Physics Lab Report

Experiment Title: The Potentiometer

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Score

Abstract (About 100 words, 3 points)

The aim of this experiment is to help us to understand the principle of a box potentiometer and to measure a thermocouple' s emf, we would derive this by calculating the Thermal emf in different Temperature.

We can get the result from this experiment that the relationship of temperature T and the thermal emf E_x is $\boldsymbol{E_x = -0.6643 + 0.04T}$.

The result tells me that the emf can be influenced by temperature (from the above formula), although the impact is very small (with a coefficient 0.0727). And since the plots in the diagram we got from data do not match a linear relationship perfectly, we can use the least-square fitting method to minimize the error in the final decided formula.

Score

Introduction (3 points)

We cannot simply attach a voltmeter to the battery and say that the voltage we read is the electromotive force (emf) of the battery. The reason for this is because the battery has its own internal resistance and when the voltmeter sends current through the battery to measure the voltage, the internal resistance of the battery affects the voltage measured. Therefore, in order to accurately measure the emf of a battery, we have to use a device that does not draw any current through the battery. The potentiometer is one such device that will accomplish this goal. This method was proposed by Johann Christian Poggendorff around 1841 and became a standard laboratory technique for measuring emf.

The objectives of this experiment are:

- Understand the principle of a box potentiometer.
- Measure a thermocouple's emf.

Score

Experimental Procedure (State main steps in order of performance, 3 points)

Lab Equipment Used:

- A box potentiometer.
- Standard power supply.
- Sensitive power supply.
- A heating vessel.
- Thermocouple.

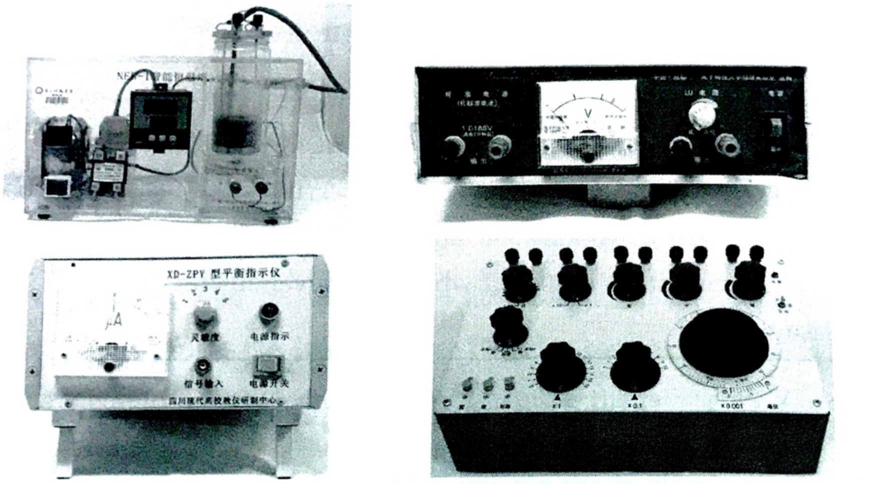


Fig. 3.15-1 Experimental apparatus

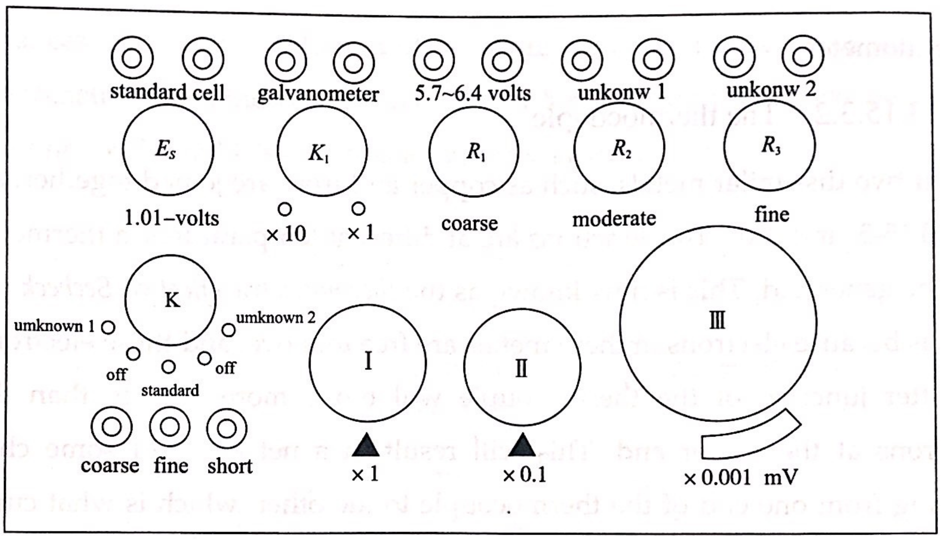


Fig. 3.15-6 Panel of the box potentiometer

Symbol (knob)	Description
E_s	The emf of standard cell. Tune the knob to set the value to 1.0185 V in this experiment.
K_1	You can select the multiples of the potentiometer.
R_1 R_2 R_3	The resistance R in Fig. 8-3. Tune them to calibrate the current in source circuit to 10.000 mA when the galvanometer reads zero.
K	It is the switch K in Fig. 8-3. When calibrating, you turn it to “standard”; when measuring, you turn it to “unknown 1” or “unknown 2”; Turn it to “off” when you not using it.
Coarse Fine Short	They are the switch K_p in Fig. 8-3. You will use it when calibrating and measuring. At the beginning of calibrating or measuring, press down the “coarse” button and you can see that the galvanometer deflects far from zero. After the galvanometer deflects close to zero you can lock the “coarse” button and push down the “Fine” button. The “short” button is used to calibrate the galvanometer.
I II III	The resistance R_B (or R_x) in Fig. 8-3. Tune them to make the measurement circuit null balance when the galvanometer reads zero. The values are transferred to millivolt due to the fixed current of 10.000 mA through R_B in the source circuit.

3.15.4.1 Heating the Water to a Setting Temperature

- Connect the potentiometer, the stable power supply, the galvanometer, and the heating vessel correctly.
- Check your circuit and turn on the power of the potentiometer, the stable supply, and the galvanometer to preheat them for at least five m inute.
- Rotate K_1 to choose the multiple of “×1”.
- Turn on the power of the heating vessel. Turn the switch on the panel to choose “auto control” mode of heating. There are two displays on the panel The upper reads the actual temperature of water and the lower reads the setting temperature.
- Press the “set” button on the panel and the digits on the lower display will flash. Press the “▼” and/or “▲” button to set the temperature to the first set value of 35 ℃. Finally, press the "set" button again and water will be heated automatically to the setting temperature.

3.15.4.2 Calibrating the Potentiometer

When the water reaches the set temperature of 35 ℃, I calibrate the potentiometer and measure the thermal emf immediately.

- Tune E_S to set the value to 1.0185 V.
- Tune the stable power supply so that the output is in the range of 5.7~6.4 V.
- Press in the "short" button to see if the galvanometer reads zero. If not, adjust it mechanically by a screwdriver. there are five sensitivity grades for the galvanometer. the greater the number, the more sensitive the galvanometer is. You can choose the sensitivity as high as possible but the pointer of the galvanometer should not oscillate when current goes through it.
- Rotate the switch k to “standard” and set grade “1” for the galvanometer. Push in the “coarse” knob at the lower left comer. if the galvanometer deflects far from zero, adjust R_1 and R_2 (see fig 3.15-6) until the galvanometer deflects little from zero. rotate the "coarse" knob to lock it. Push in the "fine" knob and increase the sensitivity of the galvanometer. Tune R_3 until the galvanometer reads zero. Choose the sensitivity as high as possible so that he pointer of the galvanometer can read zero and doesn't oscillate now, the current in the source circuit is calibrated to 10.000 mA.
- Rotate and pull out both the “fine” and “coarse” knobs.

3.15.4.3 measuring the emf produced by the thermocouple

- Turn the switch k to “unknown1” or “unknown2” to measure the emf.
- Push in the "coarse" knob. If the galvanometer deflects far from zero, adjust knobs “I” and “Ⅱ” (see Fig.3.15-6) until the galvanometer deflects little from zero. Rotate the “coarse” knob to lock it. Push in the “fine” knob. Tune knob "Ⅲ" until the galvanometer reads zero. Read the scales on the knobs “I” “Ⅱ” and “Ⅲ” and add them up. The result is the emf produced by the thermocouple at temperature of 35℃.
- Repeat Steps 6th through 13th to complete Data Table 3.15-1 for the temperatures given in the table.

Score

Results (Data tables and figures, 2 points)

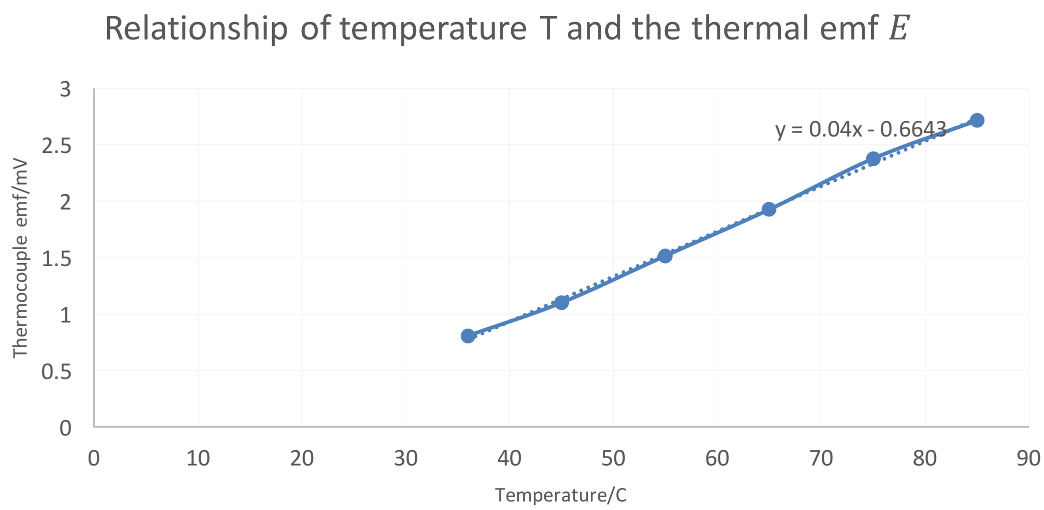
DATA TABLE 8-1 (*purpose*: to measure the emf produced by a thermocouple)

Room temperature 15°C Multiple of the potentiometer ×1

Temperature, T (℃)	36	45	55	65	75	85
Thermal emf, E_x (mV)	0.8065	1.1000	1.5153	1.9256	2.3767	2.7141

The final result we get is:

$$E_x = -0.6643 + 0.04T$$



Score

Discussion (More than 150 words, 5 points)

From the experiment we can know that this experiment is relatively easy for us to operate and we can finish experiment follow the procedure of the handbook as the experiment apparatus are highly oriented well. We should be focus on something like we should set the heater properly for on letting it over heat the water and get the wrong temperature. We should also record the right temperature we used and use these data to finish this experiment and the following calculation.

More than that, after turning on the power supply, we adjust the resistor in order to let the current in the source circuit to be 10.000 mA (As in Fig. 3.15-4).

In the beginning, I suppose that the power supply is a constant source and the resistor that we try to adjust is R. But soon we find that in this way, the calibration circuit is meaningless. Finally, we understand that the power supply is a constant voltage supply and the resistor we adjusted is R_0. We adjust R_0 to make the current in the source circuit to be 10.000 mA, which can be ensured by the calibration circuit according to the null balance measuring method, where the galvanometer in the calibration circuit reads zero.

In the end we get the relation between the temperature T and the thermocouple emf is: $E_x = -0.6643 + 0.04T$.

The principle of the potentiometer

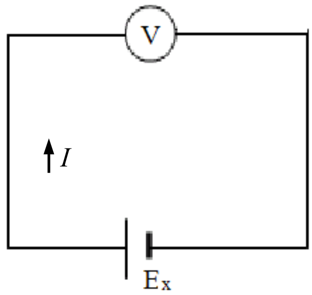


Fig. 8-1 measure the terminal voltage of a cell by a voltmeter

The terminal voltage of a cell is the potential difference between its terminals. The emf of a cell may be defined as the terminal voltage of the cell when not under load, that is, delivering no current. Fig. 8-1 shows a circuit to measure the terminal voltage of a cell by a voltmeter. Since a voltmeter is always connected in parallel with the component or components under test, it draws some current in the tested circuit. The measured terminal voltage is always lower than the emf due to the current *I* through the circuit and internal resistance of the battery.

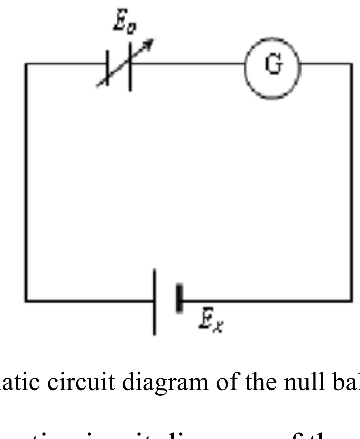


Fig. 8-2 the schematic circuit diagram of the null balance measuring method

Fig. 8-2 shows the schematic circuit diagram of the null balance measuring method. The galvanometer *G* is a sensitive device capable of indicating the presence of very small current. Its purpose is to accurately indicate a condition of zero current, rather than to indicate any specific (nonzero) quantity as a normal ammeter would. E_0 is a standard cell, whose emf is adjustable. When the deflection of the galvanometer is observed, adjust the emf of the standard cell until the galvanometer no longer deflects from zero. It means the galvanometer draws no current from the unknown source, and the magnitude of the unknown emf E_x is equal to that of the standard cell. The key point of null balance measuring method is to measure electrical potentials without any current draw.

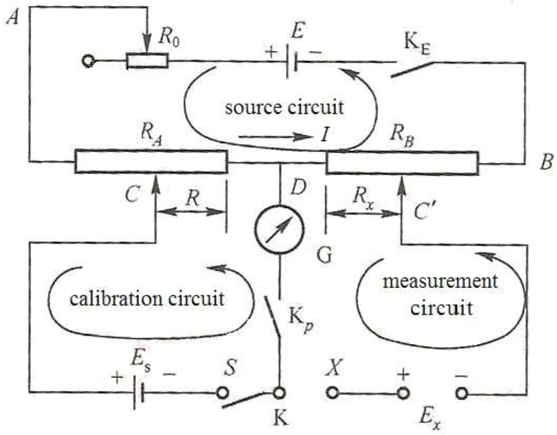


Fig. 8-3 a schematic circuit diagram of the potentiometer

The box potentiometer is constructed on the principle of null balance. A schematic diagram of the potentiometer is shown in Fig. 8-3, where *E* is a stable current source with a constant voltage greater than any voltage to be measured, E_s is a standard cell with emf of 1.0185 V, E_x is an unknown emf produced by thermocouple in this experiment, R_0 is a variable resistance, R_A and R_B are two resistances, *C* and *C'* are two sliding contacts which varies the resistances in the calibration and measurement circuits, *R* and R_x are the resistances in the calibration and measurement circuits, *G* is a sensitive galvanometer which indicates zero current when the needle deflects neither to the left nor to the right, K_E, K_P and *K* are three switches.

The first step to use a potentiometer is to calibrate it with the calibration circuit. When the source circuit and the calibration circuit is closed the movable contact *C* is adjusted to a position to set *R*=101.85 Ω. So, the current in the calibration circuit is 10.000 mA. Then adjust R_0 to a position at which the galvanometer reads zero. At this setting, the current in the source circuit is equal to the value of 10.000 mA.

Next, the switch *K* is turned to connect with *X*, that is, the standard cell is replaced by the source of unknown emf E_x. The movable contact *C'* is adjusted to find a point where the galvanometer reads zero. It indicates that the resistance R_x doesn't draw any current in the measurement circuit. The terminal voltage of R_x is the emf E_x. Thus, we have

$$\mathrm{E}_x = IR_x \tag{8-1}$$

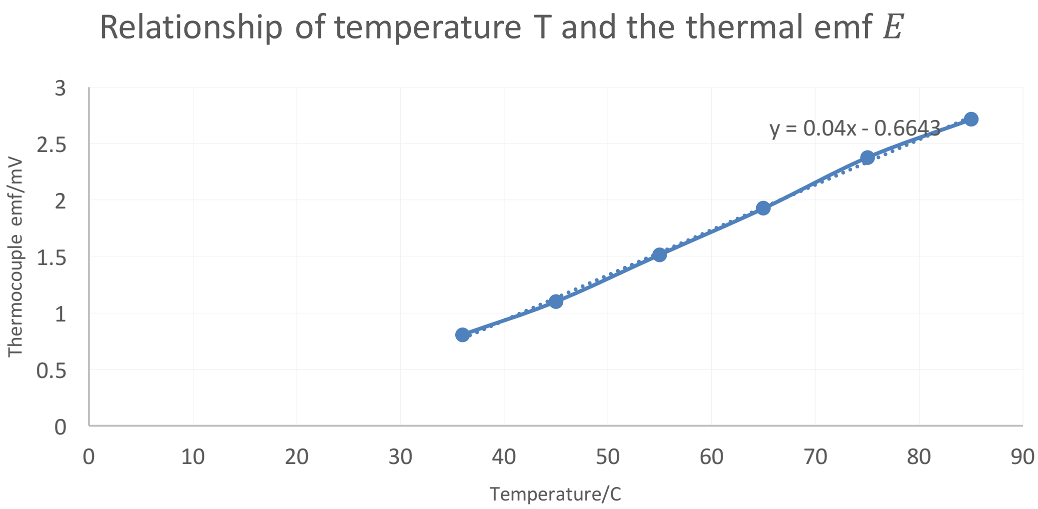
where *I*=10.000 mA, R_x can be read directly. For the box potentiometer, the current through R_B (or R_x) is fixed to 10.000 mA and the measured R_x is transferred to the value of E_x. So, we can read the emf directly from the potentiometer.

Score

Conclusions (About 50 words, 2 points)

From this experiment, we can get the result that $\boldsymbol{E_x = \text{-}0.6643 + 0.04T}$. Which is the relationship between Thermal emf and different Temperature. The result tells me that the emf can be influenced by temperature (from the above formula), although the impact is very small (with a coefficient 0.0727). Since the plots in the diagram we got from data do not match a linear relationship perfectly, we can use the least-square fitting method to minimize the error in the final decided formula.

Also, we can use the method we learned from this experiment to get an extremely accurate result.



The calculation steps (Including bringing in data) are in the appendix

We consider the thermocouple emf E_x and the temperature T are connected by a linear relation of the form $E_x = a + bT$. Use the data in the data table and the least-square fitting method to find the best estimates for the constant a and b.

According to the least-square fitting method, we need to calculate some average value $\overline{E_x}$, $\overline{T}$, $\overline{E_x}$, $\overline{T^2}$, $\overline{T}^2$, $\overline{TE_x}$.

$\overline{T} = 60$ $\quad \overline{E_x} \approx 1.5730$ $\quad \overline{T^2} \approx 3891.7$ $\quad \overline{T}^2 = 3600$ $\quad \overline{TE_x} = 115.864$

Then

$$a = \frac{\overline{T} \cdot \overline{TE_x} - \overline{E_x} \cdot \overline{T^2}}{\overline{T}^2 - \overline{T^2}} \approx -0.6643$$

$$b = \frac{\overline{T} \cdot \overline{E_x} - \overline{TE_x}}{\overline{T}^2 - \overline{T^2}} \approx 0.04$$

We can finally get $\boldsymbol{E_x = a + bx = -0.6643 + 0.04T}$.

The calculation steps (Including bringing in data) are in the appendix

Score

References (1 points)

Some parts I write on this prelab which is reference from Wikipedia and Baidu.

Some parts of my report was got from the book (Introductory physics experiments for undergraduates, Haofu)

Some of the words and formulas are from materials on BB9. Calculations were down by my partner Yue and me Musk.

Score

Answers to Questions (6 points)

1. **The output of the stable power supply is in the range of 5.7~6.4 V. We call it the working voltage of the potentiometer. Can we measure an emf by a potentiometer which is greater than the working voltage? Why?**
No, we can’t. Because there is a limitation in the value range of the resistor R_0 in the source circuit. If the huge working voltage is applied by us, the adjustable resistor R_0 may can't adjust it to become a proper resistance value where the current in the source circuit is 10.000 mA.

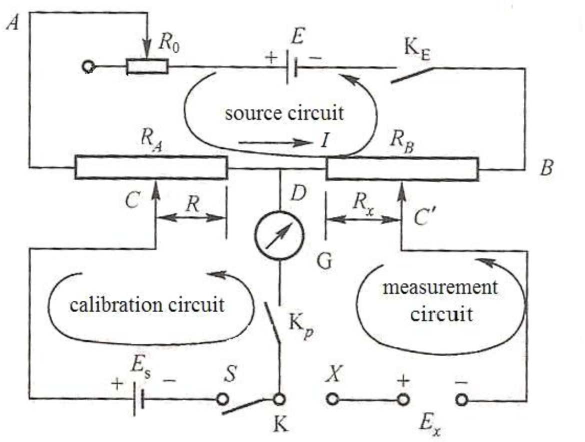


Fig. 8-3 a schematic circuit diagram of the potentiometer

2. **In Fig 3.15-4, the purpose of the calibration circuit is to get a current of 10.000mA in the source circuit. Can the calibration circuit be replaced by an ammeter? Why?**
No, it can’t. On one hand, the precision of an ammeter is much lower than that of a galvanometer, we can’t get the precise answer or the calibration results would not be good. On the other hand, the inner resistance of an ammeter will have an obvious impact on the real current of the source circuit, which will cause a significant error. So, the calibration circuit can’t be replaced by an ammeter.

Appendix

Score

(Calculations, 15 points)

Calculated by me and my partner.

We consider the thermocouple emf E_x and the temperature T are connected by a linear relation of the form $E_x = a + bT$. Use the data in the data table and the least-square fitting method to find the best estimates for the constant a and b.

According to the least-square fitting method, we need to calculate some average value $\overline{E_x}$, $\overline{T}$, $\overline{E_x}$, $\overline{T^2}$, $\overline{T}^2$, $\overline{TE_x}$.

$\overline{T} = 60$ $\overline{E_x} \approx 1.5730$ $\overline{T^2} \approx 3891.7$ $\overline{T}^2 = 3600$ $\overline{TE_x} = 115.864$

Then

$$a = \frac{\overline{T} \cdot \overline{TE_x} - \overline{E_x} \cdot \overline{T^2}}{\overline{T}^2 - \overline{T^2}} \approx -0.6643$$

$$b = \frac{\overline{T} \cdot \overline{E_x} - \overline{TE_x}}{\overline{T}^2 - \overline{T^2}} \approx 0.04$$

We can finally get $\boldsymbol{E_x = a + bx = -0.6643 + 0.04T}$.

3.15

$$E_x = a + bT$$

$$\overline{T} = \frac{1}{6}(35+45+55+65+75+85) = 60$$

$$\overline{E_x} = \frac{1}{6}(0.8065+1.1000+1.5153+1.9256+2.3767+2.7141)$$

$$\approx 1.5730$$

$$\overline{T^2} = \frac{1}{6}(35^2+45^2+55^2+65^2+75^2+85^2) \approx 3891.7$$

$$\overline{T}^2 = 3600$$

$$\overline{TE_x} = \frac{1}{6}(35\times0.8065+45\times1.1000+55\times1.5153+65\times1.9256 + 75\times2.3767+85\times2.7141)$$

$$= 115.864$$

$$a = \frac{\overline{T}\cdot\overline{TE_x} - \overline{E_x}\cdot\overline{T^2}}{\overline{T}^2 - \overline{T^2}} = \frac{60\times115.864 - 1.5730\times3891.7}{3600 - 3891.7}$$

$$\approx -0.6643$$

$$b = \frac{\overline{T}\cdot\overline{E_x} - \overline{TE_x}}{\overline{T}^2 - \overline{T^2}} = \frac{60\times1.5730 - 115.864}{3600 - 3891.7} \approx 0.04$$

$$\therefore\ E_x = -0.6643 + 0.04T$$

Calculated by me and my partner.

Appendix

(Scanned data sheets)

3.15.5 Experimental Data

Data Table 3.15-1 ***Purpose*: To measure the emf produced by a thermocouple**

Room temperature 15°C ; Multiple of the potentiometer ×1

Temperature, T/℃	~~35~~ 36	45	55	65	75	85
Thermal emf, E_x/mV	0.8065	1.1000	1.5153	1.8256	2.3767	2.7141

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