3.15 The Potentiometer

Prelab Assignment 3.15

(1)Can we use a voltmeter to measure the emf of a cell? Why?

(2)What is the null balance measuring method in electricity?

(3)In Fig. 3.15-4, consider E_s = 2.000V. What's the resistance value of R in order to obtain a working current of 5.000mA in the source circuit? In the measuring circuit, R_x is 201.5Ω when the galvanometer reads zero. What's the measured emf?

3.15.1 Introduction and Objectives

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.

After performing this experiment and analyzing the data, you should be able to:

(1)Understand the principle of a box potentiometer.

(2)Measure a thermocouple's emf.

3.15.2 Required Equipment

- A box potentiometer(Fig. 3.15-1)
- Standard power supply
- Sensitive galvanometer

- A heating vessel
- Thermocouples

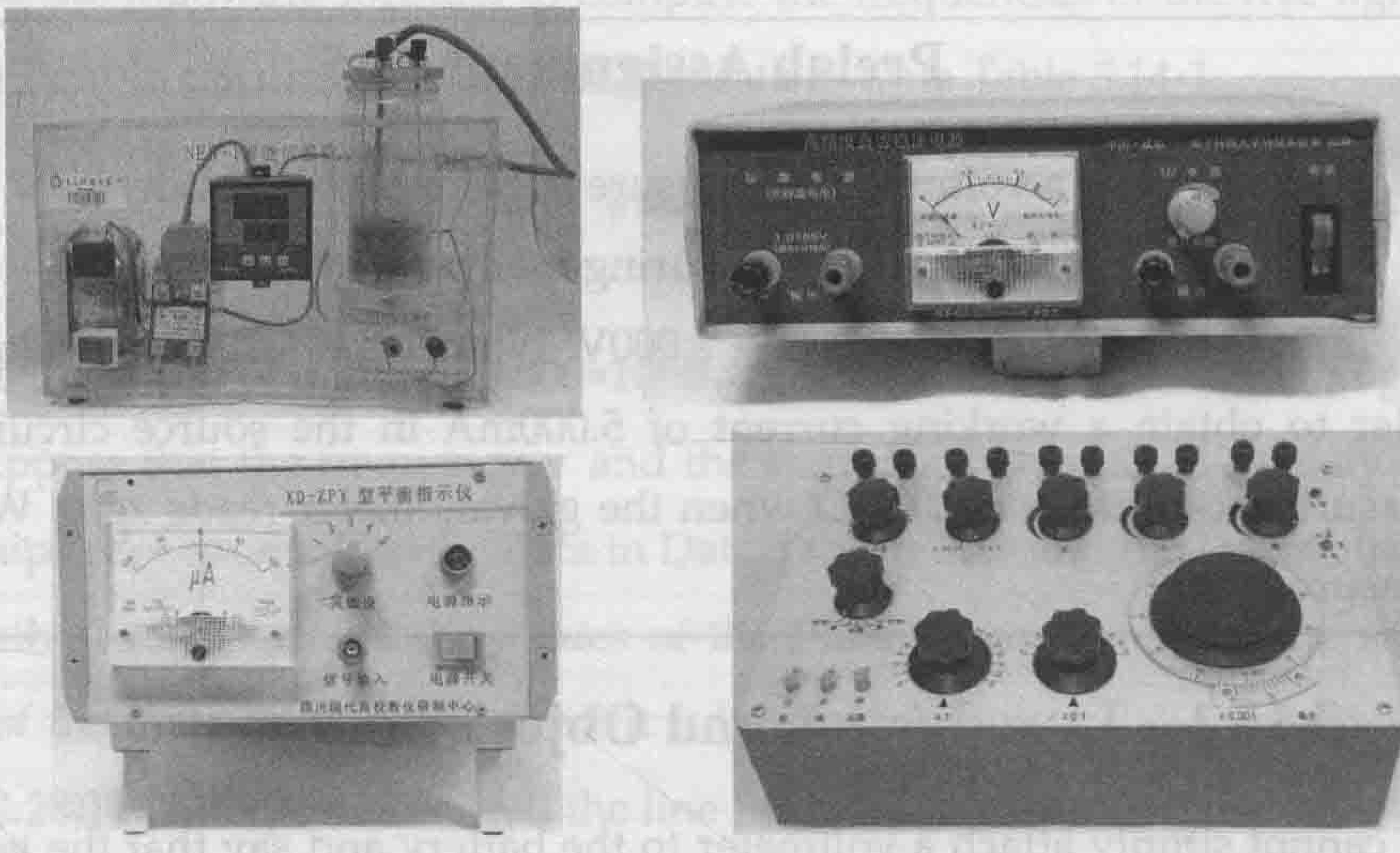

Fig. 3.15-1 Experimental apparatus

3.15.3 Theory

3.15.3.1 The Principle of the Potentiometer

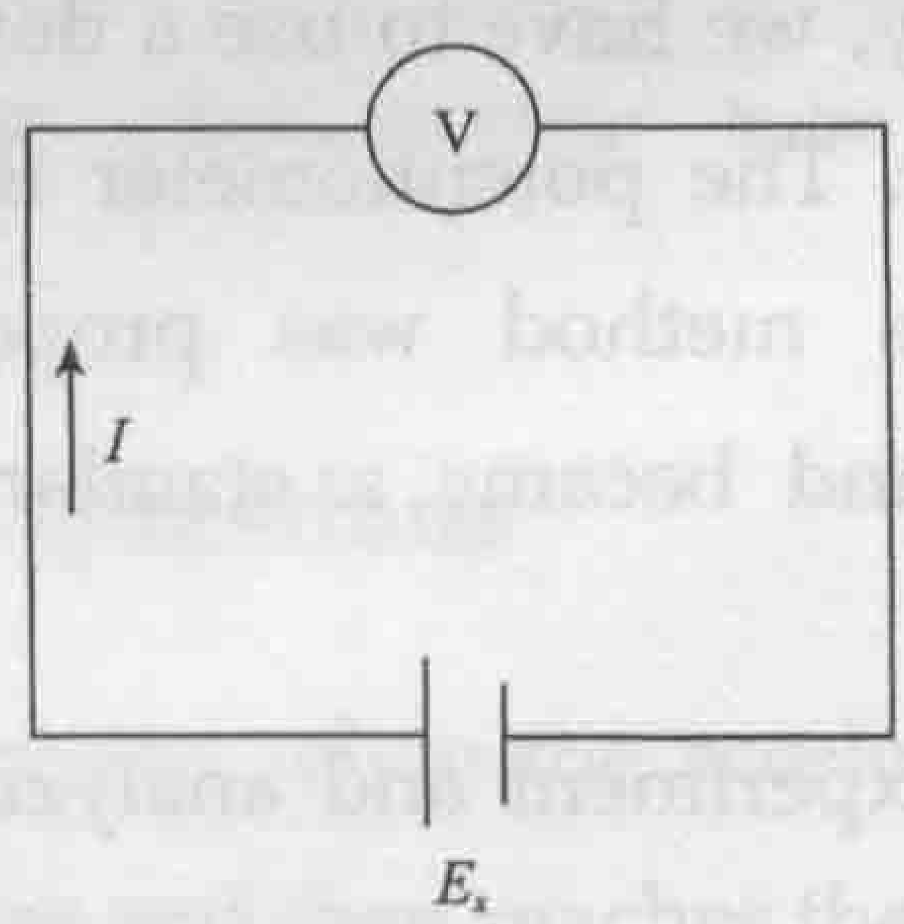

Fig. 3.15-2 Measurement of the terminal voltage of a cell by a voltmeter

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. 3.15-2 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.

Figure 3.15-3 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.

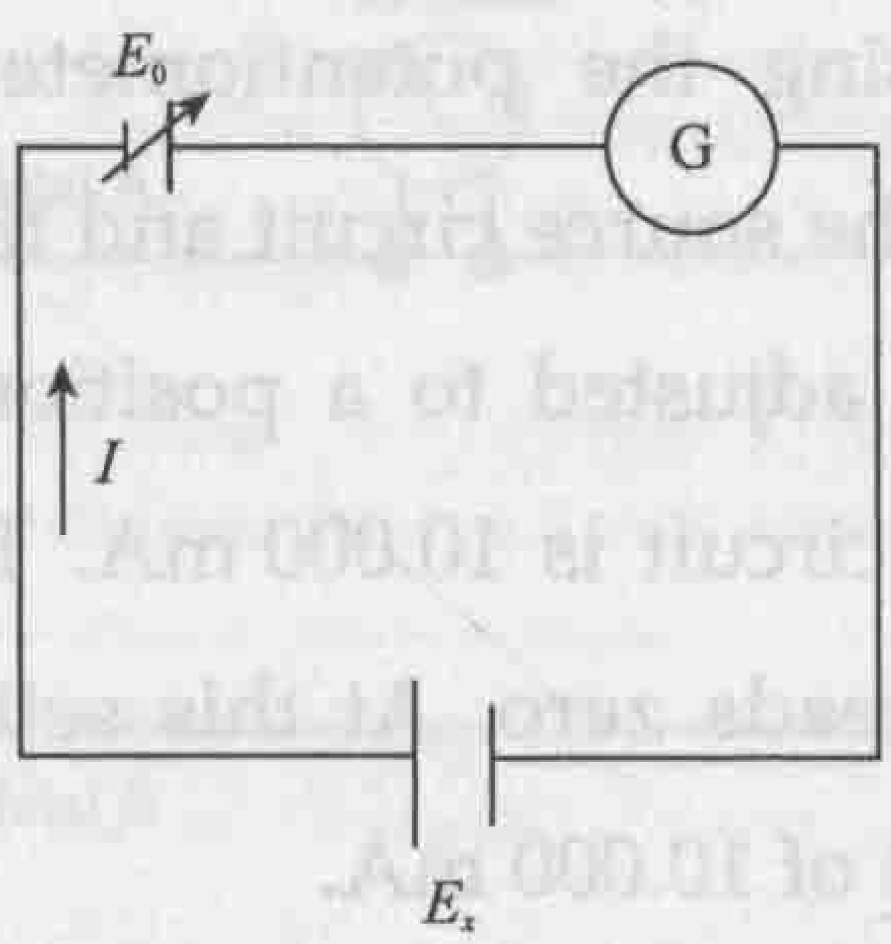

Fig. 3.15-3 Schematic circuit diagram of the null balance measuring method

The box potentiometer is constructed on the principle of null balance. A schematic diagram of the potentiometer is shown in Fig. 3.15-4, 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 resistor, R_A and R_B are two resistors, 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 pointer deflects neither to the left nor to the right, K_E, K_P and K are three switches.

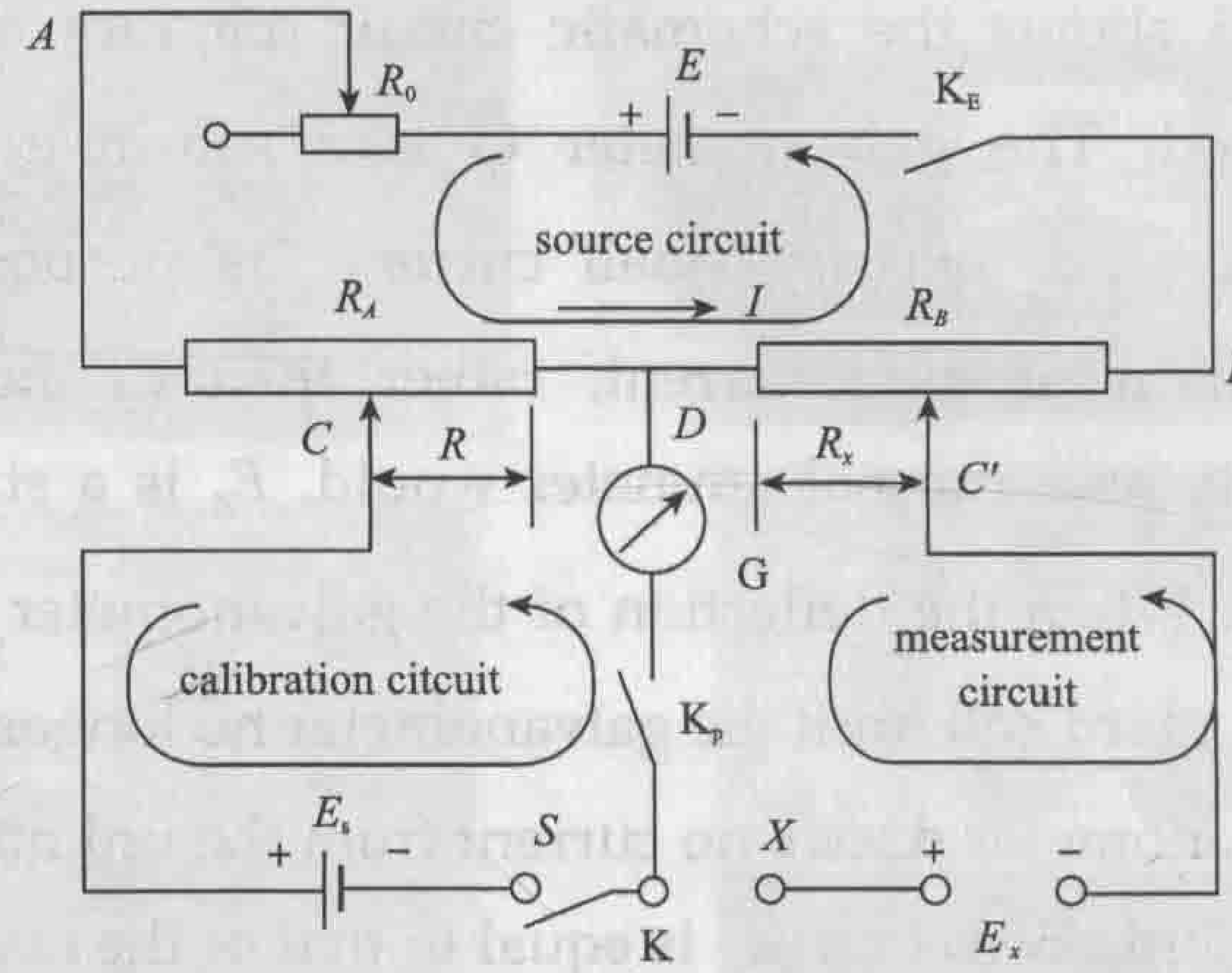

Fig. 3.15-4 A schematic circuit diagram of the potentiometer

The first step in using the potentiometer is to calibrate it with the calibration circuit. When the source circuit and the calibration circuit are 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 across R_x is the emf E_x. Thus, we have

$$E_x = IR_x \tag{3.15-1}$$

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.

3.15.3.2 The thermocouple

If two dissimilar metals, such as copper and iron, are joined together, as in Fig. 3.15-5, and if the two junctions are at different temperatures, a thermal emf will be generated. This is now known as the *thermoelectric effect* or *Seebeck effect*. This is because electrons in these metals are free to move, and those electrons at a hotter junction of the thermocouple will move more quickly than those electrons at the colder end. This will result in a net effect of some charge moving from one end of the thermocouple to the other, which is what current is. The corresponding potential difference is then called the thermal emf. This effect was discovered by the German–Estonian physicist Thomas Johann Seebeck in 1821. It is utilized in making a thermocouple, an instrument for the accurate and rapid measurement of temperatures.

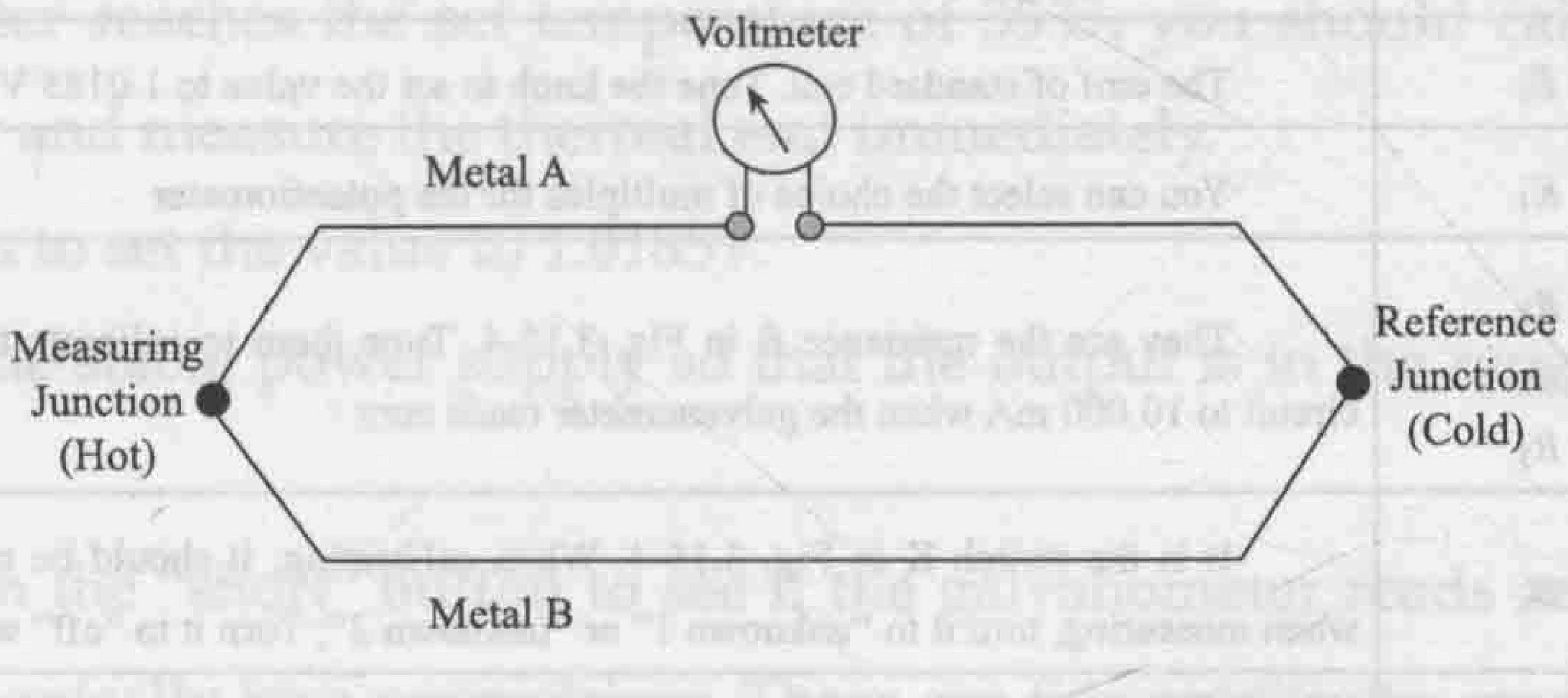

Fig. 3.15-5 A schematic circuit diagram of the thermocouple

Thermocouples are widely used in science and industry. Applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. In this experiment, the unknown emf is produced by a thermocouple.

3.15.4 Experimental Procedure

Fig. 3.15-6 shows the panel of a box potentiometer. The knobs on the panel are introduced in Table 3.15-1.

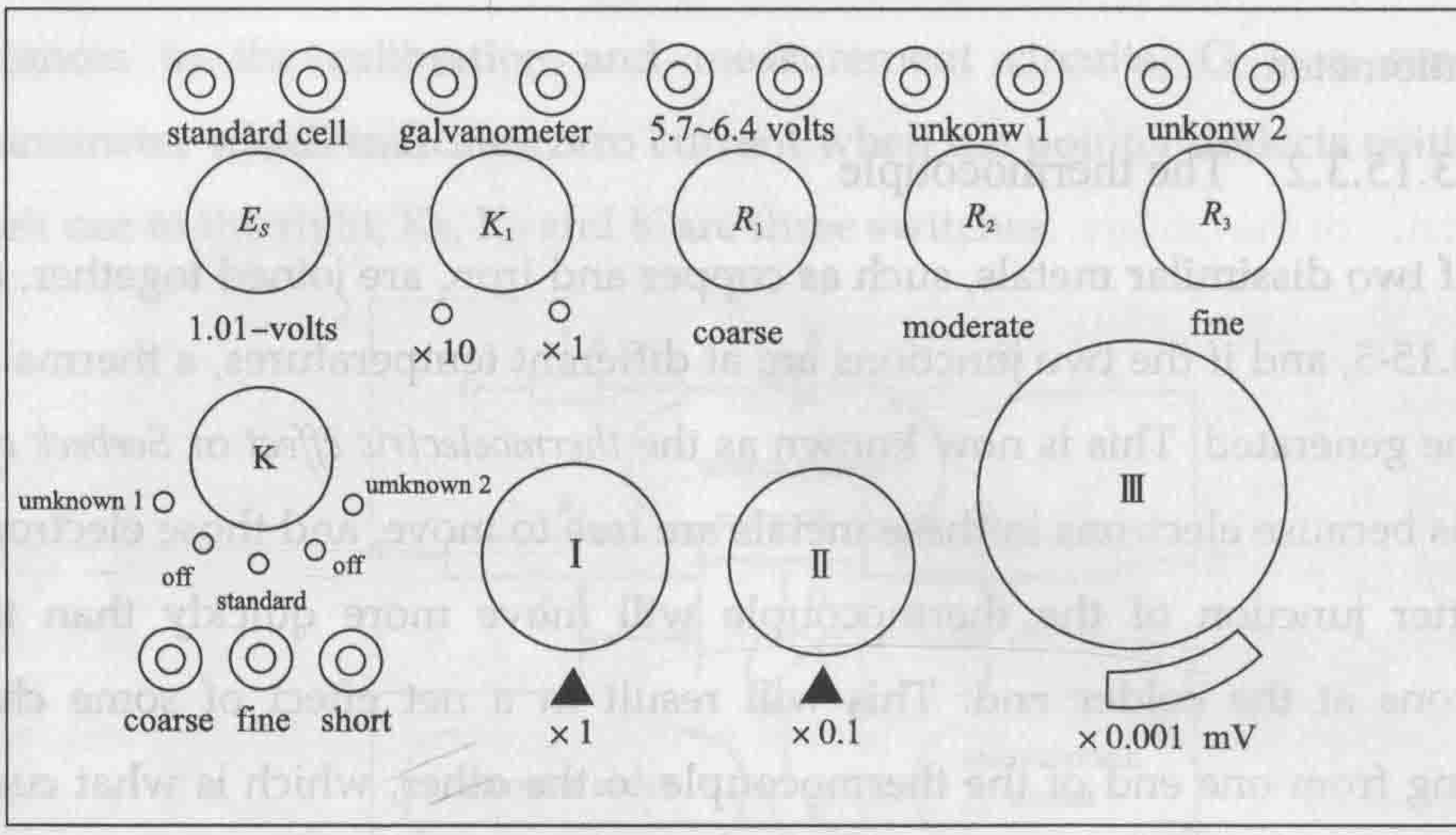

Fig. 3.15-6 Panel of the box potentiometer

Table 3.15-1 The knobs and their description on the panel of the 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 choice of multiples for the potentiometer
R_1 R_2 R_3	They are the resistance R in Fig. 3.15-4. 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. 3.15-4. When calibrating, it should be turned to "standard"; when measuring, turn it to "unknown 1" or "unknown 2"; Turn it to "off" when it is not in use
Coarse Fine Short	They are the switch K_p in Fig. 3.15-4. You will use it when calibrating and measuring. At the beginning of calibration or measuring, press down the "coarse" button and it will be observed 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. 3.15-4. 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 10.000mA through R_B in the source circuit

3.15.4.1 Heating the Water to a Setting Temperature

(1)Familiarize yourself with the potentiometer, the stable power supply, the galvanometer, and the heating vessel.

(2)Connect the potentiometer, the stable power supply, the galvanometer, and the heating vessel correctly.

(3)Check your circuit and turn on the power of the potentiometer, the stable supply, and the galvanometer to preheat them for at least five minute.

(4)Rotate K_1 to choose the multiple of "×1".

(5)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.

(6)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℃, you should calibrate the potentiometer and measure the thermal emf immediately.

(7)Tune E_s to set the value to 1.0185V.

(8)Tune the stable power supply so that the output is in the range of 5.7～6.4 V.

(9)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.

(10)Rotate the switch K to "standard" and set grade "1" for the galvanometer. Push in the "coarse" knob at the lower left corner. 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 the pointer of the galvanometer can read zero and doesn't oscillate. Now, the current in the source circuit is calibrated to 10.000 mA.

(11)Rotate and pull out both the "fine" and "coarse" knobs.

3.15.4.3 Measuring the emf Produced by the Thermocouple

(12)Turn the switch K to "unknown 1" or "unknown 2" to measure the unknown emf.

(13)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. Now, 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℃.

(14)Repeat Steps (6) through (13) to complete Data Table 3.15-1 for the temperatures given in the table.

3.15.5 Experimental Data

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

Room temperature ________ ; Multiple of the potentiometer________

Temperature, T/℃	35	45	55	65	75	85
Thermal emf, E_x/mV						

Student's name and number:______________Instructor's initial:______________

3.15.6 Calculations

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 Data Table 3.15-1 and least-squares fitting method to find the best estimates for the constants a and b.

3.15.7 Graphing

Use the data in Data Table 3.15-1 to draw a smooth line described by the data points.

3.15.8 Post Lab Questions

(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?

(2)In Fig. 3.15-4, the purpose of the calibration circuit is to get a current of 10.000 mA in the source circuit. Can the calibration circuit be replaced by an ammeter? Why?