# NATIONAL BUREAU OF STANDARDS REPORT

6422

POTENTIOMETER FOR MEASUREMENT
OF SMALL PHOTOELECTRIC CURRENTS

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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## Potentiometer for Measurement Of Small Photoelectric Currents

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# Potentiometer for Measurement of Small Photoelectric Currents

## 1. INTRODUCTION

In order to obtain sufficient accuracy in the chromaticity determinations made with a photoelectric tristimulus colorimeter, relative measurements must be made of very small photoelectric currents (of the order of $10^{-10}$ to $10^{-11}$ ampere) with three-place accuracy. The present commercially available micro-microammeters have more than sufficient sensitivity for the purpose, but the uncertainties in relative measurements made with these instruments are about ten times the acceptable uncertainties.

Measurements of the voltage drop which is developed across a high-resistance load by the photoelectric current can be made with a potentiometer with sufficient accuracy when the potentiometer is used with a sensitive low-current galvanometer as a null detector. For convenience of operation an "electronic galvanometer" should be used. Figure 1 is an elementary diagram of a system of this type. The voltage developed across the load resistor of the phototube is balanced by the voltage between the slider on potentiometer $R_I$ and the slider on potentiometer $R_{IV}$. Since a range of photoelectric currents must be measured, a number of "hi-meg" load resistors ($RL_1$, $RL_2$, and $RL_3$) and a suitably insulated selector switch ($S_L$) are required. Since only relative measurements of current are required, adjustment of the current through the potentiometer slide wire is not required. This current must, however, be stable.

## 2. THEORY OF OPERATION

A study of the circuitry of the General Radio Model 1230A Electrometer-Amplifier indicated that this instrument could be modified so that it could not only function as the "electronic galvanometer" shown in figure 1 with the sensitivity controlled by the VOLTS switch of the instrument, but that the input resistors and the input-resistance switch could be used as the load resistors for the phototube and switch $S_L$ respectively. Figure 2 is an elementary schematic diagram of the modified electrometer-amplifier with a circuit diagram of the potentiometer, and figure 3 is a circuit diagram of the electrometer-amplifier showing the modifications.

Potentiometer $R_{IV}$ is a 100,000-ohm ten-turn precision potentiometer with a linearity tolerance of 0.05%. Two D-size mercury flashlight cells (Mallory type RM-42-R) connected in series are used as the potentiometer battery $E_B$ in order to obtain sufficient stability in the potentiometer current.

Potentiometer $R_I$ is used to balance out the voltage developed across across the load resistor by the phototube dark current and by the phototube current resulting from background illumination.

Resistors $R_V$ and $R_{VI}$ have been adjusted by the addition of trimming resistors in parallel or series to reduce the voltage drop across potentiometer $R_{IV}$ to precisely one-third the normal value without changing the current through $R_{III}$. This expands the lower end of the potentiometer scale without changing the dark-current balance.

All added components except the POTENTIOMETER switch are housed in a shielded compartment attached to the bottom of the electrometer-amplifier. (See figs. 3, 5, 6.) The POTENTIOMETER switch is located in the upper left-hand corner of the instrument.

Note that the circuits of the electrometer-amplifier have been so modified that the photometer is connected between the INPUT terminal of the electrometer and ground. Thus the electrometer can be used either as a meter (as designed) or as a null detector (as modified) without changing connections of the input circuit.

When the instrument is used as a potentiometer, terminal E must be connected to ground (as is done in the modification), not to the "P-terminal" side of the instrument. Otherwise that part of the potentiometer $R_{IV}$ between the slider and ground will be shunted by $R_{15}$ of the electrometer, thereby decreasing the linearity of the voltage drop along potentiometer $R_{IV}$.

Practical wiring diagrams showing the modifications made in the circuitry of the electrometer are shown in figure 4. Figure 5 shows front and rear views of the modified instrument with the added potentiometer compartment attached to the electrometer. Figure 6 is a photograph of the interior of the potentiometer compartment.

## 3. ACCURACY OF MEASUREMENTS

Voltage differences of the order of 0.1 millivolt can be detected readily when the range switch of the electrometer is in the 30-millivolt position. However, since the linearity tolerance of the 10-turn potentiometer is 0.05% of full scale, the linearity error of the potentiometer could provide an uncertainty in the voltage measurements as large as 0.05% of the voltage applied across the potentiometer; that is, about 1 millivolt when the BATTERY SWITCH is in the HIGH position and 0.3 millivolt when this switch is in the LOW position.

Because of the possibility of other errors and instabilities in the electrometer, the maximum uncertainty in the measurement of relative currents is about 0.1% of the current which can be balanced by using the full voltage across the potentiometer. When the BATTERY SWITCH is in the HIGH position this error is approximately $0.002/r$ microampere where r is the input

resistance. When the BATTERY SWITCH is in the LOW position, the maximum uncertainty in the relative current is approximately 0.007 / r microampere.

Results of tests of the linearity and accuracy of the modified electrometer are given in table 1. In making these tests, a precision laboratory potentiometer was used to determine the applied voltage.

Table I. Calibration Check of Electrometer-Potentiometer

| POTENTIOMETER BALANCE Setting | RELATIVE INPUT BATTERY SWITCH ON HIGH | LOW |
|---|---|---|
| 1000 | 1.0000 | .3341 |
| 950 | .9505 | |
| 900 | .8999 | .2998 |
| 850 | .8500 | |
| 800 | .7998 | |
| 750 | .7493 | .2492 |
| 700 | .6994 | |
| 650 | .6494 | |
| 600 | .5989 | .1985 |
| 550 | .5488 | |
| 500 | .4986 | |
| 450 | .4485 | .1486 |
| 400 | .3986 | |
| 350 | .3487 | |
| 300 | .2980 | .0985 |
| 250 | .2486 | |
| 200 | .1989 | |
| 150 | .1490 | .0493 |
| 100 | .0990 | |
| 50 | .0491 | |

## 4. OPERATION

### 4.1 Normal Operation

To operate the unit as an indicator (normal manner), turn the POTENTIOMETER switch (in upper left corner of panel) to NORMAL. The instrument will then operate as designed. Consult General Radio Instruction Book for further details.

### 4.2 Operation as a Potentiometer

To operate the unit as a potentiometer, connect terminal P on the potentiometer compartment to terminal P on the electrometer case. Connect the ground terminal on the potentiometer compartment to the ground terminal of the electrometer. Turn GROUND switch to E and POTENTIOMETER switch to POTENTIOMETER. With OUTPUT circuit open or with power off, adjust mechanical zero of meter to zero. Depress ZERO switch. Turn POTENTIOMETER BALANCE to its zero position. Close output circuit (or turn power back on). Allow instrument to stabilize. Leave BATTERY SWITCH of the potentiometer section in the OFF position. Use the electrical ZERO adjustment of the electrometer to adjust the electrical zero. During the final stages of the adjustment, put the VOLTS switch in the 30 MV position to obtain the most accurate zero setting. Turn VOLTS switch to 3 volts. Turn BATTERY SWITCH to HIGH. Use the DARK CURRENT BALANCE adjustment to reset the electrical zero of the system, turning the VOLTS switch to the 30-millivolt position during the final stages of adjustment. The instrument is now adjusted for a dark current equal to zero. Turn VOLTS switch to 3 volts and release the ZERO switch. The electrometer now operates as a sensitive, very low-current galvanometer with a deflection which is proportional to the difference between the voltage applied between the INPUT terminal and ground and the voltage between terminal P and ground with an error sensitivity (in millivolts per meter division) determined by the position of the VOLTS switch.

### 4.3 Potentiometric Measurement of Voltage (Maximum Voltage 2 Volts)

Make adjustments outlined in Section 4.2

Set the INPUT RESISTANCE selector switch to an appropriate value. Set the BATTERY SWITCH to HIGH. Set the VOLTS switch to 3 volts. Connect the positive side of the unknown voltage to the INPUT terminal and the negative side to ground. Use the POTENTIOMETER BALANCE adjustment to obtain a meter reading of zero. Turn the VOLTS switch by steps to the 30-millivolt range as an approximate balance is obtained. Since the voltage drop across the potentiometer is not standardized, only relative measurements of voltage can be obtained unless the instrument is calibrated by measuring a source of known voltage such as a standard cell.

By turning the BATTERY SWITCH to the LOW position, the voltage across the potentiometer is reduced to precisely one-third of the voltage across the potentiometer when this switch is in the HIGH position. Hence, the potentiometer reading is increased by a factor of $3.00_0$.

If measurement of the change in voltage only is wanted, the instrument can be used as a deflection potentiometer by balancing out the initial input voltage by means of the POTENTIOMETER BALANCE. When the 30 MV range is used, the changes in voltage can then be read on the meter of the electrometer with an uncertainty of about 0.3 millivolts or 2% of the change in voltage, whichever is greater.

### 4.4 Potentiometric Measurement of Current

Current is measured by determining the voltage drop across one of the input resistors of the electrometer. Therefore, after a suitable input resistor is selected, measurements of current are made using the procedure used in the measurement of voltage. Determine the proper input resistor by turning the POTENTIOMETER switch to NORMAL (or turning this switch to POTENTIOMETER and the POTENTIOMETER BALANCE to its zero position) and turn the VOLTS switch to 3 volts. Then turn the INPUT RESISTANCE switch to the maximum resistance which will produce a voltage under 2 volts for all currents to be measured. If the maximum voltage obtained is between 0.7 and 2 volts, turn the BATTERY SWITCH to HIGH. If the voltage is below 0.7 volt, turn the BATTERY SWITCH to LOW. Turn the POTENTIOMETER switch to POTENTIOMETER and balance the system with the POTENTIOMETER BALANCE, turning the VOLTS switch to 30 MV for the final balance.

Since the current through the 10-turn potentiometer is not standardized, only relative measurements can be made. Since the values of the high-resistance input resistors are not known accurately, all relative measurements in a given group should be made using the same input resistor.

### 4.5 Dark-Current Balance

When photoelectric currents are measured, it is often desirable to compensate for the dark current of the phototube and the background illumination. This compensation can be accomplished by means of the DARK CURRENT BALANCE. After adjusting the electrical zero of the electrometer, as outlined in Section 4.2, set the INPUT RESISTANCE switch to the resistance which will be used and place the BATTERY SWITCH to the position in which it will be used. Connect the photoelectric receiver. With the light under test off, use the DARK CURRENT BALANCE to obtain a zero reading of the electrometer.

Note: The DARK CURRENT BALANCE must be readjusted whenever the setting of the INPUT RESISTANCE is changed or whenever the background illumination changes.

## 4.6 Discussion

If more precise measurements of voltage are required, the unmodified electrometer can be used in place of the usual galvanometer in conjunction with a precision potentiometer. The current drain of the electrometer is much less than the drain of the usual D'Arsonval galvanometer. Measurements of current can be made similarly by measuring the voltage developed across an external resistor of precisely known value. In this case the INPUT RESISTANCE switch should be turned to the $\infty$ position.

If the effects of alternating-current pick-up are troublesome, they can often be reduced by reversing the connections to input power, by grounding the case of the instrument, or by doing both. If these procedures are not effective, a resistance-capacitance filter of the type shown in NBS Report 5294 should be connected between the INPUT terminal and ground. For ease in balancing the potentiometer, keep the time constant of this filter as small as feasible.

## 5. SERVICING

The mercury batteries used to supply the potentiometer current should be replaced yearly. The batteries are fastened to the cover plate on the bottom of the potentiometer compartment and may be reached by removing this plate.

To remove the potentiometer compartment, turn catch on back of the potentiometer compartment to the horizontal position and slide the compartment forward after removing the connecting wires at back of unit.

To remove the electrometer chassis, remove the potentiometer compartment, then remove the four countersunk screws which pass through the plate attached to the bottom of the electrometer case and the two screws at the top of the case. Slide the chassis forward and out.

Consult the General Radio manual for servicing details.

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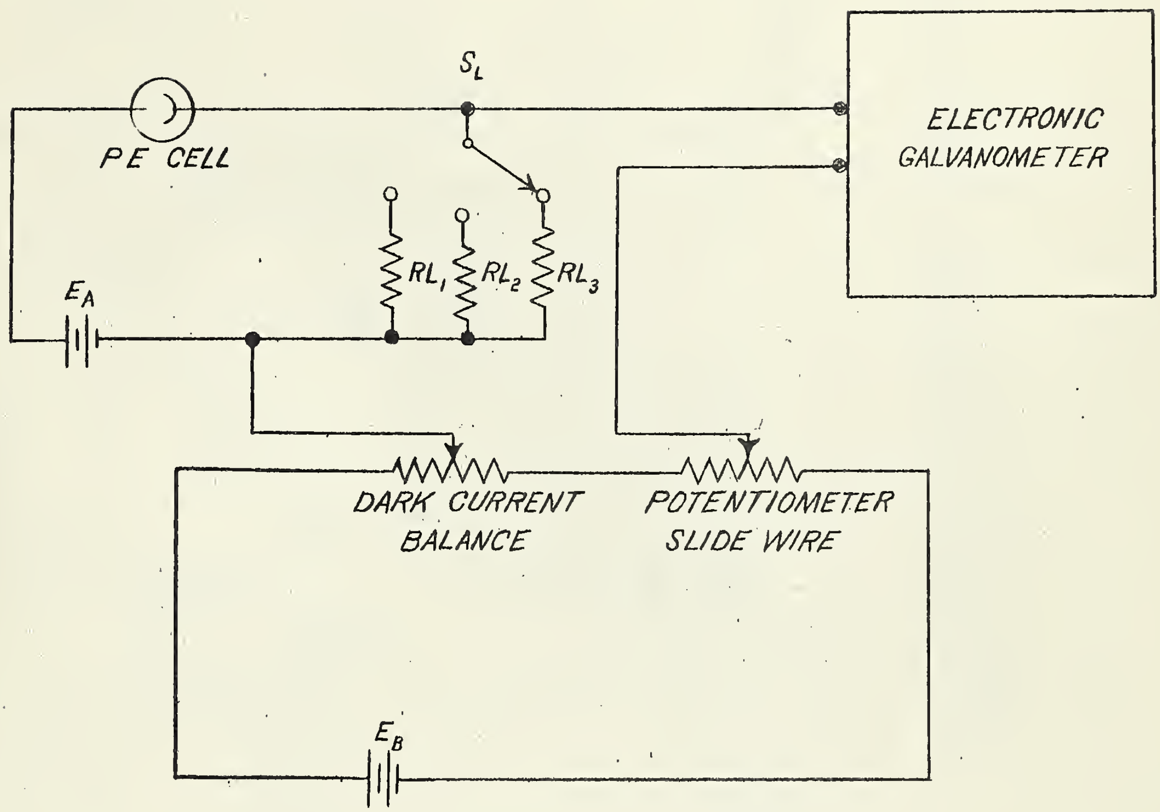


ELEMENTARY SCHEMATIC DIAGRAM OF ELECTROMETER-POTENTIOMETER

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FIGURE 1

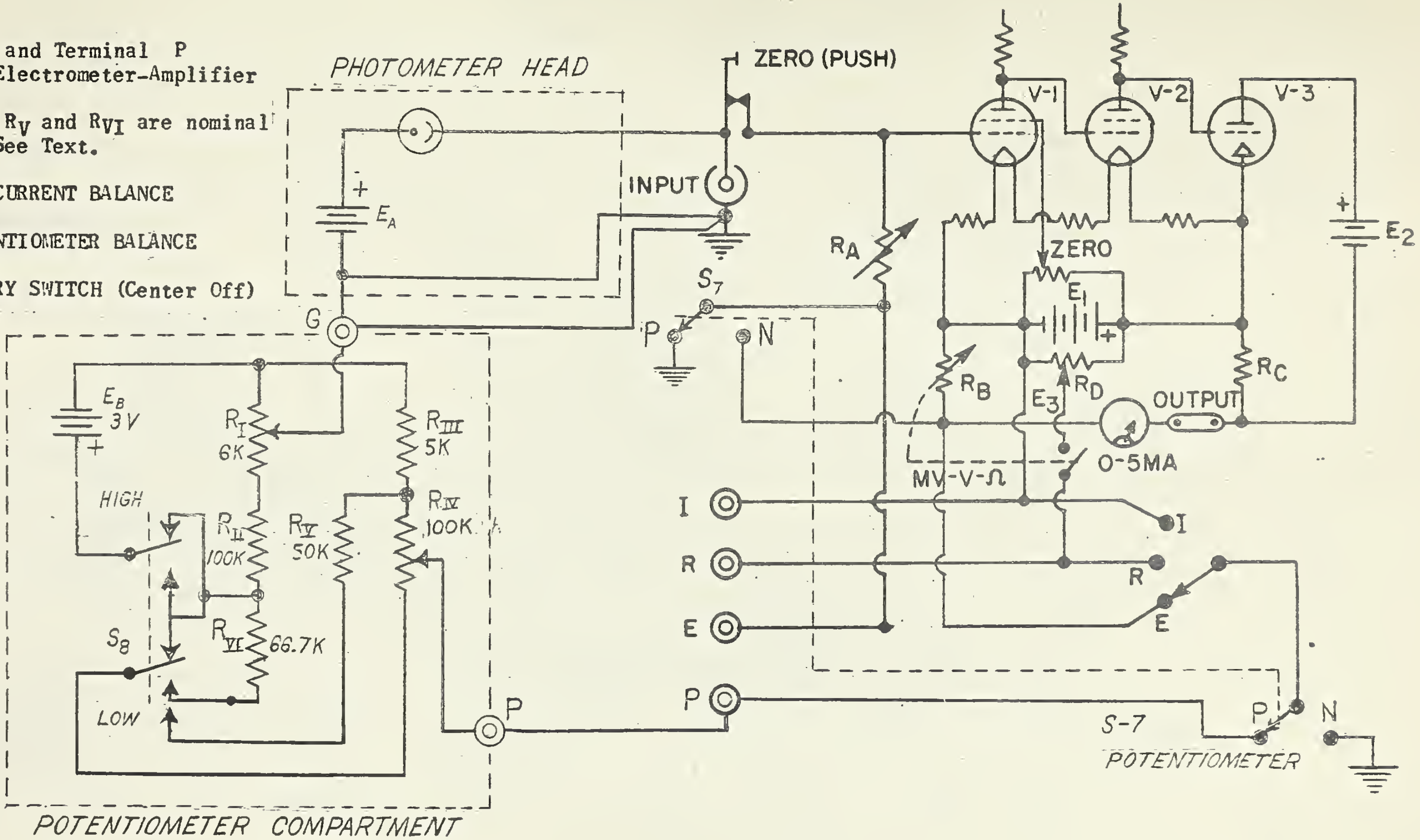
Switch $S_7$ and Terminal P added to Electrometer-Amplifier

Values of $R_V$ and $R_{VI}$ are nominal values. See Text.

$R_I$, DARK CURRENT BALANCE

$R_{IV}$, POTENTIOMETER BALANCE

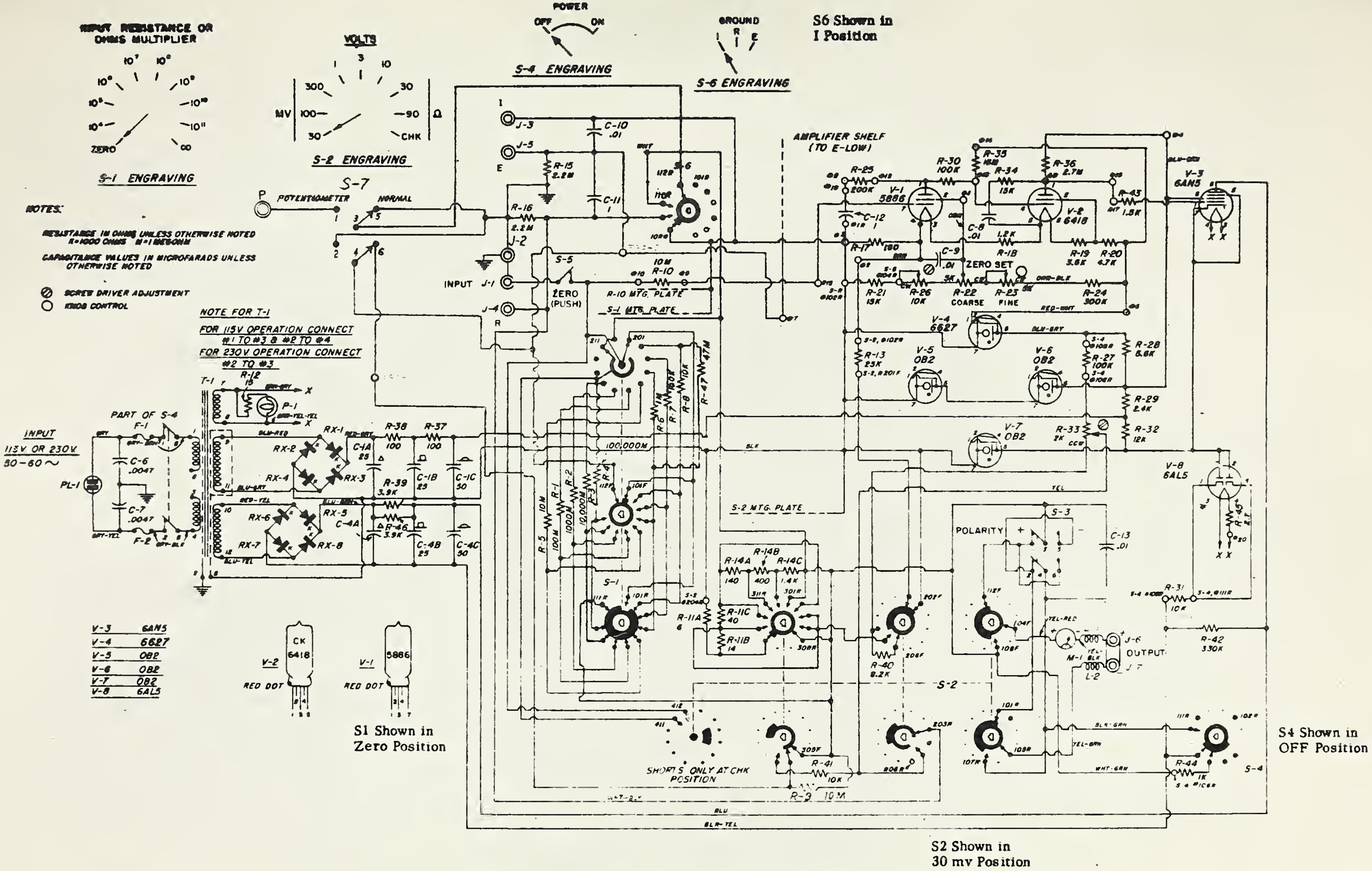
$S_8$, BATTERY SWITCH (Center Off)



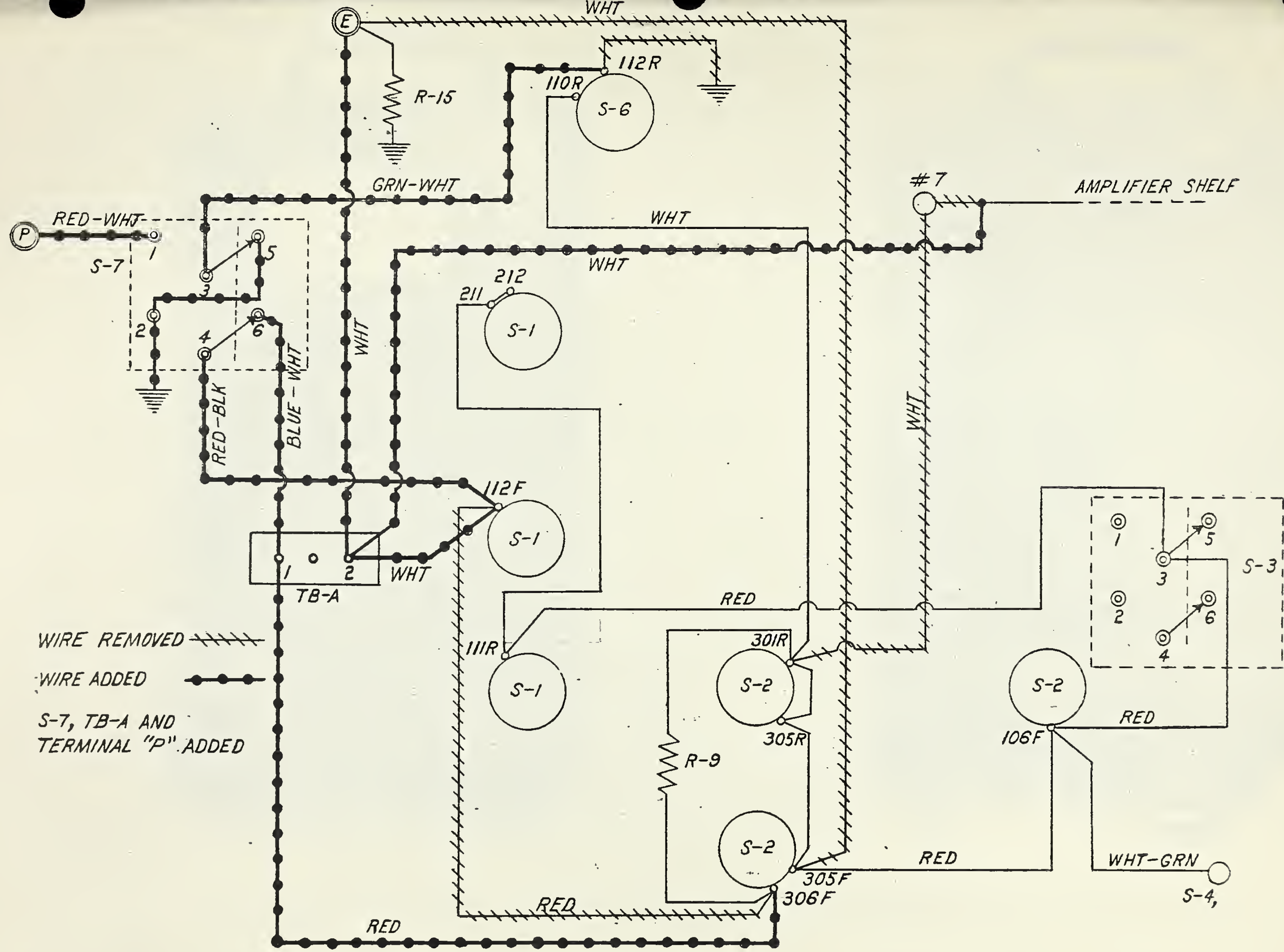

POTENTIOMETER AND ELEMENTARY SCHEMATIC DIAGRAM OF MODIFIED GENERAL RADIO TYPE 1230-A D-C AMPLIFIER AND ELECTROMETER



FIGURE 2




Detailed Schematic Diagram of Modified Type 1230-A D-C Amplifier and Electrometer Figure 3




PRACTICAL WIRING DIAGRAM SHOWING MODIFICATION OF MODEL 1230-A ELECTROMETER

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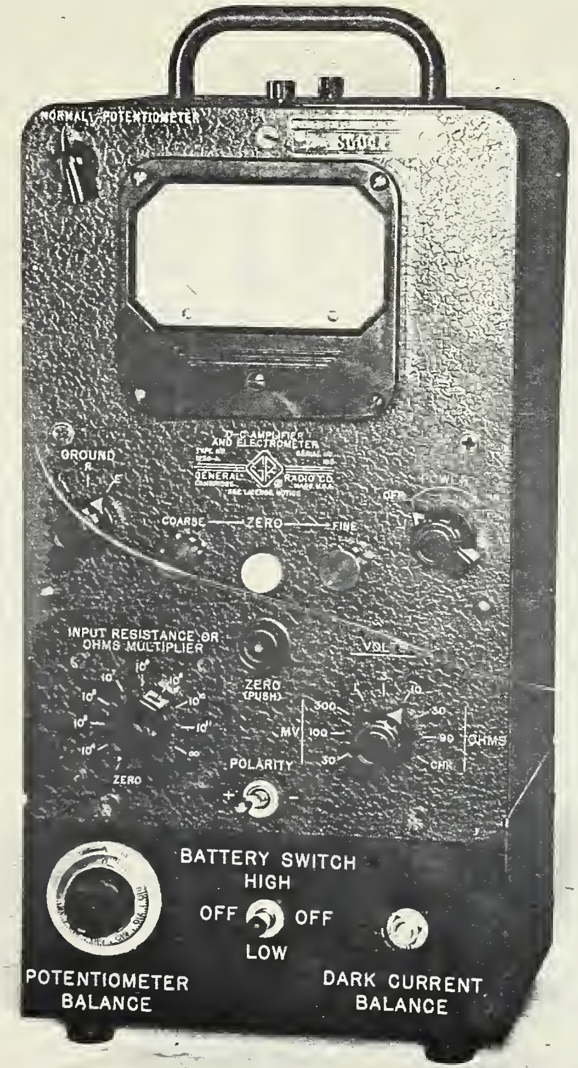
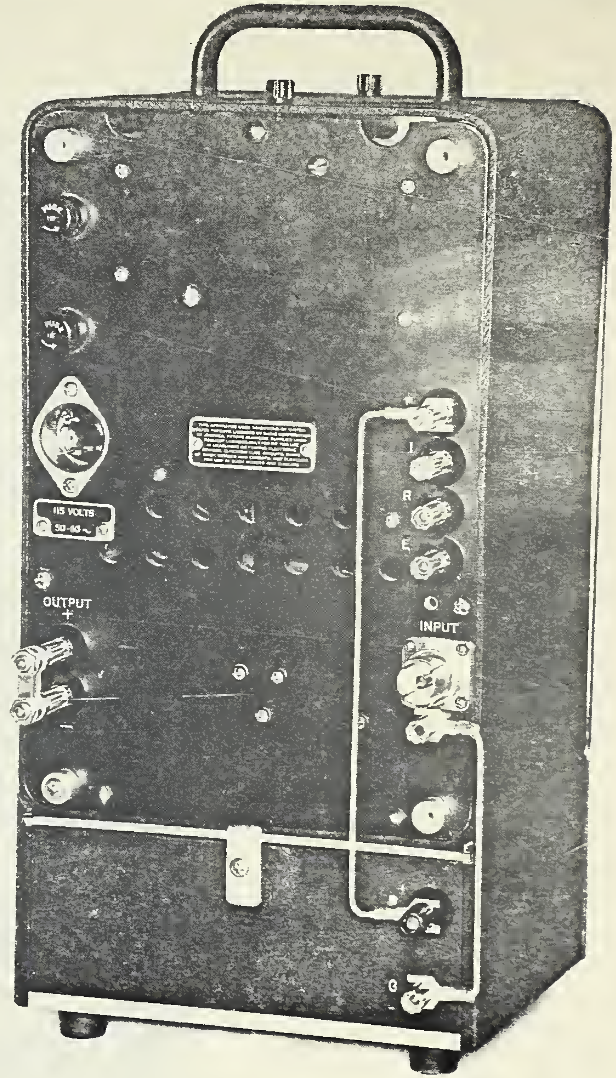
FIGURE 4




FRONT AND REAR VIEW OF MODIFIED 1230-A D-C AMPLIFIER AND ELECTROMETER

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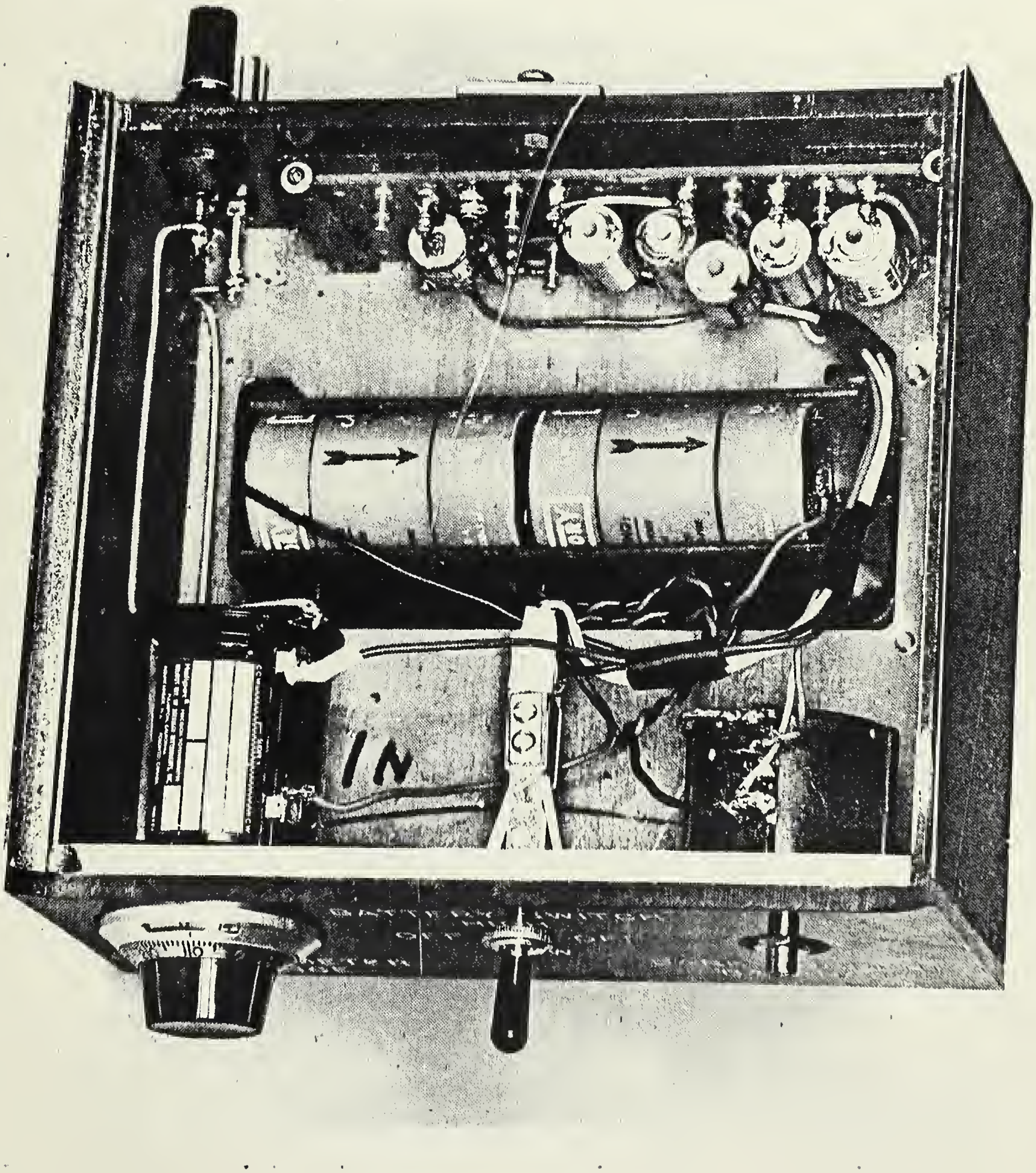
FIGURE -5




INSIDE VIEW OF POTENTIOMETER COMPARTMENT

U. S. DEPARTMENT OF COMMERCE
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