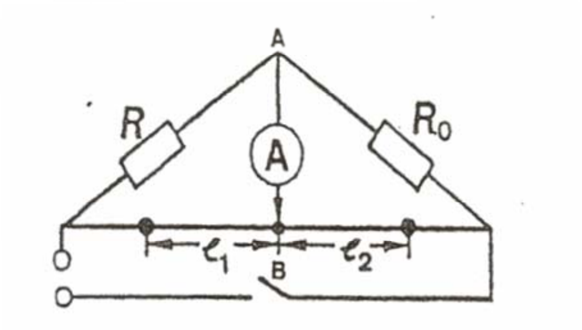
Temperature Dependence of a Semiconductor Resistor

Objective:

- Determining the resistance R of a semiconductor as a function of temperature T in a Wheatstone bridge.
- Determining the “band gap “.

Apparatus:

1	Semiconductor resistor	586 82
1	Electric Oven, 220V	555 81
1	Thermometer	
1	Demonstration measuring bridge, 1m	536 02
1	Resistance box	536 77
	Connecting leads	501 20/25/33
1	Multimeter	531 52
1	Power supply	685 44



Theory:

The following relationship applies:

$$R_T \propto e^{E_g/2kT} \qquad (1)$$

ΔE : energy gap

R_T : electric resistance

k : 1.38*10 J.K^{-1} (Boltzmann constant)

T : Absolute temperature

The specific resistance of a semiconductor falls with temperature.

The lower the band space between the valence and conduction bands in the band model, the lower the resistance.

The greater the ratio of to the thermal energy k.T of the electrons, the fewer the electrons which can be moved from the valence band to the conduction band.

The number of thermally generated pairs of electrons and holes depends exponentially on

$$\frac{E_g}{kT}$$

The following equation applies

$$n.p \propto e^{-E_g/kT} \tag{2}$$

where n: Electron concentration in the conduction band

p: Concentration of the holes in the valence band

since, n=p in the case of intrinsic conduction, it follows for the electric resistance that

$$R_T \propto \frac{1}{n} \propto e^{E_g/2kT} \tag{3}$$

$$\ln R_T = \ln R_{\circ} + \frac{E_g}{2kT} \tag{4}$$

If $\ln R_T$ is plotted against 1/T on a coordinate system, we obtain a straight line with the gradient

$$slope = E_g / 2k \tag{5}$$

It is thus possible to determine the band space ΔE form the temperature dependence of the semiconductor resistor:

$$E_g = slope * 2k \tag{6}$$

The resistance is measured in a Wheatstone bridge circuit. If the Wheatstone bridge circuit is balanced at the set temperature, i.e. the bridge branch AB is currentless, the unknown resistance is given by:

$$R_T = (L_1 / L_2)R \tag{7}$$

<u>Carrying out the experiment:</u>

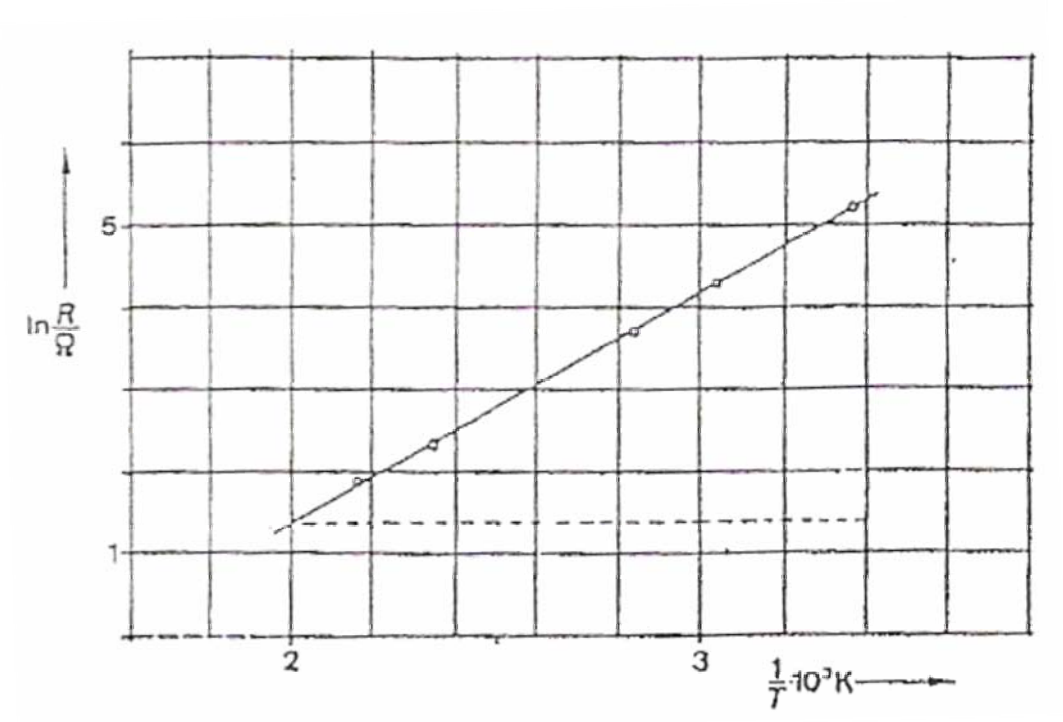
1. Set up the experiment as shown in figure.
2. Set the battery voltage to 1.5V by using the d.c. voltmeter.
3. Look for the balancing point by sliding the free end of the galvanometer over the meter bridge.
4. Make the balancing point in the middle of the meter bridge by adjusting the resistance from the resistance box (this is the adjustable resistance in the Wheatstone bridge). Don't forget that the balancing point is the point at which the galvanometer points to zero.
5. Now, turn on the oven to heat the semiconductor resistance.

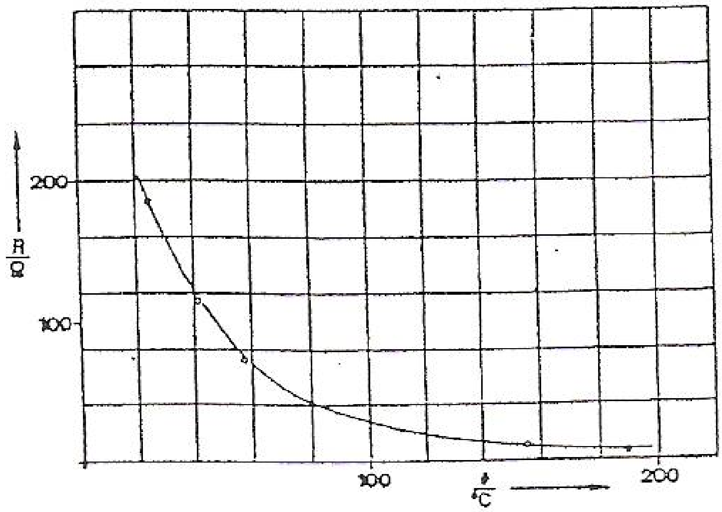
CAUTION: The noble metal resistance temperature must not exceed 180^oC.

6. Measure L_1 at every $10C^o$ decrease in temperature by looking for the balancing point.
7. Deduce L_2 and calculate R_T every time.
8. Plot R_T versus T .

9. Linearize the relationship between R_T and T by plotting $\ln R_T$ versus $1/T$.
10. Calculate the slope and then the band gap energy for the semiconductor.

Evaluation and Results:





The gradient of the straight line in the graph in the above figure is:

$$slope = \frac{3.9}{1.4*10^{-3}.K^{-1}} = 2786K$$

The energy gap:

$$E_g = slope * 2k = 2786K * 2 * 1.38 * 10^{-23} J.K^{-1}$$
$$= 7.69 * 10^{-20} J$$
$$= 0.48 eV$$
$$(1eV = 1.602 * 10^{-19} J)$$

The semiconductor resistance decreases non-linearly with increasing temperature. In the case of non-pure semiconductors, $\ln R_T$ as a function of 1/T is a linear relation only at higher temperatures, use intrinsic conduction is dominant there.

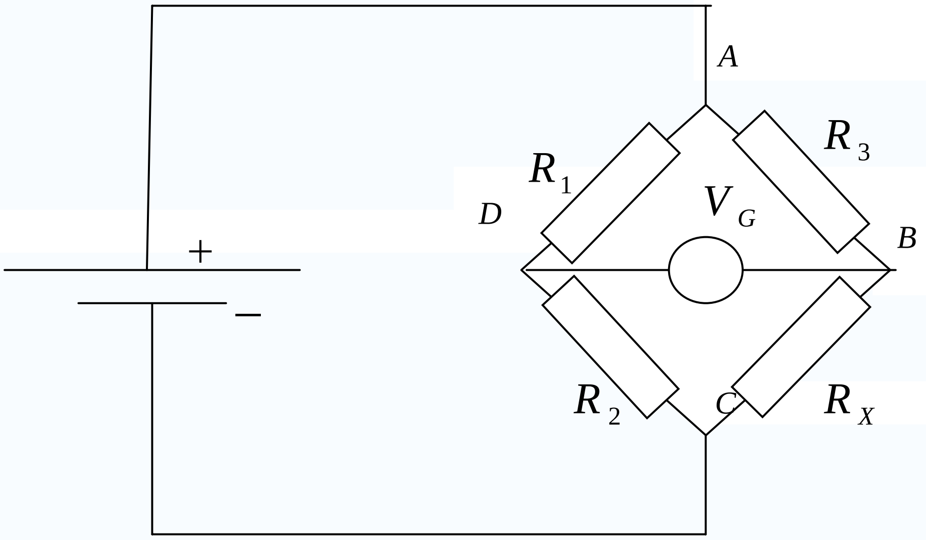
Questions:

- Describe the relationship between the semiconductor resistor and the temperature?
- Explain why does the resistance of a semiconductor resistance decrease with increasing temperature?

Wheatstone bridge

From Wikipedia, the free encyclopedia

A **Wheatstone bridge** is a measuring instrument invented by Samuel Hunter Christie in 1833 and improved and popularized by Sir Charles Wheatstone in 1843. It is used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component. Its operation is similar to the *original* potentiometer except that in potentiometer circuits the meter used is a sensitive galvanometer.



Wheatstone's bridge circuit diagram.

In the circuit at right, R_x is the unknown resistance to be measured; R_1, R_2 and R_3 are resistors of known resistance and the resistance of R_2 is adjustable. If the ratio of the two resistances in the known leg (R_2 / R_1) is equal to the ratio of the two in the unknown leg (R_x / R_3), then the voltage between the two midpoints (**B** and **D**) will be zero and no current will flow through the galvanometer V_g. R_2 is varied until this condition is reached. The current direction indicates whether R_2 is too high or too low.

Detecting zero current can be done to extremely high accuracy (see galvanometer). Therefore, if R_1, R_2 and R_3 are known to high precision, then R_x can be measured to high precision. Very small changes in R_x disrupt the balance and are readily detected.

At the point of balance, the ratio of $R_2 / R_1 = R_x / R_3$

Therefore,

$$R_X = (R_2 / R_1) R_3$$

Alternatively, if R_1, R_2, and R_3 are known, but R_2 is not adjustable, the voltage or current flow through the meter can be used to calculate the value of R_x, using Kirchhoff's circuit laws (also known as Kirchhoff's rules). This setup is frequently used in strain gauge and Resistance Temperature Detector measurements, as it is usually faster to read a voltage level off a meter than to adjust a resistance to zero the voltage.

Derivation:

First, we can use Kirchhoff's first rule to find the currents in junctions **B** and **D**:

$$I_3 - I_X + I_g = 0$$
$$I_1 - I_g - I_2 = 0$$

Then, we use Kirchhoff's second rule for finding the voltage in the loops **ABD** and **BCD**:

$$I_3 \cdot R_3 + I_g \cdot R_g - I_1 \cdot R_1 = 0$$

$$I_x \cdot R_x - I_2 \cdot R_2 - I_g \cdot R_g = 0$$

The bridge is balanced and $I_g = 0$, so we can rewrite the second set of equations:

$$I_3 \cdot R_3 = I_1 \cdot R_1$$

$$I_x \cdot R_x = I_2 \cdot R_2$$

Then, we divide the equations and rearrange them, giving:

$$R_x = \frac{R_2 \cdot I_2 \cdot I_3 \cdot R_3}{R_1 \cdot I_1 \cdot I_x}$$

From the first rule, we know that $I_3 = I_x$ and $I_1 = I_2$. The desired value of R_x is now known to be given as:

$$R_x = \frac{R_3 \cdot R_2}{R_1}$$

If all four resistor values and the supply voltage (V_s) are known, the voltage across the bridge (V) can be found by working out the voltage from each potential divider and subtracting one from the other. The equation for this is:

$$V = \frac{R_x}{R_3 + R_x} V_s - \frac{R_2}{R_1 + R_2} V_s$$

This can be simplified to:

$$V = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2} \right) V_s$$

The Wheatstone bridge illustrates the concept of a difference measurement, which can be extremely accurate. Variations on the Wheatstone bridge can be used to measure capacitance, inductance, impedance and other quantities, such as the amount of combustible gases in a sample, with an explosimeter. The **Kelvin Double bridge** was one specially adapted for measuring very low resistances. This was invented in 1861 by William Thomson, Lord Kelvin. A "Kelvin One-Quarter Bridge" has also been developed. It has been theorized that a "Three-Quarter Bridge" could exist; however, such a bridge would function identically to the "Kelvin Double Bridge."

The concept was extended to alternating current measurements by James Clerk Maxwell in 1865 and further improved by Alan Blumlein in about 1926.