Energy Gap of Germanium

When a material has the basic structure of an insulator, but with a much smaller energy gap (2 eV or less), its physical properties (e.g. conductivity) become quite different. These small energy gap materials are semiconductors. At ordinary temperatures, electrons in the highest valence levels of semiconducting materials are able to occupy states in the normally empty conduction band (when solids are formed from a collection of atoms, discrete energy levels are replaced with energy bands). At room temperature a significant number of electrons occupy the conduction band (which have many vacant states accessible to them) and move about rather easily. For each electron in the conduction band, there is a vacancy in the valence band. These add to the electrical conduction process but generally do not move as freely as electrons in the conduction band since they have fewer accessible "sites" for motion.

Increasing temperature enhances the probability that electrons are thermally activated across the energy gap resulting in an effective increase in charge carriers. As a result, the conductivity of a semi-conductor increases (resistivity decreases) as the temperature increases. This is contrary to what happens in a normal conductor or metal where resistivity increases with increasing temperature.

This experiment will demonstrate the temperature dependence of the electrical conductivity of a pure (intrinsic) semiconductor. We expect a sharp (exponential) rise in conductivity with rising temperature due to the increasing concentration of thermally produced conducting electrons and holes. The goal of this lab is to determine the energy gap of a semiconductor by measuring its temperature dependent conductivity (resistivity).

Procedure:

1. Connect a voltage source to the heating current sockets (sockets are at the back). DO NOT switch on the voltage source until just before the measurement is to be made.

2. Enter a current of 1-3mA using a constant current supply through the Ge crystal. Hereby use an ammeter and the current control option (CC) of the power supply. To measure the resistance of the crystal, measure the voltage drop across the crystal and apply Ohm's Law. (NOTE: if you measure the current with an ammeter, think first how to use it! If it is not working, there is a good chance you might have blown a fuse.)

3. To measure the thermoelectric voltage, a voltmeter is connected across the thermocouple. The voltmeter reads the difference to the ambient temperature ($\Delta V = 40\ \mu V = \Delta T = 1$ K)

4. To start the measurement, increase successively the heating current. Write down the voltage drop across the Germanium plate for each tenth of mV rise in thermoelectric voltage. Increase the heating current to finally full amperage (~3 V).

5. Make a two to three series of measurements to determine the resistance as a function of temperature. (Switch off the heating and measure the voltage drop, while the Germanium plate is cooling) The thermocouple voltage reading is linear with temperature. Gather data at least 2 times with about 20-30 points per curve.

6. From your data demonstrate that the conductivity σ (∝1/R) of the Ge crystal varies as:

$$\ln \sigma \propto 1/T$$

7. The probability that an electron is excited across the energy gap is

$$P \propto \exp(-E_g/2kT)$$

where E_g is the energy gap.

The number of charge carriers in conduction band is then

$$n \propto NP = N \exp(-E_g/2kT)$$

with N the number of electrons in the valence band and the conductivity is

$$\sigma = ne^2\tau/m \propto Ne^2\tau/m \exp(-E_g/2kT) = A \exp(-E_g/2kT).$$

Taking the ln of each side

$$\ln \sigma = \ln A - E_g/2kT.$$

8. Plot the ln σ versus 1/T in a graph. (Make sure T is in Kelvin). This is usually called an Arhenius plot. From the fit you get the slope of the curve, which equals to $E_g/2k$. From that value, calculate E_g for Germanium in eV.

Summarize your results and draw schematic representations of the activation of electrons from the valence to the conduction band.

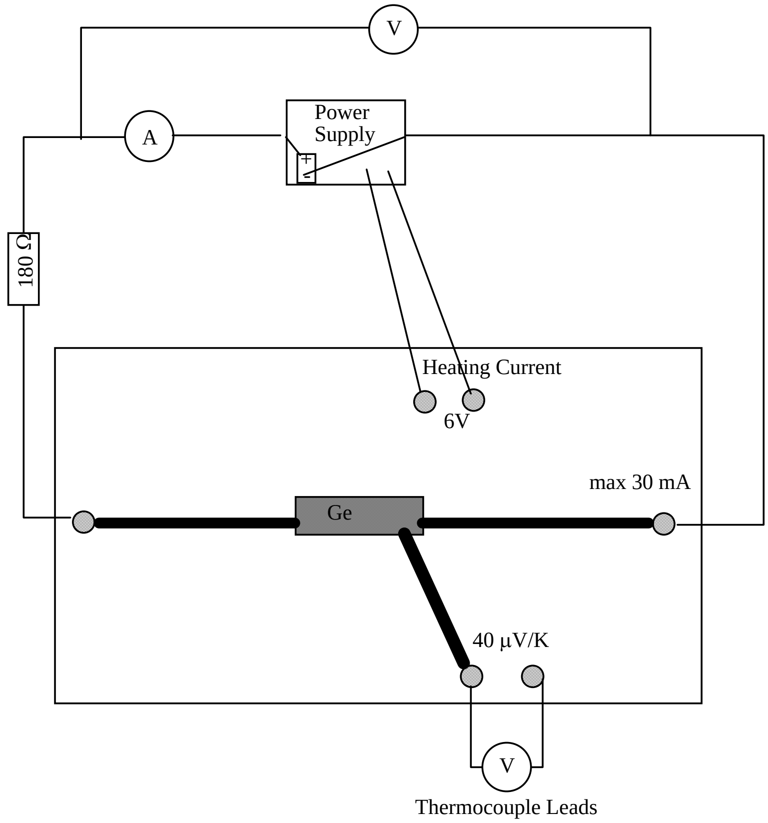

Fig: 1: Electrical connections for the Germanium probe