ON THE INFLUENCE OF MAGNETISM ON THE NATURE OF THE LIGHT EMITTED BY A SUBSTANCE.[1]

By P. ZEEMAN.

1. SEVERAL years ago, in the course of my measurements concerning the Kerr phenomenon, it occurred to me whether the light of a flame if submitted to the action of magnetism would perhaps undergo any change. The train of reasoning by which I attempted to illustrate to myself the possibility of this is of minor importance at present;[2] at any rate I was induced thereby to try the experiment. With an extemporized apparatus the spectrum of a flame, colored with sodium, placed between the poles of a Ruhmkorff electro-magnet, was looked at. The result was negative. Probably I should not have tried this experiment again so soon had not my attention been drawn some two years ago to the following quotation from Maxwell's sketch of Faraday's life. Here (Maxwell, *Collected Works*, II, 790) we read: "Before we describe this result we may mention that in 1862 he made the relation between magnetism and light the subject of his very last experimental work. He endeavored, but in vain, to detect any change in the lines of the spectrum of a flame when the flame was acted on by a powerful magnet." If a Faraday[3] thought of the possibility of the above-mentioned relation, perhaps it might be yet worth while to try the experiment again with the excellent auxiliaries of spectroscopy of the present time, as I am not aware that it has been done by others.[4] I will take the liberty of stating briefly to the readers of the *Philosophical Magazine* the results I have obtained up till now.

2. The electro-magnet used was one made by Ruhmkorff and

[1] *Philosophical Magazine* [5], 43, March 1897, p. 226.

[2] *Cf.* §§ 15 and 16.

[3] See appendix for Faraday's own description of the experiment.

[4] See appendix.

of medium size. The magnetizing current furnished by accumulators was in most of the cases 27 amperes, and could be raised to 35 amperes. The light used was analyzed by a Rowland grating, with a radius of 10 feet and with 14,938 lines per inch. The first spectrum was used, and observed with a micrometer eyepiece with a vertical cross-wire. An accurately adjustable slit is placed near the source of light under the influence of magnetism.

3. Between the paraboloidal poles of an electro-magnet the middle part of the flame from a Bunsen burner was placed. A piece of asbestos impregnated with common salt was put in the flame in such a manner that the two D lines were seen as narrow and sharply defined lines on the dark ground. The distance between the poles was about 7^{mm}. If the current was put on, the two D lines were distinctly widened. If the current was cut off they returned to their original position. The appearing and disappearing of the widening was simultaneous with the putting on and off of the current. The experiment could be repeated an indefinite number of times.

4. The flame of the Bunsen was next interchanged with a flame of coal gas fed with oxygen. In the same manner as in § 3 asbestos soaked with common salt was introduced into the flame. It ascended vertically between the poles. If the current was put on again the D lines were widened, becoming perhaps three or four times their former width.

5. With the red lines of lithium, used as carbonate, wholly analogous phenomena were observed.

6. Possibly the observed phenomena (§§ 3, 4, 5) will be regarded as nothing of any consequence. One may reason in this manner: widening of the lines of the spectrum of an incandescent vapor is caused by increasing the density of the radiating substance and by increasing the temperature.[1] 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 vapor is changed. Hence one

[1] *Cf.* however, also Pringsheim (*Wied. Ann.*, **45**, 457, 1892).

might be inclined to account in this manner for the phenomenon.

7. Another experiment is not so easily explained. A tube of porcelain, glazed inside and outside, is placed horizontally between the poles with its axis perpendicular to the line joining the poles. The inner diameter of the tube is 18^{mm}, the outer one 22^{mm}. The length of the tube is 15^{cm}. Caps are screwed on at each end of the tube;[1] these caps are closed by plates of parallel glass at one end and are surrounded by little water-jackets. In this manner, by means of a current of water, the copper caps and the glass plates may be kept sufficiently cool while the porcelain tube is rendered incandescent. In the neighborhood of the glass plates, side tubes provided with taps are fastened to the copper caps. With a large Bunsen burner the tube could be made incandescent over a length of 8^{cm}. The light of an electric lamp, placed sideways at about two meters from the electro-magnet, in order to avoid disturbing action on the arc, was made to pass through the tube by means of a metallic mirror. The spectrum of the arc was formed by means of the grating. With the eyepiece the D lines are focused. This may be done very accurately, as in the center of the bright D lines the narrow reversed lines are often seen. Now a piece of sodium was introduced into the tube. The Bunsen flame is ignited and the temperature begins to rise. A colored vapor soon begins to fill the tube, being at first of a violet, then of a blue and green color, and at last quite invisible to the naked eye. The absorption soon diminishes as the temperature is increased. The absorption is especially great in the neighborhood of the D lines. At last the two dark D lines are visible. At this moment the poles of the electro-magnet are pushed close to the tube, their distance now being about 24^{mm}. The absorption lines now are rather sharp over the greater part of their length. At the top they are thicker, where the spectrum of the lower, denser vapors was observed. Immediately after

[1] PRINGSHEIM uses similar tubes in his investigation concerning the radiation of gases, *l. c.*, p. 430.

the closing of the current the lines *widen* and are seemingly *blacker;* if the current is cut off they immediately recover their initial sharpness. The experiment could be repeated several times, till all the sodium had disappeared. The disappearance of the sodium is chiefly to be attributed to the chemical action between it and the glazing of the tube. For further experiments, therefore, unglazed tubes were used.

8. One may perhaps try to account for the last experiment (§ 7) in this direction: it is true that the tube used was not of the same temperature at the top and at the bottom; further, it appears from the shape of the D lines (§ 7) that the density of the vapor of sodium is different at different heights. Hence certainly convection currents caused by difference of temperature between the top and bottom were present. Under certain plausible suppositions one may calculate that, by the putting on of the electro-magnet, differences of pressure are originated in the tube of the same order of magnitude as those caused by the difference of temperature. Hence the magnetization will push *e. g.*, the denser layer at the bottom in the direction of the axis of the tube. The lines become widened. For their width at a given height is chiefly determined by the number of incandescent particles at that height in the direction of the axis of the tube. Although this explanation still leaves some difficulties, certainly something may be said for it.

9. The explanation of the widening of the lines attempted in § 8 is no longer applicable to the following variation of the experiment, in which an unglazed tube is used. The inner diameter of the tube, about 1^{mm} thick, was 10^{mm}. The poles of the electro-magnet could be moved till the distance was 14^{mm}. The tube was now heated by means of the blowpipe instead of with the Bunsen burner, and became in the middle part white hot. The blowpipe and the smaller diameter of the tube make it easier to bring the upper and lower parts to the same temperature. This is now higher than before (§ 7) and the sodium lines remain visible continuously.[1] One can now wait till the

[1] PRINGSHEIM, *l. c.*, p. 456.

density of the sodium vapor is the same at various heights. By rotating the tube continuously round its axis I have still further promoted this. The absorption lines now are equally broad from the top to the bottom. When the electro-magnet was put on, the absorption lines immediately widened along their whole length. Now the explanation in the manner of § 8 fails.

10. I should like to have studied the influence of magnetism on the spectrum of a solid. Oxide of erbium has, as was found by Bunsen or Bahr, the remarkable property of giving by incandescence a spectrum with bright lines. With the dispersion used, however, the edges of these lines were too indistinct to serve my purpose.

11. The different experiments from §§ 3 to 9 make it more and more probable that the absorption—and hence also the emission lines of an incandescent vapor are widened by the action of magnetism. Now if this is really the case, then by the action of magnetism on the free vibrations of the atoms, which are the cause of the line spectrum, other vibrations of changed period must be superposed. That it is really inevitable to admit this specific action of magnetism is proved, I think, by the rest of the present paper.

12. From the representation I had formed to myself of the nature of the forces acting in the magnetic field on the atoms, it seemed to me to follow that with a band spectrum and with external magnetic forces the phenomenon I had found with a line spectrum would not occur.

It is, however, very probable that the difference between a band and a line spectrum is not of a quantitative but of a qualitative kind.[1] In the case of a band spectrum the molecules are complicated; in the case of a line spectrum the widely separated molecules contain but a few atoms. Further investigation has shown that the representation I had formed of the cause of the widening in the case of a line spectrum in the main was really true.

13. A glass tube, closed at both ends by glass plates with

[1] KAYSER in Winklemann's *Handbuch*, II, 1, p. 421.

parallel faces and containing a piece of iodine, was placed between the poles of the Ruhmkorff electro-magnet in the same manner as the tube of porcelain in § 7. A small flame under the tube vaporized the iodine, the violet vapor filling the tube.

By means of electric light the absorption spectrum could be examined. As the temperature is low this is the band spectrum. With the high dispersion used, there are seen in the bands a very great number of fine dark lines. If the current around the magnet is closed, *no* change in the dark lines is observed, which is contrary to the result of the experiments with sodium vapor.

The absence of the phenomenon in this case supports the explanation, that even in the first experiment, with sodium vapor (§ 7) the convection currents had no influence. For in the case now considered, the convection currents originated by magnetism, which I believed to be possible in that case, apparently are insufficient to cause a change of the spectrum; yet, though I could not see it in the appearance of the absorption lines (*cf.* § 7), the band spectrum is, like the line spectrum, very sensible to changes of density and of temperature.

14. Although the means at my disposal did not enable me to execute more than a preliminary approximate measurement, I yet thought it of importance to determine approximately the value of the magnetic change of the period.

The widening of the sodium lines to both sides amounted to about $\frac{1}{40}$ of the distance between the said lines, the intensity of the magnetic field being about 10^4 C. G. S. units. Hence follows a positive and negative magnetic change of $\frac{1}{40000}$ of the period.

15. The train of reasoning mentioned in (1), by which I was induced to search after an influence of magnetism, was at first the following: If the hypothesis is true that in a magnetic field a rotary motion of the ether is going on, the axis of rotation being in the direction of the magnetic forces (Kelvin and Maxwell), and if the radiation of light may be imagined as caused by the motion of the atoms, relative to the center of mass of the molecule, revolving in all kinds of orbits, suppose for simplicity, circles; then the period, or what comes to the same, the

time of describing the circumference of these circles, will be determined by the forces acting between the atoms, and then deviations of the period to both sides will occur through the influence of the perturbing forces between ether and atoms. The sign of the deviation, of course, will be determined by the direction of motion, as seen from along the lines of force. The deviation will be the greater the nearer the plane of the circle approximates to a position perpendicular to the lines of force.

16. Somewhat later I elucidated the subject by representing to myself the influence exercised on the period of a vibrating system if this is linked together with another in rapid rotary motion. Lord Kelvin (now forty years ago)[1] gave the solution of the following problem: Let the two ends of a cord of any length be attached to two points at the ends of a horizontal arm made to rotate round a vertical axis through its middle point at a constant angular velocity, and let a second cord bearing a material point be attached to the middle of the first cord. The motion now is investigated in the case when the point is infinitely little disturbed from its position of equilibrium. With great angular velocity the solution becomes rather simple. Circular vibrations of the point in contrary directions have slightly different periods. If for the double pendulum we substitute a luminiferous atom, and for the rotating arm the rotational motion about the magnetic lines of force, the relation of the mechanical problem to our case will be clear.

It need not be proved that the above-mentioned considerations are at most of any value as indications of somewhat analogous cases. I communicate them, however, because they were the first motive of my experiments.

17. A real explanation of the magnetic change of the period seemed to me to follow from Professor Lorentz's theory.[2]

In this theory it is assumed that in all bodies small electri-

[1] *Proc. R. Soc.*, 1856.

[2] LORENTZ, *La Théorie électromagnétique de Maxwell.* Leyde, 1892; and *Versuch einer Theorie der electrischen und optischen Erscheinungen in bewegten Körpern.* Leyden, 1895.

cally charged particles with a definite mass are present, that all electric phenomena are dependent upon the configuration and motion of these "ions," and that light vibrations are vibrations of these ions. Then the charge, configuration, and motion of the ions completely determine the state of the ether. The said ion, moving in a magnetic field, experiences mechanical forces of the kind above mentioned, and these must explain the variation of the period. Professor Lorentz, to whom I communicated these considerations, at once kindly informed me of the manner in which, according to his theory, the motion of an ion in a magnetic field is to be calculated, and pointed out to me that, if the explanation following from his theory be true, the edges of the lines of the spectrum ought to be circularly polarized. The amount of widening might then be used to determine the ratio between charge and mass, to be attributed in this theory to a particle giving out the vibrations of light.

The above-mentioned extremely remarkable conclusion of Professor Lorentz relating to the state of polarization in the magnetically widened lines I have found to be fully confirmed by experiment (§ 20).

18. We shall now proceed to establish the equations of motion of a vibrating ion, when it is moving in the plane of (x, y) in a uniform magnetic field in which the magnetic force is everywhere parallel to the axis of z and equal to H. The axes are chosen so that if x is drawn to the east, y to the north, z is upwards. Let e be the charge (in electro-magnetic measure) of the positively charged ion, m its mass. The equations of relative motion then are:

$$\left.\begin{aligned} m\frac{d^2x}{dt^2} &= -k^2x + eH\frac{dy}{dt} \\ m\frac{d^2y}{dt^2} &= -k^2y - eH\frac{dx}{dt} \end{aligned}\right\} \qquad (1)^{[1]}$$

The first term of the second member expresses the elastic force drawing back the ion to its position of equilibrium; the

[1] These equations are like those of the Foucault pendulum, and of course lead to similar results.

second term gives the mechanical force due to the magnetic field. They are satisfied by

$$\left.\begin{aligned} x &= a\, e^{st} \\ y &= \beta\, e^{st} \end{aligned}\right\} \qquad (2)$$

provided that

$$\left.\begin{aligned} m\, s^2 a &= -\, k^2 a + e\, H s\, \beta \\ m\, s^2 \beta &= -\, k^2 \beta - e\, H s\, a \end{aligned}\right\} \qquad (3)$$

where m, k, e are to be regarded as known quantities.

For us the period T is particularly interesting. If $H = 0$, it follows from (3) that

$$S = i\frac{k}{\sqrt{m}} = i\,\frac{2\pi}{T}$$

or

$$T = \frac{2\pi\sqrt{m}}{k}. \qquad (4)$$

If H is not 0, it follows from (3) approximately that

$$S = i\frac{k}{\sqrt{m}}\left(1 \mp \frac{e\,H}{2k\sqrt{m}}\right).$$

Putting T' for the period in this case, we have

$$T' = \frac{2\pi\sqrt{m}}{k}\left(1 \pm \frac{e\,H}{2k\sqrt{m}}\right). \qquad (5)$$

Hence the ratio of the change of period to the original period becomes

$$\frac{e\,H}{2k\sqrt{m}} = \frac{e}{m} \cdot \frac{H\,T}{4\pi}. \qquad (6)$$

A particular solution of (1) is that representing the motion of the ions in circles. If revolving in the positive direction (viz., in the direction of the hands of a watch for an observer standing at the side towards which the lines of force are running) the period is somewhat less than if revolving in the negative direction. The period in the first case is determined by the value of (5) with the minus sign, in the second with the plus.

The general solution of (1) shows that the ions describe, besides circles, also slowly rotating elliptical orbits. In the general case, the original motion of the ion having an arbitrary position in space, it is perfectly clear that the projection of the motion in the plane of (x, y) has the same character. The motion resolved in the direction of the axis of z is a simple harmonic motion, independent of and not disturbing the one in the plane of (x, y), and hence one not influenced by the magnetic forces. Of course, the consideration of the motion of an ion now given is only to be regarded as the very first sketch of the theory of luminiferous motions.

19. Imagine an observer looking at a flame placed in a magnetic field in a direction such that the lines of force run towards or from him.

Let us suppose that the said observer could see the very ions of § 18 as they are revolving; then the following will be remarked: There are some ions moving in circles and hence emitting circularly polarized light; if the motion is round in the positive direction the period will, for instance, be longer than with no magnetic field; if in the negative direction, shorter. There will also be ions seemingly stationary and really moving parallel to the lines of force with unaltered period. In the third place there are ions which seem to move in rotating elliptical orbits.

If one desires to know the state of the ether originated by the moving ions one may use the following rule, deduced by Professor Lorentz from the general theory: Let us suppose that in a molecule an ion P, of which the position of equilibrium is P_0, has two or more motions *at the same time*, viz., let the vector P_0P always be obtained by adding the vectors P_0P which should occur in each of the component motions at that moment; then the state in the ether at a very great distance in comparison with P_0P will be obtained by superposing the states which would occur in the two cases taken separately.

Hence it follows in the first place that a circular motion of an ion gives circularly polarized light to points on the axis of the circle.

Further, one may choose instead of the above-considered elliptical orbits a resolution more suited to our purpose. One may resolve the motion of the ion, existing before the putting on of the magnetic force, into a rectilinear harmonic motion parallel to the axis of z and two circular (right-handed and left-handed) motions in the plane of (x, y).

The first remains unchanged under the influence of the magnetic force, the periods of the last are changed.

By the action of the grating the vibrations originated by the motion of the ions are sorted according to the period, and hence the complete motion is broken up into three groups. The line will be a triplet. At any rate one may expect that the line of the spectrum will be wider than in the absence of the magnetic field, and that the edges will give out circularly-polarized light.[1]

20. A confirmation of the last conclusion may be certainly taken as a confirmation of the guiding idea of Professor Lorentz's theory. To decide this point by experiment, the electro-magnet of § 2, but now with pierced poles, was placed so that the axes of the holes were in the same straight line with the center of the grating. The sodium lines were observed with an eyepiece with a vertical cross-wire. Between the grating and the eyepiece were placed the quarter-undulation plate and Nicol which I formerly used in my investigation of the light normally reflected from a polarly magnetized iron mirror.[2]

The plate and the Nicol were placed relatively in such a manner that right-handed circularly polarized light was quenched. Now according to the preceding the widened line must at one edge be right-handed circularly polarized, at the other edge left-handed. By a rotation of the analyzer over 90° the light that was first extinguished will be transmitted, and *vice versa*. Or, if first the right edge of the line is visible in the apparatus, a reversal of the direction of the current makes the left edge visible. The cross-wire of the eyepiece was set in the bright line. At the reversal of the current the visible line moved! This experiment could be repeated any number of times.

[1] I saw afterward that Stoney, *Trans. R. Soc., Dublin*, IV, endeavors to explain the existence of doublets and triplets in a spectrum by the rotation of the elliptical orbits of the "electrons" under the influence of perturbing forces.

[2] ZEEMAN, *Communications of the Leyden Laboratory*, No. 15.

21. A small variation of the preceding experiment is the following: With unchanged position of the quarter-wave plate the analyzer is turned round. The widened line is then, during one revolution, twice wide and twice fine.

22. The electro-magnet was turned 90° in a horizontal plane from the position of § 20, the lines of force now being perpendicular to the line joining the slit with the grating. The edges of the widened line now appeared to be plane polarized, at least in so far as the present apparatus permitted to see, the plane of polarization being perpendicular to the line of the spectrum. This phenomenon is at once evident from the consideration § 19. The circular orbits of the ions being perpendicular to the lines of force are now seen on their edges.

23. The experiments 20 to 22 may be regarded as a proof that the light vibrations are caused by the motion of ions, as introduced by Professor Lorentz in his theory of electricity. From the measured widening (§ 14) by means of relation (6), the ratio $e : m$ may now be deduced. It thus appears that $e : m$ is of the order of magnitude 10^7 electro-magnetic C. G. S. units. Of course this result from theory is only to be considered as a first approximation.

24. It may be deduced from the experiment of § 20 whether the positive or the negative ion revolves.

If the lines of force were running towards the gratings, the right-handed circularly polarized rays appeared to have the smaller period. Hence in connection with § 18 it follows that the positive ions revolve, or at least describe the greater orbit.

25. Now that the magnetization of the lines of a spectrum can be interpreted in the light of the theory of Professor Lorentz, the further consideration of it becomes specially attractive. A series of further questions already present themselves. It seems very promising to investigate the motion of the ions for various substances, under varying circumstances of temperature and pressure, with varying intensities of the magnetization. Further inquiry must also decide as to how far the strong mag-

netic forces existing according to some at the surface of the Sun may change its spectrum.

The experiments described have been made in the physical laboratory at Leyden, to the Director of which, Professor Kammerlingh Onnes, I am under great obligations for continuous interest in the present subject.

AMSTERDAM, January 1897.

APPENDIX.

Since the publication of my original paper in the *Proceedings* of the Academy at Amsterdam, and while the present paper was in the press, I have become acquainted with two attempts, till now unknown to me, in the same direction, and also with the original account of Faraday's experiment referred to in § 1. The last is to be found in Faraday's *Life* by Dr. Bence Jones, II, 449 (1870) and as it is extremely remarkable I will reprint it here:

> 1862 was the last year of experimental research. Steinheil's apparatus for producing the spectrum of different substances gave a new method by which the action of magnetic poles upon light could be tried. In January he made himself familiar with the apparatus, and then he tried the action of the great magnet on the spectrum of chloride of sodium, chloride of barium, chloride of strontium, and chloride of lithium.

On March 12 he writes:

> Apparatus as on last day (January 28) but only ten pairs of voltaic battery for the electro-magnet.
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> The colorless gas flame ascended between the poles of the magnet, and the salts of sodium, lithium, etc., were used to give color. A Nicol's polarizer was placed just before the intense magnetic field, and an analyzer at the other extreme of the apparatus. Then the electro-magnet was made, and unmade, but not the slightest trace of effect on or change in the lines in the spectrum was observed in any position of polarizer or analyzer.
>
> Two other pierced poles were adjusted at the magnet, the colored flame established between them, and only that ray taken up by the optic apparatus which came to it along the axis of the poles, *i. e.*, in the magnetic axis, or line of magnetic force. Then the electro-magnet was excited and rendered

neutral, but not the slightest effect on the polarized or unpolarized ray was observed.

This was the last experimental research that Faraday made.

In 1875 we have a paper by Professor Tait, who has kindly sent me a copy, "On a Possible Influence of Magnetism on the Absorption of Light, and some correlated subjects" (*Proc. R. Soc. Edinburgh*, session 1875–6, p. 118). Professor Tait remarks that a paper by Professor Forbes read at the Society, and some remarks upon it by Maxwell, have recalled to him an experiment tried by him several times, but which hitherto has led to no result. Then the paper proceeds:

The idea is briefly this: The explanation of Faraday's rotation of the plane of polarization of light by a transparent diamagnetic requires, as shown by Thomson, molecular rotation of the luminiferous medium. The plane-polarized ray is broken up, while in the medium, into its circularly polarized components, one of which rotates with the ether so as to have its period accelerated, the other against it in a retarded period. Now, suppose the medium to absorb one definite wave-length only, then—if the absorption is not interfered with by the magnetic action—the portion absorbed in one ray will be of a shorter, in the other of a longer, period than if there had been no magnetic force; and thus, what was originally a single dark absorption line might become a double line, the components being less dark than the single one.

Hence here the idea is perfectly clearly expressed of the experiment, tried in vain; an idea closely akin to that of § 15 above, both being in fact founded on Kelvin's theory of the molecular rotation of the luminiferous medium, though not directly applicable to the experiment of § 9, in which case the lines of magnetic force are perpendicular to the axis of the tube.

In the second place I have to mention two papers by the late M. Fievez, to which attention has been drawn by M. van Aubel, in a letter to Professor Onnes and intended for communication to the Academy of Sciences, Amsterdam. Professor Onnes read the letter at the January meeting, and made at the same time some explanatory remarks of which in the following I make free and extensive use. The papers referred to are: M. Fievez, "De l'Influence du Magnétisme sur les Caractères des Raies spectrales" (*Bulletin de l'Acad. des Sciences de Belgique*, 3e série, tome **9**, 381, 1885); and Fievez, "Essai sur l'Origine des Raies de Fraunhofer, en rapport avec la Constitution du Soleil" (*l. c.*, 3e série, tome **12**, 30, 1886). Here experiments are described as in §§ 4 and 13 of the present paper. Nothing, however, is observed about the widening of the absorption lines, nor about the polarization of the emitted light. The results obtained by M. Fievez merit careful attention and consideration. He has observed with a flame in a magnetic field not only widening but reversal and double reversal of the lines of the spectrum, the lines at the same time becoming more brilliant. Unfortunately quantitative details are not given. The facts observed in some cases by Fievez are qualitatively not in accordance with my observations or what is to be deduced from my results. Hence even in the cases where the results are qualitatively in accordance, the question remains whether Fievez has observed *the same phenomenon.* The field used by Fievez seems to have been more intense than the one I had at my disposal. Is it possible perhaps to account in this manner for the "double renversement (c'est-à-dire l'apparition d'une raie brillante au milieu de la raie noire élargie)?" I think the answer must be in the negative. For, arguing from § 19, a line must widen, or else, the field being very intense, become a triplet. We cannot but understand from Fievez's description of the experiment that the light was emitted perpendicular to the lines of force. Now the double reversed line of Fievez is not the triplet to be expected from theory, for it is expressly stated by Fievez that the line experimented upon is not the simple line of the spectrum, but one previously widened and reversed (by some agency independent of magnetism). By the action of magnetism a brilliant line in the center of the black line appears. Hence perhaps one may interpret the case of double reversal as a direct action of magnetism, but then only as a doubling of the absorption line and not as a division of the original lines into three parts. As the application of Lorentz's theory given in § 18 is confessedly only a very first sketch, further theoretical and experimental evidence is wanted before we are to able to decide whether in the experiment of Fievez a specific action of magnetism on light or perturbing circumstances have been prevalent. Indeed one may make the same objection to M. Fievez's experiment as I myself have made to my own analogous experiment in § 6.

The whole of the phenomena observed by Fievez can readily be attributed to a change of temperature by the well-known actions of the field upon the flame (change in its direction or outline, magnetic convection, etc.); and the last sentence of his paper states that "les phénomènes qui se manifestent sous l'action dù magétisme sont identiquement les mêmes que ceux produits par une élévation de température." The negative result obtained by Fievez with absorption spectra would without further consideration (as in § 12) point in the same direction. The inference to be drawn from Fievez's experiments alone would rather be, I think, that the temperature of the flame is changed in his experiments than that a specific action of magnetism on the emission and absorption of light exists. By experiments already in progress I hope to settle the dubious points.

Summarizing we may say: Had the experiments of Fievez come to my knowledge they would have been a motive for me to further investigation, Fievez not having prosecuted his inquiry up to a decisive result. At least at present it remains even doubtful whether the phenomenon observed by Fievez with a magnetized flame is really to be attributed to *the specific action of the magnetic field on the period of the vibrations of light*, which I have found and undoubtedly proved by the experimental confirmation of Lorentz's predictions.

AMSTERDAM, February 1897.