Thus

$$\mathbf{E}=\frac{e\mathbf{R}_1}{\beta^2 R^2(1-v^2\sin^2\lambda_1)^{\frac{3}{2}}},$$

$\mathbf{R}_1$ is the unit vector along $e\mathrm{P}'$, and

$$\mathrm{H}=v\mathrm{E}\sin\lambda_1.$$

These results are of course well known, but I think it will be admitted that the above is a particularly easy way of obtaining them. By extension of the principle described to quaternionic operators it is evident that the whole of the theory of Relativity can be very conveniently expressed in this notation.

In conclusion I should like to express my thanks to Dr. Silberstein for reading my paper and for his interest in it.

XLIV. *The Constitution of Atmospheric Neon.* *By* F. W. Aston, *M.A.*, *D.Sc.*, *Clerk Maxwell Student of the University of Cambridge**.

[Plates VIII. & IX.]

IN periodic tables of the elements arranged in order of their atomic weights the part lying between Fluorine on the one hand and Sodium on the other is of considerable interest.

Soon after the discovery of argon and while the monatomic nature of its molecule was still under discussion, Emerson Reynolds, in a letter to 'Nature' (March 21, 1895), described a particular periodic diagram which he had used with advantage. In this letter, referring to the occurrence of the groups Fe, Ni, Co: Ru, Rh, Pd: and Os, Ir, Pt, the following passage occurs:—

"....the distribution of the triplets throughout the whole of the best known elements is so nearly regular that it is difficult to avoid the inference that three elements should also be found in the symmetrical position between 19 and 23, *i. e.* between F and Na, ... of which argon may be one...."

In 1898 neon was isolated from the atmosphere, in which it occurs to the extent of ·00123 per cent. by volume, by

* Communicated by the Author.

Ramsay and Travers, and was accepted as an elementary monatomic gas of the helium group. Its density was measured with extreme care by Watson (J. C. S. Trans. vol. i. p. 810 (1910)), and found to correspond with an atomic weight 20·200 (O=16), making it the lightest element to diverge from the whole number rule in an unmistakable manner.

Neon has many very remarkable properties, its compressibility, viscosity, and dielectric cohesion are all abnormal; but the first suggestion that it might be a mixture was the observation in 1912 by Sir J. J. Thomson of a faint but unmistakable parabola at a position corresponding roughly to an atomic weight 22, in addition to the expected one at 20, in positive ray photographs, whenever neon was present in the discharge-bulb (*v.* 'Rays of Positive Electricity,' p. 112). The first plate which showed this was obtained from a sample of the lighter constituents of air supplied by Sir James Dewar; other specimens of impure neon gave a similar result. So also did a portion of the gas used by Watson in the atomic weight determinations, which fact, together with the complete invisibility of any parabola at 22 on hundreds of plates where neon was known to be absent, was very strong evidence that the line was ascribable to neon and to neon alone.

These facts led the author to undertake a searching investigation on the constitution of the gas by two distinct lines of attack, firstly attempts at separation, secondly accumulation of the evidence obtainable by positive rays.

Evidence of Separation.

The experiments on fractional distillation and fractional diffusion through pipeclay have already been described (F. A. Lindemann and F. W. Aston, Phil. Mag. vol. xxxvii. May 1919). The former were completely negative and only succeeded in confirming Watson's value of the density already referred to. It has recently been shown (F. A. Lindemann, Phil. Mag. July 1919) that this negative result was theoretically inevitable.

The diffusion results were more hopeful, an apparent change of density of about ·7 per cent. being obtained in the first set of experiments. On the other hand, the more elaborate automatic apparatus started in 1914 has given very disappointing results, a difference of only ·3 per cent. being obtained. This is doubtless due to the initial mistake in designing the apparatus to work at atmospheric pressure, under which conditions the mixing is very bad. It may therefore be said that the diffusion results are positive but too small to be conclusive.

Evidence of Positive Rays.

This is available on three distinct counts: the character of the lines, their position and their intensity.

Character of the parabolas.

Plate VIII. shows a dark and a light print taken from a negative obtained in 1913 by Thomson's method of analysis from a gas containing a large percentage of neon. The line due to the lighter constituent which will be called Ne^{α} can easily be recognized as the brightest on the plate, the Ne^{β} *i. e.* 22 line being the fainter one immediately below it. It can easily be seen that the latter possesses characteristics identical in all but intensity with those of the former. As has already been pointed out ('Rays of Positive Electricity,' p. 111) the prolongation of the lines towards the vertical axis indicates that the particles causing them are capable of carrying more than one charge; multiple charges not occurring on molecules but only on atoms, one is led to infer that both lines are due to elements.

Position of the parabolas.

Measurements of plates obtained in this way indicated that it was probable that the lighter constituent did not correspond in mass with the accepted atomic weight of 20·2, but the accuracy was not sufficient to make this certain.

Intensity of the parabolas.

The relative intensity of the Ne^{α} and Ne^{β} parabolas obtained from atmospheric neon untreated by diffusion has been estimated by three different observers as about 10 to 1. Its apparent invariability is corroborative evidence against the possibility of the 22 line being due to the presence of other gases in the discharge-bulb.

It will be seen that although by Thomson's system of analysis the presence of two isotopes in atmospheric neon was indicated by several lines of reasoning, none of them can be regarded as quite conclusive, and it was realized that, failing separation, the most satisfactory proof would be afforded by measurements of atomic weight so accurate as to prove beyond dispute that neither constituent corresponded with the accepted atomic weight of atmospheric neon.

Evidence of the Positive Ray Spectrograph.

The "mass-spectra" yielded by the new method of positive ray analysis recently described (F. W. Aston, Phil. Mag. Dec. 1919) supply these measurements in an entirely satisfactory manner. Plate IX. A, B, C, D, are prints from negatives obtained by means of this apparatus. Each contains a number of spectra taken with different electric and magnetic fields; the following table of values of P the potential between the electrostatic plates in volts, I the current passing through the magnet in amperes, and T the time of exposure in minutes, is given for reference:—

TABLE I.

	A					B				
	1	2	3	4	5	1	2	3	4	5
P=	240	240	240	320	320	320	320	360	240	240
I=	·130	·450	·600	·600	·800	·351	·600	·600	·600	·173
T=	4	10	10	10	10	15	15	15	15	4

	C						D					
	1	2	3	4	5	6	1	2	3	4	5	6
P=	240	240	280	320	360	360	320	320	320	320	320	320
I=	·380	·550	·550	·550	·550	·700	·482	·520	·554	·606	·701	·798
T=	15	15	15	15	15	10	10	10	10	10	10	10

On the left of each spectrum can be seen the small circular dot photographed on the plate just before or during the exposure, this is used as a register spot for measuring purposes.

Plate A was taken with carbon monoxide. That is to say, the vacuum in the discharge-tube was maintained by continual pumping with a Gaede rotating mercury pump against a small leak of CO. It must be understood that this does not imply that the contents of the discharge-bulb were pure CO, since the use of tap-grease and wax joints necessitates the presence of hydrocarbons, etc., but at least one can be certain that the quantity of neon present was negligible as none had yet been put into the apparatus. The electric deflexion is away from the register spot, the magnetic towards it, so that the heavier masses are to the right of lighter ones.

Spectrum A I. was taken with a very small magnetic field showing the lines due to the hydrogen atom and molecule. In A II. the field has been increased and a group of five lines are seen. These, which may be called the C_1 group, are 12-C, 13-CH, 14-CH_2 (or N), 15-CH_3, 16-CH_4 (or O).

They are important lines of reference and are certainly of the relative masses given above to the order of accuracy (one-tenth per cent.) claimed in the present experiment.

In A IV. the deflexion has been still further increased and a new group of lines, the C_2 group 24, 25, 26, 27, 28, 29, 30 containing the strong reference line of CO (or C_2H_4), have come into view. In A III. of the C_1 group only 15 and 16 are visible, and in A V. the C_2 group has moved to the left and the strong line 44, CO_2 is seen to the right.

Plate B was taken with CO to which about 20 per cent. of atmospheric neon had been added. Considering the spectrum B III. it will be seen that four unmistakably new lines have made their appearance, one pair between the C_1 and C_2 groups, another weaker pair to the left of the C_1 group. The first pair are $(Ne^{\alpha})^{+}$ 20 and $(Ne^{\beta})^{+}$ 22 singly charged, the second pair are the same atoms with double charges $10(Ne^{\alpha})^{++}$ and $11(Ne^{\beta})^{++}$ respectively. The other spectra consist of lines already mentioned brought into different positions to increase the convenience and accuracy of comparison and, in addition, there are on C I. two other valuable reference lines, O^{++} apparent mass 8, and on the extreme left just visible C^{++} apparent mass 6.

Method of comparing masses.

It will be noticed that although the lines are broad (the best focus was only obtained by a series of trials after these results were completed) their edges, particularly their left-hand edges, are remarkably sharp, so that measurements of a reasonably good line from the register spot repeat to a twentieth of a millimetre with certainty. Hence for accurate determination of unknown lines only two assumptions need be made. Firstly, that the masses of the reference lines are known, and secondly that, whatever the function connecting displacement with mass, any two positions on the spectrum being taken, the *ratio* of any two masses giving lines in these positions will be constant. This being so, by moving a group of reference lines into overlapping positions along the spectrum it is clear that the whole length can be plotted out and calibrated.

Fortunately there is an easy method of testing both these assumptions, for although it is impossible to measure the magnetic field to one-tenth per cent., it can be kept constant to that accuracy while the electric field is altered by a known ratio. But, for constant deflexions, $mv^2 \propto X$ and $mv \propto H = \text{const.}$ Therefore $m \propto X^{-1}$, so that, to take a typical case, the position occupied by carbon with a field of 320 volts should be exactly coincident with the position occupied by oxygen with 240 volts when the magnetic field is constant. Over the range of fields used in the case of neon, all such coincidences when expected have been found to occur within the error of experiment whatever the position on the plate.

For some reason, by no means obvious, connected with the geometry of the apparatus the relation between displacement and mass is very nearly linear, a fact which lightens the labour and increases the accuracy of calibration very considerably.

Numerical results.

In the case of plate B the masses of the neon lines were estimated by carefully drawing the calibration curve representing the relation between displacement and mass by means of the known lines 12, 13, 14, 15, 16 checked by that at 28.

With plate D another mode of procedure was adopted. A linear relation was assumed and a table of corrections made by means of reference lines, which correction when subtracted from the observed displacement gave an exactly linear relation with mass. A correction-curve (apparently parabolic) was drawn, from which the appropriate corrections for any displacements could be written down and the masses corresponding to those displacements obtained by simple proportion. The following table gives the results :—

Table II.

Plate B.

$(Ne^{\alpha})^{++}$.	$(Ne^{\beta})^{++}$.	$(Ne^{\alpha})^{+}$.	$(Ne^{\beta})^{+}$.
9·98	11·00	20·00	20·00
10·02	10·99	19·95	22·01
10·00	10·99(5)	19·97(5)	22·00(5)

Plate D.

$(Ne^{\alpha})^{++}$.	$(Ne^{\beta})^{++}$.	$(Ne^{\alpha})^{+}$.	$(Ne^{\beta})^{+}$.
10·01	11·06	20·00	21·90
9·98	10·98	19·98	22·10
9·98	11·01	20·00	22·03
—	—	19·90	21·98
9·99	11·01	19·97	22·00(5)

The method of measurement combined with a slight halation of the plate tends to make the edge of bright lines appear a little too near the register spot. This is enough to account for the reading of the very bright Ne^{+} line giving a mass a little too low. The above figures therefore can be accepted as fairly conclusive evidence that Atmospheric Neon contains two isotopes of atomic weights 20·00 and 22·00 respectively to an accuracy of about one-tenth per cent.

In order to give the accepted density the quantities required are 90 per cent. and 10 per cent., which is in good agreement with the estimated intensity of the lines.

Possibility of a Third Isotope.

On the clearest spectra obtained with neon there are distinct indications of a line corresponding to an isotope of mass 21. This line is extremely faint, so that if this constituent exists its proportion would be very small, probably well under 1 per cent., and it would not affect the density appreciably. Attempts to bring this line out more distinctly by longer exposures have not succeeded owing to the fogging from the strong neighbouring lines, but it is intended to return to this point when further improvements of the method give hope of more conclusive results. This matter is interesting in connexion with the suggestion by Emerson Reynolds already quoted *.

In conclusion the author wishes to express his thanks to M. Georges Claude, who kindly supplied the neon used, and also to the Government Grant Committee for some of the apparatus employed.

Summary.

A brief account is given of facts which lead to the idea that atmospheric neon may be a mixture of isotopes.

The results of attempts of separation are summarized.

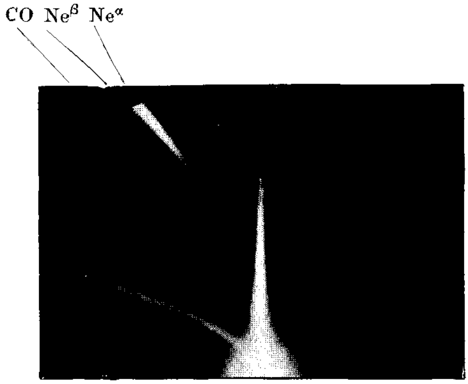
The several lines of evidence adduced from the parabolas obtained by Thomson's method of Positive Ray analysis are considered and shown to be consistent with the above theory but hardly conclusive.

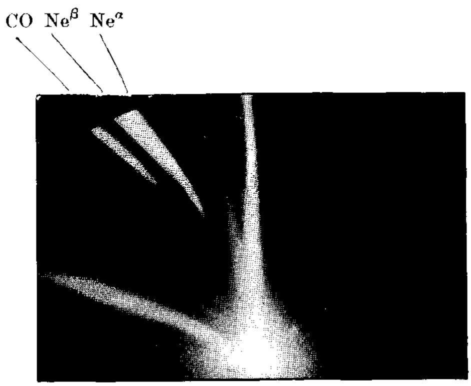
Mass-spectra obtained by means of the Positive Ray Spectrograph are produced. Measurements from these are given which prove conclusively that neon contains two isotopes having atomic weights 20·00 and 22·00 respectively to an accuracy of about one-tenth per cent., their proportions being therefore 90 per cent. and 10 per cent. by volume.

The possibility of a third constituent is indicated.

Cavendish Laboratory,
December 1919.

* Though at the time this was made isotopes were not thought of, and the modern idea of atomic members has since precluded the possibility of three distinct elements.


CO Ne$^{\beta}$ Ne$^{\alpha}$


CO Ne$^{\beta}$ Ne$^{\alpha}$


V IV III II I
A
V IV III II I
B
VII V IV III II I
C
VII V IV III II I
D