by Newton's students during the 18th century, with respect to its application to chemistry [38].

With respect to the second group, in which the forces have been liberated from matter as in the case of laser, we note that Coulomb repulsive forces are inoperable. In this case the forces in the bosons and fermions (plus atomic energy) appear to be innate and to satisfy a concept which could be interpreted along the line proposed by Colding. That is, the bosons and fermions could be interpreted with Colding's principle in

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[36] P. F. Dahl, *op. cit.* Paper V, p. 127.

[37] I. Bernard Cohen (Editor, assisted by Robert E. Schofield with explanatory prefaces by Marie Boas, Thomas S. Kuhn, Charles Coulston Gillispie and Perry Miller), *Isaac Newton's Paper and Latters on Natural Philosophy and Related Documents*, Cambridge, 1958, pp. 302, 303. This reference includes the reprint of "Four Letters from Sir Isaac Newton to Doctor Bentley containing some Arguments in Proof of Deity" (that was printed in) London for R. and J. Dodsley, Pall-Mall, MDCCLVI.

[38] Arnold Thackray (Foreword by I. Bernard Cohen), *Atoms and Powers — An Essay on Newtonian Matter — Theory and the Development of Chemistry*, Cambridge, 1970.

mind, as "free and independent entities — able to detach themselves from matter and traverse the universe with the speed of light." At the very least, Colding anticipated the existence of photons — particles of light subsumed under the category of pure force or energy emerging from the infinitely small in the same manner as gravitational energy or force submerges from the infinitely great. The suspension of man between these two extremes was Pascal's idea.

In his philosophical approach to modern science, Colding clearly distinguishes between the physical forces released by Nature in the Universe (which he treated in his discussion of Kant's cosmogony) as contrasted with the forces which are indirectly released by the force of man's intellectual understanding (as illustrated by the discovery of atomic energy and lasers).

It appears, therefore, from Colding's interpretation, that man's will to understand Nature exhibits increasing power as it perceives ever finer intellectual distinctions whereby universal forces are released. Thus, human power may be interpreted in terms of the ever-widening span between the minima and maxima being revealed in Nature by scientific research.

Since Colding assigns the human intellect as the cause of "new and refined forces of nature" in the same way as Newton assigned the cause of gravity to a sole Agent, we have a plausible metaphysical idea that may be interpreted under the rubric of the "Creation" in Oersted's law of oscillation. As time goes on, the validity of this abstract proposal will be evaluated. The part that is true and factual could be transferred into a new expression of the "Formation". In the meantime these useful forces that were predicted to exist by Colding will certainly be of benefit for all humanity unless we use them against each other.