A PRECISION DIRECT-READING SPECTROPHOTOMETER*

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Plate XIII

ABSTRACT. The experimental errors inherent in photographic photometry are discussed and a direct reading spectrophotometer for the visible especially adapted to the study of line contour and absorption and fluorescence spectra is described. Because of the higher resolution of which it is capable the method permits a more precise and complete analysis of absorption and fluorescence spectra by revealing the fine structure too small to be detected by the usual methods. A test of the instrument was carried out by determining the intensities of the lines 4078 and 4047 from Hg arc and the energy distribution in the Hβ of the solar spectrum. The system is distinguished by high sensitivity and easy adjustment and it dispenses with the labour involved in photographic photometry.

Nearly all attempts to measure intensities of spectral lines depend first on obtaining a photograph of the spectrum and then interpreting the varying densities in the plate in terms of intensities. The method involves very careful calibration of the photographic plates. Photography as an intermediate step introduces several undersirable complications and intricacies. The experimental errors inherent in the photographic method are rather difficult to estimate and are at best only approximate. It is difficult in a given case to say just what part of the error can be attributed to the different sources of error and what part to the particular method in question. Further it would be difficult to apply this method in some cases where the intensity range is large.

Within the last few years much attention is given to the problem of measuring intensity distribution in spectral lines directly and attempts have been made by several investigators in this direction. The advantages of this method are obvious because many troublesome problems whose solutions lead always to sensible errors are eliminated. If we are to gain an accurate knowledge of the physical conditions governing the process of absorption and emission, the necessity for such measures is clear. In collaboration with H. Grenat, d' Azambuja[1] at Meudon and Dunham[2] at the Mt. Wilson Observatory have undertaken research as early as 1934 for the purpose of directly measuring intensity

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distribution in spectral lines and determining the absorption line profiles in the solar spectrum. Dr. Dunham who was recently working on the same problem at the University Observatory, Oxford, is reported to have succeeded in measuring the profiles of H α and D lines in the solar spectrum using a null photoelectric method. Dr. Brück[3] working at the Solar Physics Observatory, Cambridge, developed a recording photoelectric microphotometer operating directly in the solar spectrum. All these observers have used the same general method namely the photometric measurement of high dispersion solar spectrograms by the use of a photoelectric cell and a thermionic amplifier, specially designed valves being employed for the purpose. The very feeble current generated as a result of the light falling upon the photocell is amplified about a million times.

With most standard vacuum tubes the emission of the oxide coated cathode is unstable and the grids are not sufficiently insulated. Further, fluctuations in the plate current prevent us from reaching the highest sensitivity. Tubes have been designed in recent years the grid filament resistance of which is very high. They require an anode voltage of only 8 to 10 volts. The mounting of the electrodes also is such as to ensure low surface leakage. The low filment and low anode voltage for which the valves are designed, have a distinct practical advantage, it being a simple matter to maintain steady filament and anode currents. The outstanding examples of these tubes are G. E. Pliotron F P 54 developed by Metcalfe and Thomson[4] and the electrometer Triode[5] manufactured by the G. E. C. London. All these tubes have amplification factors less than one and depend for their usefulness on the very high input resistance. The use of one of these low grid current vacuum tubes is undoubtedly an excellent method for measuring light intensities directly.

In attempting to develop a method for the purpose of recording profiles of Fraunhofer lines without recourse to photography, on account of the excessive cost of and the difficulty of getting in war time the specially designed valves, it seemed to us particularly important, the possibility of using an ordinary valve in the amplification circuit to obtain the desired sensitivity. It has been noted by various authors[6] that the input resistance of an ordinary valve can be greatly increased by a special use of its grids together with greatly reduced voltages. Further, for good insulation the lead from the control grid must emerge through the top of the tube rather than through the base.

During the past 15 months we have carried out an extensive study of the amplification of photoelectric currents and their application to spectrophotometry. After a complete study of these problems, attention was directed to the design and construction of a precision photoelectric spectrophotometer suitable for the measurement of intensities of spectral lines directly. Attempts in this direction have been so successful that it seemed worth while to publish a description of the arrangement.

Since there is considerable variation in the characteristics of individual vacuum tubes, several standard tubes were tested to determine their behaviour under the operating conditions and 1 A 6 was finally selected as it was found most satisfactory. For the amplifier circuit while any of the conventional circuits could be employed, the Dubridge[7] circuit seemed most suitable by virtue of its simplicity of construction and operation. The diagram of the circuit is shown in fig. 1. 1 A 6 is a multielectrode valve having five grids in addition to plate and filament. The two grids Nos. 3 and 5 are connected together and used as a plate while Nos. 1 and 4 are used as space charge grid and control grid respectively. Grid No. 2 and the plate are superfluous and are directly connected together to the earthed end of the battery. As a result of the high insulation resistance and the reduced voltages used, the input resistance rose to about 10^{13} ohms.

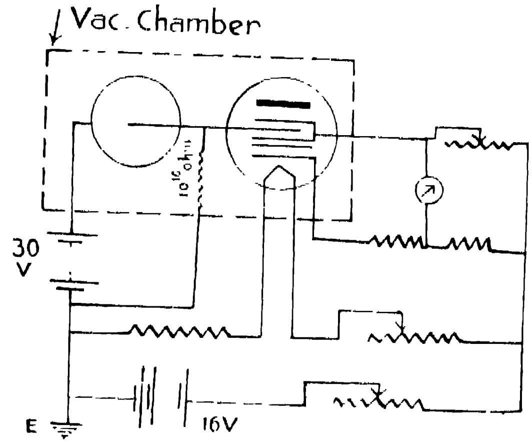

FIGURE 1

It has been shown by L. R. Hafstad[8] that improved stability can be obtained by mounting the photocell and the amplifier in an evacuated container. This precaution practically eliminates the surface leakage from the amplifier tube and the photocell as well as the tendency of the leads to pick up stray ions. The tube, grid leaks and the photocell are therefore enclosed in a heavy cast iron cylinder* which is evacuated and kept dry by a drying agent in a bottle in the pumping lead. It served as an electro-magnetic shield and permitted the photocell and the selective slit to be placed at any point in the spectrum. The vacuum cylinder is 6″ in diameter and 10″ in height and is closed by two end plates. All the parts are mounted on an ebonite base attached to the plate which closes the lower end and the wires necessary for the operation of the amplifier are brought out through sealed insulating bushings and connected by a shielded flexible cable to the control panel. In this way not only the highest insulation is maintained about the most essential points but also the grid leak resistance remains constant.

* This cylinder was kindly made for the authors by the Andhra Scientific Instrument Co.

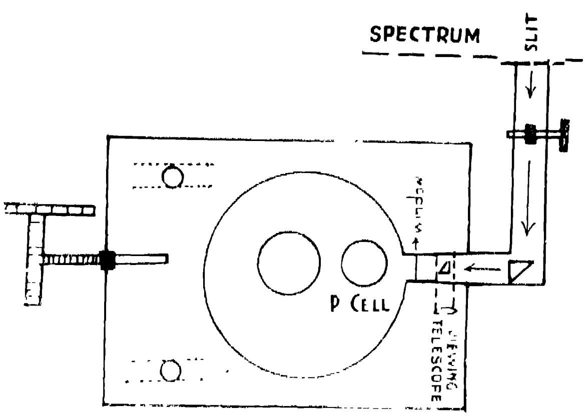

FIGURE 3

A photograph of the actual set up attached to the 20 foot Littrow spectrograph and a schematic drawing of the instrument are given in figs. 2 and 3. The cylinder is provided on one side with a window fitted to a short projecting tube. Over this is fitted the tube T with a slit S which admits the radiation from the selected line to the photocell. The tube carrying the slit has a rack and pinion motion enabling it to be placed in the focal plane of the spectrograph. It is found difficult to seal vacuum tight with sealing wax or to have rubber gaskets as they would perish with time. Instead the cylinder is ground well with the *two* end plates and vacuum grease is applied to the rims. When the pump begins to work the grease spreads itself and is found that the vacuum keeps overnight with very little leakage.

The most important part of the photometer is the arrangement by which the vacuum chamber with the attached slit is moved along the spectrum in a direction parallel to the dispersion. The cylinder is mounted on a heavy steel carriage to the underside of which are fixed hardened steel plates with '$\wedge$' faces resting on hard steel balls carried by sleeves fixed to an iron base. The base is fitted with levelling screws so that the centre of the photometer slit can be brought on to the middle of the spectrum. The carriage is fitted with a micrometer screw which gives a direct traverse of 5 cm. The screw is of pitch 1 mm and is provided with a divided head. The whole arrangement is placed on a heavy iron bracket fixed to one side of the stone pillar at the camera end of the spectrograph.

The resistance leaks employed in these measurements consisted of Xylol-alcohol mixtures* contained in soft glass tubes and Indian-ink lines drawn on strips of good drawing paper and enclosed in glass tubes. To avoid external leakages the outer surface is coated with ceresin wax and the resistances supported

* These were kindly made for the authors by Dr. S. Ramachandra Rao of the Annamalai University to whom their grateful thanks are due.

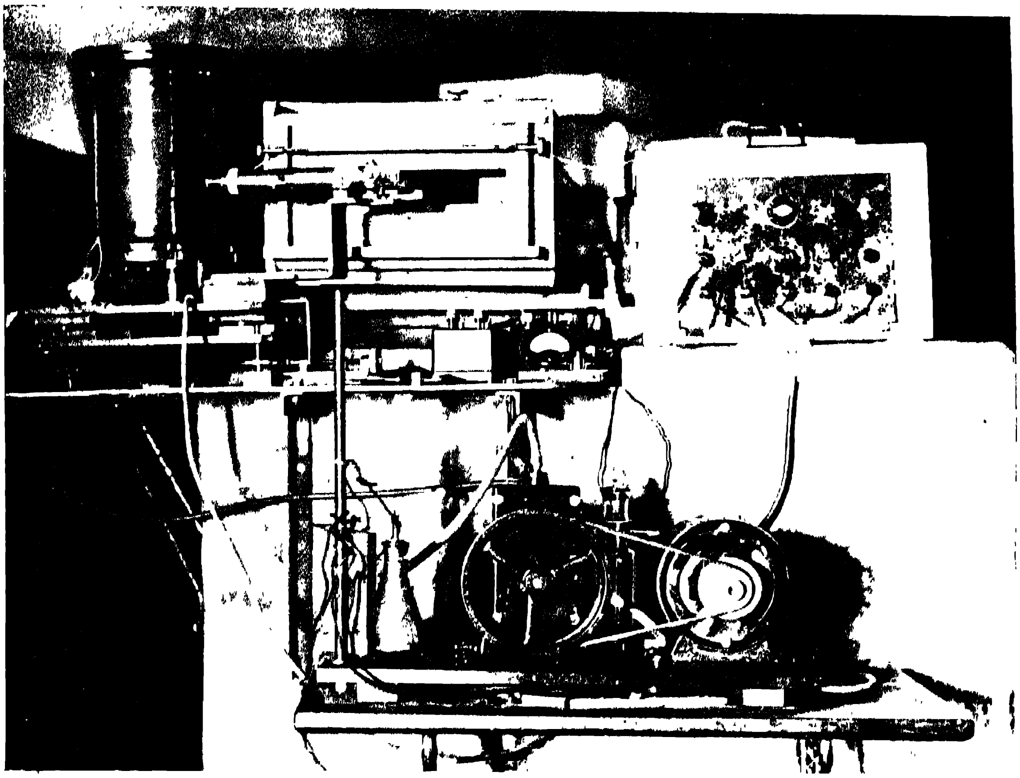

Figure 2

on connecting wires. When an attempt was made to increase the sensitivity of the instrument by placing high grid leak resistances of the order of 10^{12} ohms great difficulty was experienced. If rapid measurement are required the resistance cannot be increased above 10^{10} ohms.

Before making the observations it is necessary to adjust the photometer slit to exact parallelism with the spectral lines. This parallel alignment is checked as follows. In front of the window through which the light passes just before reaching the photocell, a small right-angle prism and a viewing lens may be inserted and the necessary adjustment is made by widening the photometer slit and turning it through the required angle. After the slit is thus adjusted, the prism and viewing lens are removed and the light path is cleared. The outline of the profile can now be easily obtained by shifting the selective slit in front of the spectrum by means of the micrometer screw.

The accuracy of the results obtained depends on how strictly the proportionality holds between the photoelectric current and the intensity of the light incident on the photocell. Before undertaking any intensity measurements it was necessary to investigate the extent to which this relation is satisfied. This was done in the following manner. Neutral perforated screens were used to diminish the intensity of light admitted into the spectrograph by known amounts. These screens each contained symmetrically placed holes of diameters 3·1, 2·5, 1·9, 1·5, 1·3, and 0·6 cm. These were in turn calibrated with a vacuum thermopile and galvanometer as this combination responds linearly to light of different intensities. The proportionality was further assured by using light of low intensity and by causing the amplification system to operate upon the straight portion of the grid bias plate current curve. It has been found that with these precautions, there exists a strictly linear relation between the incident light and the galvanometer deflection.

In order to test the performance of the instrument, some preliminary measurements were carried out with a home-made Hg arc. The observations were made with the horizontal Littrow prism spectrograph of 21 ft. focal length with optical parts of glass. Since stray radiation due to reflection and scattering by optical parts is a troublesome source of error in this type of work, special precautions were taken to reduce it to a minimum. All the inner parts of the spectrograph were painted dull black and several diaphragms were mounted inside so that there is almost no chance for any radiation to be reflected into the spectrum from the inner walls of the spectrograph. A double monochromator which allows only a small region of wavelengths to enter into the spectrograph and removes all unwanted light, was used to improve the purity of the spectrum. In a single monochromator the stray light caused by reflection and scattering in the various parts of the instrument is inevitable. Light from the Hg arc was sharply focussed on the slit of the monochromator and a series of readings were taken for various widths of the slit for different voltages. The results obtained are given in Table I.

TABLE I

Volatage applied	Slit width	Galvanometer deflection	
		λ 4077·8	λ 4046·6
65	0·08 mm.	19	21
	0·16	32	40
75	0·08	20	23
	0·16	35	43
95	0·08	23	24
	0·16	38	44

We have recently used the instrument for measuring the energy distribution in the Hβ of the solar spectrum. By means of the micrometer screw the selective slit was placed in succession at different points on the line and the galvanometer deflection observed in each case. The results are given in Table II. When the line is thus scanned and allowance is made for the systematic and accidental errors, by plotting deflections against distances the observed profile was obtained. The equivalent width found by measuring the area of the profile is 2·1 Å and the central intensity 18 per cent, which compares very well with Unsold's[9] values.

TABLE II

Hβ line λ 4861·34

Distance from center in mm.	4·5	3·5	3·0	2·5	2·0	1·5	1·0	0	0·5	1·0	1·5	2·0	2·5
Deflection	35	34	33	32	30	28	23·5	7	12	20	25	28	31

Distance from center in mm.	3·0	3·5	4·0
Deflection	34	34	36

It must be understood that these observations are of a preliminary nature and were made solely as a test of the method. The test while not sufficiently rigorous showed that the circuit functions satisfactorily when the grid leak used in below 10^{10} ohms. As compared with the method of photographic spectrophotometry the enormous gain in time obtained with the present instrument is obvious. It possesses apart from high speed, great sensitivity and easy adjustment. And the device is rapidly adaptable for photographic recording. These as well as other minor advantages should make the device a valuable aid in direct measurement of light intensities. In the case of 1 A 6 it is not practicable to use higher than 10^{10} ohms as the resistance of the input circuit approaches the unshunted resistance of the tube. Further work is in progress. A number of improvements which became evident in the course of the present study are being introduced and 1 A 6 is being replaced by an electrometer type valve which is just received, so as to increase the over-all sensitivity of the instrument. The method will be subjected to a severe test and the relative merits of the null and deflection methods together with the observations of line profiles will be discussed in a later paper.

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