LA-2280
UC-37 INSTRUMENTS
TID-4500, 14th edition

LOS ALAMOS SCIENTIFIC LABORATORY
OF THE UNIVERSITY OF CALIFORNIA LOS ALAMOS NEW MEXICO

REPORT WRITTEN: July 1958

REPORT DISTRIBUTED: April 27, 1959

**DESIGN AND OPERATION OF A NEW PHOTOELECTRIC
COMPARATOR FOR WAVELENGTH AND INTENSITY
MEASUREMENTS OF SPECTRA**

by

David W. Steinhaus

This report expresses the opinions of the author or
authors and does not necessarily reflect the opinions
or views of the Los Alamos Scientific Laboratory.

Contract W-7405-ENG. 36 with the U. S. Atomic Energy Commission

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

+

ABSTRACT

A photoelectric comparator that can be used for making wavelength measurements, intensity measurements, and observations of the shapes of spectral lines is described. The instrument is similar to one reported by Tomkins and Fred with improvements in the optics.

1
2

3

4

5
6

TABLE OF CONTENTS

INTRODUCTION	<u>Page</u> 7
DESCRIPTION OF THE PHOTOELECTRIC COMPARATOR	8
DISCUSSION	14
INSTRUCTIONS FOR OPERATION	17
Optical System Adjustments	17
Reading Procedure	19
REFERENCES	21

ILLUSTRATIONS

Fig. 1. The photoelectric comparator and its accessory equipment	22
Fig. 2. Rear of comparator with dust cover and field lamp removed	23
Fig. 3. Photoelectric comparator optical system	24
Fig. 4. Position on oscillograph screen and spectrogram as a function of time	25
Fig. 5. Photographic plate on comparator.	26
Fig. 6. Photomultiplier tube and microscope holder	27
Fig. 7. Complete assemblage for recording data	28
Fig. 8. Interferogram (top) and spectrogram (bottom) taken with a narrow spectrograph slit showing single lines on spectrogram (X) that are resolved on interferogram into more than one line.	29

2

3

4

5

INTRODUCTION

The use of photographic plates for precision wavelength measurements of spectral lines requires very accurate position measurements of the lines on the plates. In addition, it is highly desirable to obtain measurements of the relative line intensities and to record the spectral line shapes. During the past few years several instruments have been built for such measurements. Among the most recent is the equipment at The Johns Hopkins University described by G. H. Dieke, D. Dimock, and H. M. Crosswhite.⁽¹⁾ They used a photoelectric setting device, as described by F. S. Tomkins and M. Fred,⁽²⁾ on a conventional comparator along with automatic punching of IBM cards with the measurements. The design of the photoelectric setting device for the photoelectric comparator described here is very similar to Tomkins and Fred's device but the optics have been rearranged and improved. This results in more rugged construction. It also provides improved density readings and a larger light intensity on the photomultiplier tube with less light on the photographic plate, and makes possible more precise location of true line position.

DESCRIPTION OF THE PHOTOELECTRIC COMPARATOR

The photoelectric comparator and its accessory equipment are shown in Figure 1. In this picture the light shield that covers the comparator has been removed. A Gaertner Model M1205C comparator, which has a precision millimeter screw, is used for the position measurement. It can be read directly and easily to 0.001 mm on the dial. To reduce the backlash and to increase the reproducibility, a weight of about 5 pounds is hung on the carriage by means of a pulley and a nylon cord. All of the optics originally in this comparator were removed and replaced with the optics to be described. Figure 2 shows the apparatus added to the rear of the comparator and Figure 3 shows the new optical system. This optical system plus a display of the photomultiplier tube signal on an oscillograph provides the fiducial point for each position measurement, a measurement of the transmission of the spectral line on the plate, and the observation of the spectral line shape.

The single filament lamp (Leeds and Northrup No. STD 3301-AQ-2) is the same as that used in the Leeds and Northrup "Knorr-Albers" microphotometer. The image of this lamp is only about 2.5 microns wide at the photographic plate. Because the spectral lines being measured are, in general, wider than 10 microns, the oscillograph screen shows practically the full resolution of the recorded spectral lines. The lamp can be positioned horizontally, as well as rotated to make its image parallel to the spectral lines. The length of the filament image can be easily

adjusted to any length less than 500 microns.

The horizontal scanning prism is rotated at the rate of 30 rps on the shaft of a Bodine Type KYC-23 synchronous motor. This causes the image of the single filament lamp to sweep unidirectionally across the photographic plate at the rate of 120 per second. For parallel beams of light through the prism, which is approximately the case with this optical system, the apparent displacement of the single filament lamp (D) for a prism of given width (W), index of refraction n, and an angle of incidence of the light beam to the prism (i) is given by the equation:

$$D = W \sin i \left(1 - \frac{\cos i}{\sqrt{n^2 - \sin^2 i}} \right)$$

A plot of this formula, with angle i related to time, $n = 1.515$, and with the displacement at the spectrogram is shown by the dashed curve in Figure 4. The experimental points show very good agreement with this formula. Each 12 x 10 mm face of the prism is flat to 1 wavelength of green light, and the opposite faces are parallel to $\pm 1/2$ minute of arc. These tolerances keep any loss in resolution on the oscillograph screen of the spectrum to less than $1/2$ micron when the prism is approximately 6 cm from the lamp, which is the case with this optical system. The prism faces are parallel to, and centered on, the motor shaft, and the sides of each face are painted black to remove the internal reflections.

The vertical scanning prism is rotated slowly in either direction with a 1 rpm "Elexo-Action" motor (Merk-Korff Gear Co.) at a command from the switch mounted at the side of the oscillograph (see Figure 1). This allows the operator to select any portion desired along approximately 1.5 mm of the spectral line being measured, since rotation of this prism causes an apparent displacement of the single filament lamp along the spectral line according to the equation given for the horizontal scanning prism. The axis of rotation of this prism is adjustable so that the motion produced is precisely parallel to the spectral lines being measured. The two opposite 39 x 29 mm faces used are each flat to 1 wavelength of green light and are parallel to ± 5 minutes of arc. These tolerances are easily met and make measurement errors from the rotation of this prism negligible. The two faces of this prism not used are painted black, and the mask in front of the single filament lamp removes the light from internal reflections.

All of the component parts of the apparatus at the rear of the comparator are very securely mounted together and soldered to an 1/8 inch wall, 2 inch O.D., and 11 inch long brass tube that replaces the field lamp optics tube originally in the comparator. Rotation of this entire unit is sometimes useful to aid the adjustment of the vertical scanning prism so that the vertical motion is exactly parallel to the spectral lines being measured.

The front-surfaced turning mirror is mounted to the other end of the 2 inch O.D. tube. This mirror can be rotated to send the light beam, which comes from the rear of the comparator through the 2 inch O.D. tube, to the lens. The lens can be seen under the photographic plate in Figure 5. This is an achromatic lens of 22.7 mm focal length and it can be adjusted, by means of a screw, to focus the image of the single filament lamp on the photographic plate. This adjustment is made with the comparator carriage in place by means of two cords around the screw that go under and to the sides of the comparator.

The mounting of the photographic plate on the comparator carriage is shown in Figure 5. The original glass plate of the comparator was replaced by a metal plate with a rectangular opening somewhat longer and narrower than the photographic plate to be used. The bar in contact with the back of the photographic plate is spring loaded. The bar on the front has two adjustment screws that are used to align the spectrum on the photographic plate parallel with the comparator carriage motion.

The photomultiplier tube and microscope mounting are shown in both Figures 1 and 6. The microscope is used for visual inspection of the spectral lines for blemishes. It is not used for position settings. The microscope can be positioned for use by pushing it down into its mounting tube to a preset stop. This also automatically turns on the field lamp, shown in Figure 1, which illuminates a white area in front of the single filament lamp. The microscope is pulled out of the optical

path prior to use of the photomultiplier tube. The 931A photomultiplier tube can be moved in and out or rotated in its holder so that the light goes to the most sensitive part of the cathode. The dynode resistors of 10^6 ohms each are connected directly to the photomultiplier tube base.

The output of the photomultiplier tube goes directly to the y-axis direct current amplifier of a 5 inch Du Mont Type 304A oscillograph with a Type 5ADP-7 long persistence picture tube. A 3×10^5 ohm load resistor is used. The x-axis amplifier is supplied with 6 volt, 60 cycle ac from the transformer used to supply the comparator dial lights. A 200 ohm resistor is used in series with each lead to the x-axis amplifier, since the oscillograph ground is different from the ground of the comparator dial lights.

Figure 4 shows both the position of the single filament lamp on the spectrogram and the horizontal position of the light spot on the oscillograph screen for a horizontal magnification of 1000. As can be seen, the two curves coincide for about half the total horizontal sweep distance. Thus over this part of the screen there is no distortion of the spectrogram. This is sufficient for every case so far encountered.

This curve also shows that although the two sweeps go in the same direction for the first $1/120$ second, they go in the opposite direction for the second $1/120$ second. Thus the oscillograph screen shows both the normal and the mirror image transmission curve of the photographic plate. The comparator carriage is moved so that the two transmission curves of the

spectral line being measured are superimposed for the correct comparator setting. This setting can be made to within a few tenths of a micron with sharp lines. It is dependent only on the phasing of the rotating horizontal scanning prism to the oscillograph x-sweep and the positions of the elements of the optical system, if the base line on the oscillograph screen with a clear photographic plate is flat. To make this base line flat, both the single filament lamp (7.5 volt dc at 100 ma) and the photomultiplier tube (about 1000 volt dc at 0.1 ma) need good, but not exceptional, direct current power supplies. The phasing adjustment of the horizontal scanning prism to the oscillograph x-sweep is done by rotating the motor that turns the horizontal scanning prism. While the comparator is in use this motor is never stopped. The phase shift between the motor mounting and the motor shaft is considerable during the first few hours, but has been shown to be constant for many months after a day's warm-up. All of the stationary elements of the optical system are locked in place after all adjustments have been made. For spectral lines that are not symmetrical the setting is usually made only on the darker portion of the line. For very dark spectral lines the oscillograph y-axis amplifier gain is increased by a factor of 10 or more.

The oscillograph screen can be calibrated to give directly the transmission, optical density, or Seidel function $[\log \text{ transmission} - \log (1 - \text{transmission})]$ of the photographic plate. With the 5 inch screen the transmission can be measured to about 2% of the full scale reading, which is better than needed for most photographic emulsions. The oscillograph screen pattern is also used to classify the spectral line shape into several types.

Figure 7 shows an operator recording photoelectric comparator measurements on IBM cards. These cards, with the comparator readings punched on them, are used as input to an IBM 704 electronic data processing machine for the necessary mathematical operations to follow. The comparator and the oscillograph are on a very sturdy table made of 1/2 inch thick steel plates welded together. The comparator is shock mounted to this table. A black cloth light shield covers the comparator to protect the photomultiplier tube from the room lights. The power supply shown is large enough to supply another identical comparator, not shown.

DISCUSSION

Some of the advantages of the optical system used for this comparator come from the use of a very narrow line of light that is imaged on the photographic plate. The low stray light of this type of optics was shown by A. Strasheim⁽³⁾ to be of importance for the accurate measurement of spectral line densities and when complex spectra taken with a very narrow spectrograph slit are to be measured.

The use of the vertical scanning prism to move the line of light along the spectral line is of particular value if the grain size on the photographic plate is larger than a few percent of the half width of the spectral line, which is the usual case, or when the spectral line contains a blemish. If the measurement errors caused by graininess follow a completely random distribution, they are minimized by using as long

a line of light as possible. The maximum possible length along the spectral line for the optical system described here is about $1/2$ mm without changing the dimensions of both the single filament lamp and the horizontal scanning prism. This length is great enough to give consistent readings for some spectral lines, but other spectral lines give varied readings. The vertical scanning prism is used to observe these differences and if they are random the average value is taken. In some cases a blemish is observed at one place on the line with the oscillograph or is seen with the microscope. For these cases the vertical scanning prism is used to select only the good portion of the line for the setting. The vertical scanning prism is also used for precision movement between two adjacent spectrograms on the same plate.

The use of this photoelectric comparator is not restricted to ordinary spectrograms. For example, Figure 8 shows an interferogram and a spectrogram taken with a narrow spectrograph slit. The spectral range of the interferometer was just resolved by the spectrograph, and the resolving power of the interferometer was several times larger than that of the spectrograph. The interferogram can be measured along the spectrograph dispersion in the same way as the spectrogram with the exception that a short filament image length is used along with the vertical scanning prism to select the center of an interferometer fringe for each setting. The position accuracy will be no greater than with ordinary spectrograms except for lines close together which now are

resolved by the interferometer. This technique is most valuable for complex spectra very rich in lines and calling for the highest possible resolution to separate the lines. The time required to measure interferograms in this way is little longer than that required for spectrograms and much shorter than the time required to measure each interferometer pattern in the usual way by determining the ring diameters. A comparison standard spectrum cannot be used with this technique, and so several lines on each interferogram are measured in the usual way and are then used to find the formula relating the position measurements to wavelengths. Another advantage of measuring interferograms is that it reduces the adjacency effects for lines close together.

If a very small spot of light is desired instead of a line of light, the single filament lamp can be replaced by a zirconium concentrated-arc lamp. The very small, low wattage lamps are not satisfactory owing to the wander of the position of the bright spot of light, but a larger wattage lamp with a piece of metal foil containing a small pin hole works very well.

The use of this photoelectric comparator is not limited to spectra. Any transparent or opaque object could be measured. For opaque objects such as machine parts, the photomultiplier tube would be moved so that it would look at the object from the same direction as the lens.

The horizontal magnification of the photographic plate on the oscillograph screen can be changed easily by changing the prism dimensions, the focal length of the lens, or the x-axis gain of the oscillograph.

If intensity measurements on spectrochemical-analysis photographic records are desired, the magnification should be much smaller than 1000 used here because the position measurement is of importance for identification only. Also, the second scan (mirror image) should be blocked out and the use of a precision screw comparator would not be necessary. The oscillograph screen then would show an almost instantaneous transmission curve of the spectrochemical spectra being observed. This would yield line intensities far more accurate than visual enlarger comparators and faster than the moving paper chart microphotometers.

INSTRUCTIONS FOR OPERATION

Optical System Adjustments

Adjust the various elements of the optical system so that their centers are aligned on a single straight line as reflected by the mirrors. Brush dust from the photographic plate containing the spectrum to be read with a "Staticmaster" (Nuclear Products Co.) or similar brush. Place this plate on the comparator carriage with the emulsion down and so that a positive reading is obtained for the leading edge of the plate. Also, if possible, increasing readings should be the same as increasing wavelength along the plate. Focus the microscope on the emulsion; then

focus the image of the single filament lamp on the emulsion. Place a mask at the front of the lamp so that the image length is as long as possible without being greater than the spectrum lines or about one-fourth the length of a sharp interferometer fringe. Place light shield cover over comparator and turn photomultiplier tube voltage on. The photomultiplier tube voltage should never be on with the cover off the comparator. Rotate the horizontal scanning prism motor about its shaft, to adjust phasing of this prism to the 60 cycle oscillograph sweep, so that the no-signal portions on each end of the oscillograph pattern are equal. Rotate the photomultiplier tube in its holder to maximize the signal to the oscillograph. Adjust the photographic plate so that the spectrum is parallel to the comparator ways, using the adjusting screws in the front plate support. Adjust plate so that the desired portions of the spectrum can be observed with the oscillograph within the range of the vertical scanning prism. Make lamp filament parallel to the spectral line by maximizing resolution or intensity of a given spectral line. Adjust axis of rotation of the vertical scanning prism so that the movement of the single filament lamp is precisely parallel to the spectral lines.

All optical elements must be locked in place upon completion of the optical adjustments. No changes in optical adjustments can be made after reading has started.

Reading Procedure

Because of backlash, the settings are always made by rotating the comparator dial toward increasing numbers. A setting is made when the two traces of the spectral line on the oscillograph screen are exactly superimposed. For lines that are not well resolved or are asymmetric, the setting is made only on the darker portion of the line. Dark lines are best read with the oscillograph y-axis amplifier gain increased by a factor of 10 (or more), or by moving to a weaker part of the line with the vertical scanning prism. Scratches on the plate can be recognized by the change in setting for different positions of the vertical scanning prism and (or) observed with the microscope. Dirt spots on the plate can be recognized by the very rapid appearance and disappearance of the trace on the oscillograph screen with motion of the vertical scanning prism and (or) observed with the microscope. Only the portions of the line free of blemishes are used for the setting. The comparator dial reading is recorded to the nearest micron.

For intensity measurements the oscillograph zero and y-axis amplifier gain are adjusted so that the no-light and clear-plate readings are set correctly on the oscillograph screen scale. This scale can be calibrated to give directly the transmission, optical density or Seidel function $[\log \text{ transmission} - \log (1 - \text{transmission})]$ of the photographic plate. A number related to the line intensity is then read directly from the scale.

Occasionally, lines are found that are different from the usual kind.

This is recorded using the following code for remarks:

- 0 = normal symmetrical line.
- 1 = line shaded toward longer wavelength.
- 2 = line shaded toward shorter wavelength.
- 3 = double line.
- 4 = wide line.
- 5 = very wide line.
- 6 = complex line.
- 7 = line doubtful.
- 8 = reading doubtful.
- 9 = an unusual observation - see note on separate log sheet.

One IBM card is punched for each line with the comparator dial reading in columns 1-6, the number related to the line intensity in columns 7-8, and the remarks code in column 10. The plate and reading identification number is punched in columns 13-20.

The search for the next line to be read is made by observing the darkest part of the spectral lines with both the oscillograph and the microscope. Doubtful lines of an intensity about equal to the plate background intensity noise can be ignored.

At the completion of the reading of a plate, a recheck should be made of the reading of one good line about each 10 mm. The readings are good if the differences from the original readings are small or change in a smooth way with the readings.

At the end of each work period turn down the oscillograph intensity and make sure the microscope field lamp is off. The power to the remainder of the instrument should remain on. Before starting new readings at the next work period, recheck a few good lines read during the previous two work periods.

If the comparator is to be shut down for a long period of time all power should be turned off. Before readings can be started again the power should be turned on and the comparator allowed to warm up for at least 24 hours.

REFERENCES

1. Dieke, G. H., Dimock, D., and Crosswhite, H. M., "Semiautomatic Method for Spectroscopic Wavelength and Intensity Measurements," J. Opt. Soc. Am., 46, 456-462 (June, 1956).
2. Tomkins, F. S., and Fred, M., "A Photoelectric Setting Device for a Spectrum Plate Comparator," J. Opt. Soc. Am., 41, 641-643 (September, 1951).
3. Strasheim, A., "A Note on the Influence of the Optical System of a Microphotometer on the Plate Calibration Curve," Spectrochim. Acta 4, 489-495 (1952).

Figure 1. The photoelectric comparator and its accessory equipment

Figure 2. Rear of comparator with dust cover and field lamp removed

Figure 3. Photoelectric comparator optical system

Figure 4. Position on oscillograph screen and spectrogram as a function of time

Figure 5. Photographic plate on comparator

Figure 6. Photomultiplier tube and microscope holder

Figure 7. Complete assemblage for recording data

Figure 8. Interferogram (top) and spectrogram (bottom) taken with a narrow spectrograph slit showing single lines on spectrogram (X) that are resolved on interferogram into more than one line