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ACADEMISCH PROEFSCHRIFT TER VERKRIJGING VAN DEN GRAAD VAN DOCTOR IN DE WIS- EN NATUURKUNDE AAN DE RIJKS-UNIVERSITEIT TE UTRECHT, OP GEZAG VAN DEN RECTOR-MAGNIFICUS DR. A. J. P. VAN DEN BROEK, HOOGLEERAAR IN DE FACULTEIT DER GENEESKUNDE, VOLGENS BESLUIT VAN DEN SENAAT DER UNIVERSITEIT, TEGEN DE BEDENKINGEN VAN DE FACULTEIT DER WIS- EN NATUURKUNDE TE VERDEDIGEN, OP MAANDAG 19 MEI 1924, DES NAM. TEN 4 URE DOOR

HENDRIK BEREND DORGELO

GEBOREN TE AVEREEST (O.)

ELECTRISCHE DRUKKERIJ „DE INDUSTRIE" J. VAN DRUTEN — UTRECHT

AAN MIJNE OUDERS

Het is mij een voorrecht U, Hoogleeraren van de Faculteit der Wis- en Natuurkunde, mijn oprechten dank te kunnen brengen voor het onderwijs, dat ik van U heb mogen ontvangen en voor de welwillendheid, waarmede gij mij zoo vaak zijt tegemoet gekomen.

Allermeest geldt mijn dank U, Hooggeleerde Ornstein, Hooggeachte Promotor. Met hartgrondige dankbaarheid denk ik terug aan alles wat gij voor mij hebt willen zijn gedurende den tijd, dat ik uw assistent was en aan de voortdurende steun en bezieling bij de bewerking van dit proefschrift ondervonden. Gij bezit het geheim, om U heen te scheppen een sfeer van vriendschap, waarin gewerkt wordt uit liefde voor de arbeid en voor de wetenschap. Ik acht mij gelukkig deel uit te maken van den kring Uwer leerlingen.

Hooggeleerde Julius, door mij indertijd tot Uw assistent aan te stellen, hebt gij mij zeer aan U verplicht. Ik dank U voor de welwillendheid mij toen en later betoond.

U, Hooggeleerde Heeren De Vries, Nijland, Denjoy, Van Everdingen, breng ik dank voor het onderwijs van U genoten. Dat ik gedurende de mobilisatiejaren Uwe colleges niet ten volle heb kunnen volgen, heb ik steeds betreurd.

Zeergeleerde Burger, steeds hebt gij onverflauwde belangstelling getoond voor den gang en de resultaten van mijn onderzoek. Uw steun, vooral bij de bewerking van het laatste hoofdstuk van mijn proefschrift, waardeer ik in hooge mate.

U, Zeergeleerde Heeren Moll, Van Cittert en Minneart dank ik voor de bereidwillige hulp, welke ik van U nooit vergeefs heb gevraagd.

Niet minder stel ik op prijs de vriendelijke steun en raad, waarde Van Dijck, welke gij mij steeds geboden hebt.

Van den oprechten en aangenamen vriendschappelijken omgang met U, vrienden, assistenten en personeel van het Physisch Laboratorium zal ik steeds zeer prettige herinneringen bewaren.

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INTRODUCTORY.

By means of the work of many investigators in the field of spectroscopy an interesting regularity has been discovered in the spectra of many elements. This regularity regards the appearance of spectral lines in series and the occurrence of characteristic magnetic separations. These phenomena have been connected with the structure of the atoms by Bohr, Sommerfeld, Landé a. o.

The investigation of the intensity-ratios of the components in "multiple" spectral lines, which will be discussed in this dissertation, brings out a new regularity which must be made to fit in the framework of the theory of the spectral lines.

The intensity of the spectral lines gets a fundamental significance in addition to its wave-length.

Our experiments were restricted to the visible part of the spectrum.

We began by examining the groups of spectral lines occurring in the sharp series which according to Bohr's theory are caused by the "outer" electron falling from one initial energy-level to two or more final levels, a transition from the single *s*-level to the double and triple *p*-level corresponding to doublets and triplets respectively. For in the first place the ratios between the intensities of the components that then appear at once indicate the ratios of the probabilities of transition, and in the second place the phenomenon in this case is independant of the excitation-conditions of the atom. The ratios of the intensities of the various components of the groups of the sharp series will therefore immediately be proportional to the ratios of the transition-probabilities of the electron from the single *s*-level to the various *p*-levels.

With the aid of the methods to be described in the first chapter we therefore first measured the ratios of the intensities of lines of

I. Doublets of the sharp series of the alkalis *Na*, *K*, *Rb* and *Cs*.

II. Triplets of the sharp series of the earth-alkalis *Mg*, *Ca*, *Zn* and *Cd*.

We found with the triplets such a regularity in the numbers which indicated the ratios of the intensities of the three components of the earth-alkalis, that it induced us to a further examination of triplet-, quartet-, quintet-, sextet-, septet- and octetsystems. We were able to do this for:

III. a triplet of the sharp series of a sextetsystem of *Mn*

IV. a triplet of the sharp series of an octetsystem of *Mn*.

The groups of lines of the diffuse series ($p\,d$ series) with the alkalis consist of doublets if the δ-levels are not separated or only so little that this does not cause a perceptible separation of the spectral lines.

These doublets are caused by the transition of the "outer" electron of a still unseparated δ-energy-level to the two π_1- and π_2-energy-levels. [1])

The ratio of the intensities of the two components will therefore here represent the ratio of the probabilities of transition of the electron from the δ-level to the two π-levels.

In consequence of the δ-levels being more separated with the heavier metal *Cs*, the so called "complex"-doublets [2]) appear consisting of three components.

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[1]) As regards the symbols of the spectral lines we adopt the notation of A. FOWLER. (Report on Series in Line spectra 1922).

[2]) These groups of lines are called by LANDÉ "Vollständige Dublette". A. LANDÉ Z. f. Phys. V, 232, 1921.

With the $p\,d$-groups of the earth-alkalis, where the p- as well as the d-levels are threefold, "complex"-triplets appear with sufficient separation of the d-levels, which triplets consist of a group of six lines.

Of the groups of lines of the diffuse series we measured:

V. single doublets of *Na*, *K*, *Rb*.

VI. the "complex"-triplet $1\,\pi - 5\,\delta$ of *Cs*.

VII. the "complex"-triplet $1\,p - 2\,d$ of *Ca*.

The ratios of the intensities of the components of the groups of lines of the Bergmann-series ($\delta\,\phi$-series) of the alkalis could not be examined by our method, partly because of their too weak intensity partly because of their lying in the infra-red.

Of the Bergmann-series of the earth-alkalis the triplet $1\,d - 3\,b$ of *Ca* lent itself first of all to closer examination. As this triplet appears, its b-levels being not yet sufficiently separated to give the "complex"-triplet, we have to deal with transitions of the „outer" electron from one b-level to the three d-levels.

In the same way as the ratios of the intensities of the components of a triplet of the sharp series will give us the ratios of the probabilities of transition of the "outer" electron from the single s-level to the three p-levels, the ratios of the intensities of the components of these single triplets will give us the ratios of the probabilities of transition from the single b-level to the three d-levels.

In this way we measured:

VIII. The triplet $1\,d - 3\,b$ of *Ca*.

As in the numerical values which we obtained for the ratios of the intensities of the components of this triplet an interesting regularity was noticed, we have also extended our investigation to a "complex"-triplet of the $d\,b$-series. The "complex"-triplet $1\,d - 3\,b$ of *Sr* could be separated in the third order spectrum by our spectrograph, so that we were able to investigate this triplet of the Bergmann series.

Therefore was also measured:

IX. The "complex"-triplet $1\,d - 3\,b$ of *Sr.*

It appeared that the resulting ratios of the intensities of the components of the "complex"-doublets and triplets were characterised by the internalquantum-numbers of the initial and final states of the atom. This suggested the question how the components of doublets and triplets of the principal series would behave in this respect.

With these doublets and triplets the initial levels are separated but the final level is single.

In consequence for the results for the "complex"-doublets and triplets, it might be expected that here the ratios of the intensities of the components would be characterised by the internal quantum-numbers of the initial states (see on this subject chapter III).

According to this point of view the ratios of the intensities of the components of doublets and triplets of the principal series must show the same values as these of analogous groups of lines of the sharp series.

On investigating the groups of lines of the principal series of the alkalis the difficulty of selfreversion makes itself felt to a high degree. By diminishing the concentration of the salt in the arc I succeeded in obtaining the doublet $1\,\sigma - 2\,\pi$ (λ 4555,26, 4593,16) of *Cs* practically free from selfreversion.

It was further possible to investigate the triplet of the principal series $1\,s^a - 2\,p^a$ (5208,42; 5206,05 and 5204,51) of the quintet-system of *Cr.*

Of the various groups of the principal series we measured:

X. the doublet $1\,\sigma - 2\,\pi$ of *Cs* and
the triplet $1\,s^a - 2\,p^a$ of the quintet-system of *Cr.*

With a view to the rules obtained for the ratios of the intensities of the components of multiple spectral lines it seems to me to be of great importance to investigate quantitatively the ratios of the intensities of the components with the anomalous ZEEMAN-separations as well.

This investigation has already been started.

The "method A" we are going to describe lends itself immediately to this purpose.

It is also interesting to investigate, whether the ratios of the intensities of multiple spectral lines is dependent on the conditions of excitation. We have investigated this for some doublets and triplets of the sharp series, but the result was in the negative (see page 32 and 34.)

Finally I wish to point out, that "method B" (chapter I *b*) also makes it possible to investigate how under definite conditions for excitation the intensities of the lines of the successive numbers of a series decreases.

CHAPTER I.

Description of the Method.

METHOD A.

a. *For groups of lines of which the components have small differences in wave-length.*

If two intensities of light of the same (or almost the same) wave-length are equal, they cause in the same time the same density on different places of the same photographic plate.

We can avail ourselves of this fact to measure intensities with the aid of the photographic plate. The method most commonly used to compare the intensity of two close-lying spectral lines consists in photographing the lines with a properly chosen time of exposure and of making some more exposures on the same plate after reducing the light in definite degrees.

From the photographs obtained in this way the curve of densities is constructed (comp. p. 15).

This method has not only the drawback that it takes much time but still more that it requires a constant source of light, which condition is but poorly fulfilled with most sources of light which emit line-spectra. Especially for groups of weak lines which require a long exposure this method takes very much time. The photograph must be taken with five intensities at the very least, so that, if each exposure requires already a considerable time, the method referred to will take a five times longer time.

Instead of taking the spectrum a few times, weakened to certain kwown degrees, markes of intensity are often applied, by exposing the same plate during the same time of the original exposure to light of the same wave-length and kwown ratio of intensity.

The marks of intensity provide us with the functional relation between density and intensity, that holds good for the plate in question, i. e. the curve of densities.

This method takes a good deal of time as well and moreover it has the drawback that it is impracticable with intermittent sources of light in consequence of the intermittence-effect.

These drawbacks do not occur with the method which will be described below.

A source of light *Li* (see fig. 1) illuminates uniformly a lens Le_1, which forms an image of the source of light *Li* on a second lens Le_2.

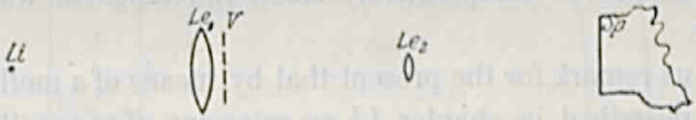

Fig. 1.

This lens Le_2 gives a well-defined image of a series of smoke-glass-plates (Rauchglas) *V* which weaken to a known degree the light that has passed through Le_1 on the slit *Sp* of the spectrograph. The used smoke-glass-plates were supplied by Zeiss. By means of Canadabalsem they were stuck on a plan-parallel glass-plate so that a scale was formed, the different parts of which transmitted ± 70, ± 55, ± 35 and ± 25 % respectively of the incident light.

The curves of fig. 9, page 28 represent the power of transmittance of the reducers for different wave-lengths. From these curves it is evident that these reducers show little selective absorption.

In this way the slit of the spectrograph is as it were divided into parts, on which light falls of various degrees of intensity[1]).

Care has been taken that a maximum amount of light falls on the grating of the spectrograph and in such a way that all the light that falls on the slit is used. The spectra of the source of light weakened to different degrees are therefore formed simultaneously on the plate (see plate I).

If the ratio of the intensities, which one wishes to measure, does not depend on the total intensity of the source of light[2]), the drawback with earlier methods caused by the instability of the source of light is removed by our method.

Now one must take into account the fact that the density caused by the same quantities of energy is dependent on the wave-length.

The method, which we have described, is therefore restricted to a comparatively small difference in wave-length.

Let us remark for the present that by means of a method to be described in chapter I *b* an extension of my method can easily be obtained for the investigation of spectral lines, which are lying so far apart that the supposition in question does not hold good any longer.

The spectrograph with which the photographs were made is the grating-spectrograph of the Physical Laboratory at Utrecht[3]).

Its arrangement gives perfectly stigmatic images, which is of course necessary for our method, because from every point of the slit a sharp image must be formed on the plate.

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[1]) It is also possible to take uniformly blackened photographic plates instead of the smoke-glass-plates. These cause however scattering of the light, that falls on them. See dissertation Utrecht 1923, R. RIWLIN, pag. 17.

[2]) Which is confirmed by the results.

[3]) P. H. VAN CITTERT. Z. S. für Instr.k. 41, 116—118, 1921.

The spectrograph is mounted on two columns of masonry: a rectangular one *A* (see fig. 2) and one in the shape of the quadrant of a circle with a radius of 2 M.

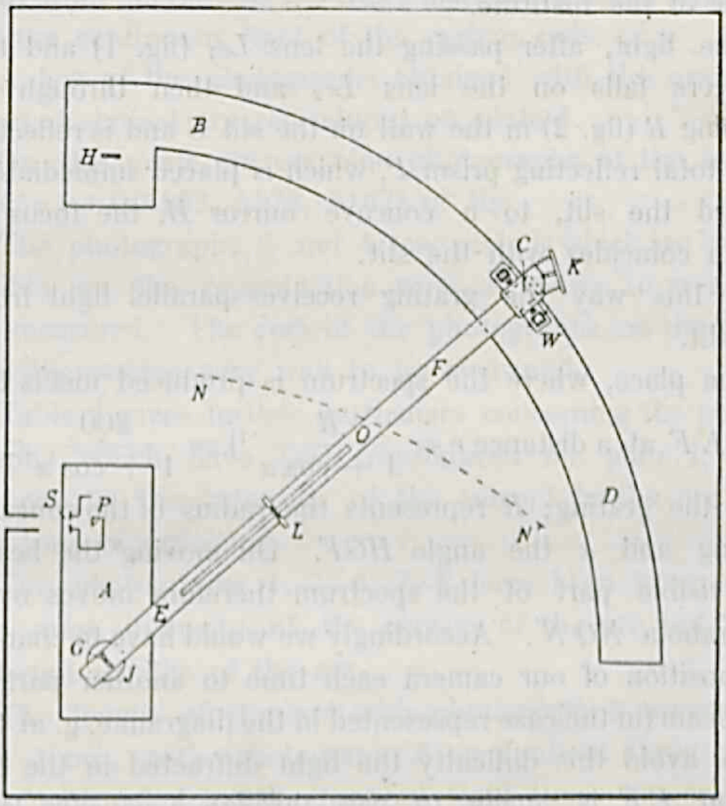

Fig. 2.

In the centre *G* of this quadrant a bronze vertical axis *J* is placed, on which rests a double *T* shaped heavy iron beam *EF* about 2 M. long.

At the other end this beam is supported by a small bronze carriage *W*, which can move over the column *B D*.

This little carriage has the shape of the segment of a circle of a radius of 2 M. and rests on wheels, the axes of which are directed towards the centre *G*, so that, even when it moves freely the carriage describes a circle of a radius of 2 M.

In *G* the concave grating is mounted in such a way that its normal is parallel to the beam *EF*.

The grating is an original Rowlandgrating of the size of $2\,{}^{1}/_{2} \times 5$ c.M^2. and contains 568 lines to the m.M. The radius of curvature amounts to 2 M. The whole apparatus is placed in a room apart from the optical cellar of the Institute.

The light, after passing the lens Le_1 (fig. 1) and the reducers falls on the lens Le_2 and then through an opening R (fig. 2) in the wall on the slit S and is reflected by a total reflecting prism P, which is placed immediately behind the slit, to a concave mirror H, the focus of which coincides with the slit.

In this way the grating receives parallel light from the slit.

The place, where the spectrum is produced meets the line EF at a distance $r = \frac{R}{1 + \cos \alpha}$ [1] $= \frac{200}{1 + \cos \alpha}$ c.M. from the grating; R represents the radius of the concave grating and α the angle HGF. On moving the beam the visible part of the spectrum therefore moves over a parabola NON'. Accordingly we would have to change the position of our camera each time to another part of the beam (in the case represented in the diagram e. g. at O).

To avoid this difficulty the light diffracted in the direction EF is made to pass through a concave lens ($f = 76{,}5$ c.M.) so that an image is not formed in O but an enlarged and wel-defined one in C. The dispersion amounts to about 5 Å per m.M. for a wave-length of 5400 Å in the first order, 3 Å per m.M. in the second and 1,8 Å per m.M. in the third order.

The source of light which was used was an electric arc, the carbons of which are cored and packed respectively with suitable salts of those metals of which the spectra would be examined (concerning this see the statement of the results for doublets and triplets of the various metals).

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[1] FABRY et BUISSON Journ. de Phys. 40 S. 9, pag. 933, 1910.

The electric arc was with the necessary resistance connected with the current 220 Volt of the town's powerstation. The lens Le_1 had a focal-length of 60 c.M. and Le_2 of 80 c.M.

In front of the lens Le_2 was a diaphragm which screened off the continuous light of the carbon rods.

A few of the photographs obtained with the arrangement described are reproduced on plate I.

On this plate we see nine photographs of the triplet $1\,p - 1\,s$ (λ 5183, 5172, 5167) of Mg.

The photographs 3 and 4 (see plate I) which are barely visible on the reproduction were of course to weak to be measured. The rest of the photographs on the plate lent themselves very well to be measured.

Table I gives further particulars concerning the photographs which have been reproduced on plate I, with respect to the intensity of the current in the arc and the time of exposure.

The photographs 1, 5, 6, 7, 8 have been taken with the same intensity of the current of the arc but with different lengths of the arc.

The length of the arc with photograph 1 was about five times, with photograph 6 en 7 about three times and with photograph 8 about eight times longer than with photograph 5.

TABLE 1 (Plate I Mg.)

Number of the photograph.	Wave-length.	i	Time of exposure.
1	5183-5172-5167	5,5 A	4 minutes
2	„	10 à 11 A	5 „
5	„	5,5 A	3 „
6	„	5,5 A	5 „
7	„	5,5 A	5 „
8	„	5,5 A	8 „
9	„	2,2 A	7 „

Part *a* (see plate I) of the spectral line is unweakened being caused by the light of the arc, which has not passed through a reducer. This intensity we call 100 %. The densities of the parts *b*, *c*, *d*, *e* and *f* have been caused bij relative intensities of 69 % (*b*), 56 % (*c*), 35 % (*d*) and 26 % (*e*), corresponding with the power of transparency of the reducers, for light of a wave-length of 518 $\mu\mu$.

The density of part *a* as well as that of part *f* of the line has been caused by the intensity of the unweakened light. We always investigated whether the density of part *a* was equal to that of part *f*, which was a test whether all reducers *V* (see fig. 1) were uniformly illuminated by the source of light. When the densities of the parts *a* and *f* are not equal this can also be caused by lack of uniformity in the sensitiveness of the photographic plate over the surface. All plates, on which the density of the parts *a* and *f* differed considerably have been rejected.

Every spectral line is therefore produced on the plate in different degrees of density (according to the number of reducers), caused by intensities of which the ratio's are known, so that for every spectral line the curve of densities can be constructed.

The densities were measured with the micro-photometer of Moll. [1]

A more detailed description of this instrument, which is particularly well adapted to measure quickly and accurately the density of narrow spectral regions, may be omitted here.

By density of a homogeneously affected part of the photographic plate is usually meant Brigg's logarithm of $\frac{i_0}{i}$, in which i and i_0 represent the intensity of the radiation, which has passed through the exposed and the unexposed part of the plate respectively. The ratio between these intensities is found by measuring the

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[1] Kon. Ak. v. Wet. 27, 566, 1919.

ratio between the corresponding deviations u and u_0 of the mirror of the galvanometer of the microphotometer.

For the deviation of the mirror is proportional to the thermo-current in the galvanometer and this current is proportional to the energy, which falls on the places of contact of the thermopile.

So we can write for the density Z

$$Z = \log \frac{i_0}{i} = \log \frac{u_0}{u}.$$

The way in which the ratio between the intensities of the lines of a group was determined from the obtained densities will be described by taking as an example the investigated triplet $1\,p - 1\,s$ of Mg (λ 5183, 5172, 5167) of plate 63^1.

For the different parts a, b, c, d, e and f (see plate I) of the spectral lines λ 5183, 5172, 5167 the deviations u were measured with the aid of the microphotometer.

These deviations u and the deviation u_0 for part a of the plate not affected by light are given in table 2.

TABLE 2.

Plate 63^1.

Part of the line.	Rel. Intensity.	u_0	u_1 for the line 5183.	u_2 for the line 5172.	u_3 for the line 5167.
a	100 %	8,02 c.M.	1,15 c.M.	1,76 c.M.	4,24 c.M.
b	69 %	„	1,60 „	2,48 „	5,32 „
c	56 %	„	1,94 „	2,84 „	5,80 „
d	35 %	„	2,95 „	4,31 „	6,97 „
e	26 %	„	3,83 „	5,34 „	7,50 „
f	100 %	„	1,12 „	1,75 „	4,14 „

From the obtained values u_0, u_1, u_2, and u_3 the value $z = \log \frac{u_0}{u}$ for each part a, b, c, d, e and f of a line can be computed. When the density Z of these different parts of the spectral line is plotted against the intensy I of the light that has fallen on the plate (the abscissa being taken proportional not to the intensity itself, but to log I as is usually done) we get the curve of densities. We did not however plot as ordinate the value $\log \frac{u_0}{u}$ but the value $\frac{u}{u_0}$. In the case that all deviations u_0 are equal for all unaffected parts near the investigated line, we can readily plot as ordinates the values u obtained with the photometer for the different densities on the plate.

This way of doing has in the first place the advantage of requiring less computing (for we plot at once the values u given by the photometer, which are read off visually) and in the second place the inclination of the curve of densities obtained in this way gives us an indication, whether the plate has been well developed. The more steep the inclination of the obtained curves the stronger the contrasts between the densities caused by different intensities.

In this way the line λ 5183 gave the curve $A\,B$ of fig. 3, in which the intensity of the investigated line of the unweakened spectrum a, has been arbitrarily supposed to be equal to 100, so that the intensities of the other four parts b, c, d and e have the values, given by the power of transmittance of the used reducers expressed in table 2.

Now, if for the second (weaker) line λ 5172 of the triplet we suppose again that the intensity of the unweakened line is 100, we obtain the curve $C\,D$ for this line. The intensity of the unweakened line is however not 100 but less and the diminished intensities of this line are less in the same ratio. Accordingly each of the points of $C\,D$ must be displaced to points, where the intensity is smaller in a definite ratio, the value u being retained. As the abscissa represents log i, this means a shifting

Curves of density Mg λ 5183, 5172, 5167

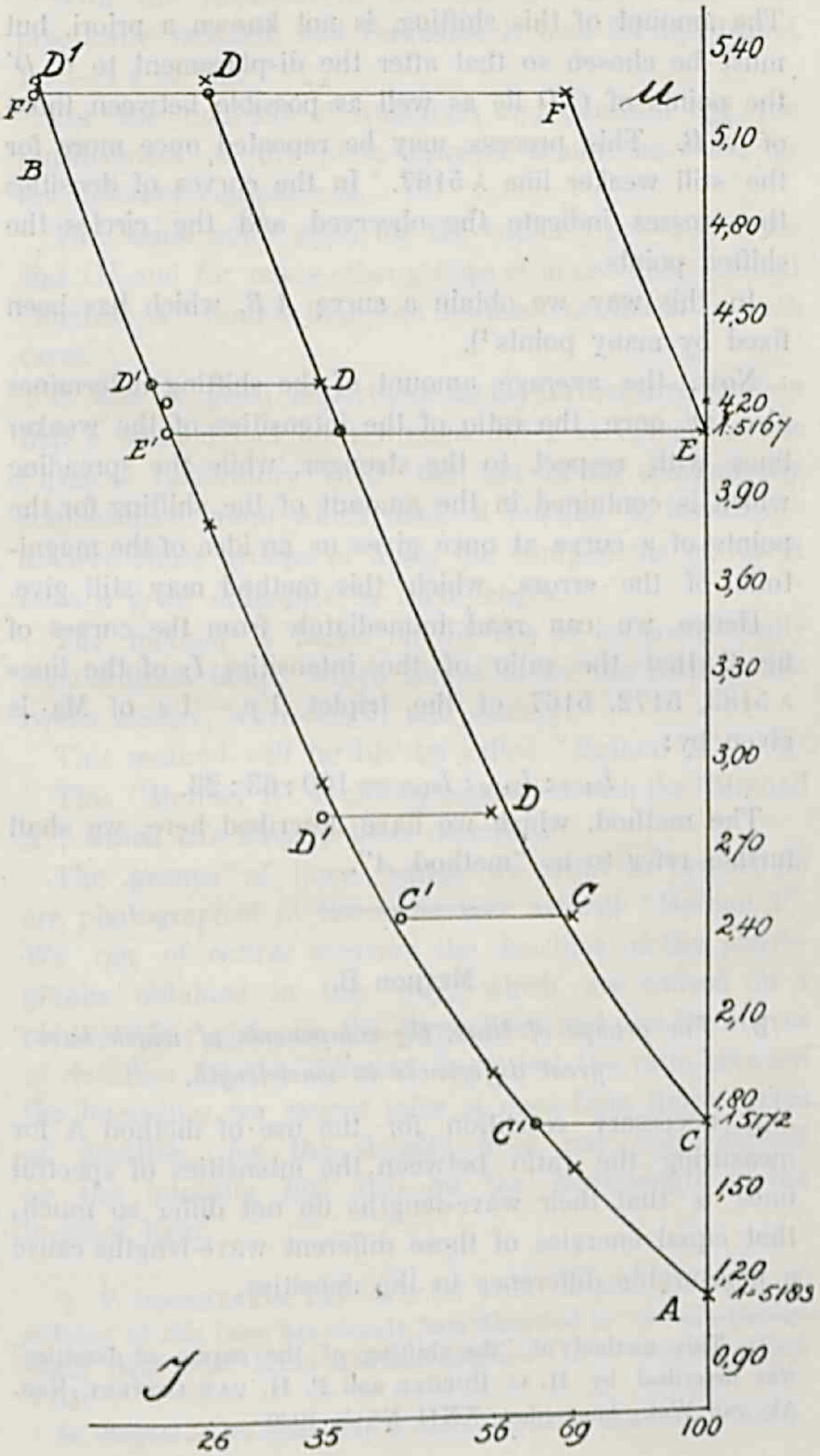

FIG. 3.

of the points of $C\,D$ over equal distances towards the left. The amount of this shifting, is not known a priori, but must be chosen so that after the displacement to $C'\,D'$ the points of $C\,D$ lie as well as possible between those of $A\,B$. This process may be repeated once more for the still weaker line λ 5167. In the curves of densities the crosses indicate the observed and the circles the shifted points.

In this way we obtain a curve $A\,B$, which has been fixed by many points[1]).

Now, the average amount of the shifting determines also at once the ratio of the intensities of the weaker lines with respect to the stronger, while the spreading which is contained in the amount of the shifting for the points of a curve at once gives us an idea of the magnitude of the errors, which this method may still give.

Hence we can read immediately from the curves of fig. 3 that the ratio of the intensities I_λ of the lines λ 5183, 5172, 5167 of the triplet $1\,p - 1\,s$ of Mg is given by:

$$I_{5183} : I_{5172} : I_{5167} = 100 : 63 : 23.$$

The method, which we have described here, we shall further refer to as "method A".

METHOD B.

b. *For groups of lines, the components of which have great differences in wave-length.*

A necessary condition for the use of method A for measuring the ratio between the intensities of spectral lines is that their wave-lengths do not differ so much, that equal energies of these different wave-lengths cause a measurable difference in the densities.

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[1]) This method of "the shifting of the curves of densities" was described by H. C. BURGER and P. H. VAN CITTERT, Kon. Ak. van Wet., Amsterdam XXII N°, 5, 1920.

With the doublets of *Na* and *Ka* this condition is practically satisfied, and the same is true for the triplet $1\,p - 1\,s$ of Mg.

For the doublets of Rubidium and Caesium e. g. the sensitiveness of the plate however is not the same for the different components.

The same holds good for the triplet $1\,p - 1\,s$ of *Zn* and *Cd* and for many other groups of lines. The sketched "method A" cannot therefore be used unaltered in such cases.

It was of great importance for my further investigation that a method had been worked out[1] at Utrecht in the Physical Laboratory (with the aid of an energetically standardized lamp) which made it possible to investigate as well those groups of lines, the components of which have a great difference in wave-length.

The method is based on the use of an energetically standardized lamp, which serves to fix the relation between energy, wave-length and density.

This method will further be called "Method B".

This "Method B" is closely connected with the "Method A", which has already been described.

The groups of lines, which we want to investigate are photographed in the same way as with "Method A". We can of course measure the densities of the photographs obtained in this way, which are caused on a photographic plate by the three lines and plot the curves of densities for the different lines, but the ratio between the intensities we cannot infer at once from those curves of densities, for the density does not only depend on the intensity but also on the wave-length of the incident light.

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[1] P. Doornenbal Physica 3. 187. 1923. In principle the standardizing of this lamp has already been described in "Scripta Universitatis atque Bibliothecae Hierosolymitarum" L. S. Ornstein 1923 VIII.

In chapter-1c we shall give a short account of this standardizing.

To find the true ratio between the intensities it is necessary first to measure the functional relation between the sensitiveness of the used plate and the wave-length.

This was obtained by using a lamp energetically standardized by Mrs v. d. Bosch and Doornenbal.

On the same plate on which the group of lines, to be investigated were photographed a photograph was taken for that same region of wave-length using the said lamp as source of light. Plate II gives a reproduction of a plate, on which the triplet $1\,p - 1\,s$ (λ 5085, 4799, 4678) of *Cd* has been photographed.

The spectrum of the standardized lamp is photographed entirely after the method A so that the continuous spectrum

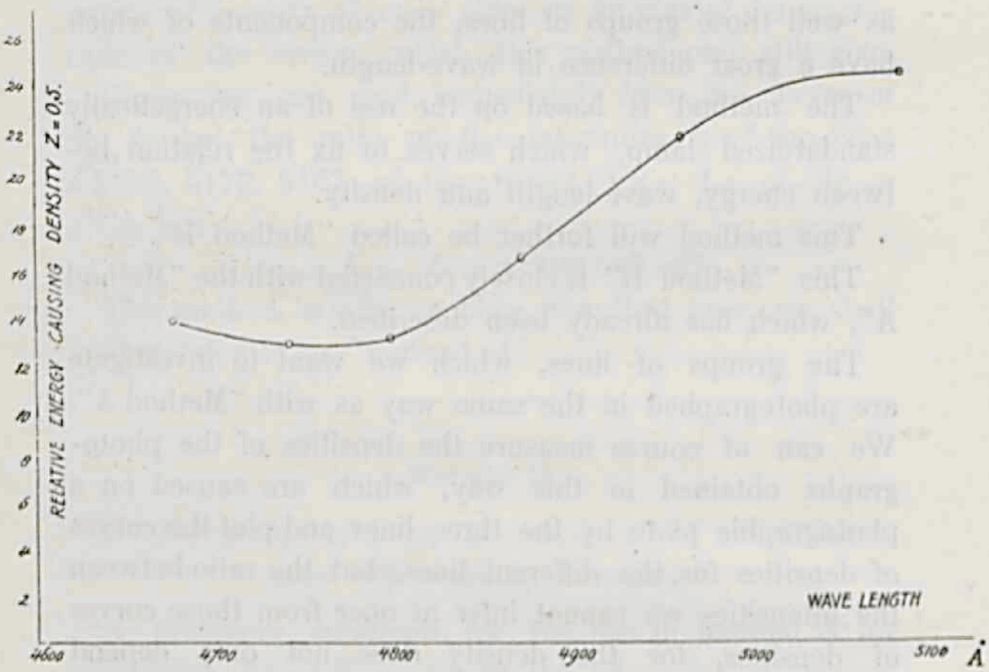

Fig. 4.

is also photographed with different intensities in one photograph.

In order to make better understood the necessity of using the standardized lamp, we have plotted in fig. 4 for the region of wave-length 4700 Å to ± 5100 Å as ordinates the relative energies causing the same densiy Z on the same plate (in this case $Z = \pm 0{,}5$).

It appears from the curve given, that about twice as much energy of light of the wave-length 5100 Å is required as of light of the wave-length 4800 Å to give about the same density.

It appears further from the curve in fig. 4 that e. g. for the wave-length 4910 Å and 4900 Å the ratio between the energies, which cause the same density is $18{,}8 : 18{,}2 = 100 : 97$. Hence it is obvious, that for groups of lines lying in this range of wave-length, having a difference in wave-length greater than 10 Å "method A" cannot directly be applied. [1]

The way of computing the ratio between the intensities of the lines, will be explained in more details with the aid of an example.

For this purpose we take the measurements of the ratio between the intensities of the components of the triplet $1\,p - 1\,s$ (λ 5085, 4799 and 4678) of *Cd* on one of our photographs (N⁰. 93). The triplet in question was photographed on a panchromatic Wratten-Wainwright plate.

The intensity of the current in the arc was ± 6 Ampère.

In fig. 5 the curves of densities obtained by means of plate N⁰. 93 are given.

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[1] The bearing of our method B will become particularly clear from what follows. On one of our plates line λ 4799 of Cd caused a greater density then the line λ 5085 whereas after measuring the ratio of the sensitiveness of the plate for the wave-lengths λ 5085 Å and λ 4799 Å the energy of line 4799 Å appeared to be ± 60 % of that of line 5085 Å.

Accordingly the intensities given e. g. in Fowler's tables (A. Fowler Report on Series in Line Spectra 1922 page 143), which for the greater part have been visually estimated according to the density of the photographic plate, are not correct.

Curves of densities (Cd λ 5085, 4799, 4678)

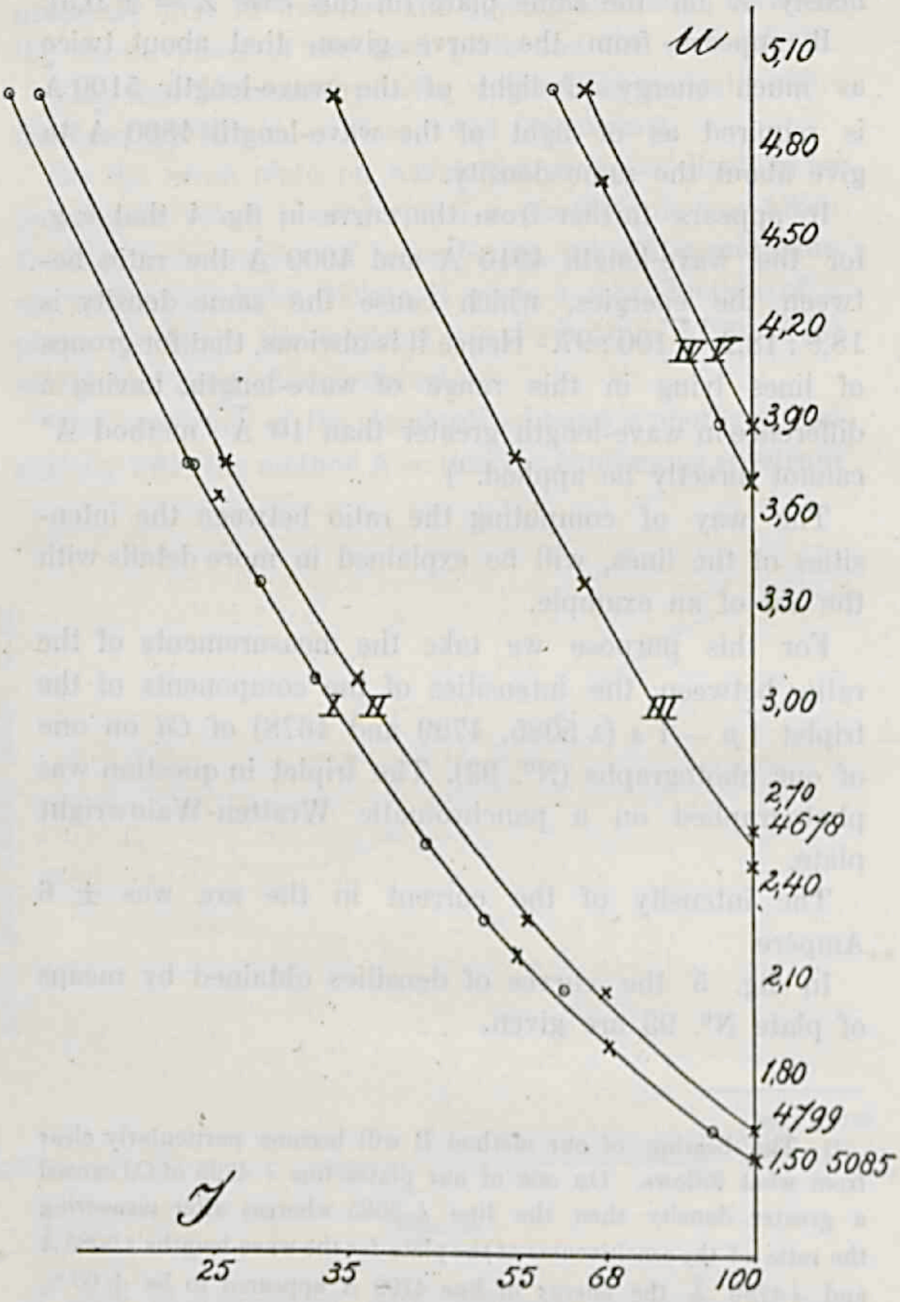

FIG. 5.

Curve I is the curve of densities of line 5085 Å, curve II of line 4799 and curve III of line 4678.

These curves can be shifted fairly well.[1] Curve V is the curve obtained from the photograph of the standardized lamp for λ 4678, Curve IV for λ 4799 and λ 5085 (the curves for these two wave-length coincided).

It appears from these curves of densities, that 90%—91% of the energy of line λ 5085 Å causes the same density as 100% of line λ 4799 Å. 43% of the energy of line λ 5085 Å causes the same density as 100% of line λ 4678 Å.

If therefore the plate had been equally sensitive to the light of these three wave-lengths the ratio between the intensities of the lines would have been:

$$100 : 91 : 43. \qquad (a)$$

The spectrum of the standardized lamp photographed on the same plate for the range of wave-length in question gives according to curves IV an V that 100% light of λ 5085 of the standardized lamp caused an equal density as 100% light of λ 4799 and that

92% light of λ 5085 of the standardized lamp caused an equal density as 100% light of λ 4678.

From the energy-curve of the used lamp it appeared that the energies E_λ of the wave-length in question have the following ratio's to each other

$$E_{5085} : E_{4799} : E_{4678} = 7.1 : 4{,}57 : 3{,}75 \qquad (b)$$

The ratio between the sensitivennss G_λ of the plate for the three wave-lengths considered is therefore:

$$G_{5085} : G_{4799} : G_{4678} = 1 : \frac{7{,}1}{4{,}57} : \frac{7{,}1}{3{,}75} \times \frac{92}{100} = 1 : 1{,}55 : 1{,}74 \ (c)$$

In order to obtain the correct ratio's between the intensities of the lines, we must still divide the values

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[1] According to FABRY et BUISSON, Revue d'optique N°. 1 page 26 1924, this will not be the case any longer for two curves of densities, one of which corresponds to visible light, the other to ultraviolet light.

obtained under (*a*) respectively by the numbers mentioned under (*c*). This gives for the correct result:

$$I_{5085} : I_{4799} : I_{4678} = 100 : 90 \text{ à } 91 \times \frac{1}{1{,}55} : 43 \times \frac{1}{1{,}74}.$$

$$I_{5085} : I_{4799} : I_{4678} = 100 : 58 \text{ à } 59 : 24 \text{ à } 25.$$

c. THE STANDARDIZED LAMP.

For standardized lamps, we used Philips Arga-lamps investigated by Mrs. v. d. Bosch and Doornenbal. [1]

The lamp was investigated, the voltage being 5 Volts. Because of the great importance of this lamp for our investigation we shall give a short account of the arrangement for the energetically standardizing of this lamp.

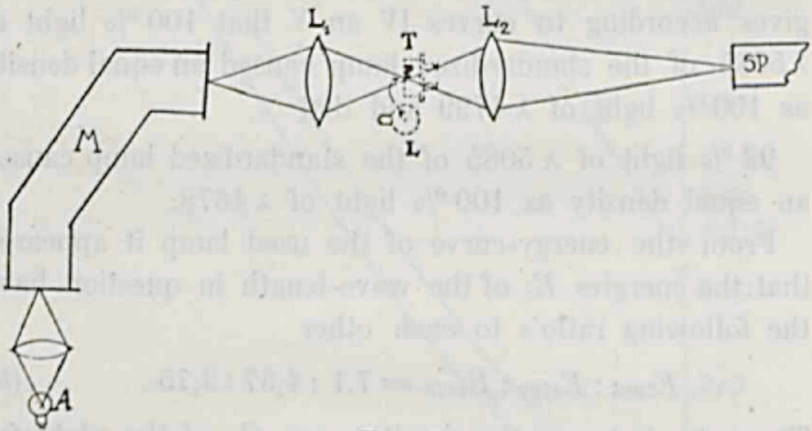

Fig. 6.

The incandescent lamp *A* burns at a constant voltage and whith the aid of the monochromator *M* [2]), when used with its central slit gives an almost monochromatic image of the slit in *P*.

This image was used as a source of light for comparison. The energy $E_\lambda \, d_\lambda$ was measured with a thermopile *T*

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[1] P. Doornenbal Physica 3. 1923.

[2] P. H. van Cittert. Physica 3. 182. 1923.
» » » Revue d'optique 2 57-60. 1923.

connected with a galvanometer of Moll. The deviations were registered.

It is evident that in this way only ratio's of energy are determined. The $d\lambda$ was kwown because once for all the range of wave length, coming out of the slit at a fixed position of the central slit of the monochromator, had been measured.

The following consideration gave the solution of the problem.

The ratio of the energy $g:b$ of the lamp A of e. g. a yellow and a blue range of wave-length is kwown. Required is $q' : b'$ for the same ranges of wave-length of the ligth-source (the lamp L) which is to be standardized, the distribution of intensity being unknown.

If we can measure $g:b'$ and $b:b'$ then $g' : b'$ is kwown from this.

The measuring ot $g:g'$ and $b:b'$, that is the measuring of the ratio's between the intensities with the same wave-length, was done by photography. If we remove the central slit of the monochromator we get a white image of the slit.

Of this light-source thus formed in P an image was formed on a photographic plate with the aid of a lens L_2 and the spectrograph Sp.

The density which was caused was measured. Light of different wave-length on its way from P to the photographic plate is absorbed, refracted etc. to a different amount.

Now this was completely eliminated, for a certain ratio between the intensities of light of different colours that reached the photographic plate corresponds to a certain ratio between the energies in P measured with the thermopile. And so the whole optical instrument, consisting of the lens Le_2, spectrograph Sp and photographic plate was standardized.

If now, on the same plate the spectrum of the lamp, which was to be standardized and which was also placed in P (this is essential for the method) was photographed with the same standardized instrument, with the same

Energy-curve of de standardized lamp.

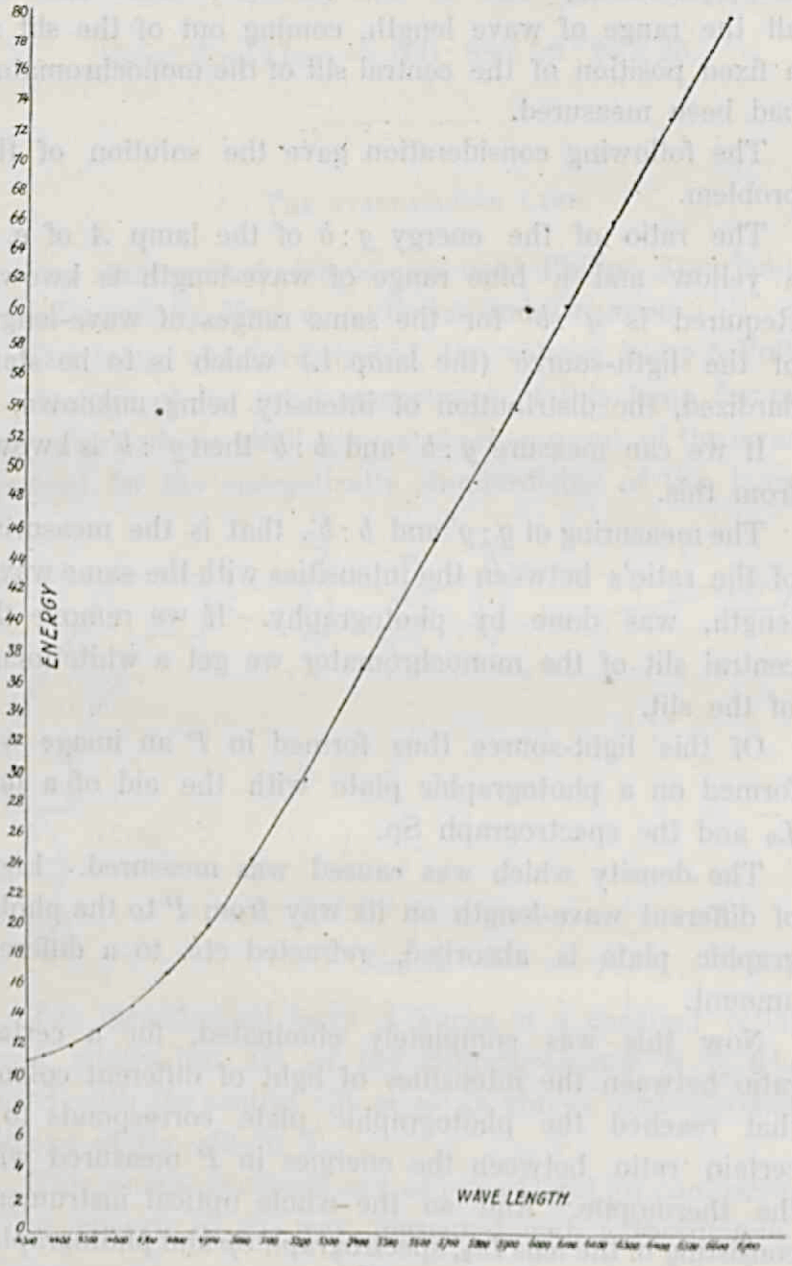

Fig. 7.

time of exposure and if we measure the density it was possible directly to determine from this the ratio between the energies of the same $d\lambda$-ranges, of which the energies in P were measured with the thermopile.

Division by $d\lambda$ gave for the lamp to be standardized the functional relation between the wave-length and the evergy E_λ. The curve which represents this functional relation for one of the two used standardized lamps is given in fig. 7.

d. THE STANDARDIZING OF THE LIGHT-REDUCERS.

We used for reducers a series of ZEISS' smoke-glass-plates. These reducers of smoke-glass are to be preferred to the photographic reducers, if the power of transmittance of the reducers cannot be measured in the apparatus itself, in which they are used, as the latter give rise to scattering[1]).

As these reducers of smoke-glass might show selective absorption the degree of weakening had to be measured for each different colour.

The percentage of the incident light transmitted by the reducers was measured in two ways. The first method which we shall call "method α" was worked out for the measuring of absorptions by Mrs L. S. ORNSTEIN and H. C. BURGER[2]).

It starts from the point, that light, passing through a monochromator and concentrated by a condensor on a thermopile, which is connected with a galvanometer, causes deviations of its mirror which can be registered.

This remarkably quick method gives very reliable data for the power of transmittance of the reducers especially in the red up to the blue part of the spectrum.

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[1]) RASSA RIWLIN Dissertation Utrecht 1923.

[2]) L. S. ORNSTEIN and H. C. BURGER, Kon. Akad. van Wet. XXIX, 1920.

See also H. A. C. DENIER VAN DER GON Archives Neerlandaises, série III A, tome VII, p. 140, (1923).

On account of the intensity of the nitralamp being too slight for the ultra-violet and violet part of the spectrum this method cannot be used satisfactorily for these parts.

For the rest the same difficulties arose with our measurements as are mentioned in the communication of Mrs L. S. Ornstein and H. C. Burger, viz. the drawbacks caused by the light scattered in the monochromator.

The second method used and which we shall call "Method β", made it possible to measure the power of transmittance of the reducers in the apparatus with which our measurements of the intensity had been made, so that the optical conditions were exactly the same during the standardizing of the reducers as during the measurements of the ratio's between the intensities.

This was not the case with the "Methode" α.

"Method β" starts from the fact, that the intensity of the light of a small range of wave-length of a continuous spectrum which falls on the photographic plate, may be supposed to be proportional to the width of the slit of the spectrograph. In this case the slit may not be too narrow as by the diffraction then arising a part of the light that has passed through the slit does not reach the grating.

In the place of the light-source *Li* (see fig. 1 page 7) was put a little nitra-lamp, burning at a constant voltage.

Photographs were then taken of the continuous spectrum of this lamp, the successive widths of the slit corresponding to 100, 60 and 31 divisions[1]) of the screw of the micrometer.

On plate III such a photograph is reproduced. We know therefore that the intensities, which are caused by the spectra a_1, a_2 and a_3 (see plate III), are to each other as 100 : 60 : 31, likewise those of b_1, b_2 and b_3.

With the aid of the "shifting method" of the density-

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[1]) Each of the divisions corresponded to a width of the slit of $\frac{1}{60}$ speed of the screw of the micrometer.

curves described in chapter I^a we were able to measure in a simple way the power of transmittance for the various reducers.

Standardizing of the reducers ($\lambda = 5844$).

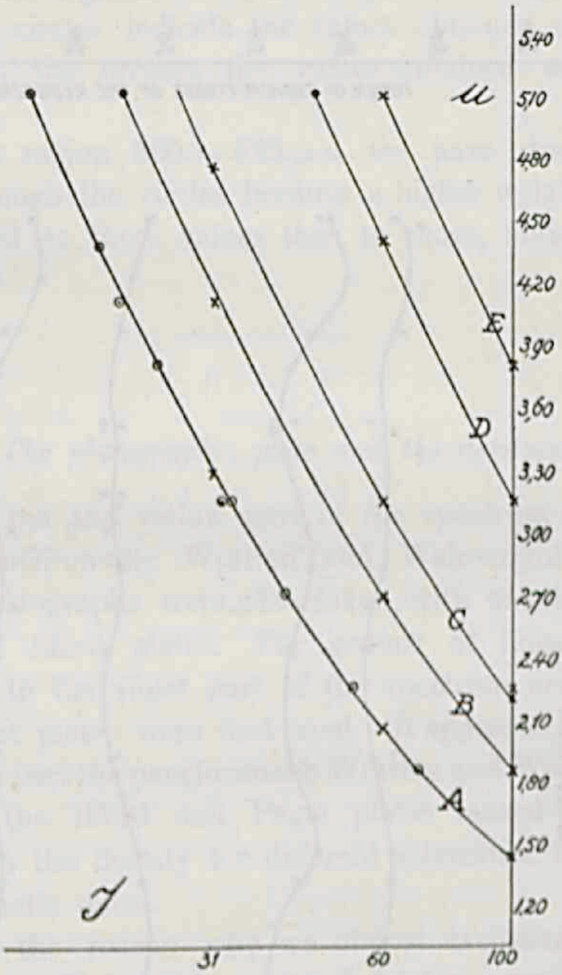

Fig. 8.

Figure 8 represents the density-curves referred to for plate 133 for λ 5844.

The curve A corresponds to the densities of the spectra a_1, a_2 and a_3 with λ 5844. The curve B to the densities of the spectra b_1, b_2, b_3 etc.

All these curves can be shifted and indicate at once that the ratio's between the intensities which cause the spectra *a*, *b*, *c*, *d* and *e* are equal to 100 : 69 : 55 : 33 : 25.

Here again we have plotted the deviations u of the galvanometer of the microphotometer against the inten-

Power of transmittance of the reducers.

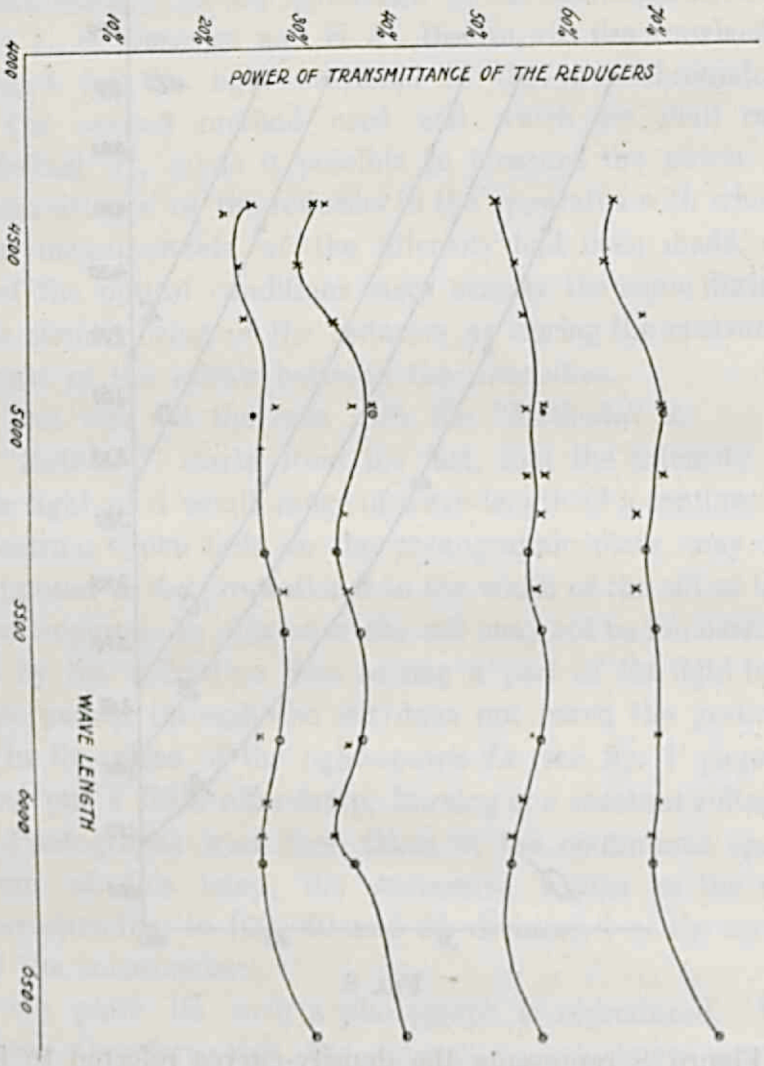

Fig. 9.

sities of the light that has fallen on the plate (for the latter the logarithmical scale is used).

The values obtained in this way for the power of transmittance of the reducers deviated 3 % at the very highest relatively to the unweakened light from those which were measured according to "Method α."

In fig. 9 giving the curves for the power of transmittance of the reducers and where the wave-length has been plotted against the percentage ot the transmitted light, the circles indicate the values obtained with the method α, the crosses the values obtained with the method β.

For the region 500 — 625 $\mu\mu$ we have drawn the curves through the circles because a higher weight could be attached to these values then to those, obtained by "Method β."

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e. *The photographic plate and the developer.*

For the red and yellow part of the spectrum we used chiefly Panchromatic Wratten and Wainwright plates. A few photographs were also taken with panchromatic Paget and Ilford plates. For groups of lines in the green up to the violet part of the spectrum orthochromatic Paget plates were first used. It appeared however that in this part the panchromatic Wratten and Wainwright and also the Ilford and Paget plates caused stronger contrasts in the density for different intensities than the orthochromatic ones.

This is the reason why we almost exclusively used Wratten and Wainwright plates for later measurements as long as our supply held out.

For developer we haven chosen glycine [1]) in a dilution of 1 : 2½ at a temperatuur of ± 15° centigrade.

The time for development is about 6 minutes.

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[1])

boiled distilled water	600 gr.	diluted with 2400 gr. of water.
sulphite of sodium	150 gr.	
glycine	30 gr.	
carbonate of potassium	150 gr.	

f. *Discussion of the errors influencing the results.*

It appears from the above how inportant a part the photographic plate played in all our measurements. Janssen has rightly called the photographic plate "la véritable rétine du savant". Owing to the plate a more close investigation of many natural phenomena has been made possible. But after having stated the possibilities which the photographic plate offers for scientific investigation we must now also point out its imperfections and these imperfections form the principal source of errors in our method.

The errors of the photographic plate may be divided (as has been traced at length by Miss Riwlin [1]) into errors caused by the glass-plate, by the layer of gelatine and by the silver of the plate.

A second circumstance which influences the exactness of our results, is the accuracy with which the power of transmittance of the reducers was determined. The error caused by this however is not great. As has already been remarked on page 16 our "shifting method" of the density-curves gives us an indication of the magnitude of the above-mentioned errors by the spreading which appears in the amount of the shifting.

The amount of this spreading always increased in the same degree as the groups of lines showed a greater difference in wave-length.

As far as "method A" was used, the largest error for lines which are not too weak can therefore be estimated at 1 °/o to 2 °/o of the intensity of the strongest line.

In "Method B", where the standardized lamp was used, the errors of the standardizing make themselves felt also.

Therefore it is a matter of course that the accuracy of the final result is less with "Method B" then with "Method A".

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[1] Rassa Riwlin. Dissertation, Utrecht, pag. 25, 1923.

Yet the largest error then obtained in the resulting values for the ratio's of the intensities may be considered to be about 5 % of the intensity of the strongest line of a group.

To avoid the errors, occurring in the proximity of the edges of the plate, the groups of lines and the continuous spectra were as much as possible and moreover repeatedly photographed in the central part of the plate.

If the intensities of the groups of lines, to be investigated are weak, so that they require a long time of exposure the photograph shows a continuous background caused by the continuous light of the glowing particles of the carbons in the arc.

The density on the place of the spectral line is therefore caused by the sum of intensities, of the line itself and the continuous light for the wave-length of the spectral line in question.

From the average of the densities to the left and to the right of the spectral line in question the relative intensity can then be determined with the aid of the continuous background relatively to the total intensity which caused the density on the place of the line. The corrections to be applied in this way did not as a rule amount to more than ± 2 to 5 % of the total intensity. In a few cases however (see results for *Cs* page 34), it amounted to ± 25 %.

CHAPTER II.

Results.

a. *Sharp Series of the alkalis (Table III).*

For the case of all investigated alkalis their chlorides were brought into the arc.

Of the sharp series of *Na* the doublets 1π-3σ (λ 6160-6154) and 1π-4σ (λ 5153-5149) were investigated. The intensity of the current of the arc was varied to make out whether the transition-probabilities of the electron were influenced by the conditions of excitation. It appeared however that no measurable influence existed.

Of the sharp series of *Ka* were investigated the doublets 1π-4σ (λ 5802-5782) and 1π-5σ (λ 5339-5323).

The intensity of the current of the arc was not varied while taking these photographs.

For the *Na*- as well as for the *Ka*-doublets "Method A" was followed.

With *Rb* and *Cs* the components of the doublets are already at a greater distance from each other so that for the investigation of the doublets of these metals "Method B" was used.

Of *Rb* the doublet 1π-4σ (λ 6160-6071) was investigated, of *Cs* the doublet 1π-5σ (λ 6034 and 5839).

In the following table the strongest line is always arbitrarily supposed to be 100, the amounts to which the measured intensities must be corrected on account of the continuous background of the lines are given for *Na*.

For the other lines these amounts have not been given but the given ratio's between the intensities represent the corrected values unless the contrary is expressly stated.

TABLE 3.

SHARP SERIES.

Photograph.	Met.	i.	λ	Ratio between the intensities uncorrected.	Cont. back ground.	Ratio between the intensities corrected.	Series.	Method.
64^1	Na	7,1	6160-6154	100 : 50 à 51	± 3 %	100 : 49	1π-3σ	A
64^4	„	3,5	„	100 : 52	± 3 %	100 : 50	„	„
64^{10}	„	8	„	100 : 50 à 52	± 3 %	100 : 48 à 50	„	„
69^1	Na	6,8	5153-5149	100 : 53	± 6 %	100 : 50	1π-4σ	A
69^3	„	4,5	„	100 : 52	± 3 %	100 : 50	„	„
70^5	„	4,5	„	100 : 54	± 8 %	100 : 50	„	„

Photograph.	Met.	λ	Ratio between the intensities.	Series.	Method.
58^1	Ka	5802-5782	100 : 49-54	1π-4σ	A
58^1	„	„	100 : 48-52	„	„
58^3	„	„	100 : 52-55	„	„
25	Ka	5339-5323	100 : 47	1π-5σ	A
38	„	„	100 : 49	„	„
72	„	„	100 : 52	„	„
84	Rb	6160-6071	100 : 50 à 54	1π-4σ	B
98	„	„	100 : 53	„	„
82	Cs	6034-5839	100 : 66 à 67 100 : 66 uncorrected for the int. of the cont. background	1π-5σ	B
97	„	„		„	„

The intensity of the continuous background, given in table 3, with the *Na*-doublets is expressed in per cents of the intensity of the strongest line.

The lines of the photographed *Cs*-doublet were very weak. The intensity of the continuous background in the neighbourhood of the line 6034 was about 20 %, that of line 5839 was ± 25 % of the intensity of the strongest line. So if we correct for this intensity of the background the ratio between the intensities of the components of this doublet becomes also ± 100 : 50.

Hence it appears, *that the ratio's between the intensities of the doublets of the alkalis is equal to 2 : 1 and independent of the nature of the metal and the ordinal number of the doublet in the series.*[1])

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b. *Sharp Series of the Earth-alkalis.*

Of the earth-alkalis we first investigated the triplet 1*p*-1*s* (λ 5183, 5172, 5167) of magnesium. The cored carbons were packed with magnesium-powder.

As appears from Table 1 page 11 with magnesium the intensity of the current was varied, but here as in the case of *Na* page 32 no influence on the ratio between the intensities of the components of the lines was measurable.

The continuous background appearing with this triplet was very slight and could be neglected entirely. As was already stated at length in Chapter I "Method A" was followed for this triplet.

Of *Ca* the triplet 1*p*-1*s* (λ 6162, 6122, 6102) was investigated. The first measurements of this triplet were made with the aid of "Method A". The photographs showed a rather strong continuous background. The results obtained by the first measurements gave as ratio between the intensities of the three components 100 : 80 : 40.

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[1]) This result is analogous to the rule of Preston for the magnetic separatians of the spectral lines.

These results showed a deviation from the regularity which could be observed in the results obtained for Mg, Cd and Zn (see table 4).

Presuming that the selfreversion of the lines, which will of course be greatest with the strongest line, was the cause of this deviation, a few more photographs were taken, the concentration of the vapour of the metal in the arc being much smaller.

This was done by mixing with carbon the salt, that was put into the cored carbons. Moreover "Method B" was used in these investigations. Corrections were made for the light of the continuous background, which was rather strong. For salt in the arc we used $Ca\,Fl_2$, as with this salt the arc could be kept much steadier than with $Ca\,Cl_2$.

The results obtained are given in table 4 and agree with those obtained with Mg. The accuracy in the case of this triplet is less than in the case of Mg, owing to the unfavourable circumstances, mentioned.

Of Zn and Cd the triplets $1p - 1s$ were investigated. Here too the concentration of the vapour of the metal in the arc was kept as low as possible in order to limit the possibility of selfreversion.

For both metals the chlorides were used to fill the carbons.

The accuracy attained is higher for Zn than for Cd, because with Cd the three components are further apart than with Zn; and therefore the unequal sensitiveness of the plate over its surface makes itself more felt.

From the above it is obvious that the ratio between the intensities of the components of the triplets of the second series of the earth-alkalis is approximately equal to 100 : 60 : 20 or 5 : 3 : 1, and independent of the nature of the metal.

We have not yet investigated whether the ratio between the intensities of the components of a triplet are

TABLE 4.

Photograph.	Met.	λ	Ratio between the intensities.	Series.	Method.
63^1	Mg.	5183 : 5172 : 5167	100 : 63 : 23	$1p - 1s$	A
63^2	„	„	100 : 63 : 23	„	„
63^6	„	„	$100 : 63 : 23^5$	„	„
63^7	„	„	100 : 63 : 23	„	„
63^8	„	„	100 : 62 : 23	„	„
63^9	„	„	100 : 62 : 23	„	„
62	„	„	100 : 61 : 21	„	„
111^2	*Ca*	6162 : 6122 : 6102	100 : 62 : 20	$1p - 1s$	B
111^3	„	„	$100 : 55 : 22^5$	„	„
112^3	„	„	100 : 65 : 26	„	„
113^3	*Zn*	4810 : 4722 : 4680	100 : 56 à 59 : 20	$1p - 1s$	B
113^1	„	„	100 : 59 à 62 : 19	„	„
95	„	„	100 : 62 : 22	„	„
88	„	„	100 : 58,5 : 20	„	„
92	*Cd*	5085 : 4799 : 4678	100 : 65 : 26	$1p - 1s$	B
93	„	„	100 : 58 : 22	„	„

independent of the ordinal number in the series. This may be done for the triplets of Mg, as soon as our methods will have been properly worked out for the ultraviolet part of the spectrum as well. ¹)

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[1] The methods worked out in the Physical Laboratory make a standardizing of the reducers for this spectral-region possible.

c. *Sharp Series of Multiplet systems.*

As a consequence of investigations made by Catalan[1] and Miss Gieseler[2] multiplet systems of spectral lines have been discovered in the spectra of *Mn* and *Cr*. Since then more multiplets have been described in rapid succession viz. by Catalan[3] for *Cr*, *Mo*, *Sc*; by Paschen[4] for C^+ and O^+ by C. C. and H. K. Kiess[5] for *Mo* and *Fe*, by Walters[6] for *Fe*, by Laporte[7] and by Meggers[8] for V.

From these investigations could be concluded that with all these multiplet systems the *s*-term is single and the *p*-term threefold.

According as the permanent maximal number of these terms is three-, four-, five, sixfold etc. we speak of of triplet-, quartet-, quintet-, sextetsystems etc.

Hence the *p*-term in all these systems being always threefold we can distinguish triplets from triplet-, quartet-, quintet-, sextetsystems etc. Now it was important to investigate what were the ratio's between the intensities of the components of these triplets.

Professor Sommerfeld suggested that as the intensities of the components of a triplet of a triplet-system are to each other as $\frac{5}{2}:\frac{3}{2}:\frac{1}{2}$, presumebly the ratio's would be

$$\text{for a quartet-system } \frac{6}{2}:\frac{4}{2}:\frac{2}{2}$$

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[1] M. A. Catalan. Trans. Roy. Soc. 223 S. 127, 1922.

[2] H. Gieseler. Ann. d. Phys. 69 S. 147, 1922.

[3] M. A. Catalan. Ann. Soc. Esp. Tis. y Quim. 21. S 84 and 213, 1923; 20 S. 606, 1922.

[4] F. Paschen. Ann. d. Phys. 71. S. 537, 1923.

[5] C. C. Kiess and H. K. Kiess. Science 56. S. 666, 1922; Journ. Wash. Acad. of Science 13. S. 270, 1923.

[6] F. M. Walters. id. 13. S. 243, 1923.

[7] O. Laporte. Naturwiss. 11. S. 779, 1923; Phys. Zeitschr. 24, 1923.

[8] W. F. Meggers. Journ. Wash. Acad. of Science 13. S. 317, 1923.

$$\text{for a quintet-system } \frac{7}{2} : \frac{5}{2} : \frac{3}{2}$$

$$\text{for a sextet-system } \frac{8}{2} : \frac{6}{2} : \frac{4}{2}$$

$$\text{for a septet-system } \frac{9}{2} : \frac{7}{2} : \frac{5}{2}$$

$$\text{for a octet-system } \frac{10}{2} : \frac{8}{2} : \frac{6}{2}.$$

He was so kind as to mention in a letter to us triplets, suitable for an experimental investigation.

Of these triplets I investigated the triplet λ 6021, 6016, 6013 of *Mn* (sextet-system) and the triplet 4823, 4783, 4754 of *Mn* (octet-system). With the other groups of lines which were mentioned, difficulties arose with our method of investigation, partly because of their being too faint, partly because they were for our method too far in the red part of the spectrum.

The results concerning the *Mn* triplets are given in in table 5. The agreement between the measured and the expected ratio's is indeed very striking.

TABLE 5.

Photograph.	Met.	i	λ	Ratio between the intensities measured.	Ratio between the intensities expected.	Method.	System.
105^1	*Mn*	±6 Ampère	6021, 6016, 6013	100 : 77 : 53	100 : 75 : 50	A	Triplet of
105^3	*Mn*	,,	,, ,,	100 : 77 : 53	,, ,,	,,	sextetsystem.
106^1	*Mn*	±6 Ampère	4823, 4783, 4754	100 : 81 ; 61	100 : 80 : 60	B	Triplet of
106^3	*Mn*	,,	,, ,,	100 : 79 : 62	,, ,,	,,	octetsystem.

d. *Diffuse Series of the alkalis.*

Of the diffuse series of *Na* we investigated the doublets $1\pi-3\delta$ (λ 5688—5682) and $1\pi-4\delta$ (λ 4982—4978).

The investigated doublets of the first diffuse series of *Ka* are $1\pi-4\delta$ (λ 5832—5812) and $1\pi-5\delta$ (λ 5359—5343), of *Rb* $1\pi-4\delta$ (λ 6298—6206), $1\pi-5\delta$ (λ 5724—5648) and $1\pi-6\delta$ (λ 5432—5363).

As salt in the arc we used chlorides of the above mentioned metals.

The doublets of the metals *Na* and *Ka* were investigated with the aid of "method A", for the doublets of *Rb* "method B" was used.

As the δ-levels are practically not separated with these doublets, single doublets are caused by the transition from the δ level to the π energy-levels.

With the metal *Cs* the doublet $1\pi-5\delta$ is a complex doublet consisting of the lines λ 6127, 6213 and 6010.

For the investigation of this group we used "method B".

Table 6 gives the results.

We may mention here that the doublet $1\pi-3\delta$ of *Na* was photographed with different intensities i of the current in the arc. For photograph 64^8 (see table 6) $i = 4$ Ampère, for photograph 66^1 i was 6,4 Ampère and for 66^5 i was 2,5 Amp. An influence on the ratio's between intensities of the components of this doublet was however not observed.

On considering the results concerning the diffuse series of the alkalis, it appears that the ratio's between the intensities of the components of single doublets of this series are equal to 100 : 50 or **2 : 1**, exactly as with those of the sharp series.

It is remarkable that with the complex doublet of *Cs* the ratio between the sum of the intensities of the lines 6212 and 6217 and the intensity of line 6010 is also approximately equal to 2 : 1 (this is more closely discussed in chapter III).

TABLE 6.

Photograph.	Metal.	λ	Ratio's of the int.	Series.	Method.
64^8	*Na*	5688 : 5682	100 : 50	1 π — 3 δ	A
66^1	„	„	100 : 50	„	„
66^5	„	„	100 : 50	„	„
24	„	„	100 : 50	„	„
20	„	„	100 : 50	„	„
69^5	*Na*	4982 : 4978	100 : 50	1 π — 4 δ	A
69^7	„	„	100 : 52	„	„
70^7	„	„	100 : 53	„	„
25	*Ka*	5832 : 5812	100 : 52	1 π — 4 δ	A
10	„	„	100 : 48	„	„
72^{12}	„	„	100 : 51 à 52	„	„
25	*Ka*	5359 : 5342	100 : 50	1 π — 5 δ	A
72	„	„	100 : 50	„	„
84	*Rb*	6298 : 6206	100 : 50	1 π — 4 δ	B
98	„	„	100 : 52 à 54	„	„
86^1	*Rb*	5724 : 5648	100 : 50	1 π — 5 δ	B
86^2	„	„	100 : 53	„	„
86^1	*Rb*	5431 : 5362	100 : 53	1 π — 6 δ	B
86^2	„	„	100 : 50	„	„
19	*Cs*	6212 : 6217	100 : 12	1 π — 5 δ	A
84	„	„	100 : 13		A
82	„	„	100 : 14		A
84	„	6212 : 6010	100 : 55		B

e. *Diffuse Series of the earth-alkalis.*

Of this series the complex triplet of $Ca\ (1\,p - 2\,d)$ was investigated. For this purpose the carbons of the arc were packed with a mixure of fluoride of Calcium and carbon.

This complex triplet consists, as is well known, of six lines which are represented in fig. 10 in the way introduced by Sommerfeld.

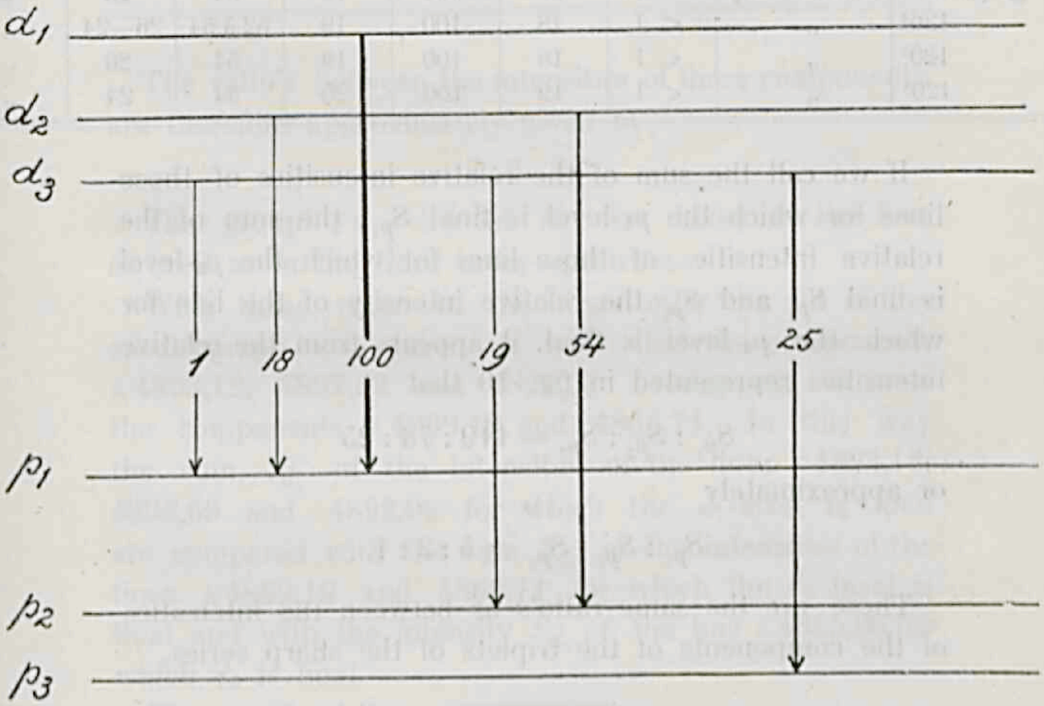

Fig. 10.

The occuring lines are $\lambda\ 4456{,}61\ (1\,p_1 - 2\,d_3)$
$\lambda\ 4455{,}88\ (1\,p_1 - 2\,d_2)$
$\lambda\ 4454{,}77\ (1\,p_1 - 2\,d_1)$
$\lambda\ 4435{,}67\ (1\,p_2 - 2\,d_3)$
$\lambda\ 4434{,}95\ (1\,p_2 - 2\,d_2)$
$\lambda\ 4425{,}43\ (1\,p_3 - 2\,d_3)$.

The observed intensities expressed in the intensity of the line λ 4454,77, this latter being arbitrarily put equal to 100, are given in table 7.

The mean values of the relative intensities given there have been printed in the vertical arrows in fig. 10, which represent the occurring spectral lines.

TABLE 7.

	Wave-length λ	4456,61	4455,88	4454,77	4435.67	4434,95	4425,43	Method.
Photograph 126^1	Rel. intensity	< 1	18	100	19	54	26	A
126^2	,,	< 1	18	100	19	52 à 54	26—24	,,
120^2	,,	< 1	18	100	19	54	26	,,
120^1	,,	< 1	19	100	20	54	24	,,

If we call the sum of the relative intensities of those lines for which the p_1-level is final S_{p_1}, the sum of the relative intensities of those lines for which the p_2-level is final S_{p_2} and S_{p_3} the relative intensity of the line for which the p_3-level is final, it appears from the relative intensities represented in fig. 10 that

$$S_{p_1} : S_{p_2} : S_{p_3} = 119 : 73 : 25$$

or approximately

$$S_{p_1} : S_{p_2} : S_{p_3} = 5 : 3 : 1.$$

These are the same ratio's as between the intensities of the components of the triplets of the sharp series.

f. *Bergmann-series of the earth-alkalis.*

As we have already seen in the introduction the groups of lines of this series are observed as single triplets as long as the b-levels of this series are not yet wide enough apart to obtain a perceptible separation in the spectrograph. These three observed components correspond to the transition of the electron from a single b-energy-level to the three levels d_1, d_2 and d_3. This case occurs with the triplet of *Ca* $1\,d - 3\,b$ (λ 4585, 4581 and 4578). The results of the measurements are given in table 8.

TABLE 8.

Photograph	Metal.	λ	Ratio between the intensities.
126^5	*Ca*	4585, 4581, 4578	100 ; 70 à 74 : 44,5
127^1	"	"	100 : 72 : 44
127^2	"	"	100 : 74 : 47

The ratio's between the intensities of these components are therefore approximately given by

$$7:5:3.$$

The group 1 *d* — 3 *b* of *Sr* was taken in the first as well as in the third order spectrum.

With those taken in the first order the slit of the spectrograph was taken so wide, that the components λ 4893,12, 4892,69 and 4892,03 overlapped, likewise the components λ 4869,19 and 4868,74. In this way the sum S_{d_1} of the intensities of the lines λ 4893,12, 4892,69 and 4892,03 for which the d_1-level is final are compared with the sum S_{d_2} of the intensities of the lines λ 4869,19 and 4869,74 for which the d_2 level is final and with the intensity S_{d_3} of the line λ 4855,08 for which d_3 is final.

The result of the measuring was:

$$\text{Photograph } 117^4 : S_{d_1} : S_{d_2} : S_{d_3} = 100:70:44.$$
$$\text{"} \quad 117^2 : S_{d_1} : S_{d_2} ; S_{d_3} = 100:71:44.$$

Hence the ratio's obtained here are the same as for the components of the single triplet 1 *d* — 3 *b* of *Ca*.

In the third order this group 1 *d* — 3 *b* of *Sr* was sufficiently separated to measure the ratio's between the intensities of the six lines of the complex triplet 1 *d* — 3 *b*.

The result is given in table 9, the intensity of the strongest line being again supposed to be equal to 100.

TABLE 9.

Photograph.		4893,12	4892,69	4892,03	4869.19	4868,74	4855,08	Method.
132	Rel. Intensity	< 1	9	100	9	70 à 72	48 à 50	B
134	„	< 1	9	100	9	67 à 68	44 à 49	B

While photograph 132 was being taken the arc contained comparatively much salt while for photograph 134 it contained little.

g. *Principal Series.*

Finally we shall mention a few measurements concerning some groups of lines of the principal series. As has already been indicated on page 4 and as will appear more clearly in Chapter III page 49 it proved to be advisable to investigate some groups of the principal series too.

The doublet $1\,\sigma - 2\,\pi$ of *Cs* (λ 4555,26 and 4593,16) was investigated. By making the concentration of the salt in the arc very slight, selfreversion was avoided as much as possible.

The result of the measurements is given in table 10.

TABLE 10.

Photograph.	Metal.	λ	Ratio between the int.	Method.
80^4	*Cs*	4555 — 4593	100 : 54 à 56	A
80^5	*Cs*	„	100 : 53 — 48	A

Further the triplet $1\,s^a - 2\,p^a$ of the principal series of *Cr* (λ 5288,42, 5206,05 and 5204,51) was investigated.

The result of the measurement with "Method A" was:

$$I_{5208} : I_{5206} : I_{5204} = 100 : 72 : 45.$$

CHAPTER III.

Summary of the results. [1]

On surveying the results, mentioned in the preceding chapter, it appears:

1°. that the ratio between the intensities of the components of the doublets of the sharp series of the alkalis is equal to 2 : 1 and independent of the nature of the metal and of the ordinal number of the doublet in the series (see table 3).

2°. that the ratio between the intensities of the triplet-components of the sharp series of the earth-alkalis is $\frac{5}{2} : \frac{3}{2} : \frac{1}{2}$, independent of the nature of the metal [2]) (see table 4).

3°. that the ratio between the intensities of the triplet-components of the sharp series of a sextet-system is 4 : 3 : 2, and of a triplet of an octet-system 5 : 4 : 3 (see table 5).

In all the cases mentioned under 1°, 2° and 3° we have to deal with lines which arise through transition of the outer electron from one initial level to a complex final level. We will now consider the following table for the J-values which have been introduced by A. Landé [3]) for the characterizing of the spectral terms and with the

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[1] This chapter gives the contents of a paper of H. C. Burger and the author. Zeitschrift für Phys. 1924.

[2] The independence of the ordinal number has not yet considered here. This will be possible, when the measurements e. g. for the Mg. triplets can be continued into the ultraviolet part of the spectrum.

[3] A. Landé. Z. f. Phys. 15. 189. 1923.

TABLE of the *J*-values of the multiplet-terms.

s		$\frac{1}{2}$						Singulets.		1						Doublets.	*s*
p			$\frac{3}{2}$							1		2					*p*
d				$\frac{5}{2}$								2	3				*d*
b					$\frac{7}{2}$								3	4			*b*
s			$\frac{3}{2}$					Triplets.				2				Quartets.	*s*
p		$\frac{1}{2}$	$\frac{3}{2}$	$\frac{5}{2}$							1	2	3				*p*
d			$\frac{3}{2}$	$\frac{5}{2}$	$\frac{7}{2}$						1	2	3	4			*d*
b				$\frac{5}{2}$	$\frac{7}{2}$	$\frac{9}{2}$						2	3	4	5		*b*
s				$\frac{5}{2}$				Quintets.				3				Sextets.	*s*
p			$\frac{3}{2}$	$\frac{5}{2}$	$\frac{7}{2}$						2	3	4				*p*
d		$\frac{1}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{7}{2}$	$\frac{9}{2}$				1	2	3	4	5			*d*
b			$\frac{3}{2}$	$\frac{5}{2}$	$\frac{7}{2}$	$\frac{9}{2}$	$\frac{11}{2}$			1	2	3	4	5	6		*b*
s				$\frac{7}{2}$				Septets.				4				Oktets.	*s*
p			$\frac{5}{2}$	$\frac{7}{2}$	$\frac{9}{2}$						3	4	5				*p*
d		$\frac{3}{2}$	$\frac{5}{2}$	$\frac{7}{2}$	$\frac{9}{2}$	$\frac{11}{2}$				2	3	4	5	6			*d*
b	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{7}{2}$	$\frac{9}{2}$	$\frac{11}{2}$	$\frac{13}{2}$		1	2	3	4	5	6	7		*b*

aid of which he is able to describe the anomalous Zeeman-separations. The J-values have been borrowed from a table, which Prof. LANDÉ [1]) has been so kind as to send me.

If we compare the observed ratio's between the intensities with these J-values of the final-levels, the results sub 1⁰, 2⁰ and 3⁰ can be summarized in the following rule:

The ratio's between the intensities of the doublet- and triplet-components of the sharp series are equal to the ratio's between the internal quantum numbers J [2]) of the final levels. (Rule I.)

Now it is very remarkable that Rule I also holds good for the cases in which the initial levels are multiple, but so close together, that the spectrograph cannot resolve the multiplicity in question.

For it appears from table 6, that the ratio between the intensities of the components of the doublets of the diffuse series of the alkalis is also 2 : 1, when the separation of the d-levels is too small to be resolved.

If we consider the d-level to be single the duplicity of the p-levels gives two components, the intensities of which, in accordance with Rule I are to each other as 2 : 1, that is to say the same ratio as between the internal quantum numbers of the two final levels.

For the group of lines $1\,d - 3\,b$ of the BERGMANN-series of Calcium this Rule I holds good too. (See for this page 43 Chapter II).

As the b-level is not separated this group consists of three components the ratio's between the intensities of which are the same as between the internal quantum numbers of the final levels d, that is to say, the intensities of the components are to each other as 7 : 5 : 3.

In these cases some of the components are complex,

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[1]) Compare also Z. f. Phys. 15. S. 192. 1923.

[2]) We adopt LANDÉ's quantum numbers. The ratio's between the intensities can also be described by means of the internal quantum numbers of SOMMERFELD.

though not resolved. Hence their intensities are equal to the sum of the intensities of the components of their common final level. The accordance just mentioned with the Rule I in the case of the unseparated initial levels led us to expect that with separated levels a corresponding regularity would exist.

The sum of the intensities of the components of a complex line, which corresponds to transitions of the electron to the same final level are to each other as the internal quantum numbers J of these final levels. (Rule II.)

This Rule II which is a extension of Rule I is confirmed by the observation of the complex doublet $1\,\pi - 5\,\delta$ of *Cs* (see chapter II *d* page 39), as well as by that of the complex triplet $1\,p - 2\,d$ of *Ca* (see chapter II *e* page 42).

Now it is important to realize that a ratio can be indicated between the intensities of the components of a complex doublet and triplet, for this means that, when the initial levels of the components to be compared are different, this ratio is likewise a number characteristic for the components concerned. Rule II points already to the same fact namely, that the ratio between the concentrations of the initial levels of the components is a number characteristic for those components, which depends not at all or only slightly on the circumstances under which the emission takes place. Though actually our rule is an approximation holding good only as long as the difference in energy between the levels in question is sufficiently slight, we shall consider it in what follows to be rigorously true and trace to what conclusion this will lead.

Hence it appears to be of some purpose to investigate the intensities of the components of a complex line of the principal series. These components namely have different initial levels but a common final level.

As a first example we mention the doublets of the principal series of the alkalis. For the ratio between the intensities of the *D*-lines of *Na*, various investigators [1]) have found the value 2 : 1, the line D_2 for which the internal quantum number of the initial level is 2 being the strongest.

This ratio 2 : 1 which has also approximately been found by us for the group $1\,\sigma - 2\,\pi$ of the principal series of *Cs* (λ 4555,26 — 4593,16) (see Chapter II^{s} page 44), is lowered considerably by self-reversion, for the concentration of the absorbing atoms is very great. The more however the density of the emitting gas is reduced, the more the ratio between the intensities of the components approaches to 2 : 1. [2])

Here the internal quantum numbers of the initial π levels are 2 and 1 and so it would seem that in the principal series the internal quantum numbers of the initial levels determine the intensities of the components.

This supposition was confirmed by the intensities of the triplet $1\,s - 2\,p$ of *Hg*.

For these three components F. Paschen [3]) gives the ratio

$$100 : 60 : 20 = 5 : 3 : 1,$$

which numbers are to each other as the internal quantum numbers J of the initial levels p_1, p_2 and p_3. As this group $1\,s - 2\,p$ is situated in the infra-red and the distance between the components is small, the investigation gives us at once the ratio between the intensities. Our measurements of the intensities of the three components of the group λ 5208,42; 5206,15; 5204,51 of *Cr* show that the ratio between them is as 100 : 72 : 45 (see chapter II^{g} page 44). The group in question belongs to the quintet-system and has for symbol $1\,s^{a} - 2\,p^{a}$.

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[1]) M. Gouy. Ann. d. chem. et de Phys. 5 (18) 70. 1879.

[2]) In the case of the *D* lines of *Na* this was ascertained once more by us.

[3]) F. Paschen. Ann. d. Phys. 27, 558, 1908.

The J-values of the initial levels are $\frac{7}{2}, \frac{5}{2}, \frac{3}{2}$. Hence with these lines of the principal series the intensities of the three components are also proportional to the internal quantum numbers J of the initial levels.

We have therefore as counterpart of Rule I:

The ratio between the intensities of multiple spectral lines of the principal series is equal to the ratio between the internal quantum numbers J of the initial states of the atom (Rule III).

As now the initial levels play the same part as the final levels with the sharp series, we tried to generalize Rule III and to test the following rule for the intensities of multiple spectral lines.

The sums of the intensities of components of a complex spectral line which corresponds to the transition of the electron from the same initial level are to each other as the internal quantum numbers J of these initial levels (Rule IV.)

This rule is the counterpart of Rule II and we maintain that the intensities of the components of every complex line must satisfy both rules. As a test we shall apply both rules to the values, given on page 41 for the relative intensities of group 1 p — 2 d of *Ca*. Of these numbers we give a survey in the following table 11.

The J-values are printed by the side of the symbols for the levels. Rule II says that the sums of the rows are proportional to the J-values $\frac{5}{2} : \frac{3}{2} : \frac{1}{2}$ of the p-levels, whereas according to Rule IV the ratio's between the sums of the columns must be equal to the J-values $\frac{3}{2} : \frac{5}{2} : \frac{7}{2}$ of the initial d-levels.

We have already tested the first assertion on page 42, the second part of the rule requires that the ratio

$$(1 + 19 + 25) : (18 + 54) : 100 = 3 : 5 : 7$$

TABLE 11.

$1\ p_1\ \left(\frac{5}{2}\right)$	1	18	100
$1\ p_2\ \left(\frac{3}{2}\right)$	19	54	0
$1\ p_3\ \left(\frac{1}{2}\right)$	25	0	0
	$2\ d_3\ \left(\frac{3}{2}\right)$	$2\ d_2\ \left(\frac{5}{2}\right)$	$2\ d_1\ \left(\frac{7}{2}\right)$

holds good. It is true that the stronger lines ares lightly too faint, but taking into account the selfreversion which certainly can not be neglected, the agreement may be considered satisfactory.

Rules II and IV together with the „selection principle" which excludes certain transitions are not sufficient for an unambiguous determination of the intensities of the investigated lines.

In the last mentioned example of the complex triplet the ratio's between the intensities of the six components must be determined, that is to say, the number of the unknows is five. Rule II and IV give each a ratio for the three sums in question and together they give four equations. Hence it follows that one more equation is required to solve the problem. In order to find this equation we will first confine ourselves to the simple case of a complex doublet.

Rules II and IV give each an equation and these two equations are sufficient to determine the ratios of the intensities of the three components of the complex doublet.

We write the result of the simple calculation at once for an arbitrary azimuthal quantum number k of the final state, the azimuthal quantum number of the initial state being equal to $k+1$. If we put $k = 1, 2, 3 \ldots.$ we obtain successively the intensities for the series *sp*, *pd*, *db*.... In the following table the sum of the three intensities has been put equal to 1.

TABLE 12.

$\frac{k}{2k-1}$	$\frac{1}{(2k-1)(2k+1)}$	$\frac{2k^2+k-1}{(2k-1)(2k+1)}$
$\frac{k-1}{2k-1}$	$\frac{2k^2-k-1}{(2k-1)(2k+1)}$	0
	$\frac{k}{2k+1}$	$\frac{k+1}{2k+1}$

The J-values of the two initial levels are k and $k+1$ these of the final levels $k-1$ and k. It is convenient to introduce instead of the internal quantum numbers J fractions which have J for numerator and of which the denominator is the sum of the J-values of all initial- and final-levels respectively. These fractions are given in the table and will henceforth be referred to as "relative" quantum numbers. In a table like the one above, the sum of the intensities in every row or column respectively must be equeal to the relative quantum number concerned, printed by the side of them. We shall now apply table 12 to the case of the diffuse series ($p\,d$ series) of the alkalis. The computed ratio between the intensities of the components is given by table 13.

TABLE 13.

$p_1\left(\frac{2}{3}\right)$	1	9
$p_2\left(\frac{1}{3}\right)$	5	0
	$d_2\left(\frac{2}{5}\right)$	$d_1\left(\frac{3}{5}\right)$

Only the numerator of the fractions for the intensities has been given, the common denominator $(2k-1)(2k+1) = 3 \times 5 = 15$ has been omitted. Applying Rule II and IV the ratio's between the intensities ought to be

$$9:5:1 = 100: \pm 55: \pm 11.$$

The observation of the complex doublet $1\pi - 5\delta$ of *Cs* has given the result (comp. chapter II$^{\text{d}}$ page 40).

$$100:55:13$$

As we see, the agreement is sufficient to confirm our rules II and IV.

In order to determine completely the ratio's between the intensities for the complex triplet and also for more complicated cases, we generalize table 12. For this we observe that there is a component the numerator for which is 1, (table 12) independent of the azimuthal quantum number. It is that very component, which according to Sommerfeld's intensity-rule [1]) must have the smallest intensity, as the change of the internal quantum number differs most from the change of the azimuthal quantum number.

Generalizing we therefore assume the validity of the following rule:

The intensity of a component of a complex line expressed in the sum of all components as a unit is a rational fraction, the denominator of which is the product of the sum of the internal quantum numbers J [2]) *of the initial and final levels respectively. The numerator is 1 for that component with which the changes of the internal quantum numbers differs most from the changes of the azimuthal quantum numbers. (Rule V).*

In all cases the rules II, IV and V are sufficient to

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[1]) A. **Sommerfeld**, Atombau und Spectrallinien 3e Auflage, S. 447, 448.

[2]) With the triplet, quintet, etc. the whole number $2J$ is taken instead of J in order to avoid fractions which makes no difference in the ratio between the intensities.

calculate, without further assumption, the ratio between the intensities of all the components of a complex line.

By the principle of selection exactly so many lines have been excluded as to make these three rules yield a sufficient number of equations.

In table 14 the intensities in this way computed for arbitrary k are given for a complex triplet.

TABLE 14.

$\frac{2k+1}{6k-3}$	$\frac{1}{(6k-3)(6k+3)}$	$\frac{11}{(6k-3)(6k+3)}$	$\frac{12k^2+12k-9}{(6k-3)(6k+3)}$
$\frac{2k-1}{6k-3}$	$\frac{11}{(6k-3)(6k+3)}$	$\frac{12k^2-14}{(6k-3)(6k+3)}$	0
$\frac{2k-3}{6k-3}$	$\frac{12k^2-12k-9}{(6k-3)(6k+3)}$	0	0
	$\frac{2k-1}{6k+3}$	$\frac{2k+1}{6k+3}$	$\frac{2k+3}{6k+3}$

The intensity-fractions can easily be deduced by means of rules II, IV and V from the relative quantum numbers added in the table; so e. g. the intensity-fraction $\frac{12k^2-12k-9}{(6k-3)(6k+3)}$ is at once equal to the relative quantum number $\frac{2k-3}{6k-3}$, as in the row of this fraction no other numbers occur. We test table 14 first by means of the pd group of Calcium, the ratio between the intensities of which is given on page 42. The intensities for $k = 2$ computed by means of the above table, we alter to the effect, that the intensity of the strongest line is equal to 100, and in this way we get:

TABLE 15.

p_1	1,6(1)	17,5(18)	100(100)
p_2	17,5(19)	54(54)	0
p_3	22,2(25)	0	0
	d_3	d_2	d_1

The results of our measurements have been added in brackets to the values computed according to the rules II, IV, V.

The group of lines $1\,d - 3\,b$ of *Sr* is also interesting. As we have seen in chapter II it was just possible with our arrangement to resolve the six components of this group in the third order of the spectrograph and to measure the ratio between their intensities.

In table 16 are given the computed and the observed intensities (the latter in brackets).

TABLE 16.

d_1	0,7($<$1)	8,1(9)	100(100)
d_2	8,1(9)	69,5(69)	0
d_3	46,7(48)	0	0
	b_3	b_2	b_1

For the two complex lines ($1\,p - 2\,d$) of *Ca* and ($1\,d - 3\,b$) of *Sr* the agreement between the results, obtained with rules II, IV and V and the observed values is striking.

We have not yet measured intensities of the components of complex groupes of lines of quartet- and quintetsystems.

It is possible however to predict in the manner indicated above the ratio between the intensities in these cases.

Finally we may observe the following:

1⁰. Our measurements hitherto only referred to lines the components of which differ comparatively little in wave-length. In this case the ratio between the intensities of the components is approximately equal to the ratio of the number of transitions of the electron producing the lines, as the energy-quantum h_ν which is emitted at every transition is practically the same for those components.

In principle it makes an important difference whether our rules are meant for the intensities or for the number of transitions.

This can only be determined by measuring the intensities of components the h_ν of which differ greatly.

2⁰. It is important to notice that the intensities according to the rules given, with increasing values of the azimuthal quantum numbers k, all converge towards zero, except the Sommerfeld's "strong" transitions, with which the changes of J and k are equal.

The components which correspond to these "strong" transitions all converge with increassing k towards the same limiting value.

Suffice it to mention this extrapolation which is of great importance for the correspondence-principle.

3⁰. For a further theoretical discussion of our intensity-rules we may refer to a publication by Mrs L. S. Ornstein and H. C. Burger which will shortly appear in the "Zeitschrift für Physik".

Plate I.

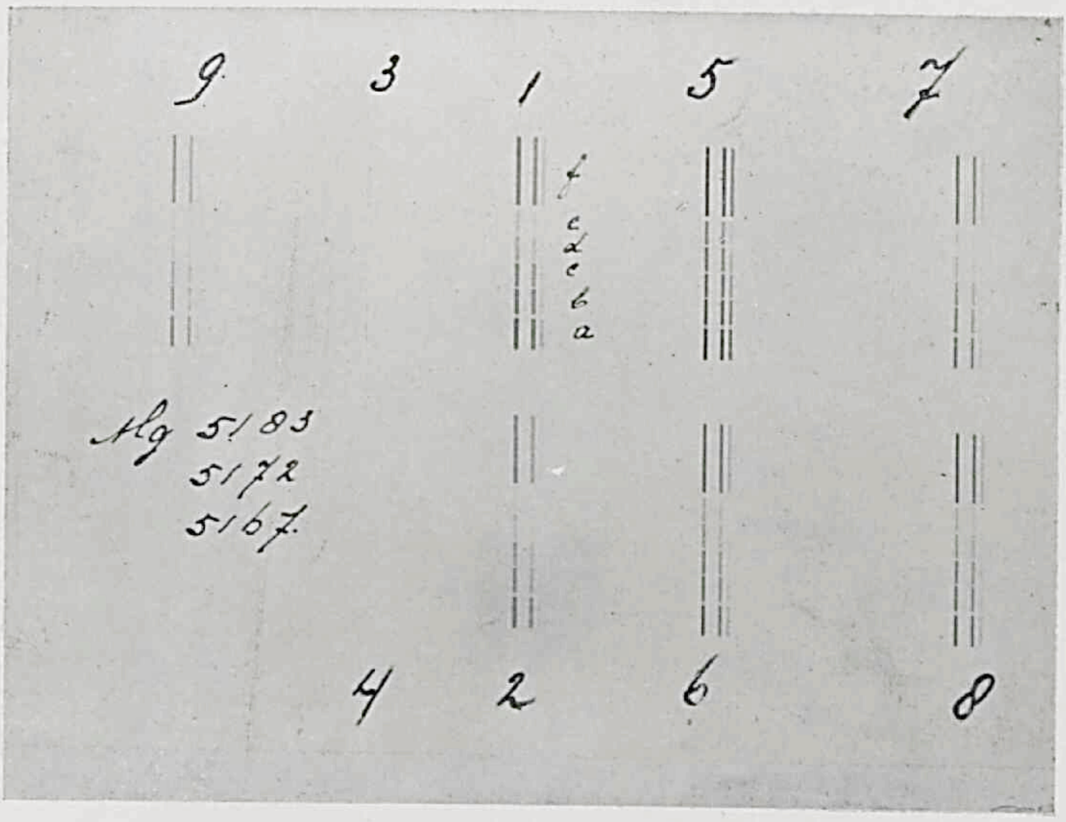


Plate II.

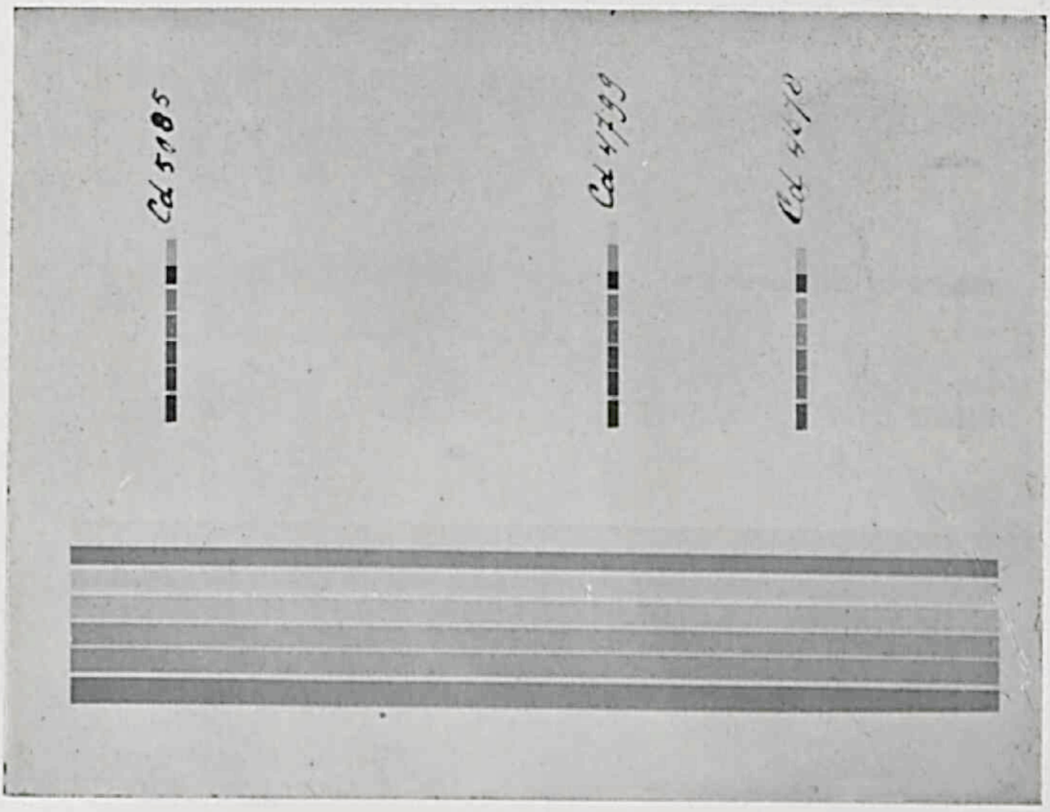
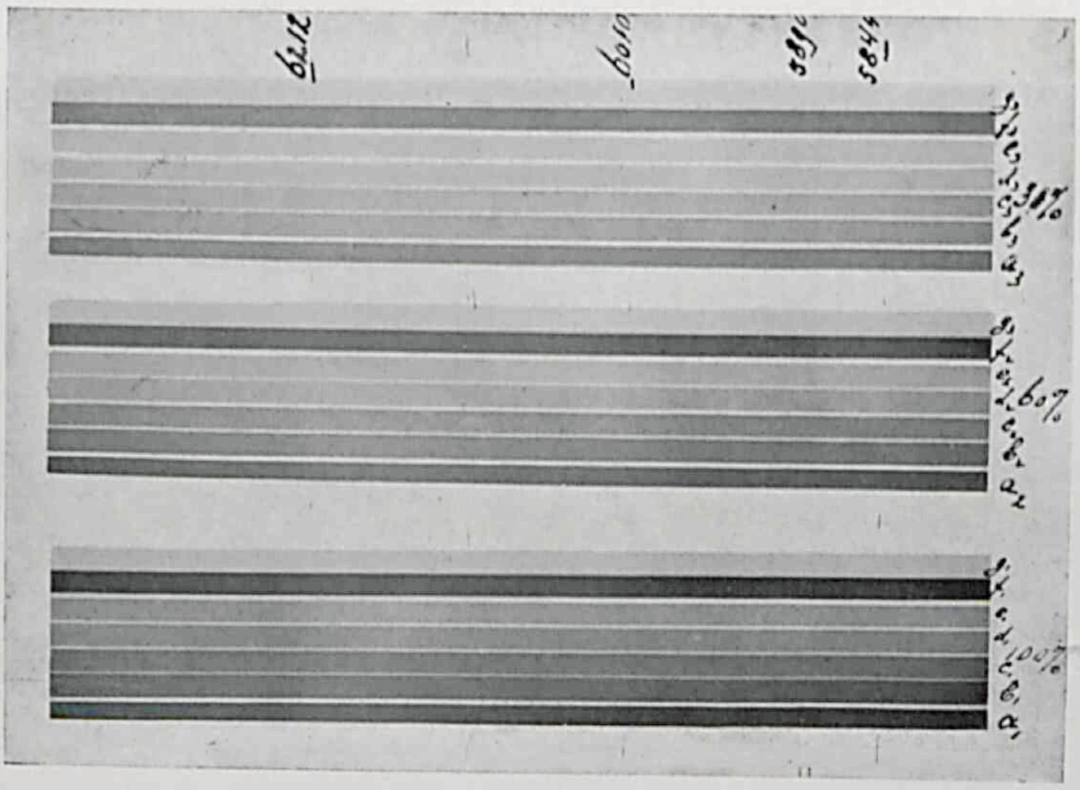


Plate III.



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STELLINGEN.

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I.

Intensiteitsmetingen van spectraal lijnen kunnen dienen ter bevestiging en opsporing van spectraal serien.

II.

De resultaten der absorptiemetingen in enge spectraal gebieden, in het bijzonder die van absorptie lijnen, hebben zeer geringe waarde.

III.

De voorstelling, welke E. RUPP geeft van de lichtemissie der Nevenserien, is onvolledig.

E. RUPP. Ann. der Phys. 73 S. 10, 1924.

IV.

De quantitatieve verklaring, die C. G. ABBOT en zijne medewerkers geven van de verandering der energieverdeeling in het zonnespectrum bij variatie van de zonneconstante, is niet houdbaar.

Ann. SMITHS. Inst. IV, blz. 206.

V.

De wijze, waarop MICHELSON en PEASE bij hunne methode tot bepaling van de middellijn van sterren rekening houden met de lichtverdeeling over het sterreoppervlak, is onbevredigend.

Astrophysical Journal vol. LIII, pag. 254, 1921.

VI.

Het convergentiebewijs van E. Czuber voor de integraal $\int_0^{\infty} e^{-yx} \frac{\sin x}{x}\, dx$ is onjuist.

E. Czuber. Vorlesungen über Differential- und Integralrechnung, II, IIIe Auflage, S. 164.

VII.

De integraal $\int_0^{\infty} \frac{dx}{(1+x)^2\,(1+x^n)}$ is voor elke reëele waarde van n gelijk aan $\frac{1}{2}$ en kan opgevat worden als bijzonder geval van meer algemeene integralen, welke een bepaalde waarde hebben, onafhankelijk van den parameter n.

(Prijsvraag 3. Wisk. Genootschap. Amst. 1924).

VIII.

De verklaring van het ontstaan der magnetische stormen door Ch. Nordmann gegeven, is onjuist.

Annales de l'observatoire de Nice. Tôme IX, 1905.

Zie ook Le Royaume des cieux. Ch. Nordmann, 1923, bladz. 109.

IX.

De behandeling der lenzenformule $x_1 \times x_2 = F_1 \times F_2$ bij het gymnasiaal en middelbaar onderwijs is te verkiezen boven die van de in de meeste leerboeken voorkomende formule $\frac{1}{b} + \frac{1}{v} = \frac{1}{f}$.