**Physics.** — *A visual spectroscopic method in heterochromatic photometry.*

By L. S. ORNSTEIN, Miss J. G. EYMERS and D. VERMEULEN. (Communication from the Physical Institute of the State University of Utrecht.)

(Communicated at the meeting of April 2, 1932.)

1. Some time ago we have built in our Institute a spectral pyrometer in which a monochromator is used in stead of a "monochromatic" filter. If we put our eye at the spot of the last slit of a monochromator we will see the illuminated field in a colour which can be chosen arbitrarily. In this way it is possible for us to compare in that colour the intensity of two lamps of which an image is formed at the same spot.

After the construction of a pyrometer with vanishing wire had been performed in this way, we found in the litterature that HENNING [1]) had used this principle already in 1910, with the only difference that he used a spectroscope in stead of a monochromator.

Now if we see which how much trouble various investigators have worked out methods for the determination of the effective wavelength of filters, it is clear that the method of HENNING had not been used to the extend it deserves. In our opinion the use of a double monochromator [2]) has great advantages as well in respect to the greater spectral purety as in respect to the greater luminosity.

During the last time we have used the monochromator-pyrometer for the solution of several problems, combining the instrument with a lamp relatively or absolutely standardised energitically for the visible. In this way it is possible to perform heterochromatic photometric measurements in a quick and accurate way. We will give a description of the method used for the measurement of:

*a.* the relative measurement of intensity for a given wavelength;

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1) F. HENNING, Z. S. f. Inst. 30, 62, 1910.

2) P. H. v. CITTERT, Rev. d'opl. 2, 57, 1923.

*b.* the measurement of reflection and absorbtion;
*c.* the measurement of the proportion of distant spectral lines;
*d.* absolute measurement of intensity;
*e.* optical pyrometry, determination of the effective wavelength of colour filters;
*f.* application to the photometry of incandescant lamps.

2. *Description of the apparatus.* In order to compare the brightness of a body with that of a lamp *L* (fig. 1) for a given wavelength we form

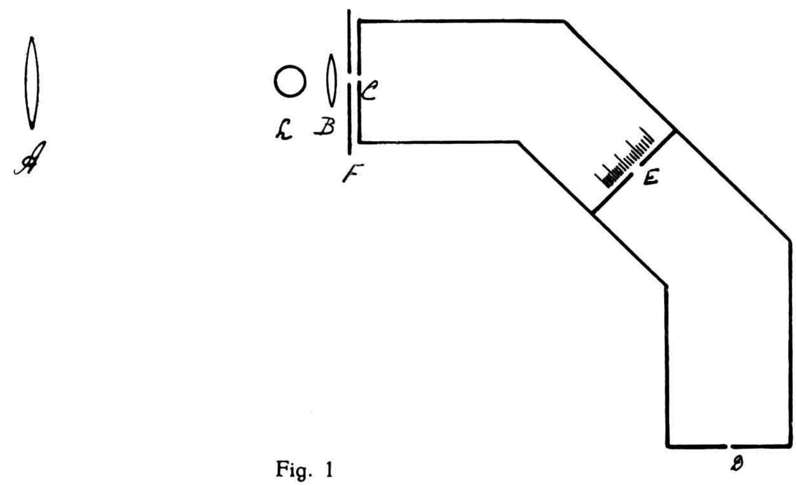


Fig. 1

with the help of a lense *A* an image of the body on the wire of the lamp, which is put before the double monochromator. The eye is put behind the last slit *D* of the monochromator. In order to understand easily the action of the apparatus one should bear in mind that the monochromator forms an image of the eye at the first slit *C* in a given wavelength. This image of the eye can be considered to look at the wire and the image of the body with the help of a lense *B*. *F* is a diaphragm. which is totally filled by the rays originating from the body, the brightness of which we wish to measure. The adjustment of the central slit can been performed with the help of a Helium geisler tube.

From the theory of the double monochromater it appears that the region originating from the monochromator is proportional to the sum of width of the slits *C* and *E* when the last slit is larger than the first and the central slit. This was always the case in our measurements. Table 1 gives the spectral region for a slitwidth of 0.3 mm. The slit width used is indicated at the different applications of the apparatus we describe below.

The method of measuring the spectral region originating from the monochromator may be sketched. An image of the last slit of the monochromater is formed perpendicular to the slit of a spectroscop. The theory of the monochromator shows that we see in this case a parallelogram.

The edges of which can be determined accurately and give the region mentioned.

TABLE I.

| Wavelength Å | Spectral region Å | Minimum Region Å |
|---|---|---|
| 6750 | 255 | 43 |
| 6135 | 174 | 29 |
| 5650 | 132 | 22 |
| 5285 | 103 | 17 |
| 4995 | 81 | 14 |
| 4760 | 65 | 11 |
| 4565 | 54 | 9 |
| 4403 | 65 | 7 |
| 4260 | 37 | 6 |

The energy distribution for the case that first and central slit are equal consist of a triangle. If the spectral region is sufficiently small so that the sensitivity of the eye and the energy of the frequencies in the spectral region under consideration may be taken as constant. The effective region coming from the monochromator can be taken half the base of the triangle. In this way table 1 has been constructed. A region of 100 Å can be determined accurate to 1 Å without any trouble in the yellow the accuracy for red and violet is somewhat less.

3. *Relative intensity measurement for a given wavelength.*

Let us take as an example the problem that the intensity of light of given intensity has to be determined for gas discharge tubes as function of the current density. The surface brightness is too large to be compared with those of the pyrometer lamp.

We have therefore put a white screen in apropriate distance of the tube and photometred the screen [1]).

The fact that we have to measure a very homogeneously illuminated surface is a great advantage for the precision of the measurement.

The width of the slits of the monochromator has been chosen in such a way that no disagreable difference in colour occurred between the wire of the pyrometer lamp and the image of the screen. At given current in the lamp to be measured the current of the pyrometer lamp was changed till the brightness of the wire of the pyrometer lamp and the field were equal.

[1]) The way in which the reflective power of the screen depends on wavelength is of no importance for the problem under consideration.

The brightness of the pyrometer lamp was standardised before as a function of the current in the pyrometer lamp circuit in which an accumulator and a precision ammeter were placed. This standardising was operated so that the pyrometer lamp was compared with the screen which was illuminated by a lamp operated on constant current and put in different known distances from the screen. By the change of distance the brightness of the pyrometer lamp for different currents was determined in a proportion of relative brightness going from 1 to 200, where the smallest intensity use is arbitrarily put 1. The standardising for larger brightness was performed in the following way. The constant lamp is put so near to the screen that the pyrometer lamp shows a brightness 200. Now the light is weakened by a neutral filter the brightness found gives immediately the transmission of the filter. Now the lamp is brought so near to the screen that the brightness is much larger than 200 — the square of the distance law now being invalid. If we now put the filter between the lamp and the screen and if the brightness found is less than 200 the intensity of the lamp can be found knowing the transmission of the filter. In this way the apparatus has been standardised for relative intensities between 1 and $10^4$ for different wavelengths.

The agreement of the current for which the difference of wire and field disappears for different observers is very good. The accuracy of a single lecture of the current is about 1 %.

The possibility of separating narrow spectral lines is limited by the smaller width of slit for which the image of the wire is not spoiled by diffraction. In column 3 of table 1 the spectral region of minimum dispersion is given. The disturbtion by straylight plays no part when a double monochromator is used.

The accuracy of measurement is the greatest when large homogeneous surfaces are photometred, for small surfaces the precision is much less. In order to attain for capillary tubes the same precision of measurement as for larger surfaces we can proceed in the following way : the pyrometer lamp is replaced by a diffusing white plane with a slit in which an image of the capillary tube is formed ; the surface itself is illuminated from one side by a lamp of which the intensity is known as a function of the current (f.i. measured in the way described above). If we now measure the current intensity at which the image of the capillary disappears in the back ground the brightness can be measured in this way.

It may be urged that it is possible to measure with the spectral pyrometer to a precision of 2 % proportions of intensities up to $10^4$. If one should like to do this with the thermoelectric, the photoelectric or the photografic method it would be a very tiresome work.

A further advantage of the visual method occurs for those cases whose electric disturbances make impossible to use the thermoelectric or photoelectric method. As an example we show some measurements of the intensity of a Helium tube in a condensed discharge.

The only other method available is now the photografic method which is used by Mr H. P. BOUWMAN [1]) for this work in our institute. We have measured for several *He* lines the energy emitted pro discharge; for this purpose we have measured the surface-brightness as a function of the discharge-potential. Multiplying this surface-brightness with the number of discharges pro second we get — as Talbot law shows — the intensity pro discharge. In Fig. 2 curve I gives the results of the spectral-pyrometric method curve II those of the photografic method kindly put to our disposal by Mr BOUWMAN; the agreement is very good.

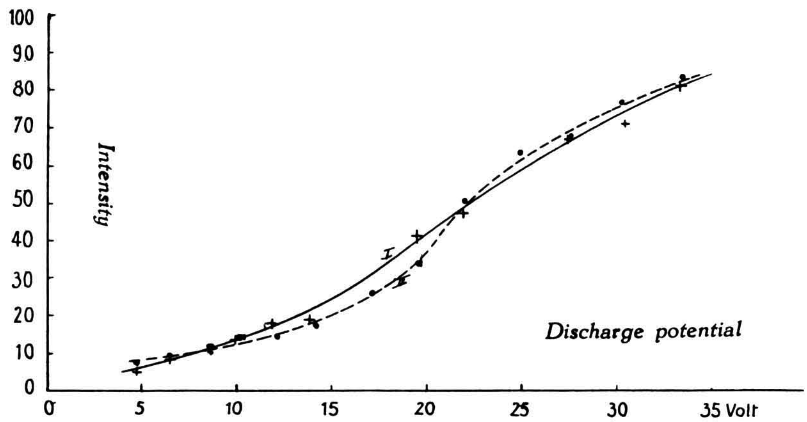


Fig. 2

4. *Measurement of reflexion and absorption.* In order to find the reflective power of a surface the intensity of a band lamp is measured with the pyrometer direct and also reflected in the surface, the current density of the band lamp being constant. The proportion of the brightness found for both cases gives for each wavelength the reflective power.

In order to measure the absorption coefficient a white surface is measured with and without the absorbing substance in the path of light. The precision of these measurements is — as already has been pointed out in the standardising — about 1 %. If there is a strong selectivity the smaller spectral region which can be used plays a part. (Compare table 1.)

The spectral pyrometer is also of great use for the measurement of colours; for this purpose a "normal white" [2]) surface has to be compared with the colours by constant illumination. In fig. 3 the reflective power of an oil-colour (flesh colour) in a painting of JAN SLUYTERS is reproduced as a function of wavelength for perpendicular incidence of the light.

The spectral-pyrometric method furnishes an important way of operating

[1]) For the electric circuiting comp. Z. S. f. Phys. 43, 839, 1927 and the Utrecht, Dissertation of H. P. BOUWMAN which will appear in a short time.

[2]) We have used „normal weisz" compare Z. S. f. Phys. **10**, **111**, 1922.

for the research of the scattering of light in turbid media particularly as large differences of intensity can be measured.

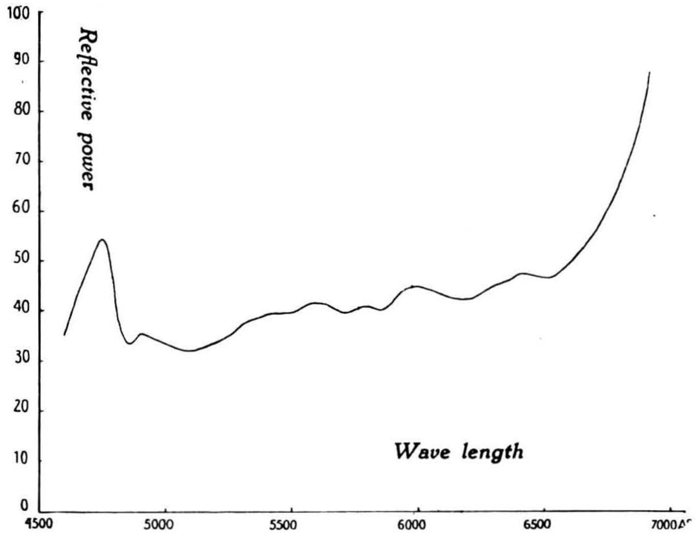


Fig. 3

5. *The measurement of two distant spectral lines with the help of a normal lamp.* In order to compare the intensity in different spectral regions it is necessary to find the correction for the specific properties which shows the apparatus for different wavelengths. With the help of a lamp standardised relatively for energy as a function of wavelength this can be done in the following way.

A white surface is illuminated by a normal lamp of given colour temperature [1]), and the currents of the pyrometer lamp $i_{\lambda_1}$ and $i_{\lambda_2}$ are determined for the wavelength $\lambda_1$ and $\lambda_2$, the spectral region passing the pyrometer may be $\triangle\lambda_1$ and $\triangle\lambda_2$. The proportion of the energies $E_1/E_2$ can be determined with the help of the Planck formula from the known colour temperature.

The observed energies in $\triangle\lambda_1$ and $\triangle\lambda_2$ are $\triangle\lambda_1$ $E_1$ and $\triangle\lambda_2$ $E_2$, the pyrometer currents $i_{\lambda_1}$ and $i_{\lambda_2}$ are a measure for those energies, which can be used in order to find the skale necessary to which the curves of standardisation of 3 must be shifted.

If one now determines the pyrometric values $i'_{\lambda_1}$ and $i'_{\lambda_2}$ for two colours, then in the changed diagram these currents give a direct measurement of the intensities of the spectral lines. The errors of the standardising of the lamp enter to their full value in the result obtained.

6. *Absolute measurements.* If an absolutely standardised lamp is

[1]) For the standardising of the lamp. comp. L. S. ORNSTEIN Journ. optic. Soc. Amer. **20**, 573, 1930.

available it is without further comment clear that intensities may be measured absolutely.

We have used this proceding in order to measure the daylight in different wavelengths. For this purpose we have made pyrometric measurements of a white surface illuminated by the daylight on the roof of the Utrecht Institute. The whole equipment was standardised absolutely with the help of a lamp (absolute energetic standard of the Institute) placed at known distance from the surface. The apparatus seems to furnish an important help for the measurement of the solar energy and the radiation of the sky in the visible, chiefly because it is very easy to interchange the absolutely standardised lamps for different observers. In this way systematic error can be avoided and the results of different observers become much better comparable. Fig. 4 gives some of the results which will be published later more fully.

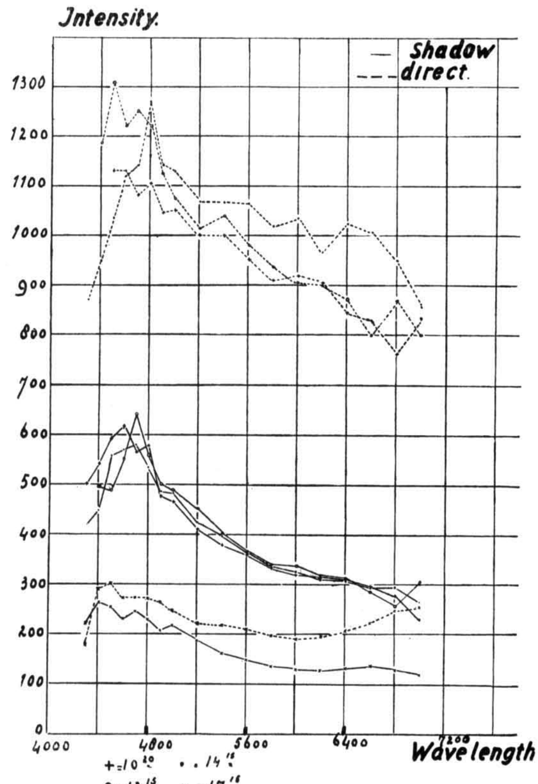


Fig. 4

7. *Optical pyrometry, effective wavelength of colour filters.* As already HENNING has pointed out the spectral pyrometer is very fitted for the pyrometric work in arbitrary wavelength regions with well defined regions of wavelength. The apparatus can also be used in order to determine the

effective wavelength of colour filters used in the optical pyrometer helping in this way to get greater accuracy for this instrument.

The effective wavelength of coloured glass has been calculated by FORSYTHE [1]) and HENNING [2]) on the base of theoretical investigations on the photometric determination of two radiating bodies of different colour temperature. W. DE GROOT [3]) has indicated a somewhat lengthy experimental method for the determination of the effective wavelength. With the help of the described apparatus the effective wavelength can be determined exactly, and quickly, the use of the monochromator is essential for this work [4]).

If the double monochromator is illuminated with white light and the middle slit is taken out, white light comes from the last slit.

Now we illuminate a white surface with a lamp of given colour temperature f.i. 2500° K. and perform a measurement with the spectropyrometer with the second slit taken out and the filter put in front of the third slit. The pyrometer lamp shows then a temperature of 1400° K. Then the middle slit is put in again and the filter taken away; and the middle slit adjusted till again the surface and the pyrometer wire have the same brightness. The wavelength indicated by the position of the middle slit when this is the case, gives the effective wavelength of the coloured glass. Several observers have determined in our Institute in this way this quantity for a green glass, from their measurements it appears that in the green an accuracy of 2 Å may be attained, which opens the possibility of much precised pyrometric measurements.

8. *Application to the photometry of lamps.* In the measurement of intensity the brightness of two fields is always compared; one field is illuminated by a known the other by an unknown source of light. The LUMMER—BRODHUN prism is generally used in order to compare the fields juxtaposed. Till now only the comparison of light sources of equal spectra distribution was possible with accuracy. When the light sources differ in colour the adjustment gets uncertain and different observers show large differences.

The method used in this paper, to see through a monochromator the world in a colour which can be chosen arbitrarely, can be applied also in the photometer bench in order to observe the field of the LUMMER—BRODHUN in one colour.

We have in a provisory optical bench in which a LUMMER—BRODHUN prism with two fields was mounted-compared two incandescent lamps.

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[1]) FORSYTHE Journ. Opt. Soc. Amer. 4, 305, 1920.

[1]) F. HENNING, Z. f. Phys. 30, 285, 1924.

[3]) W. DE GROOT, Physica 4, 157, 1924.

[4]) The HENNING apparatus as constructed by SCHMIDT and HAENSCH is less usefull for this work.

It is possible — the white illumination being 40 Lux — to observe differences in brightness for red, green and blue of 1 %.

In our opinion it is possible to characterise lamps comparing them in three colours with the normal lamp ; in this way the distribution of energy is sufficiently determined for all technical purposes.

If an absolutely standardised lamp is chosen for the known lamp as a comparison-standard, it is possible to measure absolutely the spectral composition, of a lightsource with the photometer bench.

It is also possible to measure with our method the absolute spectral composition for any lightsource.

It is our opinion that the double monochromator used in the way described can be an important help in heterochromatic photometry.

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**Physics.** — *The spectrum of the solar corona* [1]). By T. L. DE BRUIN. (Communicated by Prof. P. ZEEMAN.)

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1. *Historical note.*

References to the phenomenon of the solar corona at the time of a total eclips of the sun can be traced through the whole history of mankind [2]). The spectroscopic study of the solar corona started in the same year 1868 that the helium in the sun was discovered. The next year 1869 brought the discovery of the mysterious "coronium".

At the total eclips of August 18, 1868 POGSON, RZIHA and TENNANT observed the continuous spectrum of the corona, but no absorption or emission lines. At the total eclips of August 7, 1869, HARKNESS and YOUNG independently observed the green coronal line and YOUNG proved that it has a truly coronal origin. YOUNG's measures of the line placed it at 1474 K (KIRCHOFF scale) or in the modern scale at $\lambda$ 5317. Many additional observations later continued to place it at or near 5317 *A*. At the eclips of 1893 FOWLER photographed nine coronal rings with a slitless spectrograph, all of which agree in position with selected lines reported as of coronal origin in the 1886 eclips. At the eclips of 1898 FOWLER, SHACKLETON and W. J. LOCKYER made the interesting discovery that the famous green coronal bright line is not at 5317 but at 5303.

1) Preliminary note: Nature. March 26, 1932.

2) A very extensive report over: "Eclipses of the Sun" by S. A. MITCHELL. Chap. 3. Handbuch der Astrophysik. Bd. IV, p. 231.

Data before 1918 see: LICK. Obs. Bull. X. Nr. 318 343, p. 8. 1918 1923 by W. W. CAMPBELL a. J. H. MOORE. A short and popular note over: Kosmische spectra, see: T. L. DE BRUIN, Hemel en Dampkring. April. Mei. 1931.