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The Mechanical Theory of Electromagnetism

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MECHANICS AND ITS LIMITATIONS.

IT is perhaps owing to the particular kind of senses we are endowed with and upon whose style of news-gathering the intellect must depend for information concerning the external world, that Mechanics is so strongly impressed upon all physical science:—when we cannot make mechanics out of a new thing we feel helpless.

The equations of mechanics deal with phenomena resulting from certain elementary and general properties of matter. The science does not concern itself with the ultimate nature either of these properties, or of the matter to which they belong. Thus, in dealing with matter, mechanics does not concern itself so much with the material substance, properly so called, as with its inertia. This property "inertia" is not ultimately "explained" by any definition given of it. No more is "force" "explained" ultimately when it is stated to be that which changes the condition of matter with regard to rest or motion.

But if the definitions of these properties do not explain them ultimately, they do "define" them precisely by means of characteristic phenomena resulting from the properties. The definitions enable us, in the first place, to distinguish one property clearly from the other, which is one essential office of a definition. Next, the definitions furnish the handle, as it were, by which mathematics can lay hold of the subject, and thus they serve a most important practical purpose.

Accepting these more or less descriptive definitions of a few general properties of matter, experimentally verified, it is remarkable what co-ordination of phenomena has been achieved, thus building up mechanics into a splendid science. This success has, in some quarters, engendered something like superstition. Some "scientific men who are not natural philosophers," as Maxwell expresses it, have considered that matter has no other than these general properties, no specific ones at all, and that phenomena could be co-ordinated by appealing to those of mechanical character alone. This makes the Universe ridiculously small and is evidently unphilosophical. An "a priori" of the most unscientific kind is involved, for not a single mechanical property is itself understood in the true sense of the word, and there is no clue to an argument proving that there are no other properties of matter than those dealt with in mechanics. We do not know the number of elementary properties of matter; all we can say is that the number must be finite.

The inter-relation of the more obvious properties of tangible matter are fairly well systematised in Mechanics. The direct investigation of phenomena, not clearly mechanical, presents more difficulty. Hence it is but natural to seek for mechanical analogies to these more recondite phenomena. If such analogies can be legitimately established, then the mathematical scheme, which serves to elucidate the real mechanics, applies almost equally well to its analogue. This process is perfectly legitimate, provided we remember that we are dealing with analogies—and that analogies are apt to break down sooner or later. Thus our theories of heat are thoroughly mechanical. We do not know whether the mechanical language employed describes the actual occurrences in heat processes or not. It is certain, however, that the mechanical statements parallel the actual phenomena to a marvelous extent. Hard-headed men have carried the mechanical analogy in this case forward consistently until they have reached the Chinese wall of "entropy." There apparently the analogy breaks down for the present.

This method of study has approved itself triumphantly by the real success achieved through it. But when a too hastily and too loftily timbered-up theory collapses, the ruin is apt to make a bad impression. Thus Newton's theory of light was purely mechanical. By means of it a huge and largely successful system of Optics was built up. A hundred years ago the mechanical basis of this system was demolished and another mechanical basis more than supplied its place. Such a theoretical wreck,—and the number of such is legion,—simply shows that the demolished theory appealed to an imperfect analogy. The replacing theory furnishes a better analogy. Hence a new and better theory means simply a deeper and clearer knowledge.

One of the chief limitations of the science of Mechanics is due

to the fact that it depends almost wholly on such descriptive definitions as mentioned above. These serve excellently to distinguish the agent; they cannot represent the agent completely. As a result, difficulties of interpretation must arise very soon. Then, the definitions cannot be appealed to for aid, for their imperfection gives rise to the difficulty. A more thorough knowledge of the agent must be sought. But this can only be a knowledge of something hidden beneath the surface phenomenon, a knowledge of the kind styled "metaphysical" in Aristotle's work. Science cannot be exclusively inductive. Some of its greatest achievements smack strongly of the metaphysical.

THE INDESTRUCTIBILITY OF MATTER.

A case in point might be the "Law" of the indestructibility of matter, so often referred to in mechanics—and other sciences as well. To be really consistent Mechanics should refer to it as "persistence of inertia." Common experience teaches that all ordinary matter is extremely destructible, and so common experience would seem to be directly subversive of the very foundations of mechanics. Aristotle presented the solution of this very superficial difficulty. All ordinary matter is "specific." Any sample of ordinary matter, with the aid, generally, of some other kind or kinds of matter, can be changed readily into one or more kinds of other ordinary matter, very specifically distinct from the initial sample. The initial sample has then been utterly destroyed, as such. That "specific" substance no longer exists anywhere in the universe;—unless we adopt the extreme old atomic view.

But, independently of any view or theory, physical or chemical, the entire "mass" and its attendant inertia, of the initial sample can be accounted for exactly in the product body or bodies, derived from the initial sample. Hence something of the initial sample must have passed into the derived samples of ordinary matter. This common, non-specific ingredient of ordinary matter corresponds to the "prime matter" of Aristotle. It does not exist as such, but is capable of existing in all varieties of specific matters. Or, as Aristotle expressed it, it is capable of endowing itself with—or evolving from its potentiality—a variety of "substantial forms," and the specific characteristics of different ordinary matters, are due to the diversity of these substantial forms. This "prime matter" is the indestructible element in all material substances. It forms the basis of the "mass" of bodies, and hence in it resides the "inertia." This bit of metaphysics may appear wholly beside the mark at first sight. But it appears to offer a point of vantage from which to study

ENERGY AND ITS PERSISTENCE.

If, then, we can say what persists in matter we might be expected to do the same with energy. The difficulty confronts us at once that energy has no "personal identity" and cannot be followed up as we can trace matter. It is defined correctly as the "capacity for doing work," and work is said to be done when forces alter the configuration of a system. Against resistance, of course, otherwise no force would be called for. To get a concept of force we may appeal to our muscular sense.

To set a mass in motion a proportionate amount of force must be expended on the mass. As long as the force is applied to the mass the latter is accelerated. When the force ceases to act, the body continues to move with uniform velocity, and the textbooks tell us that the body then carries with it "kinetic energy," definite in amount and measurable by the product of one-half the mass into the square of the velocity. Suppose such a mass to be moving absolutely unhindered, therefore uniformly, in void space. Then we have about as tangible a sample of the thing called "energy" as can be found anywhere. Such a body is said to carry "energy"—what does it carry?

Observe that there are now no stresses or strains such as the impressed force maintained while acting. Considered in itself alone, the body is in precisely the same conditions in which it was before it began its present motion. So, what does the body carry?

If we considered merely the sameness of the body before and after the force was impressed, we should apparently have to conclude that the body carried—nothing. But the body is in motion. True, but were the rest of the universe canceled, we could not even say that the body was in motion. Motion is relative, and requires "a frame of reference."

Like motion, the energy conditioned upon it is something relative. It is a real entity, belonging to the category of "accident" and not to that of "substance." The energy is a property of the whole system, not of any part described for convenience as in motion relatively to another part, and therefore it vanishes with the canceling of either term.

The law of the Persistence of Energy is implied in the old metaphysical axiom "causa adaequat effectum." Material substances are true "necessary" causes producing real necessary effects when the proper conditions are established. Since physical processes are functions of time, the antecedent is referred to as cause, the consequent as effect. This effect may be antecedent to another to which therefore it stands in the relation of cause. Science has recognized that the action by one part of a system upon another part is always at the expense of the former and to the gain of the latter, both considered as causes. The metaphysical principle has therefore been made definite in physics by the statement that, considered as a whole, the "capacity for work" of the universe is constant. The convenient distinction between potential and kinetic energy is not material to the concept of energy nor the notion of its various other physical forms.

Tracing energy therefore means following the integral cause from effect to effect. Thus, forced mechanical displacement, e. g., in a generator armature, may result in electric and magnetic stresses, which, in turn, may result in mechanical displacements in the motor. We can trace something constant through this series: the original cause was itself an equivalent effect and the final turning of the motor is likewise an equivalent cause, which also has a further effect.

The inference would then seem to be that on metaphysical grounds the persistence of energy might be expected as a probable law, though of course experiment was required to verify it. No equally plain presumption can be made in favor of the persistence of inertia and this law is therefore more purely experimental.

CONNECTION BETWEEN THE CONSERVATION LAWS.

Just as inertia is referred to the determinable constituent,—the "materia prima," so energy seems referable to its determining element: substantial form. But (transferring mathematical to metaphysical language),—to the human mind the two concepts are not functions of one another, and hence if there is a connection between them, experiment must determine it. The connection does appear to exist. If either conservation law be rejected, the laws formulated by Newton prior to the recognition by science of the constancy of mass and energy would be seriously embarrassed. Philosophical, and therefore open, minds like Maxwell, Kelvin, Tait,—all "realists" of very mechanical temper, have arrived at the conclusion that the energy law is a consequence of Newton's axioms.

Accepting this conclusion, and, of course, Newton's three theses, it would seem that the constancy of mass must follow by a "reductio ad absurdum." For example: The center of gravity of a projectile carrying a given amount of kinetic energy must, according to the laws of Newton, move on undisturbed by forces intrinsic to the projectile alone. If, upon explosion, the chemical reactions involved a loss of mass, the kinetic energy would be reduced in the same proportion, unless the center of gravity speeded up. Such an event is, however, in contradiction with the second law: that acceleration is in proportion to "impressed" force. No such force can be assigned in the illustration.

LIMITATIONS OF FORMULAE.

All true scientific formulae tell the exact truth about the subject they actually deal with. This does not mean that they tell the whole truth about any tangible material thing that may be actually under consideration. A moving mass carries energy in proportion to its mass and motion. These two aspects of the body are the only things considered. The host of specific properties of the moving body are left out of account. Similarly, in studying the processes of setting a mass in motion, the mass itself and the elasticity or rigidity of the body are alone considered. A similar abstraction obtains in the case of chemical formulae. Chemical action is always attended by a movement of energy. Sometimes, as in the case of explosives, the amount of energy set in motion is enormous, when we compare it to the small mass to which it was bound. But chemical formulae, as such, pay no attention to this important ingredient of chemical processes. The Chemist is directly concerned in the masses of his agents, because by their means the law of definite proportions guides his work. He is interested in a few specific properties of each different kind of matter only as a guide to recognition. As far as the purely chemical results are concerned, the energy movements are by-products, and sometimes very inconvenient ones. Evidently chemist and physicist may take different views of the things they deal with, and the view of each embraces only a very limited part of the entire subject.

Quite frequently, however, the energy set in motion by a chemical action is the direct object aimed at. This happens whenever a fire is kindled in a furnace. Also whenever an explosive is compounded. In these, and in many another instance, it would be very convenient to have the chemical formulation embrace the energy content as well as the mass, and the chemical identity, or "forma substantialis" of the thing dealt with. In many of the simpler cases, the energy developed by unit masses is known and this knowledge when available is employed to good effect where energy development is in view. But at present it would be impossible to burden the chemical notation with an added energy symbolisation.

Still it is clear that a more complete presentation of the subject,—say of the formation of water from its elements,—must include this energy movement, for it certainly has an intimate relation to the question as to how elements exist in their compounds. Chemical equations, like those of mechanics, are measurements rather than definitions. It is very good to know that Force is equal to "time-rate of momentum" or "space-rate of energy," but this does not mean that force IS either one or the other. It is simply Force: something the nature of which is beyond mechanics. Thus, too, the chemist may say that oxygen and hydrogen are equal to water but not that they "constitute" it. It would be taking entirely too big a risk with the interpretation of formulae to maintain that both members of an equation must be identities in order that the equation may hold: that would raise all formulas to the rank and dignity of metaphysical definitions.

GRAVITATION.

In the problems of mechanics not only the inertia of masses, but their equally general property of "weight" must frequently be considered. Very probably the earliest "experiment" a future physicist ever makes is learning how to walk. At that date he has no idea whatever of what a fine co-ordination of nerve and muscle it takes to keep him from describing a "projection on a horizontal plane" every time he attempts to raise, in his small way, the potential energy of a system in which the earth is a distinct majority. Older heads than his know of the existence of a "law of Gravitation," but there, for the present, human knowledge ends.

The phenomena of gravitation are analogous to those shown by a stretched or compressed spring, which transfers its energy to the mass it accelerates. Thus, to raise a stone it must be pulled away from the earth, which implies that work must be done and stored somewhere. Something seems to have been "wound up" and all is quiet if the proper detent or support be provided. This of course is stressed to a sufficient extent to prevent the other—the mysterious gravitational stress—from getting control and discharging into the stone as kinetic—"tramp" energy—the potential energy in the "field." The field is not "in the air" exactly: a body will fall in a vacuum.

The sun and planets are falling together all the time, which assuredly would not happen were there no medium capable of transmitting the stresses necessary to provide the accelerations implied. The medium must have capacity for storing energy. This energy cannot be wholly in the earth and moon, for instance: for the further they are apart the less the force between them but the greater the energy. Great distances are not, however, specially important: were the moon to come down from where it is, or from the distance of the dog-star, there would be little difference in the striking velocity, and, therefore, in the energy. The speed would be 6.88 miles per second in the first case, and in the other only about 500 feet per second additional. It would take the moon in one instance about the same time to get here that it takes a Cunarder to cross the Atlantic: 4 days 19 hours 26 minutes; but in the other it would take nothing less than geological ages.

Cometary motions are interesting examples of the interplay of potential and kinetic energies. Space at night looks grandly peaceful and solemn. It is no such thing. In its inconceivable immensity there are vast energy fluxes and colossal stresses hurrying hither and thither with the speed of light. The disappointing Halley's comet of a year ago, after having gathered into himself what energy the conditions allowed him to annex from space, has gone off shedding it back into "space." It will be all in space again—as much as he can get rid of—and he will be lazily drifting, "marking time," as it were, somewhere beyond Neptune's track in about forty years. It will take him that interval to fall back again, when, having gathered in once more what he scattered, he will not be marking but making time close to the sun. It is a curious swinging of energy—into the body—out of it again into space, but never escaping from the SYSTEM, the universe.

IS GRAVITATION A PUSH OR A PULL?

Undoubtedly matter has a real property radicated like inertia in "materia prima," which when actuated gives it "weight." There is difficulty in the concept that it is a direct "attraction:" the force would have to terminate somewhere, thus arguing atomic structure with entire absence of gravitational force within atomic volume. No such conclusion seems necessary if matter be conceived to act upon a medium (which would have to be postulated in any case in order to avoid "actio in distans") and so modify it that a push results, tending to drive bodies together, and every single body into a smaller volume. We are not unfamiliar with the existence of both pressure and tension in regions void of all ponderable matter as far as we can provide for its removal. Thus, whether in vacuo or not, electric currents going in the same direction are pushed together by a pressure outside, while opposite electrostatic charges seem pulled together by a tension between them. In the latter case the forces actually terminate upon surfaces. But whether we assume pressure or attraction is immaterial: the result of gravitational action is the same: mechanical acceleration. Experience has taught us that when through material agency a mass is to be set in motion, direct contact is required between the two terms or the equivalent must be provided for by an intervening material medium in contact with both. This medium must transmit the necessary stresses and must therefore have definite properties. Now, in the case of gravitation enormous stresses are applied at points far apart in space,—and no material medium, obvious to the senses and possessing the requisite properties, is in evidence. And so mechanics appears at first sight to be at fault. To bridge the chasm, sense phenomena merely present the problem to be solved; they afford no direct key to the solution. The solution, if any is to be discovered, must be sought beneath the surface of sense phenomena. An appeal to some sort of metaphysics appears to be imperative.

Such an appeal has been made in a different case. Energy is transmitted across astronomical distances in the electric and magnetic form. The two are a curious pair of cosmic twins: accounting for the transmission of one solves the problem for both, and covers the transmission of light as well. Experimental mechanics, as well as philosophy, demand the existence of a proper medium to effect the energy transfer. No ordinary material medium that could serve for such a transfer is in evidence—indeed no such medium could answer the purpose. Hence the existence of a "proper" medium was inferred and it was named the "Ether."

THE ETHER.

Since it had to be a "proper" medium, it had to possess certain "properties," some of them very peculiar. Thus, evidently it had to fill all space, since it must transmit energy in all directions to the utmost limits of space which are at all accessible to our investigation. In this respect the ether is certainly a material substance. At the same time it cannot "fill" space as ordinary matter does—for it does not exclude ordinary matter from the space it occupies. Hence the thing cannot be "weighed" and therefore it is sometimes described, somewhat gratuitously, as "imponderable."

This medium must certainly have another property, namely, something analogous to perfect elasticity. This property, in any case, must depend on a host of other more recondite facts, as, for instance, the intimate constitution and perhaps structure of the ether. A number of hypotheses have been formed as to its constitution. Under the circumstances quite contradictory hypotheses may go a long way before they break down. All break down in the end, seemingly. The saving adverb is supposed to suggest that the contradictory hypotheses may be such only seemingly. In other words, a fuller knowledge of this intangible medium is desirable. But that fuller knowledge can at present be only sought for in a metaphysical direction.

Much knowledge of the kind is contained in the "inferences" drawn from the functions the "hypothetical" medium does perform. And if it performs "real" work, why should it be maligned as "hypothetical?" At any rate we have here a medium which does carry energy from point to point, and does so efficiently when ordinary material vehicles cannot possibly perform that office. Hence the ready suggestion is that the medium can store energy somehow, just as material masses can store energy. As a matter of fact, the ether plays a leading role in all electromagnetic phenomena. Its "mysteriousness" seems to be due to the fact that we have become so accustomed to expect certain properties in all matter within ordinary experimental reach, e. g., weight or inertia, that it has become difficult for us to suppose any kind of material substance divested of these properties. However, not being ourselves responsible in any way for the existence of matter, we cannot draw the line between the possible and impossible unless we can show contradiction,—which is very difficult to do. After all, we meet with properties in our dealings with ordinary matter that cause us no surprise, though a showing might be made that they

are inconsistent. Ice resists traction, water does not, and steam exhibits self-repulsion, yet they are one and the same substance.

In the ether we can recognize nothing corresponding to the "compressibility" of matter. Though wholly distinct, the two are on such intimate terms that hypotheses are not wanting which would reduce matter to a peculiar local make-up of ether. Apparently they are so bound up together that matter, out of touch with the ether, would seem incapable of action. Intimate contact and mutual influences can be traced through a great number of the most varied physical processes. For instance, light goes through glass at a materially reduced speed compared with its velocity in space, but still entirely too fast for any properties we can discover in glass alone.

Though originally invented for "luminiferous" purposes, it looks probable that the ether's largest office is to carry the great gravitational stresses which make a mechanical unit of the universe. Of course a special medium, coextensive with the ether, might be assumed for the purpose. This does not look specially philosophical and does not suit the economies of science. If there were any positive advantage in such a supposition and no objection, then it would be convenient to introduce a third ether, since it is more than a puzzle how the existing single one,—or the one which we regard as existing,—can handle both electric and magnetic phenomena. These are perfectly distinct, but so completely linked together that we hardly dare assume distinct media. "Test" experiments as to the nature of gravitation are practically out of our reach: every attempt made has given negative results, and we therefore fall back on the old philosophical dictum about not multiplying things: "non sunt multiplicanda entia sine necessitate." The actual ether offers conundrums at so many points that the very properties we know of, did we understand them better, might explain gravitation. Maxwell made an attempt towards a theory, the fundamental idea of which was that gravitational and electric fields differ as pressures and tensions differ, but he does not seem to have attached much importance to it. So much more complete, however, was his success in transferring mechanical equations into electromagnetism that he may be said to be the founder of Ether-Physics. It is to be remarked that he always wished to be understood as tracing analogies and parallels, and not as attributing actual mechanical properties to the ether. The theory might be called mechanical because it uncovered a sort of identity of plan in the "modus operandi" of the mechanical properties of matter and the electromagnetic ones of the ether, not because it supposed identity of the properties. Maxwell himself always referred to Faraday as his inspirer. The intuitions of the latter were as distinctly mechanical as was his terminology, and his interpreter retained everything in the bold structure with which he surprised science.

THE ELECTROSTATIC FIELD. MECHANICAL ANALOGY.

It would be difficult to describe the happenings in the ether which are at the base of electromagnetic phenomena without having recourse to Faraday's idea of "lines of force" or "tubes of force." The concept corresponds very closely to that of "rays" in Optics, which are lines along which energy "flows." Just as we can follow the path of these rays so we follow the direction of any force in a medium from point to point, or the path of a discrete particle in a disturbed fluid. To get an idea of these directions or "lines" of force it may be a help to consider an imaginary mechanical experiment devised to duplicate electrical conditions as nearly as possible.

Imagine two spherical water-filled cavities in an extended mass of rubber, and suppose a transient current to be established from one to the other by means of a removable mechanism. The sum of fluid volumes remains constant, and hence also that of the medium. The latter is under strain from which its elastic forces tend to relieve it by reversing dislocations, for the doing of which the necessary and sufficient energy has been stored up by them. There was a temporary "displacement current" in the medium while it was being forced away from one and towards the other cavity by the motion of the fluid, and if we suppose incompressibility, so that the medium can yield only by sliding or "shearing," then the "circulation" is in closed paths, as one current must necessarily be equal and opposite to the other. Once equilibrium exists and conditions are static, the elastic reaction pressure of the medium is everywhere normal to the bounding surface or "interface" between fluid and elastic solid. For, since the latter will certainly settle down to any possible minimum of distortion, no force tangential to the surfaces can be supposed. The reason is simple: water is a first-class "conductor" to shearing forces: it yields to them indefinitely, and dissipates into heat any energy which may be thus transferred to it.

If now, having selected any point on either interface, we undertake to trace, from point to point, the direction of the force just as

we find it, we shall begin with a perpendicular and end with another somewhere upon the other surface. With the exception of a start made along the line of centers, our path would be curved in a more or less wide sweep. But we should have traced a "line of force," a curved "ray," as it were, along which the elastic forces act, tending to restore original conditions as soon as the enlarged cavity can be made to discharge back into the contracted one. Clearly, the energy required for this has been stored up not in the fluid but in the medium. The necessary stresses are everywhere in evidence in the latter, and hence we can speak of its "field of force."

We now make the effort to imagine that the cavities may move about. At once we notice that we are either aided or resisted. For we observe that the field is thrown into changed "lines,"—not "more" lines, but longer or shorter ones, and hence is gaining or losing energy which we must take up, or provide for. If free to move, the surfaces would surely be forced together and on coming in contact be discharged. Thereafter they could be moved about without notice being taken by the medium: for no elastic stress converges upon them—they are no longer "charged."

Let, now, three such cavities be provided and let the water driven out of one be divided among the other two. Between this pair the medium is crowded against itself and they "repel" each other: they have "like" charges.

We might leave one of the three uncharged. It is, however, immersed somewhere in the field between equal and opposite charges, and hence its surface is met by lines of force whose continuity below the same is impossible. Hence there is "convergence" or termination of lines exactly as if there were a true charge. Here we must observe carefully that the total convergence is half from one and half from the other of the actually charged surfaces, because the interruption of a line stretched between these leaves two free "opposite" ends. Thus charges have been "induced" upon the otherwise neutral surface. If free to move, it will be pushed towards the nearest true charge, because such displacement gives most relief to the stresses in the field.

Close observation of the mechanical experiment would disclose the fact that, as noted above, there is a gliding motion of the medium over the bounding surfaces of the cavities while the charge is increasing or decreasing, for which reason the latter were called "conductors." The concept is important. The motion referred to is more easily studied if we suppose a short cylindrical column of rubber to be compressed between two rigid circular discs. In addition, we may suppose perfect lubrication between the contact surfaces, or else complete adhesion. In the first case we shall find that while lines of force are set up in the shortening and bulging column, its contact surface glides upon the disc,—or its lines of force do:—it amounts to the same thing. Because of adhesion—that is, more perfect continuity—no such creeping occurs in the other case. The charge sticks, as it were, and its lines of force may land obliquely to the surface. The latter is a "nonconductor."

The electro-mechanical analogies are now the following: The "mechanically elastic" "solid" is the "electrically elastic" "ether." It also represents any ether-matter complex in which the former preserves its essential property, though it may be, possibly, greatly modified just as the quality of rubber depends on "loading" admixtures. This range of modification may extend from zero to infinity, theoretically. The latter case differs from the former as perfect conductivity differs from perfect insulating power,—not "resistance." There are no perfect conductors. In them the ether would have to be absent, or equivalently so. This is unlikely, just as it is unlikely that we shall ever discover a perfect fluid. It is an experimental fact that any ether-matter complex has more electrostatic energy capacity, i. e., is less elastic, than the ether alone. Therefore the latter is the absolute insulator. It loses rigidity when loaded with matter and we have insulators, like sulphur and glass, within which the loss is slight, and conductors, like silver and copper, within which it is so great that no appreciable electric force can, under any circumstances, be maintained within them.

It is not probable that any electromagnetic phenomena could take place in the ether were all matter excluded from it. The lines of an electrostatic field are set up by the action of matter on matter, and always terminate on matter, and hence they do not and cannot form "closed" circuits. This is similar to the case of any mechanical field set up by pressure in a solid. It is necessary that some surface or surfaces be picked out, or fixed, as it were, so that the lines of force can converge upon them. Thus, if we drive a nail into a board, the stresses within the wood converge upon the surface of the nail, and vice versa. In the electrostatic field we have such terminal surfaces for the force lines: they always end upon matter, conducting or non-conducting. How they are set up we cannot say: we are ignorant of why, apparently, any physical

occurrence seems to be attended by electric stresses. Bodies are said to be charged whenever we can trace lines of force to them, and not through them, without some change in continuity. Since a true conductor interrupts them completely and can therefore permit no tangential component to its surface, it must show equal and opposite charges when placed in an electric field and none whatever when withdrawn. The lines slide on and off, divide and join again with ease, much as fluid opens up ahead of and closes in behind a solid which is drawn through it. Insulators behave somewhat differently. Thus glass does not break continuity in an electric field, but it does markedly affect it. The ether within it has lowered rigidity and hence, at the glass surfaces, there is something equivalent to convergence: a sort of differential effect. Glass may then be withdrawn from a field and show equal and opposite charges, which can be dislodged only with difficulty. When locally charged, the charge creeps slowly over the surface, showing the existence of conductivity: there is no definite connection, however, between this effect and the electric elasticity of the substance.

Between charged and neutral bodies mechanical actions occur precisely similar to those exhibited in our mechanical model. In the latter we required an elastic medium locally differentiated by the introduction of media between which mechanical action was possible. In the electric analogue we require ether and matter, and hence the general theory of electrostatic action does not postulate the existence of any special stuff called "electricity," and hence no fluid or fluids. Experiment, however, shows that "opposite" electric charges have very specific properties, and differ vastly more from one another than do mechanical pressure and tension. Recent investigation has widely separated the two kinds and it has become apparent that something like a combination of theories is necessary. Maxwell's "system of equations" would stand: he left the special question open. He speaks of electric force displacing "electricity" and not matter directly, but he does not commit himself to any definition of the former. It may happen that the "electrons" of modern science, which are supposed to exist in matter, may answer as such a definition. Perhaps the ether will itself be considered a structure of electrons.

In our every-day experiences we observe elastic forces, not in the same category with those of gravitation, equilibrating the latter in any structure on the earth's surface. In some like manner a charged body opposes its mechanical strength as a reaction against electric forces. If such a body be supposed to contract in volume the total electric convergence is not thereby diminished, but its "density" increases with the decrease of surface. The result is that the mechanical outward pull increases with the square of the density. On very small particles even a trifling charge would have, necessarily, great density, and hence they would be subjected to enormous tensions. It is quite conceivable that this tension might become so large that a molecule would, under circumstances, give way, and then corpuscles or "electrons" might well be expected to fly off with explosive violence and "charge" any body struck by them, since, of course, the ends of the lines of force, or the charge or the convergence would have to go with the torn-off particle. The fact that things of this kind do happen makes the mystery of molecules and atoms (granting that such is the structure of matter) much more impenetrable. There is no good reason for supposing that radium (or any member of its large family) is unique in being the focus of enormous stresses and energy. These bodies break up slowly and automatically, but it takes only the feeblest provocation of mechanical pressure to cause terchloride of nitrogen to go to pieces in an instant, with no little violence and "capacity for work."

THE MAGNETIC FIELD.

If a horizontal card be pierced by a vertical wire, iron filings scattered upon the card will arrange themselves according to the law of gravity alone. But if they are scattered on the surface whilst a strong current is passed through the wire, the filings will arrange themselves about it in the form of concentric circles. Again we have representations of "lines of force," but these end in themselves. This is not characteristic of an electric field: indeed, the field is "magnetic."

It is difficult to give analogies from mechanics in this instance. The most satisfactory ones involve motion, and, therefore, a mechanical momentum-field. For instance: there is tension in the rim of a revolving fly-wheel, which tension differs from that in a hoop around a barrel in being dependent upon motion. We may go further in our analysis if we suppose the wheel to be moving in a resisting medium, or else under acceleration. In such a case we may start from any point and trace the driving force around the rim back to the starting point, while the reaction of inertia follows the same path reversed. Another illustration of closed lines may

be found in the motion of liquids within which displacements always cause "circulation."

We can really not say whether the ether is in motion or not when a magnetic field exists in it, but the latter certainly has characteristics which compel us to look upon it as a kinetic phenomenon. Something analogous to a "spin"—more specifically, "vortex motion"—seems to go on within it. The "force" actually observed is a tension along the axis of the vortex. It *may* have its origin in rotation and may, in turn, bring about what we describe as a "magnetic displacement," but it is very difficult to understand the connection, unless we assume a most curious structure of the ether. Thus an ordinary vortex or "smoke-ring" tends to expand and hence its axis may be conceived as under tension. But it is not the right kind of tension, as there are no displacements directed along the axis. The comparison is therefore not wholly satisfactory.

It is assumed, therefore, in a general way, that magnetism is some kind of ether momentum. Science has no need of any hypothetical "fluid," such as is found convenient in electricity. There is nothing corresponding to "charges," as the force has no "convergence." It is non-polar, as the lines always return within themselves.

The presence of different material substances has little effect upon the force distribution: bodies are, all of them, about equally permeable. The one notable exception is iron, which seems to take the magnetic temper or stiffness out of the ether present in it, and iron has therefore a great capacity for magnetic energy. This magnetic field passes through all bodies: but it would be rather inconsistent with electrical terminology to call them magnetic conductors for that reason. In *electrostatics* the substances which transmit electric force are all "insulators."

An electric field is probably always initiated by chemical action. Once set up, its energy may be indefinitely increased by direct transformation from mechanical energy, as is done in influence machines, and may be stored up in condensers. A magnetic field, on the contrary, cannot be maintained without constant expenditure of energy: an argument that its "form" is essentially kinetic.

PERMANENT MAGNETS.

The last statement appears to contradict facts: no energy is required to maintain the field of a permanent magnet. It may be stated at once that the steel bar magnet is a most troublesome conundrum to the physicist. Externally its field resembles that of opposite electrostatic charges. Iron filings scattered on a card, best placed over the ends of bar magnets standing vertically, are regularly used to illustrate the lines of force of an electrostatic field. The smallest fragment of steel separated from the magnetized bar is known to be a complete magnet. It does not really explain anything, however, to say that the bar is a magnet because its molecules are. The only advantage is that it may be assumed that the molecules are magnets naturally, for such a statement could not be disproved. The office of an impressed magnetizing force then consists in putting order into confusion, though, of course, it must do work in getting the molecules into a highly unstable condition of equilibrium. More forces or properties must next be invented to keep the molecules in order, and further explanation is required why these forces are absent, or nearly so, in soft iron, and also why iron alloys differ markedly in magnetic properties.

The bar magnet somewhat shakes confidence in a simple momentum theory. It is the only case in which we find a magnetic field existing without a demonstrably coexisting electric field: the only case in which the "circuitation of force" is interrupted. To get consistency it is necessary to introduce the notion of magnetic "Induction," which, unfortunately for the use of terms, must mean displacement or flux and not merely electricity or magnetism due to "influence." Magnetic flux, or "induction," is always circuital. In a steel bar a magnetizing force has caused such a flux, or induction, say from the south to the north pole, within the bar. It continued through the air along the well known "lines of force" paths, back to the south "pole," and thus its circuit was completed. In this external region force and induction are identically measured and hence need not be distinguished.

Now, on the removal of the cause, there should be an elastic return to neutral conditions. But in steel some obscure molecular property inhibits this. A partial recoil occurs, but for the rest a weakened external field is sustained. The internal force—not induction—is reversed. This result might be expected: the case is paralleled in mechanics where momentum and force are convertible. When a wire is twisted and then released, the return is never complete, but tends to become so by slow creeping; showing that though the twist (induction) is not reversed, there are forces at work in a sense reversed to the twist.

From the nature of the case, the magnetization of a steel bar by a permanent magnet is always by "field-influence" and never by a division such as occurs when an electrostatic charge spreads, on contact, over a conducting surface not previously charged. The magnet resembles a glass or ebonite rod, electrified by being maintained for a time in an electrostatic field. Breaking such a rod should show opposite charges at the surfaces of fracture, just as a bar thus treated shows "poles." A less complete but more obvious similarity exists between permanent magnets and "Zamboni's dry pile"—a stack of gilt and silvered tinsel-paper discs so arranged that dissimilar metals are in contact, with the same metal always facing the same way. The terminal discs are electrostatically charged, and the stack may be divided anywhere for new terminals and charges. This field is due to chemical action and is strictly electric, and hence, within the column, is interrupted at every layer, quite unlike either the "induction" or "force," which is continuous through the mass of the bar magnet.

Such a magnet could be made to give up its fiction of poles if it be bent into a circle and the ends perfectly joined. During the process the external field draws in, vanishing entirely when the junction is made. The steel toroid would then act like any other of the same material and the existence of the internal induction could not be discovered except by a magnetizing force such as that due to an electric current. It is obviously impossible to magnetize a ring after this fashion directly from the outside by means of a bar magnet. The force of the latter would manifestly have to enter and leave somewhere at different points of the circumference, and therefore create "poles."

Leaving aside the puzzling "permanent" magnet as a special case of magnetization complicated by the properties of matter, we may now turn to study

THE TRUE MAGNET.

If a helix of insulated copper wire be wound in close turns upon a mandrel (for which we might use a bar magnet) and the latter be then withdrawn, we shall have a hollow "solenoid" of non-magnetizable metal. Upon passing a sufficiently strong current through the coil we shall discover an external field completely replacing that of the bar magnet. Upon looking for "poles" we should, however, be at some loss where to locate them. A magnetic needle or an iron rod would move up to the coil and disappear within its air-core. A very long magnetized steel wire would thus have its north pole drawn in at the south end and projected out at the north end after passing with considerable acceleration entirely through the coil. Evidently this indicates continuity of force, and we are compelled to conclude that if we could experiment with a single detached needle pole, the latter would be driven round and round indefinitely. Ejected at one end, the pole must follow the external curved force line, be drawn in at the other end, pushed through the core and be returned to its starting point, there to begin its journey over again. The speed should steadily increase: for the force is steadily acting. Hence the mass is gathering kinetic energy, for which the only source of supply is the current.

This experiment cannot be made with a bar magnet, for it can never be made hollow. A hole bored through it lengthwise is not the same thing: magnetically it is necessarily always outside the magnet. A north pole attracted to the south end of the bar will not pass into the hole, and, if forced in, will be thrown out where it entered. Nor can we conceive the experiment as possible even if the pole be supposed to move unobstructed through the molecules of the steel: The result would be a complete demagnetization of the bar, as there is no energy supply in sight except its own field.

Our coil may now be reduced, turn by turn, until there is but a single one left. The true magnet is still there: a swirl of magnetic force still passes through the enclosed area of the loop, returning externally. The wire is itself included: within it there is a mathematical axis of circuitation, so that the magnetic force is not limited to the outside of the wire. It simply falls off inwardly and outwardly, reckoning from the surface where it is most intense.

There is mechanical stress upon the wire. It is exactly the same as that in a hoop driven around a barrel, with the difference that the magnetic lines of force are the cause of pressure on the wire, and not vice versa, as is the case with hoop and barrel.

THE ELECTROMAGNETIC FIELD. ELECTRIC CURRENTS.

Whenever a magnetic force is in evidence it is always a sign that there is electric current somewhere. A "Current" implies motion of some kind, or the transfer from one place to another of a substance or of a quality or condition of the same. When a charged body is moved we may consider the convection as one possible kind of electric current. This evidently does not consist in the mere translation of the body, but rather in that of the electrostatic field, whose stresses are conveyed from one region to another, and hence in the displacements attending them. Wherever such displacement is going on we shall conceive an electric current to exist. It is always accompanied by magnetic induction and hence by magnetic force.

This apparently surprising result has its parallel in mechanics and illustrations are readily found. When transverse vibrations are carried through an elastic solid, the stresses cannot pass on without creating momentum and hence the energy is partly potential, partly kinetic.

The vector relation between the two fields is simple. The magnetic force is always at right angles to the electrostatic line of force and to the direction in which the latter is being moved. The more nearly this direction is perpendicular to the electric line also, the more intense is the magnetic force. Hence the electrostatic field must not move wholly in its own direction.

CONVECTION CURRENTS.

Conceive a charged sphere projected in any direction. The electrostatic field is in radial lines and hence one of these lines lies in the direction of motion. Nowhere on this line will any magnetic force be generated, and, for convenience, we shall use this line to mark the poles of the sphere. At the equator the electric force is everywhere at right angles to the direction of motion, and hence the magnetic force is there most intense. Imposing the condition that it must be perpendicular to the direction of translation and to the electric force determines the magnetic lines completely. In the equatorial plane they form concentric circles, their intensity diminishing outward. Similar reasoning enables us to conclude that the magnetic force is everywhere else in circles centered upon the polar axis. The situation is much as if a sphere, imbedded in an elastic medium, had been given a twist, thus throwing the medium into lines of torsion.

The description given holds for velocities not notably approaching that of light. At the latter speed the whole disturbance would draw together into the equatorial plane and would constitute an electromagnetic wave.

Such a moving charge may be called a convection current or element of a continuous flow: this latter being a succession of elements following on each other's heels. An experiment covering such conditions could be made by arming an ebonite disc with a metallic rim kept constantly charged. This is the classical experiment of Rowland, who succeeded in showing the existence of a magnetic field when such a charged disc was driven at high speed.

Textbooks tell us that static charges of like sign repel each other and that currents going in the same direction attract. Let, therefore, two similarly charged spheres move side by side. A magnetic whirl starts around them both in the same sense. Between them, therefore, the magnetic forces tend to cancel, since they are opposite, while outside of them they re-enforce each other. The resultant magnetic field then acts like an elastic band sprung about both spheres, forcing them together. Attraction has begun at the expense of repulsion. There must be some speed at which they balance: when the velocity of light is reached "attraction" is paramount.

Let, now, a system be arranged consisting of two discs, oppositely charged and moving with equal velocity in opposite directions. The magnetic fields are the same, for a negative charge moving counter to a positive charge generates the identical magnetic vector. Mathematically the sum of the two velocities is zero, while that of current, measured by magnetic effect, is double that of either "convection." Such a combination is a purely mathematical fiction, but the physical state of a live wire, supplied at one end with positive and at the other with negative electricity, is singularly suggestive of being the resultant of two interpenetrating conductors in relative motion with the speed of light, both carrying the proper charges. In the fictitious double-disc system, the kinematic "resultant" of their union gives a single motionless disc. Of course the charges promptly "neutralize" each other as well as the velocities, and the experiment is at an end. We are not without a remedy, however. We may slit the disc radially and supply positive and negative charges by introducing an electromotive force. The result will be a conduction current.

CONDUCTION CURRENTS.

The knobs of an active electrostatic machine tend to come together and any loose particles are detached from opposite poles and accelerated towards each other. Their collision energy, wholly derived from the field, is spent in heat. Imagine, now, opposite streams of such particles set in motion by the mechanical stress exerted upon them by the field. Because the particles draw together, the lines of force must shorten, and at the same time they must move sideways under their own pressures, which are becoming unbalanced. This must mean ether-momentum or magnetism, as all the conditions required for its appearance are fulfilled. Hence the axis of the stream is surrounded by a magnetic whirl created by the side-on motion of the static stress. This constitutes an electromagnetic field: the characteristic field of electric energy in motion.

It is not necessary that the particles to which the energy is delivered should have free paths of any definite magnitude. With a very large number of them, each would need but to oscillate about a mean position. The inference is that we can do altogether without mechanically discrete particles, if we can bridge the poles of the machine with a material along which the electrostatic lines can slide, transferring their hold from molecule to molecule. If their electric energy, as such, is to vanish then we must suppose that the molecules are agitated by the rapid passage over them of the electric convergence, and hence we must assign some property to them, enabling them to be thus acted upon. Their mechanical inertia might be assigned or any other property to be termed their "resistance" to electrical conduction currents. When present, this property enables matter to transform electromagnetic energy into heat.

THE VOLTAIC CELL.

We may now study the mechanism of an electric conduction current. Provide two substances, preferably such as possess conducting properties and are capable of reacting chemically. A sheet of zinc in a suitable acid will answer very well. Chemical action begins at once over the surfaces in contact. The eduction of a new substantial form, say zinc sulphate, is accompanied by the appearance of electric charges. No reason whatever can be given for the appearance of ether stress whenever substances thus react: it is simply an experimental fact that the zinc is positive, the acid negative, over the contact surface. It may be viewed in the light of a reaction against "chemical affinity," as it always inhibits the action of the latter at some stage of fixed difference of potential. Final conditions suggest that the molecules have intrenched themselves on either side of a party wall and there is a truce. One end of a wire is now to be attached to the zinc, the other end being permitted to dip into the acid. This wire must not be zinc: at least not where it enters the acid. To make contact with the latter the proper metal is one which is not equally exposed to attack by the acid, for we must avoid raising another identical party wall of difference of potential.

In order to make the suggested connections it is clear that the wire, which we may suppose a long loop with parallel sides, must penetrate the ether-stress region about the substances. This makes a breach in the wall and some of its lines of force are pushed upon the wire. These are under the side pressure of the field bulging from between the zinc-acid surface, and they are without secure foothold, since the wire is a conductor, until they move into a position where they may stand normal to the wire. Hence they move down the loop, which causes others to follow, all paying for the right of way by losing energy to the wire if the latter be supposed to have "resistance." By the time the vanguard reaches the middle of the loop the last remnant of its store is there swallowed up, a like fate awaiting the next arrival.

Meanwhile the zinc-acid molecules have become alert to the breaking down of their intrenchment and they start out for prompt repairs by "acting" on each other. The battle will never cease now as long as any metal or acid is left to keep the ether-stress keyed up between them. Once started, the machine works with perfect steadiness and smoothness: conditions are everywhere stationary in dynamic equilibrium. Lines of force burst out from between the molecules on the firing line and hurry down the wires. Where these conductors are parallel, the lines of electric force stretch across, in the plane of the wires, nearly straight and nearly normal to them. On the whole the field is much like that between oppositely charged cylinders.

In addition, closed loops of magnetic force are threaded around the wires, all of them passing through the plane containing the conductors. They exist because the electric field is in a state of flux, and they stand everywhere perpendicular to the electric lines which they accompany.

The energy set free by chemical action in the cell thus takes the electromagnetic form. It is driven out into space, all of it ultimately reaching the wire, there to be dissipated as heat. This means no more than that it will leave the wire again and return into space in the form of electromagnetic wave motion and be no longer constrained to follow a conductor. The path of the energy after leaving the battery is, with straight wires, and in their neighborhood, almost parallel to them, so that the approach is by long slants. When the wire is reached the flux turns sharply at right angles to the surface and "diffuses" into the conductor.

TRANSMISSION OF ELECTROMAGNETIC ENERGY.

From the preceding we conclude that the wire does not directly transmit the energy set free in the battery, but marks the locus where, after transmission through the air,—or whatever dielectric the circuit may be immersed in,—the energy shall be delivered, transformed and dissipated into heat No electric motor is moved by anything which gets into the wire of its coils, but by the energy intercepted on its way to them. The wire circuit guides and directs the movement of the electromagnetic energy because it is a conductor and it absorbs energy because it has resistance. To establish a current the wire must be charged, and, as has been explained, it must exhibit complementary charges distributed over its surface so that a field starting from one portion is directed through the surrounding dielectric back to the wire again at some other portion. A movement of energy then sets in towards the wire, which instantly becomes the core of a magnetic whirl. If the wire has resistance this whirl penetrates the wire so that the latter is circularly magnetized throughout its substance. Now, a magnetic line of force cannot be supported unless there is an electromotive force through the area it encloses, just as the rubber clip needs the roll of paper to keep it in tension. But inside a conductor electric force cannot hold, hence the magnetic induction must vanish and give up its energy. This is the "current" in the wire: the step from electromagnetic to heat energy. The penetration is by diffusion: a process which resembles the passage of light through a pile of thin sheets of glass by multitudes of reflections and transmissions. Conductivity here stands for reflecting power and capacity, and resistance for transparency. We should fail to get magnetic force into a perfect conductor.

OHM'S LAW.

The conduction current spoken of is the one referred to in Ohm's Law of steady currents. It might be debated whether it should be called an electric current or not. Certainly it differs greatly from Maxwell's "displacement current" in dielectrics, caused by true electric forces existing within them. Such a current, defined as "rate of electric displacement," must come to a stop when the elastic reaction consequent upon the displacement balances the force. A recovery from displacement when the impressed force is removed constitutes a reverse current also transient in character. Any trace of conducting power is inconsistent with complete recovery, and hence "the" ether, considered as electrically perfectly elastic, is absolutely the nonconductor. It has not, therefore, any resistance. This latter is essentially a dissipative property of matter.

There is nothing in physical nature corresponding, magnetically, to ohmic or "electric conduction" currents. There is such a thing as a rate of magnetic induction, but this magnetic current is always of the displacement type. This might, vaguely, be expected if magnetic induction is considered the analogue of mechanical momentum, which Newton defined as "quantitas Motus."

Nevertheless both the magnetic and electric displacement current may be attended by energy dissipation, but this is not owing to any resistance strictly so called. The former may exist in both insulators and conductors, while the latter can occur in dielectrics only. A glass plate condenser gets hot under rapidly reversed electromotive force, probably because of the equally rapidly reversed mechanical stresses. Possibly the "hysteresis" effect in iron subjected to alternating magnetizations may be explained the same way,—not the Foucault or eddy currents started in it by the electromotive action due to varying magnetic induction.

Experiment has shown that with a given difference of potential, measurable by electrometer at the zinc-acid surface of a cell, for instance, the resulting current measured in turn by its magnetic effects upon a tangent galvanometer, will depend upon the nature, and the length and cross-section of the wire. Ohm's law states that for steady currents the instruments will indicate a constant ratio. This ratio is called the ohmic resistance, or, inversely, its conductivity. Physically this evidently means that the wire itself limits the rate of energy dissipation, and that, while not really any such thing, the property by which the wire does so is analogous to friction in mechanics.

The function of the conductor in an electric circuit is, therefore, double. It directs the energy flux and sets a limit to the rate at which it will be liberated at the point of supply.

Ohm's current equation leads to the conclusion that with perfect conductivity, or zero resistance, any electromotive potential

difference would cause a current to mount to infinity. Practically such a conductor would be a very useless thing, no matter how much engineers may deplore reduced efficiency due to resistance. Any number of contradictory extremes would simultaneously become possible with such circuits of zero resistance. For instance, the biggest engine would not be able to turn the smallest dynamo, as the counter-torque of the machine would at once balance the crank effort.

The role which resistivity plays in nature is in every way as important as that filled by friction, without which the mountains would fall down. It has not thus far been found possible to coordinate the phenomena of resistance, and hence no explanation is offered why good conductors, like metals, for instance, as a rule increase in resistance when heated, and why bad ones, not exactly insulators, but conductors of the "second class," shift in the opposite direction. The tungsten filament and the Nernst glower are striking examples. We do not know why carbon, an element like tungsten, takes side with the oxides of the glower. Gases act still more mysteriously. Under usual conditions they follow the temperature characteristics of insulators and the denser they are the better their insulation. With changing pressure their behavior is anomalous. Rarefied to about one per cent of normal barometer pressure they conduct,—to become insulators again with either rise or drop of pressure.

Heat ultimately dissipates liquid and solid substances into vapor, and since for a given current the heat generated is proportional to the resistance, it follows that resistance is remotely the cause of the interruption of circuits by volatilization. Circuits including a normally liquid element,—e. g., a column of mercury,—may, however, be opened by the current itself before the rise of temperature threatens to bring about such a result. This "pinch effect," as it has been called, is due to a mechanical compression caused by the circular magnetic lines of force within and surrounding the conductor. To compare mechanical with electric currents: a water pipe, hooped about for security, tends to burst outward when a flow of liquid under pressure passes through it, and thus a conductor expands with an electric current, the latter being considered a flux of heat. But if we view it from its electromagnetic side, then, to compare, we must imagine the hoops to tighten up automatically or slacken with every increase or decrease of flow in the water pipe.

ELECTROMAGNETIC INDUCTION.

It has been pointed out above that an electrostatic field in motion generates a magnetic field, and vice versa, just as a mechanical force generates momentum, and vice versa. In point of origin the electric must probably be considered prior to the magnetic field. This seems to follow from the theory that ultimately all electromagnetic processes are initiated by the activity between matter and matter. Now, the magnetic field is non-convergent, while the electrostatic field always centers upon matter: it is this field, therefore, which is set up by chemical action. The "displacements" (not the energy) can in many instances be shown to be enormously large. Thus, for instance, the separated charges between metal and acid in an ordinary voltaic cell are spaced apart by apparently no more than molecular distance and yet the potential difference may reach two or more volts. This sounds like a small figure, but it is the rate of fall, not the fall itself, which determines the force. This rate is evidently excessive. It would be impossible to separate such surfaces mechanically without the potential rising so rapidly that no dielectric could withstand the strain, and hence discharge, more or less complete, would attend the attempt. It is for this reason that we get such small results from the "friction machine," which is otherwise similar to the voltaic cell, in that "contact" initiates charge. Influence machines are more effective because the potentials generated are more reasonable, and we are not restricted, as in the case of friction machines, to the building up of the field of such trifling charges as alone remain over after the separation of surfaces in rubbing contact. The voltaic cell is still more efficient because the charge moves out automatically as the whole circuit is conducting.

In all these cases there are two distinct surfaces of convergence, the same molecules never carrying both ends of the same line of force, and therefore the charged molecules must go in pairs.

Perhaps not more strange than any other property of either matter or ether, but certainly a distinct and independent, is that which gives rise to electromagnetic induction. It is unfortunate that the same word must serve in so many meanings: but this time the sense is that when matter is in motion relative to a magnetic field it will be subjected to an electric force. All our modern power houses are experimental expressions of this fact on a large scale. Theory demands the converse also: that motion relative to an electric field result in a magnetizing force. Experiment is difficult and not very clear on this subject: unless Rowland's demonstrations be supposed to cover the case. Mechanically interpreted, the propositions suggest in a general way that interference with momentum or stress results in stress or momentum.

The conditions under which such induction takes place are given by the same vector relations referred to as existing between electric force, magnetic force and velocity. Consider a uniform magnetic field directed horizontally north and south, and in this field a straight wire, placed horizontally east and west. Let the wire be moved, parallel to itself, upward or downward, vertically. Then opposite charges appear distributed over the conductor, increasing in density from the middle point to the opposite ends. They are maintained unchanged on condition that the motion be so maintained.

The total charge, of either sign, depends upon the strength of the magnetic field, the velocity of the body and on its vector length (east and west in the example), no matter what its shape otherwise may be. Provided the body be not moved, as a whole, in the exact direction of the field, there will always be some charge, the magnitude of which appears to be wholly independent of the body. Hence a glass rod or a silken thread should show the same charge distribution as a copper wire, all other conditions being identical. It would be merely a question of time for the conductivity of which all material insulators have a trace to transfer the convergence of the electric field wholly to the surface. The fact is remarkable, perhaps because it is recondite.

Since energy is required to set up any field whatsoever, it is now a question whether imparting a given velocity to the conductor requires any force over and above that contemplated by Newton's laws. The very fact that a transient current is required to establish the inevitable charges proves that the body must react mechanically as if its inertia were increased, as long, at least, as it is accelerated.

Many other more theoretical questions are connected with this one. For instance, whether the ether should not really be considered a resisting medium if acceleration through it is opposed in proportion to some function of the velocity itself. More plainly: a charged body—or even an uncharged body, if all bodies are largely "electrons"—moving at a certain rate of speed increase must show an increasing inertia, so that when a definite velocity is reached, the inertia is indefinitely great and further increase of velocity impossible. The answers of authorities are not wholly in agreement as to the "speed limit" in the universe. There is able argument, not less ably contradicted, that relative motion cannot, under any circumstances, exceed the speed of light, or about 180,000 miles per second. This leaves ample margin to chauffeurs and aviators, with the ether in charge of the turnpike.

In every molecule of the moving conductor an electromotive vector is in action in series with every other, helping to separate the charges, and, without necessarily doing any further work, to balance the reaction of the external field between them. Thus, a blower creates pressure difference at the ends of a shaft, but runs light and does no work if the exits are stopped, because there is then no traveling of stresses. The load "comes on" as soon as circulation is permitted. In like manner, no work is done by a motional electromotive force unless the ends of the moving wire are in contact with a conducting body not itself the seat of an equal and opposite electromotive force, motional or otherwise. Under the proper conditions a true or "ohmic current" starts with its own magnetic field accompanying it, and there is a mechanical resistance to further displacement of the moving conductor. Nothing can now keep up the motion except a supply of mechanical energy, which is sure to be dissipated in heat, if the conductor have any resistance, as surely as it would be if the conductor had to be kept moving against mechanical friction.

We have here the electrical engineer's concept of an "armature" moving in a magnetic field and that of "brushes" connecting a stationary circuit through commutator or slip rings to the coils of the armature: a mechanical device for continuous transformation of mechanical into electromagnetic energy under constraint to follow a circuit.

From a practical point of view, the current caused in a pair of tramway rails by the motion of axles bridging the rails, is of no importance, but it would certainly become so if the earth's magnetic field, whose direction is not far from normal to the plane of the rails, were to become as dense as those commonly used in electric generators. Let us suppose a single axle with its shrunk-on wheels placed across the rails in a sufficiently dense field. This in no way disturbs the magnetic induction existing everywhere between the rails. As soon, however, as the axle is pushed ahead every molecule in it reacts against being transferred through the

induction by setting up an electric ether-stress across it. The axle becomes charged: positively at one end, negatively at the other. This condition does not confine itself to the wheels. Since conducting contact exists, the charges take advantage of the same to spread ahead of and behind the moving axle as far as possible—theoretically, therefore, along their whole length and with a density depending upon the total electromotive force impressed upon the axle. We have, therefore, an electrostatic field, stretched from rail to rail, across the magnetic field. This condition travels with the moving conductor much as a wave travels with a boat towed along a canal.

Were now a second wheel-supported axle to be thrown anywhere across the rails, the same thing must happen which would occur when any oppositely charged bodies are connected by a conductor. As previously described, the electrostatic field would at once move towards it, setting up a current. In our case the current would include in its path the circuit formed of both axles and the rails between them, since the electromotive forces in the driven conductor keep the stress keyed up.

Of course the inevitable magnetic momentum would accompany this current. This induction must, however, conflict with that of the magnetic field independently existing between the rails. It is not difficult to show that the combined field must now be denser ahead of the driven axle than in its wake, and that the reverse is the case with the neutral one. Just as a rope under tension tends to straighten out and reacts against deflection, so the distorted magnetic field tends to regain its original condition, and hence a mechanical force is impressed, not only upon the moving conductor, but upon the whole circuit, as the cause of the distortion, the current, really exists everywhere. Since the axles are the only movable parts, the driven or "generator" has its speed checked while the neutral one is accelerated from rest: it has become a "motor."

Hence there is a true mechanical energy transfer between masses through an electromagnetic connecting link, which can deliver any amount of mechanical stress and never itself break down. Were there no ohmic resistance these stresses would become enormous and a curious electromagnetic and mechanical play would begin between the conductors. It is best understood by considering what would take place if a spring connection, resisting both compression and extension, existed between the moving masses. One of these is to be conceived as receiving an impulse which it transmits elastically to the other. Both move forward as a whole, while constantly vibrating at half-phase against one another. As a matter of fact, such action would be damped out by friction, just as ohmic resistance damps out the oscillation of electromagnetic energy.

Ultimately the two axles would be going at half speed and there would be no current, and hence no power transmission from one to the other. This conclusion is easily arrived at: when both masses move in the same direction and at the same speed both must act as generators, charging the rails the same way, and thus blocking any movement of the electric field other than its mere traveling along with the moving system. Distinctions cease between the parts of the system: each maintains a "counter electromotive force" against the electromotive force of the other.

GENERATORS AND MOTORS.

Based upon the preceding paragraphs, a combination of generator and motor may be described as "two power shafts geared together electromagnetically." The "gearing" cannot claim to be a "positive drive," as there is much loss in resistance of circuits, and it may become annoyingly elastic in alternate-current systems with low "power factors."

The possibility of commercial exploitation of such a power transmission system depends wholly upon the unique magnetic properties of iron: namely, that small magnetomotive forces produce in it very great flux densities. Civilization owes a great deal to that remarkable and most truly "royal" metal: a dynamo without iron would be little more than a scientific curiosity, of much less practical importance than the static influence machine.

Just as one dynamo, acting as generator, can drive a similar as motor, so one static machine can drive a second in like capacity. The parallels between the two generator-motor types are of considerable interest. Both generators create a difference of potential primarily, and both motors depend for their action upon the existence of such difference of potential. In the dynamos the active elements are, and must be, conductors, moving in a magnetic field, while in the static machines the corresponding elements are either wholly insulators or at least carefully insulated discrete conductors, moving in an electrostatic field. In the former "charge" is maintained by driving the generator conductors across a magnetic field; in the latter, by forcing the insulators across an electric field. The

corresponding motors are driven, one by the pressures of a magnetic field, the other by the tension of electrostatic lines of force. In the dynamic combination electric charges play a subordinate part, in the static there is almost entire absence of magnetic induction. High potentials are easily attained in static machines, but as the currents depend upon mechanical convection of charge, the currents are necessarily very small. On the contrary, in dynamic machines the potentials are relatively low, but the currents large, because the motion of the charges is with lightning rapidity, since nothing but conductors are in circuit.

Theoretically, it is possible to drive a static machine as motor from a dynamo generator, and vice versa. It is purely a matter of machine design, hardly of academic interest, let alone practical utility.

Generator and motor relations are not confined to the above types. It is every-day practice to drive dynamic motors from battery generators. There is no reason why the latter should fail to drive an influence machine if the experiment were worth while: very small cells should answer, provided they were series-connected by the thousands, or, better still, by the ten thousands.

It seems logical to expect to find the typical motor counterpart to the battery generator, again making a reversible arrangement, just as the mechanical devices are interchangeable. This counterpart is easily discovered in the phenomena of electrolysis. Here the molecules are set in motion by the electromagnetic gearing and work is done in transferring them into new combinations. All the general laws of power transmission hold good. No motor of any kind can "work" unless it can get up a counter electromotive force, because this e. m. f. is a factor in the measure of work done. The difference between the impressed and the counter electromotive forces drives the current, which is obviously also a factor, since there can be no flux of energy without current in some form or other.

Two identical batteries, yoked against one another, "counter" each other perfectly and permit no current to pass. If joined up in series and shortcircuited, they are both generators of electromagnetic at the expense of chemical energy. This converted energy heats the circuit at a maximum rate: the very thing which takes place when a motor is stalled. As soon as the cells, connected in opposition, differ in the least in the essential, or e. m. f. proper to each, that which has the lower fulfills motor conditions. Current is pushed up-grade, as it were; work is done in forcing the molecules out of their combinations and stored up in increased chemical energy of new substances.

The resemblance between a motor's work and that done in an electrolytic cell is remarkable. The one may pump water out of a well to a higher gravitation potential, while the other pumps the components out of the water and raises oxygen and hydrogen to their high chemical potential. "Commercial" motors are usually wound to obtain, as nearly as possible, either constant speed or constant torque: Nature's chemical motor, the electrolytic cell, is wound for constant counter e. m. f. and is always "wound" accurately.

In all the instances considered, the role of conductors in guiding or constraining the movement of energy is apparent. They never contribute to the store, but always dissipate some of it in heat. A study of almost any mechanism reveals analogous conditions. As a rule most of the material in the structure goes into constraints limiting the freedom of the active parts: thus performing the office of the wire in electric power transmission. In every steam engine power is transmitted from cylinder to power shaft under complicated constraints—the cylinder being itself not only the first in order, but of first importance besides. To reach the shaft, the last in order as far as the engine is concerned, lines of mechanical force must converge upon guides, cross-heads and bearings, and cling to them, as it were, thus imitating a mechanical "charge." To convey energy to the shaft, this charge must glide along constraints just as an electric charge must glide along a wire in order to reach the motor. To a mechanical engineer a "good conductor" is simply a well lubricated bearing, and a "hot box" a bad case of the distribution of mechanical stress potentials caused by frictional resistance.

ELECTRICAL OSCILLATIONS.

Let a condenser be discharged by applying a stout copper rod to its terminals. A rush follows, and while the electrostatic lines of force, moving in with the speed of light from all parts of the field, sink in, side-on, towards the wire, their convergences, i. e., the plus and minus charges, are dragged along the copper, and a magnetic vortex is set up about the latter. This vortex penetrates the metal at a rate which is more reasonably expressed in feet than in miles per second, and which, contrary to what might be expected,

is the lower the better the conductivity. The energy is at once transformed into heat, followed by more from the outside, wherever the electrostatic convergence is gliding on the surface. Now, if the absorption rate is below that of supply, the magnetic induction must crowd about the conductor and come to a standstill for a moment when no more electric charge is in motion, and at that moment all the undissipated energy is hung up, as it were, in magnetic potential form: the very instant when the conductor is dissipating energy at a maximum rate. The situation can only be a transient one: a circuital magnetic field without an electromotive force is impossible as a fixture. Hence the field which built up from the wire outward, now falls back upon the wire and attempts to set up an electromotive force in it. The force does build up: but only on the surface where it appears as charges driven apart by the magnetic momentum. The charges are thus forced into the condenser and accumulate there until all magnetic momentum is spent. Then "discharge" begins over again, with signs reversed: we have electric "oscillations."

In this description the action of the balance wheel of a watch can be recognized without difficulty, if hair-spring tension, wheel momentum and pivot friction be substituted for electric force, magnetic induction and ohmic resistance. It is clear how the period would be affected by a change in any of the mechanical factors, and in particular how friction would act in damping the successive throws until the wheel stops. Should we desire to carry the analogy further, we may note that the forces internal to the system cannot act unless the pivot surfaces can glide over those of the bearings. The latter then represent the conductor which becomes heated.

RADIATION OF ELECTROMAGNETIC ENERGY.

The question may now be asked: is it possible to transmit electromagnetic energy through space unconstrained? Energy cannot be got in electromagnetic form independently of matter, since there must first be "charge," and charge means convergence upon matter and therefore constraint. The ether cannot itself be charged and hence lines of electric displacement existing in it alone, or equivalently belonging to it alone, must, if they are at all possible, necessarily be circuital just as those of magnetic induction always are. Hence we might doubt whether ether energy can ever be cast loose. The doubt is, however, entirely removed by the phenomena of "radiation" or energy propagation by wave motion.

It is a familiar fact that the propagation of mechanical energy, as well as its time-rate, depends upon two properties: elasticity and inertia. The former enables matter to exert force against change of form or volume, while the latter expresses its capacity for momentum. The analogues to both exist in the ether, and hence we may expect to find in it the equivalent to periodic motion. Energy must then be propagated through it at a rate controlled by its own specific properties and the energy flux can be no longer guided, though it may possibly be interfered with, by matter.

To study the process let us assume the existence in the ether of, say, a circular line of electric displacement and let us observe what must follow. Under its own tension the line, at all points, draws radially inward, accompanied by the inevitable vortex of magnetic momentum into which it throws all its energy by the time it vanishes at the center. The momentum instantly re-establishes electric stress, reversed in sense, and travels outward with it indefinitely. Mechanical illustration of similar action is quite simple. Gently tapping a glass of water starts a circular wave (the supposed line of force) inward. When the center is reached, the heaped-up fluid falls back and the wave flashes outward,—indefinitely but for the barrier of glass.

To show that shortcircuited lines of electric force can actually be produced in the ether we must go back to the discharging condenser. Its oscillations resembled those of an ordinary pendulum going through alternate phases of potential and kinetic energy. Were all resisting influences entirely absent, a mechanical pendulum would vibrate ceaselessly with undiminished amplitude. Hence the oscillations of an electric condenser, discharging through a "perfect" conductor, would seem to be compelled to continue indefinitely. Such is, however, not the case: the two "pendulums" differ greatly.

The difference between a resistanceless electric and an unhindered mechanical pendulum is that the bob of the latter is a very limited rigid system, every molecule of which is similarly accelerated. The other "bob" is the limitless ether, not all parts of which can be identically accelerated at every instant. The reason is that the forces take time for their propagation, and at any given instant differ in direction and intensity at different points, and at the same point every instant later. To fall back on analogies again: let a pendulum bob be supposed to swing while imbedded in an electric jelly of indefinite extent. We need not be concerned about resistances or friction: the medium is now itself part of the bob and may even be looked upon as the whole of it, if we observe that the imbedded mass is but the center of application of impressed force. A little consideration will show that the oscillatory disturbance must in time cease about the origin, because at every throw a pulse starts outward in the medium, never to return. Thus: if the ball has forced the medium, say, to the right, the latter cannot force the ball back on its return stroke without continuing to push itself to the right. Hence it will not return the whole of its energy of compression to the source, and therefore every successive excursion of the bob is of less amplitude than the preceding.

It is after this fashion that an electric field can be freed from convergence upon matter. In such a case, however, it cannot possibly stand still, but must move on just as a pulse or a succession of pulses, i. e., a wave, must advance through a material elastic medium. Nor is the electric wave an exception to the general rule that the energy propagated is half kinetic, half potential, and like any wave with which we are familiar, it requires an "origin." To cause gravitational oscillations in water, a stone, for instance, must be thrown into it, and correspondingly, to provoke ether radiations, the charges in a condenser must be let go.

The physical processes in radiation are pretty difficult to follow. Remotely they resemble those in evidence when a drop of fluid is detached by its weight from the end of a pipette, or when a bubble is detached from the funnel on which it is blown. Because of its surface tension such a bubble always tends to shrink just as do the "lines" of an electrostatic field. When the funnel is smartly moved in the proper direction, air resistance causes the bubble to stretch. The result is increased tension along a line marked by a section parallel to the mouth of the funnel and across the bubble where it is most narrowed. This increased tension narrows the bubble still more, a "neck" is formed, and the bubble is promptly cut off by its own tensions,—all the lines of which become, as it were, shortcircuited over its surface. The remaining portion of the film returns to the funnel, where its own tension lines have their convergence.

Suppose the knobs of a static machine to be oppositely charged to such a potential that a spark passes. Just what happens when an insulator thus breaks down has always been a matter of speculation. It is probable that the electric displacement is withstood by the molecules directly, and that the breakdown of insulation consists in the mechanical failure of the molecules to withstand the stress beyond a certain limit. They become "ionized" gradually, by some shearing process, and when a certain point is reached, the process completes itself with enormous speed. Insulation vanishes and a current sets in.

The current is due to electromagnetic energy moving in from all points of space towards the line of discharge, a process which takes time, though it may be exceedingly little. Obviously the energy nearest the discharge path reaches it first and if it cannot be dissipated by the conductor's resistance, it is checked as magnetic momentum outside. The moment when further increase to this induction ceases is the moment when the conductor is free of all charge and marks the instant when the checked magnetic field, distributed in circles centered upon the discharge path, can begin to contract down upon the latter. This always means an electromotive force directed along the conductor. Hence the magnetic momentum is spent in establishing reversed charges upon the conducting system before the energy existing in distant parts of the field has had time to arrive. Such play cannot be made without the belated lines of force becoming shortcircuited at some distance from the conductor while a new field is building up outwardly. The latter crowds the detached, because shortcircuited, vortex forward and the first wave pulse starts into space.

As long as any electric force has convergence upon the knobs of the machine the process repeats itself: a train moves outward with the most powerful wave leading off. The energy is no longer constrained to follow a fixed path: it is being "radiated" free from any direct allegiance to ponderable matter.

THE WIRELESS TELEGRAPH.

Theoretically any current oscillation is attended by radiation. Our complicated 60-cycle power circuits with their multiplied magnetic links, should originate many wave systems all of the same length—about 3,000 miles. Theory shows that the "cast-off" occurs at a distance of something like half a wave length from the conductor. Hence our biggest plants cannot radiate more than a few ergs per year: for their force fields are insensible far within such a distance as even one hundred miles.

There is considerable difficulty in experimentally producing electromagnetic waves sustained or regular or of great energy. The ordinary condenser and spark-gap arrangement does not make a very neat job of it: the waves are a succession of confused and furious splashes. Wireless telegraph operation is not a little hampered by a peculiar situation. Rapid oscillations radiate powerfully, but conductor capacities must be small if short periods are sought, and then the difficulty arises that little energy can be put into apparatus of small compass with the means we have. If large amounts are put into such of large capacity the energy sticks to them and will not properly radiate out. Practice seems to have settled down to wave lengths between something like 200 to 800 meters, corresponding to an average of a half million periods.

ANTENNAS AS OSCILLATORS.

In wireless telegraph work the oscillating system is a tall vertical wire—the "antenna"—which is charged to a high potential and caused to spark to ground through a gap. Every spark is a hammer blow to the ether, not, however, of a kind with much analogy to the music of the "anvil chorus." The wave-generating blow is actually given at all points of an approximately ellipsodial surface to which the wire is axial, but the swings rapidly damp out or are muffled like those of a pendulum moving in glycerine. The wave-fronts of this train expand outwardly with the velocity of light and form dome-shaped surfaces or shells, one within the other. In alternate half wave lengths the electromagnetic vectors are reversed,—the relation being identical with that between crests and troughs in water waves. The magnetic induction travels in circles disposed in the wave surface like parallels of latitude on a globe, while the electric displacement expands in meridians, all of them cut off short at the equator. It is an expanding electromagnetic-energy half-bubble. In illustration, we may recall that a soap-film half-bubble can easily be formed on a sheet of wet glass, over which it will travel when air is blown into it from a quill tube, much like an electromagnetic wave runs over the ground around an antenna.

The hemispherical character would be lost and a spherical wave would form if the earth were as good an insulator as the air into which the antenna extends. Incidentally it may be remarked that the well known fact that wireless communication is more satisfactory at sea than on land is largely explained by the relatively low and uncertain conductivity, i. e., dielectric property, of the latter, which permits partial penetration of the electric force and hence disappearance of energy below the earth's surface.

In like manner the hemispherical character of the wave is lost if the antenna be stretched horizontally, no matter what may be the conducting or nonconducting qualities of the earth's surface. For "commercial purposes" this circumstance is very unfortunate, as the difficulty of raising and maintaining vertical antennas two hundred feet high, is out of all proportion against stretching any number of miles of wire fence.

The reason for this change from hemispherical to spherical wave front is easily discovered. Magnetic induction ignores the distinction between conductors and insulators. With an horizontal antenna the magnetic induction is in vertical planes, and it must therefore penetrate the ground because there is no such thing as a magnetic conductor. More, however, follows. Since the earth is something of an electrical conductor, magnetic induction in the act of penetrating it must create current owing to the electromagnetic induction (in its true sense as electromotive action) which is carried with it. Hence the electric field, though not itself disposed to penetrate directly, must nevertheless feed energy to the magnetic prodigal. That is: the whole wave system tends to sink into the ground. For mere power purposes the horizontal antenna can never cover great distances anywhere: it works only less badly on land than at sea, where the vertical antenna does its most effective work.

ANTENNAS AS RECEIVERS.

Contrary to what appears to be a common impression, electromagnetic energy always makes difficulty when it encounters a conductor. If charge-constraint compels a steady flux to a wire, the energy, diffusing comparatively slowly, is there degraded, as we have seen, into heat. On its way it avoids any other conductors not belonging to the circuit. Such bodies distributed at random in the field of a steady current, are no hindrance to its magnetic induction, but do show surface electrification. None of the energy on its way to the actual circuit passes through them: it glides around them in perfect stream lines and without ripples, just as water may flow, when moving with extreme slowness past a small, smooth obstacle.

The case is different with conductors disposed in a varying field and the more remarkably so the more rapid the oscillations.

Consider a vertical antenna upon which an electromagnetic wave front is advancing with the speed of light. If this front is to continue moving forward unbroken, no medium must be encountered in which either the wave's magnetic induction or electric displacement has its normal velocity of propagation interfered with by the medium's properties. We know what happens when water waves meet an obstacle of any kind. The wave momentum is at least partially, often, indeed, almost wholly, reversed, and reflection occurs. The opposing body is subjected to stresses and it begins to act precisely as if it were a secondary origin of waves of the same period as the incident with superposed ones due to the body's own vibrations, forced or natural.

Now, as we saw before, the rate of propagation of magnetic induction through dielectrics and conductors differs enormously. In air it is but a trifle less than the normal speed in ether, i. e., about 180,000 miles per second: in copper it is but a few feet per second. With such extremely rapid reversals as must arrive at an antenna intercepting waves not even a mile long, the result is that the copper is not penetrated at all. Hence the induction must rebound from it.

Nevertheless the general wave front goes on, necessarily closing up again by converging behind the obstacle. The latter is therefore surrounded by a detached swirl of magnetic induction precisely like that about a wire carrying a current.

This magnetic swirl, being unsupported by an electromotive force sufficient to sustain its pressure, must move its energy towards the antenna and therefore create in it a difference of potential. That is, at its own expense, the magnetic induction detached from the wave front must separate charges along the wire.

Simultaneously with the magnetic induction, the electric vector in the wave front has not been idle. Being vertical, i. e., parallel to the wire, the electric line of force in the wave front stumbles, as it were, full length upon the antenna. The accident breaks the force line's continuity, as electric force cannot hold in a conductor any more than a mechanical pull can hold in a column of liquid.

The result is the same thing over again: charges are separated along the wire, or, in other words, a current is set up in it. The wave past, the charges snap back, reversing the current. Evidently the antenna has become a secondary radiation center, since a true convergence has caught fast and must now oscillate locally. It is assisted by the next arriving wave with its reversed vectors, and thus more or less of the electromagnetic energy drifting by sweeps in upon the wire conductor. If the movements of the acquired charge are properly timed (the length of the antenna largely decides this), the surging falls into "resonance," which may become so powerful that the charge begins to spurt from the wire. It is not so mysterious: the beautiful acoustical experiment in which one tuning fork answers a similar one across the room, is a fine analogy. Actual physical antennas are, however, more like automobile horns than tuning forks: the difficulty of electrical "tuning" is notorious. For this, very likely, the erratic spark discharge in the sending conductor is most to blame.

Having got electromagnetic energy free from constraining conductors altogether too thoroughly, "wireless" interests now urge upon the physicist the study of regained control. With very short waves such control is very easy: witness the perfection of the scientific optician's mastery over light waves,—short electromagnetic ripples excited by oscillators of molecular dimensions. In fact, control over them is so easy that Illuminating Engineers find it hard to get rid of.

To confine electric wave energy in general to a definitely directed stream, the same reflecting and transparent bodies, or, identically, "conductors" and "insulators," offer the assistance of their properties. But waves have their properties also. Mechanics shows that, in order to be effective, the dimensions of reflecting surfaces must be large multiples of the wave length which they are to reflect. Considering "wireless" wave lengths, it follows that there is no use in backing up an antenna with mirrors. A very coarse wire screen or net would answer, but its dimensions would be prohibitive.

The wave lengths adopted in practice answer fairly well. It is marvelous how they stick to the earth's surface,—a decided advantage, which it seems certain would be lost, or at least much interfered with, if reflecting surfaces large enough to handle them were engineering trifles. Possibly the upper conducting strata of the atmosphere—conducting because at low pressure—act something like a huge reflector blanketing the lower dielectric layer through which the waves run. They seem not to lose power quite as fast as might otherwise with reason be expected. If this conjecture has any foundation in fact there will not be any "signaling to Mars" for some time to come.

Not a little "constraint" is actually suggested here: it begins to resemble that of an ordinary power circuit whose two copper conductors are replaced by two conducting sheets,—earth and upper atmosphere.

Claims are made that wireless signals have been picked up six thousand miles from their origin. This means that the waves have turned the best part of the earth's quadrant. Should this ever be actually covered, it would seem, since the wave front would have to begin to converge after passing an equator, as if little more power would be required to double the quadrant and reach the antipodes. Focusing there the wave would return and make the attempt to report back to headquarters.

Such converging waves of great length have not yet been produced in the laboratory of man, but there is little doubt that they occur in Nature's. Certain freaks of lightning may perhaps be explained by electric waves becoming focused and ending in "a bolt from the clear sky."

The purpose of the preceding paragraphs was to show that a knowledge of mechanical equations and a clear understanding of mechanical definitions is of no slight advantage, particularly in the study of electromagnetism. Skill in interpreting the phenomena of the latter science in terms of those of the more general and familiar one, Mechanics, renders the electrical engineer's intricate problems much less formidable to him. For whatever the actual truth may be concerning the constitution and structure of matter and ether, the genius of the inimitable James Clerk Maxwell has shown that there is a striking parallelism between the general properties of both.

Consciously or unconsciously, physicists have in recent years followed mechanical ideas in all the departments of their science. While giving caution, as they should, that there may be nothing mechanical about the ether, their knowledge of electromagnetic phenomena has become relatively so perfect that very good authorities seem preparing to familiarize us with the theory that there may be nothing mechanical about mechanics, but that it is all electromagnetism. But before that can ever be more than speculation and conjecture, it will be necessary to question again the taciturn old patriarch of all the cosmic forces: universal Gravitation.

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