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CIRCUITS FOR PHOTOMETRY

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Two instruments that have been used with considerable success for the past few years in the University of Illinois photometry laboratory are here presented as an answer to two rather common and vexing problems of the photometry laboratory. The first problem is that of measuring the currents of barrier layer-type photovoltaic cells. The currents cannot be satisfactorily measured with a galvanometer and ayrton shunt because of the change in circuit resistance as the range is changed. The multirange microammeter recommended here has as one of its features constant resistance on all ranges. The second problem is that of comparing the intensity of light sources. For years the photometer heads used for this purpose have been either of the visual type, such as the Lummer-Brodhun, or extremely complicated photoelectric devices using rotating mirrors and elaborate circuits. The null balance photoelectric photometer head presented here is very simple to construct and use.

A Multirange Microammeter

The usefulness of this instrument is not limited to the field of photometry. It can be used in any laboratory where small d-c currents must be measured. A large part of its usefulness and versatility stems from the fact that it can be quickly assembled from parts to be found in almost any physics laboratory.

An instrument for measuring small d-c voltages that has been used for many years and is still one of the best is the Poggendorff type 2 potentiometer. This potentiometer in the form used for measuring thermocouple voltages is often referred to as a "Lindeck and Rothe element," after the men who developed it for that purpose. This instrument used to measure the voltage drop across a known resistance can, like any potentiometer, be used for the measurement of currents as well as voltages.

Figure 1 shows the circuit of the instrument as used for the measurement of photocell currents. The operation is as follows:

The current I_x produced by the photocell passes through the 100 ohm resistor R causing a voltage drop across the resistor. The current through the tapped resistor R_1 is adjusted until the galvanometer indicates that the voltage drops across the two resistors are equal. The current I_1 is then read on the milliammeter and I_x is obtained from the relation I_x equals I_1 (R_1/R).

The instrument has for the tapped resistor R_1 a single length of manganin wire with taps soldered to it at suitable points. The final adjustment of this resistor was made by scraping the wire to reduce its cross section while its resistance was being measured with a Kelvin bridge. The circuit as shown has the following features:

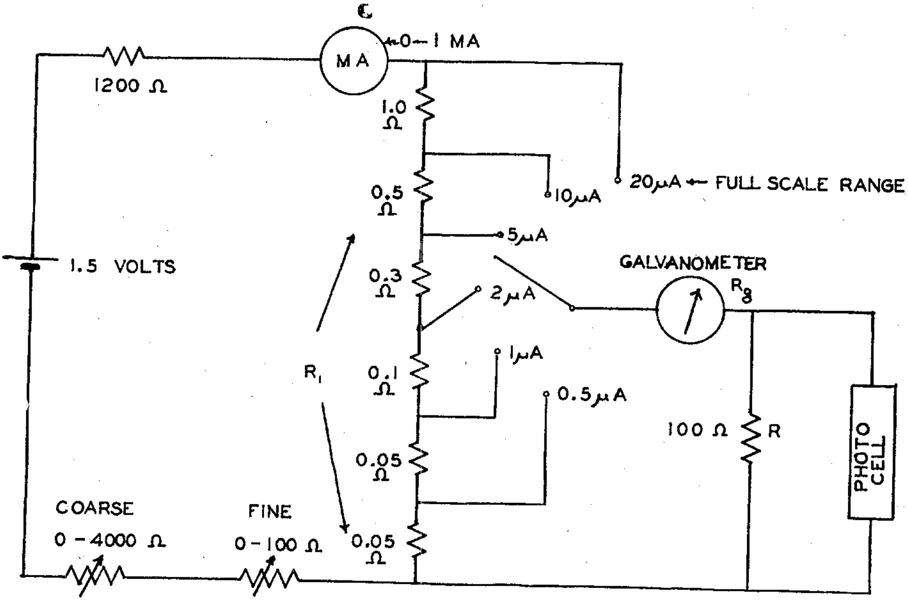

FIG. 1.—Circuit of multirange potentiometer-type microammeter.

1. The instrument is multi-range.
2. The impedance inserted into the measuring circuit is constant for all ranges.
3. The sensitivity (using proper circuit components) is essentially that of the galvanometer used.
4. The galvanometer can be critically damped for all ranges, thus speeding the instrument use.
5. The device is simple to construct from parts that can be easily obtained in most laboratories.
6. The potentiometer-type microammeter (fig. 1) has the further limitation that readings cannot be taken on the lower third of the scale. The use is thus limited to the more accurate portion of the scale.
7. The basic accuracy of the instrument is dependent on the accuracy of the milliammeter and the resistors used for R and R_1. Assuming adequate galvanometer sensitivity and 0.1 percent resistors used with a milliammeter that is accurate to 0.5 percent of full scale, a full-scale accuracy of 0.7 percent and an accuracy at ⅓ of scale of 1.7 percent is obtained.
8. The device is extremely stable. The calibration of the instrument will hold for long periods of time since it is primarily dependent on the stability of R and R_1 and on the stability of the indicating instrument.

Analyzing the circuit to determine its sensitivity gives the following result: If the current being measured changes from the value for which the circuit is balanced by an amount ΔI_x then the galvanometer current I_g is equal to $I_x/(1 + R_g/R)$, where R is the resistor through which the current I_x passes and R_g is the resistance of the galvanometer. From this analysis it is evident that as R becomes large in comparison to R_g then I_g is approximately equal to I_x. For this condition of R large in comparison to R_g, the change in the

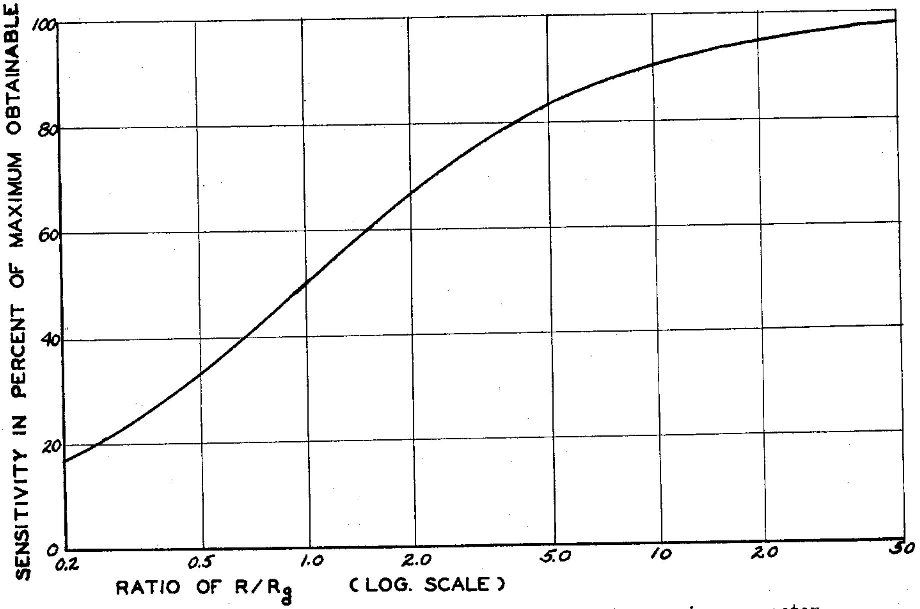

FIG. 2.—Relative sensitivity of potentiometer-type microammeter.

unknown current that can be observed approaches the minimum detectable galvanometer current. The effect of the ratio of R to R_g on the sensitivity is indicated by figure 2. The curve shows that for values of R exceeding four times R_g the sensitivity is quite comparable to the maximum sensitivity obtainable. From figure 2 and the following rules a circuit can be designed to meet almost any requirement:

1. R should be small so that it will not alter the current which is being measured. For photocell currents R should not exceed 300 ohms.
2. For maximum sensitivity the galvanometer resistance should be small compared to R.
3. The current sensitivity of the galvanometer should be such that the minimum observable deflection is less than 1/250th of the I_x range desired.

A NULL TYPE PHOTOELECTRIC PHOTOMETER

An ever-present problem of a photometry laboratory is comparing the intensity of two sources. The usual equipment for this procedure is a bar photometer plus some type of optical photometer head such as the Lummer-Brodhun. Experienced observers using such equipment usually can reproduce their results within one percent. However, owing to differences in vision and judgment, it is often noted that two individuals, while consistent in reproducing their own results, will get results that differ by several percent. Often the sources to be compared do not have the same color, so the spectral response of the observer adds another unknown to increase the uncertainty of such measurements.

In the University of Illinois photometry laboratory the special photo-

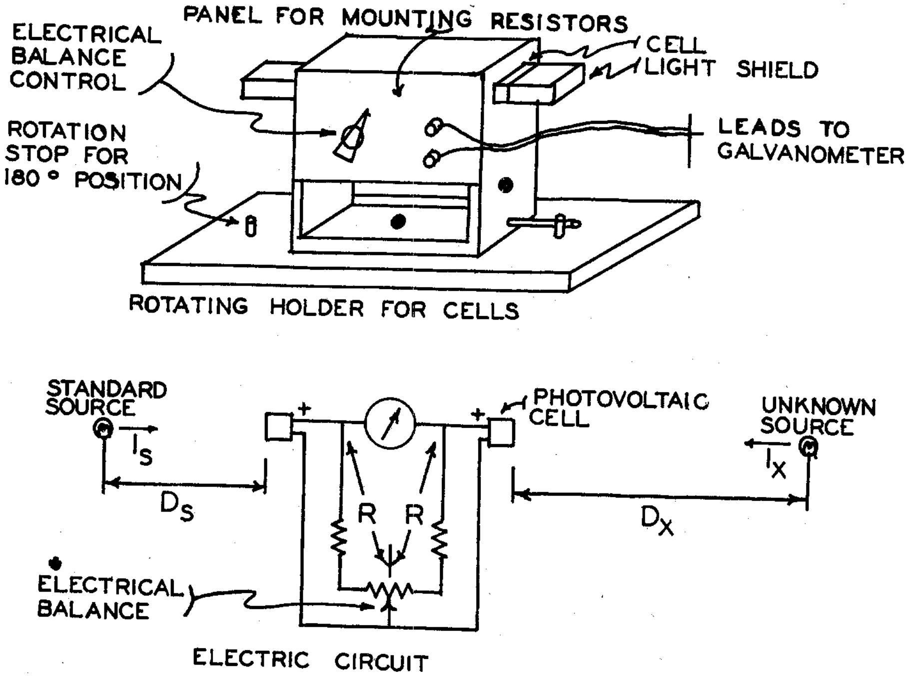

FIG. 3.—Photoelectric photometer head.

meter head and circuit (fig. 3) have been used with considerable success. This device uses a pair of selenium photovoltaic cells with filters which make their spectral response approximately that of the standard observer. An increase in sensitivity can be obtained when comparing similar sources if unfiltered cells are used.

The problem of comparing two sources using two cells is that even though the cells are purchased as "matched" they usually do not agree by better than 1 or 2 percent. The potentiometer rheostat adjustment of the circuit shown eliminates this problem. By adjusting the moving contact to the proper point the circuit is compensated for inequality of the cells. The balance procedure is as follows:

1. The two lamps are mounted on the bar with the head between them. The distance from lamp to cell is altered to obtain approximately zero galvanometer current.
2. The head is rotated 180 degrees so each cell now looks at the other lamp. The galvanometer will probably deflect because the cells are still unmatched. The galvanometer is then moved toward zero by moving the contact of the potentiometer.
3. The head is again rotated and the distance adjusted.
4. The procedure of alternately adjusting the distance and the cell match is repeated until the galvanometer reads zero when the photometer head is rotated. The cell-to-lamp distances are then determined and the intensities computed.

This circuit is sufficiently sensitive so that the control of the lamp volt-

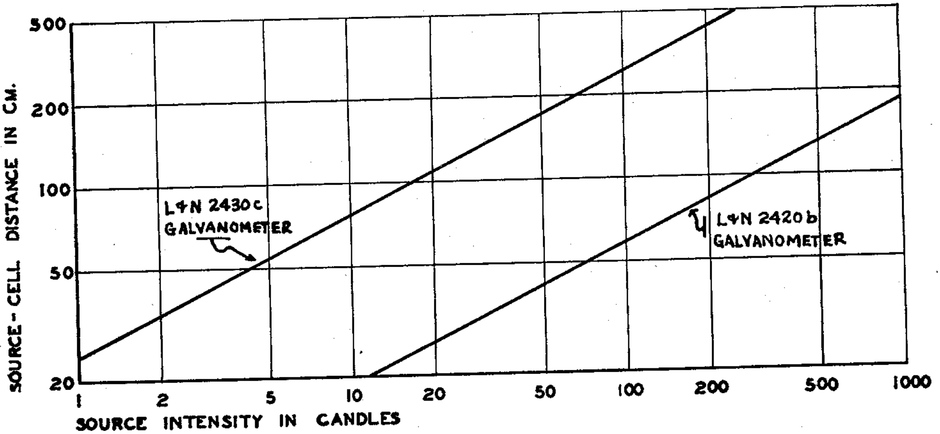

FIG. 4.—Sensitivity of photoelectric photometer.

Assumed Conditions

Galvanometer	L&N 2420b	L&N 2430c
Minimum observable current	0.01 microampere	0.0007 microampere
Galvanometer resistance	25 ohms	25 ohms
CDRX	80 ohms	350 ohms
R (See figure 3)	40 ohms	175 ohms
Photocell sensitivity	0.5 microamp./Ft-C	0.5 microamp./Ft-C
Sensitivity to distance	1 part per 1000	1 part per 1000

ages becomes a major problem. If the circuit is used with incandescent lamps, and the sensitivity is such that distance changes of 1 part in 1000 can be detected, the lamp voltages must be known and controlled to 1 part in 4000 in order to justify the sensitivity.

In this circuit, since much manipulation is needed to achieve balance, speed of galvanometer response is important. It will be best to make R equal to one half the CDRX of the galvanometer so the galvanometer will be critically damped.

If a galvanometer whose constants are known is used and its minimum detectable change in current is determined, the value of cell current corresponding to this galvanometer current can be computed. This cell-current value can be used to obtain the cell illumination required to produce such a current, which in turn serves as a basis for computing the intensity at any assumed distance. This process has been done for two galvanometers, and the resulting curves are shown in figure 4. This curve shows that with a moderately high sensitivity galvanometer the circuit will operate satisfactorily even with weak sources.

One note is needed on the balance procedure. The balance procedure roughly resembles that for an a-c bridge having a slow convergence. Therefore considerable technique is needed in order to achieve balances in a minimum amount of time. This technique can come only with practice.

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