

1.3 Energy changes in systems

Name: _____ Class: _____ Date: _____

Total: 25 marks

KEY WORDS specific heat capacity • thermal equilibrium

Objective

Use $\Delta E = mc\Delta\theta$ in all four directions, convert kJ and powers of ten, read a temperature–time graph, and describe or evaluate the RP1 specific-heat-capacity investigation. Original questions for spec statement 4.1.1.3 and required practical 1.

1 Key knowledge and worked examples

$$\Delta E = m c \Delta\theta$$

Symbol	Quantity	Unit
ΔE	change in thermal energy	J
m	mass	kg
c	specific heat capacity	J/kg °C
$\Delta\theta$	temperature <i>change</i>	°C

Specific heat capacity is the energy needed to raise the temperature of **one kilogram** of a substance by **one degree Celsius**. Water: 4200 J/kg °C. Metals: a few hundred.

$\Delta\theta$ is a *difference*: biggest minus smallest, or final minus initial. Never put an absolute temperature into the equation.

Worked example. A 2.0 kg iron block receives 26 000 J and warms from 22 °C to 50 °C. Find c .

- Known: energy, mass, two temperatures. The temperature change is $\Delta\theta = 50 - 22 = 28$ °C.

$$c = \frac{\Delta E}{m \Delta\theta} = \frac{26\,000 \text{ J}}{2.0 \text{ kg} \times 28 \text{ °C}} = 460 \text{ J/kg °C (2 s.f.)}$$

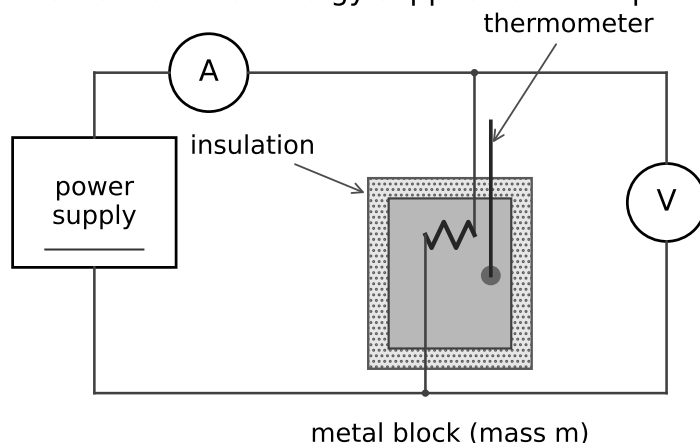
Worked example. A heater warms 0.30 kg of water ($c = 4200 \text{ J/kg °C}$) from 18 °C to 45 °C. Find the energy.

$$\Delta E = mc\Delta\theta = 0.30 \times 4200 \times (45 - 18) = 34\,000 \text{ J (2 s.f.)}$$

Unit traps that earn their own mark: $\text{kJ} \rightarrow \text{J} (\times 1000)$; $\text{J} \rightarrow \text{kJ}$; a power in kW or $\text{MW} \rightarrow \text{W}$. With very small masses (milligrams, 10^{-8} kg) keep standard form on the calculator and give 2–3 significant figures.

RP1: determination of specific heat capacity. Apparatus: metal block (two holes), immersion heater, thermometer, insulation, power supply, ammeter, voltmeter, stopwatch, balance.

RP1: measure electrical energy supplied and temperature rise



Energy supplied by the heater raises the block's thermal store.

Method: measure m ; insert heater and thermometer (a drop of water improves contact); record starting temperature; switch on; record I , V and time t ; the energy supplied is $E = VIt$ (or use the heater's power: $E = Pt$); record temperature against time; calculate $c = \Delta E / (m\Delta\theta)$.

Marks the scheme pays for:

- **Why insulate the block:** reduce energy transferred to the surroundings, so the calculated c is more accurate. Without insulation the measured $\Delta\theta$ is too small for the energy supplied, so c comes out too **high**.
- **Why wait before reading the start temperature:** the thermometer must reach thermal equilibrium with the block.
- **Repeats and a graph:** plot temperature against energy supplied; a straight line through the points averages out random error.
- **Percentage difference** between your value and the accepted value:

$$\% \text{ difference} = \frac{|\text{your value} - \text{accepted value}|}{\text{accepted value}} \times 100$$

2 Practice

2.1 A 1.5 kg aluminium block ($c = 900 \text{ J/kg } ^\circ\text{C}$) rises in temperature by $24 \text{ }^\circ\text{C}$. Calculate the energy transferred to the block. [2]

2.2 6.3 kJ raises the temperature of 0.25 kg of oil by $15 \text{ }^\circ\text{C}$. Calculate the specific heat capacity of the oil. [3]

2.3 A student's value for the specific heat capacity of water is $4410 \text{ J/kg } ^\circ\text{C}$. The accepted value is $4200 \text{ J/kg } ^\circ\text{C}$. Calculate the percentage difference between the two values. [2]

3 Exam-style questions

3.1 A heater of power 36 W runs for 8.0 minutes inside a 1.2 kg copper block ($c = 385 \text{ J/kg } ^\circ\text{C}$). The block's temperature rises from $21 \text{ }^\circ\text{C}$ to $37 \text{ }^\circ\text{C}$.

(a) Calculate the energy supplied by the heater. [3]

(b) Calculate the energy that actually raised the block's thermal store. [2]

(c) Use your answers to explain one way energy has been dissipated. [1]

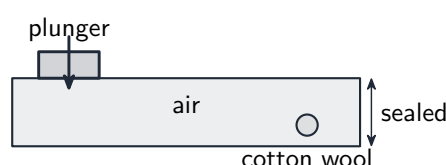
3.2 A student determines the specific heat capacity of water using an immersion heater, a joulemeter and a thermometer in an insulated beaker.

(a) Describe a method the student could use. Your answer should include how the results are used to determine c . [6]

(b) Give one hazard in this investigation and how it is controlled. [1]

(c) Give one change to the apparatus that would reduce energy lost to the surroundings. [1]

3.3 A fire piston compresses air quickly so its temperature rises enough to ignite cotton wool. The energy transferred to the air is 0.0130 J . The mass of air is $2.60 \times 10^{-8} \text{ kg}$ and the specific heat capacity of air is $1.01 \text{ kJ/kg } ^\circ\text{C}$. Calculate the temperature change of the air. [4]



Solutions

2.1 Known: mass, c , temperature change.

$$\Delta E = mc\Delta\theta = 1.5 \text{ kg} \times 900 \text{ J/kg } ^\circ\text{C} \times 24 ^\circ\text{C} = \mathbf{32\,400 \text{ J}}$$

(substitution 1, answer with unit 1.)

2.2 Convert: 6.3 kJ = 6300 J (C1).

$$c = \frac{\Delta E}{m\Delta\theta} = \frac{6300 \text{ J}}{0.25 \text{ kg} \times 15 ^\circ\text{C}} = \mathbf{1700 \text{ J/kg } ^\circ\text{C}} \text{ (2 s.f.)}$$

(rearrangement 1, answer with unit 1.)

2.3

$$\% \text{ difference} = \frac{4410 - 4200}{4200} \times 100 = \mathbf{5.0 \%}$$

(difference over accepted value 1, $\times 100$ with answer 1.)

3.1 (a) Convert time: 8.0 min = 480 s (C1). Energy from power and time.

$$E = Pt = 36 \text{ W} \times 480 \text{ s} = \mathbf{17\,280 \text{ J}}$$

(substitution 1, answer with unit 1.) (b) Use the block's own data.

$$\Delta E = mc\Delta\theta = 1.2 \times 385 \times (37 - 21) = \mathbf{7392 \text{ J}} \approx 7400 \text{ J}$$

(temperature change 1, answer with unit 1.) (c) About $17\,280 - 7400 \approx 9900 \text{ J}$ was transferred elsewhere: to the surroundings by heating, and to the heater itself and the insulation.

3.2 (a) Indicative content – measure the mass of the water with a balance (or measure its volume and use density); put the water in the insulated beaker with the heater and thermometer; record the starting temperature; switch on the heater and record the joulemeter reading and time (or record V and I and use $E = VIt$, or power $\times$ time); stir and record the temperature at regular intervals; switch off and record the highest temperature; calculate $\Delta\theta$; calculate $c = \Delta E / (m\Delta\theta)$; repeat for a mean / plot temperature against energy. Level 3 (5–6): a valid method in logical order with the calculation of c stated and at least one accuracy step (insulation, stirring, lid, repeats). Level 2 (3–4): most steps present but the processing incomplete or sequencing unclear. Level 1 (1–2): isolated relevant steps. (b) Hot water / heater can burn: keep the heater in the water when hot, lid on, allow to cool before handling (any one sensible hazard with control). (c) Insulate the beaker (further) / use a lid / surround with a jacket – any one change.

3.3 Known: energy, mass, c – all in the equation, but c is not in base units.

- Convert: $c = 1.01 \text{ kJ/kg } ^\circ\text{C} = 1010 \text{ J/kg } ^\circ\text{C}$ (C1).

$$\Delta\theta = \frac{\Delta E}{mc} = \frac{0.0130 \text{ J}}{2.60 \times 10^{-8} \text{ kg} \times 1010 \text{ J/kg } ^\circ\text{C}}$$

$$\Delta\theta = \mathbf{495 ^\circ\text{C}}$$

(rearrangement C1, substitution C1, answer A1; more than 3 s.f. allowed, fewer than 3 is not.)