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Readily cleavable parallel to *a* and *c*.

The optical axial plane is {010}. Very faint, inclined dispersion: $\varrho > v$; double refraction negative. On *c* one optical axis emerges at a small angle with the normal.

Topic axial relation : $\chi : \psi : \omega = 7.1503 : 5.3109 : 8.3556$.

Physics. — *"New observations concerning asymmetrical triplets"*. By Prof. P. Zeeman.

Asymmetry investigated by means of Fabry *and* Perot's *method.*

1. In the second part of the paper "Magnetic resolution of spectral lines and magnetic force" I [1]) investigated, by means of a method, which I called that of the non-uniform field, the asymmetry predicted from theory by Voigt [2]) in the case the original line is resolved into a triplet.

A glance at Plate II of my paper immediately shows that observation seems to confirm strikingly Voigt's theoretical result that the component of the triplet towards the red is at a somewhat smaller distance from the middle line than the one towards the violet.

In order to exclude however all doubt as to the reality of this experimental result I thought it desirable to continue my work in a direction independent of Rowland's method.

I have shown [3]) that the resolution of spectral lines by magnetic forces can be investigated by means of the semi-silvered parallel plates of Fabry and Perot.

Using the special form of instrument in which the distance of the silvered surfaces is constant, the étalon, we may yet choose between two ways of comparison of the wavelengths of the centre line and of the components, originating by the action of the magnetic field.

Firstly we may measure, the intensity of the field being arbitrarily chosen, the diameters of the interference rings. By combining only measurements of rings originating from the same ring the calculation becomes very simple; for as shown in my last paper even a knowledge of the ordinal number of the rings then is unnecessary.

2. We may use however also the method of coincidences, regulating

1) Zeeman. These Proceedings 30 November 1907.

2) Voigt. Ann. d. Phys. 1. p. 376. 1900, see also the last paper by Voigt. Physik. Zeitschrift 9. p. 122. 1908.

3) Zeeman. These Proceedings 28 December 1907.

the magnetic force in such a manner that a ring which expands by increasing magnetic intensity coincides with a contracting ring.

The rings corresponding to components towards the red then coincide with rings due to components towards the violet side of the spectrum. The intensity of the coïnciding rings is then only slightly inferior to that of the unmodified one, a circumstance favourable to the accuracy of the measurements.

Let λ_0 be the wavelength of the middle component of the triplet, λ_r that of the component towards the red, λ_v that of the component towards the violet then we may perform the calculation, ignoring the value of the ordinal numbers of the rings, by the following procedure.

Let P_0, P_r, P_v be the ordinal numbers of rings with angular diameters x_0, x_r, x_v then we have in general:

$$\lambda_r = \lambda_0 \frac{P_0}{P_r}\left(1 + \frac{x_0^2}{8} - \frac{x_r^2}{8}\right)$$

$$\lambda_v = \lambda_0 \frac{P_0}{P_v}\left(1 + \frac{x_0^2}{8} - \frac{x_v^2}{8}\right).$$

If the magnetic force is increasing a contracting ring corresponds to λ_r, an expanding one to λ_v. As I remarked on a former occasion we can put in the case of radiation in a magnetic field $P_0 = P_r$ or $P_0 = P_v$ if only rings λ_r and λ_v are considered, which originate from the same ring λ_0.

Hence in applying the method of coïncidences the simplest procedure is to consider the ring formed by superposition of two other rings, once as a ring λ_v derived from a smaller ring λ_0, and again as a ring λ_r derived from a larger one λ_0.

By measuring three rings viz. the one due to the coïncidence of the rings λ_r and λ_v (diameter $x_c = x_r = x_v$), further the larger ring with diameter x_0 and finally the smaller one with diameter x'_0, the result may be found by the simple formulae:

$$\lambda_r = \lambda_0\left(1 + \frac{x_0^2}{8} - \frac{x_c^2}{8}\right)$$

and

$$\lambda_v = \lambda_0\left(1 + \frac{x_0'^2}{8} - \frac{x_c^2}{8}\right).$$

3. Using an étalon, with an interval of nearly 5 mm. between the plates, I have made by means of the method of coïncidences some measurements of the magnetic resolution of the yellow mercury lines 5791 and 5770.

The system of rings was formed in the focal plane of a small achromatic lens of 18 m.m. aperture and of 12 cm. focus. This focal plane coincided exactly with the plane of the slit of a one-prism spectroscope. The width of the slit was so far reduced that the rings of the two yellow mercury lines could be observed separately. Reproductions of negatives (somewhat enlarged) are given on the Plate, the first with field off; the second showing the first coincidence (superposition of rings λ_r and λ_v); the third gives the second coincidence, the rings λ_r and λ_v being now in coincidence with λ_0. The plate refers to coincidences for 5770; negatives showing the coincidences for 5791 however scarcely present any difference with those now given.

By measurements on half a dozen of negatives concerning the first coincidence, the result was obtained that a separation equal to 0.166 Ångström units for line 5770, corresponds to a separation of line 5791 towards the red of 0.160 A. U., towards the violet of 0.177 A. U.

Now a separation of 0.166 A. U. corresponds, according to the data given in § 6 of my paper cited in § 1 above sub [1]), to a strength of field of 9130 Gauss.

Considering as the object of the investigation the determination of the numerical value of the asymmetry we infer from the given data that it is equal to 0.017 A. U. A discussion of the systematic errors of observations to be feared, shows that the values 0.015 A. U. and 0.019 A. U. are yet possible, that however the values 0.011 A. U. and 0.023 A. U. are very improbable.

Some measurements made by means of the method of diameters tend to show that the accuracy of results obtained by that method is somewhat superior to that now found.

The accuracy obtained is however in excellent accordance which what might be expected from data given by FABRY and PEROT [1])
if applied to our case

By our experiments with the method of silvered plates two points are clearly shown viz. first that the positive results concerning asymmetrical resolution in strong fields obtained on a former occasion by ROWLAND'S method have a real significance, secondly that also in lower fields the asymmetry remains and has an amount such as to be expected, if strength of field and asymmetry are nearly proportional.

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[1]) FABRY et PEROT. Ann. de Chim. et de Phys. Janvier 1902.

Determination of the total charge of the electrons.

4. Taking for granted the existence and also the nature of the asymmetrical resolution as being in accordance with VOIGT's theory, it certainly is extremely interesting to interprete the result in the language of electronic theory.

LORENTZ [1]) has deduced VOIGT's equations from the theory of electrons or more accurately expressed he gives a system of equations which come to the same thing as those of VOIGT.

Let H be the intensity of the magnetic field, λ the wavelength, $\delta\lambda_1$ and $\delta\lambda_2$ the differences of wavelengths between the middle component and those towards violet and red, V the velocity of light in the aether, and $\frac{e}{m}$ the well-known ratio of charge and mass of the electron, then according to LORENTZ:

$$\frac{e}{m} = \frac{4\pi V}{H\lambda^2} \sqrt{\delta\lambda_1 \, . \, \delta\lambda_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For $\delta\lambda_1 = \delta\lambda_2$ this formula changes into the equation, which first enabled us to determine $\frac{e}{m}$. This ratio is found in electromagnetic units.

If N denote the number of molecules per unit volume, one electron vibrating in each molecule, we have also according to LORENTZ

$$Ne = \frac{H}{2\lambda V} \frac{\delta\lambda_1 - \delta\lambda_2}{\sqrt{\delta\lambda_1 \, . \, \delta\lambda_2}} . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

These formulae were already communicated by GEHRCKE and VON BAEYER [2]).

My own observations concerning asymmetry (§ 5 of my paper cited [3]) and § 3 above) seem at first sight to be in contradiction with this formula. One of my results being that the asymmetry varies with strength of field, according to (2) Ne must vary also, because H and $\sqrt{\delta\lambda_1 \, . \, \delta\lambda_2}$ change in nearly the same ratio. Now an increase of Ne, or of the number of radiating particles per unit volume, must manifest itself in the radiating power of the vacuum tube. An inspection of Plate II (paper cited sub [3])) shows that in my experiments the intensity of the light of the components really has been a maximum in the strongest part of the field. We must therefore conclude that the circumstances of the luminous mercury vapour in the Geissler tube were slightly different in the various parts of the non-uniform magnetic field.

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[1]) LORENTZ. Rapports présentés au congrès international de physique 1900.

[2]) GEHRCKE u. v. BAEYER. Verhandl. deutsch. physik. Gesellsch. 7. p. 401. 1906.

[3]) ZEEMAN. These Proceedings 30 November 1907.

It therefore seems probable to accept with Prof. VOIGT[1]) that the change of value of the assymmetry is due to differences in the circumstances of the radiating vapour.

5. The following table embodies the result of the calculations according to (1) and (2) of my observations concerning line 5791.

MERCURY LINE 5791.

$\frac{e}{m}$	*Ne*	Mean resolution 5770	*H*
1.92×10^{7}	8.10×10^{-4}	0.532 A. E.	29220
1.92	6.24	0.440 „	24140
1.90	5.97	0.399 „	21910
1.87	5.03	0.328 „	18020
1.87	4.33	0.270 „	14800
(2.07	4.58	0.166 „	9130)

The last line in this table refers to the observations recorded in § 1 of this paper.

Dividing the numbers of the second column by those of the first one we infer that the vibrating mass (probably wholly electromagnetic) only amounts from $4{\cdot}10^{-11}$ to 2.10^{-11} gram per cm³.

Accepting J. J. THOMSON's value of e viz. $1{,}1.10^{-20}$ electromagnetic units, we may find the number N. The number of electrons per unit volume causing the radiation of the mercury line 5791 in a vacuum tube, appears then in the circumstances of our experiments and according to the magnetic force to lay between 8.10^{16} and 4.10^{16} per cm³.

In these experiments the temperature of the vacuum tube may be taken as somewhere between 100° and 120°. According to HERTZ the pressures of mercury vapour corresponding to these temperatures are 0.29 resp. 0.78 m.m. From these facts in connection with other well known data we may conclude that the number of electrons participating in the emission of line 5791 is of the same order of magnitude as the number of atoms present.

There seems to be no obstacle in accepting this result and the hypothesis that all atoms participate simultaneously in the emission of light might even seem the most natural. It is however of some

[1]) VOIGT. Physik. Zeitschr. 9. S. 120. 1908.

interest to compare with this result some consequences issuing from work done in the Amsterdam laboratory by HALLO on the magnetic rotation of the plane of polarisation in sodium vapour [1]), and by GEEST on magnetic double refraction in the same substance [2]), and from one of the results of JEAN BECQUEREL [3]) in his remarkable experiments concerning the behaviour of tysonite and other crystals at low temperature and in a magnetic field.

These physicists come to the conclusion that in the substances they have experimented on, only a small part of the atoms are participating simultaneously in the emission or absorption phenomena.

Of course there is not the least improbability in accepting that in a Geissler tube the circumstances are quite different, and to admit that in a vacuum tube the number of atoms vibrating at a given instant is very large.

Asymmetries of Wolframium and Molybdenum lines. Observations of Mr. JACK.

6. Not only the lines of mercury and iron, which I investigated, but also those of other substances give in the magnetic field asymmetrical triplets. Some examples of very pronounced asymmetries, have been met with by Mr. JACK in the physical laboratory at Göttingen, and I am indebted to the kindness of Prof. VOIGT in being able to communicate these here. In the annexed table the wavelengths are given in ÅNGSTROM units, the separations however in m.m. as measured on the plates. For a knowledge of the relative asymmetry this is sufficient.

With some lines the asymmetry is reversed, the component towards the red being at a larger distance. According to the remarks of Mr. JACK it is not excluded however that in these cases the structure of the lines is not quite simple.

The intensities given can only have a relative value according to the results of my paper in these Proceedings of October 1907.

Observation parallel to the lines of force.

7. In a direction parallel to the magnetic force the two components of the doublet must be placed, according to the elementary theory, symmetrically relatively to the unmodified line. It seemed rather superfluous to test this point. However at the very outset

1) HALLO. Thesis, Amsterdam 1902. Arch. Néerl. (2) T. 10 p. 148. 1905.

2) GEEST. Thesis, Amsterdam 1904 Arch. Néerl. (2). T. 10, p. 291, 1905.

3) See especially JEAN BECQUEREL. Influence des variations de Température sur la dispersion. Le Radium. 1907.

Substance	Wave-length (λ)	Separation in mm. [— tow. violet / + „ red]	Intensity	Substance	Wave-length (λ)	Separation in mm [— tow violet / + „ red]	Intensity
Wolframium	2488.89	— .1474 0 + .1155	4 3 4	Wolframium	2856.20	— .1559 0 + .1375	3 1 3
	2522.14	— .1458 0 + 1172	3 2 3		3049.80	— .2892 0 + .2519	6 2 6
	2555.23	— .1524 0 + .1140	3 2 3		3311.53	— .1590 0 + .1814	8 10 8
	2580.63	— .1281 0 + .1012	3 2 3		3361.25	— .1239 0 + .1394	3 4 3
	2606.50	— .1487 0 + .1553	3 2 3		*3373.88	— .0780 0 + .0923	6 6 4
	2633.24	— .1353 0 + .1010	3 1 3	Shade on violet side of violet component, but no other line to give component.	*3413.09	— .0844 0 + .1080	6 6 6
	2697.81	— .1695 0 + .1498	5 3 5		*3429.79	— .0687 0 + .0837	6 6 3
	2774.12	— .1769 0 + .1332	4 2 4		3448.96	— 0770 0 + .0879	3 3 1
	2774.60	— .1530 0 + .1364	4 2 4		4022.27	— .2324 0 + .2032	3 8 3
	2792.85	— .1720 } 889 — .0831 } 0 + .0828 } 759 + .1586 }	2 2 2 2 2		4298.55	— 5339 — .1235 0 + .1242 + .4561	1 2 2 2 1
				Molybdene	2672.93	— .2224 0 + .1674	10 5 10

of my experiments in this direction I made an observation which seemed irreconcilable with a symmetrical position of the components of the doublet.

Looking at the doublets of the lines 5791 and 5770, which were very brilliant, I observed a narrow and extremely weak line between the components of the two lines. This weak line seemed with 5770 precisely midway between the components, with 5791, however it seemed to be displaced somewhat towards the red.

These weak lines evidently are due to reflection of light, radiating nearly at right angles to the direction of the magnetic force, from the inner surface of the capillary of the Geissler tube. LOHMANN [1]) investigating the neon lines, observed a similar, but in his case entirely symmetrical perturbation. I found the weak line to be linearly polarized, as was to be expected.

The whole image, apart then from the ratio of intensities and the character of the polarization, strikingly resembles the type of effect observed at right angles to the magnetic force. No good photographs showing the extremely weak line at the same time with the two components of the doublet were obtained.

I therefore tried to bring into the field of view the unmodified line at the same time with the doublet. It is well known that the use of a spectrum of comparison in measurements where a high degree of precision is wanted, is not without serious objections. KAYSER [2]) therefore recommends as the most suitable method to produce the lines necessary for comparison in the source itself. In our case this is naturally out of question.

The sidelong displacement, which the luminous line in the vacuum tube undergoes by the action of the field, makes it already impossible, even if the position of the vacuum tube remains unchanged, accurately to compare a negative taken with the field off, with one taken when the field is on.

The best manner of procedure in the given circumstances therefore seemed to reflect into the spectroscope by means of a semi-silvered mirror the light of a separate vacuum tube placed sideways and to analyse this light simultaneously with that of the tube between the poles. However also this comparison succeeded only incompletely in view of the extreme accuracy wanted. In some comparisons the line of the unmodified source seemed to be in a symmetrical position for line 5770 as well as for 5791. I hesitate however to attach even a very moderate value to this result. The experiments however forcibly suggested the question :

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[1]) LOHMANN, Beiträge zur Kenntniss des ZEEMAN-Phänomens. Dissertation. Halle a. d S. S. 62. 1907. Zeitschr. f. Wissensch. Photographie. Band 6. Heft 1 u. 2. 1908.

[2]) KAYSER, Handbuch der Spectroscopie. Band I. p. 732.

Has the middle line of a triplet the same wavelength as the unmodified line?

9. The change of wavelength here contemplated undoubtedly must be extremely small, for no one of the physicists occupied with the radiation phenomena in a magnetic field has, to my knowledge, come across phenomena which decide the question put above this paragraph.

Some observations made with an echelon spectroscope have given me evidence, that different spectral lines and among these the mercury lines undergo in very strong fields displacements of the order of 6 or 10 thousandth parts of an Angström unit, in most cases towards the violet. The matter seems of sufficient interest to be treated in a separate paper, which I hope to give rather soon.

Physics. — *"Change of wavelength of the middle line of triplets."* (First Part). By Prof. P. ZEEMAN.

1. In dealing with radiation in a magnetic field it has been tacitly assumed by all experimentalists I know of, that the middle line of triplets or of other symmetrical separation figures occupies the same position in the spectrum as the unmodified line. During a rather detailed investigation of the asymmetrical separation shown by some lines (see the paper immediately preceding) experiments on the light emitted in the direction of the magnetic force showed that symmetry was not always present where it was expected.

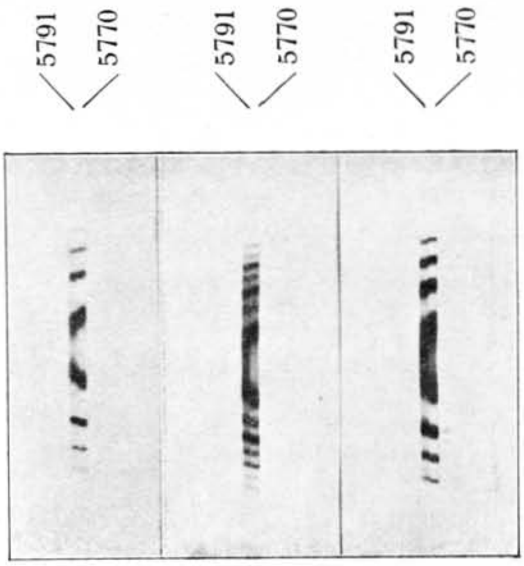
The interest attaching to the encountered anomaly suggested the question whether the original line is displaced during magnetisation. The following paper gives sufficient evidence to assert that such is the case. The asymmetrical position of the very weak line observed between the components of the doublet of line 5791 (see § 8 of the paper immediately preceding) is not explained however by this displacement. The contrary is the case. The theoretical interest of the subject is probably intimately connected with the existence of couplings between vibrations parallel and perpendicular to the field [1]).

2. For the further discussion I will recapitulate here very briefly the formulae [2]) giving for MICHELSON's echelon grating the angular

[1]) Cf. however VOIGT. Annalen d. Phys Bd. **24**, p. 195, 1907.

[2]) MICHELSON. Journal de Physique, (3), Vol. 8, p. 305, 1899.
Fürst B. GALITZIN. Zur Theorie des Stufenspectroscops. Bull. de l'Acad. Imp. des Sciences St. Pétersbourg 1905 (5) T. 23. N⁰. 1 et 2.

P. ZEEMAN. New observations concerning asymmetrical triplets.



field off. 1st coïncidence 2d coïncidence.