The Zeeman Effect[1].

By

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With 12 Figures.

I. Introduction.

1. Historical survey. In 1896 at Leiden (Holland) PIETER ZEEMAN (1865—1943) discovered the influence of an external homogeneous magnetic field on the frequencies of spectral lines emitted by a light source, placed in that magnetic field. He published his first experiments in the proceedings of the Royal Academy of Amsterdam in 1896 [2]. In this paper he points out that his work was stimulated by the experiments already done before by FARADAY. In 1845 Faraday discovered the influence of a magnetic field on the plane of polarisation of linearly polarised light[3]. At that time already FARADAY was convinced of the fact that light and magnetism were closely related. Accordingly, Maxwell describes[4] how Faraday devoted his last experiments to the study of the influence of a magnetic field on the light emitted by a light source, placed in the magnetic field. However he did not come to a result, because of the imperfection of his experimental mounting and the smallness of the effect. After him, other research workers tried to repeat his experiment, but they failed too. ZEEMAN was the first who came to a definite result[2]. Just as FARADAY he put a bunsen flame with sodium chloride between the poles of an electromagnet, which gave a field strength of 10000 oersted. It was a good idea of ZEEMAN that he did not put down the negative results of FARADAY and others to the lacking of the effect of the magnetic field, but to the smallness of the effect. So he used a ROWLAND grating with a radius of 10 ft and 14438 lines to an inch as a spectral apparatus, which gave a much higher resolving power than those used by FARADAY and others. He observed the sodium *D*-lines with an eyepiece and with the aid of this instrument he observed the broadening of the lines, when putting on the magnetic field. When switching off the magnetic current the lines were again as sharp as before. The experiment could be repeated indefinitely, always with the same result. Very carefully ZEEMAN interpreted his results. He remarks:

"Possibly the observed phenomena will be regarded as not being remarkable at all. One may reason this way: widening of the lines of the spectrum of an incandescent vapour is caused by increasing the density of the radiating substance and by increasing the temperature. Now, under the influence of the magnet, the outline of the flame is undoubtedly changed (as is easily seen), hence the temperature and possibly also the density of the vapour is changed. Hence one might be inclined to account for the phenomenon in this manner."

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[1] In this article, the vector model has been used throughout. For the quantum mechanical treatment, cf. H. A. BETHE and E. E. SALPETER, Vol. XXXV of this Encyclopedia, pp. 291 to 314. See also P. KUSCH and V. W. HUGHES in Vol. XXXVII for the atomic beam method.

[2] P. ZEEMAN: Proc. Roy. Acad. Amst. **5**, 181, 242 (1896).

[3] M. FARADAY: Experimental Researches, 19th series.

[4] J. CL. MAXWELL: Collected Works **2**, 790.

W. Gordy et al., *Spektroskopie II / Spectroscopy II*

The years after 1896, however, proved that the phenomenon he had observed was indeed the influence of the magnetic field on the frequencies of the sodium D-lines. ZEEMAN himself proved this already when studying the influence of the magnetic field on the D-lines as absorption lines[1]. Also he investigated the influence of a magnetic field on the band spectrum of iodine[1]. Though this spectrum is very sensitive to changes in density and temperature, no influence was observed. So the broadening of the sodium D-lines, just as that of the red lithium line 6708 Å[1] was a real, new and very remarkable effect.

It proved indeed that there is a connection between light and magnetism, as was already suggested by FARADAY. Apart from the broadening of the lines, two details were observed by ZEEMAN[1]:

1. When observing at right angles to the magnetic field, the central part of the line was linearly polarised, parallel to the magnetic field, whereas the edges of the lines were linearly polarised at right angles to the magnetic field.

2. When observing the effect parallel to the magnetic field, only the edges were visible. These edges were circularly polarised.

Just before the discovery of the magnetic splitting of spectral lines, LORENTZ had published his "theory of electrons"[2]. From this theory, the observed magnetic influence on light vibrations could completely explained. Also the fact that the edges of the lines were circularly polarised, followed from LORENTZ' theory, whereas from the direction of polarisation of the vibrations, displaced to shorter and longer wavelength, compared with the wavelength of the original line, the sign of the electron could be determined as being negative.

Finally ZEEMAN could calculate from the width ot the splitting of the lines the value of e/m for the electron. ZEEMAN remarks[1]:

"The extremely remarkable conclusion of Prof. LORENTZ relating to the state of polarisation in the magnetically widened lines, I have found to be fully confirmed by experiment."

After these first experiments many other physicists investigated the magnetic splitting of spectral lines. We especially draw the attention of the reader to the work of PRESTON[3], RUNGE and PASCHEN[4], and LANDÉ[5]. The main result of these investigations was that most lines were not split into three, but into more components by the magnetic field. For this effect the theory of LORENTZ was not sufficient, and in spite of all efforts to extend the theory and to make it suitable for the anomalous Zeeman effect, a really sufficient explanation could not be given before the spin of the electron was introduced by UHLENBECK and GOUDSMIT[6] in 1925. In this case it was clear once more, that the "normal" effect (splitting of a spectral line by a magnetic field in three components with a mutual distance of one LORENTZ' unit) is an exception in atomic spectra.

Two very important rules were published during the first ten years after the discovery of the Zeeman effect, one by PRESTON[7] and one by RUNGE[8]. PRESTON'S rule was of very great importance to understand the relation between the magnetic splitting of a spectral line and its origin in the atom in question.

[1] See footnote 2, p. 296.

[2] H. A. LORENTZ: La théorie electromagnitique de MAXWELL. Leiden 1892. — Versuch einer Theorie der eletrischen und optischen Erscheinungen in bewegten Körpern. Leiden 1895.

[3] TH. PRESTON: Phil. Mag. **45**, 325 (1895). — Nature, Lond. **59**, 224 (1899).

[4] C. RUNGE, and F. PASCHEN: Phys. Z. **1**, 180 (1900); **8**, 232 (1907). — Astrophys. J. **15**, 235 (1902); **16**, 118 (1902).

[5] A. LANDÉ: Z. Physik **5**, 231 (1921); **15**, 189 (1923).

[6] G. E. UHLENBECK and S. GOUDSMIT: Naturwiss. **13**, 953 (1925). — Nature, Lond. **107**, 264 (1926).

[7] TH. PRESTON: Nature, Lond. **59**, 224 (1899). — Dublin Transact. **7**, 7 (1899).

[8] C. RUNGE: Phys. Z. **8**, 232 (1907).