of mammals even with a very strong precipitin-serum, which was obtained with and against an arbitrary mammifer-albumen ("mammalian reaction"). HAUSER [1]) comes to a similar result; only quantitative differences remain.

Also with relation to the amboceptor such a diminution of the specific action seems to me sufficiently well pointed out.

Physics. — *"Arbitrary distribution of light in dispersion bands, and its bearing on spectroscopy and astrophysics."* By Prof. W. H. JULIUS.

In experimental spectroscopy as well as in the application of its results to astrophysical problems, it is customary to draw conclusions from the appearance and behaviour of spectral lines, as to the temperature, density and motion cf gases in or near the source of light,

These conclusions must in many cases be entirely wrong, if the origin of the dark lines is exclusively sought in absorption and that of the bright ones exclusively in selective emission, without taking into account the fact that the distribution of light in the spectrum is also dependent on the anomalous dispersion of the rays in the absorbing medium.

It is not in exceptional cases only that this influence makes itself felt. Of the vapours of many metals it is already known that they bring about anomalous dispersion with those kinds of light that belong to the neighbourhood of several of their absorption lines [2]). In all these cases the appearance of the absorption lines must to a greater or less extent be modified by the above mentioned influence, since the mass of vapour, traversed by the light, is never quite homogeneous.

Hence it is necessary, separately to investigate the effect of dispersion on spectral lines; we must try to separate it entirely from the phenomena of pure emission and absorption.

A first attempt in this direction were the formerly described experiments with a long sodium flame [3]), in which a beam of white

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[1]) Münch. Med. Wochenschrift, 1904, n⁰ 7, S. 289.

[2]) After WOOD, LUMMER and PRINGSHEIM, EBERT, especially PUCCIANTI has investigated the anomalous dispersion of various metallic vapours. In Nuovo Cimento, Serie V, Vol. IX, p. 303 (1905) PUCCIANTI describes over a hundred lines, showing the phenomenon.

[3]) W. H. JULIUS, "Dispersion bands in absorption spectra." Proc. Roy. Acad. Amst. VII, p. 134—140 (1904).

light alternately travelled along different paths through that flame. With these relative displacements of beam and flame the rays of the anomalously dispersed light were much more bent, on account of the uneven distribution of the sodium vapour, than the other rays of the spectrum; absorption and emission changed relatively little. The result was, that the distribution of the light in the neighbourhood of D_1 and D_2 could be made very strongly asymmetrical, which could easily be explained in all details as the result of curvature of the rays. The existence of "dispersion bands" was thus proved beyond doubt.

But the pure effect of emission and absorption was not absolutely constant in these experiments and concerning the density of the sodium vapour in the different parts of the flame only conjectures could be made. Moreover, the whirling ascent of the hot gases caused all rays, also those which suffered no anomalous dispersion, sensibly to deviate from the straight line, so that the phenomena were too complicate and variable to show the effect of dispersion strictly separated from that of emission and absorption.

So our object was to obtain a mass of vapour as homogeneous as possible and, besides, an arrangement that would allow us to bring about arbitrarily, in this vapour, local differences of density in such a manner, that the average density was not materially altered. The absorbing power might then be regarded as constant. At the same time it would be desirable to investigate the vapour at a relatively low temperature, so that its emission spectrum had not to be reckoned with.

In a series of fine investigations on the refractive power and the fluorescence of sodium vapour R. W. WOOD[1]) caused the vapour to be developed in an electrically heated vacuum tube. It appeared possible, by adjusting the current, to keep the density of the vapour very constant. Availing myself of this experience I made the following arrangement for the investigation of dispersion bands.

Apparatus.

NN' (see fig. 1) is a nickel tube of 60 centimetres length, 5.5 cms. diameter and 0,07 cm. thickness. Its middle part, having a length of 30 cms., is placed inside an electrical furnace of HERAEUS (pattern E 3). Over its extremities covers are placed, the edges of which fit into circular rims, soldered to the tube, and which consequently

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1) R W. WOOD, Phil. Mag. [6], 3, p. 128; 6, p. 362.

shut air-tight when the rims are filled with cement. When the furnace is in action a steady current of water, passing through the two mantles M and M', keeps the ends of the tube cool. Each of the two caps has a rectangular plate glass window and also, on both sides of this, openings a and b (b' and a'), placed diametrically
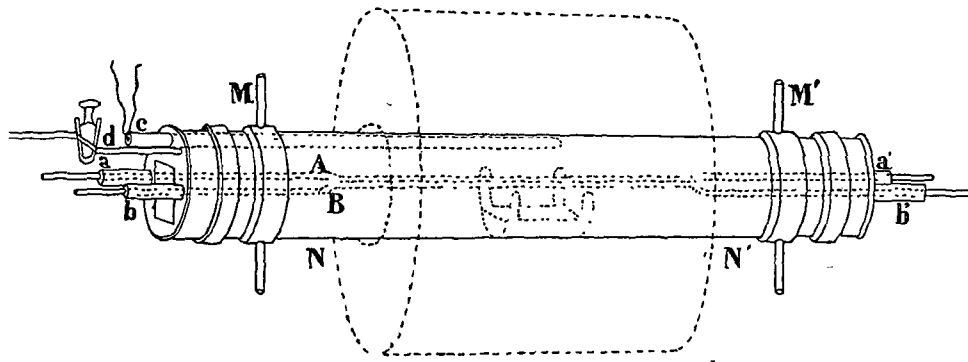

Fig. 1.

opposite to each other and provided with short brass tubes, the purpose of which will appear presently. Moreover in one of the two caps (see also fig, 2) two other short tubes c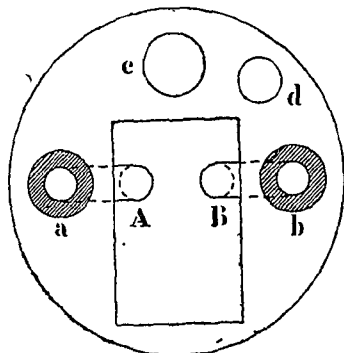 and d are fastened in openings: through c the porcelain tube of a LE CHATELIER pyrometer is fitted air-tight, while on d a glass cock with mercury lock is cemented, leading to a mano-meter and a Geryk air-pump. As soon as the sodium (a carefully cleaned piece of about 7 grammes) had been pushed to the middle of the tube in a small nickel dish provided with elastic rings, the tube had been immediately closed and exhausted.

Fig. 2.

We shall now describe the arrangement by which inside the mass of vapour arbitrary inequalities in the density distribution were produced. It consists of two nickel tubes A and B of 0,5 cm. diameter, leading from a to a' and from b to b' and so bent that in the heated middle part of the wide tube they run parallel over a length of 30 centimetres at a distance of only 0.8 cms. In the four openings of the caps, A and B are fastened air-tight by means of rubber packing, This kind of connection leaves some play so that by temperature differences between the wide and the narrow tubes these latter need

- 4 -

not alter their shape through tension. At the same time the rubber insulates A and B electrically from NN'. The four ends of the narrow tubes which stick out are kept cool by mantles with streaming water (these are not represented in the figure).

If now an electric current is passed through A or B, the temperature of this tube rises a little above that of its surroundings; if an air-current is passed through it, the temperature falls a little below that of its surroundings. The intensities of the currents and, consequently, the differences of temperature can in either case be easily regulated and kept constant for a long time.

Fig 3 gives a sketch of the whole arrangement. The light of the positive carbon L is concentrated by the lens E on a screen Q, having a slit-shaped aperture of adjustable breadth. The lens F forms in the plane of the slit S of the spectrograph a sharp image of the diaphragm P. The optical axis of the two lenses passes through the middle of the tube containing the sodium vapour, exactly between the two small tubes A and B.

If now the opening in the diaphragm P has the shape of a vertical narrow slit and if its image falls exactly on the slit of the spectograph, then in this latter the continuous spectrum of the arc-light appears with great brightness. If the tube NN' is not heated, D_1 and D_2 are seen as extremely fine dark lines, attributed to absorption by the sodium, which is always present in the neighbourhood of the carbons. In order that this phenomenon might always be present in the field of view of the spectograph as a comparison spectrum, also when the tube is heated, a small totally reflecting prism was placed before part of the slit S, to which part of the principal beam of light was led by a simple combination of lenses and mirrors without passing the electric furnace. So on each photograph that was taken the unmodified spectrum of the source is also seen.

The spectral arrangement used consists of a plane diffraction grating 10 cms. diameter (ruled surface 8 by 5 cms.) with 14436 lines to the inch, and two silvered mirrors of ZEISS; the collimator mirror has a focal distance of 150 cms., the other of 250 cms. Most of the work was done in the second spectrum.
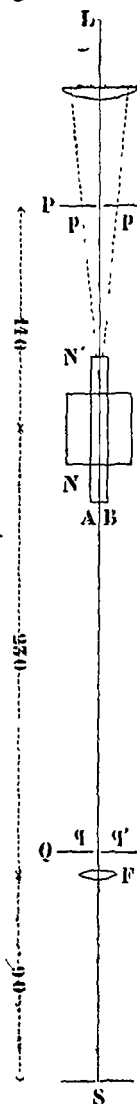

Fig. 3.

When heating the sodium for the first time a pretty large quantity of gas escaped from it (according to Wood hydrogen), which of course was pumped off. After the apparatus had functionated a couple of times, the tension within the tube remained for weeks less than 1 mm. of mercury, also during the heating, which, in the experiments described in this paper, never went beyond 450°. The inner wall of NN' and also the small tubes A and B are after a short time covered with a layer of condensed sodium, which favours the homogeneous development of the vapour in subsequent heatings. It is remarkable that scarcely any sodium condenses on the parts of the tube that stick out of the furnace, so that also the windows remain perfectly clear. The density of saturated sodium vapour at temperatures between 368° and 420° has been experimentally determined by Jewett [1]. He gives the following table.

temperature	density
368°	0.00000009
373	0.00000020
376	0.00000035
380	0.00000043
385	0.00000103
387	0.00000135
390	0.00000160
395	0.00000270
400	0.00000350
406	0.00000480
408	0.00000543
412	0.00000590
418	0.00000714
420	0.00000750

These densities are of the same order of magnitude as those of mercury vapour between 70° and 120°. At 387° the density of

[1] F. B. Jewett, A new Method of determining the Vapour-Density of Metallic Vapours, and an Experimental Application to the Cases of Sodium and Mercury. Phil. Mag. [6], 4, p. 546. (1902).

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saturated sodium vapour is about $\frac{1}{1000}$ of that of the atmospheric air at 0° and 76 cms.

Observations.

If we now regulate the intensity of the current in the furnace in such a manner that the thermo-couple indicates a steady temperature (in many of our experiments 390°), then within the tube the density of the vapour is not everywhere the same, to be sure, for the temperature falls from the middle towards the ends, but since the surfaces of equal temperature are practically perpendicular to the beam of light, all rays pass nearly rectilinearly through the vapour. Accordingly the spectrum is only little changed; the two D-lines have become somewhat stronger, which we shall, for the present, ascribe to absorption by the sodium vapour in the tube.

We now blow a feeble current of air through the tube A which thus is slightly cooled, so that sodium condenses on it, the vapour density in its neighbourhood diminishing. We soon see the sodium lines broaden considerably. This cannot be the consequence of increased absorption, since the average vapour density has decreased a little. The reason is that rays of light with very great refractive indices are now bent towards q' (fig. 3), rays with very small indices towards q; hence in the image of the slit P which is formed on S, rays belonging to regions on both sides of the D-lines no longer occur, while yet this image remains perfectly sharp since the course of all other rays of the spectrum has not been perceptibly altered. If now at the same time the tube B is heated by a current of e.g. 20 Ampères, by which the density gradient in the space between the tubes is increased, the breadth of the lines becomes distinctly greater still. The heat generated in the tube by the current is about 1 calory per second; it is, however, for the greater part conducted away to the cooled ends of the tube, so that the rise of temperature can only be small.

By switching a current key and a cock, A and B can be made to suddenly exchange parts, so that A is heated, B cooled. The dark bands then shrink, pass into sharp D-lines and then expand again, until, after a few minutes, they have recovered their original breadth.

Fine and sharp, however, the lines in the transition stage are only if the temperature of the furnace is very constant. If it rises or sinks the minimal breadth appears to be not so small. In this

case, however, there certainly exist currents in the mass of vapour which cause the distribution of density to be less regular. Also when A and B are at equal temperatures, we sometimes see the sodium lines slightly broadened; it stands to reason to attribute this also to refraction in such accidental irregularities.

That spectral lines possess some breadth is commonly ascribed either to motion of the light-emitting molecules in the line of sight or to changes in the vibrational period of the electrons by the collisions of the molecules. We now have a third cause: anomalous dispersion in the absorbing medium. The whole series of phenomena, observed in our sodium tube, corroborates the opinion that this latter cause must in general be regarded as by far the most important. It will appear that this conclusion holds not only for dark but also for bright spectral lines.

If the slit in the diaphragm P is made much broader towards p', this has no influence on the spectrum as long as A and B are at the surrounding temperature. The D-lines appear as in α, Pl. I. If now A is cooled below this temperature, B raised above it, the dark D-lines only broaden in the direction of the shorter wave-lengths, while at the side of the longer wave-lengths the intensity of the light is even increased, since now also anomalously bent rays from the radiation field p' can reach the point S through the slit Q. (see β, Pl. I). The spectrum β passes into γ when the temperature difference between A and B is made to change its sign or also when the original temperature difference is maintained and the slit in P is made much broader towards p instead of towards p'. A small shifting of the whole diaphragm P (starting from the condition in which it was when taking β) so that S falls exactly in the shadow, causes the spectrum δ to appear, which makes the impression of an emission spectrum of sodium with slightly shifted lines, although it is evidently only due to rays from the field p' which have undergone anomalous dispersion in the vapour.

Let us now return to the diaphragm P with a narrow slit placed on the optical axis. (A piece of glass coated with tinfoil in which a slit was cut out, was generally used). The spectrum then shows broad bands when there is a density gradient between A and B. If beside the slit an opening is cut in the tinfoil, a group of rays of definite refractivity (and consequently also of definite wave-lengths) is given an opportunity to reach S through Q, and a bright spot is formed in the dark band, the shape of which depends on the shape of the opening in the tinfoil, but is by no means identical with it.
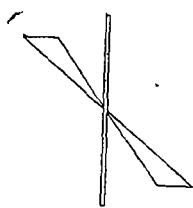
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If e. g. the opening in the diaphragm has the shape of fig. 4, then the spectrum ε is obtained. When the density gradient is diminished the figure shrinks, ζ; if now the density gradient is made to change its sign and to increase, the spectrum proceeds through the stages a (gradient exactly zero) and η to θ.
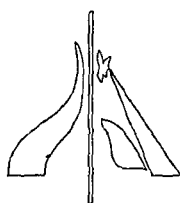
Fig. 4.   The relation between the shape of the opening in the diaphragm and that of the bright spots in the spectrum might easily have been foretold from the shape of the dispersion curve. Having, however, experimentally found the relation between the two figures for a simple case as the one above, it is not difficult to design for any desired distribution of light the shape of the required opening in the diaphragm. The

Fig. 5.   flower ι and its inversion $\varkappa$ required the diaphragm, represented in fig. 5. By reversing the gradient the image ι passes into $\varkappa$.

So in this way one may also arbitrarily produce duplications, reversals, bright or dark ramifications of spectral lines and it would e. g. be possible faithfully to reproduce all phenomena observed in this respect in the spectra of sun-spots, faculae or prominences. On Plate II a number of arbitrary distributions of light have been collected. They were all produced in sodium vapour of $390°$ on the average; a' is again the spectrum with equal temperatures of the tubes A and B. In v on the dark dispersion band D_2 a bright double line is seen, reminding us of the spectrum of the calcium flocculi of HALE. In the same negative D_1 also shows a line double line, which however is no longer visible in the reproduction. The spectra φ, χ, ψ imitate the origin of a sun spot and prominence spectrum; φ namely represents the spectrum of the quiet solar limb with radially placed slit; in χ a prominence appears and a spot with phenomena of reversal; ψ shows all this in a stronger degree. If now the density gradient is made to change sign, the image first shrinks again to φ after which it expands to ω, in a certain sense the inversion of ψ. The remarkable aspect of these gradual changes, admitting of perfect regulation, is only imperfectly rendered by the photographs.

The relation between the curvature of the rays and the density gradient.

The question arises whether it is *probable* that circumstances as were realised in our experiments are also met with in nature, or in

common spectroscopical investigations undertaken with entirely diffe-rent purposes.

We remark in the first place that curiously shaped diaphragm openings are not absolutely essential for the production of phenomena as those described above. If e.g. our source of light had a constant, say circular shape; if on the other hand the direction and magnitude of the density gradient in our tube had not been so regular, but very different in various places of the field reproduced by the lens F, then the D-lines would also have shown all sorts of excrescences, now determined by the configuration of the density distribution.

In the second place we will try to form some idea of the quan-titative relations.

The radius of curvature ϱ of the path of the most deviated rays, occurring in our photographs, may be easily estimated from the distance d of the diaphragm to the middle of the furnace, the distance δ of the most distant diaphragm openings to the optical axis, and the length l of the space in which the incurvation of the rays is brought about. For:

$$\varrho : l = d : \delta.$$

Putting $\delta=1$ cm., $d=110$ cms., $l=27$ cms. this gives: $\varrho=3000$ cms. The average density Δ of the sodium vapour was in this case about $\dfrac{1}{1000}$ of that of the atmospheric air.

Let us see how ϱ changes with the density gradient.

We always have:

$$\varrho = \frac{n}{n'} \qquad \qquad . \quad (1)$$

if n represents the local index of refraction of the medium for the ray under consideration and $n' = \dfrac{dn}{ds}$ the change of this index per cm. in the direction of the centre of curvature. Approximately we have, for a given kind of light:

$$\frac{n-1}{\Delta} = \text{constant} = R$$

$$n = R\Delta + 1$$

$$n' = \frac{dn}{ds} = R\frac{d\Delta}{ds}$$

From this follows:

$$\varrho = \frac{R\Delta + 1}{R\dfrac{d\Delta}{ds}} ;$$

but since for rarefied gases n differs little from unity, even for the anomalously dispersed rays which we consider, $R\Delta$ may be neglected with regard to 1 and we may write

$$\varrho = \frac{1}{R\dfrac{d\Delta}{ds}} \qquad \ldots \ldots \ldots \ldots (2)$$

For every kind of light ϱ is consequently inversely proportional to the density gradient of the vapour in the direction perpendicular to that of propagation.

An estimate of the magnitude of the density gradient existing, in our experiments, between A and B, may be obtained in two ways. It may namely be inferred from the produced difference of temperature, or from formula (2).

The temperature difference between A and B would have been pretty easy to determine thermo-electrically; up to the present, however, I had no opportunity to make the necessary arrangement. Besides, the relation between the density distribution in the space, passed by the rays, and the temperatures of A and B cannot be so very simple, since we have to deal not with two parallel planes but with tubes, from which moreover hang many drops of liquid sodium.

The second method at once gives an average value of $\dfrac{d\Delta}{ds}$ for the space passed by the rays. It requires a knowledge of $R = \dfrac{n-1}{\Delta}$ for a kind of ray for which in our experiments also ϱ has been determined.

Now Wood (Phil. Mag. [6], 8, p. 319) gives a table for the values of n for rays from the immediate vicinity of the D-lines. These data, however, refer to saturated sodium vapour of 644°; but we may deduce from them the values of n for vapour of 390° by means of the table which he gives in his paper on page 317.

For, when we heat from 389° to 508', the refractive power of the vapour (measured by the number of passing interference fringes of helium light $\lambda = 5875$) becomes $\dfrac{98}{9} = 11$ times greater, and at further heating from 508° to 644° again $\dfrac{50}{4} = 12.5$ times greater (now found by interference measurement with light from the mercury line $\lambda = 5461$); hence from 390° to 644° the refractive power increases in ratio of 1 to $11 \times 12.5 = 137$.

Since now for rays, situated at 0,4 Ångström-unit from the D-

lines [1]) we have $n — 1 = \pm\, 0.36$, (as the average of three values taken from WOOD's table on page 319), we ought to have with sodium vapour at $390°$ for the same kind of rays

$$n—1 = \frac{0.36}{137} = 0.0026.$$

The density Δ at $390°$ is, according to JEWETT, 0.0000016, hence

$$R = \frac{n-1}{\Delta} = \frac{0.0026}{0.0000016} = 1600.$$

Then from formula (2) follows

$$\frac{d\Delta}{ds} = \frac{1}{R\varrho} = \frac{1}{1600 \times 3000} = 0,0000002.$$

Dispersion bands in the spectra of terrestrial sources.

It is very probable that, when metals evaporate in the electric arc, values of the density gradient are found in the neighbourhood of the carbons that are more than a thousand times greater than the feeble density gradient in our tube with rarefied sodium vapour [2]).

The radius of curvature will, therefore, in these cases be over a thousand times smaller than 30 meters and so may be no more than a few centimetres or even less. A short path through the vapour mass is then already sufficient to alter the direction of certain rays very perceptibly.

If now an image of the carbon points is produced on the slit of a spectroscope, then this is a *pure* image only as far as it is formed by rays that have been little refracted in the arc, but the rays which undergo anomalous dispersion do not contribute to it. Light of this latter kind, coming from the crater, may be lacking in the image of the crater and on the other hand penetrate the slit between the images of the carbon points. Thus in ordinary spectroscopic observations, not only broadening of absorption lines, but also of emission lines, must often to a considerable extent be attributed to anomalous dispersion.

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[1]) The spectrum ε in our plate shows that the extremities of the peaks correspond pretty well to light of this wave-length; for they approach the D-lines to a distance which certainly is no more than $1/_{16}$ of the distance of the D-lines which amounts to 6 ÅNGSTR.-units. For these rays the opening of the diaphragm was 1 cm. distant from the optical axis.

[2]) If we e. g. put the vapour density of the metal in the crater, where it boils, at 0.001, the density of the vapour outside the arc at a distance of 1 cm. from the crater, at 0.0001, then we have already an average gradient 5000 times as large as that used in our experiments.

When we bear this in mind, many until now mysterious phenomena will find a ready explanation. So e.g. the fact that LIVEING and DEWAR[1]) saw the sodium lines strongly broadened each time when vapour was vividly developed after bringing in fresh material, but saw them become narrower again when the mass came to rest, although the density of the vapour did not diminish. If by pumping nitrogen into the evaporated space the pressure was gradually increased, the lines remained sharp; but if the pressure was suddenly released, they were broadened. All this becomes clear as soon as one has recognised in the lines dispersion bands, which must be broad when the density of the absorbing vapour is irregular, but narrow, even with dense vapour, if only the vapour is evenly spread through the space.

Another instance. According to the investigations of KAYSER and RUNGE the lines, belonging to the second secondary series in the spectra of magnesium, calcium, cadmium, zinc, mercury, are always hazy towards the red and are sharply bordered towards the violet, whereas lines, belonging to the first secondary series or to other series are often distinctly more widened towards the violet. With regard to the spectrum of magnesium they say:[2]) "Auffallend ist bei mehreren Linien, die wir nach Roth verbreitert gefunden haben, dass sie im ROWLAND'schen Atlas ganz scharf sind, und dann stets etwas kleinere Wellenlänge haben. So haben wir 4703,33, ROWLAND 4703,17; wir 5528,75, ROWLAND 5528,62. Unschärfe nach Roth verleitet ja leicht der Linie grössere Wellenlänge zuzuschreiben; so gross kann aber der Fehler nicht sein, denn die ROWLAND'sche Ablesung liegt ganz ausserhalb des Randes unserer Linie. Wir wissen daher nicht, woher diese Differenz rührt." KAYSER has later[1]) given an explanation of this fact, based on a combination of reversal with asymmetrical widening; but a more probable solution is, in my opinion, to regard the widened serial lines as dispersion bands.

If we namely assume that, when we proceed from the positive carbon point, which emits the brightest light, to the middle of the arc, the number of the particles associated with the second secondary series decreases, then rays coming from the crater and whose wavelength is slightly greater than that of the said serial lines will be curved so as to turn their concave side to the carbon point. Their origin is erroneously supposed to be in the prolongation of their final direction, so they *seem* to come from the arc, and one believes

[1]) LIVEING and DEWAR, On the reversal of the lines of metallic vapours, Proc. Roy. Soc. 27, p. 132—136; 28, p. 367—372 (1878—1879).

[2]) KAYSER und RUNGE, Über die Spektren der Elemente, IV, S. 13.

[1]) KAYSER. Handbuch der Spektroskopie II, S. 366.

to see light emitted by the vapour, in which light different wavelengths occur, all greater than the exact wave-length of the serial lines. The observed displaced lines of the second secondary series are consequently comparableto apparent emission lines of the spectrum *d* of our plate I.

In this explanation things have been represented as if the light of .these serial lines had to be *exclusively* attributed to anomalous dispersion. Probably however in the majority of cases emission proper will indeed perceptibly contribute to the formation of the line; the sharp edge must then appear in the exact place belonging to the particular wave-length.

How can we now explain that lines of other series are diffuse at the opposite side? Also this may be explained as the result of anomalous dispersion if we assume that of the emission centres of these other series the density *increases* when we move away from the positive carbon point. In this case namely the rays originating in the crater, which are concave towards the carbon point and consequently seem to come from the arc, possess shorter wave-lengths than the serial lines, i. e. the serial lines appear widened towards the violet. This supposition is not unlikely. For the positive and negative atomic ions which according to STARK's theory are formed in the arc by the collision of negative electronic ions, move in opposite directions under the influence of the electric field; hence the density gradients will have opposite signs for the two kinds. Series whose lines are diffuse towards the red and series whose lines flow out towards the violet would, according to this conception, belong to atomic ions of opposite signs — a conclusion which at all events deserves nearer investigation.

The examples given may suffice to .show that it is necessary systematically to investigate to what extent the already known spectral phenomena may be the result of anomalous dispersion. A number of cases in which the until now neglected principle of ray-curving has undoubtedly been at the root of the matter are found in KAYSER's handbook II, p. 292—298, 304, 306, 348—351, 359—361, 366.

Dispersion bands in the spectra of celestial bodies.

Since almost any peculiarity in the appearance of spectral lines may be explained by anomalous dispersion if only we are at liberty to assume the required density distributions, we must ask when applying this principle to astrophysical phenomena: can the values of the density gradient for the different absorbing gases in celestial

bodies really be such, that the rays are sufficiently curved to exert such a distinct influence on the distribution of light in the spectrum?

In former communications [1] I showed that the sun e.g. may be conceived as a gaseous-body, the constituents of which are intimately mixed, since all luminous phenomena giving the impression as if the substances occurring in the sun were separated, may be brought about in such a gaseous mixture by anomalous dispersion. We will now try to prove that not only this *may* be the case, but that it *must* be so on account of the most likely distribution of density.

Let us put the density of our atmosphere at the surface of the earth at 0.001293. At a height of 1050 cms. it is smaller by $\frac{1}{760}$ of this amount, so that the vertical density gradient is

$$\frac{0.001293}{1050 \times 760} = 16 \times 10^{-10}.$$

The horizontal gradients occurring in the vicinity of depressions are much smaller; even during storms they are only about $\frac{1}{1000}$ of the said value [2]. Over small distances the density gradient in the atmosphere may of course occasionally be larger, through local heating or other causes.

Similar considerations applied to the sun, mutatis mutandis, cannot lead however to a reliable estimate of the density gradients there occurring. A principal reason why this is for the present impossible is found in our inadequate knowledge of the magnitude of the influence, exerted by *radiation pressure* on the distribution of matter in the sun. If there were no radiation pressure, we might presuppose, as is always done, that at the level of the photosphere gravitation is 28 times as great as on the earth; but it is counteracted by radiation pressure to a degree, dependent on the size of the particles; for some particles it may even be entirely abolished. The radial density gradient must, therefore, in any case be much smaller than one might be inclined to calculate on the basis of gravitational action only.

Fortunately we possess another means for determining the radial density gradient in the photoshere, at any rate as far as the order of magnitude is concerned. According to SCHMIDT's theory the photosphere is nothing but a critical sphere the radius of which is equal

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[1] Proc. Roy. Academy Amsterdam, II, p. 575; IV, p. 195; V, p. 162, 589 and 662; VI, p. 270; VIII, p. 184, 140 and 323.

[2] ARRHENIUS. Lehrbuch der kosmischen Physik, S. 676.

to the radius of curvature of luminous rays whose path is horizontal at a point of its surface. This radius of curvature is consequently $\varrho = 7 \times 10^{10}$ cms., a value which we may introduce into the expression for the density gradient:

$$\frac{d\Delta}{ds} = \frac{1}{R\varrho}$$

The refractive equivalent R for rays that undergo no anomalous dispersion varies with different substances, to be sure; but in an approximate calculation we may put $R = 0,5$. Then at the height of the critical sphere we shall have :

$$\frac{d\Delta}{ds} = \frac{1}{0.5 \times 7 \times 10^{10}} = 0.29 \times 10^{-10},$$

(this is 50 times less than the density gradient in our atmosphere). All arguments supporting Schmidt's explanation of the sun's limb, are at the same time in favour of this estimate of the radial density gradient in the gaseous mixture.

Let us now consider rays that do undergo anomalous dispersion. In order that e.g. light, the wave-length of which differs but very little from that of one of the sodium lines, may seem to come from points situated some arc seconds outside the sun's limb, the radius of curvature of such anomalously bent rays need only be slightly smaller than 7×10^{10} cms. Let us e.g. put

$$\varrho' = 6 \times 10^{10} \text{ c.m.}$$

If we further assume that of the kind of light under consideration the wave-length is 0.4 Ångström-units greater than that of D_1, then for this kind of light $R' = 1600$, as may be derived from the observations of Wood and of Jewett [1]; we thus find for the density gradient of the sodium vapour

$$\frac{d\Delta'}{ds} = \frac{1}{R'\varrho'} = \frac{1}{1600 \times 6 \times 10^{10}} = 0.0001 \times 10^{-10},$$

a quantity, 2900 times smaller than the density gradient of the gaseous mixture.

Hence if only $\frac{1}{3000}$ part of the gaseous mixture consists of sodium vapour, then, on account of the radial density gradient, the critical sphere will already seem to be surrounded by a "chromosphere" of light, this light having a striking resemblance with sodium light. This kind of light has, so to say, its own critical sphere which is larger than the critical sphere of the not anomalously refracted light. If the

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[1] See page 352.

percentage of sodium were larger, the "sodium chromosphere" would appear higher.

It is customary to draw conclusions from the size of the chromospheric and flash crescents, observed during a total eclipse with the prismatic camera, as to the *height* to which various vapours occur in the solar atmosphere. According to us this is an unjustified conclusion. On the other hand it will be possible to derive from these observations data concerning *the ratio in which these substances are present in the gaseous mixture*, provided that the dispersion curves of the metallic vapours, at known densities, will first have been investigated in the laboratory.

Until now we only dealt with the normal radial density gradient. By convection and vortex motion however irregularities in the density distribution arise, with gradients of various direction and magnitude. And since on the sun the resultant of- gravitation and radiation pressure is relatively small, there the irregular density gradients may sooner than on the earth reach values that approach the radial gradient or are occasionally larger.

The incurvation of the rays in these irregularities must produce capriciously shaped sodium prominences, the size of which depends, among other causes, on the percentage of sodium vapour in the gaseous mixture.

So the large hydrogen and calcium prominences prove that relatively much hydrogen and calcium vapour is present in the outer parts of the sun; but perhaps even an amount of a few percents would already suffice to account for the phenomena [1].

If we justly supposed that non-radially directed density gradients are of frequent occurrence in the sun, and there disturb the general radial gradient much more than on the earth, then not only rays from the marginal region but also rays from the other parts of the solar disc must sensibly deviate from the straight line. Chiefly concerned are of course the rays that undergo anomalous dispersion. *Every absorption line of the solar spectrum must consequently be enveloped in a dispersion band.*

To be sure, absorption lines of elements which in the gaseous mixture only occur in a highly rarefied condition, present themselves as almost sharp lines, since for these substances all density gradients are much smaller than for the chief constituents, and so the curvature of the rays from the vicinity of these lines becomes imperceptible.

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[1] This result would be in accordance with a hypothesis of Schmidt (Phys. Zeitschr. 4, S. 232 and 341) according to which the chief constituent of the solar atmosphere would be a very light, until now unknown gas.
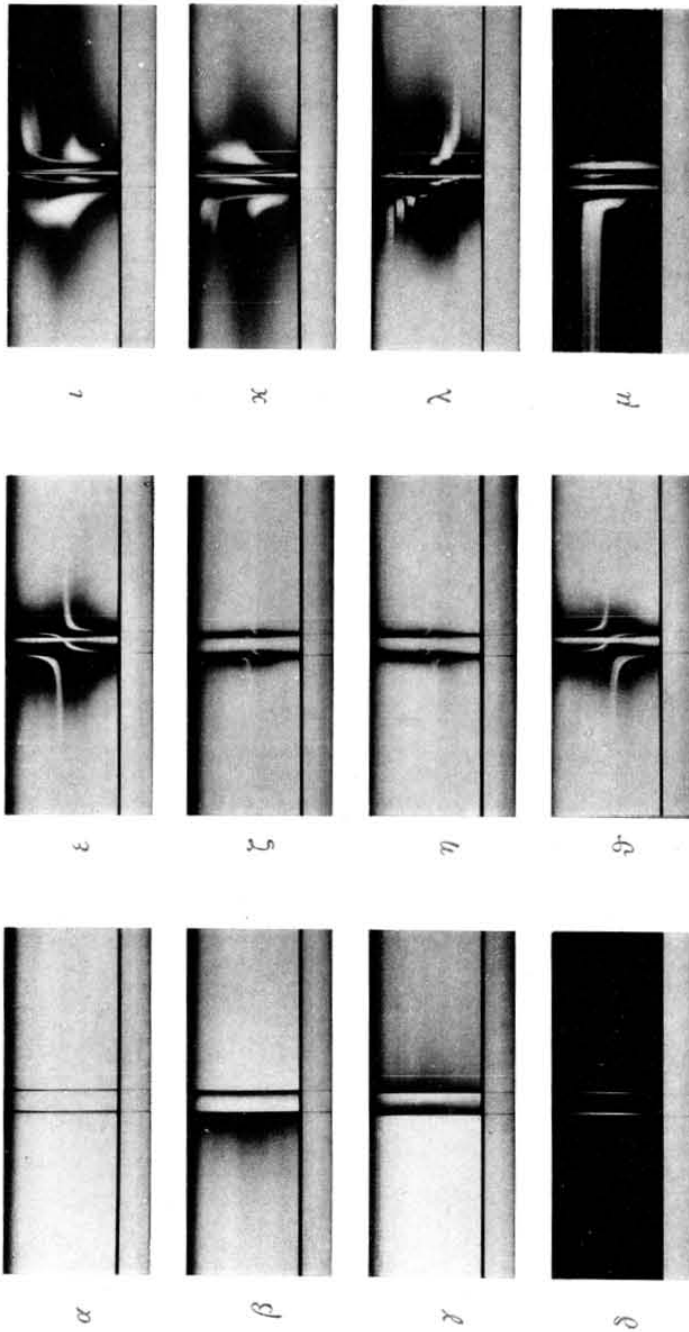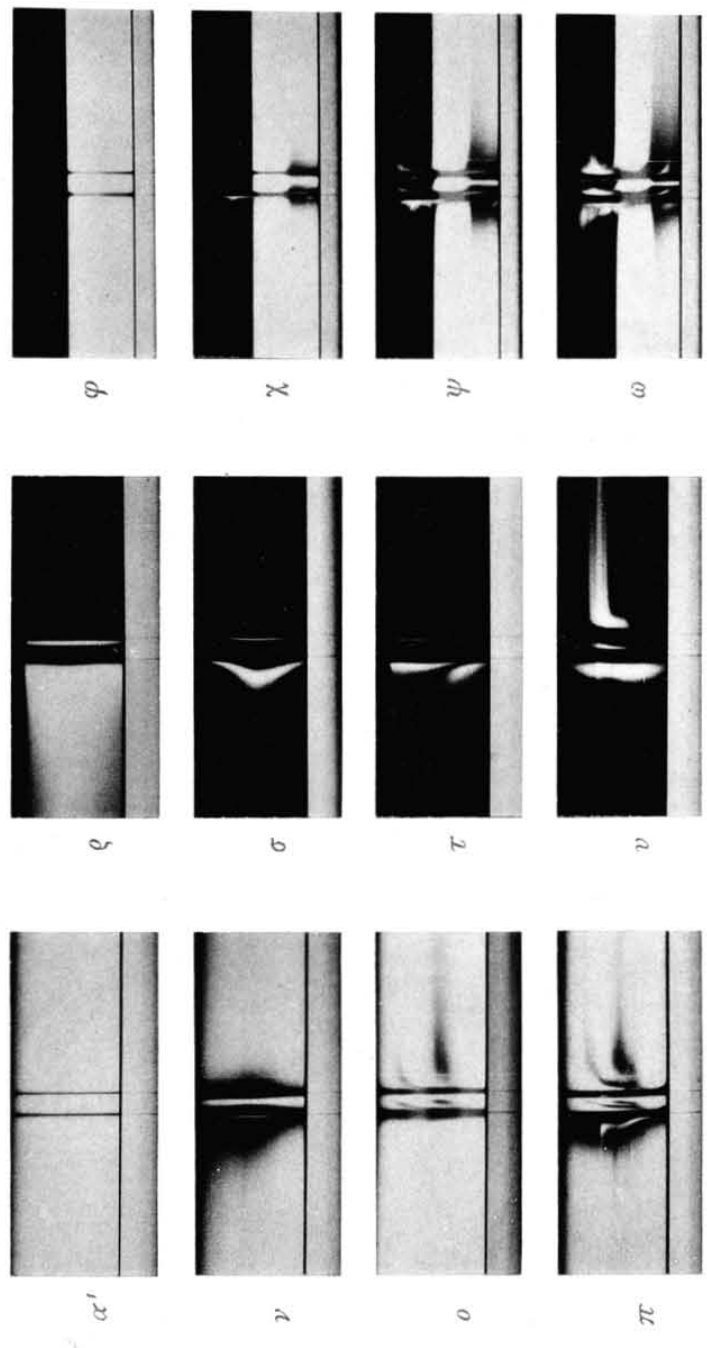
Heliotype, Van Leer, Amsterdam.

Heliotype, Van Leer, Amsterdam.

Also of strongly represented elements some lines may appear sharp, since not all lines of the same element, with given density, cause anomalous dispersion in the same degree. Perhaps even there are absorption lines which under no condition give rise to this phenomenon; though this were rather improbable from the point of view of the theory of light.

Be this as it may, the mentioned limitations do not invalidate our principal conclusion: that the general interpretation of the solar spectrum has to be modified. We are obliged to see in FRAUNHOFER's lines not only absorption lines, as KIRCHHOF does, but chiefly dispersion bands (or dispersion lines). And that also on the distribution of light in the stellar spectra refraction has a preponderant influence, cannot be doubted either.

We must become familiar with the idea that in the neighbourhood of the celestial bodies the rays of light are in general curved, and that consequently the whole interstellar space is filled with *non-homogeneous radiation fields* [1]) of different structure for the various kinds of light.

Chemistry. — *"On a substance which possesses numerous* [2]) *different liquid phases of which three at least are stable in regard to the isotropous liquid."* By Dr. F. M. JAEGER. (Communicated by Prof. H. W. BAKHUIS ROOZEBOOM).

§ 1. The compound which exhibits the highly remarkable phenomena to be described, is *cholesteryl-cinnamylate*: $C_{27} H_{45} O_2 C . CH : CH C_6 H_5$.

I have prepared this substance by melting together equal quantities of pure cholesterol and cinnamyl-chloride in a small flask, which was heated for about two hours in an oilbath at 190°. It is of the greatest importance, not to exceed this temperature and the time of heating, as otherwise the liquid mass, which commences to darken, even under these conditions, yields instead of the desired derivative a brown resin which in solution exhibits a green fluorescence.

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[1]) Das ungleichmassige Strahlungsfeld und die Dispersionsbanden. Physik. Zeitschr. 6, S. 239—248, 1905.

[2]) In the Dutch publication, I have said : five. Since that time however, more extended microscopical observation has taught me, that probably there are an infinite number of anisotropous liquid phases, no sharply fixed transition being observed in this manner. The hypothesis, that the transition of the first anisotropous liquid phase into the isotropous should be continuous, would therefore be made more probable in this way. However there are observed some irreversibilities by passing from solid to liquid state and vice-versa, which yet I cannot explain at this moment.