

PHYSICS NOTES

© The Institute of Education 2016



SUBJECT: Physics
LEVEL: Higher
TEACHER: Pat Doyle

Topics Covered:

Temperature and Thermometers

About Pat:

Pat graduated with a Masters Degree in Physics in 1986 and has taught Physics in the Institute for over 30 years. He has been a regular contributor to Science Plus, a Science and Mathematics publication for the Leaving Cert. He recently co-wrote Exploring Science, Exploring Science Workbook and Revise Wise Science for the Junior Certificate.



The Institute of Education
79-85 Lower Leeson Street, Dublin 2

Chapter 1 Temperature and Thermometers

Definition of temperature: Temperature is the measure of the hotness or coldness of a body.

Unit of temperature:

- The S.I. unit of temperature is the **kelvin (K)**
- For practical work in the laboratory we use the **degree Celsius (° C)**

$$\theta / ^\circ C = T / K - 273.15 \dots\dots\dots P. 58$$

- Sample question 1:** (i) convert 300 K to ° C
(ii) convert 15 ° C to K

Solution :

(i) $\theta / ^\circ C = T / K - 273.15$
 $\theta / ^\circ C = 300 - 273.15 = 26.85 ^\circ C$

(ii) $\theta / ^\circ C = T / K - 273.15$
 $15 ^\circ C = T / K - 273.15$
 $288.15 ^\circ C = T / K$

Trick ! : Be careful not to confuse temperature θ and temperature change $\Delta\theta$

Water in a beaker is heated and the temperature changes from 15 ° C to 20 ° C . Calculate the temperature rise in kelvin.

Initial temperature = 15 ° C = 288.15 K Final temperature = 20 ° C = 293.15 K

$$\Delta\theta = 5 ^\circ C = 5 K \quad \text{!!!!!!!!!!!!!!}$$

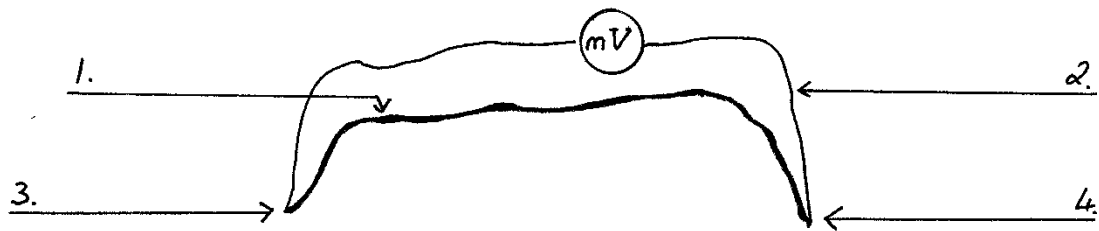
Thermometric properties

Definition of thermometric property: A thermometric property is the physical property of a thermometer that changes measurably with temperature.

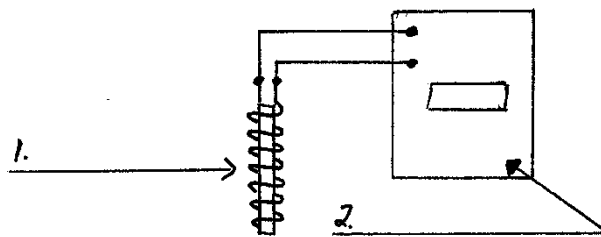
Length of a column of mercury:



- A glass tube with a very narrow bore is sealed at both ends
- One end is enlarged and contains mercury. This is the mercury reservoir.
- If this end is placed in a beaker of warm water the mercury expands and this causes the mercury to rise up the tube.
- The length of the column of mercury is determined by the temperature of the warm water.

Emf of a thermocouple :

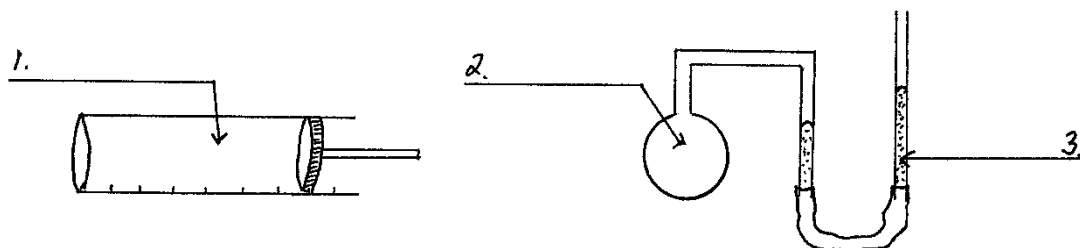
- Two wires made of different metals (**copper and constantan**) are joined at both ends.
- If the ends are at a different temperature then an emf (**Seebeck emf**) is generated .
- The size of the emf depends on the temperature difference between the ends of the wires.
- The size of the emf can be used to measure the temperature.

Resistance of a wire:

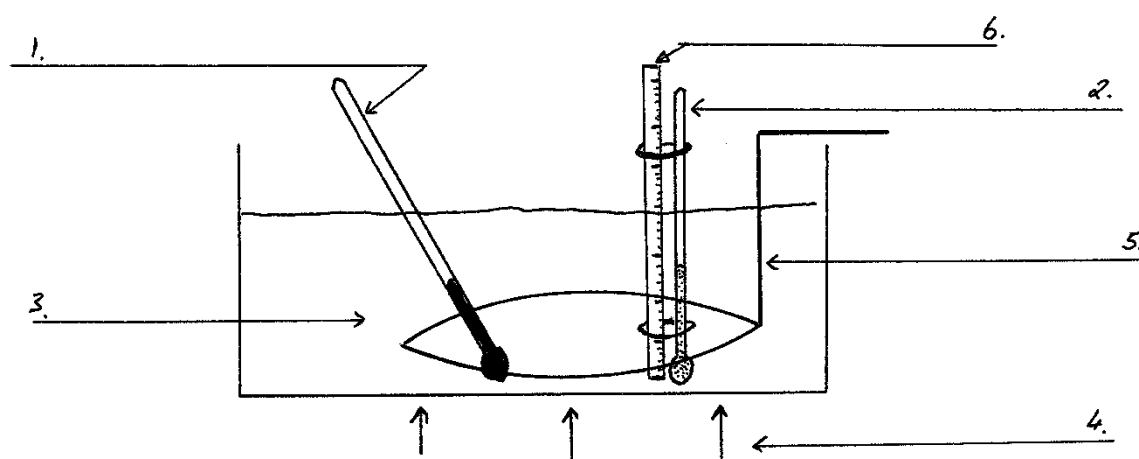
- As the temperature of the wire increases so also does the resistance of the wire.
- Since resistance depends on temperature then resistance can be used to measure temperature.

Colour of liquid crystals:

- Temperature changes can affect the colour of a liquid crystal, which makes them useful for temperature measurement.
- For example if the thermometer is black and it is put onto someone's forehead it will change colour depending on the temperature of the person.

A gas :

- The pressure of a fixed mass of gas at a constant volume is the thermometric property of the constant volume gas thermometer.
- The volume of a fixed mass of gas at constant pressure is another thermometric property involving a gas.

Mandatory experiment: To calibrate a liquid-in-glass thermometer:

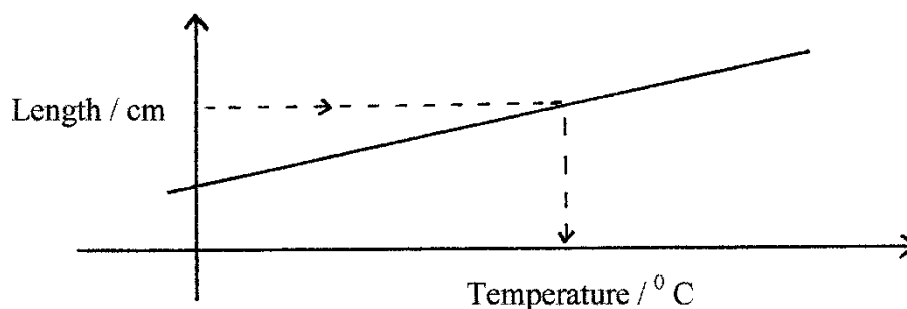
- A half metre stick is attached to a hollow glass tube which contains a coloured liquid.
- This is placed in a beaker of melting ice at 0°C .
- The temperature of the ice is measured with a mercury thermometer, i.e. **the laboratory mercury thermometer is used as the standard thermometer.**

Data:

- Note and record the temperature of the ice and the length of the coloured liquid in the glass tube.
- By slowly heating the arrangement note and record both the temperature and the length of liquid at a range of different temperatures, 10°C , 20°C

Graph:

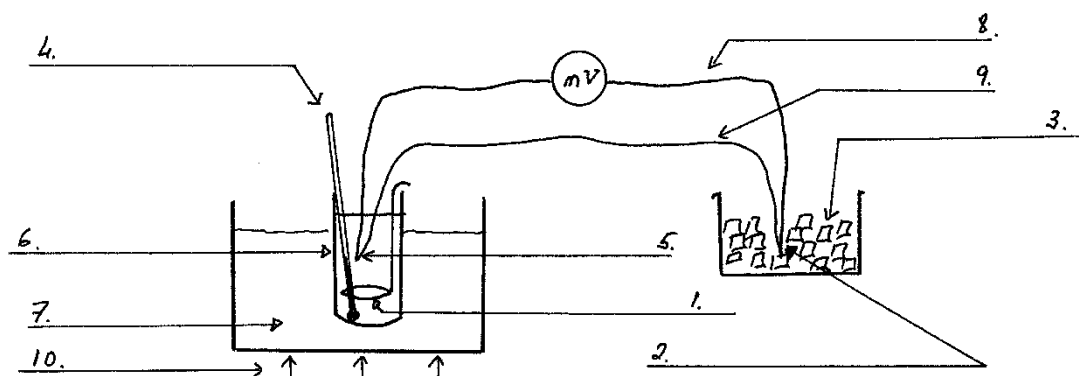
- Plot a graph of length of liquid on the y-axis and temperature on the x-axis.

**Accuracy:**

- The use of a stirrer ensures that the water in the beaker has a uniform temperature.
- Avoid the error of parallax when using the half metre stick to measure the length of the liquid in the glass tube.
- Make sure the half metre stick stays firmly attached to the glass tube for the duration of the experiment.

To use the newly calibrated thermometer:

- Place the glass tube and half metre stick in the substance whose temperature is required.
- Note the length of the liquid column.
- Draw a horizontal line from this length value on the y-axis to the straight line graph.
- Draw a vertical line to the x-axis and note the temperature value.

Mandatory experiment: To calibrate a thermocouple thermometer:

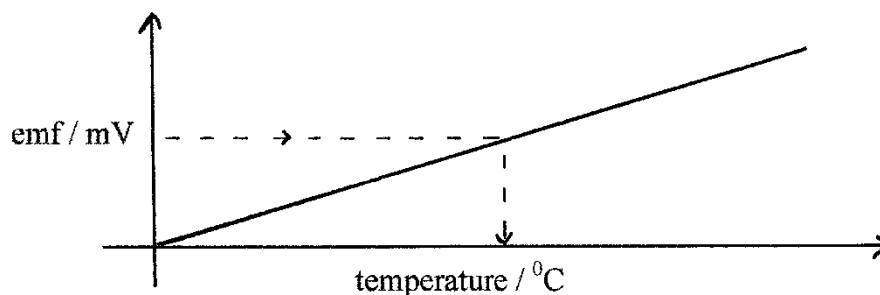
- A copper constantan thermocouple is arranged with the hot junction in a test tube of oil and the cold junction (**reference junction**) in melting ice.
- A Bunsen burner heats the water bath which heats the oil in the test tube which in turn heats the hot junction.
- The temperature of the oil and hot junction is recorded with a mercury thermometer, i.e. a **laboratory mercury thermometer is used as the standard thermometer.**

Data:

- Note and record the temperature of the hot junction (0°C , 10°C , 20°C ) and the corresponding values of emf as indicated by the millivoltmeter.

Graph:

- Plot a graph of emf on the y-axis and temperature of hot junction on the x-axis.

**Accuracy:**

- The use of a stirrer ensures that the oil has a uniform temperature. Thus the temperature of the oil is the temperature of the hot junction.
- Heat the oil slowly to further ensure the temperature of the oil is the temperature of the hot junction.
- Check and correct if necessary any zero error on the millivoltmeter

To use the newly calibrated thermometer:

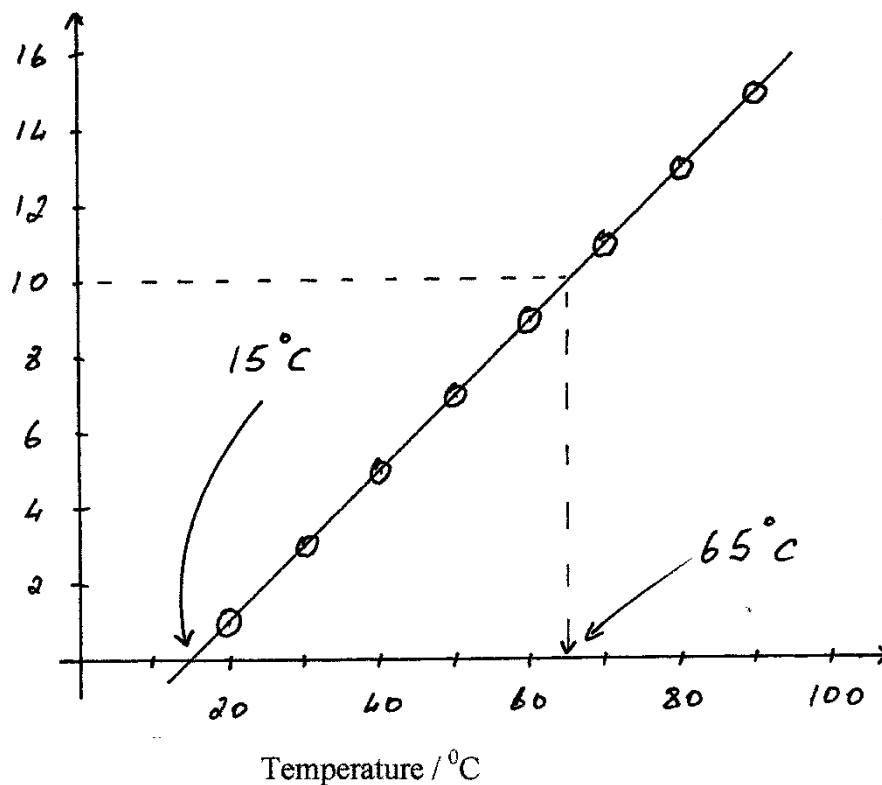
- The hot junction is placed in the substance whose temperature is required and the emf is noted.
- The reference junction must be kept in the melting ice.
- Draw a horizontal line from the emf value on the y-axis to the straight line graph.
- Draw a vertical line to the x-axis and note the temperature.

Sample question 2: In an experiment to calibrate a thermocouple thermometer the following data were obtained.

Temperature / $^{\circ}\text{C}$	20	30	40	50	60	70	80	90
Emf / mV	1	3	5	7	9	11	13	15

- Draw a suitable calibration graph for this thermometer
- From the graph calculate the temperature of the reference junction.
- When the thermometer was placed in a beaker of warm water the emf recorded was 10 mV. Find the temperature of this water.

Solution: (i) emf / mV



- The temperature of the reference junction is obtained by finding the value of the point of intersection of the graph and the x-axis.
Temperature of reference junction = 15°C
- Draw a horizontal line from 10 on the y-axis to the graph. Drop a line vertically to the x-axis.
An emf of 10 mV would correspond to a temperature of 65°C .

Sample question 3:

A student carried out an experiment to obtain the calibration curve of a thermometer. The following is an extract from her report.

I placed the thermometer I was calibrating in a beaker of water along with a mercury thermometer which I used as the standard. I recorded the value of the thermometric property of my thermometer and the temperature of the water as shown on the mercury thermometer. I repeated this procedure at different temperatures. The following is the table of results that I obtained.

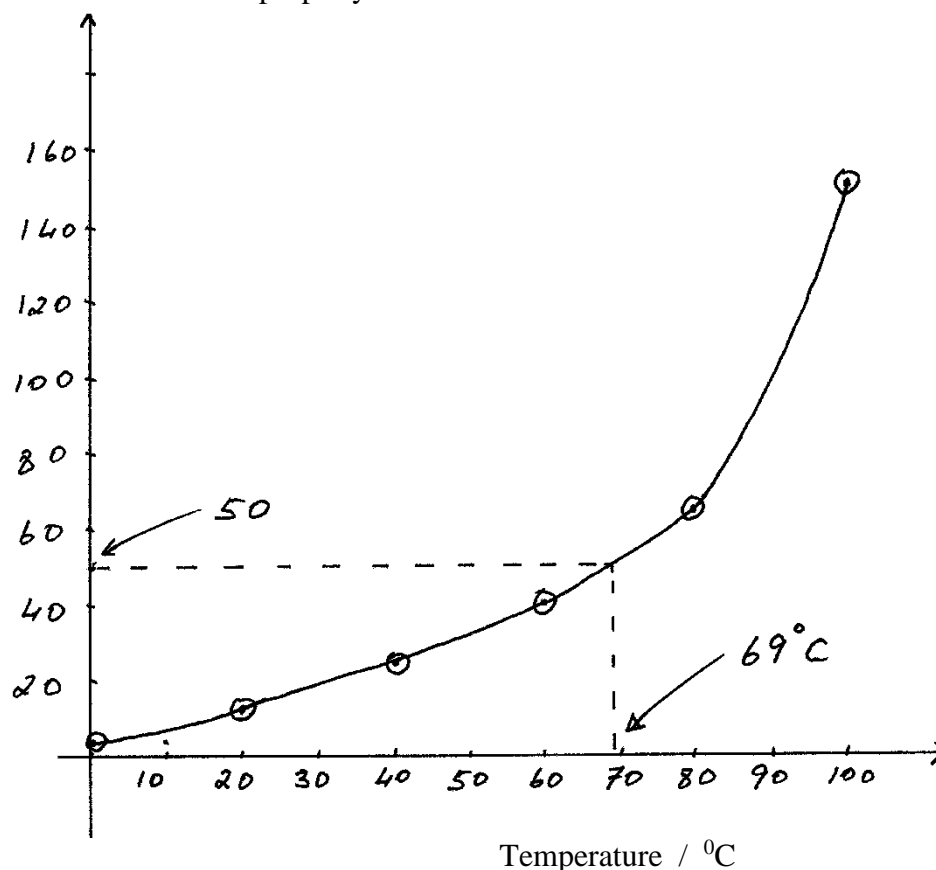
Temperature / $^{\circ}\text{C}$	0	20	40	60	80	100
Value of thermometric property	4	12	24	40	64	150

- (i) Using the data in the table, draw a graph on graph paper of the value of the thermometric property against its temperature. Put temperature on the horizontal axis (X-axis).

- (ii) Use your graph to estimate the temperature when the value of the thermometric property is 50.

Solution:

- (i) Value of thermometric property

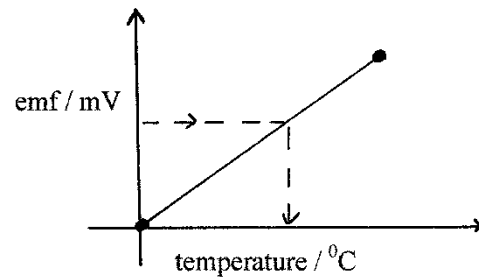
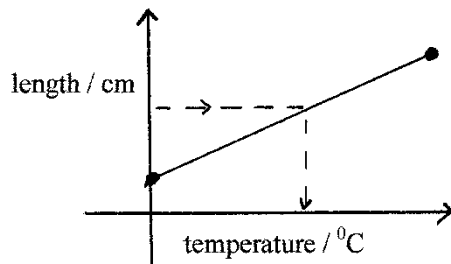


- (ii) when the thermometric property is 50 the temperature is 69°C

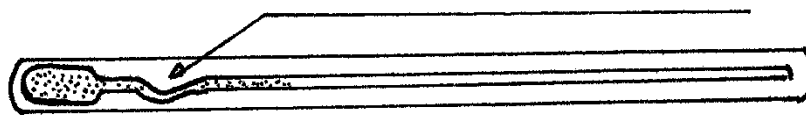
Note: It is not clear what the actual thermometric property is. !!!!!!!!!!!!!

Thermometers do not agree:

- If the two thermometers mentioned earlier, the liquid-in-glass thermometer and the thermocouple, are calibrated using only two values of temperature, melting ice at 0°C and boiling water at 100°C , straight line graphs will be obtained.
- Now these two thermometers are used to measure the temperature of a substance. A length value and an emf value will be noted. The graphs can be used to convert these values into temperature.
- **The values of temperature will most likely not be the same.**

**Note:**

- The discrepancy arises because thermometric properties do not vary in the same way as each other as the temperature changes
- **Different thermometers based on different thermometric properties respond in a different way to a given rise in temperature giving somewhat different values.**
- You cannot assume that one value of temperature is more correct than another. To resolve the situation we choose a **standard thermometer** against which all other thermometers can be compared.

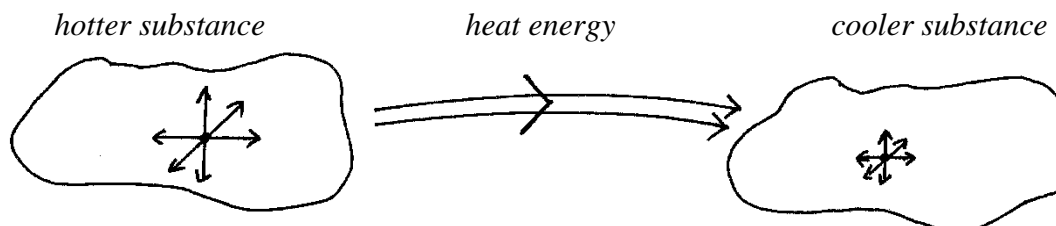
Clinical thermometer:

- The constriction is designed to stop the liquid (mercury) falling back into the reservoir when the thermometer is taken from the patient's mouth.
- This allows for an accurate value of temperature to be recorded.
- The thermometer is shaken before being used again to force the liquid back into the reservoir.

Oven thermometer / boiler thermometer:

- A thermocouple thermometer could be used to measure the temperature inside an oven or boiler.
- The emf generated would be translated to a temperature reading.

Chapter 2: Heat



- The atoms in both substances above are moving in a 3 dimensional type of vibration.
- The atoms would have both kinetic energy and potential energy and this energy is correctly called **internal energy**.
- The kinetic energy due to vibrations is greater in the hotter substance. The hotter substance has more internal energy.
- **Heat is the form of energy transferred from the hotter substance to the cooler substance as a result of the temperature difference between them.**

Definition of heat capacity: The heat capacity of an object is the heat energy needed to change the temperature of the object by 1 K

The symbol is C

Unit is $J K^{-1}$

Definition of specific heat capacity: The specific heat capacity of an object is the heat energy needed to change the temperature of 1 kg of the object by 1 K

the symbol is c

Unit is $J kg^{-1} K^{-1}$

Math note: the energy needed to change temperature is $\Delta E = m c \Delta\theta$ P.58

(m = mass of substance; c = specific heat capacity; $\Delta\theta$ = temperature change)

Sample question 1: An object is moving at a speed of $16 m s^{-1}$. Assuming that all the kinetic energy of the object is changed to heat energy gained by the object, calculate the rise in temperature.

(specific heat capacity of the material of the object = $400 J kg^{-1} K^{-1}$)

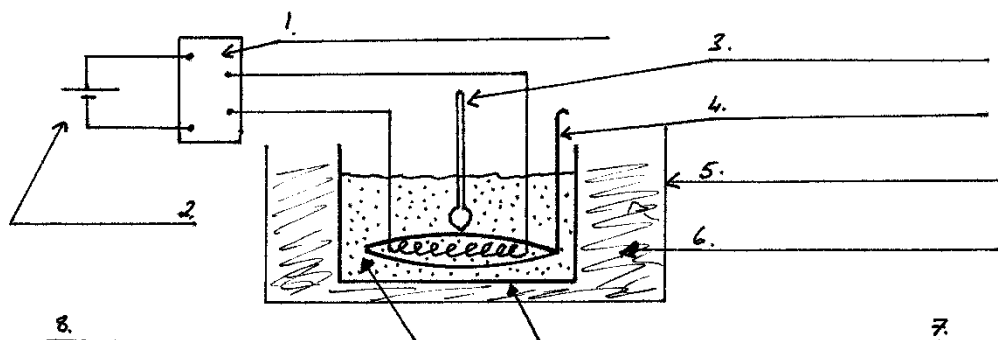
Solution: energy needed to change temperature = kinetic energy

$$m c \Delta\theta = \frac{1}{2} m v^2$$

$$\Delta\theta = \frac{v^2}{2 c}$$

$$\Delta\theta = \frac{16^2}{2 \times 400}$$

$$\Delta\theta = 0.32 K$$

Mandatory experiment: To measure specific heat capacity by an electrical method:

- Allow the experimental arrangement above to stand for several minutes before the electricity is switched on. This ensures that the temperature of the liquid equals the temperature of the calorimeter.

Data:

- Measure and record the mass of the calorimeter and the mass of the liquid.
- Measure and record the initial temperature of the liquid and calorimeter.
- Allow the current flow for five minutes and record the electrical energy supplied by using the joulemeter.
- Measure and record the final temperature of the liquid and calorimeter.

Calculations:

Electrical energy supplied = heat energy gain of liquid + heat energy gain of calorimeter

$$E = m_l c_l \Delta\theta_l + m_c c_c \Delta\theta_c$$

(m_l = mass of liquid; m_c = mass of calorimeter; c_l = specific heat capacity of liquid; c_c = specific heat capacity of material of calorimeter; $\Delta\theta_l = \Delta\theta_c =$ temperature rise)

- Note:** (i) To measure c_l you must previously know c_c and visa versa.
(ii) If a joulemeter is not available then you need to use an ammeter, a voltmeter and a timer. Electrical energy supplied = $V I t$
(iii) Recall that Power = $V I$, therefore Electrical energy supplied = Power $\times t$

Accuracy:

- Lag the calorimeter to reduce heat loss to the surrounding air.
- Put an insulating lid on the calorimeter to reduce heat loss to the surrounding air.
- Avoid a very small rise in temperature as measuring small values results in greater percentage errors.
- Avoid very large rises in temperature as this causes large loss of heat to the surrounding air.
- Use a sensitive thermometer to get a precise value of the temperature rise.
- If possible try to arrange the experiment so that room temperature is about half way between the initial and final temperature of the liquid and calorimeter. This way the heat loss to the surrounding air at the end of the experiment is approximately equal to the heat gain from the surrounding air at the start of the experiment.

Sample question 2: In an experiment to measure the specific heat capacity of a liquid a student heated a quantity of the liquid in a copper calorimeter. The following data were obtained.

Mass of calorimeter	26.5 g
Mass of calorimeter + liquid	71.3 g
Initial temperature of liquid + calorimeter	16°C
Final temperature of liquid + calorimeter	21°C
Electrical energy supplied	584 J

Using these measurements calculate a value for the specific heat capacity of the liquid given that the specific heat capacity of copper is $390 \text{ J kg}^{-1} \text{ K}^{-1}$

Solution:

Electrical energy supplied = heat energy gain of liquid + heat energy gain of calorimeter

$$\begin{aligned}
 E &= m_l c_l \Delta\theta_l & + & m_c c_c \Delta\theta_c \\
 584 &= 44.8 \times 10^{-3} \times c_l \times 5 & + & 26.5 \times 10^{-3} \times 390 \times 5 \\
 584 &= 0.224 c_l & + & 51.675 \\
 532.325 &= 0.224 c_l \\
 2376 \text{ J kg}^{-1} \text{ K}^{-1} &= c_l
 \end{aligned}$$

Sample question 3: In an experiment to measure the specific heat capacity of a liquid a student used a 200 W heating coil for 5 minutes to heat the liquid and calorimeter. Calculate the electrical heat energy supplied to the liquid and calorimeter.

Solution:

$$\begin{aligned}
 \text{Electrical energy supplied} &= \text{Power} \times t \\
 &= 200 \times 5 \times 60 \\
 &= 60\,000 \text{ joule.}
 \end{aligned}$$

Storage heaters:

- Storage heaters contain concrete blocks that have a large value of heat capacity.
- They heat up at night when the demand for electricity is reduced and the price is cheaper.
- They absorb large amounts of heat because of the large heat capacity.
- During the day they cool down by releasing their heat to the surrounding air.

Water has a large specific heat capacity:

- Water can absorb large amounts of heat and is very useful as the liquid in radiators.
- On a sunny day the land is warmer than the sea. It takes more heat to raise the temperature of water compared to land as water has a larger specific heat capacity

