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THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

FACT AND THEORY IN SPECTROSCOPY[1]

BEFORE passing to some present problems in physics, let us pause a moment to consider the losses which our science has sustained since the last annual meeting.

The life and work of Professor Langley, who died on the twenty-seventh of February last, will long continue to form an important chapter in the history of astrophysics. To the study of this science he brought rare skill, perseverance and clearness of purpose. Among his most important contributions is to be mentioned his epoch-making determination of the distribution of energy through the spectra of various sources, including especially the sun, moon and firefly. His measurement of the lifting power of an aeroplane driven at a definite angle with a definite speed, his exquisite discussion of the 'Internal Work of the Wind' with its accompanying explanation of soaring and his still later achievement of actual flight are matters which have perhaps only recently received fair appreciation. The recent performance of the Wright brothers in Ohio and the flight of Santos Dumont in a 'manned' machine are but two events in the logical series which Professor Langley did much to initiate.

On the nineteenth of April, 1906, occurred a great tragedy. Nothing in the behavior of that remarkable element which

[1] Vice-presidential address before Section B of the American Association for the Advancement of Science, New York, December 28, 1906.

he helped to discover can be considered more unexpected or more inexplicable than the death of Professor Pierre Curie.

The manner in which the clew given by uranium rays was taken up and followed out with persistent endeavor, clearness of vision, simplicity of life and modesty of character, has been rarely paralleled in the history of physics.

Our admiration for his scholarship and for his generous chivalric nature is united with a keen sense of loss to science and a warm sympathy for his brilliant and loyal comrade.

On the fifth of July, last, Germany and the rest of the world suffered a deplorable and inexplicable loss in the death of Professor Paul Drude. Brilliant and numerous as his achievements were, it is difficult to believe that his work was more than half done. Perhaps no better illustration of his genius can be found than in the beautiful manner in which he has quantitatively connected the subjects of thermal and electric conductions, on the basis of the electron theory; while his two splendid volumes have rendered all students of physics his debtors.

The death of Boltzmann, two months later, was an equally great mystery. The most valuable work of this remarkable and somewhat bizarre character undoubtedly lies in the field of the kinetic theory of gases.

His treatise on this subject constitutes for me—I confess it freely, but sadly—a sealed volume. Were I to attempt to convey to you any idea of its importance I should feel, only in a much truer sense, what Boltzmann himself expresses in the preface of his wonderfully lucid exposition of Maxwell's electromagnetic theory, when he quotes from 'Faust.'

> "So soll ich denn mit saurem Schweiss,
> Euch lehren was ich selbst nicht weiss."

Boltzmann's two visits to America, one in 1898 and one in 1904, were full of interest for many of the members of this section. Suffice it to say that some of his colleagues have expressed the opinion that since the death of Helmholtz, Boltzmann has been the leading physicist of Germany.

I beg now to call your attention to a matter which seems to me somewhat intimately connected with spectroscopic progress. And one can perhaps do this most simply by first offering a definition of spectroscopy; secondly, stating what may be considered the fundamental facts of the science; and, thirdly, considering to what extent these facts—for one hesitates even yet to call them 'principles'—are explained by any general theory of the subject.

Any explanation of light which is general and satisfactory may be said to include at least two chapters, namely, one which shall explain the transmission of radiation and another which shall treat of the origin or production of radiation. The first chapter treats of the electromagnetic ether; the second treats of matter which is at once 'the source and recipient of radiation.'

It was in the autumn of 1888 that the experiments of Hertz in a certain sense closed the chapter on the transmission of light, a large part of which had been written by Maxwell in 1864. Since then, the second portion of the theory—that dealing with the radiant atom—has assumed larger importance. Any treatment of the production of radiation falls more or less naturally into three parts, namely, (1) the radiation of solid and liquid bodies which is almost, but not quite, independent of atomic structure; (2) the radiation which takes its rise in radioactive substances and which is apparently dependent upon atomic collapse; and (3) the radiation of gaseous substances, dependent almost entirely upon normal atomic structure, and possibly also upon the mode of excitation.

The subject to which your consideration is invited has to deal only with radiation of this third class. Radiation which in terms of the electron theory is said to be due not to abrupt or discontinuous acceleration but to periodic acceleration.

DEFINITION OF SPECTROSCOPY

The science of spectrum analysis which was born, one might almost say, in Bunsen's laboratory in 1859, developed within a period of four or five years into a science of a totally different character, a science which enabled Kirchhoff at once to study the physical structure as well as the chemical constitution of the sun, a science which permitted Huggins as early as 1864 to distinguish between star clusters and nebulæ, a science much wider than spectrum analysis, a branch of learning which we now call spectroscopy. Briefly defined, it is that science which has for its object the general description of radiation, including the production of radiation, the analysis of radiation, the registration of radiation and the measurement of radiation.

The theory of separating, recording and comparing radiation is by no means simple or complete. That these last three operations demand in practise the highest degree of skill is exemplified by the work of Rayleigh, Rowland, Michelson, Perot and Fabry, and Hale.

There is, however, a certain very true sense in which these last three processes are merely preparatory to a more profound study of the first, namely, the production of radiation. From this point of view, spectroscopy hinges upon the radiant atom—if there be an atom—and may be defined imperfectly and narrowly perhaps as *the science of the radiant atom.*

More than one brilliant and partially successful attempt has been made within the last quarter century to establish an adequate foundation for this science by devising what may be called a satisfactory atom. But before considering any of these attempts it may be well to state briefly what seem to be the criteria by which any such foundation is to be judged.

Perhaps it may be fair to consider that atom as most competent which will explain satisfactorily the largest number of the following nine facts.

CRITERIA

1. The fact that spectral lines are in general approximately sharp.

2. The fact that spectral lines are never perfectly sharp; but always have a finite physical width.

3. The fact that certain spectral lines are arranged in series and bands after the manner described so perfectly by Balmer's equation and its generalized forms.

4. The fact that increase of pressure causes a shift of spectral lines toward the red as discovered by Humphreys and Mohler.

5. The fact that a magnetic field will transform single lines into multiple polarized lines as discovered by Zeeman.

6. We come now to a group of phenomena which are not easily described under a single caption. I refer to phenomena such as those observed by Plücker and Hittorf, when they found one and the same gas in one and the same tube yielding very different spectra according to the mode in which the electric discharge was applied to make the gas luminous. In the same category doubtless belongs the extinction of air lines by the insertion of self-induction into the discharge circuit. Here may belong also the fact studied by Lenard and others that the region near the electrode of an arc gives a spectrum different from the region near the center of the arc; the fact also that the so-called 'spark lines' are introduced into an arc by reducing the current to small values, a fact first studied by Hartmann.

And certainly in this same category belongs the fact that the spectrum of an arc is modified when the arc is surrounded by an atmosphere different from ordinary air.

Here also lie the profound differences between arc and spark spectra of the same element.

Notwithstanding the fact that 'multiple spectra' is a term which has hitherto been employed to describe the Plücker tube variations, I propose that we generalize it and use it to describe this entire group of facts. Since the name is so appropriate, let us call the sixth fundamental phenomenon that of 'multiple spectra.'

7. Any competent atom must allow us to infer the relations which have been proved to exist between spectral phenomena and atomic weights.

8. The phenomena of line reversals and absorption bands.

9. The fact that heat alone, at least within the range of our highest artificial temperatures, produces characteristic spectra in only a few rare instances.

These, briefly, are the parts of the spectroscopic superstructure for which a foundation is sought. These are the various parts which it is hoped will, some day, be cemented together, by a simple and general theory, into a harmonious structure.

But there is a final criterion, even more fundamental than any of those which have been mentioned, that such a theory must satisfy, namely, this hypothetical radiant atom must not in its behavior, except as a very last resort, contradict any of the established principles of physical science, be they mechanical, electrical or chemical.

The principle of the conservation of energy must be satisfied even if it is necessary to assign an undreamed of amount of energy to each atom; in like manner Newton's third law is to be satisfied, even if the electromagnetic ether is called upon to furnish the reaction.

But even with this added criterion, the preceding list of nine phenomena is confessedly incomplete; the only object of such a catalogue is to include those typical fundamental facts which ought, apparently, to follow as immediate consequences from the structure of the radiating body, so soon as that structure is correctly guessed. Thus Doppler's principle is omitted on the ground of its being rather a kinematic law, governing periodic disturbances in any medium, than a dynamical fact to be explained in terms of atomic structure and forces.

THE SATURNIAN ATOM

Having established a set of criteria by which we may estimate the fitness of a radiant atom, it would be interesting, if I were competent, and if time permitted, to pass in review some of the various atoms which have been proposed in recent times; such as that of Kelvin, 1884, or those suggested by the Hertzian oscillator.

But neither of these two conditions is fulfilled, and I propose, therefore, to consider only one atom, namely, the one which by common consent, I think I may safely say, comes more nearly satisfying the demands of experimental fact than any other ever devised. I refer to the atom first proposed in a general way by Lord Kelvin in his paper entitled 'Epinus Atomized,'[2] and afterwards profoundly modified by Lorentz, Thomson and Larmor.

So much work along this line has been done in the Cavendish Laboratory that one feels impelled to call this 'the Cambridge atom'; in view, however, of its structure, perhaps 'the Saturnian atom' is a more appropriate designation.

Now as to the proper conception of the normal Saturnian atom—I am not certain that I know what this is, but my mental

[2] Baltimore Lectures, p. 541 (Cambridge, 1904).

picture of it is somewhat like the following:

1. Conceive a single negatively charged electron—whatever that may be—placed inside a mass of positive electrification—whatever that may be. On the basis of the Zeeman effect, we may imagine this electron to be revolving about the center of the positive charge; and we may assume its rate of revolution such that it is in equilibrium under the first-power-of-the-distance law.

But even if we did not have the Zeeman effect to suggest rotation we should be compelled, as Jeans[3] has shown, to introduce rotation, on the basis of Earnshaw's theorem, to secure stability. Any acceleration of this electron which is periodic will produce a periodic radiation of energy. Precisely such an acceleration is here present in the familiar rw^2 centrifugal acceleration which is periodic when we consider radiation along any one fixed direction. The frequency of this acceleration determines that of the radiation just mentioned. The electromagnetic effect is roughly that of an alternating displacement current.

2. Let us next suppose that instead of a single corpuscle we have a large number distributed throughout the same orbit. Their radiation is now almost nil, the vector sum of the accelerations being zero and the electromagnetic effect being roughly that of a *steady* current.

If the ring does not contain so many of these self-repellent corpuscles as to become unstable we have a simple type of a non-luminous and, during stability, non-radioactive element.

Imagine now that these electrons are the same for all elements; then one element differs from another mainly in the number, disposition and character of the rings which surround the central attracting charge, the number of corpuscles being 'of the same order as the atomic weight.'[4]

Such is a rough sketch of the normal Saturnian atom. The beautiful manner in which this structure permitted J. J. Thomson to infer the same periodicity in electro-chemical properties as that contained in Mendelejeff's table is already familiar to you. But for the present inquiry this exquisite achievement of Thomson's is merely an 'aside.' So also is Drude's elegant connection of electrical and thermal conductivities in metals. Likewise his explanation of the Hall effect.

We come now to the question which is fundamental to all spectroscopic theory, namely, *under what conditions* does a gas atom become radiant.

This question may be asked and answered in two different senses:

First, one may inquire as to the laboratory conditions necessary to produce luminosity in a gas; the corresponding answer is threefold: either a high temperature, thus obtaining, in some rare cases, a heat spectrum, or secondly, a rapid chemical change as in flames, or thirdly, an electric field as in the arc, spark and vacuum discharge.

Again, one may ask what is the difference between the internal conditions of a radiant and non-radiant atom. So far as I am aware, this latter query has never received an answer which is definite or based upon indisputable experimental evidence. However, the Zeeman effect points to rotation in the luminous source and suggests the revolving electron as the light-giving body; but it is difficult to see how one electron could give rise to more than one line in the spectrum. Not only so, but, since the electrons are the same for all elements, it is clear that the electrons alone can not emit characteristic spectra, the

[3] Jeans, *Phil. Mag.*, **2**, 425, 1901.

[4] J. J. Thomson, *Phil. Mag.*, **11**, 774, 1906.

'sign-manual of the elements.' Riecke and Stark[5] have furnished us excellent experimental reasons, by observing the motion of luminous lithium vapor towards the cathode, for thinking that the radiant source is the positive ion; this, it will be noted, is not at all inconsistent with the evidence of the Zeeman effect, since the positive ion carries with it probably a large number of negative electrons, being itself merely a neutral atom minus one or more negatively charged corpuscles.

Thomson has recently presented three different lines of argument for thinking that the number of corpuscles in the atom is of the same order as its *usual* atomic weight, *i. e.*, in terms of hydrogen as unity. But most elements emit a number of spectral lines which is enormously greater than their respective atomic weights.

Thomson is, therefore, driven to conclude that "when an atom of an element is giving out its spectrum either in a flame or in an electric discharge, it is surrounded by a swarm of corpuscles; and combinations not permanent, indeed, but lasting sufficiently long for the emission of a large number of vibrations, might be expected to be formed. These systems would give out characteristic spectrum lines; but these lines would be due not to the vibrations of the corpuscles inside the atom, but of corpuscles vibrating in the field of force outside the atom."[6] The immediate cause of luminosity would be the bombardment of this system by free corpuscles, or in the case of flames the disturbing cause would presumably be molecular collapse.

At another time and place Thomson fortifies his view as to the complexity of the radiating atom, by citing the discovery of Lenard, that the speed with which the corpuscles are expelled from the atom by ultra-violet light does *not* depend upon the intensity of the incident ultra-violet light; thus indicating the necessity of at least two independent vibrating systems within the radiant atom.

I am not clear as to the proper interpretation of the measurements which have been made by Stark[7] upon the Doppler effect in hydrogen canal rays; but in any event they would seem to prove that the luminous source in the vacuum tube is not the simple corpuscle of the cathode rays, but the more complex, positive ion (not necessarily the positive charge) of the canal rays. While the experiments of Hull[8] during the past year combined with that of Schuster and Hemsalech point to a luminous source of such size and complexity that a condition of luminosity may be 'propagated along' it.

The upshot of the whole matter, then, is that we are landed with a picture of the radiant atom which is complex quite beyond description. One is reminded, indeed, of the words which Marie Corelli puts in the mouth of Lionel, the youthful hero of her 'Mighty Atom.' "Oh, dear Atom!" says he, "you must be very much more than I have been taught to believe you are."

Let us, however, accept the structure as we have received it and, with apologies for any feature of it which has not been correctly represented to you, let us now ask ourselves, how well it can serve as a foundation for our spectroscopic edifice.

APPLICATION OF CRITERIA

We may make this test most easily perhaps by asking how this atom will account for the nine fundamental phenomena mentioned above, and—

1. Does this Saturnian system give sharp lines? Can one predict from its structure that its radiation will be concentrated in a

[5] Riecke & Stark, *Physik. Zeitsch.*, **5**, 537, 1904.

[6] Thomson, *Phil. Mag.*, **11**, 774, 1906.

[7] Stark, *Ann. d. Physik.*, **21**, 401, 1906.

[8] Hull, *Proc. Roy. Soc.*, A, 521, p. 80, 1906.

few definite positions in the scale of wave lengths? I think it must be admitted frankly that, in the picture of the atom as given us, there is nothing which determines the rate of rotation of the corpuscle in its orbit, and nothing, therefore, which gives the same periodicity of radiation for all atoms of any one element.

This difficulty has been stated in a very forcible manner by Professor Jeans, and again by Lord Rayleigh. Each of them has proposed a method of getting around the difficulty, one[9] by introducing a law of electrical action different from the simple law of inverse squares, the other[10] by introducing mobile negative particles, which do not revolve, but which vibrate about their positions of equilibrium located in a rigid positive charge.

But the adoption of either of these suggestions would completely change the entire character of the atom. It may be that we shall later be driven into the corner and be compelled to accept some such mode of escape. But at present these devices impress one as highly artificial, and too inconsistent with other facts to warrant adoption.

The crux of the situation seems to be just here, if one assumes that the frequency of the radiation is identical with the rate of revolution of the corpuscles, he can not expect sharp lines in the spectrum. If, on the other hand, one assumes that light is due to the internal vibrations of the corpuscles, then not only does he fail to predict the Zeeman effect, but he is forced to conclude that since the corpuscles appear to be the same for all elements, the spectra of all elements should be identical. To derive the Zeeman effect from a rectilinear vibration by substituting for it two circular vibrations would seem to employ a purely kinematic device instead of offering a physical explanation. Nor is this all: The value of e/m obtained from the Zeeman effect is, if not correct, at least in beautiful accord with values determined in a variety of other ways.

Summarizing, one might say that the adoption of the Saturnian atom would compel us either to give up the Zeeman effect, or to give up sharp lines in the spectrum. On the other hand, I am not aware that it has ever been shown that even in a gas-spectrum the region between any two lines *is* entirely free from radiation. Is there any spectrograph so free from diffused light as to make an experimental answer to this question anything other than a more or less rough approximation? But even if every spectrum is, to some slight extent, continuous, the fact remains that spectral lines are essentially sharp.

2. Passing now to the second fundamental fact, which is that spectral lines are *not* perfectly sharp, but (within limits not yet resolved by any grating) possess a complicated structure, Professor Michelson[11] and Lord Rayleigh[12] have shown that in the case of a gas at low pressure the chief, if not the only, cause of widened lines is motion in the line of sight, an effect which depends as much upon pressure and temperature as upon atomic structure. But when it comes to the asymmetric distribution of intensity within these narrow lines, *i. e.*, a linear structure such as has been revealed to us especially by the interferometer in the hands of Michelson, an effect which would appear to be a function solely of atomic structure, then the chances of explanation in terms of the Saturnian atom appear even more remote than in the case of perfectly sharp lines.

3. The next query to be presented to the Saturnian atom is what explanation can be offered for the fact that very many lines in

[9] Jeans, *Phil. Mag.*, **11**, 607, 1906.

[10] Rayleigh, *Phil. Mag.*, **11**, 118, 1906.

[11] *Astroph. Jour.*, **2**, 251, 1895.

[12] *Phil. Mag.*, April, 1889.

the spectra of the elements are arranged in series such that the wave lengths of any one series are functions of only two constants and the successive whole numbers?

So far as I am aware, no answer which is even approximately satisfactory has ever been offered in reply to this question. The fundamental difficulty here has been shown by Lord Rayleigh to lie in our measure of force, so to speak; in the fact that force is a second derivative of displacement with respect to time. Describe any dynamical system you please in terms of a differential equation; integrate it under conditions which yield a periodic solution; solve for the frequency, and you will find its value always entering to the second power.

But the difficulty under which the Cambridge atom here suffers is not peculiar to it alone.

Ritz,[13] in a doctor's dissertation of extraordinary merit, offered at Göttingen, has succeeded in devising a formula which contains fewer constants than that of Kayser and Runge, yet represents the observed wave lengths with a distinctly higher accuracy. And it might, at first glance, appear that we have here a truly dynamical explanation of the series phenomenon. But on closer inspection one finds that the fundamental picture—the mechanism, if you please—from which Ritz derives his differential equation is one having properties which are purely hypothetical and, in nature as we know it on a larger scale, quite impossible.

His vibrating body is a square (sometimes a plate, sometimes a membrane), whose behavior he studies under different boundary conditions. But it has this remarkable property that the effect of any one element of the membrane upon any other element is not merely a function of the distance separating the elements, but varies directly as this distance. A device so artificial could at most be called quasi-kinematical or purely mathematical. However, in each of the particular cases which he has integrated the frequency expression turns out to be practically identical with Rydberg's formula. The only dynamical justification for the entire proceeding appears to lie in the fact that he has chosen a two-dimensional body to yield a double infinite number of spectral lines.

Garbasso[14] has made an interesting attempt to obtain the Kayser and Runge series from certain combinations of Hertzian oscillators. And his solutions have this special merit, namely, they all refer to physically realizable models. But the number of frequencies which he has computed is too small to furnish even an approximate test as to whether they satisfy the law of Kayser and Runge, much less do they point out a general dynamical system from which the law of the series may be derived.

In spite of the fact that no satisfactory explanation has been obtained, one can hardly avoid the conclusion that Rydberg's formula is something more than a convenient expression for interpolation. The fact that his second constant, N_0, is the same for all elements, while another has a characteristic value for each particular element, and that a third constant locates the particular series in any one element, would seem to indicate that these three quantities are in some sense parameters of matter. Yet I am aware that this view is a mere suspicion and is not at present capable of proof.

When other types of spectra, such as that of iron, are brought under the 'reign of law' we may find a simpler view; or what is more likely, we may feel, with

[13] Ritz, *Ann. der Physik.*, **12**, 264–310, 1903.

[14] Garbasso, 'Theoretische Spectroskopie,' pp. 130 and 180, 1906.

Professor Runge, that 'nature is getting more and more disorderly every day.'

4. Passing now to the pressure shift, we owe to Dr. Humphreys, one of the discoverers of the phenomenon, a clear explanation in terms of the Saturnian atom.

He points out first of all that an atom built on the model indicated, with quantitative specifications such as these given, by experiment, will exert an enormously powerful field at points near its center. And since the convection currents here existing are practically equivalent to Amperian currents in circuits devoid of resistance, it is clear that any currents induced in these atoms by attempting to thrust through them more or fewer lines of force than they now contain will be permanent and, therefore, unlike the induced currents in the wire circuits of our laboratories.

But an increase of current in such an atom means an increase of speed in the corpuscles, and this in turn means presumably an increase of frequency. From this it follows that, if by any means two atoms are brought closer together there will in general be a change of frequency, and one may expect this change to be sometimes an increase and sometimes a decrease; that is to say, two atoms which are made to approach by pressure, and which we may imagine as strung on a common axis, will sometimes be rotating in the same sense and sometimes in the opposite sense. The increase and decrease of frequency thus secured by pressure will have the effect of widening the line. The plausibility of this argument is much enhanced by the enormous strength of the magnetic field in the neighborhood of one of the magnetic atoms; in the case of the iron atom amounting to as much as 150,000 C.G.S. units at a distance of ten radii from the center and, of course, a thousand times greater than this at the center. So much for the widening due to pressure.

But Dr. Humphreys has also very cleverly suggested that this widening will not be symmetrical about the original position of the line, but about a new position on the red side of the old. For when two atoms happen to be rotating in the *same* direction they will attract each other and then get 'into the stronger portion of each other's magnetic field.'[15] In other words, those effects which result in lengthening the waves will be much more marked than those which shorten the waves. Hence increase of pressure will be accompanied by shift towards the red. It would be exceedingly interesting to know what difference of structure exists between the radiant sources of lines and of bands which causes this explanation to break down when applied to the latter.

5. Passing now to the effect of a magnetic field, an experimental fact which largely established, although it did not suggest, Lorentz's conception of the electron vibrating about an attracting center, it is at once evident that the Zeeman phenomenon must follow as a deduction from the Saturnian atom.

But Preston and Runge and Paschen have shown that the normal triplet is by no means an ordinary occurrence; on the other hand the breaking up is very much more complicated, a single line yielding anywhere from 3 to 14 components.[16]

Beautiful as the general agreement beween fact and theory here is, one finds it peculiarly difficult to understand how the central line of the normal triplet—the one due to the component of motion along the lines of force—can be split up at all by the magnetic field. But since, as a matter of fact, this component *is* split up, it is

[15] Humphreys, *Astrop. Jour.*, **23**, 243, 1906.
[16] Runge & Paschen, *Abh. Ber. Akad.*, February 6, 1902.

only fair warning that the forces here involved are possibly not to be limited to those of purely electrical origin; but it is not obvious what experiment can be devised to answer these questions.

6. Passing next to that somewhat motley group of phenomena which we have classed under the head of Multiple Spectra, I am not certain that there is a single fact in the entire group that can be predicted from the structure of the atom which has been assumed.

In his Royal Institution lecture[17] of this year, J. J. Thomson has suggested an atom with certain capacities for receiving and spending energy, and has described this atom by simple differential equations, involving certain atomic constants; but the connection between these constants and the Saturnian atom are by no means clear.

So that while he accomplishes the explanation of the phenomena for which this new atom is introduced, the explanation can hardly be said to hinge upon the atomic structure, which has so highly recommended itself in other directions.

At present, we seem to be justified in going little farther than to say that *rapidity of change of electric field* seems to be *a* (not *the*) determining factor in nearly every case. The main difference between the arc and the spark appears to be confined to the earlier stages of the spark. The oscillograph shows that spark lines are introduced into the metallic arc when the break is quickened; the interruption of an intermittent arc is very much hastened by a hydrogen atmosphere; and one might think that, therefore, the action of hydrogen in introducing the spark lines is completely accounted for, and perhaps justly so, if it had not been discovered by Hale, Adams and Gale[18] that an arc fed by a small steady current and surrounded by hydrogen also yields spark lines. But this calls for an examination of the steady (?) current by means of the oscillograph.

The effect of a very minute current in introducing spark lines probably also rests upon the greater rapidity with which the small current is interrupted. The effect of self-induction is to retard the break, and hence obviously to obliterate spark lines. The effect of a parallel capacity is, of course, to increase the speed of break. The spark lines obtained in arc under water are apparently special cases of the effect of a hydrogen atmosphere and a consequent rapidity of break.

A most valuable research at the present time would be one which would determine whether for a 'quickness of break' as a unifying principle we should substitute 'rate at which energy is delivered' or, as Thomson suggests, 'rate at which energy is delivered *combined with rate at which energy is spent.*'

Until more definite information upon this point is obtained, it remains almost impossible to say how the Saturnian atom must be modified in order to explain multiple spectra.

7. As to the relation between spectral phenomena and atomic masses, we must, I think, all feel the most hearty admiration for the manner in which Professor J. J. Thomson has succeeded in picturing the periodic law as an almost immediate consequence of the atomic structure which he has proposed. The way in which the normal atom, by the addition of a few subatoms, becomes electro-positive or electronegative is especially attractive. The achievements of Runge and Precht[19] in closely approximating if not accurately determining the atomic mass of radium is

[17] Thomson, *Chemical News*, **94**, 197, 1906.

[18] Hale, Adams and Gale, *Astroph. Jour.*, **24**, 213, 1906.

[19] Runge & Precht, *Physikal. Zeitschrift*, **4**, 285–287, 1903.

equally striking. Rydberg[20] has pointed out that certain spectroscopic properties of the elements recur with exactly the same periodicity as that discovered by Mendelejeff.

But it is important to observe that in none of these laws is the question of atomic structure involved, but only that of atomic mass. Not a single one of these phenomena has been predicted from previous notions concerning the atom, and indeed all our views concerning the Saturnian atom, with the single exception of the Zeeman phenomena, appear to be singularly devoid of that spirit of prophecy which characterizes all sound theory.

8. When confronted with the fact that many spectral lines show self-reversal, the atom which is now on the witness stand replies that its explanation of this phenomenon is identical with that of any other atom which consists of a vibrating mechanism.

The essential feature of a line-reversal appears to consist of a source *within* the arc or spark which emits, from whatsoever cause, a relatively wide line—thus approximating in small degree the incandescent solid first used by Kirchhoff. The *outside* region of the arc or spark emits, from whatsoever cause, a relatively narrow line, and its radiant atoms are, therefore, capable of absorbing only certain periods from those which appear in the broad or inner source.

Accordingly, the phenomenon of reversal is, in a certain very true sense, *not* an atomic problem. The fundamental question here involved is, however, the following, namely, how does it happen that, in the *inner* source, some atoms have their frequencies slightly increased while others have theirs slightly diminished? And this *is* an atomic problem.

[20] Rydberg, 'Rapports Congrès de Physique' (Paris), II., 217.

We may say that it is due to 'increased density' of the luminous vapor, but we are little wiser for that. In this emergency, the Cambridge atom with its entourage of stray corpuscles shows itself very capable; for it is exactly in such a region, as the interior of an arc, where the electric field is strong, and where collisions are frequent, that one might expect this 'swarm of corpuscles' to be varying largely—thus altering slightly the period of the radiant source, whatever that may be, both by change of inertia, and by change of electric field—acting, so to speak, both upon the numerator and denominator of the expression for the period. The case of double reversals has been reduced to that of single reversals by the clever experiments of Dr. Humphreys.[21]

The case of Wolf-Rayet stars[22] where H^{α} and H^{β} are bright while the remaining hydrogen lines are dark is, so far as I am aware, an unsolved puzzle.

9. Regarding the last of the nine criteria which have been cited, namely, the well-nigh impossible feat of securing a line-spectrum from a gas by means of heat alone, the situation seems to be as follows.

If one assumes that ordinary temperatures are due to the translational energy of the atom, while light consists in dissipation of vibrational energy *in* the atom, then Jeans[23] has proved, on dynamical grounds, that it is possible only in a minute degree to transfer energy 'from the principal degrees of freedom to the vibratory degrees of freedom'—at least with any temperatures which are encountered on this planet. In the case of ordinary collisions, the transfer is infinitesimal on account of the high frequency of the vibrations as compared with the duration of the collision; in the case of those rare collisions in which the

[21] Humphreys, *Astroph. Jour.*, **18**, 204, 1903.

[22] Campbell, *ibid.*, **2**, 177, 1895.

[23] Jeans, 'Dynamical Theory of Gases,' Ch. IX.

duration of collision is comparable with the period of vibration, the transfer of energy is 'infinitesimal on account of the extreme rarity of these collisions.'

This point of view has, I think, been supported by the experience of every one who has attempted to obtain characteristic spectra from gases under conditions in which electrical and chemical processes were excluded.

The assumptions back of Jeans's discussion are to be justified, if at all, by experiment. Hence the importance of such work as that which King,[24] Hale[25] and others have recently been doing by means of the electric oven, and of the fundamental experiments of Wood upon optical resonance.

As to the bearing of the Saturnian atom upon this fact, one finds it in about the same position as any other elastic atom, except that for ordinary mechanical rigidity one has to substitute the quasi-rigidity which comes from rotation of the electrons about the positively charged center.

The effort to render a gas radiant by means of high temperature alone has been aptly characterized by J. J. Thomson as an effort to boil a tea-kettle by burning down the kitchen; the spectroscopic analogue of Lamb's roast pig.

In view of all the evidence, the conclusion would appear to be that spectroscopists have greatly exaggerated the rôle of temperature in terrestrial sources. That the behavior of an arc or spark is determined largely by the temperature of its *electrodes* there can be no doubt; but it seems almost equally certain that the effect of changing temperature upon the character of the spectra is produced through the intermediation of changed electrical conditions in the source.

CONCLUSION

In turning the pages of Kayser's great compendium, which so adequately represents the present phase of spectroscopy, there is but one tinge of disappointment; and this is that, in the presence of such a wealth of facts, there is so little in the way of fundamental well-established unifying principles. And yet the only remedy appears to be one of the homeopathic sort, namely, more facts.

There is, however, this comfort: things are not as bad as they used to be. Our condition is somewhat that of the old judge who never liked to admit that he was not in perfect health. On one occasion, when he was just recovering from an illness, a friend met him on the street and asked him how he was feeling. "Well!" said the judge in reply, "I am not quite myself, but I am a great deal better than I was at the time when I was not so well as I am now." This, too, is to be remembered, that we can never hope for any solution which can in any sense be called final—*all* solutions are merely passing phases—the problem is not one either of mathematics or of history.

Let us then continue our search for the facts of the case confident in the belief that when this work has been properly accomplished, the unifying principle will be at hand. It should be to us a matter of no small pride that it is to our fellow members in this section that spectroscopy owes the bolometer, the curved-grating, the echelon, the spectroheliograph, and, therefore, in large measure the beautiful results obtained with these instruments.

In the meantime we must, I believe, all gladly admit two things: first, that the atom which we associate so closely with the Cavendish Laboratory more nearly supplies the desired principle than anything else which has been offered, and secondly, that the emission of a line spectrum is a very imperfectly comprehended phenomenon.

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[24] King, *Astroph. Jour.*, **21**, 236, 1905.

[25] Hale, Adams and Gale, *ibid.*, **24**, 213, 1906.