It was now clearly shown, that a number of rootlets, which had curved geotropically, were completely free from starch. Whatever views we may adopt with regard to the harmful action of the aluminium on the plant, or with regard to the fact that by no means all roots were free from starch, the fact, established with certainty, that roots, the tip of which had become starch-free, nevertheless curved geotropically, proves conclusively that the perception of the stimulus of gravity can take place *without* statoliths.

At most the protagonists of the statolith theory may still maintain, that the starch grains could in any case accelerate the perception of gravity. On this point a conclusive answer could only be obtained by determining the presentation time for geotropism in roots with and without starch. This determination was unsuccessful, for two reasons: In the first place the harmfulness of the solution and the tendency to traumatotropic curvature make it necessary to stimulate somewhat longer in order to get curvatures which can be readily observed and secondly these water cultures cannot be placed on a clinostat during the latent period, a condition which is necessary in the case of this object, in order to obtain definite curvatures with the presentation time.

Utrecht, October 1909.

Physics. — "*The degree of completeness of the circular polarization of magnetically divided lines.*" By Prof. P. Zeeman.

1. A luminous gas placed between the poles of an electromagnet observed along the lines of force, gives in the simplest case, two spectral lines of different wavelengths. These lines are situated at both sides of the original line. In accordance with Lorentz's elementary theory my observations so far published tend to show almost perfect polarisation of the lines of this doublet, the polarization being right-handed for one, left-handed for the other of its components. If the direction of the field is reversed the sign of the polarization becomes opposite.

Corresponding to the doublet, observed parallel to the field, a triplet is seen when the light emitted at right angles to the field is analysed. The components of this triplet are linearly polarized.

Lorentz as early as 1898[1] showed that some conclusions concerning the polarization of the components of magnetically divided

[1]) Lorentz. These Proceedings June 1898. p. 113. The Theory of Electrons. Teubner. Leipzig. p. 149. 1909.

lines can be drawn from general principles, independently of any particular theory.

One of these results is that light of a definite frequency radiated along the lines of force, can never show a trace of linear or elliptic polarization; it must either be unpolarized, or have a circular polarization, partial or perfect.

LARMOR [1]) in 1900 concluded that perfect circular polarization of the components of the doublet, would prove that the corresponding permanent types of vibration in the molecules are exactly circular.

In order to explain the more complicated magnetic effects VOIGT [2]) specialised the general theory of vibrating electric systems by supposing particular magnetic links between electrons and by introducing the hypothesis that the luminous particles take a definite orientation under the action of the field. A particular direction, the "axis" of each particle, becomes under the action of the field parallel to the lines of force.

A rotation of the particles around this specified axis undoubtedly is possible, at least it is not excluded. This rotation has no influence upon the frequency. The orbits of the electrons however are rotated as also are the orbits of the "equivalent" electrons recently introduced by LORENTZ [3]) in order to simplify the theory of systems containing a number of electrons.

The linear polarization of the light emitted normally to the field, proves that the orbits of the electrons either are straight lines parallel to the lines of force or ellipses in planes perpendicular to the field.

The completeness of the circular polarization parallel to the magnetic force would prove that the ellipses are circles. Partial circular polarization however would prove the existence of ellipses with all possible fortuitous orientations in planes normal to the field.

In general one would expect, that the components of a magnetically subdivided line emit partially polarized light parallel to the field. Without hypothesis or further measurements this more general statement must even be regarded as the most probable. A quantitative examination of the ratio of circularly polarized light contained in the total light emitted by the components, has not been made till now.

2. My observations with ROWLAND's grating are consistent with

1) LARMOR. Aether and Matter. p. 345.

2) VOIGT. Magneto- und Elektrooptik, Teubner, Leipzig. p. 98. 1908.

3) LORENTZ. Theorie der magneto-optischen Phänomene. Encyclopadie der mathematischen Wissenschaften. V. 3. Heft 2. p. 217. 1909.

the opinion that the radiation of the components of the doublet is accompanied by a rather high percentage of ordinary light.

The brightness of grating spectra is only small compared with the intensity of the original, incident light. The amount of ordinary light contained in the total radiation of the doublet easily could remain below the limiting value necessary for perception, and notwithstanding its intensity compared with that of the spectral line be by no means small.

In order to decide experimentally between the two possibilities, I have made some experiments on the completeness of the circular polarization.

As regards intensity of light MICHELSON's echelon spectroscope certainly surpasses all other spectroscopes of high resolving power. It therefore was the most suitable instrument for the projected experiments and satisfied a first condition I had to attend to.

A second condition to be satisfied for the projected experiments is that the source of light be as intense as possible.

I therefore for the present only investigated the spectra of sodium, mercury and thallium, which can be obtained with great intensity. These few elements moreover have the advantage of exhibiting several different types of magnetic separations.

The methods used for the investigation of the circularly polarized light are given in §§ 3—5. Particulars concerning the sources of light are contained in § 6. The observations and conclusions concerning the chief subject of this paper form the end of this communication §§ 7—13.

3. *Verification of the circular analysers.*

In order to investigate the circularly polarized light of the components it is simplest to use either quarter-wave plates or FRESNEL's rhomb.

The last contrivance has the advantage of suiting simultaneously the necessary conditions for a large part of the spectrum. The quarter-wave plates, however, can be selected only for a very limited part of the spectrum. They can easily be adjusted for the purpose in view rather by splitting mica sheets.

The interference colour exhibited, when the plate is placed between crossed Nicols, in parallel light, gives a measure of the retardation produced.

As the estimation of this colour is, however, always a matter of some difficulty and if a somewhat great accuracy is desired, it is a much better plan to analyse the light leaving the second Nicol with the aid of a spectroscope. The result becomes more accurate, if one combines a moderately thin plate of double refracting crystal with the mica sheet. The simple theory of the dark bands, now visible in the spectrum, is well known and needs not to be given here. Since the time of Fizeau and Foucault many physicists have used them for the measurement of phase differences. [1])

A plate of quartz, cut parallel to the optical axis, and of about 2 m.m. thickness, gives 18 bands between the red and violet hydrogen lines.

These bands are most distinct, if the principal sections of the Nicols and the mica be inclined at an angle of 45°.

If the mica and the quartz plate be superposed in such a manner, that the principal sections correspond, a displacement of the bands in a certain sense, e.g. towards the red is observed.

If then the mica be rotated through 90° the displacement is towards the violet.

The amount of the total displacement observed, by the interchange of the two positions of the mica, is easily measured. The ratio of half this displacement and the distance of two succeeding bands gives the difference of phase produced by the mica for the region of the spectrum under consideration.

König [2]) and Cornu [3]) suggested the use of a double quarter-wave plate with horizontal boundary line for the easier observation of the longitudinal magnetic effect.

I myself often make use of mica plates of the same kind but divided into three fields, as indicated in the figure. The principal

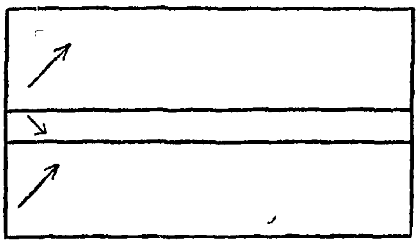

Fig. 1.

sections of the fields are indicated by the arrows.

[1]) See f. i. Cornu in the paper cited sub 3.

[2]) W. König, Wied. Ann. 63 S. 268. 1897.

[3]) A. Cornu. C. R. 125 p. 555. Octobre 1897, Eclairage Electrique 13 p. 246. 1897.

Such a three-fold plate is made nearly as easily by the experimenter as a double one, whereas for measurements its use allows of a somewhat higher accuracy by reason of the symmetry of the field of view.

Using either these double or three-fold mica plates one immediately gets the total displacement of the bands, if a quartz plate be superposed and the combination placed between crossed Nicols. An image of the horizontal lines of separation is projected by means of an *achromatic* lens upon the slit of a spectroscope.

In fig. 1 of the Plate a photograph taken with a three-fold mica-plate is given. The relative retardation produced by the mica is a quarter of a wave-length, if the distance of two bands in the outer fields is just halved by one in the middle field.

A comparison spectrum from $\lambda = 6561$ (H) to $\lambda = 4078$ (Hg) is taken simultaneously. How largely the phase-difference in the mica depends upon the wavelength is very clearly shown.

4. FRESNEL's rhomb gives, as is well known, circularly polarized light after two total reflexions of light polarized at an azimuth of 45°.

This arrangement, if perfect, has the advantage of giving circularly polarized light for all colours of the whole visible spectrum. I examined as to how far the rhomb at my disposition satisfied the requirements imposed by the object I had in view.

The chief purpose of my investigation requires a rather close approach to the ideal condition. For this reason and also because, as far as I know, FRESNEL's beautiful invention was never investigated by the method of interference bands, I may be allowed to give a more extensive treatment of the results than I otherwise would have contemplated.

In order to obtain also with FRESNEL's rhomb two fields in which the bands are shifted in opposite directions, the rhomb is to be combined with a double plate. I used a double-plate [1]) made of a plate of quartz, 1.7 m.m. thick, and cut parallel to the axis. This plate is cut in two halves by a line making angles of 45° with the principal section; one half is then rotated round an axis perpendicular to the line of separation, through 180°.

Fig. 2 was obtained by means of this double-plate and a rhomb, many years old and belonging to the collection of the Amsterdam laboratory. The deviation from an ideal apparatus is very apparent on inspection of the photograph. Measurement shows that the bands are

[1]) cf. CORNU l.c.

shifted from the position they should occupy with an accurate quarter-wave apparatus, by an amount, which in the red is nearly 11 °/₀ of the distance of two succeeding bands. In the green and violet this amount becomes 9 resp. 10.5 °/₀.

5. Much smaller deviations gives a recently obtained rhomb, as is readily seen by comparison of the photographs 2 and 3.

A somewhat higher accuracy was still obtained by interchanging the prism of the spectroscope used by a more dispersive one. It now, however, became impossible to photograph the whole spectrum at one operation. Fig. 4 and fig. 5 have been obtained with the old FRESNEL-rhomb and the higher dispersion. With the last dispersion and the new rhomb one can without measurements scarcely decide upon the sense of the error in the relative position of the two band systems (see fig. 6 and fig. 7). The deviation of a band in one field, from the centre of two bands in the other, never exceeds 3.2 °/₀ of the distance of the bands. (The deviations are 1.7, 2.6 and 3.2 °/₀ for the red, green and violet).

Let the deviation, defined in this manner, be p percent, then the corresponding error of the phase becomes $\frac{p}{200} \times 360° = 1.8 \cdot p$ degrees. For the green p is about 3 °/₀, hence 5°.4. An error of this amount in the phase difference of 90°, which exists between the two linear components into which circularly polarized light can be resolved, may easily be shown to have no influence in the case of the measurements of intensity described in § 7.

Let completely circularly polarized light be incident upon the rhomb, then the light after reflexion by the rhomb, giving a retardation of 90° diminished or increased with a small angle δ, may be represented by:

$$\left.\begin{array}{l} x = a \cos nt \\ y = a \cos (nt + \delta) \end{array}\right\} .$$

Hence

$$x^2 - 2xy \cos \delta + y^2 = a^2 \sin^2 \delta .$$

The principal axes of this ellipse, become: $\frac{1}{2} a \sqrt{2} \sin \delta$ and $a \sqrt{2}$, hence their ratio $\frac{1}{2} \sin \delta$.

When $\delta = 6°$, then $\frac{1}{2} \sin \delta = 0.0522$.

The intensity of the light leaving a Nicol with its plane of vibration perpendicular to the major axis of the ellipse, becomes $(0.0522)^2 = 0.0027$.

As the minimum intensity, which under the circumstances of our observations may be recognized, will appear to be of the order 0.01, even an error twice or three times the one now accepted for FRESNEL's rhomb, cannot disturb our results.

6. *Sources of light.* Vacuum tubes charged with mercury, thallium or sodium, and heated to the required temperatures, were used as sources of light. The tubes were excited by means of an induction coil with high-speed interruptor.

In order to render the luminosity of the tubes as high as possible, the current in the coil was gradually increased to the maximum just possible without impairing the narrowness of the spectral lines.

In the case of sodium the troublesome separate heating of the tube was eliminated by following a somewhat modified procedure. Mercury tubes require only a preliminary heating, the current once started being sufficient to supply the necessary heat. It was tried to mix up some fine powder of previously heated chloride of sodium with the mercury. The tube now exhibited, besides the mercury lines, the sodium lines with extremely great intensity. Often only some parts of the capillary are radiating; the most suitable part is then selected. In the experiments with sodium the coil was actuated by an alternate current, a maximum of 12 Amp. being possible before the widening of the sodium lines considerably interfered with the work.

7. *Arrangement of the experiments.* A few words will suffice to describe the disposition of the experiments.

A DU BOIS-electromagnet with one perforated polar piece was used. The light emitted parallel to the field and made parallel by means of an achromatic lens, traversed FRESNEL's rhomb, then a second achromatic lens, which forms an image on the slit of the auxiliary spectroscope.

This preliminary analysis enables us to select a definite spectral line for further investigation by means of the echelon spectroscope, a more detailed description of which I gave on a former occasion[1]). Between the second lens and the slit of the auxiliary spectroscope a Nicol's prism was introduced, mounted upon a divided circle, which gave the rotation of the Nicol in degrees.

The front plane of the rhomb was placed accurately perpendicular to the beam.

The plane of incidence of the FRESNEL rhomb was made vertical in most experiments. In a few observations it was set at an azimuth of 45° with the horizontal plane.

In the first case the emergent linear vibrations are at an angle of

1) ZEEMAN. These Proceedings Nov. 30, 1901, p. 247.

45° with a vertical line; in the second case they are either horizontal or vertical.

The method of procedure is very simple. The nearly ideal FRESNEL rhomb transforms light of completely circularly polarized doublets into two perpendicular, linear vibrations. By means of a Nicol either the one or the other of the lines can be completely quenched, *provided there is no trace of ordinary light in the double lines.*

The observations with the lines investigated, indeed show that such must be the case. The value of the result depends upon the sensitivity of the method.

The observations consisted in finding the two positions, on either side of the position of extinction, at which the light was just recognizable with certainty.

If α be the angle the Nicol is then rotated from the zero position, $I \sin^2 \alpha$ represents the brightness of the emergent light, I being the intensity of the linear vibration.

We can be sure that the quantity of ordinary light, emitted by one of the components, must be below $I \sin^2 \alpha$.

8. *Results.* The observations consist in determining the value of α for the different spectral lines. I will arrange the results according to the different types of subdivisions, observed normally to the field.

Triplet, mercury, $\lambda = 5791$, doublet parallel to the field, $\alpha = 7°$ $\sin^2\alpha = 0.0144$. The observation is somewhat hindered by satellites of the principal lines.

Triplet, $\lambda = 5771$, doublet in direction of field.

In extremely strong fields every component is resolved into three lines. This strength of field was not reached.

$$\alpha = 5° \quad \sin^2\alpha = 0.0076.$$

Quartet, sodium, $\lambda = 5896$, doublet in direction of field.

$$\alpha = 5° \quad \sin^2\alpha = 0.0076$$

Sextet, sodium, $\lambda = 5890$, quartet in direction of field.

$$\alpha = 6° \quad \sin^2\alpha = 0.0108$$

Nonet, mercury, $\lambda = 5461$, strong green mercury line, sextet in direction of field.

$$\alpha = 5° \quad \sin^2\alpha = 0.0076.$$

Sextet, thallium, $\lambda = 5351$, quartet in direction of field,

$$\alpha = 8° \quad \sin^2\alpha = 0.0196$$

Probably a lower limit can be obtained, when a more satisfactory thallium tube is made use of.

9. *Influence of reflexions from the walls of the vacuum tube.*

In the course of the investigation different mercury tubes were used. With one of these I had the opportunity of repeating an observation, made on a former occasion [1]), under very less favourable circumstances. I will give some details for a case of simple magnetic separation.

The yellow mercury lines split into two components, if the light is examined parallel to the field. Observing in the latter direction and while using a new tube I was astonished to see the yellow mercury lines divided into *triplets*, the three components being of equal intensity. The plane of incidence of the rhomb was under this observation vertical. The intensity of the central line of the triplet was a maximum when the plane of vibration of the Nicol was horizontal, being zero when it was vertical. The central line apparently is linearly polarized. It is easily seen by means of a figure that this central line may be due to light, emitted nearly at right angles to the direction of the field, and, after being reflected once or twice from the inner surface of the capillary, emerging in the direction of the axis of the electromagnet.

Apparently in the direction of the axis a doublet, circularly polarized, is seen superposed upon a triplet with linear polarization. In the specified position of the FRESNEL rhomb, at an azimuth of 45° of the Nicol one of the components of the doublet, after a rotation of 135° the other component must vanish; then, however, the vertical component of the reflected triplet still must remain visible, its intensity being halved, because the principal section of the Nicol makes in the case now considered an angle of 45° with the vertical line. The outer components of the yellow mercury triplets only have about one half of the intensity of the central component, hence, if expressed in the intensity of the latter only $^1/_4$ remains for the vertical vibrations. Observation wholly confirms this.

If the FRESNEL rhomb be brought into such a position that the plane of incidence makes an angle of 45° with the horizontal plane, the central component must be expected to exhibit circular polarization.

This also was confirmed by observation, as other conclusions to be drawn in the case now under review.

I may be permitted to mention, that the central component in the case of the mercury line 5790 has an asymmetrical position; symmetrical, however, in the case of 5771. This appearance corresponds

1) ZEEMAN, These Proceedings 29 Febr. 1908, p. 573.
LOHMANN, Diss. Halle S. 62, 1907.

exactly to what is observed in a direction normal to the lines of force [1].

The described phenomena in so far as they are due to the reflected light, ordinarily are only just recognizable, the intensity of the light being rather small. The capillary used in the last mentioned observations was of wide bore. With fine capillaries the intensities of the reflected components are considerably weakened.

The diameter of the luminous filament, which emits the most intense light, and which is visible while the vacuum tube is subjected to magnetic forces, probably has as much influence as the width of the capillary in determining the intensity of the reflexion phenomena under consideration. The results of § 8 have been obtained with tubes exhibiting only slight perturbations due to reflected light.

10. The middle component in one or two of the experiments appeared to exhibit only *nearly* plane polarization. The reason of the very small ellipticity of the reflected light might perhaps be due to the elliptic polarisation, which VOIGT predicted, in the case light is emitted in a direction inclined to the lines of force.

Such obliquely emitted light undoubtedly contributes to intensifying the observed central line.

A somewhat faulty position, however, of FRESNEL's rhomb also may be responsible for a slight ellipticity of the polarization. New experiments of course are wanted before the predicted elliptic polarization can be considered as proved by experiment. In my present observations only a very first trace of the effect may perhaps be operative.

11. Before leaving the subject of reflexions in the tube, one point may be considered somewhat more in detail. Is it possible that the circularly polarized light of the components of the doublet, *reflected* back in the original direction may disturb the purity of the observed effect?

The same electron, which emits right-handed circularly polarized light in the direction of the lines of force, which, let us assume, proceed to us, in the opposite direction sends left-handed circularly polarized light of the same period. By reflexion, however, the sense of the circular polarization is reversed, hence the direct as well as the reflected beams enter the eye right-handed circularly polarized. The

[1]) ZEEMAN, These Proceedings 30 Nov. 1907. p. 351.

only effect is an increasing of the intensity of the doublet components. It is easily shown that also multiple reflexions from those parts of the wall of the capillary, which are normal to the field, will only modify the intensity.

12. *Experiments with absorption lines.* I have made also some experiments on the sensitiveness of the inverse effect, a sodium flame placed between the perforated poles of a large DU BOIS-electromagnet being traversed by the white light of an arc-lamp. A large concave ROWLAND grating was made use of for the analysis of the light. The ROWLAND grating can be used for the study of the inverse magnetic effect, because the brightness of the arc-lamp more than compensates the feeble reflexion by the grating.

A double quarter-wave plate and a Nicol are traversed by the beam. By means of the mounted Nicol the right-handed circularly polarized component in one part of the field, the left-handed in the other can be made absolutely black. The corresponding position of the Nicol we call the zero-position. In this position not the slightest trace of absorption can be seen at the places of the other components, which only appear after a considerable rotation of the Nicol. The positions of the Nicol, on either side of the zero-position, were found at which the earliest recognition of the absorption lines was possible. The first trace of the lines only became visible after a rotation of 20° from the zero. Hence, we conclude, that the absorption must already be considerable before being perceptible and that ordinary light in the components of the doublet can be recognized more readily by observations on the direct effect.

13. *Conclusions.* I think I have proved by the experiments described 1 that we must accept, till the contrary has been proved, that in the case of *line* spectra the displaced[1]) components of magnetically subdivided lines, emit parallel to the lines of force completely circularly polarized light.

2. that the amount of ordinary light which might be emitted simultaneously with the circularly polarized light, is in the case of several spectral lines less than 1 % of the total intensity of the spectral line.

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[1]) I expressly speak of *displaced* components in order to except a component which has the same position as the unmodified line. The groups of oppositely circularly polarized components then have a central line in common, which must be unpolarized. The quintets $\lambda = 3788.01$ and $\lambda = 3743.45$ of the iron spectrum, investigated by H. BECQUEREL and DESLANDRES and lately measured by Mrs. VAN BILDERBECK in the Amsterdam laboratory, provide examples of the type. [Note added to the englisch translation].

As the intensity of light of the apparatus used (ROWLAND's grating, then MICHELSON's echelon) has increased, so the percentage of ordinary light, possibly present, has decreased.

We must conclude, that the orbits of the equivalent electrons, in planes normal to the magnetic force, are with great approximation circles. Elliptic orbits, fortuitously distributed in planes normal to the field, need not be conjectured for the representation of the phenomena.

Rather closely connected with the subject of this paper, are the latest investigations of JEAN BECQUEREL [1]) and A. DUFOUR [2]). DUFOUR obtained various new results concerning the banded emission spectra of the alkaline-earth fluorides and chlorides radiating in a magnetic field and in some cases observed incomplete circular polarization. Several absorption bands of xenotime and tysonite according to J. BECQUEREL also exhibited incomplete circular polarization in a longitudinal magnetic field. He showed, however, lately [3]) that in the case of these crystals there is no real incomplete polarization, but that under the action of the magnetic field besides the principal components, others of slightly different wavelength, come into existence, which exhibit a polarization opposite to that of the principal lines.

Physics. — "*On photo- and electrochemical equilibria.*" By Prof. A. SMITS. (Communicated by Prof. J. D. VAN DER WAALS.)

Already previously [4]) I pointed out that if a dark or thermochemical equilibrium is exposed to the action of light or electrical energy, and the system is *susceptible* to these forms of energy, a new equilibrium will be established, which deviates from the thermodynamic equilibrium, or in other words which is thermic metastable.

On that occasion the heterogeneous photochemical equilibria in the systems $Ag_2Cl—Cl_2$ and $S—CS_2$, and further the homogeneous photochemical equilibrium $2\,SO_3 \rightleftarrows SO_2 + O_2$ and the homogeneous electrochemical equilibrium $3\,O_2 \rightleftarrows 2\,O_3$ were discussed, in which a photochemical dissociation equilibrium with HCl was predicted.

1) JEAN BECQUEREL C. R. T. **145**, p. 413. 1907.

2) A. DUFOUR C. R. T. **146**, p. 118 et p. 229. 1908. Journal de Physique Avril 1909.

3) JEAN BECQUEREL. These Proc. p. 146. June 1909. Contribution à la connaissance du phénomène de ZEEMAN dans les cristaux. See also supplement N°. 20. Leyden communications.

4) Inaugural Address. Amsterdam Dec. 9th 1907.