Frederick Engels'

Dialectics of Nature

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Engels' Dialectics of Nature

Preface

MARXISM has a two-fold bearing on science. In the first place Marxists study science among other human activities. They show how the scientific activities of any society depend on its changing needs, and so in the long run on its productive methods, and how science changes the productive methods, and therefore the whole society. This analysis is needed for any scientific approach to history, and even non-Marxists are now accepting parts of it. But secondly Marx and Engels were not content to analyse the changes in society. In dialectics they saw the science of the general laws of change, not only in society and in human thought, but in the external world which is mirrored by human thought. That is to say it can be applied to problems of "pure" science as well as to the social relations of science.

Scientists are becoming familiar with the application of Marxist ideas to the place of science in society. Some accept it in whole or in part, others fight against it vigorously, and say that they are pursuing pure knowledge for its own sake. But many of them are unaware that Marxism has any bearing on scientific problems considered out of their relation to society, for example to the problems of tautomerism in chemistry or individuality in biology. And certain Marxists are inclined to regard the study of such scientific and philosophical problems as unimportant. Yet they have before them the example of Lenin. In 1908 the Russian Revolution had failed. It was necessary to build up the revolutionary movement afresh. Lenin saw that this could only be done on a sound theoretical basis. So he wrote *Materialism and Empirio- criticism*. This involved a study, not only of philosophers such as Mach and Pearson, whom he criticised, but of physicists such as Hertz, J. J. Thomson, and Becquerel, whose discoveries could be interpreted from a materialistic or an idealistic point of view. However, Lenin did not attempt to cover the whole of science. He was mainly concerned with the revolution in physics which was then in progress, and had little to say on astronomy, geology, chemistry, or biology.

But thirty years before Lenin, Engels had tried to discuss the whole of science from a Marxist standpoint. He had always been a student of science. Since 1861 he had been in close touch with the chemist Schorlemmer at Manchester, and had discussed scientific problems with him and Marx for many years. In 1871 he came to London, and started reading scientific books and journals on a large scale. He intended to write a great book to show "that in nature the same dialectical laws of movement are carried out in the confusion of its countless changes, as also govern the apparent contingency of events in history." If this book had been written, it would have been of immense importance for the development of science.

But apart from political work, other intellectual tasks lay before Engels. Dühring had to be answered, and perhaps *Anti-Dühring*, which covers the whole field of human knowledge, is a greater book than *Dialectics of Nature* would have been had Engels completed it. After Marx's death in 1883 he had the gigantic task of editing and completing *Capital*, besides which he wrote *Feuerbach* and *The Origin of the Family*. So *Dialectics of Nature* was never finished. The manuscript consists of four bundles, all in Engels' handwriting, save for a number of quotations from Greek philosophers in that of Marx. Part of the manuscript is ready for publication, though, as we shall see, it would almost certainly have been revised. Much of it merely consists of rough notes, which Engels hoped to work up later. They are often hard to read, and full of abbreviations, *e.g.* Mag. for magnet and magnetism. There are occasional scribbles and sketches in the margin. Finally, although the bulk of the manuscript is in German, Engels thought equally well in English and French, and occasionally produced a hybrid sentence, such as "Wenn Coulomb von particles of electricity spricht, which repel each other inversely as the square of the distance, so nimmt Thomson das ruhig hin als bewiesen." Or "In der heutigen Gesellschaft, dans le méchanisme civilisé, herrscht duplicité d'action, contrariété de l'interêt individuel avec le collectif; es ist une queue universelle des individus contre les masses." The translation has been a very difficult task, and the order of the different parts is somewhat uncertain.

Most of the manuscript seems to have been written between 1872 and 1882, that is to say it refers to the science of sixty years ago. Hence it is often hard to follow if one does not know the history of the scientific practice and theory of that time. The idea of what is now called the conservation of energy was beginning to permeate physics, chemistry, and biology. But it was still very incompletely realised, and still more incompletely applied. Words such as "force," "motion," and "*vis viva*" were used where we should now speak of energy. The essays on "Basic forms of motion," "The measure of motion - work," and "Heat" are largely concerned with the controversies which arose from incomplete or faulty theories about energy. They are interesting as showing how ideas on this subject developed, and how Engels tackled the controversies of his day. However many of these controversies are now settled. The expression *vis viva* is no longer used for double the kinetic energy, and "force" has acquired a definite meaning in physics. Engels would not have published them in their present form, if only because, in the later essay on tidal friction, he uses a more modern terminology. Their interest lies not so much in their detailed criticism of theories, many of which have ceased to be of importance, but in showing how Engels grappled with intellectual problems. The essay on electricity "dates" even more. As a criticism of Wiedemann's inconsistencies it is interesting, and it ends with a plea for a closer investigation of the connection between chemical and electrical action, which, as Engels said, "will lead to important results in both spheres of investigation." This prophecy has, of course, been amply fulfilled. Arrhenius' ionic theory has transformed chemistry, and Thomson's electron theory has revolutionised physics. Here again, the manuscript would certainly have been revised before publication. In a letter to Marx on November 23rd, 1882, he points out that Siemens, in his presidential address to the British Association, has defined a new unit, that of electric power, the Watt, which is proportional to the resistance multiplied by the square of the current whereas the electromotive force is proportional to the resistance multiplied by the current. He compares these with the expressions for momentum and energy, discussed in the essay on "The measure of motion - work," and points out that in each case we have simple proportionality (momentum as velocity and electromotive force as current) when we are not dealing with transformation of one form of energy into another. But when the energy is transformed into heat or work the correct value is found by squaring the velocity or current. "So it is a general law of motion which I was the first to formulate." We can now see why this is so. The momentum and the electromotive force, having directions, are reversed when the speed and current are reversed. But the energy remains unaltered. So the speed or the current must come into the formula as the square (or some even power) since $(-x)^2 = x^2$.

In the essay on " Tidal friction," Engels made a serious mistake, or more accurately a mistake which would have been serious had he published it. But I very much doubt whether he would have done so. In the manuscript notes for Anti-Dühring,[1] he supported the view, quite commonly held in the nineteenth century, that we find truths such as mathematical axioms self-evident because our ancestors have been convinced of their validity, while they would not appear self-evident to a Bushman or Australian black. Now this view is almost certainly incorrect, and Engels presumably saw the fallacy, and did not have it printed. I have little doubt that either he or one of his scientific friends such as Schorlemmer would have detected the mistake in the essay on "Tidal friction." But even as a mistake it is interesting, because it is one of the mistakes which lead to a correct result (namely that the day would shorten even if there were no oceans) by incorrect reasoning. Such mistakes have been extremely fruitful in the history of science.

Elsewhere there are statements which are certainly untrue, for example in the sections on stars and Protozoa. But here Engels cannot be blamed for following some of the best astronomers and zoologists of his day. The technical improvement of the telescope and microscope has of course led to great increases in our knowledge here in the last sixty years.

On the other hand, Engels' remarks on the differential calculus, though inapplicable to that branch of mathematics as now taught, were correct in his own day, and for some time after. He points out that it actually developed by contradiction, and is none the worse for that. To-day "rigorous" proofs are given of many of the theorems to which he refers, and some mathematicians claim to have eliminated the contradictions. Actually they have only pushed the contradictions into the background, where they remain in the field of mathematical logic. Not only has every effort to deduce all mathematics from a set of axioms, and rules for applying them, failed, but Gödel has proved that they must fail. So the fact that the calculus can be taught without involving the particular contradictions mentioned by Engels in no way impugns the validity of his dialectical argument.

When all such criticisms have been made, it is astonishing how Engels anticipated the progress of science in the sixty years which have elapsed since he wrote. He certainly did not like the atomic theory of electricity, which held sway from 1900 to 1930, and until it turned out that the electron behaved not only like a particle but like a system of moving waves he might well have been thought to have "backed the wrong horse." His insistence that life is the characteristic mode of behaviour of proteins appeared to be very one-sided to most biochemists since every cell contains many other complicated organ substances besides proteins. Only in the last four years has it turned out that certain pure proteins do exhibit one of the most essential features of living things, reproducing themselves in a variety of environments.

While we can everywhere study Engels' method of thinking with advantage, I believe that the sections of the book which deal with biology are the most immediately valuable to scientists to-day. This may of course be because as a biologist I can detect subtleties of Engels' thought which I have missed in the physical sections. It may be because biology has undergone less spectacular changes than physics in the last two generations.

In order to help readers to follow the development of science since Engels' time, I have added some notes. A few readers may object to my pointing out that Engels was occasionally wrong. Engels would not have objected. He was well aware that he was not infallible, and that the Labour Movement wants no popes or inspired scriptures. *The Condition of the Working Class in England in 1844*, of which an English translation had been published in America in 1885, was first published in England in 1892. In his preface written after fortyeight years he says:

"I have taken great care not to strike out of the text the many prophecies, amongst others that of an imminent social revolution in England, which my youthful ardour induced me to venture upon. The wonder is, not that a good many of them proved wrong, but that so many of them have proved right."

I think that readers of *Dialectics of Nature* will come to a similar conclusion.

I have not yet mentioned the sections on the history of science. These are among the most brilliant passages in the whole book, but they represent a line of thought which was followed by Marx and Engels in many of their books and which has since been developed by others, so most readers will find them less novel. Finally, there is the delightful essay on "Scientific research into the spirit world." There is a tendency among materialists to neglect the problems here dealt with. It is worthwhile noticing that Engels did not do so. On the contrary he produced a number of phenomena which were regarded as "occult" and mysterious in his day, and arrived at the same conclusions as most scientific investigators in this field have reached, provided that, like Engels, they brought to their work robust common sense, and also a sense of humour.

It was a great misfortune, not only for Marxism, but for all branches of natural science, that Bernstein, into whose hands the manuscript came when Engels died in 1895, did not publish it. In 1924 he submitted it (or part of it) to Einstein, who, though he did not think it of great interest from the standpoint of modern physics, was on the whole in favour of publication. If, as seems likely, Einstein only saw the essay on electricity, his hesitation can easily be understood, since this deals almost wholly with questions which now seem remote. The manuscript was first edited by Riazanov, and printed in 1927. However, Adoratski's edition of 1935 is more satisfactory, as several passages which made nonsense in the earlier edition have now been deciphered.

Had Engels' method of thinking been more familiar, the transformations of our ideas on physics which have occurred during the last thirty years would have been smoother. Had his remarks on Darwinism been generally known, I for one would have been saved a certain amount of muddled thinking. I therefore welcome wholeheartedly the publication of an English translation of *Dialectics of Nature*, and hope that future generations of scientists will find that it helps them to elasticity of thought.

But it must not be thought that *Dialectics of Nature* is only of interest to scientists. Any educated person, and, above all, anyone who is a student of philosophy, will find much to interest him or her throughout the book, though particularly in Chapters I, II, VII, IX, and X. One reason why Engels was such a great writer is that he was probably the most widely educated man of his day. Not only had he a profound knowledge of economics and history, but he knew enough to discuss the meaning of an obscure Latin phrase concerning Roman marriage law, or the processes taking place when a piece of impure zinc was dipped into sulphuric acid. And he contrived to accumulate this immense knowledge, not by leading a life of cloistered learning, but while playing an active part in politics, running a business, and even fox-hunting!

He needed this knowledge because dialectical materialism, the philosophy which, along with Marx, he founded, is not merely a philosophy of history, but a philosophy which illuminates all events whatever, from the falling of a stone to a poet's imaginings. And it lays particular emphasis on the inter-connection of all processes, and the artificial character of the distinctions which men have drawn, not merely between vertebrates and invertebrates or liquids and gases, but between the different fields of human knowledge such as economics, history, and natural science.

Chapter II contains an outline of this philosophy in its relation to natural science. A very careful and condensed summary of it is given in Chapter IV of the *History of the C.P.S.U.(B)*, but the main sources for its study are Engels' *Feuerbach* and *Anti-Dühring*, Lenin's *Materialism and Empirio-criticism*, and a number of passages in the works of Marx. Just because it is a living philosophy with innumerable concrete applications its full power and importance can only be gradually understood, when we see it applied to history, science, or whatever field of study interests us most. For this reason a reader whose concern lies primarily in the political or economic field will come back to his main interest a better dialectical materialist, and therefore a clearer-sighted politician or economist, after studying how Engels applied Dialectics to Nature.

At the present moment, clear thinking is vitally necessary if we are to understand the extremely complicated situation in which the whole human race, and our own nation in particular, is placed, and to see the way out of it to a better world. A study of Engels will warn us against some of the facile solutions which are put forward to-day, and help us to play an intelligent and courageous part in the great events of our own time.

J. B. S. HALDANE.
November, 1939.

Notes

1. See p. 314.

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1. INTRODUCTION

MODERN natural science, which alone has achieved an all-round systematic and scientific development, as contrasted with the brilliant natural-philosophical intuitions of antiquity and the extremely important but sporadic discoveries of the Arabs, which for the most part vanished without results - this modern natural science dates, like all more recent history, from that mighty epoch which we Germans term the Reformation, from the national misfortune that overtook us at that time, and which the French term the Renaissance and the Italians the Cinquecento, although it is not fully expressed by any of these names. It is the epoch which had its rise in the last half of the fifteenth century. Royalty, with the support of the burghers of the towns, broke the power of the feudal nobility and established the great monarchies, based essentially on nationality, within which the modern European nations and modern bourgeois society came to development. And while the burghers and nobles were still fighting one another, the peasant war in Germany pointed prophetically to future class struggles, not only by bringing on to the stage the peasants in revolt - that was no longer anything new - but behind them the beginnings of the modern proletariat, with the red flag in their hands and the demand for common ownership of goods on their lips. In the manuscripts saved from the fall of Byzantium, in the antique statues dug out of the ruins of Rome, a new world was revealed to the astonished West, that of ancient Greece: the ghosts of the Middle Ages vanished before its shining forms; Italy rose to an undreamt-of flowering of art, which seemed like a reflection of classical antiquity and was never attained again. In Italy, France, and Germany a new literature arose, the first, modern literature; shortly afterwards came the classical epochs of English and Spanish literature. The bounds of the old *orbis terrarum* were pierced. Only now for the first time was the world really discovered and the basis laid for subsequent world trade and the transition from handicraft to manufacture, which in its turn formed the starting-point for modern large scale industry. The dictatorship of the Church over men's minds was shattered; it was directly cast off by the majority of the Germanic peoples, who adopted Protestantism, while among the Latins a cheerful spirit of free thought, taken over from the Arabs and nourished by the newly-discovered Greek philosophy, took root more and more and prepared the way for the materialism of the eighteenth century.

It was the greatest progressive revolution that mankind has so far experienced, a time which called for giants and produced giants - giants in power of thought, passion, and character, in universality and learning. The men who founded the modern rule of the bourgeoisie had anything but bourgeois limitations. On the contrary, the adventurous character of the time inspired them to a greater or less degree. There was hardly any man of importance then living who had not travelled extensively, who did not command four or five languages, who did not shine in a number of fields. Leonardo da Vinci was not only a great painter but also a great mathematician, mechanician, and engineer, to whom the most diverse branches of physics are indebted for important discoveries. Albrecht Durer was painter, engraver, sculptor, and architect, and in addition invented a system of fortification embodying many of the ideas that much later were again taken up by Montalembert and the modern German science of fortification. Machiavelli was statesman, historian, poet, and at the same time the first notable military author of modern times. Luther not only cleaned the Augean stable of the Church but also that of the German language; he created modern German prose and composed the text and melody of that triumphal hymn which became the Marseillaise of the sixteenth century. The heroes of that time had not yet come under the servitude of the division of labour, the restricting effects of which, with its production of onesidedness, we so often notice in their successors. But what is especially characteristic of them is that they almost all pursue their lives and activities in the midst of the contemporary movements, in the practical struggle; they take sides and join in the fight, one by speaking and writing, another with the sword, many with both. Hence the fullness and force of character that makes them r.omplete men. Men of the study are the exception - either persons of second or third rank or cautious philistines who do not want to burn their fingers.

At that time natural science also developed in the midst of the general revolution and was itself thoroughly revolutionary; it had to win in struggle its right of existence. Side by side with the great Italians from whom modern philosophy dates, it provided its martyrs for the stake and the prisons of the Inquisition. And it is characteristic that Protestants outdid Catholics in persecuting the free investigation of nature. Calvin had Servetus burnt at the stake when the latter was on the point of discovering the circulation of the blood, and indeed he kept him roasting alive during two hours; for the Inquisition at least it sufficed to have Giordano Bruno simply burnt alive.

The revolutionary act by which natural science declared its independence and, as it were, repeated Luther's burning of the Papal Bull was the publication of the immortal work by which Copernicus, though timidly and, so to speak, only from his deathbed, threw down the gauntlet to ecclesiastical authority in the affairs of nature. The emancipation of natural science from theology dates from this act, although the fighting out of the particular antagonistic claims has dragged out up to our day and in many minds is still far from completion. Thenceforward, however, the development of the sciences proceeded with giant strides, and, it might be said, gained in force in proportion to the square of the distance (in time) from its point of departure. It was as if the world were to be shown that henceforth the reciprocal law of motion would be as valid for the highest product of organic matter, the human mind, as for inorganic substance.

The main work in the first period of natural science that now opened lay in mastering the material immediately at hand. In most fields a start had to be made from the very beginning. Antiquity had bequeathed Euclid and the Ptolemaic solar system; the Arabs had left behind the decimal notation, the beginnings of algebra, the modern numerals, and alchemy; the Christian Middle Ages nothing at all. Of necessity, in this situation the most fundamental natural science, the mechanics of terrestrial and heavenly bodies, occupied first place, and alongside of it, as handmaiden to it, the discovery and perfecting of mathematical methods. Great work was achieved here. At the end of the period characterised by Newton and Linnaus we find these branches of science brought to a certain perfection. The basic features of the most essential mathematical methods were established; analytical geometry by Descartes especially, logarithms by Napier, and the differential and integral calculus by Leibniz and perhaps Newton. The same holds good of the mechanics of rigid bodies, the main laws of which were made clear once for all. Finally in the astronomy of the solar system Kepler discovered the laws of planetary movement and Newton formulated them from the point of view of the general laws of motion of matter. The other branches of natural science were far removed even from this preliminary perfection. Only towards the end of the period did the mechanics of fluid and gaseous bodies receive further treatment. Physics proper had still not gone beyond its first beginnings, with the exception of optics, the exceptional progress of which was due to the practical needs of astronomy. By the phlogistic theory, chemistry for the first time emancipated itself from alchemy. Geology had not yet gone beyond the embryonic stage of mineralogy; hence paleontology could not yet exist at all. Finally, in the field of biology the essential preoccupation was still with the collection and first sifting of the immense material, not only botanical and zoological but also anatomical and even physiological. There could as yet be hardly any talk of the comparison of the various forms of life, of the investigation of their geographical distribution and their climatic, etc., living conditions. Here only botany and zoology arrived at an approximate completion owing to Linnæus.

But what especially characterises this period is the elaboration of a peculiar general outlook, in which the central point is the view of the *absolute immutability of nature*. In whatever way nature itself might have come into being, once present it remained as it was as long as it continued to exist. The planets and their satellites, once set in motion by the mysterious "first impulse", circled on and on in their predestined ellipses for all eternity, or at any rate until the end of all things. The stars remained for ever fixed and immovable in their places, keeping one another therein by "universal gravitation". The earth had persisted without alteration from all eternity, or, alternatively, from the first day of its creation. The "five continents" of the present day had always existed, and they had always had the same mountains, valleys, and rivers, the same climate, and the same flora and fauna, except in so far as change or cultivation had taken place at the hand of man. The species of plants and animals had been established once for all when they came into existence; like continually produced like, and it was already a good deal for Linnaus to have conceded that possibly here and there new species could have arisen by crossing. In contrast to the history of mankind, which develops in time, there was ascribed to the history of nature only an unfolding in space. All change, all development in nature, was denied. Natural science, so revolutionary at the outset, suddenly found itself confronted by an out-and-out conservative nature in which even to-day everything was as it had been at the beginning and in which - to the end of the world or for all eternity - everything would remain as it had been since the beginning.

High as the natural science of the first half of the eighteenth century stood above Greek antiquity in knowledge and even in the sifting of its material, it stood just as deeply below Greek antiquity in the theoretical mastery of this material, in the general outlook on nature. For the Greek philosophers the world was essentially something that had emerged from chaos, something that had developed, that had come into being. For the natural scientists of the period that we are dealing with it was something ossified, something immutable, and for most of them something that had been created at one stroke. Science was still deeply enmeshed in theology. Everywhere it sought and found its ultimate resort in an impulse from outside that was not to be explained from nature itself. Even if attraction, by Newton pompously baptised as "universal gravitation", was conceived as an essential property of matter, whence comes the unexplained tangential force which first gives rise to the orbits of the planets? How did the innumerable varieties of animals and plants arise? And how, above all, did man arise, since after all it was certain that he was not present from all eternity? To such questions natural science only too frequently answered by making the creator of all things responsible. Copernicus, at the beginning of the period, writes a letter renouncing theology; Newton closes the period with the postulate of a divine first impulse. The highest general idea to which this natural science attained was that of the purposiveness of the arrangements of nature, the shallow teleology of Wolff, according to which cats were created to eat mice, mice to he eaten by cats, and the whole of nature to testify to the wisdom of the creator. It is to the highest credit of the philosophy of the time that it did not let itself be led astray by the restricted state of contemporary natural knowledge, and that - from Spinoza right to the great French materialists - it insisted on explaining the world from the world itself and left the justification in detail to the natural science of the future.

I include the materialists of the eighteenth century in this period because no natural scientific material was available to them other than that above described. Kant's epoch- making work remained a secret to them, and Laplace came long after them. We should not forget that this obsolete outlook on nature, although riddled through and through by the progress of science, dominated the entire first half of the nineteenth century, and in substance is even now still taught in all schools. [1]

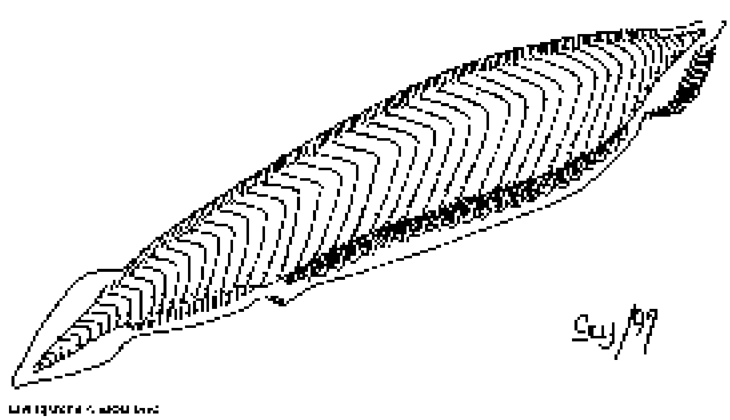
The first breach in this petrified outlook on nature was made not by a natural scientist but by a philosopher. In 1755 appeared *Kant's Allgemeine Naturgesehichte und Theorie des Himmels [General Natural History and Theory of the Heavens]*. The question of the first impulse was abolished; the earth and the whole solar system appeared as something that had come into being in the course of time. If the great majority of the natural scientists had had a little less of the repugnance to thinking that Newton expressed in the warning: "Physics, beware of metaphysics!", they would have been compelled from this single brilliant discovery of Kant's to draw conclusions that would have spared them endless deviations and immeasurable amounts of time and labour wasted in false directions. For Kant's discovery contained the point of departure for all further progress. If the earth were something that had come into being, then its present geological, geographical, and climatic state, and its plants and animals likewise, must be something that had come into being; it must have had a history not only of co-existence in space but also of succession in time. If st once further investigations had been resolutely pursued in this direction, natural science would now be considerably further advanced than it is. Rut what good could come of philosophy? Kant's work remained without immediate results, until many years later Laplace and Herschel expounded its contents and gave them a deeper foundation, thereby gradually bringing the "nebular hypothesis" into favour. Further discoveries finally brought it victory; the most important of these were: the proper motion of the fixed stars, the demonstration of a resistant medium in universal space, the proof furnished by spectral analysis of the chemical identity of the matter of the universe and the existence of such glowing nebular masses as Kant had postulated.

It is, however, permissible to doubt whether the majority of natural scientists would so soon have become conscious of the contradiction of a changing earth that bore immutable organisms, had not the dawning conception that nature does not just *exist*, but *comes into being and passes away*, derived support from another quarter. Geology arose and pointed out, not only the terrestrial strata formed one after another and deposited one upon another, but also the shells and skeletons of extinct animals and the trunks, leaves, and fruits of no longer existing plants contained in these strata. It had finally to be acknowledged that not only the earth as a whole but also its present surface and the plants and animals living on it possessed a history in time. At first the acknowledgement occurred reluctantly enough. Cuvier's theory of the revolutions of the earth was revolutionary in phrase and reactionary in substance. In place of a single divine creation, he put a whole series of repeated acts of creation, making the miracle an essential natural agent. Lyell first brought sense into geology by substituting for the sudden revolutions due to the moods of the creator the gradual effects of a slow transformation of the earth. [2]

Lyell's theory was even more incompatible than any of its predecessors with the assumption of constant organic species. Gradual transformation of the earth's surface and of all conditions of life led directly to gradual transformation of the organisms and their adaptation to the changing environment, to the mutability of species. But tradition is a power not only in the Catholic Church but also in natural science. For years, Lyell himself did not see the contradiction, and his pupils still less. This is only to be explained by the division of labour that had meanwhile become dominant in natural science, which more or less restricted each person to his special sphere, there being only a few whom it did not rob of a comprehensive view. Meanwhile physics had made mighty advances, the results of which were summed up almost simultaneously by three different persons in the year 1842, an epoch-making year for this branch of natural investigation. Mayer in Heilbronn and Joule in Manchester demonstrated the transformation of heat into mechanical energy and of mechanical energy into heat. The determination of the mechanical equivalent of heat put this result beyond question. Simultaneously, by simply working up the separate physical results already arrived at, Grove - not a natural scientist by profession, but an English lawyer - proved that all so-called physical energy, mechanical energy, heat, light, electricity magnetism, indeed even so-called chemical energy, become transformed into one another under definite conditions without any loss of energy occurring, and so proved *post factum* along physical lines Descartes' principle that the quantity of motion present in the world is constant. With that the special physical energies, the as it were immutable "species" of physics, were resolved into variously differentiated forms of the motion of matter, convertible into one another according to definite laws. The fortuitousness of the existence of a number of physical energies was abolished from science by the proof of their interconnections and transitions. Physics, like astronomy before it, had arrived at a result that necessarily pointed to the eternal cycle of matter in motion as the ultimate reality.

The wonderfully rapid development of chemistry, since Lavoisier, and especially since Dalton, attacked the old ideas of nature from another aspect. The preparation by inorganic means of compounds that hitherto had been produced only in the living organism proved that the laws of chemistry have the same validity for organic as for inorganic bodies, and to a large extent bridged the gulf between inorganic and organic nature, a gulf that even Kant regarded as for ever impassable.

Finally, in the sphere of biological research also the scientific journeys and expeditions that had been systematically organised since the middle of the previous century, the more thorough exploration of the European colonies in all parts of the world by specialists living there, and further the progress of paleontology, anatomy, and physiology in general, particularly since the systematic use of the microscope and the discovery of the cell, had ar.cumulated so much material that the application of the comparative method became possible and at the same time indispensable. On the one hand the conditions of life of the various floras and faunas were determined by means of comparative physical geography; on the other hand the various organisms were compared with one another according to their homologous organs, and this not only in the adult condition but at all stages of development. The more deeply and exactly this research was carried on, the more did the rigid system of an



immutable, fixed organic nature crumble away at its touch. Not only did the separate species of plants and animals become more and more inextricably intermingled, but animals turned up, such as *Amphioxus* and *Lepidosiren*, that made a mockery of all previous classification, and finally organisms were encountered of which it was not possible to say whether they belonged to the plant or animal kingdom. More and more the gaps in the

paleontological record were filled up, compelling even the most reluctant to acknowledge the striking parallelism between the evolutionary history of the organic world as a whole and that of the individual organism, the Ariadne's thread that was to lead the way out of the labyrinth in which botany and zoology appeared to have become more and more deeply lost. It was characteristic that, almost simultaneously with Kant's attack on the eternity of the solar system, C. F. Wolff in 1759 launched the first attack on the fixity of species and proclaimed the theory of descent. But what in his case was still only a brilliant anticipation took firm shape in the hands of Oken, Lamarck, Baer, and was victoriously carried through by Darwin in 1859, exactly a hundred years later. Almost simultaneously it was established that protoplasm and the cell, which had already been shown to be the ultimate morphological constituents of all organisms, occurred independently as the lowest forms of organic life. This not only reduced the gulf between inorganic and organic nature to a minimum but removed one of the most essential difficulties that had previously stood in the way of the theory of descent of organisms. The new conception of nature was complete in its main features; all rigidity was dissolved, all fixity dissipated, all particularity that had been regarded as eternal became transient, the whole of nature shown as moving in eternal flux and cyclical course.

Thus we have once again returned to the point of view of the great founders of Greek philosophy, the view that the whole of nature, from the smallest element to the greatest,

from grains of sand to suns, from protista to men, has its existence in eternal coming into being and passing away, in ceaseless flux, in un-resting motion and change, only with the essential difference that what for the Greeks was a brilliant intuition, is in our case the result of strictly scientific research in accordance with experience, and hence also it emerges in a much more definite and clear form. It is true that the empirical proof of this motion is not wholly free from gaps, but these are insignificant in comparison with what has already been firmly established, and with each year they become more and more filled up. And how could the proof in detail be otherwise than defective when one bears in mind that the most essential branches of science —trans-planetary astronomy, chemistry', geology— have a scientific existence of barely a hundred years, and the comparative method in physiology one of barely fifty years, and that the basic form of almost all organic development, the cell, is a discovery not yet forty years old?

The innumerable suns and solar systems of our island universe, bounded by the outermost stellar rings of the Milky Way, developed from swirling, glowing masses of vapour, the laws of motion of which will perhaps be disclosed after the observations of some centuries have given us an insight into the proper motion of the stars. Obviously, this development did not proceed everywhere at the same rate. Recognition of. the existence of dark bodies, not merely planetary in nature, hence extinct suns in our stellar system, more and more forces itself on astronomy (Mädler); on the other hand (according to Secchi) a part of the vaporous nebular patches belong to our stellar system as suns not yet fully formed, whereby it is not excluded that other nebulae, as Mädler maintains, are distant independent island universes, the relative stage of development of which must be determined by the spectroscope.

How a solar system develops from an individual nebular mass has been shown in detail by Laplace in a manner still unsurpassed; subsequent science has more and more confirmed him.

On the separate bodies so formed - suns as well as planets and satellites - the form of motion of matter at first prevailing is that which we call heat. There can be no question of chemical compounds of the elements even at a temperature like that still possessed by the sun; the extent to which heat is transformed into electricity or magnetism under such conditions, continued solar observations will show; it is already as good as proved that the mechanical motion taking place in the sun arises solely from the conflict of heat with gravity.

The smaller the individual bodies, the quicker they cool down, the satellites, asteroids, and meteors first of all, just as our moon has long been extinct. The planets cool more slowly, the central body slowest of all.

With progressive cooling the interplay of the physical forms of motion which become transformed into one another comes more and more to the forefront until finally a point is reached from when on chemical affinity begins to make itself felt, the previously chemically indifferent elements become differentiated chemically one after another, obtain chemical properties, and enter into combination with one another. These compounds change continually with the decreasing temperature, which affects differently not only each element but also each separate compound of the elements, changing also with the consequent passage of part of the gaseous matter first to the liquid and then the solid state, and with the new conditions thus created.

The period when the planet has a firm shell and accumulations of water on its surface coincides with that when its intrinsic heat diminishes more and more in comparison to the heat emitted to it from the central body. Its atmosphere becomes the arena of meteorological phenomena in the sense in which we now understand the word; its surface becomes the arena of geological changes in which the deposits resulting from atmospheric precipitation become of ever greater importance in comparison to the slowly decreasing external effects of the hot fluid interior.

If, finally, the temperature becomes so far equalised that over a considerable portion of the surface at least it does not exceed the limits within which protein is capable of life, then, if other chemical conditions are favourable, living protoplasm is formed. What these conditions are, we do not yet know, which is not to be wondered at since so far not even the chemical formula of protein has been established

- we do not even know how many chemically different protein bodies there are - and since it is only about ten years ago that the fact became known that completely structureless protein exercises all the essential functions of life, digestion, excretion, movement, contraction, reaction to stimuli, and reproduction.

Thousands of years may have passed before the conditions arose in which the next advance could take place and this formless protein produce the first cell by formation of nucleus and cell membrane. Rut this first cell also provided the foundation for the morphological development of the whole organic world; the first to develop, as it is permissible to assume from the whole analogy of the palæontological record, were innumerable species of non-cellular and cellular protista, of which *Eozoon canadense* alone has come down to us, and of which some were gradually differentiated into the first plants and others into the first animals. And from the first animals were developed, essentially by further differentiation, the numerous classes, orders, families, genera, and species of animals; and finally mammals, the form in which the nervous system attains its fullest development; and among these again finally that mammal in which nature attains consciousness of itself - man.

Man too arises by differentiation. Not only individually, by differentiation from a single egg cell to the most complicated organism that nature produces - no, also historically. When after thousands of years of struggle the differentiation of hand from foot, and erect gait, were finally established, man became distinct from the monkey and the basis was laid for the development of articulate speech and the mighty development of the brain that has since made the gulf between man and monkey an unbridgeable one. The specialisation of the hand - this implies the tool, and the tool implies specific human activity, the transforming reaction of man on nature, production. Animals in the narrower sense also have tools, but only as limbs of their bodies: the ant, the bee, the beaver; animals also produce, but their productive effect on surrounding nature in relation to the latter amounts to nothing at all. Man alone has succeeded in impressing his stamp on nature, not only by shifting the plant and animal world from one place to another, but also by so altering the aspect and climate of his dwelling place, and even the plants and animals themselves, that the consequences of his activity can disappear only with the general extinction of the terrestrial globe. And he has accomplished this primarily and essentially by means of the hand. Even the steam engine, so far his most powerful tool for the transformation of nature, depends, because it is a tool, in the last resort on *the hand*. But step by step with the development of the hand went that of the brain; first of all consciousness of the conditions for separate practically useful actions, and later, among the more favoured peoples and arising from the preceding, insight into the natural laws governing them. And with the rapidly growing knowledge of the laws of nature the means for reacting on nature also grew; the hand alone would never have achieved the steam engine if the brain of man had not attained a correlative development with it, and parallel to it, and partly owing to it.

With men we enter *history*. Animals also have a history, that of their derivation and gradual evolution to their present position. This history, however, is made for them, and in so far as they themselves take part in it, this occurs without their knowledge or desire. On the other hand, the more that human beings become removed from animals in the narrower sense of the word, the more they make their own history consciously, the less becomes the influence of unforeseen effects and uncontrolled forces of this history, and the more accurately does the historical result correspond to the aim laid down in advance. If, however, we apply this measure to human history, to that of even the most developed peoples of the present day, we find that there still exists here a colossal disproportion between the proposed aims and the results arrived at, that unforeseen effects predominate, and that the uncontrolled forces are far more powerful than those set into motion according to plan. And this cannot be otherwise as long as the most essential historical activity of men, the one which has raised them from bestiality to humanity and which forms the material foundation of all their other activities, namely the production of their requirements of life, that is to-day social production, is above all subject to the interplay of unintended effects from uncontrolled forces and achieves its desired end only by way of exception and, much more frequently, the exact opposite. In the most advanced industrial countries we have subdued the forces of nature and pressed them into the service of mankind; we have thereby infinitely multiplied production, so that a child now produces more than a hundred adults previously did. And what is the result? Increasing overwork and increasing misery of the masses, and every ten years a great collapse. Darwin did not know what a bitter satire he wrote on mankind, and especially on his countrymen, when he showed that free competition, the struggle for existence, which the economists celebrate as the highest historical achievement, is the normal state of the *animal kingdom*. Only conscious organisation of social production, in which production and distribution are carried on in a planned way, can lift mankind above the rest of the animal world as regards the social aspect, in the same way that production in general has done this for men in their aspect as species. Historical evolution makes such an organisation daily more indispensable, but also with every day more possible. From it will date a new epoch of history, in which mankind itself, and with mankind all branches of its activity, and especially natural science, will experience an advance that will put everything preceding it in the deepest shade.

Nevertheless, "all that comes into being deserves to perish". Millions of years may elapse, hundreds of thousands of generations be born and die, but inexorably the time will come when the declining warmth of the sun will no longer suffice to melt the ice thrusting itself forward from the poles; when the human race, crowding more and more about the equator, will finally no longer find even there enough heat for life; when gradually even the last trace of organic life will vanish; and the earth, an extinct frozen globe like the moon, will circle in deepest darkness and in an ever narrower orbit about the equally extinct sun, and at last fall into it. Other planets will have preceded it, others will follow it; instead of the bright, warm solar system with its harmonious arrangement of members, only a cold, dead sphere will still pursue its lonely path through universal space. And what will happen to our solar system will happen sooner or later to all the other systems of our island universe; it will happen to all the other innumerable island universes, even to those the light of which will never reach the earth while there is a living human eye to receive it.

And when such a solar system has completed its life history and succumbs to the fate of all that is finite, death, what then? Will the sun's corpse roll on for all eternity through infinite space, and all the once infinitely diverse, differentiated natural forces pass for ever into one single form of motion, attraction ? "Or" - as Secchi asks - "do forces exist in nature which can re-convert the dead system into its original state of an incandescent nebula and re-awake it to new life? We do not know".

At all events we do not know in the sense that we know that 2 x 2 = 4, or that the attraction of matter increases and decreases according to the square of the distance. In theoretical natural science, however, which as far as possible builds up its view of nature into a harmonious whole, and without which nowadays even the most thoughtless empiricist cannot get anywhere, we have very often to reckon with incompletely known magnitudes; and logical consistency of thought must at all times help to get over defective knowledge. Modern natural science has had to take over from philosophy the principle of the indestructibility of motion; it cannot any longer exist without this principle. But the motion of matter is not merely crude mechanical motion, mere change of place, it is heat and light, electric and magnetic stress, chemical combination and dissociation, life and, finally, consciousness. To say that matter during the whole unlimited time of its existence has only once, and for what is an infinitesimally short period in comparison to its eternity, found itself able to differentiate its motion and thereby to unfold the whole wealth of this motion, and that before and a.fter this remains restricted for eternity to mere change of place - this is equivalent to maintaining that matter is mortal and motion transitory. The indestructibility of motion cannot be merely quantitative, it must also be conceived qualitatively; matter whose purely mechanical change of place includes indeed the possibility under favourable conditions of being transformed into heat, electricity, chemical action, or life, but which is not capable of producing these conditions from out of itself, such matter has *forfeited motion;* motion which has lost the capacity of being transformed into the various forms appropriate to it may indeed still have *dynamis* but no longer *energeia*, and so has become partially destroyed. Both, however, are unthinkable.

This much is certain: there was a time when the matter of our island universe had *transformed* a quantity of motion - of what kind we do not yet know - into heat, such that there could be developed from it the solar systems appertaining to (according to Mädler) at least twenty million stars, the gradual extinction of which is likewise certain. How did this transformation take place? We know just as little as Father Secchi knows whether the future *caput mortuum* of our solar system will once again be converted into the raw material of a new solar system. But here either we must have recourse to a creator, or we are forced to the conclusion that the incandescent raw material for the solar system of our universe was produced in a natural way by transformations of motion which are *by nature inherent* in moving matter, and the conditions of which therefore also must be reproduced by matter, even if only after millions and millions of years and more or less by chance but with the necessity that is also inherent in chance.

The possibility of such a transformation is more and more being conceded. The view is being arrived at that the heavenly bodies are ultimately destined to fall into one another, and one even calculates the amount of heat which must be developed on such collisions. The sudden flaring up of new stars, and the equally sudden increase in brightness of familiar ones, of which we are informed by astronomy, is most easily explained by such collisions. Not only does our group of planets move about the sun, and our sun within our island universe, but our whole island universe also moves in space in temporary, relative equilibrium with the other island universes, for even the relative equilibrium of freely moving bodies can only exist where the motion is reciprocally determined; and it is assumed by many that the temperature in space is not everywhere the same. Finally, we know that, with the exception of an infinitesimal portion, the heat of the innumerable suns of our island universe vanishes into space and fails to raise the temperature of space even by a millionth of a degree centigrade. What becomes of all this enormous quantity of heat? Is it for ever dissipated in the attempt to heat universal space, has it ceased to exist practically, and does it only continue to exist theoretically, in the fact that universal space has become warmer by a decimal fraction of a degree beginning with ten or more noughts? The indestructibility of motion forbids such an assumption, but it allows the possibility that by the successive falling into one another of the bodies of the universe all existing mechanical motion will be converted into heat and the latter radiated into space, so that in spite of all "indestructibility of force" all motion in general would have ceased. (Incidentally it is seen here how inaccurate is the term "indestructibility of force" instead of "indestructibility of motion".) Hence we arrive at the conclusion that in some way, which it will later be the task of scientific research to demonstrate, the heat radiated into space must be able to become transformed into another form of motion, in which it can once more be stored up and rendered active. Thereby the chief difficulty in the way of the reconversion of extinct suns into incandescent vapour disappears.

For the rest, the eternally repeated succession of worlds in infinite time is only the logical complement to the co-existence of innumerable worlds in infinite space - a principle the necessity of which has forced itself even on the anti-theoretical Yankee brain of Draper. [3]

It is an eternal cycle in which matter moves, a cycle that certainly only completes its orbit in periods of time for which our terrestrial year is no adequate measure, a cycle in which the time of highest development, the time of organic life and still more that of the life of beings conscious of nature and of themselves, is just as narrowly restricted as the space in which life and self-consciousness come into operation; a cycle in which every finite mode of existence of matter, whether it be sun or nebular vapour, single animal or genus of animals, chemical combination or dissociation, is equally transient, and wherein nothing is eternal but eternally changing, eternally moving matter and the laws according to which it moves and changes. But however often, and however relentlessly, this cycle is completed in time and space, however many millions of suns and earths may arise and pass away, however long it may last before the conditions for organic life develop, however innumerable the organic beings that have to arise and to pass away before animals with a brain capable of thought are developed from their midst, and for a short span of time find conditions suitable for life, only to be exterminated later without mercy, we have the certainty that matter remains eternally the same in all its transformations, that none of its attributes can ever be lost, and therefore, also, that with the same iron necessity that it will exterminate on the earth its highest creation, the thinking mind, it must somewhere else and at another time again produce it.

Notes

1. How tenaciously even in 1861 this view could be held by a man whose scientific achievements had provided highly important material for abolishing it is shown by the following classic words: "All the arraignments of our solar system, so far as we are capable of comprehending them, aim st preservation of what exists and at unchanging continuance. Just as since the most ancient times no animal and no plant on the earth has become more perfect or in any way different, just as we find in all organisms only stages alongside of one another and not following one another, just as our own race has always remained the same in corporeal respects - so even the greatest diversity in the co-existing heavenly bodies does not justify us in assuming that these forms are merely different stages of development; it is rather that everything created is equally perfect in itself." (Madler, *Popular Astronomy* Berlin, 1881, 5th edition, p. 316.)

2. The defect of Lyell's view - at least in its first form - lay in conceiving the forces at work on the earth as constant, both in quality and quantity. The cooling of the earth does not exist for him; the earth does not develop in a definite direction but merely changes in an inconsequent fortuitous manner.

3. "The multiplicity of worlds in infinite space leads to the conception of a succession of worlds in infinite time." J. W. Draper, *History of the Intellectual Development of Europe*, 1864. Vol. 2, p. 325.

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Engels' Dialectics of Nature

II. Dialectics

(The general nature of dialectics to be developed as the science of interconnections, in contrast to metaphysics.)

It is, therefore, from the history of nature and human society that the laws of dialectics are abstracted. For they are nothing but the most general laws of these two aspects of historical development, as well as of thought itself. And indeed they can be reduced in the main to three:

The law of the transformation of quantity into quality and *vice versa*;
The law of the interpenetration of opposites;
The law of the negation of the negation.

All three are developed by Hegel in his idealist fashion as mere laws of *thought*: the first, in the first part of his *Logic,* in the *Doctrine of Being*; the second fills the whole of the second and by far the most important part of his *Logic,* the *Doctrine of Essence*; finally the third figures as the fundamental law for the construction of the whole system. The mistake lies in the fact that these laws are foisted on nature and history as laws of thought, and not deduced from them. This is the source of the whole forced and often outrageous treatment; the universe, willy-nilly, is made out to be arranged in accordance with a system of thought which itself is only the product of a definite stage of evolution of human thought. If we turn the thing round, then everything becomes simple, and the dialectical laws that look so extremely mysterious in idealist philosophy at once become simple and clear as noonday.

Moreover, anyone who is even only slightly acquainted with his Hegel will be aware that in hundreds of passages Hegel is capable of giving the most striking individual illustrations from nature and history of the dialectical laws.

We are not concerned here with writing a handbook of dialectics, but only with showing that the dialectical laws are really laws of development of nature, and therefore are valid also for theoretical natural science. Hence we cannot go into the inner interconnection of these laws with one another.

1. The law of the transformation of quantity into quality and *vice versa*. For our purpose, we could express this by saying that in nature, in a manner exactly fixed for each individual case, qualitative changes can only occur by the quantitative addition or subtraction of matter or motion (so-called energy).

All qualitative differences in nature rest on differences of chemical composition or on different quantities or forms of motion (energy) or, as is almost always the case, on both. Hence it is impossible to alter the quality of a body without addition or subtraction of matter or motion, i.e. without quantitative alteration of the body concerned. In this form, therefore, Hegel's mysterious principle appears not only quite rational but even rather obvious.

It is surely hardly necessary to point out that the various allotropic and aggregational states of bodies, because they depend on various groupings of the molecules, depend on greater or lesser quantities of motion communicated to the bodies.

But what is the position in regard to change of form of motion, or so-called energy? If we change heat into mechanical motion or *vice versa*, is not the quality altered while the quantity remains the same? Quite correct. But it is with change of form of motion as with Heine's vices; anyone can be virtuous by himself, for vices two are always necessary. Change of form of motion is always a process that takes place between at least two bodies, of which one loses a definite quantity of motion of one quality (e.g. heat), while the other gains a corresponding quantity of motion of another quality (mechanical motion, electricity, chemical decomposition). Here, therefore, quantity and quality mutually correspond to each other. So far it has not been found possible to convert motion from one form to another inside a single isolated body.

We are concerned here in the first place with nonliving bodies; the same law holds for living bodies, but it operates under very complex conditions and at present quantitative measurement is still often impossible for us.

If we imagine any non-living body cut up into smaller and smaller portions, at first no qualitative change occurs. But this has a limit: if we succeed, as by evaporation, in obtaining the separate molecules in the free state, then it is true that we can usually divide these still further, yet only with a complete change of quality. The molecule is decomposed into its separate atoms, which have quite different properties from those of the molecule. In the case of molecules composed of various chemical elements, atoms or molecules of these elements themselves make their appearance in the place of the compound molecule; in the case of molecules of elements, the free atoms appear, which exert quite distinct qualitative effects: the free atoms of nascent oxygen are easily able to effect what the atoms of atmospheric oxygen, bound together in the molecule, can never achieve.

But the molecule is also qualitatively different from the mass of the body to which it belongs. It can carry out movements independently of this mass and while the latter remains apparently at rest, e.g. heat oscillations; by means of a change of position and of connection with neighbouring molecules it can change the body into an allotrope or a different state of aggregation.

Thus we see that the purely quantitative operation of division has a limit at which it becomes transformed into a qualitative difference: the mass consists solely of molecules, but it is something essentially different from the molecule, just as the latter is different from the atom. It is this difference that is the basis for the separation of mechanics, as the science of heavenly and terrestrial masses, from physics, as the mechanics of the molecule, and from chemistry, as the physics of the atom.

In mechanics, no qualities occur; at most, states such as equilibrium, motion, potential energy, which all depend on measurable transference of motion and are themselves capable of quantitative expression. Hence, in so far as qualitative change takes place here, it is determined by a corresponding quantitative change.

In physics, bodies are treated as chemically unalterable or indifferent; we have to do with changes of their molecular states and with the change of form of the motion which in all cases, at least on one of the two sides, brings the molecule into play. Here every change is a transformation of quantity into quality, a consequence of the quantitative change of the quantity of motion of one form or another that is inherent in the body or communicated to it. "Thus, for instance, the temperature of water is first of all indifferent in relation to its state as a liquid; but by increasing or decreasing the temperature of liquid water a point is reached at which this state of cohesion alters and the water becomes transformed on the one side into steam and on the other into ice." (Hegel, *Encyclopedia*, Collected Works, VI, p. 217.) Similarly, a definite minimum current strength is required to cause the platinum wire of an electric incandescent lamp to glow; and every metal has its temperature of incandescence and fusion, every liquid its definite freezing and boiling point at a given pressure - in so far as our means allow us to produce the temperature required; finally also every gas has its critical point at which it can be liquefied by pressure and cooling. In short, the so-called physical constants are for the most part nothing but designations of the nodal points at which quantitative addition or subtraction of motion produces qualitative alteration in the state of the body concerned, at which, therefore, quantity is transformed into quality.

The sphere, however, in which the law of nature discovered by Hegel celebrates its most important triumphs is that of chemistry. Chemistry can be termed the science of the qualitative changes of bodies as a result of changed quantitative composition. That was already known to Hegel himself (*Logic*, Collected Works, III, p. 488). As in the case of oxygen: if three atoms unite into a molecule, instead of the usual two, we get ozone, a body which is very considerably different from ordinary oxygen in its odour and reactions. Again, one can take the various proportions in which oxygen combines with nitrogen or sulphur, each of which produces a substance qualitatively different from any of the others! How different laughing gas (nitrogen monoxide N_2O) is from nitric anhydride (nitrogen pentoxide, N_2O_5) ! The first is a gas, the second at ordinary temperatures a solid crystalline substance. And yet the whole difference in composition is that the second contains five times as much oxygen as the first, and between the two of them are three more oxides of nitrogen (N0, N_2O_3, NO_2), each of which is qualitatively different from the first two and from each other.

This is seen still more strikingly in the homologous series of carbon compounds, especially in the simpler hydrocarbons. Of the normal paraffins, the lowest is methane, CH_4; here the four linkages of the carbon atom are saturated by four atoms of hydrogen. The second, ethane, C_2H_6, has two atoms of carbon joined together and the six free linkages are saturated by six atoms of hydrogen. And so it goes on, with C_3H_8, C_4H_{10}, etc., according t,o the algebraic formula C_nH_{2n+2}, so that by each addition of CH_2 a body is formed that is qualitatively distinct from the preceding one. The three lowest members of the series are gases, the highest known, hexadecane, $C_{16}H_{34}$, is a solid body with a boiling point of 270º C. Exactly the same holds good for the series of primary alcohols with formula C_nH_{2n+20}, derived (theoretically) from the paraffins, and the series of monobasic fatty acids (formula $C_nH_{2n}O_2$). What qualitative difference can be caused by the quantitative addition of C_3H_6 is taught by experience if we consume ethyl alcohol, $C_2H_{12}O$, in any drinkable form without addition of other alcohols, and on another occasion take the same ethyl alcohol but with a slight addition of amyl alcohol, $C_5H_{12}O$, which forms the main constituent of the notorious fusel oil. One's head will certainly be aware of it the next morning, much to its detriment; so that one could even say that the intoxication, and subsequent "morning after" feeling, is also quantity transformed into quality, on the one hand of ethyl alcohol and on the other hand of this added C_3H_6.

In these series we encounter the Hegelian law in yet another form. The lower members permit only of a single mutual arrangement of the atoms. If, however, the number of atoms united into a molecule attains a size definitely fixed for each series, the grouping of the atoms in the molecule can take place in more than one way; so that two or more isomeric substances can be formed, having equal numbers of C, H, and 0 atoms in the molecule but nevertheless qualitatively distinct from one another. We can even calculate how many such isomers are possible for each member of the series. Thus, in the paraffin series, for C_4H_{10} there are two, for C_6H_{12} there are three; among the higher members the number of possible isomers mounts very rapidly. Hence once again it is the quantitative number of atoms in the molecule that determines the possibility and, in so far as it has been proved, also the actual existence of such qualitatively distinct isomers.

Still more. From the analogy of the substances with which we are acquainted in each of these series, we can draw conclusions as to the physical properties of the still unknown members of the series and, at least for the members immediately following the known ones, predict their properties, boiling point, etc., with fair certainty.

Finally, the Hegelian law is valid not only for compound substances but also for the chemical elements themselves. We now know that "the chemical properties of the elements are a periodic function of their atomic weights" (Roscoe-Schorlemmer, *Complete Text-Book of Chemistry*, II, p. 823), and that, therefore, their quality is determined by the quantity of their atomic weight. And the test of this has been brilliantly carried out. Mendeleyev proved that various gaps occur in the series of related elements arranged according to atomic weights indicating that here new elements remain to be discovered. He described in advance the general chemical properties of one of these unknown elements, which he termed eka-aluminium, because it follows after aluminium in the series beginning with the latter, and he predicted its approximate specific and atomic weight as well as its atomic volume. A few years later, Lecoq de Boisbaudran actually discovered this element, and Mendeleyev's predictions fitted with only very slight discrepancies. Eka-aluminium was realised in gallium (ibid., p. 828). By means of the - unconscious - application of Hegel's law of the transformation of quantity into quality, Mendeleyev achieved a scientific feat which it is not too bold to put on a par with that of Leverrier in calculating the orbit of the still unknown planet Neptune.

In biology, as in the history of human society, the same law holds good at every step, but we prefer to dwell here on examples from the exact sciences, since here the quantities are accurately measurable and traceable.

Probably the same gentlemen who up to now have decried the transformation of quantity into quality as mysticism and incomprehensible transcendentalism will now declare that it is indeed something quite self-evident, trivial, and commonplace, which they have long employed, and so they have been taught nothing new.

But to have formulated for the first time in its universally valid form a general law of development of nature, society, and thought, will always remain an act of historic importance. And if these gentlemen have for years caused quantity and quality to be transformed into one another, without knowing what they did, then they will have to console themselves with Moliere's Monsieur Jourdain who had spoken prose all his life without having the slightest inkling of it.

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III. Basic Forms of Motion

Motion in the most general sense, conceived as the mode of existence, the inherent attribute of matter, comprehends all changes and processes occurring in the universe, from mere change of place right to thinking. The investigation of the nature of motion had, as a matter of course, to start from the lowest, simplest forms of this motion and to learn to grasp these before it could achieve anything in the way of explanation of the higher and more complicated forms. Hence, in the historical evolution of the natural sciences we see how first of all the theory of simplest change of place, the mechanics of heavenly bodies and terrestrial masses, was developed; it was followed by the theory of molecular motion, physics, and immediately afterwards, almost alongside of it and in some places in advance of it, the science of the motion of atoms, chemistry. Only after these different branches of the knowledge of the forms of motion governing non-living nature had attained a high degree of development could the explanation of the processes of motion represented by the life process be successfully tackled. This advanced in proportion with the progress of mechanics, physics, and chemistry. Consequently, while mechanics has for a fairly long time already been able adequately to refer to the effects in the animal body of the bony levers set into motion by muscular contraction and to the laws that prevail also in non-living nature, the physico-chemical establishment of the other phenomena of life is still pretty much at the beginning of its course. Hence, in investigating here the nature of motion, we are compelled to leave the organic forms of motion out of account. We are compelled to restrict ourselves - in accordance with the state of science - to the forms of motion of non-living nature.

All motion is bound up with some change of place, whether it be change of place of heavenly bodies, terrestrial masses, molecules, atoms, or ether particles. The higher the form of motion, the smaller this change of place. It in no way exhausts the nature of the motion concerned, but it is inseparable from the motion. It, therefore, has to be investigated before anything else.

The whole of nature accessible to us forms a system, an interconnected totality of bodies, and by bodies we understand here all material existence extending from stars to atoms, indeed right to ether particles, in so far as one grants the existence of the last named. In the fact that these bodies are interconnected is already included that they react on one another, and it is precisely this mutual reaction that constitutes motion. It already becomes evident here that matter is unthinkable without motion. And if, in addition, matter confronts us as something given, equally uncreatable as indestructible, it follows that motion also is as uncreatable as indestructible. It became impossible to reject this conclusion as soon as it was recognised that the universe is a system, an interconnection of bodies. And since this recognition had been reached by philosophy long before it came into effective operation in natural science, it is explicable why philosophy, fully two hundred years before natural science, drew the conclusion of the uncreatability and indestructibility of motion. Even the form in which it did so is still superior to the present day formulation of natural science. Descartes' principle, that the amount of motion present in the universe is always the same, has only the formal defect of applying a finite expression to an infinite magnitude. On the other hand, two expressions of the same law are at present current in natural science: Helmholtz's law of the conservation of force, and the newer, more precise, one of the conservation of energy. Of these, the one, as we shall see, says the exact opposite of the other, and moreover each of them expresses only one side of the relation.

When two bodies act on each other so that a change of place of one or both of them results, this change of place can consist only in an approach or a separation. They either attract each other or they repel each other. Or, as mechanics expresses it, the forces operating between them are central, acting along the line joining their centres. That this happens, that it is the case throughout the universe without exception, however complicated many movements may appear to be, is nowadays accepted as a matter of course. It would seem nonsensical to us to assume, when two bodies act on each other and their mutual interaction is not opposed by any obstacle or the influence of a third body, that this action should be effected otherwise than along the shortest and most direct path, i.e. along the straight line joining their centres. It is well known, moreover, that Helmholtz (*Erhaltung der Kraft [The Conservation of Force]*, Berlin, 1847, Sections 1 and 2) has provided the mathematical proof that central action and unalterability of the quantity of motion are reciprocally conditioned and that the assumption of other than central actions leads to results in which motion could be either created or destroyed. Hence the basic form of all motion is approximation and separation, contraction and expansion - in short, the old polar opposites of *attraction* and *repulsion*.

It is expressly to be noted that attraction and repulsion are not regarded here as so-called "*forces*" but as *simple forms of motion*, just as Kant had already conceived matter as the unity of attraction and repulsion. What is to be understood by the conception of "forces" will be shown in due course.

All motion consists in the interplay of attraction and repulsion. Motion, however, is only possible when each individual attraction is compensated by a corresponding repulsion somewhere else. Otherwise in time one side would get the preponderance over the other and then motion would finally cease. Hence all attractions and all repulsions in the universe must mutually balance one another. Thus the law of the indestructibility and uncreatibility of motion takes the form that each movement of attraction in the universe must have as its complement an equivalent movement of repulsion and *vice versa*; or, as ancient philosophy - long before the natural scientific formulation of the law of conservation of force or energy - expressed it: the sum of all attractions in the universe is equal to the sum of all repulsions.

However it appears that there are still two possibilities for all motion to cease at some time or other, either by repulsion and attraction finally cancelling each other out in actual fact, or by the total repulsion finally taking possession of one part of matter and the total attraction of the other part. For the dialectical conception, these possibilities are excluded from the outset. Dialectics has proved from the results of our experience of nature so far that all polar opposites in general are determined by the mutual action of the two opposite poles on one another, that the separation and opposition of these poles exists only within their unity and inter-connection, and, conversely, that their inter-connection exists only in their separation and their unity only in their opposition. This once established, there can be no question of a final cancelling out of repulsion and attraction, or of a final partition between the one form of motion in one half of matter and the other form in the other half, consequently there can be no question of mutual penetration or of absolute separation of the two poles. It would be equivalent to demanding in the first case that the north and south poles of a magnet should mutually cancel themselves out or, in the second case, that dividing a magnet in the middle between the two poles should produce on one side a north half without a south pole, and on the other side a south half without a north pole. Although, however, the impermissibility of such assumptions follows at once from the dialectical nature of polar opposites, nevertheless, thanks to the prevailing metaphysical mode of thought of natural scientists, the second assumption at least plays a certain part in physical theory. This will be dealt with in its place.

How does motion present itself in the interaction of attraction and repulsion? We can best investigate this in the separate forms of motion itself. At the end, the general aspect of the matter will show itself.

Let us take the motion of a planet about its central body. The ordinary school textbook of astronomy follows Newton in explaining the ellipse described as the result of the joint action of two forces, the attraction of the central body and a tangential force driving the planet along the normal to the direction of this attraction. Thus it assumes, besides the form of motion directed centrally, also another direction of motion or so-called "force" perpendicular to the line joining the central points. Thereby it contradicts the above-mentioned basic law according to which all motion in our universe can only take place along the line joining the central points of the bodies acting on one another, or, as one says, is caused only by centrally acting forces. Equally, it introduces into the theory an element of motion which, as we have likewise seen, necessarily leads to the creation and destruction of motion, and therefore presupposes a creator. What had to be done, therefore, was to reduce this mysterious tangential force to a form of motion acting centrally, and this the Kant-Laplace theory of cosmogony accomplished. As is well known, according to this conception the whole solar system arose from a rotating, extremely tenuous, gaseous mass by gradual contraction. The rotational motion is obviously strongest at the equator of this gaseous sphere, and individual gaseous rings separate themselves from the mass and clump themselves together into planets, planetoids, etc., which revolve round the central body in the direction of the original rotation. This rotation itself is usually explained from the motion characteristic of the individual particles of gas. This motion takes place in all directions, hut finally an excess in one particular direction makes itself evident and so causes the rotating motion, which is bound to become stronger and stronger with the progressive contraction of the gaseous sphere. But whatever hypothesis is assumed of the origin of the rotation, it abolishes the tangential force, dissolving it in a special form of the phenomena of centrally acting motion. If the one element of planetary motion, the directly central one, is represented by gravitation, the attraction between the planet and the central body, then the other tangential element appears as a relic, in a derivative or altered form, of the original repulsion of the individual particles of the gaseous sphere. Then the life process of a solar system presents itself as an interplay of attraction and repulsion, in which attraction gradually more and more gets the upper hand owing to repulsion being radiated into space in the form of heat and thus more and more becoming lost to the system.

One sees at a glance that the form of motion here conceived as repulsion is the same as that which modern physics terms "*energy*." By the contraction of the system and the resulting detachment of the individual bodies of which it consists to-day, the system has lost "energy," and indeed this loss, according to Helmholtz's well-known calculation, already amounts to 453/454 of the total quantity of motion originally present in the form of repulsion.

Let us take now a mass in the shape of a body on our earth itself. It is connected with the earth by gravitation, as the earth in turn is with the sun; but unlike the earth it is incapable of a free planetary motion. It can be set in motion only by an impulse from outside, and even then, as soon as the impulse ceases, its movement speedily comes to a standstill, whether by the effect of gravity alone or by the latter in combination with the resistance of the medium in which it moves. This resistance also is in the last resort an effect of gravity, in the absence of which the earth would not have on its surface any resistant medium, any atmosphere. Hence in pure mechanical motion on the earth's surface we are concerned with a situation in which gravitation, attraction, decisively predominates, where therefore the production of the motion shows both phases: first counteracting gravity and then allowing gravity to act - in a word, production of rising and falling.

Thus we have again mutual action between attraction on the one hand and a form of motion taking place in the opposite direction to it, hence a repelling form of motion, on the other hand. But within the sphere of terrestrial *pure* mechanics (which deals with masses of *given* states of aggregation and cohesion taken by it as unalterable) this repelling form of motion does not occur in nature. The physical and chemical conditions under which a lump of rock becomes separated from a mountain top, or a fall of water becomes possible, lie outside our sphere. Therefore, in terrestrial pure mechanics, the repelling, raising motion must be produced artificially: by human force, animal force, water or steam power, etc. And this circumstance, this necessity to combat the natural attraction artificially, causes the mechanicians to adopt the view that attraction, gravitation, or, as they say, the force of gravity, is the most important, indeed the basic, form of motion in nature.

When, for instance, a weight is raised and communicates motion to other bodies by falling directly or indirectly, then according to the usual view of mechanics it is not the raising of the weight which communicates this motion but the force of gravity. Thus Helmholtz, for instance, makes "the force which is the simplest and the one with which we are best acquainted, viz. gravity, act as the driving force... for instance in grandfather clocks that are actuated by a weight. The weight... cannot comply with the pull of gravity without setting the whole clockwork in motion." But it cannot set the clockwork in motion without itself sinking and it goes on sinking until the string from which it hangs is completely unwound:

"Then the clock comes to a stop, for the operative capacity of the weight is exhausted for the time being. Its weight is not lost or diminished, it remains attracted to the same extent by the earth, but the capacity of this weight to produce movements has been lost.... We can, however, wind up the clock by the power of the human arm, whereby the weight is once more raised up. As soon as this has happened, it regains its previous operative capacity and can again keep the clock in motion." (Helmholtz, *Popular Lectures*, German Edition, II. pp. 144 - 5.)

According to Helmholtz, therefore, it is not the active communication of motion, the raising of the weight, that sets the clock into motion, but the passive heaviness of the weight, although this same heaviness is only withdrawn from its passivity by the raising, and once again returns to passivity after the string of the weight has unwound. If then according to the modern conception, as we saw above, energy is only another expression for repulsion, here in the older Helmholtz conception force appears as another expression for the opposite of repulsion, for attraction. For the time being we shall simply put this on record.

When this process, as far as terrestrial mechanics is concerned, has reached its end, when the heavy mass has first of all been raised and then again let fall through the same height, what becomes of the motion that constituted it? For pure mechanics, it has disappeared. But we know now that it has by no means been destroyed. To a lesser extent it has been conveyed into the air as oscillations of sound waves, to a much greater extent into heat - which has been communicated in part to the resisting atmosphere, in part to the falling body itself, and finally in part to the floor, on which the weight comes to rest. The clock weight has also gradually given up its motion in the form of frictional heat to the separate driving wheels of the clockwork. But, although usually expressed in this way, it is not the falling motion, i.e.. the attraction, that has passed into heat, and therefore into a form of repulsion. On the contrary, as Helmholtz correctly remarks, the attraction, the heaviness, remains what it previously was and, accurately speaking, becomes even greater. Rather it is the repulsion communicated to the raised body by rising that is mechanically destroyed by falling and reappears as heat. The repulsion of masses is transformed into molecular repulsion.

Heat, as already stated, is a form of repulsion. It sets the molecules of solid bodies into oscillation, thereby loosening the connections of the separate molecules until finally the transition to the liquid state takes place. In the liquid state also, on continued addition of heat, it increases the motion of the molecules until a degree is reached at which the latter split off altogether from the mass and, at a definite velocity determined for each molecule by its chemical constitution, they move away individually in the free state. With a still further addition of heat, this velocity is further increased, and so the molecules are more and more repelled from one another.

But heat is a form of so-called "energy"; here once again the latter proves to be identical with repulsion.

In the phenomena of static electricity and magnetism, we have a polar division of attraction and repulsion. Whatever hypothesis may be adopted of the *modus operandi* of these two forms of motion, in view of the facts no one has any doubt that attraction and repulsion, in so far as they are produced by static electricity or magnetism and are able to develop unhindered, completely compensate one another, as in fact necessarily follows from the very nature of the polar division. Two poles whose activities did not completely compensate each other would indeed not be poles, and also have so far not been discovered in nature. For the time being we will leave galvanism out of account, because in its case the process is determined by chemical reactions, which makes it more complicated. Therefore, let us investigate rather the chemical processes of motion themselves.

When two parts by weight of hydrogen combine with 15.96 parts by weight of oxygen to form water vapour, an amount of heat of 68,924 heat units is developed during the process. Conversely, if 17.96 parts by weight of water vapour are to be decomposed into 2 parts by weight of hydrogen and 15.96 parts by weight of oxygen, this is only possible on condition that the water vapour has communicated to it an amount of motion equivalent to 68,924 heat units - whether in the form of heat itself or of electrical motion. The same thing holds for all other chemical processes. In the overwhelming majority of cases, motion is given off on combination and must be supplied on decomposition. Here, too, as a rule, repulsion is the active side of the process more endowed with motion or requiring the addition of motion, while attraction is the passive side producing a surplus of motion and giving off motion. On this account, the modern theory also declares that, on the whole, energy is set free on the combination of elements and is bound up on decomposition. And Helmholtz declares:

"This force (chemical affinity) can be conceived as a force of *attraction*.... This force of attraction between the atoms of carbon and oxygen performs work quite as much as that exerted on a raised weight by the earth in the form of gravitation.... When carbon and oxygen atoms rush at one another and combine to form carbonic acid, the newly-formed particles of carbonic acid must be in very violent molecular motion, i.e. in heat motion.... When after they have given up their heat to the environment, we still have in the carbonic acid all the carbon, all the oxygen, and in addition the affinity of both continuing to exist just as powerfully as before. But this affinity now expresses itself solely in the fact that the atoms of carbon and oxygen stick fast to one another, and do not allow of their being separated" (Helmholtz, *loc. cit*., p. 169).

It is just as before: Helmholtz insists that in chemistry as in mechanics *force* consists only in *attraction*, and therefore is the exact opposite of what other physicists call energy and which is identical with repulsion.

Hence we have now no longer the two simple basic forms of attraction and repulsion, but a whole series of sub-forms in which the winding up and running down process of universal motion goes on in opposition to both attraction and repulsion. It is, however, by no means merely in our mind that these manifold forms of appearance are comprehended under the single expression of motion. On the contrary, they themselves prove in action that they are forms of one and the same motion by passing into one another under given conditions. Mechanical motion of masses passes into heat, into electricity, into magnetism; heat and electricity pass into chemical decomposition; chemical combination in turn develops heat and electricity and, by means of the latter, magnetism; and finally, heat and electricity produce once more mechanical movement of masses. Moreover, these changes take place in such a way that a given quantity of motion of one form always has corresponding to it an exactly fixed quantity of another form. Further, it is a matter of indifference which form of motion provides the unit by which the amount of motion is measured, whether it serves for measuring mass motion, heat, so-called electromotive force, or the motion undergoing transformation in chemical processes.

We base ourselves here on the theory of the "conservation of energy" established by J. R. Mayer [1] in 1842 and afterwards worked out internationally with such brilliant success, and we have now to investigate the fundamental concepts nowadays made use of by this theory. These are the concepts of "force", "energy", and "work".

It has been shown above that according to the modern view, now fairly generally accepted, energy is the term used for repulsion, while Helmholtz generally uses the word force to express attraction. One could regard this as a mere distinction of form, inasmuch as attraction and repulsion compensate each other in the universe, and accordingly it would appear a matter of indifference which side of the relation is taken as positive and which as negative, just as it is of no importance in itself whether the positive abscissae are counted to the right or the left of a point in a given line. Nevertheless, this is not absolutely so.

For we are concerned here, first of all, not with the universe, but with phenomena occurring on the earth and conditioned by the exact position of the earth in the solar system, and of the solar system in the universe. At every moment, however, our solar system gives out enormous quantities of motion into space, and motion of a very definite quality, viz. the sun's heat, *i.e.* repulsion. But our earth itself allows of the existence of life on it only owing to the sun's heat, and it in turn finally radiates into space the sun's heat received, after it has converted a portion of this heat into other forms of motion. Consequently, in the solar system and above all on the earth, attraction already considerably preponderates over repulsion. Without the repulsive motion radiated to us from the sun, all motion on the earth would cease. If to-morrow the sun were to become cold, the attraction on the earth would still, other circumstances remaining the same, be what it is to-day. As before, a stone of 100 kilogrammes, wherever situated, would weigh 100 kilogrammes. But the motion, both of masses and of molecules and atoms, would come to what we would regard as an absolute standstill. Therefore it is clear that for processes occurring on the *earth* to-day it is by no means a matter of indifference whether attraction or repulsion is conceived as the active side of motion, hence as "force" or "energy." On the contrary, on the earth to-day attraction has already become *altogether passive* owing to its decisive preponderance over repulsion; we owe all active motion to the supply of repulsion from the sun. Therefore, the modern school - even if it remains unclear about the nature of the relation constituting motion - nevertheless, in point of fact and for *terrestrial* processes, indeed for the whole solar system, is absolutely right in conceiving energy as repulsion.

The expression "energy" by no means correctly expresses all the relationships of motion, for it comprehends only one aspect, the action but not the reaction. It still makes it appear as if "energy" was something external to matter, something implanted in it. But in all circumstances it is to be preferred to the expression "force."

As conceded on all hands (from Hegel to Helmholtz), the notion of force is derived from the activity of the human organism within its environment. We speak of muscular force, of the lifting force of the arm, of the leaping power of the legs, of the digestive force of the stomach and intestinal canal, of the sensory force of the nerves, of the secretory force of the glands, etc. In other words, in order to save having to give the real cause of a change brought about by a function of our organism, we fabricate a fictitious cause, a so-called force corresponding to the change. Then we carry this convenient method over to the external world also, and so invent as many forces as there are diverse phenomena.

In Hegel's time natural science (with the exception perhaps of heavenly and terrestrial mechanics) was still in this naive state, and Hegel quite correctly attacks the prevailing way of denoting forces (passage to be quoted).[2] Similarly in another passage:

"It is better (to say) that a magnet has a *Soul* (as Thales expresses it) than that it has an attracting force; force is a kind of property which is *separable from matter* and put forward as a predicate - while soul, on the other hand, *is its movement, identical with the nature of matter*." (*Geschichte der Philosophie* [History of Philosophy], I, p. 208.)

To-day we no longer make it so easy for ourselves in regard to forces. Let us listen to Helmholtz:

"If we are fully acquainted with a natural law, we must also demand that it should operate without exception.... Thus the law confronts us as an objective power, and accordingly we term it a *force*. For instance, we objectivise the law of the refraction of light as a refractive power of transparent substances, the law of chemical affinities as a force of affinity of the various substances for one another. Thus we speak of the electrical force of contact of metals, of the force of adhesion, capillary force, and so on. These names objectivise laws which in the first place embrace only a limited series of natural processes, *the conditions for which are still rather complicated*.... Force is only the objectivised law of action.... The abstract idea of force introduced by us only makes the addition that we have not arbitrarily invented this law but that it is a compulsory law of phenomena. Hence our demand to *understand* the phenomena of nature, *i.e.* to find out their laws, takes on another form of expression, viz. that we have to seek out the *forces* which are the causes of the phenomena." (*Loc. chit*., pp. 189 - 191. Innsbruck lecture of 1869.)

Firstly, it is certainly a peculiar manner of "objectivising" if the *purely subjective* notion of *force* is introduced into a natural law that has already been established as independent of our subjectivity and therefore completely *objective*. At most an Old-Hegelian of the strictest type might permit himself such a thing, but not a Neo-Kantian like Helmholtz. Neither the law, when once established, nor its objectivity, nor that of its action, acquires the slightest new objectivity by our interpolating a force into it; what is added is our *subjective assertion* that it acts in virtue of some so far entirely unknown force. The secret meaning, however, of this interpolating is seen as soon as Helmholtz gives us examples: refraction of light, chemical affinity, contact electricity, adhesion, capillarity, and confers on the laws that govern these phenomena the "objective" honorary rank of *forces*. "These names objectivise laws which in the first place embrace only a limited series of natural processes, the conditions for which *are still rather complicated*." And it is just here that the "objectivising," which is rather subjectivising, gets its meaning; not because we have become fully acquainted with the law, hut just because this is *not* the case. Just because we are *not* yet clear about the "rather complicated conditions" of these phenomena, we often resort here to the word force. We express thereby not our scientific knowledge, but our *lack* of scientific knowledge of the nature of the law and its mode of action. In this sense, as a short expression for a causal connection that has not yet been explained, as a makeshift expression, it may pass for current usage.

Anything more than that is bad. With just as much right as Helmholtz explains physical phenomena from so-called refractive force, electrical force of contact, etc., the medieval scholastics explained temperature changes by means of a *vis calorifica* and a *vis frigifaciens* and thus saved themselves all further investigation of heat phenomena.

And even in this sense it is one-sided, for it expresses everything in a one-sided manner. All natural processes are two-sided, they rest on the relation of at least two effective parts, action and reaction. The notion of force, however, owing to its origin from the action of the human organism on the external world, and further because of terrestrial mechanics, implies that only one part is active, effective, the other part being passive, receptive; hence it lays down a not yet demonstrable extension of the difference between the sexes to non-living objects. The reaction of the second part, on which the force works, appears at most as a passive reaction, as a *resistance*. This mode of conception is permissible in a number of fields even outside pure mechanics, namely where it is a matter of the simple transference of motion and its quantitative calculation. But already in the more complicated physical processes it is no longer adequate, as Helmholtz's own examples prove. The refractive force lies just as much in the light itself as in the transparent bodies. In the case of adhesion and capillarity, it is certain that the "force" is just as much situated in the surface of the solid as in the liquid. In contact electricity, at any rate, it is certain that *both* metals contribute to it, and "chemical affinity" also is situated, if anywhere, in *both* the parts entering into combination. But a force which consists of separated forces, an action which does not evoke its reaction, but which exists solely by itself, is no force in the sense of terrestrial mechanics, the only science in which one really knows what is meant by a force. For the basic conditions of terrestrial mechanics are, firstly, refusal to investigate the causes of the impulse, *i.e.* the nature of the particular force, and, secondly, the view of the one-sidedness of the force, it being everywhere opposed by au identical gravitational force, such that in comparison with any terrestrial distance of fall the earth's radius = *(infinity)*.

But let us see further how Helmholtz, "objectivises" his "forces" into natural laws.

In a lecture of 1854 (*loc. cit.*., p. 119) he examines the "store of working force" originally contained in the nebular sphere from which our solar system was formed. "In point of fact it received an enormously large legacy in this respect, if only in the form of the general force of attraction of all its parts for one another." This indubitably is so. But it is equally indubitable that the whole of this legacy of gravitation is present undiminished in the solar system to-day, apart perhaps from the minute quantity that was lost together with the matter ' We should now call this potential energy. which was flung out, possibly irrevocably, into space. Further, "The chemical forces too must have been already present and ready to act; but as these forces could become effective only on intimate contact of the various kinds of masses, condensation had to take place before they came into play." If, as Hclmholtz does above, we regard these chemical forces as forces of affinity, hence as *attraction*, then again we are bound to say that the sum-total of these chemical forces of attraction still exists undiminished within the solar system.

But on the same page Helmholtz gives us the results of his calculations "that perhaps only the 454th part of the original mechanical force exists as such" - that is to say, in the solar system. How is one to make sense of that? The force of attraction, general as well as chemical, is still present unimpaired in the solar system. Helmholtz does not mention any other certain source of force. In any case, according to Helmholtz, these forces have performed tremendous work. But they have neither increased nor diminished on that account. As it is with the clock weight mentioned above, so it is with every molecule in the solar system and with the solar system itself. "Its gravitation is neither lost nor diminished." What happens to carbon and oxygen as previously mentioned holds good for all chemical elements: the total given quantity of each one remains, and "the total force of affinity continues to exist just as powerfully as before." What have we lost then? And what "force" has performed the tremendous work which is 453 times as big as that which, according to his calculation, the solar system is still able to perform? Up to this point Helmholtz has given no answer. But further on he says:

"Whether a further *reserve of force in the shape of heat* was present, we do not know." - But, if we may be allowed to mention it, heat is a repulsive "force," it acts therefore *against* the direction of both gravitation and chemical attraction, being minus if these are put as plus. Hence if, according to Helmholtz, the original store of force is composed of general and chemical attraction, an extra reserve of heat would have to be, not added to that reserve of force, but subtracted from it. Otherwise the sun's heat would have had to *strengthen* the force of attraction of the earth when it causes water to evaporate in direct opposition to this attraction, and the water vapour to rise; or the heat of an incandescent iron tube through which steam is passed would *strengthen* the chemical attraction of oxygen and water, whereas it puts it out of action. Or, to make the same thing clear in another form: let us assume that the nebular sphere with radius *r*, and therefore with volume $4/3(\text{pi})r^3$ has a temperature *t*. Let us further assume a second nebular sphere of equal mass having at the higher temperature T the larger radius R and volume $4/3(\text{pi})R^3$. Now it is obvious that in the second nebular sphere the attraction, mechanical as well as physical and chemical, can act with the same force as in the first only when it has shrunk from radius R to radius *r, i.e.* when it has radiated into world space heat corresponding to the temperature difference T - *t*. A hotter nebular sphere will therefore condense later than a colder one; consequently the heat, considered from Helmholtz's standpoint as an obstacle to condensation, is no plus but a minus of the "reserve of force." Helmholtz, by pre-supposing the possibility of a quantum of *repulsive* motion in the form of heat becoming added to the *attractive* forms of motion and increasing the total of these latter, commits a definite error of calculation.

Let us now bring the whole of this "reserve of force", possible as well as demonstrable, under the same mathematical sign so that an addition is possible. Since for the time being we cannot reverse the heat and replace its repulsion by the equivalent attraction, we shall have to perform this reversal with the two forms of attraction. Then, instead of the general force of attraction, instead of the chemical affinity, and instead of the heat, which moreover possibly already exists as such at the outset, we have simply to put - the sum of the repulsive motion or so-called energy present in the gaseous sphere at the moment when it becomes independent. And by so doing Helmholtz's calculation will also hold, in which he wants to calculate "the heating that must arise from the assumed initial condensation of the heavenly bodies of our system from nebulously scattered matter." By thus reducing the whole "reserve of force" to heat, repulsion, he also makes it possible to add on the assumed "heat reserve force". The calculation then asserts that 453/454 of all the energy, *i.e.* repulsion, originally present in the gaseous sphere has been radiated into space in the form of heat, or, to put it accurately, that the sum of all attraction in the present solar system is to the sum of all repulsion, still present in the same, as 453: 1. But then it directly contradicts the text of the lecture to which it is added as proof.

If then the notion of force, even in the case of a physicist like Helmholtz, gives rise to such confusion of ideas, this is the best proof that it is in general not susceptible of scientific use in all branches of investigation which go beyond the calculations of mechanics. In mechanics the causes of motion are taken as given and their origin is disregarded, only their effects being taken into account. Hence if a cause of motion is termed a force, this does no damage to mechanics as such; but it becomes the custom to transfer this term also to physics, chemistry, and biology, and then confusion is inevitable. We have already seen this and shall frequently see it again.

For the concept of work, see the next chapter.

Notes

1. Helmholtz, in his *Pop. Vorlesungen [Popular Lectures]*, II, p. 113, appears to ascribe a certain share in the natural scientific proof of Descartes' principle of the quantitative immutability of motion to himself as well as to Mayer, Joule, and Colding. "I myself, without knowing anything of Mayer and Codling, and only becoming acquainted with Joule's experiments at the end of my work, *proceeded along the same path*; I occupied myself especially with searching out all the relations between the various processes of nature that could be deduced from the given mode of consideration, and I published my investigations in 1847 in a little work entitled *Uber die Erhaltung der Kraft [On the Conservation of Force]*." - But in this work there is to be found nothing new for the position in 1847 beyond the above-mentioned, mathematically very valuable, development that "conservation of force" and central action of the forces active between the various bodies of a system are only two different expressions for the same thing, and further a more accurate formulation of the law that the sum of the live and tensional forces in a given *mechanical* system is constant. In every other respect, it was already superseded since Mayer's second paper of 1845. Already in 1842 Mayer maintained the "indestructibility of force", and from his new standpoint in 1845 he had much more brilliant things to say about the "relations between the various processes of nature" than Helmholtz had in 1847.

2. See Appendix II, p. 881.

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Engels' Dialectics of Nature

IV. The Measure of Motion - Work

"On the other hand, I have always found hitherto that the basic concepts in this field (*i.e.* "the basic physical concepts of work and their unalterability ") seem very difficult to grasp for persons who have not gone through the school of mathematical mechanics, in spite of all zeal, all intelligence, and even a fairly high degree of scientific knowledge. Moreover, it cannot be denied that they are abstractions of a quite peculiar kind. It was not without difficulty that even such an intellect as that of I. Kant succeeded in understanding them, as is proved by his polemic against Leibniz on this subject."

So says Helmholtz (*Pop. wiss. Vorträge* [*Popular Scientific Lectures*], II, Preface).

According to this, we are venturing now into a very dangerous field, the more so since we cannot very well take the liberty of guiding the reader "through the school of mathematical mechanics." Perhaps, however, it will turn out that, where it is a question of concepts, dialectical thinking will carry us at least as far as mathematical calculation.

Galileo discovered, on the one hand, the law of falling, according to which the distances traversed by falling bodies are proportional to the squares of the times taken in falling. On the other hand, as we shall see, he put forward the not quite compatible law that the magnitude of motion of a body (its *impeto* or *momento*) is determined by the mass and the velocity in such a way that for constant mass it is proportional to the velocity. Descartes adopted this latter law and made the product of the mass and the velocity of the moving body quite generally into the measure of its motion.

Huyghens had already found that, on elastic impact, the sum of the products of the masses, multiplied by the squares of their velocities, remains the same before and after impact, and that an analogous law holds good in various other cases of motion to a system of connected bodies.

Leibniz was the first to realise that the Cartesian measure of motion was in contradiction to the law of falling. On the other hand, it could not be denied that in many cases the Cartesian measure was correct. Accordingly, Leibniz divided moving forces into dead forces and live forces. The dead were the "pushes" or "pulls" of resting bodies, and their measure the product of the mass and the velocity with which the body would move if it were to pass from a state of rest to one of motion. On the other hand, he put forward as the measure of *vis viva*, of the real motion of a body, the product of the mass and the square of the velocity. This new measure of motion he derived directly from the law of falling.

"The same force is required," so Leibniz concluded, " to raise a body of four pounds in weight one foot as to raise a body of one pound in weight four feet; but the distances are proportional to the square of the velocity, for when a body has fallen four feet, it attains twice the velocity reached on falling only one foot. However, bodies on falling acquire the force for rising to the same height as that from which they fell; hence the forces are proportional to the square of the velocity." (Suter, *Geschichte der Mathematik* [*History of Mathematics*], II, p. 367.)

But he showed further that the measure of motion *mv* is in contradiction to the Cartesian law of the constancy of the quantity of motion, for if it was really valid the force (*i.e.* the quantity of motion) in nature would continually increase or diminish. He even devised an apparatus (1690, *Acta Eruditorum*) which, if the measure *mv* were correct, would be bound to act as a *perpetuum mobile* with continual gain of force, which, however, would be absurd. Recently, Helmholtz has again frequently employed this kind of argument.

The Cartesians protested with might and main and there developed a famous controversy lasting many years, in which Kant also participated in his very first work (*Gedanken von der wahren Schätzung der lebendigen Kräfte* [*Thoughts on the True Estimation of Live Forces*], 1746), without, however, seeing clearly into the matter. Mathematicians to-day look down with a certain amount of scorn on this "barren " controversy which "dragged out for more than forty years and divided the mathematicians of Europe into two hostile camps, until at last d'Alembert by his *Traité de dynamique* (1743), as it were by a final verdict, put an end to the *useless verbal dispute*, for it was nothing else." (Suter, *ibid*., p. 366.)

It would, however, seem that a controversy could not rest entirely on a useless verbal dispute when it had been initiated by a Leibniz against a Descartes, and had occupied a man like Kant to such an extent that he devoted to it his first work, a fairly large volume. And in point of fact, how is it to be understood that motion has two contradictory measures, that on one occasion it is proportional to the velocity, and on another to the square of the velocity? Suter makes it very easy for himself; he says both sides were right and both were wrong; "nevertheless, the expression '*vis viva*' has endured up to the present day; *only it no longer serves as the measure of force*, but is merely a term that was once adopted for the product of the mass and half the square of the velocity, a product so full of significance in mechanics." Hence, *mv* remains the measure of motion, and *vis viva* is only another expression for $mv^2/2$, concerning which formula we learn indeed that it is of great significance for mechanics, but now most certainly do not know what significance it has.

Let us, however, take up the salvation-bringing *Traité de dynamique* and look more closely at d'Alembert's "final verdict"; it is to be found in the *preface*. In the text, it says, the whole question does not occur, on account of *l'inutilité parfaite dont elle est pour la mécanique*. This is quite correct for *purely mathematical* mechanics, in which, as in the case of Suter above, words used as designations are only other expressions, or names, for algebraic formulae, names in connection with which it is best not to think at all. Nevertheless, since such important people have concerned themselves with the matter, he desires to examine it briefly in the preface. Clearness of thought demands that by the force of moving bodies one should understand only their property of overcoming obstacles or resisting them. Hence, force is to be measured neither by mv^2 nor by XXX, but solely by the obstacles and the resistance they offer.

Now, there are, he says, three kinds of obstacles: (1) insuperable obstacles which totally destroy the motion, and for that very reason cannot be taken into account here; (2) obstacles whose resistance suffices to arrest the motion and to do so instantaneously: the case of equilibrium; (3) obstacles which only gradually arrest the motion: the case of retarded motion.

"Or tout le monde convient qu'il y a équilibre entre deux corps, quand les produits de leurs masses par leurs vitesses virtuelles, c'est à dire par les vitesses avec lesquelles ils tendent à se mouvoir, sont égaux de part et d'autre. Donc dans l'équilibre le produit de la masse par la vitesse, ou, ce qui est la même chose, la quantité de mouvement, peut représenter la force. Tout le monde convient aussi que dans le mouvement retardé, le nombre des obstacles vaincus est comme le carré de la vitesse, en sorte qu'un corps qui a fermé un ressort, par exemple, avec une certaine vitesse, pourra, avec une vitesse double, fermer ou tout à la fois, ou successivement, non pas deux, mais quatre ressorts semblables au premier, neuf avec une vitesse triple, et ainsi du reste. D'où les partisans des forces vives [the Leibnizians] concluent que la force des corps qui se meuvent actuellement, est en général comme le produit de la masse par le carré de la vitesse. Au fond, quel inconvénient pourrait-il y avoir, à ce que la mesure des forces fût différente dans l'équilibre et dans le mouvement retardé, puisque, si on veut ne raisonner que d'après des idées claires, on doit n'entendre par le mot *force* que l'effet produit en surmontant l'obstacle ou en lui résistant?" (Preface, pp. 19-20, of the original edition.)

D'Alembert, however, is far too much of a philosopher not to realise that the contradiction of a twofold measure of one and the same force is not to be got over so easily. Therefore, after repeating what is basically only the same thing as Leibniz had already said - for his *équilibre* is precisely the same thing as the "dead pressure " of Leibniz - he suddenly goes over to the side of the Cartesians and finds the following expedient: the product *mv* can serve as a measure of force, even in the case of delayed motion,

"si dans ce dernier cas on mesure la force, non par la quantité absolue des obstacles, mais par la somme des résistances de ces mêmes obstacles. Car on ne saurait douter que cette somme des résistances ne soit proportionelle à la quantité du mouvement *mv*, puisque, de l'aveu de tout le monde, la quantité du mouvement que le corps perd à chaque instant, est proportionelle au produit de la résistance par la durée infiniment petite de l'instant, et que la somme de ces produits est evidemment la résistance totale."

This latter mode of calculation seems to him the more natural one, "car un obstacle n'est tel qu'en tant qu'il résiste et c'est, à proprement parler, la somme des résistances qui est 1'obstacle vaincu; d'ailleurs, en estimant ainsi la force, on a l'avantage d'avoir pour l'équilibre et pour le mouvement retardé une mesure commune." Still, everyone can take that as he likes. And so, believing he has solved the question, by what, as Suter himself acknowledges, is a mathematical blunder, he concludes with unkind remarks on the confusion reigning among his predecessors, and asserts that after the above remarks there is possible only a very futile metaphysical discussion or a still more discreditable purely verbal dispute.

D'Alembert's proposal for reaching a reconciliation amounts to the following calculation:

A mass 1, with velocity 1, compresses 1 spring in unit time.

A mass 1, with velocity 2, compresses 4 springs, but requires two units of time; *i.e.* only 2 springs pcr unit of time.

A mass 1, with velocity 3, compresses 9 springs in three units of time, *i.e.* only 3 springs per unit of time.

Hence if we divide the effect by the time required for it, we again come from mv^2 to*mv*.

This is the same argument that Catelan in particular had already employed against Leibniz; it is true that a body with velocity 2 rises against gravity four times as high as one with velocity 1, but it requires double the time for it; consequently the quantity of motion must be divided by the time, and =2, not =4. Curiously enough, this is also Suter's view, who indeed deprived the expression "*vis viva*" of all logical meaning and left it only a mathematical one. But this is natural. For Suter it is a question of saving the formula *mv* in its significance as sole measure of the quantity of motion; hence logically mv^2 is sacrificed in order to arise again transfigured in the heaven of mathematics.

However, this much is correct: Catelan's argument provides one of the bridges connecting *mv* with mv^2, and so is of importance.

The mechanicians subsequent to d'Alembert by no means accepted his verdict, for his final verdict was indeed in favour of *mv* as the measure of motion. They adhered to his expression of the distinction which Leibniz had already made between dead and live forces: *mv* is valid for equilibrium, *i.e.* for statics; mv^2 is valid for motion against resistance, *i.e.* for dynamics. Although on the whole correct, the distinction in this form has, however, logically no more meaning than the famous pronouncement of the junior officer: on duty always " to me," off duty always " me." It is accepted tacitly, it just exists. We cannot alter it, and if a contradiction lurks in this double measure, how can we help it?

Thus, for instance, Thomson and Tait say (*A Treatise on Natural Philosophy*, Oxford, 1867, p. 102); "The*quantity of motion* or the *momentum* of a rigid body moving without rotation is proportional to its mass and velocity conjointly. Double mass or double velocity would correspond to double quantity of motion." And immediately below that they say: " The *vis viva* or *kinetic energy* of a moving body is proportional to the mass and the square of the velocity conjointly."

The two contradictory measures of motion are put side by side in this very glaring form. Not so much as the slightest attempt is made to explain the contradiction, or even to disguise it. In the book by these two Scotsmen, thinking is forbidden, only calculation is permitted. No wonder that at least one of them, Tait, is accounted one of the most pious Christians of pious Scotland.

In Kirchhoff's *Vorlesungen über mathematische Mechanik* [*Lectures on Mathematical Mechanics*] the formulae *mv* and mv^2 do not occur at all *in this form*.

Perhaps Helmholtz will aid us. In his *Erhaltung der Kraft* [*Conservation of Force*] he proposes to express *vis viva* by $mv^2/2$, a point to which we shall return later. Then, on page 20 *et seq.*, he enumerates briefly the cases in which so far the principle of the conservation of *vis viva* (hence of $mv^2/2$) has been recognised and made use of. Included therein under No. 2 is

"the transference of motion by incompressible solid and fluid bodies, in so far as friction or impact of inelastic materials does not occur. For these cases our general principle is usually expressed in the rule that motion propagated and altered by mechanical powers always decreases in intensity of force in the same proportion as it increases in velocity. If, therefore, we imagine a weight *m* being raised with velocity *c* by a machine in which a force for performing work is produced uniformly by some process or other, then with a different mechanical arrangement the weight *nm* could be raised, but only with velocity *c/n*, so that in both cases the quantity of tensile force produced by the machine in unit time is represented by *mgc*, where *g* is the intensity of the gravitational force."

Thus, here too we have the contradiction that an "intensity of force," which decreases and increases in simple proportion to the velocity, has to serve as proof for the conservation of an intensity of force which decreases and increases in proportion to the square of the velocity.

In any case, it becomes evident here that *mv*and mv^2 serve to determine two quite distinct processes, but we certainly knew long ago that mv^2 cannot equal *mv*, unless v=l. What has to be done is to make it comprehensible why motion should have a twofold measure, a thing which is surely just as unpermissible in natural science as in commerce. Let us, therefore, attempt this in another way.

By *mv*, then, one measures "a motion propagated and altered by mechanical powers "; hence this measure holds good for the lever and all its derivatives, for wheels, screws, etc., in short, for all machinery for the transference of motion. But from a very simple and by no means new consideration it becomes evident that in so far as *mv* applies here, so also does mv^2. Let us take any mechanical contrivance in which the sums of the lever-arms on the two sides are related to each other as 4:1, in which, therefore, a weight of 1 kg. holds a weight of 4 kg. in equilibrium. Hence, by a quite insignificant additional force on one arm of the lever we can raise 1 kg. by 20 m.; the same additional force, when applied to the other arm of the lever, raises 4 kg. a distance of 5 m., and the preponderating weight sinks in the same time that the other weight requires for rising. Mass and velocity are inversely proportional to one another; *mv*, 1x20=*m*'*v*', 4x5. On the other hand, if we let each of the weights, after it has been raised, fall freely to the original level, then the one, 1 kg., after falling a distance of 20 m. (the acceleration due to gravity is put in round figures =10 m. instead of 9,81 m.), attains a velocity of 20 m.: the other, 4 kg., after falling a distance of 5 m., attains a velocity of 10 m.

$mv^2 = 1 \times 20 \times 20 = 400 = m'v'^2 = 4 \times 10 \times 10 = 400$

On the other hand the times of fall are different: the 4 kg. traverse their 5 m. in 1 second, the 1 kg. traverses its 20 m. in 2 seconds. Friction and air resistance are, of course, neglected here.

But after each of the two bodies has fallen from its, height, its motion ceases. Therefore, *mv* appears here as the measure of simple transferred, hence lasting, mechanical motion, and mv^2 as the measure of the vanished mechanical motion.

Further, the same thing applies to the impact of perfectly elastic bodies: the sum of both *mv* and of mv^2 is unaltered before and after impact. Both measures have the same validity.

'This is not the case on impact of inelastic bodies. Here, too, the current elementary textbooks (higher mechanics is hardly concerned at all with such trifles) teach that before and after impact the sum of *mv* remains the same. On the other hand a loss of *vis viva* occurs, for if the sum of mv^2 after impact is subtracted from the sum of mv^2 *before* impact, there is under all circumstances a positive remainder. By this amount (or the half of it, according to the notation adopted) the *vis viva* is diminished owing both to the mutual penetration and to the change of form of the colliding bodies. The latter is now clear and obvious, but not so the first assertion that the sum of *mv* remains the same before and after impact. In spite of Suter, *vis viva* is motion, and if a part of it is lost, motion is lost. Consequently, either*mv* here incorrectly expresses the quantity of motion, or the above assertion is untrue. In general the whole theorem has been handed down from a period when there was as yet no inkling of the transformation of motion; when, therefore, a disappearance of mechanical motion was only conceded where there was no other way out. Thus, the equality here of the sum of *mv* before and after impact was taken as proved by the fact that no loss or gain of this sum had been introduced. If, however, the bodies lose *vis viva* in internal friction corresponding to their inelasticity, they also lose velocity, and the sum of *mv* after impact must be smaller than before. For it is surely not possible to neglect the internal friction in calculating *mv*, When it makes itself felt so clearly in calculating mv^2.

But this does not matter. Even if we admit the theorem, and calculate the velocity after falling, on the assumption that the sum of *mv* has remained the same, this decrease of the sum of mv^2 is still found. Here, therefore, *mv* and mv^2 conflict, and they do so by the difference of the mechanical motion that has actually disappeared. Moreover, the calculation itself shows that the sum of mv^2 expresses the quantity of motion correctly, while the sum of *mv* expresses it incorrectly.

Such are pretty nearly all the cases in which *mv* is employed in mechanics. Let us now glance at some cases in which mv^2 is employed.

When a cannon-ball is fired, it uses up in its course an amount of motion that is proportional to *mv^2*, irrespective of whether it encounters a solid target or comes to a standstill owing to air resistance and gravitation. If a railway train runs into a stationary one, the violence of the collision, and the corresponding destruction, is proportional to its *mv^2*. Similarly, *mv^2* serves wherever it is necessary to calculate the mechanical force required for overcoming a resistance.

But what is the meaning of this convenient phrase, so current in mechanics: overcoming a resistance?

If we overcome the resistance of gravity by raising a weight, there disappears a quantity of motion, a quantity of mechanical force, equal to that produced anew by the direct or indirect fall of the raised weight from the height reached back to its original level. The quantity is measured by half the product of the mass and the final velocity after falling, $mv^2/2$. What then occurred on raising the weight? Mechanical motion, or force, disappeared as such. But it has not been annihilated; it has been converted into mechanical force of tension, to use Helmholtz's expression; into potential energy, as the moderns say; into ergal as Clausius calls it; and this can at any moment, by any mechanically appropriate means, be reconverted into the same quantity of mechanical motion as was necessary to produce it. The potential energy is only the negative expression of the *vis viva* and *vice versa*.

A 24-lb. cannon-ball moving with a velocity of 400 m. per second strikes the one-metre thick armour-plating of a warship and under these conditions has apparently no effect on the armour. Consequently an amount of mechanical motion has vanished equal to $mv^2/2$, *i.e.* (since 24 lbs. =12 kg.) =12 X 400 X 400 X 1/2= 960,000 kilogram-metres. Wat has become of it? A small portion has been expended in the concussion and molecular alteration of the armour-plate. A second portion goes in smashing the cannon-ball into innumerable fragments. But the greater part has been converted into heat and raises the temperature of the cannon-hall to red heat. When the Prussians, in passing over to Alsen in 1864, brought their heavy batteries into play against the armoured sides of the Rolf Krake, after each hit they saw in the darkness the flare produced by the suddenly glowing shot. Even earlier, Whitworth had proved by experiment that explosive shells need no detonator when used against armoured warships; the glowing metal itself ignites the charge. Taking the mechanical equivalent of the unit of heat as 424 kilogram-metres, the quantity of heat corresponding to the above-mentioned amount of mechanical motion is 2,264 units. The specific heat of iron=0.1140; that is to say, the amount of heat that raises the ternperature of 1 kg. of water by 1º C. (which serves as the unit of heat) suffices to raise the temperature of 1/0.1140 = 8.772 kg. of iron by 1º C. Therefore the 2,264 heat-units mentioned above raise the temperature of 1 kg. of iron by 8.772 X 2,264 =19,860º C. or 19,860 kg. of iron by 1º C. Since this quantity of heat is distributed uniformly in the armour and the shot, the latter has its temperature raised by 19,860/2X12=828º, amounting to quite a good glowing heat. But since the foremost, striking end of the shot receives at any rate by far the greater part of the heat, certainly double that of the rear half, the former would be raised to a temperature of 1,104º C. and the latter to 552º C., which would fully suffice to explain the glowing effect even if we make a big deduction for the actual mechanical work performed on impact.

Mechanical motion also disappears in friction, to reappear as heat; it is well known that, by the most accurate possible measurement of the two processes, Joule in Manchester and Codling in Copenhagen were the first to make an approximate experimental measurement of the mechanical equivalent of heat.

The same thing applies to the production of an electric current in a magneto-electrical machine by means of mechanical force, *e.g.* from a steam engine. The quantity of so-called electromotive force produced in a given time is proportional to the quantity of mechanical motion used up in the same period, being equal to it if expressed in the same units. We can imagine this quantity of mechanical motion being produced, not by a steam engine, but by a weight falling in accordance with the pressure of gravity. The mechanical force that this is capable of supplying is measured by the *vis viva* that it would obtain on falling freely through the same distance, or by the force required to raise it again to the original height; in both cases $mv^2/2$.

Hence we find that while it is true that mechanical motion has a two-fold measure, each of these measures holds good for a very definitely demarcated series of phenomena. If already existing mechanical motion is transferred in such a way that it remains as mechanical motion, the transference takes place in proportion to the product of the mass and the velocity. If, however, it is transferred in such a way that. it disappears as mechanical motion in order to reappear in the form of potential energy, heat, electricity, etc., in short, if it is converted into another form of motion, then the quantity of this new form of motion is proportional to the product of the originally moving mass and the square of the velocity. In short, *mv* is mechanical motion measured as mechanical motion; $mv^2/2$ is mechanical motion measured by its capacity to become converted into a definite quantity of another form of motion. And, as we have seen, these two measures, because different, do not contradict one another.

It becomes clear from this that Leibniz's quarrel with the Cartesians was by no means a mere verbal dispute, and that d'Alembert's verdict in point of fact settled nothing at all. D'Alembert. might have spared himself his tirades on the unclearness of his predecessors, for he was just as unclear as they were. In fact, as long as it was not known what becomes of the apparently annihilated mechanical motion. the absence of clarity was inevitable. And as long as mathematical mechanicians like Suter remain obstinately shut in by the four walls of their special science, they are bound to remain just as unclear as d'Alembert and to put us off with empty and contradictory phrases.

But how does modern mechanics express this conversion of mechanical motion into another form of motion, proportional in quantity to the former? It has *performed work*, and indeed a definite amount of work.

But this does not exhaust the concept of work in the physical sense of the word. If, as in a steam or heat engine, heat is converted into mechanical motion,*i.e.* molecular motion is converted into mass motion, if heat breaks up a chemical compound, if it becomes converted into electricity in a thermopile, if an electric current sets free the elements of water from dilute sulphuric acid, or, conversely, if the motion (alias energy) produced in the chemical process of a current-producing cell takes the form of electricity and this in the circuit once more becomes converted into heat - in all these processes the form of motion that initiates the process, and which is converted by it into another form, performs work, and indeed a quantity of work corresponding to its own quantity.

Work, therefore, is change of form of motion regarded in its quantitative aspect.

But how so? If a raised weight remains suspended and at rest, is its potential energy during the period of rest also a form of motion? Certainly. Even Tait arrives at the conviction that potential energy is subsequently resolved into a form of actual motion (*Nature*, XIV p.459). And, apart from that, Kirchhoff goes much further in saying (*Mathematical Mechanics*, p. 32) "Rest is a special case of motion," and thus proves that he can not only calculate but can also think dialectically.

Hence, by a consideration of the two measures of rnechanical motion, we arrive incidentally, easily, and almost as a matter of course, at the concept of work, which was described to us as being so difficult to comprehend without mathematical mechanics. At any rate, we now know more about it than from Helmholtz's lecture *On the Conservation of Force*(1862), which was intended precisely "to make as clear as possible the fundamental physical concepts of work and their invariability." All that we learn there about work is: that it is something which is expressed in foot-pounds or in units of heat, and that the number of these foot-pounds or units of heat is invariable for a definite quantity of work; and, further, that besides mechanical forces and heat, chemical and electric forces can perform work, but that all these forces exhaust their capacity for work in the measure that they actually result in work. We learn also that it follows from this that the sum of all effective quantities of force in nature as a whole remains eternally and invariably the same throughout all the changes taking place in nature. The concept of work is neither developed, nor even defined.[1] And it is precisely the quantitative invariability of the magnitude of work which prevents him from realising that the qualitative alteration, the change of form, is the basic condition for all physical work. And so Helmholtz can go so far as to assert that " friction and inelastic impact are processes in which *mechanical work is destroyed*and heat is produced instead." (*Pop. Vorträge* [*Popular Lectures*], II, p. 166.) Just the contrary. Here mechanical work is not *destroyed*, here mechanical work is *performed*. It is mechanical *motion* that is apparently destroyed. But mechanical motion *can* never perform even a millionth part of a kilogram-metre of work, without apparently being destroyed as such, without becoming converted into another form of motion.

But, as we have seen, the capacity for work contained in a given quantity of mechanical motion is what is known as its *vis viva*, and until recently was measured by mv^2. And here a new contradiction arose. Let us listen to Helmholtz (*Conservation of Force*, p. 9).

We read there that the magnitude of work can be expressed by a weight *m* being raised to a height *h*, when, if the force of gravity is put as *g*, the magnitude of work =*mgh*. For the body *m* to rise freely to the vertical height *h*, it requires a velocity v= (square root of)2gh, and it attains the same velocity on falling. Consequently, *mgh*=$mv^2/2$ and Helmholtz proposes " to take the magnitude $mv^2/2$ as the quantity of *vis viva*, whereby it becomes identical with the measure of the magnitude of work. From the viewpoint of how the concept of *vis viva* has been applied hitherto... this change has no significance, but it will offer essential advantages in the future."

It is scarcely to be believed. In 1847, Helmholtz was so little clear about the mutual relations of *vis viva* and work, that he totally fails to notice how he transforms the former proportional measure of *vis viva*into its absolute measure, and remains quite unconscious of the important discovery he has made by his audacious handling, recommending his $mv^2/2$ only because of its convenience as compared with mv^2! And it is as a matter of convenience that mechanicians have adopted $mv^2/2$. Only gradually was $mv^2/2$ also proved mathematically. Naumann (*Allg. Chemie* [*General Chemistry*], p. 7) gives an algebraical proof, Clausius (*Mechanische Wärmetheorie* [*The Mechanical Theory of Heat*], 2nd Cdition, p. 18), an analytical one, which is then to be met with in another form and a different method of deduction in Kirchhoff (*ibid*., p. 27) Clerk Maxwell (*ibid*., p. 88) gives an elegant algebraical proof of the deduction of $mv^2/2$ from *mv*. This does not prevent our two Scotsmen, Thomson and Tait, from asserting (*ibid*., p. 168): " The *vis viva* or kinetic energy of a moving body is proportional to the mass and the square of the velocity conjointly. If we adopt the same units of mass as above (namely, unit of mass moving with unit velocity) there is a *particular advantage* in defining kinetic energy as *half* the product of the mass and the square of the velocity." Here, therefore, we find that not only the ability to think, but also to calculate, has come to a standstill in the two foremost mechanicians of Scotland. The particular advantage, the convenience of the formula, accomplishes everything in the most beautiful fashion.

For us, who have seen that *vis viva* is nothing but the capacity of a given quantity of mechanical motion to perform work, it is obvious on the face of it that the expression in mechanical terms of this capacity for work and the work actually performed by the latter must be equal to each other; and that, consequently, if $mv^2/2$ measures the work, the *vis viva* must likewise be measured by $mv^2/2$. But that is what happens in science. Theoretical mechanics arrives at the concept of *vis viva*, the practical mechanics of the engineer arrives at the concept of work and forces it on the theoreticians. And, immersed in their calculations, the theoreticians have become so unaccustomed to thinking that for years they fail to recognise the connection between the two concepts, measuring one of them by mv^2, the other by $mv^2/2$, and finally accepting $mv^2/2$ for both, not from comprehension, but for the sake of simplicity of calculation! [2]

Notes

1. We get no further by consulting Clerk Maxwell. The latter says (*Theory of Heat*, 4th edition, London, 1875, p. 87): "Work is done when resistance is overcome," and on p. 183, " The energy of a body is its capacity for doing work." That is all that we learn about it. [*Note by F. Engels.*]

2. The word "work" and the corresponding idea is derived from English engineers. But in English practical work is called "work," while work in the economic sense is called " labour." Hence, physical work also is termed "work," thereby excluding all confusion with work in the economic sense. This is not the case in German; therefore it has been possible in recent pseudo-scientific literature to make various peculiar applications of work in the physical sense to economic conditions of labour and *vice versa*. But we have also the word " *Werk*" which, like the English word "work," is excellently adapted for signifying physical work. Economics, however, being a sphere far too remote from our natural scientists, they will scarcely decide to introduce it to replace the word *Arbeit*, which has already obtained general currency - unless, perhaps, when it is too late. Only Clausius has made the attempt to retain the expression " *Werk*," at least alongside the expression " *Arbeit*." [*Note by F. Engels.*]

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Engels' Dialectics of Nature

V. Heat

As we have seen, there are two forms in which mechanical motion, *vis viva*, disappears. The first is its conversion into mechanical potential energy, for instance on lifting a weight. This form has the peculiarity that not only can it be re-transformed into mechanical motion - this mechanical motion, moreover, having the same *vis viva* as the original one - but also that it is capable only of this change of form. Mechanical potential energy can never produce heat or electricity, unless it has been converted first into real mechanical motion. To use Clausius' term, it is a "reversible process."

The second form in which mechanical motion disappears is in friction and impact - which differ only in degree. Friction can be conceived as a series of small impacts occurring successively and side by side, impact as friction concentrated at one spot and in a single moment of time. Friction is chronic impact, impact is acute friction. The mechanical motion that disappears here, disappears altogether *as such*. It can never be restored immediately out of itself. The process is not directly reversible. The motion has been transformed into qualitatively different forms of motion, into heat, electricity - into forms of molecular motion.

Hence, friction and impact lead from the motion of masses, the subject matter of mechanics, to molecular motion, the subject matter of physics.

In calling physics the mechanics of molecular motion, it has not been overlooked that this expression by no means covers the entire field of contemporary physics. On the contrary. Ether vibrations, which are responsible for the phenomena of light and radiant heat, are certainly not molecular motions in the modern sense of the word. But their terrestrial actions concern molecules first and foremost: refraction of light, polarisation of light, etc., are determined by the molecular constitution of the bodies concerned. Similarly almost all the most important scientists now[1] regard electricity as a motion of ether particles, and Clausius even says of heat[2] that in "the movement of ponderable atoms (it would be better to say molecules)... the ether within the body can also participate" (*Mechanische Wärmetheorie* [*Mechanical Theory of Heat*] I, p. 22).[3] But in the phenomena of electricity and heat, once again it is primarily molecular motions that have to be considered; it could not be otherwise, so long as our knowledge of the ether is so small. But when we have got so far as to be able to present the mechanics of the ether, this subject will include a great deal that is now of necessity allocated to physics.[4]

The physical processes in which the structure of the molecule is altered, or even destroyed, will be dealt with later on: they form the transition from physics to chemistry.

Only with molecular motion does the change of form of motion acquire complete freedom. Whereas, at the boundary of mechanics the motion of masses can assume only a few other forms - heat or electricity - here, a quite different and more lively capacity for change of form is to be seen. Heat passes into electricity in the thermopile, it becomes identical[5] with light at a certain stage of radiation, and in its turn reproduces mechanical motion. Electricity and magnetism, a twin pair like heat and light, not only become transformed into each other, but also into heat and light as well as mechanical motion. And this takes place in such definite measure relations that a given quantity of any one of these forms of energy can be expressed in any other - in kilogram-metres, in heat units, in volts,[6] and similarly any unit of measurement can be translated into any other.

The practical discovery of the conversion of mechanical motion into heat is so very ancient that it can be taken as dating from the beginning of human history.[7] Whatever discoveries, in the way of tools and domestication of animals,[8] may have preceded it, the making of fire by friction was the first instance of men pressing a non- living force of nature into their service. Popular superstitions to-day still show how greatly the almost immeasurable import of this gigantic advance impressed itself on the mind of mankind. Long after the introduction of the use of bronze and iron the discovery of the stone knife, the first tool, continued to be celebrated, all religious sacrifices being performed with stone knives. According to the Jewish legend, Joshua decreed that men born in the wilderness should be circumcised with stone knives; the Celts and Germans used stone knives exclusively in their human sacrifices. But all this long ago passed into oblivion. It was different with the making of fire by friction. Long after other methods of producing fire had become known, every sacred fire among the majority of peoples had to be obtained by friction. But even to- day, popular superstition in the majority of the European countries insists that fire with miraculous powers (*e.g.* our German bonfire against epidemics) may be lighted only by means of friction. Thus, down to our own day, the grateful memory of the first great victory of mankind over nature lives on - half unconsciously - in popular superstition, in the relics of heathen-mythological recollections, among the most educated peoples in the world.

However, the process of making fire by friction is still one-sided. By it mechanical motion is converted into heat. To complete the process, it must be reversed; heat must be converted into mechanical motion. Only in that case is justice done to the dialectics of the process, the cycle of the process being completed - for the first stage, at least. But history has its own pace, and however dialectical its course may be in the last analysis, dialectics has often to wait for history a fairly long time. Many thousands of years must have elapsed between the discovery of fire by friction and the time when Hero of Alexandria (*ca*. 120 B.C.) invented a machine which was set in rotary motion by the steam issuing from it. And almost another two thousand years elapsed before the first steam engine was built, the first apparatus for the conversion of heat into really useable mechanical motion.

The steam engine was the first really international invention, and this fact, in turn, testifies to a mighty historical advance. The Frenchman, Papin, invented the first steam engine, and he invented it in Germany. It was the German, Leibniz, scattering around him, as always, brilliant ideas, without caring whether the merit for them would be awarded to him or someone else, who, as we know now from Papin's correspondence (published by Gerland), gave him the main idea of the machine: the employment of a cylinder and piston. Soon after that, the Englishmen, Savery and Newcomen, invented similar machines; finally, their fellow- country-man, Watt, by introducing a separate condenser, brought the steam engine in principle up to the level of to-day. The cycle of inventions in this sphere was completed; the conversion of heat into mechanical motion was achieved. What came afterwards were improvements in details.

Practice, therefore, solved after its own fashion the problem of the relations between mechanical motion and heat. It had, to begin with, converted the first into the second, and then it converted the second into the first. But how did matters stand in regard to theory?

The situation was pitiable enough. Although it was just in the seventeenth and eighteenth centuries that innumerable accounts of travel appeared, teeming with descriptions of savages who knew no way of producing fire other than by friction, yet physicists were almost uninterested in it; they were equally indifferent to the steam engine during the whole of the eighteenth century and the first decades of the nineteenth. For the most part they were satisfied simply to record the facts.

Finally, in the twenties, Sadi Carnot took the matter in hand, and indeed so very skilfully that his best calculations, afterwards presented by Clapeyron in geometrical form, have been accepted up to the present day by Clausius and Clerk Maxwell. Sadi Carnot almost got to the bottom of the question. It was not the lack of factual data that prevented him from completely solving it, but solely a preconceived *false theory*. Moreover, this false theory was not one which had been forced upon physicists by some variety of malicious philosophy, but was a theory contrived by the physicists themselves, by means of their own naturalistic mode of thought, so very superior to the metaphysical-philosophical method.

In the seventeenth century heat was regarded, at any rate in England, as a property of bodies, as "a *motion* of a particular kind, the nature of which has never been explained in a satisfactory manner". This is what Th. Thomson called it, two years before the discovery of the mechanical theory of heat (*Outline of the Sciences of Heat and Electricity*, 2nd edition, London, 1840). But in the eighteenth century the view came more and more to the fore that heat, as also light, electricity, and magnetism, is a special substance, and that all these peculiar substances differ from ordinary matter in having no weight, in being imponderable.

Notes

1. At this time the ideas of Faraday and Maxwell were dominant, and physicists tended to regard electricity as primarily located in the field between charged bodies.

2. A body at any temperature is in equilibrium with a certain density of radiation, though very little of the energy in a given volume is "in the ether," *i.e.* in the form of radiation, at ordinary temperatures.

3. See Appendix II, pp. 333-4.

4. This has certainly been verified in the sense that for modern physics the properties of particles can be regarded as essentially repulsions and attractions in the space around them, which is also full of radiation. On the other hand, the idea of the ether has proved so full of internal contradictions that the word is now little used.

5. As we saw, some of the heat in a hot body takes the form of radiation. When the body gets red hot this becomes partially visible (*i.e.* light).

6. This is, of course, a mistake. The volt is not an energy unit, as Engels would soon have known had he ever had to pay an electricity bill!

7. Even *Sinanthropus*, a type of man very different physically from ourselves, possessed fire, though of course we do not know how he made it.

8. The use of fire immensely preceded domestication.

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Engels' Dialectics of Nature

VI. Electricity [1]

ELECTRICITY, like heat, only in a different way, has also a certain omnipresent character. Hardly any change can occur in the world without it being possible to demonstrate the presence of electrical phenomena. If water evaporates, if a flame burns, if two different metals, or two metals of different temperature, touch, or if iron touches a solution of copper sulphate, and so on, electrical processes take place simultaneously with the more apparent physical and chemical phenomena. The more exactly we investigate natural processes of the most diverse nature, the more do we find evidence of electricity. In spite of its omnipresence, in spite of the fact that for half a century electricity has become more and more pressed into the industrial service of mankind, it remains precisely that form of motion the nature of which is still enveloped in the greatest obscurity.

The discovery of the galvanic current is approximately 25 years younger than that of oxygen and is at least as significant. for the theory of electricity as the latter discovery was for chemistry. Yet what a difference obtains even to-day between the two fields ! In chemistry, thanks especially to Dalton's discovery of atomic weights, there is order, relative certainty about what has been achieved, and systematic, almost planned, attack on the territory still unconquered, comparable to the regular siege of a fortress. In the theory of electricity there is a barren lumber of ancient, doubtful experiments, neither definitely confirmed nor definitely refuted; , an uncertain fumbling in the dark, uncoordinated research and experiment on the part of numerous isolated individuals, who attack the unknown territory with their scattered forces like the attack of a swarm of nomadic horsemen. It must be admitted, indeed, that in the sphere of electricity a discovery like that of Dalton, giving the whole science a central point and a firm basis for research, is still to seek.[2] It is essentially this unsettled state of the theory of electricity, which for the time being makes it impossible to establish a comprehensive theory, that is responsible for the fact that a one-sided empiricism prevails in this sphere, an empiricism which as far as possible itself forbids thought, and which precisely for that reason not only thinks incorrectly but also is incapable of faithfully pursuing the facts or even of reporting them faithfully, and which, therefore, becomes transformed into the opposite of true empiricism.

If in general those natural scientists, who cannot say anything bad enough of the crazy *a priori* speculations of the German philosophy of nature, are to be recommended to read the theoretico-physical works of the empirical school, not only of the contemporary but even of a much later period, this holds good quite especially for the theory of electricity. Let us take a work of the year 1840: *An Outline of the Sciences of Heat and Electricity*, by Thomas Thomson. Old Thomson was indeed an authority in his day ; moreover he had already at his disposal a very considerable part of the work of the greatest electrician so far - Faraday. Yet his book contains at least just as crazy things as the corresponding section of the much older Hegelian philosophy of nature. The description of the electric spark, for instance, might have been translated directly from the corresponding passage in Hegel. Both enumerate all the wonders that people sought to discover in the electric spark, prior to knowledge of its real nature and manifold diversity, and which have now been shown to be mainly special cases or errors.

Still better, Thomson recounts quite seriously on p. 446 Dessaigne's cock-and-bull stories, such as that, with a rising barometer and falling thermometer, glass, resin, silk, etc., become negatively electrified on immersion in mercury, but positively if instead the barometer is falling and the temperature rising ; that in summer gold and several other metals become positive on warming and negative on cooling, but in winter the reverse; that with a high barometer and northerly wind they are strongly electric, positive if the temperature is rising and I negative if it is falling, etc.

So much for the treatment of the facts. As regards *a priori* speculation, Thomson favours us with the following treatment of the electric spark, derived from no lesser person than Faraday himself:

"The spark is a discharge ... or weakening of the polarised inductive state of many dielectric particles by means of a peculiar action of a few of these particles occupying a very small and limited space. Faraday assumes that the few particles situated where the discharge occurs are not merely pushed apart, but assume a peculiar, highly exalted, condition for the time, *i.e.* that they have thrown on them all the surrounding forces in succession and are thus brought into a proportionate intensity of condition, perhaps equal to that of chemically combining atoms; that they then discharge the powers, in the same manner as the atoms do theirs, in some way at present unknown to us and so the end of the whole. The ultimate effect is exactly as if a metallic wire had been put into the place of the discharging particles, and it does not seem impossible that the principles of action in both cases may, hereafter, prove to be the same." [3]

I have, adds Thomson, given this explanation of Faraday's in his own words, because I do not understand it clearly. This will certainly have been the experience of other persons also, quite as much as when they read in Hegel that in the electric spark " the special materiality of the charged body does not as yet enter into the process but is determined within it only in an elementary and spiritual way," and that electricity is " the anger, the effervescence, proper to the body," its "angry self " that " is exhibited by every body when excited." (*Philosophy of Nature*, paragraph 324, addendum.) [4]

Yet the basic thought of both Hegel and Faraday is the same. Both oppose the idea that electricity is not a state of matter but a special, distinct variety of matter. And since in the spark electricity is apparently exhibited as independent, free from any foreign material substratum, separated out and yet perceptible to the senses, they arrive at the necessity, in the state of science at the time, of having to conceive of the spark as a transient phenomenal form of a " force " momentarily freed from all matter. For us, of course, the riddle is solved, since we know that on the spark discharge between metal electrodes real "metallic particles" leap across, and hence in actual fact " the special materiality of the charged body enters into the process."

As is well known, electricity and magnetism, like heat and light, were at first regarded as special imponderable substances. As far as electricity is concerned, it is well known that the view soon developed that there are two opposing substances, two " fluids," one positive and one negative, which in the normal state neutralise each other, until they are forced apart by a so-called " electric force of separation." It is then possible to charge two bodies, one with positive, the other with negative electricity; on uniting them by a third conducting body equalisation occurs, either suddenly or by means of a lasting current, according to circumstances. The sudden equalisation appeared very simple and comprehensible, but the current offered difficulties. The simplest hypothesis, that the current in every case is a movement of either purely positive or purely negative electricity, was opposed by Fechner, and in more detail by Weber, with the view that in every circuit two equal currents of positive and negative electricity flow in opposite directions in channels lying side by side between the ponderable molecules of the bodies.[5] Weber's detailed mathematical working out of this theory finally arrives at the result that a function, of no interest to us here, is multiplied by a magnitude *l/r*, the latter signifying "*the ratio . . . of the unit of* *electricity to the milligram.*" (Wiedemann, *Lehre vom Galvanismus, etc.* [*Theory of Galvanism, etc.*], 2nd edition, III, p. 569). The ratio to a measure of weight can naturally only be a weight ratio. Hence one-side empiricism had already to such an extent forgotten the practice of thought in calculating that here it even makes the imponderable electricity ponderable and introduces its weight into the mathematical calculation.

The formula derived by Weber sufficed only within certain limits, and Helmholtz, in particular, only a few years ago calculated results that come into conflict with the principle of the conservation of energy. In opposition to Weber's hypothesis of the double current flowing in opposite directions, C. Naumann in 1871 put forward the other hypothesis that in the current only one of the two electricities, for instance the positive, moves, while the other negative one remains firmly bound up with the mass of the body. On this Wiedemann includes the remark: " This hypothesis could be linked up with that of Weber if to Weber's supposed double current of electric masses ±½*e* flowing in opposite directions, there were added a further current of neutral electricity, externally inactive, which carried with it amounts of electricity ±½*e* in the direction of the positive current." (III, p. 577.)

This statement is once again characteristic of one-sided empiricism. In order to bring about the flow of electricity at all, it is decomposed into positive and negative. All attempts, however, to explain the current with these two substances, meet with difficulties; both the assumption that only one of them is present in the current and that the two of them flow in opposite directions simultaneously, and finally, the third assumption also that one flows and the other is at rest. If we adopt this last assumption how are we to explain the inexplicable idea that negative electricity, which is mobile enough in the electrostatic machine and the Leyden jar, in the current is firmly united with the mass of the body? Quite simply. Besides the positive current +*e*, flowing through the wire to the right, and the negative current, -*e*, flowing to the left, we make yet another current, this time of neutral electricity, ±½*e*, flow to the right. First we assume that the two electricities, to be able to flow at all, must be separated from one another ; and then, in order to explain the phenomena that occur on the flow of the separated electricities, we assume that they can also flow unseparated. First we make a supposition to explain a particular phenomenon, and at the first difficulty encountered we make a second supposition which directly negates the first one. What must be the sort of philosophy that these gentlemen have the right to complain of?

However, alongside this view of the material nature of electricity, there soon appeared a second view, according to which it is to be regarded as a mere state of the body, a " force " or, as we would say to-day, a special form of motion. We saw above that Hegel, and later Faraday, adhered to this view. After the discovery of the mechanical equivalent of heat had finally disposed of the idea of a special " heat stuff," and heat was shown to be a molecular motion, the next step was to treat electricity also according to the new method and to attempt to determine its mechanical equivalent. This attempt was fully successful. Particularly owing to the experiments of Joule, Favre, and Raoult, not only was the mechanical and thermal equivalent of the so-called " electromotive force " of the galvanic current established, but also its complete equivalence with the energy liberated by chemical processes in the exciting cell or used up in the decomposition cell. This made the assumption that electricity is a special material fluid more and more untenable.

The analogy, however, between heat and electricity was not perfect. The galvanic currents still differed in very essential respects from the conduction of heat. It was still not possible to say *what* it was that moved in the electrically affected bodies. The assumption of a mere molecular vibration as in the case of heat seemed insufficient. In view of the enormous velocity of motion of electricity, even exceeding that of light,[6] it remained difficult to overcome the view that here some material substance is in motion between the molecules of the body.

Here the most recent theories put forward by Clerk Maxwell (1864), Hankel (1865), Reynard (1870), and Edlund (1872) are in complete agreement with the assumption already advanced in 1846, first of all as a suggestion by Faraday, that electricity is a movement of the elastic medium permeating the whole of space and hence all bodies as well, the discrete particles of which medium repel one another according to the law of the inverse square of the distance. In other words, it is a motion of ether particles, and the molecules of the body take part in this motion. As to the manner of this motion, the various theories are divergent; those of Maxwell, Hankel, and Reynard, taking as their basis modern investigations of vortex motion, explain it in various ways from vortices, so that the vortex of old Descartes also once more comes into favour in an increasing number of new fields. We refrain from going more closely into the details of these theories. They differ strongly from one another and they will certainly still experience many transformations. But a decisive advance appears to lie in their common basic conception: that electricity is a motion of the particles of the luminiferous ether that penetrates all ponderable matter, this motion reacting on the molecules of the body. This conception reconciles the two earlier ones. According to it, it is true that in electrical phenomena it is something substantial that moves, something different from ponderable matter. But this substance is not electricity itself, which in fact proves rather to be a form of motion, although not a form of the immediate direct motion of ponderable matter. While, on the one hand, the ether theory shows a way of getting over the primitive clumsy idea of two opposed electrical fluids, on the other hand it gives a prospect of explaining *what* the real, substantial substratum of electrical motion is, *what* sort of a thing it is whose motion produces electrical phenomena .[7]

The ether theory has already had *one* decisive success. As is well known, there is at least one point where electricity directly alters the motion of light: it rotates the latter's plane of polarisation. On the basis of his theory mentioned above, Clerk Maxwell calculates that the electric specific inductive capacity of a body is equal to the square of its index of refraction. Boltzmann has investigated dielectric coefficients of various nonconductors and he found that in sulphur, rosin, and paraffin, the square roots of these coefficients were respectively equal to their indices of refraction. The highest deviation - in sulphur - amounted to only 4 per cent. Consequently, the Maxwellian ether theory in this particular has hereby been experimentally confirmed.[8]

It will, however, require a lengthy period and cost much labour before new series of experiments will have extracted a firm kernel from these mutually contradictory hypotheses. Until then, or until the ether theory, too, is perhaps supplanted by an entirely new one, the theory of electricity finds itself in the uncomfortable position of having to employ a mode of expression which it itself admits to be false. Its whole terminology is still based on the idea of two electric fluids. It still speaks quite unashamedly of " electric masses flowing in the bodies," of " a division of electricities in every molecule," etc. This is a misfortune which for the most part, as already said, follows inevitably from the present transitional state of science, but which also, with the one-sided empiricism particularly prevalent in this branch of investigation, contributes not a little to preserving the existing confusion of thought.

The opposition between so-called static or frictional electricity and dynamic electricity or galvanism can now be regarded as bridged over, since we have learned to produce constant currents by means of the electric machine and, conversely, by means of the galvanic current to produce so-called static electricity, to charge Leyden jars, etc. We shall not here touch on the subform of static electricity, nor likewise on magnetism, which is now recognised to be also a sub-form of electricity. The theoretical explanation of the phenomena belonging here will under all circumstances have to be sought in the theory of the galvanic current, and consequently we shall keep mainly to this.

A constant current can be produced in many different ways. Mechanical mass motion produces *directly*, by friction, in the first place only static electricity, and a constant current only with great dissipation of energy. For the major part, at least, to become transformed into electric motion, the intervention of magnetism is required, as in the well- known magneto-electric machines[9] of Gramme, Siemens, and others. Heat can be converted directly into current electricity, as especially occurs at the junction of two different metals. The energy set free by chemical action, which under ordinary circumstances appears in the form of heat, is converted under appropriate conditions into electric motion. Conversely, the latter form of motion, as soon as the requisite conditions are present, passes into any other form of motion: into mass motion, to a very small extent directly into electro-dynamic attractions and repulsions; to a large extent, however, by the intervention of magnetism in the electro-magnetic machine; into heat - throughout a closed circuit, unless other changes are brought about; into chemical energy - in decomposition cells and voltameters introduced into the circuit, where the current dissociates compounds that are attacked in vain by other means.

All these transformations are governed by the basic law of the quantitative equivalence of motion through all its changes of form. Or, as Wiedemann expresses it: "By the law of conservation of force the mechanical work exerted in any way for the production of the current must be equivalent to the work exerted in producing all the effects of the current." The conversion of mass motion or heat into electricity[10] offers us no difficulties here; it has been shown that the so- called "electromotive force"[11] in the first case is equal to the work expended on that motion, and in the second case it is " at every junction of the thermopile directly proportional to its absolute temperature " (Wiedemann, III, p. 482), *i.e.* to the quantity of heat present at every junction measured in absolute units. The same law has in fact been proved valid also for electricity produced from chemical energy. But here the matter seems to be not so simple, at least for the theory now current. Let us, therefore, go into this somewhat more deeply.

One of the most beautiful series of experiments on the transformations of form of motion as a result of the action of a galvanic cell is that of Favre (1857-58). He put a Smee cell of five elements in a calorimeter; in a second calorimeter he put a small electro-magnetic motor, with the main axle and driving wheel projecting so as to be available for any kind of coupling. Each production in the cell of one gram of hydrogen, or solution of 32·6 grams of zinc (the old chemical equivalent of zinc, equal to half the now accepted atomic weight 65·2, and expressed in grams), gave the following results:

A. The cell enclosed in the calorimeter, excluding the motor: heat production 18,682 or 18,674 units of heat.

B. Cell and motor linked in the circuit, but the motor prevented from moving: heat in the cell 16,448, in the motor 2,219, together 18,667 units of heat.

C. As B, but the motor in motion without however lifting a weight: heat in the cell 13,888, in the motor 4,769, together 18,657 units of heat.

D. As C, but the motor raises a weight and so performs mechanical work==131,24 kilogram-metres: heat in the cell 15,427, in the motor 2,947, total 18,374 units of heat; loss in contrast to the above 18,682 equals 308 units of heat. But the mechanical work performed amounting to 131,24 kilogram-metres, multiplied by 1,000 (in order to bring the kilograms into line with the grams of the chemical results) and divided by the mechanical equivalent of heat== 423,5 kilogram-metres, gives 309 units of heat, hence exactly the loss mentioned above as the heat equivalent of the mechanical work performed.

The equivalence of motion in all its transformations is, therefore, strikingly proved for electric motion also, within the limits of unavoidable error. And it is likewise proved that the " electromotive force " of the galvanic battery is nothing but chemical energy converted into electricity, and the battery itself nothing but an apparatus that converts chemical energy on its liberation into electricity, just as a steam engine trans forms the heat supplied to it into mechanical motion, without in either case the converting apparatus supplying further energy on its own account.

A difficulty arises here, however, in relation to the traditional mode of conception. The latter ascribes an "*electric force of separation.*" to the battery in virtue of the conditions of contact present in it between the fluids and metals, which force is proportional to the electromotive force and therefore for a given battery represents a definite quantity of energy. What then is the relation of this electric force of separation, which according to the traditional mode of conception of the battery as such is inherently a source of energy even without chemical action, to the energy set free by chemical action? And if it is a source of energy independent of the latter, whence comes the energy furnished by it?

This question in a more or less unclear form constitutes the point of dispute between the contact theory founded by Volta and the chemical theory of the galvanic current that arose immediately afterwards.

The contact theory explained the current from the electric stresses arising in the battery on contact of the metals with one or more of the liquids, or even merely on contact of the liquids themselves, and from their neutralisation or that of the opposing electricities thus generated in the circuit. The pure contact theory regarded any chemical changes that might thereby occur as quite secondary. On the other hand, as early as 1805, Ritter maintained that a current could only be formed if the excitants reacted chemically even *before* closing the circuit. In general this older chemical theory is summarised by Wiedemann (I, p. 284) to the effect that according to it so-called contact electricity "makes its appearance only if at the same time there comes into play a real chemical action of the bodies in contact, or at any rate a disturbance of the chemical equilibrium, even if not directly bound up with chemical processes, a `tendency towards chemical action' between the bodies in contact."

It is seen that both sides put the question of the source of energy of the current only indirectly, as indeed could hardly be otherwise at the time. Volta and his successors found it quite in order that the mere contact of heterogeneous bodies should produce a constant current, and consequently be able to perform definite work without equivalent return. Ritter and his supporters are just as little clear how the chemical action makes the battery capable of producing the current and its performance of work. But if this point has long ago been cleared up for chemical theory by Joule, Favre, Raoult, and others, the opposite is the case for the contact theory. In so far as it has persisted, it remains essentially at the point where it started. Notions belonging to a period long outlived, a period when one had to be satisfied to ascribe a particular effect to the first available apparent cause that showed itself on the surface, regardless of whether motion was thereby made to arise out of nothing- notions that directly contradict the principle of the conservation of energy-thus continue to exist in the theory of electricity of to-day. And if the objectionable aspects of these ideas are shorn off, weakened, watered down, castrated, glossed over, this does not improve matters at all: the confusion is bound to become only so much the worse.

As we have seen, even the older chemical theory of the current declares the contact relations of the battery to be absolutely indispensable for the formation of the current: it maintains only that these contacts can never achieve a constant current without simultaneous chemical action. And even to-day it is still taken as a matter of course that the contact arrangements of the battery provide precisely the apparatus by means of which liberated chemical energy is transformed into electricity, and that it depends essentially on these contact arrangements whether and how much chemical energy actually passes into electric motion.

Wiedemann, as a one-sided empiricist, seeks to save what can be saved of the old contact theory. Let us follow what he has to say. He declares (I, p. 799):

" In contrast to what was formerly believed, the effect of contact of chemically indifferent bodies, *e.g.* of metals, is *neither indispensable for the theory of the pile*, nor proved by the facts that *Ohm* derived his law from it, a law that can be derived without this assumption, and that *Fechner*, who confirmed this law experimentally, likewise defended the contact theory. Nevertheless, the excitation of electricity by *metallic* contact, according to the experiments now available at least, is not to be denied, even though the quantitative results obtainable in this respect may always be tainted with an inevitable uncertainty owing to the impossibility of keeping absolutely clean the surfaces of the bodies in contact."

It is seen that the contact theory has become very modest. It concedes that it is not at all indispensable for explaining the current, and neither proved theoretically by Ohm nor experimentally by Fechner. It even concedes then that the so-called fundamental experiments, on which alone it can still rest, can never furnish other than uncertain results in a quantitative respect, and finally it asks us merely to recognise that in general it is by contact - although only of *metals*! - that electric motion occurs.

If the contact theory remained content with this, there would not be a word to say against it. It will certainly be granted that on the contact of two metals electrical phenomena occur, in virtue of which a preparation of a frog's leg can be made to twitch, an electroscope charged, and other movements brought about. The only question that arises in the first place is: whence comes the energy required for this?

To answer this question, we shall, according to Wiedemann (I, p.14)

"adduce *more or less the following* considerations: if the heterogeneous metal plates A and B are brought within a close distance of each other, they attract each other in consequence of the forces of adhesion. On mutual contact they lose the *vis viva*[12] of motion imparted to them by this attraction. (If we assume that the molecules of the metals are in a state of permanent vibration, it *could* also happen that, if on contact of the heterogeneous metals the molecules not vibrating simultaneously come into contact, an alteration of their vibration is thereby brought about with loss of *vis viva*.) The lost *vis viva* is *to a large extent* converted into heat. A *small portion* of it, however, is expended in bringing about a different distribution of the electricities previously unseparated. As we have already mentioned above, the bodies brought together become charged with equal quantities of positive and negative electricity, *possibly* as the result of an unequal attraction for the two electricities."

The modesty of the contact theory becomes greater and greater. At first it is admitted that the powerful electric force of separation, which has later such a gigantic work to perform, in itself possesses no energy of its own, and that it cannot function if energy is not supplied to it from outside. And then it has allotted to it a more than diminutive source of energy, the *vis viva* of adhesion, which only comes into play at scarcely measurable distances and which allows the bodies to travel a scarcely measurable length. But it does not matter: it indisputably exists and equally undeniably vanishes on contact. But even this minute source still furnishes too much energy for our purpose: a *large* part is converted into heat and only a *small* portion serves to evoke the electric force of separation. Now, although it is well known that cases enough occur in nature where extremely minute impulses bring about extremely powerful effects, Wiedemann himself seems to feel that his hardly trickling source of energy can with difficulty suffice here, and he seeks a possible second source in the assumption of an interference of the molecular vibrations of the two metals at the surfaces of contact. Apart from other difficulties encountered here, Grove and Gassiot have shown that for exciting electricity actual contact is not at all indispensable, as Wiedemann himself tells us on the previous page. In short, the more we examine it the more does the source of energy for the electric force of separation dwindle to nothing.

Yet up to now we hardly know of any other source for the excitation of electricity on metallic contact. According to Naumann (*Allg. u. phys. Chemie* [*General and Physical Chemistry*], Heidelberg, 1877, p. 675), "the contact-electromotive forces convert heat into electricity"; he finds "the assumption natural that the ability of these forces to produce electric motion depends on the quantity of heat present, or, in other words, that it is a function of the temperature," as has also been proved experimentally by Le Roux. Here too we find ourselves groping in the dark. The law of the voltaic series of metals forbids us to have recourse to the chemical processes that to a small extent are continually taking place at the contact surfaces, which are always covered by a thin layer of air and impure water, a layer as good as inseparable as far as we are concerned. An electrolyte should produce a constant current in the circuit, but the electricity of mere metallic contact, on the contrary, disappears on closing the circuit. And here we come to the real point: whether, and in what manner, the production of a constant current on the contact of chemically indifferent bodies is made possible by this "electric force of separation," which Wiedemann himself first of all restricted to metals, declaring it incapable of functioning without energy being supplied from outside, and then referred exclusively to a truly microscopical source of energy.

The voltaic series arranges the metals in such a sequence that each one behaves as electro-negative in relation to the preceding one and as electro-positive in relation to the one that follows it. Hence if we arrange a series of pieces of metal in this order, *e.g.* zinc, tin, iron, copper, platinum, we shall be able to obtain differences of electric potential at the two ends. If, however, we arrange the series of metals to form a circuit so that the zinc and platinum are in contact, the electric stress is at once neutralised and disappears. "Therefore the production of a constant current of electricity is not possible in a closed circuit of bodies belonging to the voltaic series." Wiedemann further supports this statement by the following theoretical consideration:

"In fact, if a constant electric current were to make its appearance in the circuit, it would produce heat in the metallic conductors themselves, and this heating could at the most be counterbalanced by cooling at the metallic junctions. In any case it would give rise to an uneven distribution of heat; moreover an electro-magnetic motor could be driven continuously by the current without any sort of supply from outside, and thus work would be performed, which is impossible, since on firmly joining the metals, for instance by soldering, no further changes to compensate for this work could take place even at the contact surfaces."

And not content with the theoretical and experimental proof that the contact electricity of metals by itself cannot produce any current, we shall see too that Wiedemann finds himself compelled to put forward a special hypothesis to abolish its activity even where it might perhaps make itself evident in the current.

Let us, therefore, try another way of passing from contact electricity to the current. Let us imagine, with Wiedemann, "two metals, such as a zinc rod and a copper rod, soldered together at one end, but with their free ends connected by a third body that does *not* act electromotively in relation to the two metals, but only conducts the opposing electricities collected on its surfaces, so that they are neutralised in it. Then the electric force of separation would always restore the previous difference of potential, thus a constant electric current would make its appearance in the circuit, a current that would be able to perform work without any compensation, which again is impossible. - Accordingly, there cannot be a body which only conducts electricity without electromotive activity in relation to the other bodies." We are no better off than before: the impossibility of creating motion again bars the way. By the contact of chemically indifferent bodies, hence by contact electricity as such, we shall never produce a current.

Let us therefore go back again and try a third way pointed out by Wiedemann:

"Finally, if we immerse a zinc plate and a copper plate in a liquid that contains a so- called *binary* compound,[13] which therefore can be decomposed into two chemically distinct constituents that completely saturate one another, *e.g.* dilute hydrochloric acid (H+Cl), etc., then according to paragraph 27 the zinc becomes negatively charged and the copper positively. On joining the metals, these electricities neutralise one another through the place of contact, through which, therefore, a *current of positive electricity* flows from the copper to the zinc. Moreover, since the electric force of separation making its appearance on the contact of these two metals carries away the positive electricity *in the same direction*, the effects of the electric forces of separation are *not* abolished as in a closed metallic circuit. *Hence there arises a constant current of positive electricity*, flowing in the closed circuit through the copper-zinc junction in the direction of the latter, and through the liquid from the zinc to the copper. We shall return in a moment (paragraph 34, *et seq.*) to the question how far the individual electric forces of separation present in the enclosed circuit *really* participate in the formation of the current. - A combination of conductors providing such a 'galvanic current' we term a galvanic element, or also a galvanic battery." (I, p. 45.)

Thus the miracle has been accomplished. By the mere electric contact force of separation, which, according to Wiedemann himself, cannot be effective without energy being supplied from outside, a constant current. has been produced. And if we were offered nothing more for its explanation than the above passage from Wiedemann, it would indeed be an absolute miracle. What have we learned here about the process?

1. If zinc and copper are immersed in a liquid containing a so-called *binary* compound, then, according to paragraph 27, the zinc becomes negatively charged and the copper positively charged. But in the whole of paragraph 27 there is no word of any binary compound. It describes only a simple voltaic element of a zinc plate and copper plate, with a piece of cloth moistened by an *acid* liquid interposed between them, and then investigates, without mentioning any chemical processes, the resulting static- electric charges of the two metals.

Hence, the so-called *binary* compound has been smuggled in here by the back-door.

2. What this binary compound is doing here remains completely mysterious. The circumstance that it "*can* be decomposed into two chemical constituents that fully saturate each other" (fully saturate each other after they have been decomposed?!) could at most teach us something new if it were *actually to decompose*. But we are not told a word about that, hence for the time being we have to assume that it does *not* decompose, *e.g.* in the case of paraffin.

3. When the zinc in the liquid has been negatively charged, and the copper positively charged, we bring

them into contact (outside the liquid). At once "these electricities neutralise one another through the place of contact, through which therefore a current of *positive electricity* flows from the copper to the zinc." Again, we do not learn why only a current of "positive" electricity flows in the one direction, and not also a current of "negative", electricity in the opposite direction. We do not learn at all what becomes of the negative electricity, which, hitherto, was just as necessary as the positive; the effect of the electric force of separation consisted precisely in setting them free to oppose one another. Now it has been suddenly suppressed, as it were eliminated, and it is made to appear as if there exists only positive electricity.

But then again, on p. 51, the precise opposite is said, for here "*the electricities unite* in one current"; consequently both negative and positive flow in it! Who will rescue us from this confusion?

4. "Moreover, since the electric force of separation making its appearance on the contact with these two metals *carries away* the positive electricity *in the same direction*, the effects of the electric forces of separation are not abolished as in a closed metallic circuit. *Hence*, there arises a constant current," etc. - This is a bit thick. For as we shall see a few pages later (p. 52), Wiedemann proves to us that on the "formation of a constant current ... the electric force of separation at the place of contact of the metals ... *must be inactive*, that not only does a current occur even when this force, instead of carrying away the positive electricity in the same direction, acts in opposition to the direction of the current, but that in this case too it is not compensated by a definite share of the force of separation of the battery and, hence, once again is inactive." Consequently, how can Wiedemann on p. 45 make an electric force of separation participate as a necessary factor in the formation of the current when on p. 52 he puts it out of action for the duration of the current, and that, moreover, by a hypothesis erected specially for this purpose?

5. " Hence there arises a *constant current* of positive electricity, flowing in the closed circuit from the copper through its place of contact with the zinc, in the direction of the latter, and through the liquid from the zinc to the copper." - But in the case of such a constant electric current, "heat would be produced by it in the conductors themselves," and also it would be possible for "an electro-magnetic motor to be driven by it and thus work performed," which, however, is impossible without supply of energy. Since Wiedemann up to now has not breathed a syllable as to whether such a supply of energy occurs, or whence it comes, the constant current so far remains just as much an impossibility as in both the previously investigated cases.

No one feels this more than Wiedemann himself. So he finds it desirable to hurry as quickly as possible over the many ticklish points of this remarkable explanation of current formation, and instead to entertain the reader throughout several pages with all kinds of elementary anecdotes about the thermal, chemical, magnetic, and physiological effects of this still mysterious current, in the course of which by way of exception he even adopts a quite popular tone. Then he suddenly continues (p. 49):

"We have now to investigate in what way the electric forces of separation are active in a closed circuit of two metals and a liquid, *e.g.* zinc, copper, and hydrochloric acid."

" We *know* that when the current traverses the liquid the constituents of the binary compound (HCl) contained in it become separated in such a manner that one constituent (H) *is set free* on the copper, and an equivalent amount of the other (Cl) on the zinc, *whereby* the latter constituent combines with an equivalent amount of zinc to form ZnCl."

We know! If we know this, we certainly do not know it from Wiedemann who, as we have seen, so far has not breathed a syllable about this process. Further, *if* we do know anything of this process, it is that it cannot proceed in the way described by Wiedemann.

On the formation of a molecule of HCl from hydrogen and chlorine, an amount of energy ==22,000 units of heat is liberated (Julius Thomsen). Therefore, to break away the chlorine from its combination with hydrogen, the same quantity of energy must be supplied from outside for each molecule of HCl. Where does the battery derive this energy? Wiedemann's description does not tell us, so let us look for ourselves.

When chlorine combines with zinc to form zinc chloride a considerably greater quantity of energy is liberated than is necessary to separate chlorine from hydrogen; (Zn,Cl_2) develops 97,210 and 2(H,Cl) 44,000 units of heat (Julius Thomsen). With that the process in the battery becomes comprehensible. Hence it is not, as Wiedemann relates, that hydrogen without more ado is liberated from the copper, and chlorine from the zinc, "whereby" then subsequently and accidentally the zinc and chlorine enter into combination. On the contrary, the union of the zinc with the chlorine is the essential, basic condition for the whole process, and as long as this does not take place, one would wait in vain for hydrogen on the copper.

The excess of energy liberated on formation of a molecule of $ZnCl_2$ over that expended on liberating two atoms of H from two molecules of HCl, is converted in the battery into electric motion and provides the entire "electromotive force" that makes its appearance in the current circuit. Hence it is not a mysterious "electric force of separation" that tears asunder hydrogen and chlorine without any demonstrable source of energy, it is the total chemical process taking place in the battery that endows all the "electric forces of separation" and "electromotive forces" of the circuit with the energy necessary for their existence.

For the time being, therefore, we put on record that Wiedemann's *second* explanation of the current gives us just as little assistance as his first one, and let us proceed further with the text:

"This process proves that the behaviour of the binary substance between the metals does not consist merely in a simple predominant attraction of its entire mass for one electricity or the other, as in the case of metals, but that in addition a special action of its constituents is exhibited. Since the constituent Cl is given off where the current of positive electricity enters the fluid, and the constituent H where the negative electricity enters, *we assume* that each equivalent of chlorine in the compound HCl is charged with a definite amount of negative electricity determining its attraction by the entering positive electricity. It is the *electro-negative constituent* of the compound. Similarly the equivalent H must be charged with positive electricity and so represent the electro-positive constituent of the compound. These charges *could* be produced on the combination of H and Cl in just the same way as on the contact of zinc and copper. Since the compound HCl as such is non-electric, *we must assume* accordingly that in it the atoms of the positive and negative constituents contain *equal* quantities of positive and negative electricity.

If now a zinc plate and a copper plate are dipped in dilute hydrochloric acid, *we can suppose* that the zinc has a stronger attraction towards the electro-negative constituent (Cl) than towards the electropositive one (H). Consequently, the molecules of hydrochloric acid in contact with the zinc *would* dispose themselves so that their electro- negative constituents are turned towards the zinc, and their electro-positive constituents towards the copper. Owing to the constituents when so arranged exerting their electrical attraction on the constituents of the next molecules of HCl, the whole series of molecules between the zinc and copper plates becomes arranged as in Fig. 10:

- Zinc											Copper +
	-	+	-	+	-	+	-	+	-	+	
	Cl	H	Cl	H	Cl	H	Cl	H	Cl	H	

If the second metal acts on the positive hydrogen as the zinc does on the negative chlorine, it would help to promote the arrangement. If it acted in the opposite manner, only more weakly, at least the direction would remain unaltered.

By the influence exerted by the negative electricity of the electro-negative constituent Cl adjacent to the zinc, the electricity *would* be so distributed in the zinc that places on it which are close to the Cl of the immediately adjacent atom of acid would become charged positively, those farther away negatively.

Similarly, negative electricity would accumulate in the .copper next to the electro-positive constituent (H) of the adjacent atom of hydrochloric acid, and the positive electricity would be driven to the more remote parts.

Next, the positive electricity in the zinc *would* combine with the negative electricity of the immediately adjacent atom of Cl, and the latter itself with the zinc, to form non-electric $ZnCl_2$. The electro-positive atom H, which was previously combined with this atom of Cl, *would* unite with the atom of Cl turned towards it belonging to the second atom of HCl, with simultaneous combination of the electricities contained in these atoms; similarly, the H of the second atom of HCl *would combine* with the Cl of the third atom, and so on, until finally an atom of H *would* be set free on the copper, the positive electricity of which would unite with the distributed negative electricity of the copper, so that it escapes in a non-electrified condition." This process would "repeat itself until the repulsive action of the electricities accumulated in the metal plates on the electricities of the hydrochloric acid constituents turned towards them balances the chemical attraction of the latter by the metals. If, however, the metal plates are joined by a conductor, the free electricities of the metal plates unite with one another and the above-mentioned processes can recommence. *In this way* a constant current of electricity comes into being. - It is evident that in the course of it a continual loss of *vis viva* occurs, owing to the constituents of the binary compound on their migration to the metals moving to the latter with a definite velocity and then coming to rest, either with formation of a compound ($ZnCl_2$) or by escaping in the free state (H). (*Note* [*by Wiedemann*]: Since the gain in *vis viva* on separation of the constituents Cl and H ... is compensated by the *vis viva* lost on the union of these constituents with the constituents of the adjacent atoms, the influence of this process can be neglected.) This loss of *vis viva* is equivalent to the quantity of heat which is set free in the visibly occurring chemical process, essentially, therefore, that produced on the solution of an equivalent of zinc in the dilute acid. This value must be the same as that of the work expended on separating the electricities. If, therefore, the electricities unite to form a current, then, during the solution of an equivalent of zinc and the giving off of an equivalent of hydrogen from the liquid, there must make its appearance in the whole circuit, whether in the form of heat or in the form of external performance of work, an amount of work that is likewise equivalent to the development of heat corresponding to this chemical process."

"Let us assume - could - we must assume - we can suppose - would be distributed - would become charged," etc., etc. Sheer conjecture and subjunctives from which only three actual indicatives can be definitely extracted: firstly, that the combination of the zinc with the chlorine is *now* pronounced to be the condition for the liberation of hydrogen; secondly, as we now learn right at the end and as it were incidentally, that the energy herewith liberated is the source, and indeed the exclusive source, of all energy required for formation of the current; and thirdly, that this explanation of the current formation is as directly in contradiction to both those previously given as the latter are themselves mutually contradictory.

Further it is said:

"For the formation of a constant current, therefore, there is active wholly and solely the electric force of separation which is derived from the unequal attraction and polarisation of the atoms of the binary compound in the exciting liquid of the battery by the metal electrodes; at the place of contact of the metals, at which no further mechanical changes can occur, the electric force of separation *must on the other hand be inactive*. That this force, if by chance it *counteracts* the electromotive excitation of the metals by the liquid (as on immersion of zinc and lead in potassium cyanide solution), is not compensated by a definite share of the force of separation at the place of contact, is proved by the above-mentioned complete proportionality of the total electric force of separation (and electromotive force) in the circuit, with the abovementioned heat equivalent of the chemical process. Hence it must be neutralised in another way. This would most simply occur on the assumption that on contact of the exciting liquid with the metals the electromotive force is produced in a double manner; on the one hand by an unequally strong attraction of the *mass* of the liquid as a whole towards one or the other electricity, on the other hand by the unequal attraction of the metals towards the *constituents* of the liquid charged with opposite electricities. ... Owing to the former unequal (mass) attraction towards the electricities, the liquids would fully conform to the law of the voltaic series of metals, and in a closed circuit ... complete neutralisation to zero of the electric forces of separation (and electromotive forces) take place; the second (*chemical*) action ... on the other hand would be provided *solely* by the electric force of separation necessary for formation of the current and the corresponding electromotive force." (I, pp. 52-3.)

Herewith the last relics of the contact theory are now happily eliminated from formation of the current, and simultaneously also the last relics of Wiedemann's first explanation of current formation given on p. 45. It is finally conceded without reservation that the galvanic battery is a simple apparatus for converting liberated chemical energy into electric motion, into so-called electric force of separation and electromotive force, in exactly the same way as the steam engine is an apparatus for converting heat energy into mechanical motion. In the one case, as in the other, the apparatus provides only the conditions for liberation and further transformation of the energy, but supplies no energy on its own account. This once established, it remains for us now to make a closer examination of this third version of Wiedemann's explanation of the current.

How are the energy transformations in the circuit of the battery represented here?

It is evident, he says, that in the battery

"a continual loss of *vis viva* occurs, owing to the constituents of the binary compound on their migration to the metals moving to the latter with a definite velocity and then coming to rest, either with formation of a compound ($ZnCl_2$) or by escaping in the free state (H).

This loss is equivalent to the quantity of heat which is set free in the visibly occurring chemical process, essentially, therefore, that produced on the solution of an equivalent of zinc in the dilute acid."

Firstly, if the process goes on in *pure* form, no heat at all is set free in the battery on solution of the zinc; the liberated energy is indeed converted directly into electricity and only from this converted once again into heat by the resistance of the whole circuit.

Secondly, *vis viva* is half the product of the mass and the square of the velocity. Hence the above statement would read: the energy set free on solution of an equivalent of zinc in dilute hydrochloric acid, ==so many calories, is likewise equivalent to half the product of the mass of the ions and the square of the velocity with which they migrate to the metals. Expressed in this way, the sentence is obviously false: the *vis viva* appearing on the migration of the ions is far removed from being equivalent to the energy set free by the chemical process.[14] But if it were to be so, no current would be possible, since there would be no energy remaining over for the current in the remainder of the circuit. Hence the further remark is introduced that the ions come to rest "either with formation of a compound ($ZnCl_2$) or by escaping in the free state." But if the loss of *vis viva* is to include also the energy changes taking place on these two processes, then we have indeed arrived at a deadlock. For it is precisely to these two processes taken together that we owe the whole liberated energy, so that there can be absolutely no question here of a *loss* of *vis viva*, but at most of a *gain*.

It is therefore obvious that Wiedemann himself did not mean anything definite by this sentence, rather the "loss of *vis viva*" represents only the *deus ex machina* which is to enable him to make the fatal leap from the old contact theory to the chemical explanation of the current. In point of fact, the loss of *vis viva* has now performed its function and is dismissed; henceforth the chemical process in the battery has undisputed sway as the sole source of energy for current formation, and the only remaining anxiety of our author is as to how he can politely get rid from the current of the last relic of excitation of electricity by the contact of chemically indifferent bodies, namely, the force of separation active at the place of contact of the two metals.

Reading the above explanation of current formation given by Wiedemann, one could believe oneself in the presence of a specimen of the kind of apologia that wholly - and half-credulous theologians of almost forty years ago employed to meet the philologico-historical bible criticism of Strauss, Wilke, Bruno Bauer, etc. The method is exactly the same, and it is bound to be so. For in both cases it is a question of saving the *heritage of tradition* from scientific thought. Exclusive empiricism, which at most allows thinking in the form of mathematical calculation, imagines that it operates only with undeniable facts. In reality, however, it operates predominantly with out-of-date notions, with the largely obsolete products of thought of its predecessors, and such are positive and negative electricity; the electric force of separation, the contact theory. These serve it as the foundation of endless mathematical calculations in which, owing to the strictness of the mathematical formulation, the hypothetical nature of the premises gets comfortably forgotten. This kind of empiricism is as credulous towards the results of the thought of its predecessors as it is sceptical in its attitude to the results of contemporary thought. For it the experimentally established facts have gradually become inseparable from the traditional interpretation associated with them; the simplest electric phenomenon is presented falsely, *e.g.* by smuggling in the two electricities; this empiricism *cannot* any longer describe the facts correctly, because the traditional interpretation is woven into the description. In short, we have here in the field of the theory of electricity a tradition just as highly developed as that in the field of theology. And since in both fields the results of recent research, the establishment of hitherto unknown or disputed facts and of the necessarily following theoretical conclusions, run pitilessly counter to the old traditions, the defenders of these traditions find themselves in the direst dilemma. They have to resort to all kinds of subterfuges and untenable expedients, to the glossing over of irreconcilable contradictions, and thus finally land themselves into a medley of contradictions from which they have no escape. It is this faith in all the old theory of electricity that entangles Wiedemann here in the most hopeless contradictions, simply owing to the hopeless attempt to reconcile rationally the old explanation of the current by "contact force," with the modern one by liberation of chemical energy.

It will perhaps be objected that the above criticism of Wiedemann's explanation of the current rests on juggling with words. It may be objected that, although at the beginning Wiedemann expresses himself somewhat carelessly and inaccurately, still he does finally give the correct account in accord with the principle of the conservation of energy and so sets everything right. As against this view, we give below another example, his description of the process in the battery: zinc-dilute sulphuric acid-copper:

"If, however, the two plates are joined by a wire, a galvanic current arises .... *By the electrolytic process*, one equivalent of hydrogen is given off at the copper plate from the water of the dilute sulphuric acid, this hydrogen escaping in bubbles. At the zinc there is formed one equivalent of oxygen which oxidises the zinc to form zinc oxide, the latter becoming dissolved in the surrounding acid to form sulphuric zinc oxide." (I, pp. 592-3.)

To break up water into hydrogen and oxygen requires an amount of energy of 69,924 heat- units for each molecule of water. From where then comes the energy in the above cell? "By the electrolytic process." And from where does the electrolytic process get it? No answer is given.

But Wiedemann further tells us, not once, but at least twice (I, p. 472 and p. 614), that "according to recent knowledge the water itself is not decomposed," but that in our case it is the sulphuric acid H_2SO_4 that splits up into H_2 on the one hand and into SO_3+O on the other hand, whereby under suitable conditions H_2 and O can escape in gaseous form. But this alters the whole nature of the process. The H_2 of the H_2SO_4 is directly replaced by the bivalent zinc, forming zinc sulphate, $ZnSO_4$. There remains over, on the one side H_2, on the other SO_3+O. The two gases escape in the proportions in which they unite to form water, the SO_3 unites with the water of the solvent to reform H_2SO_4, *i.e.* sulphuric acid. The formation of $ZnSO_4$, however, develops sufficient energy not only to replace and liberate the hydrogen of the sulphuric acid, but also to leave over a considerable excess, which in our case is expended in forming the current. Hence the zinc does not wait until the electrolytic process puts free oxygen at its disposal, in order first to become oxidised and then to become dissolved in the acid. On the contrary, it enters directly into the process, which only comes into being at all *by this participation of the zinc*.

We see here how obsolete chemical notions come to the aid of the obsolete contact notions. According to modern views, a salt is an acid in which hydrogen has been replaced by a metal. The process under investigation confirms this view; the direct replacement of the hydrogen of the acid by the zinc fully explains the energy change. The old view, adhered to by Wiedemann, regards a salt as a compound of a metallic oxide with an acid and therefore speaks of sulphuric zinc oxide instead of zinc sulphate. But to arrive at sulphuric zinc oxide in our battery of zinc and sulphuric acid, the zinc must first be oxidised. In order to oxidise the zinc fast enough, we must have free oxygen. In order to get free oxygen, we must assume - since hydrogen appears at the copper plate - that the water is decomposed. In order to decompose water, we need tremendous energy. How are we to get this? Simply "by the electrolytic process" which itself cannot come into operation as long as its chemical end product, the "sulphuric zinc oxide," has not begun to be formed. The child gives birth to the mother.

Consequently, here again Wiedemann puts the whole course of the process absolutely the wrong way round and upside down. And the reason is that he lumps together active and passive electrolysis, two directly opposite processes, simply as electrolysis.

So far we have only examined the events in the battery, *i.e.* that process in which an excess of energy is set free by chemical action and is converted into electricity by the arrangements of the battery. But it is well known that this process can also be reversed: the electricity of a constant current produced in the battery from chemical energy can, in its turn, be reconverted into chemical energy in a decomposition cell inserted in the circuit. The two processes are obviously the opposites of each other; if the first is regarded as chemico-electric, then the second is electro-chemical. Both can take place in the same circuit with the same substances. Thus, the voltaic pile from gas elements, the current of which is produced by the union of hydrogen and oxygen to form water, can, in a decomposition cell inserted in the circuit, furnish hydrogen and oxygen in the proportion in which they form water. The usual mode of view lumps these two opposite processes together under the single expression: electrolysis, and does not even distinguish between active and passive electrolysis, between an exciting liquid and a passive electrolyte. Thus Wiedemann treats of electrolysis in general for 143 pages and then adds at the end some remarks on "electrolysis in the battery," in which, moreover, the processes in actual batteries only occupy the lesser part of the seventeen pages of this section. Also in the "theory of electrolysis" that follows, this contrast of battery and decomposition cell is not even mentioned, and anyone who looked for some treatment of the energy changes in the circuit in the next chapter, "the influence of electrolysis on the conduction resistance and the electromotive force in the circuit" would be bitterly disappointed.

Let us now consider the irresistible "electrolytic process" which is able to separate H_2 from O without visible supply of energy, and which plays the same role in the present section of the book as did previously the mysterious "electric force of separation."

"Besides the *primary, purely electrolytic* process of separation of the ions, a quantity of *secondary, purely chemical* processes, quite independent of the first, take place by the action of the ions split off by the current. This action can take place on the material of the electrodes and on the bodies that are decomposed, and in the case of solutions also on the solvent." (I, p. 481.) Let us return to the above-mentioned battery: zinc and copper in dilute sulphuric acid. Here, according to Wiedemann's own statement, the separated ions are the H_2 and O of the water. Consequently for him the oxidation of the zinc and the formation of $ZnSO_4$ is a secondary, purely chemical process, independent of the electrolytic process, in spite of the fact that it is only through it that the primary process becomes possible.

Let us now examine somewhat in detail the confusion that must necessarily arise from this inversion of the true course of events:

Let us consider in the first place the so-called secondary processes in the decomposition cell, of which Wiedemann puts forward some examples [15] (pp. 481, 482).

I. "The electrolysis of Na_2SO_4 dissolved in water. This "breaks up ... into 1 equivalent of SO_3+O ... and 1 equivalent of Na .... The latter, however, reacts on the water solvent and splits off from it 1 equivalent of

H, while 1 equivalent of sodium is formed and becomes dissolved in the surrounding water."

The equation is

$Na_2SO_4+2H_2O==O+SO_3+2NaOH+2H$.

In fact, in this example the decomposition

$Na_2SO_4==Na_2+SO_3+O$

could be regarded as the primary electro-chemical process, and the further transformation

$Na_2+2H_2O==2NaHO+2H$

as the secondary, purely chemical one. But this secondary process is effected immediately at the electrode where the hydrogen appears, the very considerable quantity of energy (111,810 heat-units for Na, O, H, aq. according to Julius Thomsen) thereby liberated is therefore, at least for the most part, converted into electricity, and only a portion in the cell is transformed directly into heat. But the latter can also happen to the chemical energy directly or primarily liberated in the *battery*. The quantity of energy which has thus become available and converted into electricity, however, is to be subtracted from that which the current has to supply for continued decomposition of the Na_2SO_4 If the conversion of sodium into hydrated oxide appeared in the *first* moment of the total process as a secondary process, from the second moment on wards it becomes an essential factor of the total process and so ceases to be secondary.

But yet a third process takes place in this decomposition cell: SO_3 combines with H_2O to form H_2SO_4, sulphuric acid, provided the SO_3 does not enter into combination with the metal of the positive electrode, in which case again energy would be liberated. But this change does not necessarily proceed immediately at the electrode, and consequently the quantity of energy (21,320 heat-units, J. Thomsen) thereby liberated becomes converted wholly or mainly into heat in the cell itself, and provides at most a very small portion of the electricity in the current. The only really secondary process occurring in this cell is therefore not mentioned at all by Wiedemann.

II. "If a solution of copper sulphate is electrolysed between a positive copper electrode and a negative one of platinum, 1 equivalent of copper separates out for 1 equivalent of water decomposed at the negative platinum electrode, with simultaneous decomposition of sulphuric acid in the same current circuit; at the positive electrode, 1 equivalent of SO_4 should make its appearance; but this combines with the copper of the electrode to form one equivalent of $CuSO_4$, which becomes dissolved in the water of the electrolysed solution."

In the modern chemical mode of expression we have, therefore, to represent the process as follows: copper is deposited on the platinum; the liberated SO_4, which cannot exist by itself, splits up into SO_3+O, the latter escaping in the free state; the SO_3 takes up H_2O from the aqueous solvent and forms H_2SO_4, which again combines with the copper of the electrode to form $CuSO_4$, H_2 being set free. Accurately speaking, we have here three processes: (1) the separation of Cu and SO_4; (2) $SO_3+O+H_2O==H_2SO_4+O$; (3) $H_2SO_4+Cu==H_2+Cu SO_4$. It is natural to regard the first as primary, the two others as secondary. But if we inquire into the energy changes, we find that the first process is completely compensated by a part of the third: the separation of copper from SO_4 by the reuniting of both at the other electrode. If we leave out of account the energy required for shifting the copper from one electrode to the other, and likewise the inevitable, not accurately determinable, loss of energy in the cell by conversion into heat, we have here a case where the so-called primary process withdraws no energy from the current. The current provides energy exclusively to make possible the separation of H_2 and O, which moreover is indirect, and this proves to be the real chemical result of the whole process - hence, for carrying out a *secondary*, or even tertiary, process.

Nevertheless, in both the above examples, as in other cases also, it is undeniable that the distinction of primary and secondary processes has a relative justification. Thus in both cases, among other things, water also is apparently decomposed and the elements of water given off at the opposite electrodes. Since, according to the most recent experiments, absolutely pure water comes as near as possible to being an ideal non-conductor, hence also a non-electrolyte, it is important to show that in these and similar cases it is not the water that is directly electro-chemically decomposed, but that the elements of water are separated from the acid, in the formation of which here it is true the water solvent must participate.

III. "If one electrolyses hydrochloric acid simultaneously in two U-tubes ... using in one tube a zinc positive electrode and in the other tube one of copper, then in the first tube a quantity of zinc 32.53 is dissolved, in the other a quantity of copper 2 x 32.7."

For the time being let us leave the copper out of account and consider the zinc. The decomposition of HCl is regarded here as the primary process, the solution of Zn as secondary.

According to this conception, therefore, the current brings to the decomposition cell from outside the energy necessary for the separation of H and Cl, and after this separation is completed the Cl combines with the Zn, whereby a quantity of energy is set free that is subtracted from that required for separating H and Cl; the current needs only therefore to supply the difference. So far everything agrees beautifully; but if we consider the two amounts of energy more closely we find that the one liberated on the formation of $ZnCl_2$ is *larger* than that used up in separating 2HCl; consequently, that the current not only does not need to supply energy, but on the contrary *receives energy*. We are no longer confronted by a passive electrolyte, but by an exciting fluid, not a decomposition cell but a *battery*, which strengthens the current-forming voltaic pile by a new element; the process which we are supposed to conceive as secondary becomes absolutely primary, becoming the source of energy of the whole process and making the latter independent of the current supplied by the voltaic pile.

We see clearly here the source of the whole confusion prevailing in Wiedemann's theoretical description. Wiedemann's point of departure is electrolysis; whether this is active or passive, battery or decomposition cell, is all one to him: saw-bones is saw-bones, as the sergeant-major said to the doctor of philosophy doing his year's military service. And since it is easier to study electrolysis in the decomposition cell than in the battery, he does, in fact, take the decomposition cell as his point of departure, and he makes the processes taking place in it, and the partly justifiable division of them into primary and secondary, the measure of the altogether reverse processes in the battery, not even noticing when his decomposition cell becomes surreptitiously transformed into a battery. Hence he is able to put forward the statement: "the chemical affinity that the separated substances have for the electrodes has no influence on the electrolytic process as such" (I, p. 471), a sentence which in this absolute form, as we have seen, is totally false. Hence, further, his threefold theory of current formation: firstly, the old traditional one, by means of pure contact; secondly, that derived by means of the abstractly conceived electric force of separation, which in an inexplicable manner obtains for itself or for the "electrolytic process" the requisite energy for splitting apart the H and Cl in the battery and for forming a current as well; and finally, the modern, chemico-electric theory which demonstrates the source of this energy in the algebraic sum of the chemical reactions in the battery. Just as he does not notice that the second explanation overthrows the first, so also he has no idea that the third in its turn overthrows the second. On the contrary, the principle of the conservation of energy is merely added in a quite superficial way to the old theory handed down from routine, just as a new geometrical theorem is appended to an earlier one. He has no inkling that this principle makes necessary a revision of the whole traditional point of view in this as in all other fields of natural science. Hence Wiedemann confines himself to noting the principle in his explanation of the current, and then calmly puts it on one side, taking it up again only right at the end of the book, in the chapter on the work performed by the current. Even in the theory of the excitation of electricity by contact (I, p. 781 *et seq*.) the conservation of energy plays no role at all in relation to the chief subject dealt with, and is only incidentally brought in for throwing light on subsidiary matters: it is and remains a " secondary process."

Let us return to the above example III. There the same current was used to electrolyse hydrochloric acid in two U-tubes, but in one there was a positive electrode of zinc, in the other, the positive electrode used was of copper. According to Faraday's basic law of electrolysis, the same galvanic current decomposes in each cell equivalent quantities of electrolyte, and the quantities of the substances liberated at the two electrodes are also in proportion to their equivalents (I, p. 470). In the above case it was found that in the first tube a quantity of zinc 32.53 was dissolved, and in the other a quantity of copper 2 x 31.7. "Nevertheless," continues Wiedemann, "this is no proof for the equivalence of these values. They are observed only in the case of very weak currents with the formation of zinc chloride ... on the one hand, and of copper chloride ... on the other. In the case of denser currents, with the same amount of zinc dissolved, the quantity of dissolved copper would sink with formation of increasing quantities of chloride ... up to 31.7."

It is well known that zinc forms only a single compound with chlorine, zinc chloride, ZnCl; copper on the other hand forms two compounds, cupric chloride, $CuCl_2$, and cuprous chloride, Cu_2Cl_2. Hence the process is that the weak current splits off two copper atoms from the electrode for each two chlorine atoms, the two copper atoms remaining united by *one* of their two valencies, while their two free valencies unite with the two chlorine atoms:

Cu--Cl
|
Cu--Cl

On the other hand, if the current becomes stronger, it splits the copper atoms apart altogether, and each one unites with two chlorine atoms.

Cl

/

Cu
\
Cl

In the case of currents of medium strength, both compounds are formed side by side. Thus it is solely the strength of the current that determines the formation of one or the other compound, and therefore the process is essentially *electro*-chemical, if this word has any meaning at all. Nevertheless Wiedemann declares explicitly that it is secondary, hence not electro-chemical, but purely chemical.

The above experiment is one performed by Renault (1867) and is one of a whole series of similar experiments in which the same current is led in one U-tube through salt solution (positive electrode - zinc), and in another cell through a varying electrolyte with various metals as the positive electrode. The amounts of the other metals dissolved here for each equivalent of zinc diverged very considerably, and Wiedemann gives the results of the whole series of experiments which, however, in point of fact, are mostly self-evident chemically and could not be otherwise. Thus, for one equivalent of zinc, only two-thirds of an equivalent of gold is dissolved in hydrochloric acid. This can only appear remarkable if, like Wiedemann, one adheres to the old equivalent weights and writes ZnCl for zinc chloride, according to which both the chlorine and the zinc appear in the chloride with only a *single* valency. In reality two chlorine atoms are included to one zinc atom, $ZnCl_2$, and as soon as we know this formula we see at once that in the above determination of equivalents, the chlorine atom is to be taken as the unit and not the zinc atom. The formula for gold chloride, however, is $AuCl_3$, from which it is at once seen that $3ZnCl_2$ contains exactly as much chlorine as $2AuCl_3$, and so all primary, secondary, and tertiary processes in the battery or cell are compelled to transform, for each part by weight[16] of zinc converted into zinc chloride, neither more nor less than two-thirds of a part by weight of gold into gold chloride. This holds absolutely unless the compound $AuCl_3$[17] also could be prepared by galvanic means, in which case two equivalents of gold even would have to be dissolved for one equivalent of zinc, when also similar variations according to the current strength could occur as in the case of copper and chlorine mentioned above. The value of Renault's researches consists in the fact that they show how Faraday's law is confirmed by facts that appear to contradict it. But what they are supposed to contribute in throwing light on secondary processes in electrolysis is not evident.

Wiedemann's third example led us again from the decomposition cell to the battery, and in fact the battery offers by far the greatest interest when one investigates the electrolytic processes in relation to the transformations of energy taking place. Thus we not infrequently encounter batteries in which the chemico-electric processes seem to take place in direct contradiction to the law of the conservation of energy and in opposition to chemical affinity.

According to Poggendorff's measurements, the battery: zinc - concentrated salt solution - platinum, provides a current of strength 134.6. Hence we have here quite a respectable quantity of electricity, one third more than in the Daniell cell. What is the source of the energy appearing here as electricity? The "primary" process is the replacement of sodium in the chlorine compound by zinc. But in ordinary chemistry it is not zinc that replaces sodium, but *vice versa*, sodium replacing zinc from chlorine and other compounds. The "primary" process, far from being able to give the current the above quantity of energy, on the contrary requires itself a supply of energy from outside in order to come into being. Hence, with the mere "primary" process we are again at a standstill. Let us look, therefore, at the real process. We find that the change is not

$Zn+2NaCl==ZnCl_2+2Na$,

but

$Zn+2NaCl+2H_2O==ZnCl_2+2NaOH+H_2$.

In other words, the sodium is not split off in the free state at the negative electrode, but forms a hydroxide as in the above example I (pp. 118-119). To calculate the energy changes taking place here, Julius Thomsen's determinations provide us at least with certain important data. According to them, the energy liberated on combination is as follows:

$(ZnCl_2)==97,210$, $(ZnCl_2$, aqua$)==15,630$,

making a total for dissolved

zinc chloride	==112,840	heat-units.
2 (Na, O, H, aqua)	==223,620	" "
	336,460	" "

Deducting consumption of energy on the separations:

2(Na, Cl, aq.)	==193,020	heat-units.
$2(H_2O)$	==136,720	" "
	329,740	" "

The excess of liberated energy equals 6,720 heat-units.

This amount is obviously small for the current strength obtained, but it suffices to explain, on the one hand, the separation of the sodium from chlorine, and on the other hand, the current formation in general.

We have here a striking example of the fact that the distinction of primary and secondary processes is purely relative and leads us *ad absurdum* as soon as we take it absolutely. The primary electrolytic process, taken alone, not only cannot produce any current, but cannot even take place itself. It is only the secondary, ostensibly purely chemical process that makes the primary one possible and, moreover, supplies the whole surplus energy for current formation. In reality, therefore, it proves to be the primary process and the other the secondary one. When the rigid differences and opposites, as imagined by the metaphysicians and metaphysical natural scientists, were dialectically reversed into their opposites by Hegel, it was said that he had twisted the words in their mouths. But if nature itself proceeds exactly like old Hegel, it is surely time to examine the matter more closely.

With greater justification one can regard as secondary those processes which, while taking place *in consequence* of the chemico-electric process of the battery or the electro- chemical process of the decomposition cell, do so independently and separately, occurring therefore at the same distance from the electrodes. The energy changes taking place in such secondary processes likewise do not enter into the electric process; directly they neither withdraw energy from it nor supply energy to it. Such processes occur very frequently in the decomposition cell; we saw an instance in the example I above on the formation of sulphuric acid during electrolysis of sodium sulphate. They are, however, of lesser interest here. Their occurrence in the battery, on the other hand, is of greater practical importance. For although they do not directly supply energy to, or withdraw it from, the chemico-electric process, nevertheless they alter the total available energy present in the battery and thus affect it indirectly.

There belong here, besides subsequent chemical changes of the ordinary kind, the phenomena that occur when the ions are liberated at the electrodes in a different condition from that in which they usually occur in the free state, and when they pass over to the latter only after moving away from the electrodes. In such cases the ions can assume a different density or a different state of aggregation. They can also undergo considerable changes in regard to their molecular constitution, and this case is the most interesting. In all these cases, an analogous heat change corresponds to the secondary chemical or physical change of the ions taking place at a certain distance from the electrodes; usually heat is set free, in some cases it is consumed. This heat change is, of course, restricted in the first place to the place where it occurs: the liquid in the battery or decomposition cell becomes warmer or cooler while the rest of the circuit remains unaffected. Hence this heat is called *local* heat. The liberated chemical energy available for conversion into electricity is, therefore, diminished or increased by the equivalent of this positive or negative local heat produced in the battery. According to Favre, in a battery with hydrogen peroxide and hydrochloric acid two-thirds of the total energy set free is consumed as local heat; the Grove cell, on the other hand, on closing the circuit became considerably cooler and therefore supplied energy from outside to the circuit by absorption of heat. Hence we see that these secondary processes also react on the primary one. We can make whatever approach we like; the distinction between primary and secondary processes remains merely a relative one and is regularly suspended in the interaction of the one with the other. If this is forgotten and such relative opposites treated as absolute, one finally gets hopelessly involved in contradictions, as we have seen above.

As is well known, on the electrolytic separation of gases the metal electrodes become covered with a thin layer of gas; in consequence the current strength decreases until the electrodes are saturated with gas, whereupon the weakened current again becomes constant. Favre and Silbermann have shown that local heat arises also in such a decomposition cell; this local heat, therefore, can only be due to the fact that the gases are not liberated at the electrodes in the state in which they usually occur, but that they are only brought into their usual state, after their separation from the electrode, by a further process bound up with the development of heat. But what is the state in which the gases are given off at the electrodes? It is impossible to express oneself more cautiously on this than Wiedemann does. He terms it "a certain," an "allotropic," an "active," and finally, in the case of oxygen, several times an "ozonised" state. In the case of hydrogen his statements are still more mysterious. Incidentally, the view comes out that ozone and, hydrogen peroxide are the forms in which this "active" state is realised. Our author is so keen in his pursuit of ozone that he even explains the extreme electro-negative properties of certain peroxides from the fact that they possibly "contain a part of the oxygen in the *ozonised state!*" (I, p. 57.) Certainly both ozone and hydrogen peroxide are formed on the so-called decomposition of water, but only in small quantities. There is no basis at all for assuming that in the case mentioned local heat is produced first of all by the origin and then by the decomposition of any large quantities of the above two compounds. We do not know the heat of formation of ozone, O_3, from *free* oxygen atoms. According to Berthelot the heat of formation of hydrogen peroxide from H_2O (liquid)+O=-21,480; the origin of this compound in any large amount would therefore give rise to a large excess of energy (about 30 per cent. of the energy required for the separation of H_2 and O), which could not but be evident and demonstrable. Finally, ozone and hydrogen peroxide would only take oxygen into account (apart from current reversals, where both gases would come together at the same electrode), but not hydrogen. Yet the latter also escapes in an "active" state, so much so that in the combination: potassium nitrate solution between platinum electrodes, it combines directly with the nitrogen split off from the acid to form ammonia.

In point of fact, all these difficulties and doubts have no existence. The electrolytic process has no monopoly of splitting off bodies "in an active state." Every chemical decomposition does the same thing. It splits off the liberated chemical elements in the first place in the form of free atoms of O, H, N, etc., which only after their liberation can unite to form molecules, O_2, H_2, N_2, etc., and on thus uniting give off a definite, though up-to-now still undetermined,[18] quantity of energy which appears as heat. But during the infinitesimal moment of time when the atoms are free, they are the bearers of the total quantity of energy that they can take up at all; while possessed of their maximum energy they are free to enter into any combination offered them. Hence they are "in an active state" in contrast to the molecules O_2, H_2, N_2, which have already surrendered a part of this energy and cannot enter into combination with other elements without this quantity of energy surrendered being re-supplied from outside. We have no need, therefore, to resort to ozone and hydrogen peroxide, which themselves are only products of this active state. For instance, we can undertake the above-mentioned formation of ammonia on electrolysis of potassium nitrate even without a battery, simply by chemical means, by adding to nitric acid or a nitrate solution a liquid in which hydrogen is set free by a chemical process. In both cases the active state of the hydrogen is the same. But the interesting point about the electrolytic process is that here the transitory existence of the free atoms becomes as it were tangible. The process here is divided into two phases: the electrolysis provides free atoms at the electrodes, but their combination to form molecules occurs at some distance from the electrodes. However infinitesimally minute this distance may be compared to measurements where masses are concerned, it suffices to prevent the energy liberated on formation of the molecules being used for the electric process, at least for the most part, and so determines its conversion into heat - the local heat in the battery. But it is owing to this that the fact is established that the elements are split off as free atoms and for a moment have existed in the battery as free atoms. This fact, which in pure chemistry can only be established by theoretical conclusions,[19] is here proved experimentally, in so far as this is possible without sensuous perception of the atoms and molecules themselves. Herein lies the high scientific importance of the so-called local heat of the battery.

The conversion of chemical energy into electricity by means of the battery is a process about whose course we know next to nothing, and which we shall get to know in more detail only when the *modus operandi* of electric motion itself becomes better known.

The battery has ascribed to it an "electric force of separation" which is given for each particular battery. As we saw at the outset, Wiedemann conceded that this electric force of separation is not a definite form of energy. On the contrary, it is primarily nothing more than the capacity, the property, of a battery to convert a definite quantity of liberated chemical energy into electricity in unit time. Throughout the whole course of events, this chemical energy itself never assumes the form of an "electric force of separation," but, on the contrary, at once and immediately takes on the form of so-called "electromotive force" *i.e.* of electric motion. If in ordinary life we speak of the force of a steam engine in the sense that it is capable in unit time of converting a definite quantity of heat into the motion of masses, this is not a reason for introducing the same confusion of ideas into scientific thought also. We might just as well speak of the varying force of a pistol, a carbine, a smooth-bored gun, and a blunderbuss, because, with equal gunpowder charges and projectiles of equal weight, they shoot varying distances. But here the wrongness of the expression is quite obvious. Everyone knows that it is the ignition of the gunpowder charge that drives the bullet, and that the varying range of the weapon is only determined by the greater or lesser dissipation of energy according to the length of the barrel, the form of the projectile, and the tightness of its fitting. But it is the same for steam power and for the electric force of separation. Two steam engines - other conditions being equal, *i.e.* assuming the quantity of energy liberated in equal periods of time to be equal in both - or two galvanic batteries, of which the same thing holds good, differ as regards performance of work only owing to their greater or lesser dissipation of energy. And if until now all armies have been able to develop the technique of firearms without the assumption of a special shooting force of weapons, the science of electricity has absolutely no excuse for assuming an "electric force of separation" analogous to this shooting force, a force which embodies absolutely no energy and which therefore of itself cannot perform a millionth of a milligram-metre of work.

The same thing holds good for the second form of this "force of separation," the "electric force of contact of metals" mentioned by Helmholtz. It is nothing but the property of metals to convert on their contact the existing energy of another form into electricity. Hence it is likewise a force that does not contain a particle of energy. If we assume with Wiedemann that the source of energy of contact electricity lies in the *vis viva* of the motion of adhesion, then this energy exists in the first place in the form of this mass motion and on its vanishing becomes converted immediately into electric motion, without even for a moment assuming the form of an "electric force of contact."

And now we are assured in addition that the electromotive force, *i.e.* the chemical energy, reappearing as electric motion is proportional to this "electric force of separation," which not only contains no energy, but owing to the very conception of it *cannot* contain any! This proportionality between non-energy and energy obviously belongs to the same mathematics as that in which there figures the "ratio of the unit of electricity to the milligram." But the absurd form, which owes its existence only to the conception of a *simple property* as a *mystical* force, conceals a quite simple tautology: the capacity of a given battery to convert liberated chemical energy into electricity is measured - by what? By the quantity of the energy reappearing in the circuit as electricity in relation to the chemical energy consumed in the battery. That is all.

In order to arrive at an electric force of separation, one must take seriously the device of the two electric fluids. To convert this from its neutrality to its polarity, hence to split it apart, requires a certain expenditure of energy - the electric force of separation. Once separated, the two electricities can, on being reunited, again give off the same quantity of energy - electromotive force. But since nowadays no one, not even Wiedemann, regards the two electricities as having a real existence, it means that one is writing for a defunct public if one deals at length with such a point of view.

The basic error of the contact theory consists in the fact that it cannot divorce itself from the idea that contact force or electric force of separation is a *source of energy*, which of course was difficult when the mere capacity of an apparatus to bring about transformation of energy had been converted into a *force*; for indeed, a *force* ought precisely to be a definite form of energy. Because Wiedemann cannot rid himself of this unclear notion of force, although alongside of it the modern ideas of indestructible and uncreatable energy have been forced upon him, he falls into his nonsensical explanation of the current, No. 1, and into all the later demonstrated contradictions.

If the expression "electric force of separation" is directly contrary to reason, the other "electromotive force" is at least superfluous. We had heat engines long before we had electro-motors, and yet the theory of heat has been developed quite well without any special thermo-motor force. Just as the simple expression heat includes all phenomena of motion that belong to this form of energy, so also can the expression electricity in its own sphere. Moreover, very many forms of action of electricity are not at all directly "motor": the magnetisation of iron, chemical decomposition, conversion into heat. And finally, in every natural science, even in mechanics, it is always an advance if the word *force* can somehow be got rid of.[20]

We saw that Wiedemann did not accept the chemical explanation of the processes in the battery without a certain reluctance. This reluctance continually attacks him; where he can blame anything on the so-called chemical theory, this is certain to occur. Thus, "it is by no means established that the electromotive force is proportional to the intensity of chemical action." (I, p. 791.) Certainly not in every case; but where this proportionality does not occur, it is only a proof that the battery has been badly constructed, that dissipation of energy takes place in it. For that reason Wiedemann is quite right in paying no attention in his theoretical deductions to such subsidiary circumstances which falsify the purity of the process, but in simply assuring us that the electromotive force of a cell is equal to the mechanical equivalent of the chemical action taking place in it in unit time with unit intensity of current.

In another passage we read:

"That further, in the acid-alkali battery, the combination of acid and alkali is not the cause of current formation follows from the experiments paragraph 61 (Becquerel and Fechner), paragraph 260 (Dubois-Raymond), and paragraph 261 (Worm-Müller), according to which in certain cases when these are present in equivalent quantities no current makes its appearance, and likewise from the experiments (Henrici) mentioned in paragraph 62, that on interposing a solution of potassium nitrate between the potassium hydroxide and nitric acid, the electromotive force makes its appearance in the same way as without this interposition." (I, p. 791.)

The question whether the combination of acid and alkali is the cause of current formation is a matter of very serious concern for our author. Put in this form it is very easy to answer. The combination of acid and alkali is first of all the cause of a *salt* being formed with liberation of energy. Whether this energy wholly or partly takes the form of electricity depends on the circumstances under which it is liberated. For instance, in the battery: nitric acid and potassium hydroxide between platinum electrodes, this will be at least partially the case, and it is a matter of indifference for the *formation* of the current whether a potassium nitrate solution is interposed between the acid and alkali or not, since this can at most delay the salt formation but not prevent it. If, however, a battery is formed like one of Worm-Müller's, to which Wiedemann constantly refers, where the acid and alkali solution is in the middle, but a solution of their salt at both ends, and in the same concentration as the solution that is formed in the battery, then it is obvious that no current can arise, because on account of the end members - since everywhere identical bodies are formed - *no ions can be produced*. Hence the conversion of the liberated energy into electricity has been prevented in as direct a manner as if the circuit had not been closed; it is therefore not to be wondered at that no current is obtained. But that acid and alkali can in general produce a current is proved by the battery: carbon, sulphuric acid (one part in ten of water), potassium hydroxide (one part in ten of water), carbon, which according to Raoult has a current strength of 73.[21] And that, with suitable arrangement of the battery, acid and alkali can provide a current strength corresponding to the large quantity of energy set free on their combination, is seen from the fact that the most powerful batteries known depend almost exclusively on the formation of alkali salts, *e.g.* that of Wheatstone: platinum, platinic chloride, potassium amalgam - current strength 230; lead peroxide, dilute sulphuric acid, potassium amalgam==326; manganese peroxide instead of lead peroxide==280; in each case, if zinc amalgam was employed instead of potassium amalgam, the current strength fell almost exactly by 100. Similarly in the battery: manganese dioxide, potassium permanganate solution, potassium hydroxide, potassium, Beetz obtained the current strength 302, and further: platinum, dilute sulphuric acid, potassium==293.8 ; Joule: platinum, nitric acid, potassium hydroxide, potassium amalgam==302. The "cause" of these exceptionally strong current strengths is certainly the combination of acid and alkali, or alkali metal, and the large quantity of energy thereby liberated.

A few pages further on it is again stated:

"It must, however, be carefully borne in mind that the equivalent in work of the whole chemical action taking place at the place of contact of the heterogeneous bodies is not to be directly regarded as the measure of the electromotive force in the circuit. When, for instance, in the acid-alkali battery (*iterum Crispinus!*) of Becquerel, these two substances combine, when carbon is consumed in the battery: platinum, molten potassium nitrate, carbon, when the zinc is rapidly dissolved in an ordinary cell of copper, impure zinc, dilute sulphuric acid, with formation of local currents, then a large part of the work produced (it should read: energy liberated) in these chemical processes . . . is converted into heat and is thus lost for the total current circuit." (I, p. 798.)

All these processes are to be referred to loss of energy in the battery; they do not affect the fact that the electric motion arises from transformed chemical energy, but only affect the quantity of energy transformed.

Electricians have devoted an endless amount of time and trouble to composing the most diverse batteries and measuring their "electromotive force." The experimental material thus accumulated contains very much of value, but certainly still more that is valueless. For instance, what is the scientific value of experiments in which "water" is employed as the electrolyte, when, as has now been proved by F. Kohlrausch, water is the worst conductor and therefore also the worst electrolyte,[22] and where, therefore, it is not the water but its unknown impurities that caused the process? And yet, for instance, almost half of all Fechner's experiments depend on such employment of water, even his "*experimentum crucis*," by which he sought to establish the contact theory impregnably on the ruins of the chemical theory. As is already evident from this, in almost all such experiments, a few only excepted, the chemical processes in the battery, which however form the source of the so-called electromotive force, remain practically disregarded. There are, however, a number of batteries whose chemical composition does not allow of any certain conclusion being drawn as to the chemical changes proceeding in them when the current circuit is closed. On the contrary, as Wiedemann (I, p. 797) says, it is "not to be denied that we are by no means in all cases able to obtain an insight into the chemical attractions in the battery." Hence, from the ever more important chemical aspect, all such experiments are valueless in so far as they are not repeated with these processes under control.

In these experiments it is indeed only quite by way of exception that any account is taken of the energy changes taking place in the battery. Many of them were made before the law of the equivalence of motion was recognised in natural science, but as a matter of custom they continue to be dragged from one textbook into another without being controlled or their value summed up. It has been said that electricity has no inertia (which has about as much sense as saying velocity has no specific gravity), but this certainly cannot be said of the *theory* of electricity.

So far, we have regarded the galvanic cell as all arrangement in which, in consequence of the contact relations established, chemical energy is liberated in some way for the time being unknown, and converted into electricity. We have likewise described the decomposition cell as an apparatus in which the reverse process is set up, electric motion being converted into chemical energy and used up as such. In so doing we had to put in the foreground the chemical side of the process that has been so much neglected by electricians, because this was the only way of getting rid of the lumber of notions handed down from the old contact theory and the theory of the two electric fluids. This once accomplished, the question was whether the chemical process in the battery takes place under the same conditions as outside it, or whether special phenomena make their appearance that are dependent on the electric excitation.

In every science, incorrect notions are, in the last resort, apart from errors of observation, incorrect notions of correct facts. The latter remain even when the former are shown to be false. Although we have discarded the old contact theory, the established facts remain, of which they were supposed to be the explanation. Let us consider these and with them the electric aspect proper of the process in the battery.

It is not disputed that on the contact of heterogeneous bodies, with or without chemical changes, an excitation of electricity occurs which can be demonstrated by means of an electroscope or a galvanometer. As we have already seen at the outset, it is difficult to establish in a particular battery the source of energy of these in themselves extremely minute phenomena of motion; it suffices that the existence of such an external source is generally conceded.

In 1850-53, Kohlrausch published a series of experiments in which he assembled the separate components of a battery in pairs and tested the static electric stresses produced in each case; the electromotive force of the cell should then be composed of the algebraic sum of these stresses. Thus, taking the stress of Zn/Cu==100, he calculates the relative strengths of the Daniell and Grove cells as follows:

For the Daniell cell:

$Zn/Cu+amalg.Zn/H_2SO_4+Cu/SO_4==100+149-21==228.$

For the Grove cell:

$Zn/Pt+amalg.Zn/H_2SO_4+Pt/HNO_3==107+149+149==405,$

which closely agrees with the direct measurement of the current strengths of these cells. These results, however, are by no means certain. In the first place, Wiedemann himself calls attention to the fact that

Kohlrausch only gives the final result but "unfortunately no figures for the results of the separate experiments." In the second place, Woodman himself repeatedly recognises that all attempts to determine quantitatively the electric excitation on contact of metals, and still more on contact of metal and fluid, are at least very uncertain on account of the numerous unavoidable sources of error. If, nevertheless, lie repeatedly uses Kohlrausch's figures in his calculations, we shall do better not to follow him here, the more so as another means of determination is available which is not open to these objections.

If the two exciting plates of a battery are immersed in the liquid and then joined into a circuit by the terminals of a galvanometer, according to Wiedemann, "the initial deflection of its magnetic needle, before chemical changes have altered the strength of the electric excitation, is a measure of the sum of electromotive forces in the circuit." Batteries of various strengths, therefore, give initial deflections of various strengths, and the magnitude of these initial deflections is proportional to the current strength of the corresponding batteries.

It looks as if we had here tangibly before our eyes the "electric force of separation," the "contact force," which causes motion independently of any chemical action. And this in fact is the opinion of the whole contact theory. In reality we are confronted here by a relation between electric excitation and chemical action that we have not yet investigated. In order to pass to this subject, we shall first of all examine rather more closely the so- called electromotive law; in so doing, we shall find that here also the traditional contact notions not only provide no explanation, but once again directly bar the way to an explanation.

If in any cell consisting of two metals and a liquid, *e.g.* zinc, dilute hydrochloric acid, and copper, one inserts a third metal such as a platinum plate, without connecting it to the external circuit by a wire, then the initial deflection of the galvanometer will be exactly the same as *without* the platinum plate. Consequently it has no effect on the excitation of electricity. But it is not permissible to express this so simply in electromotive language. Hence one reads:

"The sum of the electromotive forces of zinc and platinum and platinum and copper now takes the place of the electromotive force of zinc and copper in the liquid. Since the path of the electricities is not perceptibly altered by the insertion of the platinum plate, we can conclude from the identity of the galvanometer readings in the two cases, that the electromotive force of zinc and copper in the liquid is equal to that of zinc and platinum plus that of platinum and copper in the same liquid. This would correspond to Volta's theory of the excitation of electricity between the metals as such. The result, which holds good for all liquids and metals, is expressed by saying: On their electromotive excitation by liquids, metals follow the law of the voltaic series. This law is also given the name of the *electromotive law*." (Wiedemann, I, p. 62.)

In saying that in this combination the platinum does not act at all as an exciter of electricity, one expresses what is simply a fact. If one says that it does act as an exciter of electricity, but in two opposite directions with equal strength so that the effect is neutralised, the fact is converted into a hypothesis merely for the sake of doing honour to the "electromotive force." In both cases the platinum plays the role of a fictitious person.

During the first deflection there is still no closed circuit. The acids, being undecomposed,[23] do not conduct; they can only conduct by means of the ions. If the third metal has no influence on the first deflection, this is simply the result of the fact that it is still *isolated*.

How does the third metal behave *after* the establishment of the constant current and during the latter?

In the voltaic series of metals in most liquids, zinc lies after the alkali metals fairly close to the positive end and platinum at the negative end, copper being between the two. Hence, if platinum is put as above between copper and zinc it is negative to them both. If the platinum had any effect at all, the current in the liquid would have to flow to the platinum both from the zinc and from the copper, that is away from both electrodes to the unconnected platinum; which would be a *contradictio in adjectio*. The basic condition for the action of several different metals in the battery consists precisely in their being connected among themselves externally to the circuit. An unconnected, superfluous metal in the battery acts as a non-conductor; it can neither form ions nor allow them to pass through, and without ions we know of no conduction in electrolytes. Hence it is not merely a fictitious person, it even stands in the way by forcing the ions to go round it.

The same thing holds good if we connect the zinc and platinum, leaving the copper unconnected in the middle; here the latter, if it had any effect at all, would produce a current from the zinc to the copper and another from the copper to the platinum; hence it would have to act as a sort of intermediary electrode and give off hydrogen on the side turned towards the zinc, which again is impossible.

If we discard the traditional electromotive mode of expression the case becomes extremely simple. As we have seen, the galvanic battery is an apparatus in which chemical energy is liberated and transformed into electricity. It consists as a rule of one or more liquids and two metals as electrodes, which must be connected together by a conductor outside the liquids. This completes the apparatus. Anything else that is dipped unconnected into the exciting liquid, whether metal, glass, resin, or whatever you like, cannot participate in the chemico-electric process taking place in the battery, in the formation of the current, so long as the liquid is not chemically altered; it can at most *hinder* the process. Whatever the capacity for exciting electricity of a third metal dipped into the liquid may be, or that of one or both electrodes of the battery, it cannot have any effect so long as this metal is not connected to the circuit outside the liquid.

Consequently, not only is Wiedemann's *derivation*, as given above, of the so- called electromotive law false, but the interpretation which he gives to this law is also false. One can speak neither of a compensating electromotive activity of the unconnected metal, since the sole condition for such activity is cut off from the outset; nor can the so- called electromotive law be deduced from a fact which lies outside the sphere of this law.

In 1845, old Poggendorff published a series of experiments in which he measured the electromotive force of various batteries, that is to say the quantity of electricity supplied by each of them in unit time.[24] Of these experiments, the first twenty-seven are of special value, in each of which three given metals were one after another connected in the same exciting liquid to three different batteries, and the latter investigated and compared as regards the quantity of electricity produced. As a good adherent of the contact theory, Poggendorff also put the third metal unconnected in the battery in each experiment and so had the satisfaction of convincing himself that in all eighty-one batteries this third metal remained a pure inactive element in the combination. But the significance of these experiments by no means consists in this fact but rather in the confirmation and establishment of the correct meaning of the so-called electromotive law.

Let us consider the above series of batteries in which zinc, copper, and platinum are connected together in pairs in dilute hydrochloric acid. Here Poggendorff found the quantities of electricity produced to be as follows, taking that of a Daniell cell as 100:

Zinc-copper	..	.. 78.8
Copper-platinum		.. 74.3
Total	..	..153.1
Zinc-platinum	..	..153.7

Thus, zinc in direct connection with platinum produced almost exactly the same quantity of electricity as zinc-copper copper-platinum. The same thing occurred in all other batteries, whatever liquids and metals were employed. When, from a series of metals in the same exciting liquid, batteries were formed in such a way that in each case, according to the voltaic series valid for this liquid, the second, third, fourth, etc., one after the other were made to serve as negative electrodes for the preceding one and as positive electrodes for that which followed, then the sum of the quantities of electricity produced by all these batteries is equal to the quantity of electricity produced by a battery formed directly between the two end members of the whole metallic series. For instance, in dilute hydrochloric acid the sum total of the quantities of electricity produced by the batteries zinc-zinc, zinc-iron, iron- copper, copper-silver, and silver-platinum, would be equal to that produced by the battery: zinc-platinum. A pile formed from all the cells of the above series would, other things being equal, be exactly neutralised by the introduction of a zinc-platinum cell with a current of the opposite direction.

In this form, the so-called electromotive law has a real and considerable significance. It reveals a new aspect of the inter-connection between chemical and electrical action. Hitherto, on investigating mainly the *source* of energy of the galvanic current, this source, the chemical change, appeared as the active side of the process; the electricity was produced from it and therefore appeared primarily as passive. Now this is reversed. The electric excitation determined by the constitution of the heterogeneous bodies put into contact in the battery can neither add nor subtract energy from the chemical action (other than by conversion of liberated energy into electricity). It can, however, according as the battery is made up, accelerate or slow down this action.

If the battery, zinc-dilute hydrochloric acid-copper, produced in unit time only half as much electricity for the current as the battery, zinc-dilute hydrochloric acid-platinum, this means in chemical terms that the first battery produces in unit time only half as much zinc chloride and hydrogen as the second. *Hence the chemical action has been doubled, although the purely chemical conditions for this action have remained the same*. The electric excitation has become the regulator of the chemical action; it appears now as the active side, the chemical action being the passive side.

Thus, it becomes comprehensible that a number of processes previously regarded as purely chemical now appear as electro-chemical. Chemically pure zinc is not attacked at all by dilute acid, or only very weakly; ordinary commercial zinc, on the other hand, is rapidly dissolved with formation of a salt and production of hydrogen; it contains an admixture of other metals and carbon, which make their appearance in unequal amounts at various places of the surface. Local currents are formed in the acid between them and the zinc itself, the zinc areas forming the positive electrodes and the other metals the negative electrodes, the hydrogen bubbles being given off on the latter. Likewise the phenomenon that when iron is dipped into a solution of copper sulphate it becomes covered with a layer of copper is now seen to be an electro-chemical phenomenon, one determined by the currents which arise between the heterogeneous areas of the surface of the iron.

In accordance with this we find also that the voltaic series of metals in liquids corresponds on the whole to the series in which metals replace one another from their compounds with halogens and acid radicles. At the extreme negative end of the voltaic series we regularly find the metals of the gold group, gold, platinum, palladium, rhodium, which oxidise with difficulty, are little or not at all attacked by acids, and which are easily precipitated from their salts by other metals. At the extreme positive end are the alkali metals which exhibit exactly the opposite behaviour: they are scarcely to be split off from their oxides except with the greatest expenditure of energy; they occur in nature almost exclusively in the form of salts, and of all the metals they have by far the greatest affinity for halogens and acid radicles. Between these two come the other metals in somewhat varying sequence, but such that on the whole electrical and chemical behaviour correspond to one another. The sequence of the separate members varies according to the liquids and has hardly been finally established for any single liquid. It is even permissible to doubt whether there exists such an *absolute* voltaic series of metals for any single liquid. Given suitable batteries and decomposition cells, two pieces of the same metal can act as positive and negative electrodes respectively, hence the same metal can be both positive and negative towards itself. In thermocells which convert heat into electricity, with large temperature differences at the two junctions, the direction of the current is reversed; the previously positive metal becomes negative and *vice versa*. Similarly, there is no absolute series according to which the metals replace one another from their chemical compounds with a particular halogen or acid radicle; in many cases by supplying energy in the form of heat we are able almost at will to alter and reverse the series valid for ordinary temperatures.

Hence we find here a peculiar interaction between chemical action and electricity. The chemical action in the battery, which provides the electricity with the total energy for current formation, is in many cases first brought into operation, and in all cases quantitatively regulated, by the electric charges developed in the battery. If previously the processes in the battery seemed to be chemico-electric in nature, we see here that they are just as much electro-chemical. From the point of view of formation of the *constant current*, chemical action appears to be the primary thing: from the point of view of *excitation* of current it appears as secondary and accessory. The reciprocal action excludes any absolute primary or absolute secondary; but it is just as much a double-sided process which from its very nature can be regarded from two different standpoints; to be understood in its totality it must even be investigated from both standpoints one after the other, before the total result can be arrived at. If, however, we adhere onesidedly to a single standpoint as the absolute one in contrast to the other, or if we arbitrarily jump from one to the other according to the momentary needs of our argument, we shall remain entangled in the onesidedness of metaphysical thinking; the interconnection escapes us and we become involved in one contradiction after another.

We saw above that, according to Wiedemann, the initial deflection of the galvanometer, immediately after dipping the exciting plates into the liquid of the battery and before chemical changes have altered the strength of the electric excitation, is "a measure of the sum of electromotive forces in the circuit."

So far we have become acquainted with the so-called electromotive force as a form of energy, which in our case was produced in an equivalent amount from chemical energy, and which in the further course of the process became reconverted into equivalent quantities of heat, mass motion, etc. Here we learn all at once that the "sum of the electromotive forces in the circuit" is already in existence *before* this energy has been liberated by chemical changes; in other words, that the electromotive force is nothing but the capacity of a particular cell to liberate a particular quantity of chemical energy in unit time and to convert it into electric motion. As previously in the case of the electric force of separation, so here also the electromotive force appears as a force which does not contain a single spark of energy. Consequently, Wiedemann understands by "electromotive force" two totally different things: on the one hand, the capacity of a battery to liberate a definite quantity of given chemical energy and to convert it into electric motion, on the other hand, the quantity of electric motion itself that is developed. The fact that the two are proportional, that the one is a measure for the other, does not do away with the distinction between them. The chemical action in the battery, the quantity of electricity developed, and the heat in the circuit derived from it, when no other work is performed, are even more than proportional, they are equivalent; but that does not infringe the diversity between them. The capacity of a steam engine with a given cylinder bore and piston stroke to produce a given quantity of mechanical motion from the heat supplied is very different from this mechanical motion itself, however proportional to it it may be. And while such a mode of speech was tolerable at a time when natural science had not yet said anything of the conservation of energy, nevertheless it is obvious that since the recognition of this basic law it is no longer permissible to confuse real active energy in any form with the capacity of an apparatus to impart this form to energy which is being liberated. This confusion is a corollary of the confusion of force and energy in the case of the electric force of separation; these two confusions provide a harmonious background for Wiedemann's three mutually contradictory explanations of the current, and in the last resort are the basis in general for all his errors and confusions in regard to so-called "electromotive force."

Besides the above-considered peculiar interaction between chemical action and electricity there is also a second point that they have in common which likewise indicates a closer kinship between these two forms of motion. Both can exist only for an *infinitesimal* period. The chemical process takes place suddenly for each group of atoms undergoing it. It can be prolonged only by the presence of new material that continually renews it. The same thing holds for electric motion. Hardly has it been produced from some other form of motion before it is once more converted into a third form; only the continual readiness of available energy can produce the constant current, in which at each moment new quantities of motion assume the form of energy and lose it again.

An insight into this close connection of chemical and electric action and *vice versa* will lead to important results in both spheres of investigation.[25] Such an insight is already becoming more and more widespread. Among chemists, Lothar Meyer, and after him Kekulé, have plainly stated that a revival of the electro-chemical theory in a rejuvenated form is impending. Among electricians also, as indicated especially by the latest works of F. Kohlrausch, the conviction seems finally to have taken hold that only exact attention to the chemical processes in the battery and decomposition cell can help their science to emerge from the blind alley of old traditions.

And in fact one cannot see how else a firm foundation is to be given to the theory of galvanism and so secondarily to that of magnetism and static electricity, other than by a chemically exact general revision of all traditional uncontrolled experiments made from an obsolete scientific standpoint, with exact attention to establishing the energy changes and preliminary rejection of all traditional theoretical notions about electricity.

Notes

1. For the factual material in this chapter we rely mainly on Wiedemann's *Lehre vom Galvanismus and Elektromagnetismus* [*Theory of Galvanism and Electro-Magnetism*], 2 vols. in 3 parts, 2nd edition,

Braunschweig, 1874.

In *Nature*, June 15, 1882, there is a reference to this "admirable treatise, which in its forthcoming shape, with electrostatics added, will be the greatest experimental treatise on electricity in existence." [*Note by F. Engels.*]

2. The central discovery was J. J. Thomson's discovery of the electron.

3., 4. See Appendix II, p. 334.?????

5. We now know that a current in metals is due to a movement of electrons, whereas in electrolytes, e.g. salt water and gases, molecules with both positive and negative charges carry it.

6. This is incorrect, but was generally stated in textbooks at the time when Engels wrote.

7. The view that electrical energy was located in the ether was the basis of the experiments which gave us radio. It seemed in turn to have been negated by the discovery of electrons. However, the electron in turn is now regarded by many physicists as a system of waves rather than a well-defined particle.

8. Every broadcast is a confirmation of this theory to-day.

9. Now called dynamos.

10. I use the term " electricity " in the sense of electric motion with the same justification that the general term " heat " is used to express the form of motion that our senses perceive as heat. This is the less open to objection in as much as any possible confusion with the state of stress of electricity is here expressly excluded in advance. [Note by F. Engels.]

11. Once more it must be remembered that this term was very loosely used sixty years ago, and now has a definite meaning, not of course equivalent to any form of energy.

12. *I.e.* kinetic energy.

13. As we should now say, an electrolyte.

14. F. Kohlrausch has recently calculated (Wiedemann's *Annalen*, VI, p. 206) that "immense forces" are required to drive the ions through the water solvent. To cause one milligram to move through a distance of one millimetre requires an attractive force which for H ==32,500 kg., for Cl=5,200 kg., hence for HCl=37,700 kg. - Even if these figures are absolutely correct, they do not affect what has been said above. But the calculation contains the hypothetical factors hitherto inevitable in the sphere of electricity and therefore requires control by experiment.[*] Such control appears possible. In the first place, these "immense forces" must reappear as a definite quantity of energy in the place where they are consumed, *i.e.* in the above case in the battery. Secondly, the energy consumed by them must be smaller than that supplied by the chemical processes of the battery, and there should be a definite difference. Thirdly, this difference must be used up in the rest of the circuit and likewise be quantitatively demonstrable there. Only after confirmation by this control can the above figures be regarded as final. The demonstration in the decomposition cell appears still more susceptible of realisation. (*Note by F. Engels*.)

* Actually the hypothesis was incorrect. It is now believed that when HCl is dissolved in water, it is

almost completely broken up into positive H ions and negative Cl ions, which do not require "immense forces" to drive them. Engels was fully justified in his scepticism.

15. It may be noted here once for all that Wiedemann employs throughout the old chemical equivalent values, writing HO, ZnCl, etc. In my equations, the modern atomic weights are everywhere employed, putting, therefore, H_2O, $ZnCl_2$, etc. [*Note by F. Engels*.]

16. As it stands this is untrue. Probably "part by weight" is a slip of Engels' pen for "equivalent by weight" or some such phrase.

17. Again this does not make sense as it stands. Presumably Engels meant to refer to a hypothetical AuCl.

18. This quantity has now not only been determined but utilised. Thus if the hydrogen is previously split into atoms, the ordinary oxy-hydrogen flame can be made a great deal hotter.

19. It has since been proved experimentally.

20. This statement has been very fully confirmed by the progress of physics in the last fifty years. It is interesting to note that idealistic writers have used this disappearance of the notion of force as an argument that materialism is being refuted!

21. In all the following data relating to current strength, the Daniell cell is put==100. [*Note by F. Engels*.]

22. A column of the purest water prepared by Kohlrausch 1mm. in length offered the same resistance as a copper conductor of the same diameter and a length approximately that of the moon's orbit. Naumann, *Allgemeine Chemie* [*General Chemistry*], p. 729.[**] [*Note by F. Engels*.]

** Appendix II, p. 335.

23. This statement is in accord with theory fifty years ago, but incorrect.

24. This is, of course, not electromotive force in the modern sense of the term.

25. This has, of course, been very completely verified by the researches of the last fifty years. Electrical theory was revolutionised by Thomson's study of electrical conduction in gases, which led to his discovery of electrons. And the whole of chemistry, including the chemistry of such unions as that between carbon and hydrogen, which at first sight is quite unconnected with electrical phenomena, has been restated in terms of electrons.

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Dialectics of Nature - Notes

Under Construction...

Engels' Dialectics of Nature

VIII: Tidal Friction, Kant and Thomson-Tait
On the Rotation of the Earth and Lunar Attraction

THOMSON and Tait, *Nat. Philos.*, I, p. 191 (paragraph .276):

"There are also indirect resistances, owing to friction impeding the tidal motions, on all bodies which, like the earth, have portions of their free surfaces covered by liquid, which, as long as these bodies move relatively to neighbouring bodies, must keep drawing off energy from their relative motions. Thus, if we consider, in the first place, the action of the moon alone, on the earth with its oceans, lakes, and rivers, we perceive that it must tend to equalise the periods of the earth's rotation about its axis, and of the revolution of the two bodies about their centre of inertia; because as long as these periods differ, the tidal action of the earth's surface must keep subtracting energy from their motions. To view the subject more in detail, and, at the same time, to avoid unnecessary complications, let us suppose the moon to be a uniform spherical body, the mutual action and reaction of gravitation between her mass and the earth's will be equivalent to a single force in some line through her centre; *and must be such as to impede the earth's rotation as long as this is performed in a shorter period than the moon's motion round the earth*. It must, therefore, lie in some such direction as the line MQ in the diagram, which represents, necessarily with enormous exaggeration, its deviation, OQ, from the earth's centre. Now the actual force on the moon in the line MQ may be regarded as consisting of a force in the line MO towards the earth's centre, sensibly equal in amount to the whole force, and a comparatively very small force in the line MT perpendicular to MO. This latter is very nearly tangential to the moon's path, and is in the direction *with* her motion. Such a force, if suddenly commencing to act, would, in the first place, increase the moon's velocity; but after a certain time she would have moved so much farther from the earth, in virtue of this acceleration, as to have lost, by moving against the earth's attraction, as much velocity as she had gained

Fig. 1 Dialectics of Nature - Tidal Friction

by the tangential accelerating force. The effect of a continued tangential force, acting with the motion, but so small in amount as to make only a small deviation at any moment from the circular form of the orbit, is to gradually increase the distance from the central body, and to cause as much again as its own amount of work to be done against the attraction of the central mass, by the kinetic energy of motion lost. The circumstances will be readily understood by considering this motion round the central body in a very gradual spiral path tending outwards. Provided the law of force is the inverse square of the distance, the tangential component of gravity against the motion will be twice as great as the disturbing tangential force in the direction with the motion; and therefore one-half of the amount of work done against the former, is done by the latter, and the other half by kinetic energy taken from the motion. The integral effect on the moon's motion, of the particular disturbing cause now under consideration, is most easily found by using the principle of moments of momenta. Thus we see that as much moment of momentum is gained in any time by the motions of the centres of inertia, of the moon and earth relatively to their common centre of inertia, as is lost by the earth's rotation about its axis. The sum of the moments of momentum of the centres of inertia of the moon and earth as moving at present, is about 4.45 times the present moment of momentum of the earth's rotation.

The average plane of the former is the ecliptic; and therefore the axes of the two moments are inclined to one another at the average angle of 23° 27.5', which, as we are neglecting the sun's influence on the plane of the moon's motion, may be taken as the actual inclination of the two axes at present. The resultant, or whole moment of momentum, is therefore 5.38 times that of the earth's present rotation, and its axis is inclined 19° 13' to the axis of the earth. Hence the ultimate tendency of the *tides* is to reduce the earth and moon to a simple uniform rotation with this resultant moment round this resultant axis, as if they were two parts of one rigid body: in which condition the moon's distance would be increased (approximately) in the ratio 1:1.46, being the ratio of the square of the present moment of momentum of the centres of inertia to the square of the whole moment of momentum; and the period of revolution in the ratio 1:1.77, being that of the cubes of the same quantities. The distance would therefore be increased to 847,100 miles, and the period lengthened to 48.36 days. Were there no other body in the universe but the earth and the moon, these two bodies might go on moving thus for ever, in circular orbits round their common centre of inertia, and the earth rotating about its axis in the same period, so as always to turn the same face to the moon, and, therefore, to have all the liquids at its surface at rest relatively to the solid. But the existence of the sun would prevent any such state of things from being permanent. There would be solar tides - twice high water and twice low water - in the period of the earth's revolution relatively to the sun (that is to say, twice in the solar day, or, which would be the same thing, the month). This could not go on without *loss of energy by fluid friction*. It is not easy to trace the whole course of the disturbance in the earth's and moon's motions which this cause would produce, but its ultimate effect must be to bring the earth, moon, and sun to rotate round their common centre of inertia, like parts of one rigid body."[1]

Kant, in 1754, was the first to put forward the view that the rotation of the earth is retarded by tidal friction and that this effect will only reach its conclusion "when its (the earth's) surface will be at relative rest in relation to the moon, *i.e.* when it will rotate on its axis in the same period that the moon takes to revolve round the earth, and consequently will always turn the same side to the latter." He held the view that this retardation had its origin in tidal friction alone, arising, therefore, from the presence of fluid masses on the earth:

"If the earth were a quite solid mass without any fluid, neither the attraction of the sun nor of the moon would do anything to alter its free axial rotation; for it draws with equal force both the eastern and western parts of the terrestrial sphere and so does not cause any inclination either to the one or to the other side; consequently it allows the earth full freedom to continue this rotation unhindered as if there were no external influence on it."

Kant could rest content with this result. All scientific pre-requisites were lacking at that time for penetrating deeper into the effect of the moon on the rotation of the earth. Indeed, it required almost a hundred years before Kant's theory obtained general recognition, and still longer before it was discovered that the ebb and flow of the tides are only the *visible* aspect of the effect exercised by the attraction of the sun and moon on the rotation of the earth.

This more general conception of the matter is just that which has been developed by Thomson and Tait. The attraction of the moon and sun affects not only the fluids of the terrestrial body or its surface, but the whole mass of the earth in general in a manner that hinders the rotation of the earth. As long as the period of the earth's rotation does not coincide with the period of the moon's revolution round the earth, so long the attraction of the moon - to deal with this alone first of all - has the effect of bringing the two periods closer and closer together. If the rotational period of the (relative) central body were longer than the period of revolution of. the satellite, the former would be gradually lengthened; [2] if it were shorter, as is the case for the earth, it would be slowed down. But neither in the one case will kinetic energy be created out of nothing, nor in the other will it be annihilated. In the first case, the satellite would approach closer to the central body and shorten its period of revolution, in the second it would increase its distance from it and acquire a longer period of revolution. In the first case, the satellite by approaching the central body loses exactly as much potential energy as the central body gains in kinetic energy from the accelerated rotation; in the second case the satellite, by increasing its distance gains exactly the same amount of potential energy as the central body loses in kinetic energy of rotation. The total amount of dynamic energy, potential and kinetic, present in the earth-moon system remains the same; the system is fully conservative.[3]

It is seen that this theory is entirely independent of the physico-chemical constitution of the bodies concerned. It is derived from the general laws of motion of free heavenly bodies, the connection between them being produced by attraction in proportion to their masses and inverse proportion to the square of the distances between them. The theory has obviously arisen as a generalisation of Kant's theory of tidal friction, and is even presented here by Thomson and Tait as its substantiation on mathematical lines. But in reality - and remarkably enough the authors have simply no inkling of this - in reality it excludes the special case of tidal friction.

Friction is hindrance to the motion of mass, and for centuries it was regarded as the destruction of such motion, and therefore of kinetic energy. We now know that friction and impact are the two forms in which kinetic energy is converted into molecular energy, into heat. In all friction, therefore, kinetic energy as such is lost in order to re-appear, not as potential energy in the sense of dynamics, but as molecular motion in the definite form of heat. The kinetic energy lost by friction is, therefore, in the first place *really lost* for the dynamic aspects of the system concerned. It can only become dynamically effective again if it is *re-converted* from the form of heat into kinetic energy.

How then does the matter stand in the case of tidal friction? It is obvious that here also the whole of the kinetic energy communicated to the masses of water on the earth's surface by lunar attraction is converted into heat, whether by friction of the water particles among themselves in virtue of the viscosity of the water, or by friction at the rigid surface of the earth and the comminution of rocks which stand up against the tidal motion. Of this heat there is re-converted into kinetic energy only the infinitesimally small part that contributes to evaporation at the surface of the water. But even this infinitesimally small amount of kinetic energy, leaving the total system earth-moon at a part of the earth's surface, remains first of all subject to the conditions prevailing at the earth's surface, and these conditions lead to all energy active there reaching one and the same final destiny: final conversion into heat and radiation into space.

Consequently, to the extent that tidal friction indisputably acts in an impeding manner on the rotation of the earth, the kinetic energy used for this purpose is absolutely lost to the dynamic system earth-moon. It can therefore not re-appear within this system as dynamic potential energy. In other words, of the kinetic energy expended in impeding the earth's rotation by means of the attraction of the moon, only that part that acts on the *solid* mass of the earth's body can entirely re-appear as dynamic potential energy, and hence be compensated for by a corresponding increase of the distance of the moon. On the other hand, the part that acts on the fluid masses of the earth can do so only in so far as it does not set these masses themselves into a motion opposite in direction to that of the earth's rotation, for such a motion is *wholly* converted into heat and is finally lost to the system by radiation.

What holds good for tidal friction at the surface of the earth is equally valid for the so often hypothetically assumed tidal friction of a supposed fluid nucleus of the earth's interior.

The most peculiar part of the matter is that Thomson and Tait do not notice that in order to establish the theory of tidal friction they are putting forward a theory that proceeds from the tacit assumption that the earth is *an entirely rigid body*,[4] and so exclude any possibility of tidal flow and hence also of tidal friction.

Notes

1. This theory has since been greatly developed, and the actual rate at which tidal friction is lengthening the day has been approximately found.

2. A slip of the pen; the word should obviously be "shortened."

3. There can be no doubt that Engels was right when he pointed out Thomson and Tait's error in saying that the changes in the length of the day and month "could not go on without loss of energy by fluid friction." We now know that there are tides in the earth as well as in the ocean. But Engels was wrong in supposing that the moon could move away from the earth without loss of energy. For in a system such as the earth and moon the angular momentum (moment of momentum) remains constant unless it is diminished or increased by the tidal action of some external body. If both momentum and energy are conserved no systematic slowing down can occur. This is readily seen in the simplified case where the moon is supposed to go round in a circle in the plane of the earth's equator. In this case there are only two possible variables, the lengths of the day and month. But so long as the moment of momentum and the energy of the system are unchanged we have two equations to determine these quantities, and they are therefore fixed.

4. Although Engels formulated his criticism of Thomson and Tait incorrectly, he was right in a fundamental point. The earth-moon system would evolve in such a way as to lengthen the day and month even if there were no ocean. For the earth is a *solid* (*fester*) body, but not a *rigid* (*starrer*) body in the sense in which this latter word is used in theoretical mechanics, that is to say a body whose shape is unaltered by the forces on it. Of course a rigid body is a mathematical abstraction, like a flat surface. There are no perfectly rigid bodies nor flat surfaces. And it has now been shown that the solid earth bends slightly as the moon's attraction varies. There are solid tides as well as liquid tides though much smaller. These act in the same way as the tides in the ocean, though much more slowly.

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IX: The Part Played by Labour in the Transition from Ape to Man

LABOUR is the source of all wealth, the economists assert. It is this next to nature, which supplies it with the material that it converts into wealth. But it is also infinitely more than this. It is the primary basic condition for all human existence, and this to such an extent that, in a sense, we have to say that labour created man himself.

Many hundreds of thousands of years ago, during an epoch, not yet definitely determined, of that period of the earth's history which geologists call the Tertiary period, most likely towards the end of it, a specially highly-developed race of anthropoid apes lived somewhere in the tropical zone - probably on a great continent that has now sunk to the bottom of the Indian Ocean.[1] Darwin has given us an approximate description of these ancestors of ours. They were completely covered with hair, they had beards and pointed ears, and they lived in bands in the trees.

Almost certainly as an immediate consequence of their mode of life, for in climbing the hands fulfil quite different functions from the feet, these apes when moving on level ground began to drop the habit of using their hands and to adopt a more and more erect posture in walking. This was *the decisive step in the transition from ape to man*.

All anthropoid apes of the present day can stand erect and move about on their feet alone, but only in case of need and in a very clumsy way. Their natural gait is in a half-erect posture and includes the use of the hands. The majority rest the knuckles of the fist on the ground and, with legs drawn up, swing the body through their long arms, much as a cripple moves with the aid of crutches. In general, we can to-day still observe among apes all the transition stages from walking on all fours to walking on two legs. But for none of them has the latter method become more than a makeshift.

For erect gait among our hairy ancestors to have become first the rule and in time a necessity presupposes that in the meantime the hands became more and more devoted to other functions.[2] Even among the apes there already prevails a certain separation in the employment of the hands and feet. As already mentioned, in climbing the hands are used differently from the feet. The former serve primarily for collecting and holding food, as already occurs in the use of the fore paws among lower mammals. Many monkeys use their hands to build nests for themselves in the trees or even, like the chimpanzee, to construct roofs between the branches for protection against the weather. With their hands they seize hold of clubs to defend themselves against enemies, or bombard the latter with fruits and stones. In captivity, they carry out with their hands a number of simple operations copied from human beings.[3] But it is just. here that one sees how great is the gulf between the undeveloped hand of even the most anthropoid of apes and the human hand that has been highly perfected by the labour of hundreds of thousands of years. The number and general arrangement of the bones and muscles are the same in both; but the hand of the lowest savage can perform hundreds of operations that no monkey's hand can imitate. No simian hand has ever fashioned even the crudest stone knife.

At first, therefore, the operations, for which our ancestors gradually learned to adapt their hands during the many thousands of years of transition from ape to man, could only have been very simple. The lowest savages, even those in whom a regression to a more animal-like condition, with a simultaneous physical degeneration, can be assumed to have occurred, are nevertheless far superior to these transitional beings. Before the first flint could be fashioned into a knife by human hands, a period of time must probably have elapsed in comparison with which the historical period known to us appears insignificant. But the decisive step was taken: *the hand became free* and could henceforth attain ever greater dexterity and skill, and the greater flexibility thus acquired was inherited and increased from generation to generation.

Thus the hand is not only the organ of labour, *it is also the product of labour*. Only by labour, by adaptation to ever new operations, by inheritance of the resulting special development of muscles, ligaments, and, over longer periods of time, bones as well, and by the ever-renewed employment of these inherited improvements in new, more and more complicated operations, has the human hand attained the high degree of perfection that has enabled it to conjure into being the pictures of Raphael, the statues of Thorwaldsen, the music of Paganini.

But the hand did not exist by itself. It was only one member of an entire, highly complex organism. And what benefited the hand, benefited also the whole body it served; and this in two ways.

In the first place, the body benefited in consequence of the law of correlation of growth, as Darwin called it. According to this law, particular forms of the individual parts of an organic being are always bound up with certain forms of other parts that apparently have no connection with the first. Thus all animals that have red blood cells without a cell nucleus, and in which the neck is connected to the first vertebra by means of a double articulation (condyles), also without exception possess lacteal glands for suckling their young. Similarly cloven hooves in mammals are regularly associated with the possession of a multiple stomach for rumination. Changes in certain forms involve changes in the form of other parts of the body, although we cannot explain this connection. [4] Perfectly white cats with blue eyes are always, or almost always, deaf. The gradual perfecting of the human hand, and the development that keeps pace with it in the adaptation of the feet for erect gait, has undoubtedly also, by virtue of such correlation, reacted on other parts of the organism. However, this action has as yet been much too little investigated for us to be able to do more here than to state the fact in general terms.

Much more important is the direct, demonstrable reaction of the development of the hand on the rest of the organism. As already said, our simian ancestors were gregarious; it is obviously impossible to seek the derivation of man, the most social of all animals, from non- gregarious immediate ancestors. The mastery over nature, which begins with the development of the hand, with labour, widened man's horizon at every new advance. He was continually discovering new, hitherto unknown, properties of natural objects. On the other hand, the development of labour necessarily helped to bring the members of society closer together by multiplying cases of mutual support, joint activity, and by making clear the advantage of this joint activity to each individual. In short, men in the making arrived at the point where *they had something to say* to one another. The need led to the creation of its organ; the undeveloped larynx of the ape was slowly but surely transformed by means of gradually increased modulation, and the organs of the mouth gradually learned to pronounce one articulate letter after another.

Comparison with animals proves that this explanation of the origin of language from and in the process of labour is the only correct one. The little that even the most highly- developed animals need to communicate to one another can be communicated even without the aid of articulate speech. In a state of nature, no animal feels its inability to speak or to understand human speech. It is quite different when it has been tamed by man. The dog and the horse, by association with man, have developed such a good ear for articulate speech that they easily learn to understand any language within the range of their circle of ideas. Moreover they have acquired the capacity for feelings, such as affection for man, gratitude, etc., which were previously foreign to them. Anyone who has had much to do with such animals will hardly be able to escape the conviction that there are plenty of cases where they now feel their inability to speak is a defect, although, unfortunately, it can no longer be remedied owing to their vocal organs being specialised in a definite direction. However, where the organ exists, within certain limits even this inability disappears. The buccal organs of birds are of course radically different from those of man, yet birds are the only animals that can learn to speak; and it is the bird with the most hideous voice, the parrot, that speaks best of all. It need not be objected that the parrot does not understand what it says. It is true that for the sheer pleasure of talking and associating with human beings, the parrot will chatter for hours at a time, continuing to repeat its whole vocabulary. But within the limits of its circle of ideas it can also learn to understand what it is saying. Teach a parrot swear words in such a way that it gets an idea of their significance (one of the great amusements of sailors returning from the tropics); on teasing it one will soon discover that it knows how to use its swear words just as correctly as a Berlin costermonger. Similarly with begging for titbits.

First comes labour, after it, and then side by side with it, articulate speech - these were the two most essential stimuli under the influence of which the brain of the ape gradually changed into that of man, which for all its similarity to the former is far larger and more perfect. Hand in hand with the development of the brain went the development of its most immediate instruments - the sense organs. Just as the gradual development of speech is inevitably accompanied by a corresponding refinement of the organ of hearing, so the development of the brain as a whole is accompanied by a refinement of all the senses. The eagle sees much farther than man, but the human eye sees considerably more in things than does the eye of the eagle. The dog has a far keener sense of smell than man, but it does not distinguish a hundredth part of the odours that for man are definite features of different things.[5] And the sense of touch, which the ape hardly possesses in its crudest initial form, has been developed side by side with the development of the human hand itself, through the medium of labour.

The reaction on labour and speech of the development of the brain and its attendant senses, of the increasing clarity of consciousness, power of abstraction and of judgement, gave an ever-renewed impulse to the further development of both labour and speech. This further development did not reach its conclusion when man finally became distinct from the monkey, but, on the whole, continued to make powerful progress, varying in degree and direction among different peoples and at different times, and here and there even interrupted by a local or temporary regression. This further development has been strongly urged forward, on the one hand, and has been guided along more definite directions on the other hand, owing to a new element which came into play with the appearance of fully-fledged man, viz. *society*.

Hundreds of thousands of years - of no greater significance in the history of the earth than one second in the life of man[6] - certainly elapsed before human society arose out of a band of tree-climbing monkeys. Yet it did finally appear. And what do we find once more as the characteristic difference between the band of monkeys and human society ? *Labour*. The ape horde was satisfied to browse over the feeding area determined for it by geographical conditions or the degree of resistance of neighbouring hordes; it undertook migrations and struggles to win new feeding grounds, but it was incapable of extracting from the area which supplied it with food more than the region offered in its natural state, except, perhaps, that the horde unconsciously fertilised the soil with its own excrements. As soon as all possible feeding grounds were occupied, further increase of the monkey population could not occur; the number of animals could at best remain stationary. But all animals waste a great deal of food, and, in addition, destroy in embryo the next generation of the food supply. Unlike the hunter, the wolf does not spare the doe which would provide it with young deer in the next year; the goats in Greece, which graze down the young bushes before they can grow up, have eaten bare all the mountains of the country. This "predatory economy" of animals plays an important part in the gradual transformation of species by forcing them to adapt themselves to other than the usual food, thanks to which their blood acquires a different chemical composition and the whole physical constitution gradually alters,[7] while species that were once established die out. There is no doubt that this predatory economy has powerfully contributed to the gradual evolution of our ancestors into men. In a race of apes that far surpassed all others in intelligence and adaptability, this predatory economy could not help leading to a continual increase in the number of plants used for food and to the devouring of more and more edible parts of these plants. In short, it led to the food becoming more and more varied, hence also the substances entering the body, the chemical premises for the transition to man. But all that was not yet labour in the proper sense of the word. The labour process begins with the making of tools. And what are the most ancient tools that we find - the most ancient judging by the heirlooms of prehistoric man that have been discovered, and by the mode of life of the earliest historical peoples and of the most primitive of contemporary savages? They are hunting and fishing implements, the former at the same time serving as weapons. But hunting and fishing presuppose the transition from an exclusively vegetable diet to the concomitant use of meat, and this is an important step in the transition to man. A *meat diet* contains in an almost ready state the most essential ingredients required by the organism for its metabolism. It shortened the time required, not only for digestion, but also for the other vegetative bodily processes corresponding to those of plant life, and thus gained further time, material, and energy for the active manifestation of animal life in the proper sense of the word. And the further that man in the making became removed from the plant kingdom, the higher he rose also over animals. Just as becoming accustomed to a plant diet side by side with meat has converted wild cats and dogs into the servants of man, so also adaptation to a flesh diet, side by side with a vegetable diet, has considerably contributed to giving bodily strength and independence to man in the making. The most essential effect, however, of a flesh diet was on the brain, which now received a far richer flow of the materials necessary for its nourishment and development, and which therefore could become more rapidly and perfectly developed from generation to generation.[8] With all respect to the vegetarians, it has to be recognised that man did not come into existence without a flesh diet, and if the latter, among all peoples known to us, has led to cannibalism at some time or another (the forefathers of the Berliners, the Weletabians or Wilzians, used to eat their parents as late as the tenth century), that is of no consequence to us to-day.

A meat diet led to two new advances of decisive importance: to the mastery of fire and the taming of animals. The first still further shortened the digestive process, as it provided the mouth with food already as it were semi-digested; the second made meat more copious by opening up a new, more regular source of supply in addition to hunting, and moreover provided, in milk and its products, a new article of food at least as valuable as meat in its composition. Thus, both these advances became directly new means of emancipation for man. It would lead us too far to dwell here in detail on their indirect effects notwithstanding the great importance they have had for the development of man and society.

Just as man learned to consume everything edible, he learned also to live in any climate. He spread over the whole of the habitable world, being the only animal that by its very nature had the power to do so.

The other animals that have become accustomed to all climates - domestic animals and vermin- did not become so independently, but only in the wake of man. And the transition from the uniformly hot climate of the original home of man to colder regions, where the year is divided into summer and winter, created new requirements: shelter and clothing as protection against cold and damp, new spheres for labour and hence new forms of activity, which further and further separated man from the animal.

By the co-operation of hands, organs of speech, and brain, not only in each individual, but also in society, human beings became capable of executing more and more complicated operations, and of setting themselves, and achieving, higher and higher aims. With each generation,[9] labour itself became different, more perfect, more diversified. Agriculture was added to hunting and cattle-breeding, then spinning, weaving, metal-working, pottery, and navigation. Along with trade and industry, there appeared finally art and science. From tribes there developed nations and states. Law and politics arose, and with them the fantastic reflection of human things in the human mind: religion. In the face of all these creations, which appeared in the first place to be products of the mind, and which seemed to dominate human society, the more modest productions of the working hand retreated into the background, the more so since the mind that plans the labour process already at a very early stage of development of society (*e.g.* already in the simply family), was able to have the labour that had been planned carried out by other hands than its own. All merit for the swift advance of civilisation was ascribed to the mind, to the development and activity of the brain. Men became accustomed to explain their actions from their thoughts, instead of from their needs - (which in any case are reflected and come to consciousness in the mind) - and so there arose in the course of time that idealistic outlook on the world which, especially since the decline of the ancient world, has dominated men's minds. It still rules them to such a degree that even the most materialistic natural scientists of the Darwinian school are still unable to form any clear idea of the origin of man, because under this ideological influence they do not recognise the part that has been played therein by labour.

Animals, as already indicated, change external nature by their activities just as man does, if not to the same extent, and these changes made by them in their environment, as we have seen, in turn react upon and change their originators. For in nature nothing takes place in isolation. Everything affects every other thing and *vice versa*, and it is usually because this many-sided motion and interaction is forgotten that our natural scientists are prevented from clearly seeing the simplest things. We have seen how goats have prevented the regeneration of forest in Greece; on the island of St. Helena, goats and pigs brought by the first arrivals have succeeded in exterminating almost completely the old vegetation of the island, and so have prepared the soil for the spreading of plants brought by later sailors and colonists. But if animals exert a lasting effect on their environment, it happens unintentionally, and, as far as the animals themselves are concerned, it is an accident. The further men become removed from animals, however, the more their effect on nature assumes the character of a premeditated, planned action directed towards definite ends known in advance. The animal destroys the vegetation of a locality without realising what it is doing. Man destroys it in order to sow field crops on the soil thus released, or to plant trees or vines which he knows will yield many times the amount sown. He transfers useful plants and domestic animals from one country to another and thus changes the flora and fauna of whole continents. More than this. Under artificial cultivation, both plants and animals are so changed by the hand of man that they become unrecognisable. The wild plants from which our grain varieties originated are still being sought in vain.[10] The question of the wild animal from which our dogs are descended, the dogs themselves being so different from one another, or our equally numerous breeds of horses, is still under dispute.

In any case, of course, we have no intention of disputing the ability of animals to act in a planned and premeditated fashion. On the contrary, a planned mode of action exists in embryo wherever protoplasm, living protein, exists and reacts, *i.e.* carries out definite, even if extremely simple, movements as a result of definite external stimuli. Such reaction takes place even where there is as yet no cell at all, far less a nerve cell. The manner in which insectivorous plants capture their prey appears likewise in a certain respect as a planned action, although performed quite unconsciously. In animals the capacity for conscious, planned action develops side by side with the development of the nervous system and among mammals it attains quite a high level. While fox-hunting in England, one can daily observe how unerringly the fox knows how to make use of its excellent knowledge of the locality in order to escape from its pursuers, and how well it knows and turns to account all favourable features of the ground that cause the scent to be interrupted. Among our domestic animals, more highly developed thanks to association with man, every day one can note acts of cunning on exactly the same level as those of children. For, just as the developmental history of the human embryo in the mother's womb is only an abbreviated repetition of the history, extending over millions of years, of the bodily evolution of our animal ancestors, beginning from the worm, so the mental development of the human child is only a still more abbreviated repetition of the intellectual development of these same ancestors, at least of the later ones. But all the planned action of all animals has never resulted in impressing the stamp of their will upon nature. For that, man was required.

In short, the animal merely *uses* external nature, and brings about changes in it simply by his presence; man by his changes makes it serve his ends, *masters* it. This is the final, essential distinction between man and other animals, and once again it is labour that brings about this distinction.

Let us not, however, flatter ourselves overmuch on account of our human conquest over nature. For each such conquest takes its revenge on us. Each of them, it is true, has in the first place the consequences on which we counted, but in the second and third places it has quite different, unforeseen effects which only too often cancel out the first. The people who, in Mesopotamia, Greece, Asia Minor, and elsewhere, destroyed the forests to obtain cultivable land, never dreamed that they were laying the basis for the present devastated condition of these countries, by removing along with the forests the collecting centres and reservoirs of moisture. When, on the southern slopes of the mountains, the Italians of the Alps used up the pine forests so carefully cherished on the northern slopes, they had no inkling that by doing so they were cutting at the roots of the dairy industry in their region; they had still less inkling that they were thereby depriving their mountain springs of water for the greater part of the year, with the effect that these would be able to pour still more furious flood torrents on the plains during the rainy seasons. Those who spread the potato in Europe were not aware that they were at the same time spreading the disease of scrofula.[11] Thus at every step we are reminded that we by no means rule over nature like a conqueror over a foreign people, like someone standing outside nature - but that we, with flesh, blood, and brain, belong to nature, and exist in its midst, and that all our mastery of it consists in the fact that we have the advantage over all other beings of being able to know and correctly apply its laws.

And, in fact, with every day that passes we are learning to understand these laws more correctly, and getting to know both the more immediate and the more remote consequences of our interference with the traditional course of nature. In particular, after the mighty advances of natural science in the present century, we are more and more getting to know, and hence to control, even the more remote natural consequences at least of our more ordinary productive activities. But the more this happens, the more will men not only feel, but also know, their unity with nature, and thus the more impossible will become the senseless and antinatural idea of a contradiction between mind and matter, man and nature, soul and body, such as arose in Europe after the decline of classic antiquity and which obtained its highest elaboration in Christianity.

But if it has already required the labour of thousands of years for us to learn to some extent to calculate the more remote *natural* consequences of our actions aiming at production, it has been still more difficult in regard to the more remote *social* consequences of these actions. We mentioned the potato and the resulting spread of scrofula. But what is scrofula in comparison with the effect on the living conditions of the masses of the people in whole countries resulting from the workers being reduced to a potato diet, or in comparison with the famine which overtook Ireland in 1847 in consequence of the potato disease, and which put under the earth a million Irishmen, nourished solely or almost exclusively on potatoes, and forced the emigration overseas of two million more? When the Arabs learned to distil alcohol, it never entered their heads that by so doing they were creating one of the chief weapons for the annihilation of the original inhabitants of the still undiscovered American continent. And when afterwards Columbus discovered America, he did not know that by doing so he was giving new life to slavery, which in Europe had long ago been done away with, and laying the basis for the Negro slave traffic. The men who in the seventeenth and eighteenth centuries laboured to create the steam engine had no idea that they were preparing the instrument which more than any other was to revolutionise social conditions throughout the world. Especially in Europe, by concentrating wealth in the hands of a minority, the huge majority being rendered propertyless, this instrument was destined at first to give social and political domination to the bourgeoisie, and then, however, to give rise to a class struggle between bourgeoisie and proletariat, which can end only in the otherthrow of the bourgeoisie and the abolition of all class contradictions. But even in this sphere, by long and often cruel experience and by collecting and analysing the historical material, we are gradually learning to get a clear view of the indirect, more remote, social effects of our productive activity, and so the possibility is afforded us of mastering and controlling these effects as well.

To carry out this control requires something more than mere knowledge. It requires a complete revolution in our hitherto existing mode of production, and with it of our whole contemporary social order.

All hitherto existing modes of production have aimed merely at achieving the most immediately and directly useful effect of labour. The further consequences, which only appear later on and become effective through gradual repetition and accumulation, were totally neglected. Primitive communal ownership of land corresponded, on the one hand, to a level of development of human beings in which their horizon was restricted in general to what lay immediately at hand, and presupposed, on the other hand, a certain surplus of available land, allowing a certain latitude for correcting any possible bad results of this primitive forest type of economy. When this surplus land was exhausted, communal ownership also declined. All higher forms of production, however, proceeded in their development to the division of the population into different classes and thereby to the contradiction of ruling and oppressed classes. But thanks to this, the interest of the ruling class became the driving factor of production, in so far as the latter was not restricted to the barest means of subsistence of the oppressed people. This has been carried through most completely in the capitalist mode of production prevailing to-day in Western Europe. The individual capitalists, who dominate production and exchange, are able to concern themselves only with the most immediate useful effect of their actions. Indeed, even this useful effect - in as much as it is a question of the usefulness of the commodity that is produced or exchanged - retreats right into the background, and the sole incentive becomes the profit to be gained on selling.

The social science of the bourgeoisie, classical political economy, is predominantly occupied only with the directly intended social effects of human actions connected with production and exchange. This fully corresponds to the social organisation of which it is the theoretical expression. When individual capitalists are engaged in production and exchange for the sake of the immediate profit, only the nearest, most immediate results can be taken into account in the first place. When an individual manufacturer or merchant sells a manufactured or purchased commodity with only the usual small profit, he is satisfied, and he is not concerned as to what becomes of the commodity afterwards or who are its purchasers. The same thing applies to the natural effects of the same actions. What did the Spanish planters in Cuba, who burned down forests the slopes of the mountains and obtained from the ashes sufficient fertiliser for *one* generation of very highly profitable coffee trees, care that the tropical rainfall afterwards washed away the now unprotected upper stratum of the soil, leaving behind only bare rock? In relation to nature, as to society, the present mode of production is predominantly concerned only about the first, tangible success; and then surprise is expressed that the more remote effects of actions directed to this end turn out to be of quite a different, mainly even of quite an opposite, character; that the harmony of demand and supply becomes transformed into their polar opposites, as shown by the course of each ten years' industrial cycle, and of which even Germany has experienced a little preliminary in the "crash"; that private ownership based on individual labour necessarily develops into the propertylessness of the workers, while all wealth becomes more and more concentrated in the hands of non-workers; that ...[12]

Notes

1. This is rather unlikely. A broad ridge across the Indian Ocean has been found in the region indicated, but if it represents a sunken continent, this probably sank before our ancestors had evolved so far.

2. It has been suggested that this process was speeded up by the dying out of forests in central Asia, so that our ancestors were forced to run after their prey.

3. Chimpanzees can carry out some operations on their own initiative.

4. The connection can now be explained in a few cases. Thus white onions are more susceptible to moulds than the coloured forms, because they lack an antiseptic substance as well as colouring matter. The antiseptic is a necessary stage in building up the pigment.

5. This is doubtful. A dog cannot distinguish betweeen smells which are distinct to men, but the converse is also true.

6. A leading authority in this respect, Sir W. Thomson, has calculated that *little more than a hundred million years*[*] could have elapsed since the time when the earth had cooled sufficiently for plants and animals to be able to live on it. [*Note by F. Engels.*]

* This time has been greatly extended by the discovery of radioactivity. The correct figure is probably about fifteen hundred million years.

7. It is very doubtful whether evolution occurs as a result of this process.

8. Engels' belief in a meat diet is by no means shared universally by students of biochemistry, although it must be remembered that most so-called vegetarians partake of milk or its products.

9. This is probably an exaggeration. A study of stone-age technique suggests that periods of stagnation lasted for scores or hundreds of generations. Of course the time occupied by human evolution is much longer than Engels (or his scientific contemporaries) thought possible.

10. They are now, in many cases, known with fair certainty.

11. At the time when Engels wrote it was widely believed in medical circles that scrofula (tuberculosis of the neck glands) was due to eating potatoes. There is a causal connection in the sense that it is a disease of inadequately fed people, including those who live on a diet mainly of potatoes. But there is no real evidence that potatoes, as such, play any part in causing it.

12. The manuscript here breaks off abruptly.

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Engels' Dialectics of Nature

Natural Science and the Spirit World[1]

THE dialectics that has found its way into popular consciousness finds expression in the old saying that extremes meet. In accordance with this we should hardly err in looking for the most extreme degree of fantasy, credulity, and superstition, not in that trend of natural science which, like the German philosophy of nature, tries to force the objective world into the framework of its subjective thought, but rather in the opposite trend, which, relying on mere experience, treats thought with sovereign disdain and really has gone to the furthest extreme in emptiness of thought. This school prevails in England. Its father, the much lauded Francis Bacon, already advanced the demand that his new empirical-inductive method should be pursued to attain by its means, above all, longer life, rejuvenation - to a certain extent, alteration of stature and features, transformation of one body into another, the production of new species, power over the air and the production of storms. He complains that such investigations have been abandoned, and in his natural history he actually gives recipes for making gold and performing various miracles. Similarly Isaac Newton in his old age greatly busied himself with expounding the revelation of St. John. So it is not to be wondered at if in recent years English empiricism in the person of some of its representatives - and not the worst of them - should seem to have fallen a hopeless victim to the spirit-rapping and spirit-seeing imported from America.

The first natural scientist belonging here is the very eminent zoologist and botanist, Alfred Russell Wallace, the man who simultaneously with Darwin put forward the theory of the evolution of species by natural selection. In his little work, *On Miracles and Modern Spiritualism*, London, Burns, 1875, he relates that his first s experiences in this branch of natural knowledge date from 1844, when he attended the lectures of Mr. Spencer Hall on mesmerism and as a result carried out similar experiments on his pupils. "I was extremely interested in the subject and pursued it with ardour." He not only produced magnetic sleep together with the phenomena of articular rigidity, and local loss of sensation, he also confirmed the correctness of Gall's map of the skull, because on touching any one of Gall's organs the corresponding activity was aroused in the magnetised patient and exhibited by appropriate and lively gestures. Further, he established that his patient, merely by being touched, partook of all the sensations of the operator; he made him drunk with a glass of water as soon as he told him that it was brandy. He could make one of the young men so stupid, even in the waking condition, that he no longer knew his own name, a feat, however, that other schoolmasters are capable of accomplishing without any mesmerism. And so on.

Now it happens that I also saw this Mr. Spencer Hall in the winter of 1843-4 in Manchester. He was a very mediocre charlatan, who travelled the country under the patronage of some parsons and undertook magnetico-phrenological performances with a young girl in order to prove thereby the existence of God, the immortality of the soul, and the incorrectness of the materialism that was being preached at that time by the Owenites in all big towns. The lady was sent into a magnetico-sleep and then, as soon as the operator touched any part of the skull corresponding to one of Gall's organs, she gave a bountiful display of theatrical, demonstrative gestures and poses representing the activity of the organ concerned; for instance, for the organ of philoprogenitiveness she fondled and kissed an imaginary baby, etc. Moreover, the good Mr. Hall had enriched Gall's geography of the skull with a new island of Barataria: right at the top of the skull he had discovered an organ of veneration, on touching which his hypnotic miss sank on to her knees, folded her hands in prayer, and depicted to the astonished, philistine audience an angel wrapt in veneration. That was the climax and conclusion of the exhibition. The existence of God had been proved.

The effect on me and one of my acquaintances was exactly the same as on Mr. Wallace; the phenomena interested us and we tried to find out how far we could reproduce them. A wideawake young boy of 12 years old offered himself as subject. Gently gazing into his eyes, or stroking, sent him without difficulty into the hypnotic condition. But since we were rather less credulous than Mr. Wallace and set to work with rather less fervour, we arrived at quite different results. Apart from muscular rigidity and loss of sensation, which were easy to produce, we found also a state of complete passivity of the will bound up with a peculiar hypersensitivity of sensation. The patient, when aroused from his lethargy by any external stimulus, exhibited very much greater liveliness than in the waking condition. There was no trace of any mysterious relation to the operator; anyone else could just as easily set the sleeper into activity. To set Gall's cranial organs into action was the least that we achieved; we went much further, we could not only exchange them for one another, or make their seat anywhere in the whole body, but we also fabricated any amount of other organs, organs of singing, whistling, piping, dancing, boxing, sewing, cobbling, tobacco-smoking, etc., and we could make their seat wherever we wanted. Wallace made his patients drunk on water, but we discovered in the great toe an organ of drunkenness which only had to be touched in order to cause the finest drunken comedy to be enacted. But it must be well understood, no organ showed a trace of action until the patient was given to understand what was expected of him; the boy soon perfected himself by practice to such an extent that the merest indication sufficed. The organs produced in this way then retained their validity for later occasions of putting to sleep, as long as they were not altered in the same way. The patient had even a double memory, one for the waking state and a second quite separate one for the hypnotic condition., As regards the passivity of the will and its absolute subjection to the will of a third person, this loses all its miraculous appearance when we bear in mind that the whole condition began with the subjection of the will of the patient to that of the operator, and cannot be restored without it. The most powerful magician of a magnetiser in the world will come to the end of his resources as soon as his patient laughs him in the face.

While we with our frivolous scepticism thus found that the basis of magnetico- phrenological charlatanry lay in a series of phenomena which for the most part differ only in degree from those of the waking state and require no mystical interpretation, Mr. Wallace's "ardour" led him into a series of self-deceptions, in virtue of which he confirmed Gall's map of the skull in all its details and noted a mysterious relation between operator and patient.[2] Everywhere in Mr. Wallace's account, the sincerity of which reaches the degree of naivété, it becomes apparent that he was much less concerned in investigating the factual background of charlatanry than in reproducing all the phenomena at all costs. Only this frame of mind is needed for the man who was originally a scientist to be quickly converted into an "adept" by means of simple and facile self-deception. Mr. Wallace ended up with faith in magnetico-phrenological miracles and so already stood with one foot in the world of spirits.

He drew the other foot after him in 1865. On returning from his twelve years of travel in the tropical zone, experiments in table-turning introduced him to the society of various "mediums." How rapid his progress was, and how complete his mastery of the subject, is testified to by the above-mentioned booklet. He expects us to take for good coin not only all the alleged miracles of Home, the brothers Davenport, and other "mediums" who all more or less exhibit themselves for money and who have for the most part been frequently exposed as impostors, but also a whole series of allegedly authentic spirit histories from early times. The Pythonesses of the Greek oracle, the witches of the Middle Ages, were all "mediums," and Iamblichus[3] in his *De divinatione* already described quite accurately "the most astonishing phenomena of modern spiritualism."

Just one example to show how lightly Mr. Wallace deals with the scientific corroboration and authentication of these miracles. It is certainly a strong assumption that we should believe that the aforesaid spirits should allow themselves to be photographed, and we have surely the right to demand that such spirit photographs should be authenticated in the most indubitable manner before we accept them as genuine. Now Mr. Wallace recounts on p.187 that in March, 1872, a leading medium, Mrs. Guppy, *née* Nicholls, had herself photographed together with her husband and small boy at Mr. Hudson's in Notting Hill, and on two different photographs a tall female figure, finely draped in white gauze robes, with somewhat Eastern features, was to be seen behind her in a pose as if giving a benediction. "Here, then, one of two things are absolutely certain.[4] Either there was a living intelligent, but invisible being present, or Mr. and Mrs. Guppy, the photographer, and some fourth person planned a wicked imposture and have maintained it ever since. Knowing Mr. and Mrs. Guppy so well as I do, I feel an *absolute conviction* that they are as incapable of an imposture of this kind as any earnest inquirer after truth in the department of natural science."[5]

Consequently, either deception or spirit photography. Quite so. And, if deception, either the spirit was already on the photographic plates, or four persons must have been concerned, or three if we leave out as weak-minded or duped old Mr. Guppy who died in January, 1875, at the age of 84 (it only needed that he should be sent behind the Spanish screen of the background). That a photographer could obtain a "model" for the spirit without difficulty does not need to be argued. But the photographer Hudson, shortly afterwards, was publicly prosecuted for habitual falsification of spirit photographs, so Mr. Wallace remarks in mitigation: "One thing is clear, if an imposture has occurred, it was at once detected by spiritualists themselves." Hence there is not much reliance to be placed on the photographer. Remains Mrs. Guppy, and for her there is only the "absolute conviction" of our friend Wallace and nothing more. Nothing more? Not at all. The absolute trustworthiness of Mrs. Guppy is evidenced by her assertion that one evening, early in June, 1871, she was carried through the air in a state of unconsciousness from her house in Highbury Hill Park to 69, Lamb's Conduit Street - three English miles as the crow flies - and deposited in the said house of No. 69 on the table in the midst of a spiritualistic séance. The doors of the room were closed, and although Mrs. Guppy was one of the stoutest women in London, which is certainly saying a good deal, nevertheless her sudden incursion did not leave behind the slightest hole either in the doors or in the ceiling. (Reported in the London .Echo, June 8, 1871.) And if anyone still does not believe in the genuineness of spirit photography, there's no helping him.

The second eminent adept among English natural scientists is Mr. William Crookes, the discoverer of the chemical element thallium and of the radiometer (in Germany also called "*Lichtmühle*" [light-mill]). Mr. Crookes began to investigate spiritualistic manifestations about 1871, and employed for this purpose a number of physical and mechanical appliances, spring balances, electric batteries, etc. Whether he brought to his task the main apparatus required, a sceptically critical mind, or whether he remained to the end in a fit state for working, we shall see. At any rate, within a not very long period, Mr. Crookes was just as completely captivated as Mr. Wallace. "For some years," he relates, "a young lady, Miss Florence Cook, has exhibited remarkable mediumship, which latterly culminated in the production of an entire female form purporting to be of spiritual origin, and which appeared barefooted and in white flowing robes while she lay entranced in dark clothing and securely bound in a cabinet or adjoining room." This spirit, which called itself Katie, and which looked remarkably like Miss Cook, was one evening suddenly seized round the waist by Mr. Volckmann - the present husband of Mrs. Guppy - and held fast in order to see whether it was not indeed Miss Cook in another edition. The spirit proved to be a quite sturdy damsel, it defended itself vigorously, the onlookers intervened, the gas was turned out, and when, after some scuffling, peace was reestablished and the room re-lit, the spirit had vanished and Miss Cook lay bound and unconscious in her corner. Nevertheless, Mr. Volckmann is said to maintain up to the present day that he had seized hold of Miss Cook and nobody else. In order to establish this scientifically, Mr. Varley, a well-known electrician, on the occasion of a new experiment, arranged for the current from a battery to flow through the medium, Miss Cook, in such a way that she could not play the part of the spirit without interrupting the current. Nevertheless, the spirit made its appearance. It was, therefore, indeed a being different from Miss Cook. To establish this further was the task of Mr. Crookes. His first step was to win the *confidence* of the spiritualistic lady. This confidence, so he says himself in the *Spiritualist*, June 5, 1874, "increased gradually to such an extent that she refused to give a séance unless *I made the arrangements*. She said that she always wanted *me* to be near her and in the neighbourhood of the cabinet; I found that - when this confidence had been established and she was sure that *I would not break any promise made to her* - the phenomena increased considerably in strength and there was freely forthcoming evidence that would have been unobtainable in any other way. She frequently *consulted me* in regard to the persons present at the séances and the places to be given them, for she had recently become very nervous as a result of certain ill-advised suggestions that, besides other more scientific methods of investigation, *force* also should be applied."

The spirit lady rewarded this confidence, which was as kind as it was scientific, in the highest measure. She even made her appearance - which can no longer surprise us - in Mr. Crookes' house, played with his children and told them "anecdotes from her adventures in India," treated Mr. Crookes to an account of "some of the bitter experiences of her past life," allowed him to take her by the arm so that he could convince himself of her evident materiality, allowed him to take her pulse and count the number of her respirations per minute, and finally allowed herself to be photographed next to Mr. Crookes. "This figure," says Mr. Wallace, "after she had been seen, touched, photographed, and conversed with, *vanished absolutely* out of a small room from which there was no other exit than an adjoining room filled with spectators" - which was not such a great feat, provided that the spectators were polite enough to show as much faith in Mr. Crookes, in whose house this happened, as Mr. Crookes did in the spirit.

Unfortunately these "fully authenticated phenomena" are not immediately credible even for spiritualists. We saw above how the very spiritualistic Mr. Volckmann permitted himself to make a very material grab. And now a clergyman, a member of the committee of the "British National Association of Spiritualists," has also been present at a séance with Miss Cook, and he established the fact without difficulty that the room through the door of which the spirit came and disappeared communicated with the outer world by a *second door*. The behaviour of Mr. Crookes, who was also present, gave "the final death blow to my belief that there might be something in the manifestations." (*Mystic London*, by the Rev. C. Maurice Davies, London, Tinsley Brothers).[6] And, over and above that, it came to light in America how "Katies" were "materialised." A married couple named Holmes held séances in Philadelphia in which likewise a "Katie" appeared and received bountiful presents from the believers. However, one sceptic refused to rest until he got on the track of the said Katie, who, anyway, had already gone on strike once because of lack of pay; he discovered her in a boarding-house as a young lady of unquestionable flesh and bone, and in possession of all the presents that had been given to the spirit.

Meanwhile the Continent also had its scientific spiritseers. A scientific association at St. Petersburg - I do not know exactly whether the University or even the Academy itself - charged the Councillor of State, Aksakov, and the chemist, Butlerov, to examine the basis of the spiritualistic phenomena, but it dbes not seem that very much came of this. On the other hand - if the noisy announcements of the spiritualists are to be believed - Germany has now also put forward its man in the person of Professor Zöllner in Leipzig.

For years, as is well known, Herr Zöllner has been hard at work on the "fourth dimension" of space, and has discovered that many things that are impossible in a space of three dimensions, are a simple matter of course in a space of four dimensions. Thus, in the latter kind of space, a closed metal sphere can be turned inside out like a glove, without making a hole in it; similarly a knot can be tied in an endless string or one which has both ends fastened, and two separate closed rings can be interlinked without opening either of them, and many more such feats. According to the recent triumphant reports from the spirit world, it is said now that Professor Zöllner has addressed himself to one or more mediums in order with their aid to determine more details of the locality of the fourth dimension. The success is said to have been surprising. After the session the arm of the chair, on which he rested his arm while his hand never left the table, was found to have become interlocked with his arm, a string that had both ends sealed to the table was found tied into four knots, and so on. In short, all the miracles of the fourth dimension are said to have been performed by the spirits with the utmost ease. It must be borne in mind: *relata refero,* I do not vouch for the correctness of the spirit bulletin, and if it should contain any inaccuracy, Herr Zöllner ought to be thankful that I am giving him the opportunity to make a correction. If, however, it reproduces the experiences of Herr Zöllner without falsification, then it obviously signifies a new era both in the science of spiritualism and that of mathematics. The spirits prove the existence of the fourth dimension, just as the fourth dimension vouches for the existence of spirits. And this once established, an entirely new, immeasurable field is opened to science. All previous mathematics and natural science will be only a preparatory school for the mathematics of the fourth and still higher dimensions, and for the mechanics, physics, chemistry, and physiology of the spirits dwelling in these higher dimensions. Has not Mr. Crookes scientifically determined how much weight is lost by tables and other articles of furniture on their passage into the fourth dimension - as we may now well be permitted to call it - and does not Mr. Wallace declare it proven that fire there does no harm to the human body? And now we have even the physiology of the spirit bodies! They breathe, they have a pulse, therefore lungs, heart, and a circulatory apparatus, and in consequence are at least as admirably equipped as our own in regard to the other bodily organs. For breathing requires carbohydrates which undergo combustion in the lungs, and these carbohydrates can only be supplied from without; hence, stomach, intestines, and their accessories - and if we have once established so much, the rest follows without difficulty. The existence of such organs, however, implies the possibility of their falling a prey to disease, hence it may still come to pass that Herr Virchow will have to compile a cellular pathology of the spirit world. And since most of these spirits are very handsome young ladies, who are not to be distinguished in any respect whatsoever from terrestrial damsels, other than by their supra-mundane beauty, it could not be very long before they come into contact with "men who feel the passion of love"; and since, as established by Mr. Crookes from the beat of the pulse, "the female heart is not absent," natural selection also has opened before it the prospect of a fourth dimension, one in which it has no longer any need to fear of being confused with wicked social-democracy.

Enough. Here it becomes palpably evident which is the most certain path from natural science to mysticism. It is not the extravagant theorising of the philosophy of nature, but the shallowest empiricism that spurns all theory and distrusts all thought. It is not *a priori* necessity that proves the existence .of spirits, but the empirical observations of Messrs. Wallace, Crookes, and Co. If we trust the spectrum-analysis observations of Crookes, which led to the discovery of the metal thallium, or the rich zoological discoveries of Wallace in the Malay Archipelago, we are asked to place the same trust in the spiritualistic experiences and discoveries of these two scientists. And if we express the opinion that, after all, there is a little difference between the two, namely, that we can verify the one but not the other, then the spirit-seers retort that this is not the case, and that they are ready to give us the opportunity of verifying also the spirit phenomena.

Indeed, dialectics cannot be despised with impunity. However great one's contempt for all theoretical thought, nevertheless one cannot bring two natural facts into relation with one another, or understand the connection existing between them, without theoretical thought. The only question is whether one's thinking is correct or not, and contempt of theory is evidently the most certain way to think naturalistically, and therefore incorrectly. But, according to an old and well-known dialectic law, incorrect thinking, carried to its logical conclusion, inevitably arrives at the opposite of its point of departure. Hence, the empirical contempt of dialectics on the part of some of the most sober empiricists is punished by their being led into the most barren of all superstitions, into modern spiritualism.

It is the same with mathematics. The ordinary metaphysical mathematicians boast with enormous pride of the absolute irrefutability of the results of their science. But these results include also imaginary magnitudes, which thereby acquire a certain reality. When one has once become accustomed to ascribe some kind of reality outside of our minds to √-1, or to the fourth dimension, then it is not a matter of much importance if one goes a step further and also accepts the spirit world of the mediums. It is as Ketteler said about Döllinger[7]: "The man has defended so much nonsense in his life, he really could have accepted infallibility into the bargain!"

In fact, mere empiricism is incapable of refuting the spiritualists. In the first place, the "higher" phenomena always show themselves only when the "investigator" concerned is already so far in the toils that he now only sees what he is meant to see or wants to see - as Crookes himself describes with such inimitable naivété. In the second place, however, the spiritualist cares nothing that hundreds of alleged facts are exposed as imposture and dozens of alleged mediums as ordinary tricksters. As long as *every* single alleged miracle has not been explained away, they have still room enough to carry on, as indeed Wallace says clearly enough in connection with the falsified spirit photographs. The existence of falsifications proves the genuineness of the genuine ones.

And so empiricism finds itself compelled to refute the importunate spirit-seers not by means of empirical experiments, but by theoretical considerations, and to say, with Huxley[8]: "The only good that I can see in the demonstration of the truth of `spiritualism' is to furnish an additional argument against suicide. Better live a crossing-sweeper than die and be made to talk twaddle by a `medium' hired at a guinea a séance!"

Notes

1. From a manuscript of Engels probably written in 1878, and first published in the "*Illustrierter Neue Welt-Kalender für das Jahr 1898*."

2. As already said, the patients perfect themselves by practice. It is therefore quite possible that, when the subjection of the will has become habitual, the relation of the participants becomes more intimate, individual phenomena are intensified and are reflected weakly even in the waking state. [*Note by F.*

Engels.]

3. See Appendix II, p. 368.

4. The spirit world is superior to grammar. A joker once caused the spirit of the grammarian Lindley Murray to testify. To the question whether he was there, he answered: "I are." (American for I am.) The medium was from America. [*Note by F. Engels.*]

5. See Appendix II, p. 369.

6. See Appendix II, p. 370.

7. A catholic scholar who did not accept the dogma of papal infallibility.

8. See Appendix II, p. 370.

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Appendix: Notes to Anti-Dühring

The following notes were written by Engels towards the end of 1877 and beginning of 1878, after the publication in separate form of the first section (Philosophy) of "Anti- Dühring," *to the pages of which he refers at the beginning of each note. In view of their great intrinsic importance and their close connection with the subjects dealt with in* Dialectics of Nature, *they are included here as an appendix.*

(a) On the Prototype of Mathematical "Infinity" in the Real World.

Re pp. 17-18*: Concordance of thought and being - Mathematical infinity.*

The fact that our subjective thought and the objective world are subject to the same laws, and that consequently too in the final analysis they cannot be in contradiction to one another in their results, but must coincide, governs absolutely our whole theoretical thought. It is the unconscious and unconditional premise for theoretical thought. Eighteenth century materialism, owing to its essentially metaphysical character, investigated this premise only as regards content. It restricted itself to the proof that the content of all thought and knowledge must derive from sensuous experience, and revived the principle: *nihil est in intellectu, quod non fuerit in sensu*. It was modern idealistic, but at the same time dialectical, philosophy, and especially Hegel, which for the first time investigated it also as regards *form*. In spite of all the innumerable arbitrary constructions and fantasies that we encounter here, in spite of the idealist, topsy-turvy, form of its result - the unity of thought and being - it is undeniable that this philosophy proved the analogy of the processes of thought to those of nature and history and *vice versa*, and the validity of similar laws for all these processes, in numerous cases and in the most diverse fields. On the other hand, modern natural science has extended the principle of the origin of all thought content from experience in a way that breaks down its old metaphysical limitation and formulation. By recognising the inheritance of acquired characters, it extends the subject of experience from the individual to the genus; the single individual that must have experienced is no longer necessary, its individual experience can be replaced to a certain extent by the results of the experiences of a number of its ancestors. If, for instance, among us the mathematical axioms seem self-evident to every eight-year-old child, and in no need of proof from experience, this is solely the result of "accumulated inheritance." It would be difficult to teach them by a proof to a bushman or Australian negro.

In the present work dialectics is conceived as the science of the most general laws of *all* motion. Therein is included that their laws must be equally valid for motion in nature and human history and for the motion of thought. Such a law can be recognised in two of these three spheres, indeed even in all three, without the metaphysical philistine being clearly aware that it is one and the same law that he has come to know.

Let us take an example. Of all theoretical advances there is surely none that ranks so high as a triumph of the human mind as the discovery of the infinitesimal calculus in the last half of the seventeenth century. If anywhere, it is here that we have a pure and exclusive feat of human intelligence. The mystery which even to-day surrounds the magnitudes employed in the infinitesimal calculus, the differentials and infinites of various degree, is the best proof that it is still imagined that what are dealt with here are pure "free creations and imaginings " of the human mind, to which there is nothing corresponding in the objective world. Yet the contrary is the case. Nature offers prototypes for all these imaginary magnitudes.

Our geometry has, as its starting point, space relations, and our arithmetic and algebra numerical magnitudes, which correspond to our terrestrial conditions, which therefore correspond to the magnitude of bodies that mechanics terms masses - masses such as occur on earth and are moved by men. In comparison to these masses, the mass of the earth seems infinitely large and indeed terrestrial mechanics treats it as infinitely large. The radius of the earth == ∞, this is the basic principle of all mechanics in the law of falling. But not merely the earth but the whole solar system and the distances occurring in the latter in their turn appear infinitely small as soon as we have to deal with the distances reckoned in light years in the stellar system visible to us through the telescope. We have here, therefore, already an infinity, not only of the first but of the second degree, and we can leave it to the imagination of our readers to construct further infinities of a higher degree in infinite space, if they feel inclined to do so.

According to the view prevailing in physics and chemistry today, however, the terrestrial masses, the bodies with which mechanics operates, consists of molecules, of smallest particles which cannot be further divided without abolishing the physical and chemical identity of the body concerned. According to W. Thomson's calculations, the diameter of the smallest of these molecules cannot be smaller than a fifty-millionth of a millimetre. But even if we assume that the largest molecule itself attains a diameter of a twentyfive- millionth of a millimetre, it still remains an infinitesimally small magnitude compared with the smallest mass dealt with by mechanics, physics, or even chemistry. Nevertheless, it is endowed with all the properties peculiar to the mass in question, it can represent the mass physically and chemically, and does actually represent it in all chemical equations. In short, it has the same properties in relation to the corresponding mass as the mathematical differential has in relation to its variable. The only difference is that what seems mysterious and inexplicable to us in the case of the differential, here seems a matter of course and as it were obvious.

Nature operates with these differentials, the molecules, in exactly the same way and according to the same laws as mathematics does with its abstract differentials. Thus, for instance, the differential of $x^3 == 3x^2dx$, where $3xdx^2$ and dx^3 are neglected. If we put this in geometrical form, we have a cube with sides of length x, the length being increased by the infinitely small amount dx. Let us suppose that this cube consists of a sublimated element, say sulphur; and that three of the surfaces around one corner are protected, the other three being free. Let us now expose this sulphur cube to an atmosphere of sulphur vapour and lower the temperature sufficiently; sulphur will be deposited on the three free sides of the cube. We remain quite within the ordinary mode of procedure of physics and chemistry in supposing, in order to picture the process in its pure form, that in the first place a layer of thickness of a single molecule is deposited on each of these three sides. The length x of the sides of the cubes will have increased by the diameter of a molecule dx. The content of the cube x^3 has increased by the difference between x^3 and $x^3+3x^2dx+3xdx^2+dx^3$, where dx^3, a *single* molecule and $3xdx^2$, three rows of length $x+dx$, consisting merely of lineally arranged molecules, can be neglected with the same justification as in mathematics. The result is the same, the increase in mass of the cube is $3x^2dx$.

Strictly speaking dx^3 and $3xdx^2$ do not occur in the case of the sulphur molecule, because two or three molecules cannot occupy the same space, and the cube's increase of bulk is therefore exactly $3x^2dx+3xdx+dx$. This is explained by the fact that in mathematics dx is a linear magnitude, while it is well known that such lines, without thickness or breadth, do not occur independently in nature, hence also the mathematical abstractions have unrestricted validity only in pure mathematics. And since the latter neglects $3xdx^2+dx^3$, it makes no difference.

Similarly in evaporation. When the uppermost molecular layer in a glass of water evaporates, the height of the water layer, x, is decreased by dx, and the continual flight of one molecular layer after another is actually a continued differentiation. And when the warm vapour is once more condensed to water in a vessel by pressure and cooling, and one molecular layer is deposited on another (it is permissible to leave out of account secondary circumstances that make the process an impure one) until the vessel is full, then literally an integration has been performed which differs from the mathematical one only in that the one is consciously carried out by the human brain, while the other is unconsciously carried out by nature. But it is not only in a transition from the liquid to the gaseous state and vice versa that processes occur which are completely analogous to those of the infinitesimal calculus.

When mass motion, as such, is abolished - by impact - becomes transformed into heat, molecular motion, what is it that happens but that the mass motion is differentiated? And when the movements of the molecules of steam in the cylinder of the steam engine become added together so that they lift the piston by a definite amount, so that they become transformed into mass motion, have they not been integrated? Chemistry dissociates the molecules into atoms, magnitudes of more minute mass and spatial extension, but magnitudes of the same order, so that the two stand in definite, finite relations to one another. Hence, all the chemical equations which express the molecular composition of bodies are in their form differential equations. But in reality they are already integrated in the atomic weights which figure in them. For chemistry calculates with differentials, the mutual proportions of their magnitudes being known.

Atoms, however, are in no wise regarded as simple, or in general as the smallest known particles of matter. Apart from chemistry itself, which is more and more inclining to the view that atoms are compound, the majority of physicists assert that the luminiferous ether, which transmits light and heat radiations, likewise consists of discrete particles, which, however, are so small that they have the same relation to chemical atoms and physical molecules as these have to mechanical masses, that is to say as d^2x to dx. Here, therefore, in the now usual notion of the constitution of matter, we have likewise a differential of the second degree, and there is no reason at all why anyone, to whom it would give satisfaction, should not imagine that analogies of d^3x, d^4x, etc., also occur in nature.

Hence, whatever view one may hold of the constitution of matter, this much is certain, that it is divided up into a series of big, well-defined groups of a relatively massive character in such a way that the members of each separate group stand to one another in definite finite mass ratios, in contrast to which those of the next group stand to them in the ratio of the infinitely large or infinitely small in the mathematical sense. The visible system of stars, the solar system, terrestrial masses, molecules and atoms, and finally ether particles, each of them form such a group. It does not alter the case that intermediate links can be found between the separate groups. Thus, between the masses of the solar system and terrestrial masses come the asteroids (some of which have a diameter no greater than, for example, that of the Reuss principality, younger branch), meteors, etc. Thus, in the organic world the cell stands between terrestrial masses and molecules. These intermediate links prove only that there is no leap in nature, *precisely because* nature is composed entirely of leaps.

In so far as mathematics calculates with real magnitudes, it also employs this mode of outlook without hesitation. For terrestrial mechanics the mass of the earth is regarded as infinitely large, just as for astronomy terrestrial masses and the corresponding masses of meteors are regarded as infinitely small, and just as the distances and masses of the planets of the solar system are reduced to nothing as soon as astronomy investigates the constitution of our system of stars extending beyond the nearest fixed stars. As soon, however, as the mathematicians withdraw into their impregnable fortress of abstraction, so-called pure mathematics, all these analogies are forgotten, infinity becomes something totally mysterious, and the manner in which operations are carried out with it in analysis appears as something absolutely incomprehensible, contradicting all experience and all reason. The stupidities and absurdities by which mathematicians have rather excused than explained their mode of procedure, which remarkably enough always leads to correct results, exceed the most pronounced apparent and real fantasies, *e.g.* of the Hegelian philosophy of nature, about which mathematicians and natural scientists can never adequately express their horror. What they charge Hegel with doing, viz. pushing abstractions to the extreme limit, they do themselves on a far greater scale. They forget that the whole of so-called pure mathematics is concerned with abstractions, that *all* their magnitudes, taken in a strict sense, are imaginary, and that all abstractions when pushed to extremes are transformed into nonsense or into their opposite. Mathematical infinity is taken from reality although unconsciously, and consequently also can only be explained from reality and not from itself, from mathematical abstraction. And, as we have seen, if we investigate reality in this regard we come also upon the real relations from which the mathematical relation of infinity is taken, and even the natural analogies of the way in which this relation operates. And thereby the matter is explained. (Hæckel's bad reproduction of the identity of thinking and being.) But also *the contradiction between continuous and discrete matter*, see Hegel.

(b) On the "Mechanical Conception of Nature.

Note 2. *Re page* 46*: The various forms of motion and the sciences dealing with them.*

Since the above article appeared (*Vorwärts*, Feb. 9, 1877), Kekulé (*Die wissenschaftlichen Ziele and Leistungen der Chemie* [*The Scientific Aims and Achievements of Chemistry*] has defined mechanics, physics, and chemistry in a very similar way:

"If this idea of the nature of matter is made the basis, one could define chemistry as the science of atoms and physics as the science of molecules, and then it would be natural to separate that part of modern physics which deals with masses as a special science, reserving for it the name of mechanics. Thus mechanics appears as the basic science of physics and chemistry, in so far as in certain aspects and especially in certain calculations both of these have to treat their molecules or atoms as masses."

It will be seen that this formulation differs from that in the text and in the previous note only by being rather less definite. But when an English journal (*Nature*)[1] translated the above statement of Kekulé to the effect that mechanics is the statics and dynamics of masses, physics the statics and dynamics of molecules, and chemistry the statics and dynamics of atoms, then it seems to me that this unconditional reduction of even chemical processes to something merely mechanical unduly restricts the field, at least of chemistry. And yet it is so much the fashion that, for instance, Hæckel continually uses "mechanical" and "monistic" as having the same meaning, and in his opinion "modern physiology ... in its field allows only of the operation of physico-chemical - r in the wider sense, mechanical - forces." (*Perigenesis*.[2])

If I term physics the mechanics of molecules, chemistry the physics of atoms, and furthermore biology the chemistry of proteins, I wish thereby to express the transition of each of these sciences into the other, hence both the connection, the continuity, and the distinction, the discrete separation. To go further and to define chemistry as likewise a kind of mechanics seems to me inadmissible. Mechanics - in the broader or narrower sense - knows only quantities, it calculates with velocities and masses, and at most with volumes. When the quality of bodies comes across its path, as in hydrostatics and aerostatics, it cannot achieve anything without going into molecular states and molecular motion, it is itself only a mere auxiliary science, the prerequisite for physics. In physics, however, and still more in chemistry, not only does continual qualitative change take place in consequence of quantitative change, the transformation of quantity into quality, but there are also many qualitative changes to be taken into account whose dependence on quantitative change is by no means proven. That the present tendency of science goes in this direction can be readily granted, but does not prove that this direction is the exclusively correct one, that the pursuit of this tendency will exhaust the whole of physics and chemistry. All motion includes mechanical motion, change of place of the largest or smallest portions of matter, and the *first* task of science, but only the *first*, is to obtain knowledge of this motion. But this mechanical motion does not exhaust motion as a whole. Motion is not merely change of place, in fields higher than mechanics it is also change of quality. The discovery that heat is a molecular motion was epoch-making. But if I have nothing more to say of heat than that it is a certain displacement of molecules, I should best be silent. Chemistry seems to be well on the way to explaining a number of chemical and physical properties or elements from the ratio of the atomic volumes to the atomic weights. But no chemist would assert that all the properties of an element are exhaustively expressed by its position in the Lothar Meyer curve,[3] that it will ever be possible by this alone to explain, for instance, the peculiar constitution of carbon that makes it the essential bearer of organic life, or the necessity for phosphorus in the brain. Yet the "mechanical" conception amounts to nothing else. It explains all change from change of place, all qualitative differences from quantitative, and overlooks that the relation of quality and quantity is reciprocal, that quality can become transformed into quantity just as much as quantity into quality, that, in fact, reciprocal action takes place. If all differences and changes of quality are to be reduced to quantitative differences and changes, to mechanical displacement, then we inevitably arrive at the proposition that all matter consists of *identical*, smallest particles, and that all qualitative differences of the chemical elements of matter are caused by quantitative differences in number and by the spatial grouping of those smallest particles to form atoms. But we have not got so far yet.

It is our modern natural scientists' lack of acquaintance with any other philosophy than the most mediocre vulgar philosophy, like that now rampant in the German universities, which allows them to use expressions like "mechanical" in this way, without taking into account, or even suspecting, the consequences with which they thereby necessarily burden themselves. The theory of the absolute qualitative identity of matter has its supporters - empirically it is equally impossible to refute it or to prove it. But if one asks these people who want to explain everything "mechanically" whether they are conscious of this consequence and accept the identity of matter, what a variety of answers will be heard!

The most comical part about it is that to make "materialist" equivalent to "mechanical" derives from Hegel, who wanted to throw contempt on materialism by the addition "mechanical." Now the materialism criticised by Hegel - the French materialism of the eighteenth century - was in fact exclusively *mechanical*, and indeed for the very natural reason that at that time physics, chemistry, and biology were still in their infancy, and were very far from being able to offer the basis for a general outlook on nature. Similarly Hæckel takes from Hegel the translation: *causae efficientes*==mechanically acting causes, and *causae finales*==purposively acting causes; where Hegel, therefore, puts mechanical as equivalent to blindly acting, unconsciously acting, and not as equivalent to mechanical in Hæckel's sense of the word.[4] But this whole antithesis is for Hegel himself so much a superseded standpoint that he *does not even mention it* in either of his two accounts of causality in his *Logic* - but only in his *History of Philosophy*, in the place where it comes historically (hence a sheer misunderstanding on Hæckel's part due to superficiality!) and quite incidentally in dealing with teleology (*Logic*, III, II, 3) where he mentions it as the form in which the *old metaphysics* conceived the antagonism of mechanism and teleology, but otherwise treating it as a long superseded standpoint.[5] Hence Hæckel copied incorrectly in his joy at finding a confirmation of his "mechanical" conception and so arrives at the beautiful result that if a particular change is produced in an animal or plant by natural selection it has been effected by a *causa efficiens*, but if the same change arises by *artificial* selection then it has been effected by a *causa finalis!* The breeder as *causa finalis*! Of course a dialectician of Hegel's calibre could not be caught in the vicious circle of the narrow opposition of *causa efficiens*, and *causa finalis*. And for the modern standpoint the whole hopeless rubbish about this opposition is put an end to because we *know* from experience and from theory that both matter and its mode of existence, motion, are uncreatable and are, therefore, their own final cause; while to give the name *effective* causes to the individual causes which momentarily and locally become isolated in the mutual interaction of the motion of the universe, or which are isolated by our reflecting mind, adds absolutely no new determination but only a confusing element. A cause that is not effective is no cause.

N.B. Matter as such is a pure creation of thought and an abstraction. We leave out of account the qualitative difference of things in comprehending them as corporeally existing things under the concept matter. Hence matter as such, as distinct from definite existing pieces of matter, is not anything sensuously existing. If natural science directs its efforts to seeking out uniform matter as such, to reducing qualitative differences to merely quantitative differences in combining identical smallest particles, it would be doing the same thing as demanding to see fruit as such instead of cherries, pears, apples, or the mammal as such instead of cats, dogs, sheep, etc., gas as such, metal, stone, chemical compound as such, motion as such. The Darwinian theory demands such a primordial mammal, Hæckel's pro-mammal, but it, at the same time, has to admit that if this pro-mammal contains within itself in *germ* all future and existing mammals, it was in reality lower in rank than all existing mammals and exceedingly crude, hence more transitory than any of them. As Hegel has already shown, *Encyclopædia* I, p.199,[6] this view is therefore "a one-sided mathematical standpoint," according to which matter must be looked upon as having only quantitative determination, but, qualitatively, as identical originally, "no other standpoint than that" of the French materialism of the eighteenth century. It is even a retreat to Pythagoras, who regarded number, quantitative determination as the essence of things.

In the first place, Kekulé. Then: the systematising of natural science, which is now becoming more and more necessary, cannot be found in any other way than in the interconnections of phenomena themselves. Thus the mechanical motion of small masses on any heavenly body ends in the contact of two bodies, which has two forms, distinct from one another only in degree, viz. friction and impact. So we investigate first of all the mechanical effect of friction and impact. But we find that they are not thereby exhausted: friction produces heat, light, and electricity, impact produces heat and light if not electricity also - hence conversion of motion of masses into molecular motion. We enter the realm of molecular motion, physics, and investigate further. But here too we find that molecular motion does not represent the conclusion of the investigation. Electricity passes into and arises from chemical reaction. Heat and light, ditto. Molecular motion becomes transformed into motion of atoms - chemistry. The investigation of chemical processes is confronted by the organic world as a field for research, that is to say, a world in which chemical processes take place, although under different conditions, according to the same laws as in the inorganic world, for the explanation of which chemistry suffices. In the organic world, on the other hand, all chemical investigations lead back in the last resort to a body - protein - which, while being the result of ordinary chemical processes, is distinguished from all others by being a self-acting, permanent chemical process. If chemistry succeeds in preparing this protein, a so-called protoplasm, with the specific nature which it obviously had at its origin, a specificity, or rather absence of specificity, such that it contains potentially within itself all other forms of protein (though it is not necessary to assume that there is only one kind of protoplasm), then the dialectical transition has also been accomplished in reality, hence completely accomplished. Until then, it remains a matter of thought, alias of hypothesis. When chemistry produces protein, the chemical process will reach out beyond itself, as in the case of the mechanical process above, that is, it will come into a more comprehensive realm, that of the organism. Physiology is, of course, the chemistry and especially the physics of the living body, but with that it also ceases to be specially chemistry, on the one hand its domain becomes restricted but, on the other hand, inside this domain it becomes raised to a higher power.

(c) On Nageli's Incapacity to Know the Infinite.

Nägeli,[7] *pp.* 12, 13.

Nägeli first of all says that we cannot know real qualitative differences, and immediately afterwards says that such "absolute differences" do not occur in Nature! P.12.

In the first place, every qualitative infinity has many quantitative gradations, *e.g.* shades of colour, hardness and softness, length of life, etc., and these, although qualitatively distinct, are measurable and knowable.

In the second place, qualities do not exist but only things *with* qualities and indeed with infinitely many qualities. Two different things always have certain qualities (properties attaching to corporeality at least) in common, others differing in degree, while still others may be entirely absent in one of them. If we consider two such extremely different things - *e.g.* a meteorite and a man - together but in separation, we get very little out of it, at most that heaviness and other corporeal properties are common to both. But an infinite series of other natural objects and natural processes can be put between the two things, permitting us to complete the series from meteorite to man and to allocate to each its place in the interconnection of nature and thus to *know* them. Nägeli himself admits this.

Thirdly, our various senses might give us absolutely different impressions as regards quality. According to this, properties which we experience by means of sight, hearing, smell, taste, and touch would be absolutely different. But even here the differences disappear with the progress of investigation. Smell and taste have long ago been recognised as allied senses belonging together, which perceive conjoint if not identical properties; sight and hearing both perceive wave oscillations. The sense of touch and sight are mutually complementary to such an extent that from the appearance of an object we can often enough predict its tactile properties. And, finally, it is always the same "I" that receives and elaborates all these different sense impressions, that comprehends them into a unity, and likewise these various impressions are provided by the same thing, appearing as its *common* properties, and therefore helping us to know it. To explain these different properties, accessible only to different senses, to bring them into connection with one another, is therefore the task of science which so far has not complained because we have not a general sense in place of the five special senses, or because we are not able to see or hear tastes and smells.

Wherever we look, nowhere in nature are there to be found such "qualitatively or absolutely distinct fields," which are put forward as incomprehensible. The whole confusion springs from the confusion about quality and quantity. In accordance with the prevailing mechanical view, Nägeli regards all qualitative differences as explained only in so far as they can be reduced to quantitative differences (on which what is necessary to be said will be found elsewhere), or because quality and quantity are for him absolutely distinct categories. Metaphysics.

"We can know *only the finite*, etc." This is quite correct in so far as only finite objects enter the sphere of our knowledge. But the statement needs to be completed by this: "fundamentally we can know *only the infinite*." In fact all real, exhaustive knowledge consists solely in raising the single thing in thought from singularity into particularity and from this into universality in seeking and establishing the infinite in the finite, the eternal in the transitory. The form of universality, however, is the form of self-completeness, hence infinity; it is the comprehension of the many finites in the infinite. We know that chlorine and hydrogen within certain limits of temperature and pressure and under the influence of light, combine with an explosion to form hydrochloric acid gas, and as soon as we know this, we know also that this *takes place everywhere* and *at all times* where the above conditions are present, and it can be a matter of indifference, whether this occurs once or is repeated a million times, or on how many heavenly bodies. The form of universality in nature is *law*, and no one talks more of *the eternal character of the laws of nature* than the natural scientist. Hence if Nägeli says that the finite is made impossible to establish by not desiring to investigate merely this finite, adding instead something eternal to it, then he denies either the possibility of knowing the laws of nature or their eternal character. All true knowledge of nature is knowledge of the eternal, the infinite, and hence essentially absolute.

But this absolute knowledge has an important drawback. Just as the infinity of knowable matter is composed of the purely finite, so the infinity of thought which knows the absolute is composed of an infinite number of finite human minds, working side by side and successively at this infinite knowledge, committing practical and theoretical blunders, setting out from erroneous, one-sided, and false premises, pursuing false, tortuous, and uncertain paths, and often not even finding the right one when they run their noses against it (Priestley[8]).

The cognition of the infinite is therefore beset with double difficulty and from its very nature can only take place in an infinite asymptotic progress. And that fully suffices us in order to be able to say: the infinite is just as much knowable as unknowable, and that is all that we need.

Curiously enough, Nägeli says the same thing: "We can know only the finite, but also we can know *all that is finite* that comes into the sphere of our sensuous perception." The finite that comes into the sphere, etc., constitutes in sum precisely the infinite, for *it is just from this that Nägeli has derived his idea of the infinite!* Without this finite, etc., he would have indeed no idea of the infinite!

(Bad infinity, as such, to be dealt with elsewhere.)

(Before this investigation of infinity comes the following):

(1) The "insignificant sphere" in regard to space and time.

(2) The "probably defective elaboration of the sense organs."

(3) That we can only know the finite, transitory, changing and what differs in degree, the relative, etc. (as far as), "we do not know what time, space, force and matter, motion and rest, cause and effect are."

It is the old story. First of all one makes sensuous things into abstractions and then one wants to know them through the senses, to see time and smell space. The empiricist becomes so steeped in the habit of empirical experience, that he believes that he is still in the field of sensuous knowledge when he is operating with abstractions. We know what an hour is, or a metre, but not what time and space are! As if time was anything other than just hours, and space anything but just cubic metres! The two forms of existence of matter are naturally nothing without matter, empty concepts, abstractions which exist only in our minds. But, of course, we are also not supposed to know what matter and motion are! Of course not, for matter as such and motion as such have not yet been seen or otherwise experienced by anyone, but only the various, actually existing material things and forms of motion. Matter is nothing but the totality of material things from which this concept is abstracted, and motion as such nothing but the totality of all sensuously perceptible forms of motion; words like matter and motion are nothing but *abbreviations* in which we comprehend many different sensuously perceptible things according to their common properties. Hence matter and motion *cannot* be known in any other way than by investigation of the separate material things and forms of motion, and by knowing these, we also *pro tanto* know matter and motion *as such*. Consequently, in saying that we do not know what time, space, motion, cause, and effect are, Nägeli merely says that first of all we make abstractions of the real world through our minds, and then cannot know these self-made abstractions because they are creations of thought and not sensuous objects, while all knowing is *sensuous measurement!* This is just like the difficulty mentioned by Hegel, we can eat cherries and plums, but not *fruit*, because no one has so far eaten fruit as such.

When Nägeli asserts that there are probably a whole number of forms of motion in nature which we cannot perceive by our senses, that is a poor apology, equivalent to the suspension - at least for our knowledge - of the law of the uncreatability of motion. For they could certainly be *transformed into motion perceptible to us!* That would be an easy explanation, of, for instance, contact electricity.

Ad vocem Nägeli. Impossibility of conceiving the infinite. As soon as we say that matter and motion are not created and are indestructible, we are saying that the world exists as infinite progress, *i.e.* in the form of bad infinity, and thereby we have conceived all of this process that is to be conceived. At the most the question still arises whether this process is an eternal repetition - in a great cycle - or whether the cycles have upward and downward portions.

Notes

1. See quotation in Appendix II, p. 329.

2. See Appendix II, p. 330.

3. In which atomic volumes are plotted against atomic weights.

4., 5. See Appendix 11, p. 330.

6. See Appendix II, p. 331.

7. C. von Nägeli. *Über die Schranken der naturwissenschaftlichen Erkenntnis* [*The Limits of Scientific Knowledge*], September, 1877.

8. Priestley discovered oxygen without knowing it.

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Appendix II

Under Construction...

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