We must remember that we are observing rotations which result from a pair of absorption-bands, which may behave in different ways, that is they may conspire for wave-lengths on the blue side and oppose each other for the longer waves on the red side. If, for example, the stronger band at wave-length 5790 gave positive rotations for the red waves, and negative rotations for the green, and the fainter band gave negative rotations for both red and green, the absence of a sharply marked extinction-band on the red side is at once explained. Both types of rotation curves are theoretically possible according to Drude, according to the fundamental hypothesis adopted. The second type is characteristic of sodium vapour, as is well known.

I am now preparing a set of these films for Dr. Bates, of the Bureau of Standards, who plans to investigate them with a large and very accurate polarimeter.

XXIII. *On the Existence of Positive Electrons in the Sodium Atom.* By R. W. Wood, *Professor of Experimental Physics in the Johns Hopkins University* *.

[Plate XIV.]

THE greater part of the evidence which we have obtained thus far regarding the structure of the atom, indicates that the centres of vibration which emit the spectral lines are negatively charged corpuscles. The positive charges appear to be associated with the atom as a whole, and the assumption is often made that the positive electrification is of uniform distribution.

The Zeeman effect shows us that the D lines of sodium are due to vibrators carrying negative charges, a fact which is true of all other lines which show the effect. That a negative charge is associated with the centres of vibration which emit the D lines is also shown by the direction (positive) of the magnetic rotation of the plane of polarization, for waves of very nearly the same frequency as that of the D lines. As is well known band spectra do not show the Zeeman effect at all, consequently we are unable to apply this test to the investigation of the nature of the charge associated with the centres of emission of the lines of which the bands are made up.

Some of the lines which make up the complicated channelled

* Communicated by the Author.

absorption spectrum of sodium vapour, have, as I have shown in previous papers (Phil. Mag. Oct. 1905, Nov. 1906), the power of rotating the plane of polarization when the light is passed through the magnetized vapour in the direction of the lines of force.

White light is passed through a nicol prism and a steel tube which passes through the pole-pieces of a large electromagnet. An analysing nicol, condensing-lens, and spectroscope follow in succession. The tube contains metallic sodium and is highly exhausted, for the vapour loses its rotating power when mixed with an inert gas. If we set the second nicol for extinction, the spectrum of the crater of the arc-lamp disappears, but on heating the tube and exciting the magnet, a vast number of bright lines appear in the red and green-blue regions of the spectrum. Spectra obtained in this way, since they are radically different from spectra of other types, I have named "magnetic-rotation spectra." Macaluso and Corbino observed the effect at the D lines, employing a sodium flame between the poles of a magnet, but they missed the complicated bright-line spectra which only appear when very dense sodium vapour is formed *in vacuo*.

In the case of the rotation for wave-lengths in the vicinity of the D lines, there is no difficulty in determining the direction, *i.e.*, whether positive or negative, for the broad bands of rotated light which border the absorption-lines can be moved from side to side by slight rotations of the analysing nicol; or we may employ the device so frequently used, the Fresnel double prism of right- and left-handed quartz, which tells us at a glance the direction of the rotation. In the case of the narrow lines of the channelled spectra, no information can be gathered as to whether the rotation is positive or negative by rotating the analysing nicol, for the smallest possible turn from the position of extinction causes the continuous spectrum to brighten up, obliterating the rotation lines. It is, however, of the utmost importance to determine the nature of the rotation in this case, as it will furnish many additional clues to the structure of the atom. An attempt was first made to employ metallic arcs in place of the white-hot crater, as the source of the light, on the chance that some of the lines might be of the right wavelength to suffer rotation in the region of the channelled spectra. If any of the lines were found to be rotated by the vapour, the direction of the rotation could be easily determined by rotating the analysing nicol until they were extinguished.

No lines were found, however, which had just the right wave-length. It then occurred to me that the selective rotatory power of the vapour could be utilized to furnish a source of light made up of just the right wave-lengths; in other words, magnetized sodium vapour between crossed nicols could be used as a light filter. The light passed by the crossed nicols when the magnetic field was excited was accordingly sent through another magnetized tube of vapour and examined with a third nicol and spectroscope. It was hoped that by setting the third nicol for extinction, and causing the bright-line spectrum to appear again by excitation of the second magnet, it would be possible to determine the direction of rotation of the lines by observing in which direction it was necessary to rotate the third nicol in order to blot them out. The first magnet, with its sodium tube and polarizing prisms, delivers plane-polarized light of exactly the wave-lengths of the bright lines of the magnetic-rotation spectrum. This light is then passed through a second magnetized tube of sodium vapour, a nicol prism, and a spectroscope. The nicol having been set for extinction the bright-line spectrum disappeared, reappearing again as soon as the magnet was excited. It was found, however, that rotation of the third nicol was wholly without effect on the appearance of the lines, notwithstanding the fact that the light was originally plane-polarized. *The magnetized sodium vapour appeared to have completely depolarized the light.* The cause of this phenomenon is not difficult to explain. The lines which make up the magnetic-rotation spectrum, though they appeared as narrow as the iron arc-lines in a photograph which I made two years ago with a concave grating of 12 feet radius, are not in reality monochromatic. The action of an absorption-line is to rotate the plane of polarization of waves of nearly the same wave-length through various angles depending on their proximity to the absorption-line. It is these waves which are transmitted by the nicol. The line therefore has a finite, though narrow, width, and the second tube of magnetized vapour rotates the monochromatic constituents, of which the line is made up, through various angles. Some of the light in the line is therefore passed by the third nicol in every position.

From their analogy to the bright rotated lines which border the D lines when examined under similar conditions, we should expect all of the lines of the magnetic-rotation spectrum to be double, and I have spent a good deal of time in attempts to show their duplicity, using an échelon grating.

No very definite results were obtained, however, and more recent experiments show pretty conclusively that the rotatory power of most of the absorption lines is confined to wave-lengths on one side of the line only. This same action is observed in an exaggerated degree by the ultra-violet absorption-line of mercury ($\lambda=2536$) which, as I have shown in a previous paper (Astrophys. Journ. July 1907), broadens very unsymmetrically. The form of the absorption-curve, and the magnetic rotation as shown with the Fresnel rotating quartz prisms, is shown in Pl. XIV. fig. 1, *a* and *b*. The spectrum obtained by passing white light through the vapour placed between crossed polarizing prisms is shown in fig. 1 *c*, the fainter line being rotated 270°.

The behaviour of mercury vapour will be fully treated in a subsequent paper, and for the present we need only remark that an absorption-band is possible which only gives an appreciable magnetic-rotation for wave-lengths bordering it one side.

This shows us that the lines of the magnetic-rotation spectrum would not necessarily appear double, even with the highest resolving powers (neglecting rotations larger than 90°). Though the lines appear as narrow as arc-lines even with a large grating, the magnetized sodium vapour and polarizing prism show us that in reality each line embraces a narrow range of the spectrum, the individual components of which are rotated through very different angles by the vapour.

The experiment which finally showed clearly the nature of the rotation was made with a pair of Fresnel quartz-prisms. They were much thinner than those usually employed, as it was felt that it would be better to work with a single broad band of extinction, than a large number of parallel bands. The magnetically rotated lines are faint in comparison with the continuous spectrum from which they are derived, and it is consequently important to have the background upon which they are to show up as dark as possible. With a thick Fresnel prism we have the continuous spectrum at its full intensity traversed by a number of parallel dark bands, which correspond to the points on the slit at which the plane of polarization is parallel to the plane of extinction (long diagonal) of the analysing nicol, which is placed immediately behind the slit. There is in consequence more or less diffused light from the grating, which renders the background (the dark bands), upon which the rotated lines are to appear, much too luminous. To get rid of this effect, the best method is to use a thin prism, and cover the slit except for a small portion immediately above and below the single dark band of extinction.

With this arrangement of the apparatus the magnetically rotated line should penetrate the dark band from above or below, according to whether the rotation is positive or negative. If we excite the magnet and gradually heat the sodium tube, we see sharp needles of light shoot down from the continuous spectrum into the dark region immediately to the right and left of the D lines, as has been described by Macaluso and Corbino, Zeeman, and others. If we reverse the magnetic field the needles of light shoot up from below. The direction in which the plane of polarization is rotated by the D lines indicates that they are caused by vibrations of negative electrons. The important question to be answered is whether the absorption-lines of the band-spectra rotate the plane of polarization in the same or in the opposite direction, and whether they all behave alike.

The magnetic-rotation spectrum being much brighter in the red and orange than in the green and blue region, the first observations were made in this part of the spectrum. The spectroscope was a medium-sized instrument, consisting of a telescope and collimator of about 180 cms. focus, furnished with a plane grating.

The sodium tube was heated until the fine black absorption-lines in the red appeared distinctly in the continuous spectrum above and below the horizontal dark band due to the Fresnel prism. The current was then thrown into the magnet, the self-induction of which is so great that the field does not rise to its full intensity for several seconds, so that there was plenty of time to see exactly what happened. As soon as the switch was closed numerous needles of light commenced to penetrate the dark region, *some of them shooting down from above, others shooting up from below.* Of these, some only extended halfway or less across the dark band, while others crossed it completely. On opening the switch the luminous needles slowly withdrew from the dark background into the bright region from which they came, reminding one of the tentacles of an alarmed hydroid. The phenomenon is one of the most beautiful that I have seen for some time, for it shows us at once that some of the absorption-lines rotate the plane of polarization in the positive direction, while others rotate it negatively.

A very satisfactory photograph of the phenomenon was obtained on a Wratten and Wainwright panchromatic plate with an exposure of one hour. An enlargement was made of the plate, which is reproduced in fig. 2 *a*. Fig. 2 *b* is a contact print from the original negative, and fig. 2 *c* is a print from a plate made with a small two-prism spectroscope, showing the entire visible spectrum and the phenomenon at the D lines. It will be observed that in the case of some of the lines the bright needles of light have withdrawn almost entirely from the absorption-spectrum, leaving a dark line. (Compare the upper and lower spectra at the points indicated by the arrows.)

If the positive rotation at the D lines can be used as an argument that they are due to negatively charged electrons, it appears to me that the two types of rotation in the channelled spectrum is an evidence that we have both positive and negative electrons in the atom. It is perhaps unwise to speak of a positive electron, since electron has come to mean the disembodied negative charge, after it has been expelled from the atom.

Whether the two types of magnetic rotation proves the existence within the atom of both positively and negatively charged discrete particles is for the theoretical physicists to answer. The observations recorded in this paper merely prove that some of the absorption-lines give a rotation opposite to that given by the D lines.

Becquerel has inferred the existence of positive electrons in certain crystalline minerals, from the change in the appearance of the absorption-band when the crystal is placed in a magnetic field. The conditions in this case are, however, much more complicated than in the case of sodium vapour, for he is dealing with molecules of the rare earths in combination with or imbedded in other substances.

It will be extremely interesting to determine the direction of the rotation of the lines in the green and blue region, for these have been found to coincide with the regularly spaced series of lines in the fluorescence spectra excited by monochromatic radiations *. I am now investigating this subject in collaboration with Mr. Felix Hackett, Fellow of the Royal University of Ireland.

* See previous paper on "The Fluorescence and Magnetic Rotation Spectra of Sodium Vapour, and their Analysis." Phil. Mag. Nov. 1906.

FIG. 1.

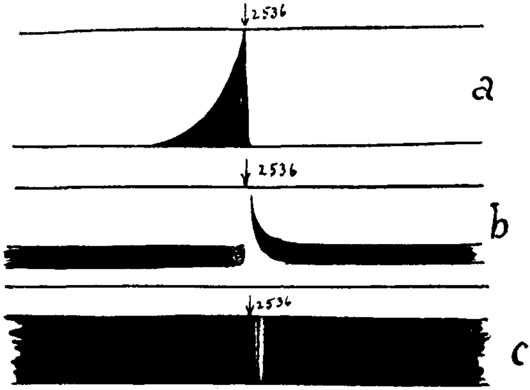

FIG. 2.