up on the flanks, first attacking them in Vermont. The Ordovician sea followed and its sediments reached points well into the crystalline area. Pursuing the thought further we may raise the query, were the crystallines then reduced to a base-level and did submergence gradually bury them, and did the Ordovician sea and the subsequent Silurian sea go all across from side to side with a continuous mantle of sediments? Or were the crystallines a great island during all this time and have they remained so with minor faultings and upheavals to the present? These are questions easy to ask and difficult to answer. The most that we shall say about them now is that they are another story.

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ON KATHODE RAYS AND SOME RELATED PHENOMENA.

II.

The view here briefly formulated, although first suggested by Wiechert, owes its development chiefly to J. J. Thomson. The number of instances in which its consequences are at least qualitatively confirmed is already surprisingly large. Thus it has been known for some time that a wire or carbon filament, when heated to incandescence in vacuo, sends off negatively charged particles. Thomson * has recently shown that the ratio e/m for such particles is the same as for the kathode rays. Many metals also are capable of giving off negatively charged particles when illuminated by ultra-violet light; at sufficiently high vacua, rays may be produced in this way which possess all the essential properties of the ordinary kathode rays.† In this case also, the ratio e/m is found to be the same.‡ In these cases we have an indication that the corpuscles may be separated from the molecules of a substance by processes different from those which occur at the kathode. That intense heat, on account of the violent collisions between molecules, should make it easier for the corpuscles to escape, is quite natural. And that the rapid electrical vibrations set up by light, especially by that of short wave-lengths, should produce a similar effect, agrees equally well with the corpuscular hypothesis.

* *Phil. Mag.*, 48, p. 547, 1899.

† Merritt and Stewart, *Physikalische Zeitsch.*, 1, p. 338, 1900.

‡ Thomson, *Phil. Mag.*, 48, p. 547, 1899.

If the light radiated by a molecule of gas is due to the vibration or orbital motion of these charged corpuscles, a highly concrete and satisfactory explanation is at once obtained of the Zeeman effect. The theory has shown itself capable of accounting not only for the comparatively simple phenomena first observed, but also for the more complicated modifications of the spectral lines detected later. The ratio e/m as determined from the Zeeman effect is of the same order of magnitude as that determined from observations on the kathode rays.

Perhaps the strongest confirmation of Thomson's corpuscular hypothesis is that afforded by the recent investigations, of the Becquerel rays. In 1899 it was found that some of these rays, notably those produced by certain preparations of radium, were deflected in passing through a magnetic field.* More recently, it has been found that the rays are electrostatically deflected† and that they carry a negative charge. In fact, they behave in all respects like kathode rays. Within the last few months the ratio e/m has been determined by Becquerel‡ and found to have approximately the same value as in the case of the Zeeman effect and the kathode rays.

* Meyer and v. Schweidler, *Phys. Zeitsch.*, November 25 and December 2, 1899. Giesel, *Wied. Ann.*, 69, 834, 1899. Becquerel, *Comptes rendus*, 129, p. 996, 1899.

† Dorn, *Abhandlungen d. Naturforsch. Gesell.*, Halle, March 11, 1900.

‡ *Comptes rendus*, 130, p. 809, March 26, 1900.

It appears, therefore, that the same rapidly moving corpuscles which form the kathode rays, and which give practically the only concrete explanation of the Zeeman effect, also form one constituent at least of the Becquerel rays. In the latter case it would appear that the escape of the corpuscles is a result of violent internal disturbances among the molecules of the active substance. Such disturbances may accompany a gradual change from an unstable molecular grouping to one that is more permanent. This view removes all difficulty concerning the source of energy of these rays, a question which a few years since caused a great deal of needless annoyance.

The Becquerel rays developed by a given active substance usually consist of a mixture of rays, differing widely in their various properties. Not all of these rays are deflected by a magnet. In some instances the rays are more similar to the X-rays than to kathode rays, both as regards their behavior in a magnetic field and their other properties. In such cases it seems to me probable that X-rays are in reality present. Some of the magnetically deflectable rays, which are nothing more than kathode rays, naturally fall upon the active substance itself. There is no reason why this bombardment should not result in the development of X-rays, just as it would in the interior of a vacuum tube. That Lenard's kathode rays are able to produce X-rays even in the open air has already been shown by Des Coudres.*

The hypothesis of electrified corpuscles has been employed, in a form which does not necessarily imply the extreme smallness of the particles considered, by numerous physicists. For example, Lorentz† found it useful in discussing the electrical and optical phenomena in moving bodies: while Helmholtz* has used it in his electromagnetic theory of dispersion. An explanation of metallic conduction analogous to that of electrolytic conduction has often been sought. Recently this subject has been developed quite extensively by Riecke† whose results appear extremely promising. The assumption of positive and negative ions, different perhaps from those of ordinary electrolysis, permits a very concrete qualitative explanation of a great number of well-known phenomena. Among these may be mentioned the various thermoelectric phenomena, the Hall effect, together with its thermal analogue, and the Thomson effect. Views similar to those developed by Riecke have recently been supported by J. J. Thomson.‡

Enough has been said to show that the hypothesis of electrified corpuscles has much in its favor. That the present form of the hypothesis is very incomplete and leaves much to be explained, no one would attempt to deny. But by means of it we have obtained provisional explanations, at least, of many complex phenomena; while the usefulness of the hypothesis as an aid to further investigation has already been amply demonstrated. Now that we recognize the futility of attempting an ultimate explanation of natural phenomena, can we demand more than this of any theory or hypothesis? Let us therefore adopt the new theory in those cases where its adoption leads to clearness and concreteness, and make use of it as long as it aids in the advancement of science. As our knowledge increases, the theory will be continually modified and improved. Sooner or later it will doubtless be found insufficient, and will be abandoned; and something better

* *Wied. Ann.*, 62, p. 134, 1897.

† Versuch einer Theorie der elektrischen und optischen Erscheinungen in bewegten Körpern. Leiden, 1895.

* *Wied. Ann.*, 48, p. 389, 1893.

† *Wied. Ann.*, 66, p. 353 and 545, 1898.

‡ *Nature*, May 10, 1900.

will take its place. Such is, and such ought to be, the life history of all scientific theory.

The more promising a new theory appears, the more is it deserving of a careful and critical scrutiny, both from its adherents and from its opponents. The hypothesis of electrified corpuscles, which is involved in the modified Crookes theory, has proved its right to a hearing. It now has a right to demand the severest of friendly criticism. An elaborate critical discussion of the theory would be out of place in an address of this kind, even if sufficient time for the purpose were available. I wish, however, to call attention briefly to some points in connection with the subject which I think have not previously received the attention that they deserve.

Let us compare, for example, the values of e/m determined by different observers. The discrepancies between the values obtained by Wiechert and by J. J. Thomson is not surprising, since they were the first determinations of this kind that had been made. As a preliminary test of the theory, the fact that results obtained by such widely different methods were of the same order of magnitude is eminently satisfactory. A number of new determinations have been made, however, during the past two years. Since the more recent determinations were undertaken with a full understanding of the necessary experimental precautions, we should expect a close agreement among their results. But discrepancies of considerable magnitude still remain. It appears to me that the variation in the values of e/m obtained by different observers is greater than can be accounted for by experimental errors. To bring out this point, and in the hope of getting some idea of where the cause of the discrepancy is to be sought, I have prepared the following table, which contains practically all the values of e/m that have been obtained by experiments upon the kathode rays. Some of the values obtained by other methods have also been added for comparison.

The values of e/m are arranged in groups according to the method by which they were determined. The results of the most recent experiments, and presumably, therefore, the most accurate ones, are in each case placed last.

Leaving aside the results of Schuster and Wien and the first results of Wiechert, all of which were obtained by experiments of a purely preliminary character, we see that the results obtained by different observers show a satisfactory agreement, *provided that the same method was used.* Compare, for example, the two results of Kaufmann, obtained by different modifications of the same method, with that obtained by Simon. A more satisfactory agreement could scarcely be desired. Similarly, the values obtained by Lenard agree quite well with those that were obtained by J. J. Thomson when using the same method. But the smallest value obtained by the first method is twice as great as the largest value obtained by the last method. The results obtained by the second and third methods agree fairly well with each other, and are intermediate between the two extremes just mentioned. Wiechert's later determinations, however (Method III.), are subject to a possible constant error, so that these results must be regarded as uncertain.* The third method is liable to experimental error for several reasons, notably because its results are especially likely to be influenced by the conductivity of the residual gas. The effect of this source of error, as pointed out by Thomson, would be to make the results larger than they should be. Objections might also be raised to the assumptions on which the method is based. On the whole, it appears to me that the results of the first and fourth methods are to be

* *Wied. Ann.*, 69, p. 739, 1899.

regarded as the most reliable. And yet these are the methods whose results differ most widely.

As the difference appears too great to be explained by the accidental errors of observation, it is natural to seek its explanation in the assumptions upon which the two methods are based. Both methods employ the magnetic deflection of the rays and assume the same relation between deflection and velocity. But in the method of Kaufmann and Simon it is assumed that the whole potential energy of the corpuscle when at the surface of the kathode is transformed into kinetic energy of translation; *i. e.*, retarding forces due to friction or other causes are assumed to be entirely absent. The method has been criticised on that account by Schuster.* The effect of

VALUES OF e/m FOR KATHODE RAYS.

(The results are expressed in c. g. s. electromagnetic units.)

Observer.	Date.	Remarks.	Velocity. [Velocity of Light = 1].	$e/m \div 10^6$
I. Magnetic deflection and kathode potential. $Hev = \frac{mv^2}{r}$. $\frac{1}{2}mv^2 = eV$.				
Schuster.	1890			[1.1]
Schuster.	1898	Revision of former data.		[3.6]
Wiechert.	1897		About 0.3	[Less than 40]
Kaufmann.	1897	Used different gases and kathodes. Holtz machine.		17.7
Kaufmann.	1898	Holtz machine.		18.6
Simon.	1899	Holtz machine.		18.65
II. Magnetic deflection and velocity of rays. $Hev = \frac{mv^2}{r}$. v determined by the method of Des Condres.				
Wiechert.	1897		0.1	[20 — 40]
Wiechert.	1899	Hydrogen.	0.132 — 0.167	11.9 — 14.2
III. Magnetic deflection; heat developed; charge carried. $Hev = \frac{mv^2}{r}$. $\frac{1}{2}Nmv^2 =$ heat. $Ne =$ charge.				
J. J. Thomson.	1897	Different gases used. Induction coil.	0.077 — 0.12	10 — 14.3
IV. Magnetic deflection and electrostatic deflection. $Hev = \frac{mv^2}{2}$. $Hev = Fe$ [Two deflecting forces balanced].				
J. J. Thomson.	1897	Several gases. Induction coil.	0.077 — 0.4	6.7 — 9.1
Wien.	1898	Lenard rays.	About 0.3	[20]
Lenard.	1898	Lenard rays. Induction coil.	0.22 — 0.27	6.32 — 6.49

e/m from Zeemann effect.	(Various observers)	10 — 30
" " Ultraviolet light discharge.	J. J. Thomson.	5.8 — 8.5
" " Edison effect.	J. J. Thomson.	7.8 — 11.3
" " Becquerel rays.	Becquerel.	About 10.

The symbols used in the formulæ have the following significance: $e =$ charge carried by each corpuscle; $m =$ mass of corpuscle; $v =$ velocity; $N =$ number of corpuscles; $H =$ strength of magnetic field; $F =$ strength of electric field; $r =$ radius of curvature of the rays when deflected in a magnetic field.

* *Wied. Ann.*, 65, p. 877, 1898.

neglecting the influence of retarding forces when such are really present would be to give values of e/m that are larger than the true value. For this reason, Schuster looked upon the method as giving merely a superior limit for the ratio. The experiments of Lenard make it unlikely that retarding forces can be present after the rays have emerged from the dark space. But it appears to me that in the immediate neighborhood of the kathode their equivalent might well be present. Before the electrified corpuscles can yield to the repulsion of the kathode and fly off to form the kathode rays, they must be torn loose from the molecules of which they form a part. Is it not possible that an appreciable fraction of the whole potential energy is expended in effecting this separation? Again, although it is certain that the kathode rays start from points very close to the kathode, have we any reason to suppose that they originate *exactly* at the surface? If the rays start a little in front of the kathode, the effect is the same, so far as the results obtained by Schuster's method are concerned, as if the corpuscles were subjected to retarding forces.

The most serious reason for doubting the correctness of the values obtained for e/m arises from the almost incredible velocity of the kathode rays. What right have we to suppose that ordinary electrical and mechanical laws are applicable to a particle moving at one-third the velocity of light? It appears to me that we have before us the most stupendous piece of extrapolation in the whole history of physics. Let us consider briefly the assumptions that are made and their experimental basis. The chief assumptions are as follows:

(1) The force exerted upon a corpuscle when passing through a magnetic field is proportional to the speed, being equal to Hev, where H is the field strength, e the charge, and v the speed.

(2) The force exerted upon a corpuscle when passing through an electric field is the same as though the corpuscle were at rest.

The experiments of Rowland and Himstedt afford indirect experimental evidence that the law stated in (1) is true for velocities up to about 10,000 cm. per second. In computing e/m the assumption is made that the same law holds for velocities a million times greater!

So far as I am aware, the question of the force exerted upon a moving charge by a stationary electrostatic field has never been made the subject of direct experimental inquiry. Lenard,* however, has made some experiments upon the kathode rays themselves which are of the greatest importance in connection with this question. Upon passing the rays through an intense electrostatic field in a direction parallel to the lines of force, he found that the rays were either accelerated or retarded according to the direction of the field. The change in velocity was determined by measurements of the magnetic deflection and was in some cases as great as fifty per cent. The observed change was the same in amount as would be expected if the force upon the charged corpuscles was the same as though they were at rest.

The dynamics and electrodynamics of a charged body in rapid motion have been attacked from a theoretical standpoint by J. J. Thomson,† Heaviside,‡ and Schuster.§ Rowland‖ has recently called attention to the fact that this is a case for the application of an extremely fundamental scientific law, namely, that of the 'conservation of knowledge.' Our real knowledge of the subject, based upon experiment, is practic-

* *Wied. Ann.*, 65, p. 504, 1898.

† Recent Researches in Electricity and Magnetism.

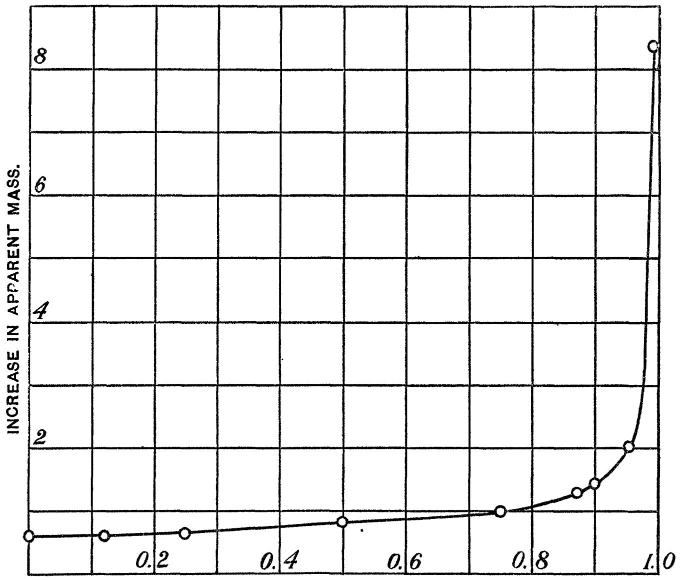
‡ Electrical Papers, Vol. 2.

§ *Phil. Mag.*, 43, p. 1, 1897.

‖ Presidential Address before the American Physical Society, *Bulletin of the American Physical Society*, Vol. I., No. 1.

ally *nil:* no amount of analytical manipulation, however complicated, will add to it one iota.

In the present condition of our experimental knowledge, theoretical discussions of this nature are indeed pure speculation. But we must remember also that scientific speculation has always been one of the most important aids in the advancement of science. For a visionary enthusiast speculation is a plaything, dangerous to himself and annoying to others. But in the hands of the trained and conservative scientist it is a valuable tool, without whose aid the progress of knowledge would be slow indeed. The present case is one to whose study scientific speculation is particularly applicable. The motion of charged bodies at a speed nearly equal to that of light is a subject that we cannot hope to study by direct experiment. If we ever get a knowledge of the laws that apply in such cases, it must be by indirect methods. It is therefore simply a question of trying one hypothesis after another, deriving the consequences of each, and testing the conclusions by experiment. The kathode rays and the Becquerel rays offer the means by which such tests may be applied.



Although the theoretical results of Thomson and Heaviside are not in complete agreement, they both indicate considerable deviations from simple laws when the speed approaches that of light. Thomson states his results in convenient form by saying that the effect of a charge is to increase the apparent mass of the moving body. So long as the speed is small, the increase is inappreciable. But at high speeds it becomes important, and at the velocity of light the apparent mass becomes infinite. Since the effective mass is a function of the speed, we might therefore expect the ratio e/m to vary with the velocity of the kathode rays. But the hope of explaining the observed discrepancies in this way is illusory, as the apparent mass remains practically constant until the speed is nearly equal to that of light. The manner in which the apparent mass varies with the speed, as computed according to Thomson's theory, is shown in the accompanying curve. Ordinates represent the apparent increase in mass, while abscissæ give the corresponding speeds. The speed of light is put equal to unity. It will be noticed that the ordinates remain nearly constant up to a speed of about eight-tenths that of light, after which the variation is rapid. In quantitative experiments on the kathode rays the speed has never exceeded one-half that of light. Previous experiments therefore afford no opportunity of testing the theory. The problem of increasing the speed still further is certainly a most promising subject of experimental investigation.

Since the apparent increase in mass is due to the energy of the field moving with the charge, it would appear that the amount of the increase must depend upon the form of the tube through which the rays pass. So far as I am aware, no experiments have heretofore been made to test this point. It may be that the variation, if it exists, is too small to be detected.

The suggestion has recently been made that perhaps the whole mass of the corpuscle is fictitious; that we really have to do with free electric charges, or electrons, existing apart from matter. This view is even more startling than that which makes the corpuscles smaller than atoms. The novelty of the suggestion is certainly not to be regarded as a serious objection. But direct experimental evidence in favor of this view is as yet lacking. Here, too, it appears to me that a quantitative study of the kathode rays *at the greatest attainable velocities* offers the most promising means of testing the theory.

We see that in this subject, as in every branch of natural science, each step in advance suggests still more important problems for further study and aids in their solution. In the kathode rays we have gained a new weapon with which to attack the great problems of ether and matter. What results will be achieved no one can predict. But great as have been the advances during the past decade, we can scarcely doubt that the progress during the decade that is just beginning will be even greater.

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MATHEMATICS AND ASTRONOMY AT THE AMERICAN ASSOCIATION.

THE meeting of Section A was arranged with a view to complete co-operation with the Astronomical and Astrophysical Society in the astronomical part of the program and with the American Mathematical Society in the mathematical part. The full effect of such co-operation was secured by means of joint sessions, Section A meeting in joint session with the Astronomical Society on Tuesday and on Wednesday morning, and with the Mathematical Society in joint session or as guests, Wednesday afternoon, Thursday, and Friday. From this arrangement Section A received the benefit of adding to its program the papers of the two affiliated societies and having the presence of their members in its meetings while in turn, it gave the same aid to them. It is to be hoped that every year in which it is practicable some such arrangement for co-operation may be made.

Reports of the meetings of the Astronomical and Astrophysical Society and the American Mathematical Society will be published separately, hence it would be out of place to here discuss any of the papers presented by them. Among the papers of Section A, that of Henry S. Pritchett, who is leaving the Superintendency of the Coast and Geodetic Survey to become President of the Massachusetts Institute of Technology, is of perhaps the widest general interest; it is on the 'Functions, Organization and future Work of the U. S. Coast Survey.'