OBJECTIVE

Record characteristics for various thermocouples and determine their sensitivity

EXPERIMENT PROCEDURE

- **Measure the thermocouple voltage U_{th} as a function of temperature T_1 and confirm that there is a linear relationship between for each of three different thermocouples.**
- **Determine the sensitivity S from the plots of U_{th} and T_1.**
- **Estimate the reference temperature T_2 from the measured curves.**

SUMMARY

If the ends of a metal wire are at different temperatures, since the thermally generated motions of the electrons have different velocities, thermal diffusion will occur between the hot and cold ends of the wire. The current resulting from this diffusion causes the cold end to be negatively charged with respect to the warmer end. The thermal diffusion voltage that arises is proportional to the difference in temperature between the two ends with the constant of proportionality being known as the Seebeck coefficient. If wires of two different metals are joined together, with contact points held at different temperatures, and a voltmeter is connected between the two unjoined ends, the result is a thermocouple. The voltmeter will then display a voltage which is directly proportional to the difference in temperature between the contact points. The experiment investigates this phenomenon with three different combinations of metals.

REQUIRED APPARATUS

Quantity	Description	Number
1	Set of 3 Thermocouples	1017904
1	Thermometer -20 – 110°C	1003384
1	Thermometer clip	1003528
1	Set of 10 Beakers, Tall Form	1002873
1	Magnetic Stirrer with Heater (230 V, 50/60 Hz)	1002807 or
	Magnetic Stirrer with Heater (115 V, 50/60 Hz)	1002806
1	Microvoltmeter (230 V, 50/60 Hz)	1001016 or
	Microvoltmeter (115 V, 50/60 Hz)	1001015

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BASIC PRINCIPLES

If the ends of a metal wire are at different temperatures, since the thermally generated motions of the electrons have different velocities, thermal diffusion will occur. Since the thermal motion of electrons at the hot end is faster than that of those at the cooler end, more electrons on average move from the warm end to the cold end than the other way round. The current resulting from this diffusion causes the cold end to be negatively charged with respect to the warmer end resulting in a voltage between the two ends. This increasingly acts against the flow of electrons until the diffusion current ceases to flow.

The thermal diffusion voltage U_{td} is proportional to the difference in temperature $T_1 - T_2$ between the ends, with the constant of proportionality being known as the Seebeck coefficient k:

(1) $$U_{td} = k \cdot (T_1 - T_2)$$

U_{td}: Thermal diffusion voltage,
k: Seebeck coefficient,
T_1: Temperature at hot end
T_2: Temperature at cold end

If wires of two different metals are joined together, with contact points held at different temperatures, a thermoelectric current will result. The metal with the larger thermal diffusion voltage will determine the direction of the current flow. If a voltmeter is then connected between the ends, the result is a thermocouple. Due to the high input resistance, very little current will then flow and the voltmeter will indicate a voltage which is directly proportional to the difference in temperature between the contact points:

(2) $$U_{th} = U_{td,B} - U_{td,A} = (k_B - k_A) \cdot (T_1 - T_2)$$

U_{th}: Thermocouple voltage,
$U_{td,A}$, $U_{td,B}$: Thermal diffusion voltages for metals A and B
k_A, k_B: Seebeck coefficients for metals A and B

Only the differential between the Seebeck coefficients

(3) $$k_{BA} = k_B - k_A$$

which appears in equation (2) can be measured without difficulty. This corresponds to the sensitivity of a thermocouple consisting of metals A and B, given by the following:

(4) $$S = \frac{dU_{th}}{dT_1}$$

It is common to use platinum, Pt, as the reference material, whereby the coefficients are given as K_{APt}.

This experiment involves measuring sensitivities S for three different pairs of metals. Water in a beaker will be heated to a temperature T_1 and one end of the thermocouple will be immersed in that. The other end of the thermocouple will be connected to a microvoltmeter in order to measure the voltage. The microvoltmeter sockets are at a constant temperature T_2.

EVALUATION

The thermocouple voltage will be plotted against temperature in a graph of U_{th} against T_1 for each of the three thermocouples. A straight line is drawn to fit each set of points and the sensitivities of each element can then be determined from the gradients of the lines.

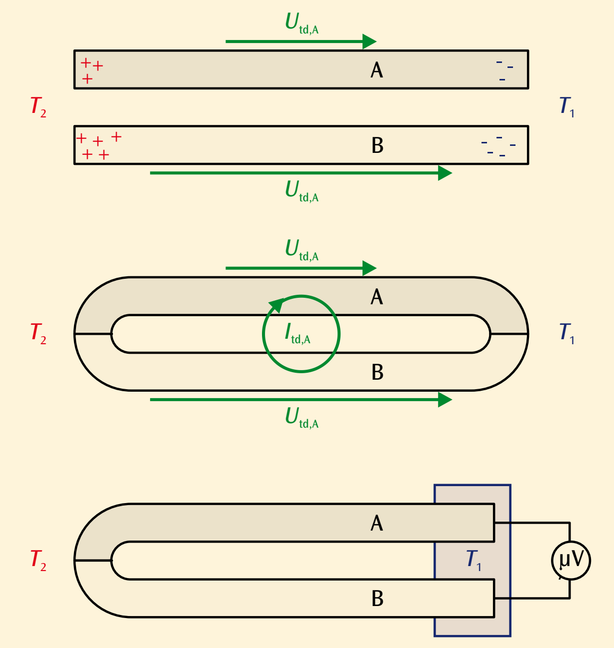

Fig. 1: Thermal diffusion in metal wires (top), thermoelectric current (centre) and thermocouple voltage in a loop made of two different metals (bottom)

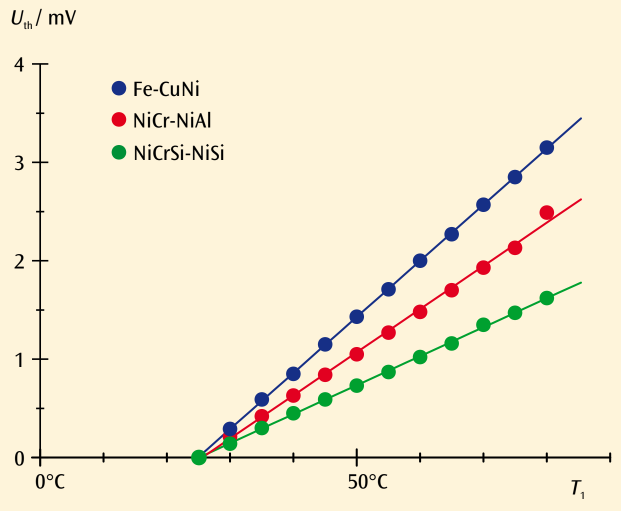

Fig. 2: Thermocouple voltages as a function of temperature for Fe-CuNi, NiCr-NiAl and NiCrSi-NiSi thermocouples. The measured curves cross the T_1 axis of the graph at the reference temperature T_2 = 23°C