

5.1 Heating, latent heat and thermistor calibration

Name: _____ Class: _____ Date: _____

Total: 30 marks

KEY WORDS Internal energy • Specific heat capacity • Specific latent heat
• thermistor • potential divider

Objective

Develop heating, latent heat and thermistor calibration from the WPH15 specification and mapped 2025 exam demands. These are original training questions. Use the constants stated in each task.

1 Key knowledge and worked examples

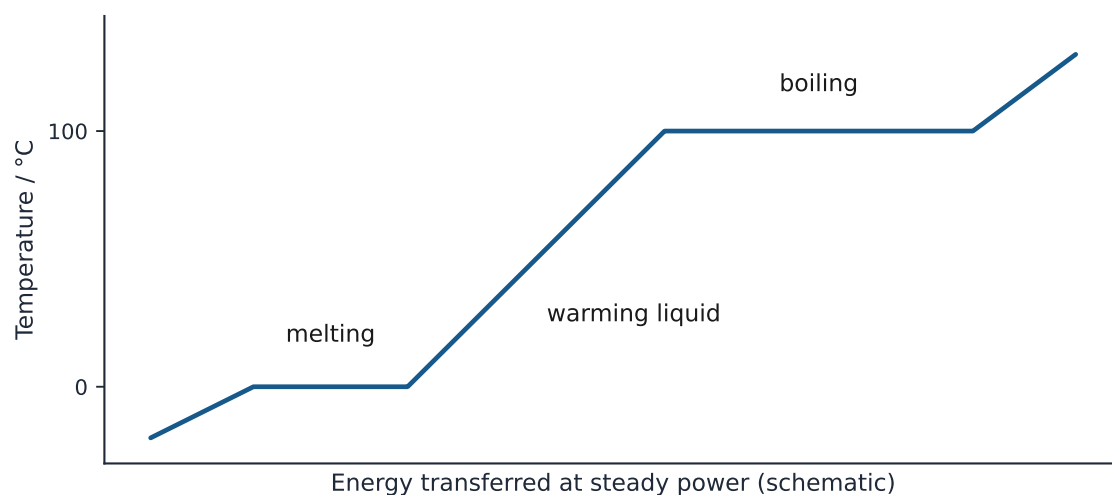
■ Follow the energy, not only the temperature

Internal energy is the total energy in the random motion and interactions of molecules: random kinetic energy plus intermolecular potential energy. It excludes the kinetic energy of the whole object moving together. Temperature relates to average random molecular kinetic energy, not total internal energy. Two samples at the same temperature can have different internal energies because their amounts and states differ.

Specific heat capacity c is the energy needed per kilogram for a one-kelvin temperature rise without a change of state. **Specific latent heat** L is the energy transferred per kilogram during a particular change of state at constant temperature.

$$\Delta E = mc\Delta\theta \quad \Delta E = L\Delta m$$

A temperature difference of 1 °C equals a difference of 1 K. Absolute temperatures in gas and radiation laws must be kelvin. During melting or boiling, energy changes molecular arrangements and potential energy while temperature remains constant in the ideal constant-pressure phase change. An ice pack absorbs energy from the food/surroundings as it melts. It does not send “cold energy” into the food.



At constant heating power, steeper temperature–time gradients mean smaller mc , provided heat loss is negligible. A flat section does not mean that energy transfer has stopped. For a heater, input energy is $E_{\text{in}} = Pt = VIt$; useful thermal energy can be smaller because energy escapes to surroundings.

Worked example. A 0.40 kg block of ice at $-10\text{ }^{\circ}\text{C}$ melts to water at $0\text{ }^{\circ}\text{C}$. Use $c_{\text{ice}} = 2100\text{ J kg}^{-1}\text{ K}^{-1}$ and $L_f = 3.4 \times 10^5\text{ J kg}^{-1}$.

Known: mass, initial/final temperatures and material constants. Why: warming the solid and melting it are separate energy transfers.

$$E_{\text{warm}} = mc\Delta\theta = 0.40\text{ kg} \times 2100\text{ J kg}^{-1}\text{ K}^{-1} \times 10\text{ K} = 8.40 \times 10^3\text{ J}$$

$$E_{\text{melt}} = mL_f = 0.40\text{ kg} \times 3.4 \times 10^5\text{ J kg}^{-1} = 1.36 \times 10^5\text{ J}$$

$$E_{\text{total}} = E_{\text{warm}} + E_{\text{melt}} = (8.40 \times 10^3 + 1.36 \times 10^5)\text{ J} = 1.44 \times 10^5\text{ J}$$

Worked example. A 1000 W heater boils away 0.20 kg of water in 600 s. Find efficiency, using $L_v = 2.26 \times 10^6\text{ J kg}^{-1}$.

$$E_{\text{useful}} = mL_v = 0.20\text{ kg} \times 2.26 \times 10^6\text{ J kg}^{-1} = 4.52 \times 10^5\text{ J}$$

$$E_{\text{input}} = Pt = 1000\text{ W} \times 600\text{ s} = 6.00 \times 10^5\text{ J}$$

$$\eta = \frac{E_{\text{useful}}}{E_{\text{input}}} = \frac{4.52 \times 10^5\text{ J}}{6.00 \times 10^5\text{ J}} = 0.753 \approx 75\%$$

For repeated kettle loads, calculate total water volume, number of loads and total operating time. Compare energies over the same stated interval. Standby loss over a

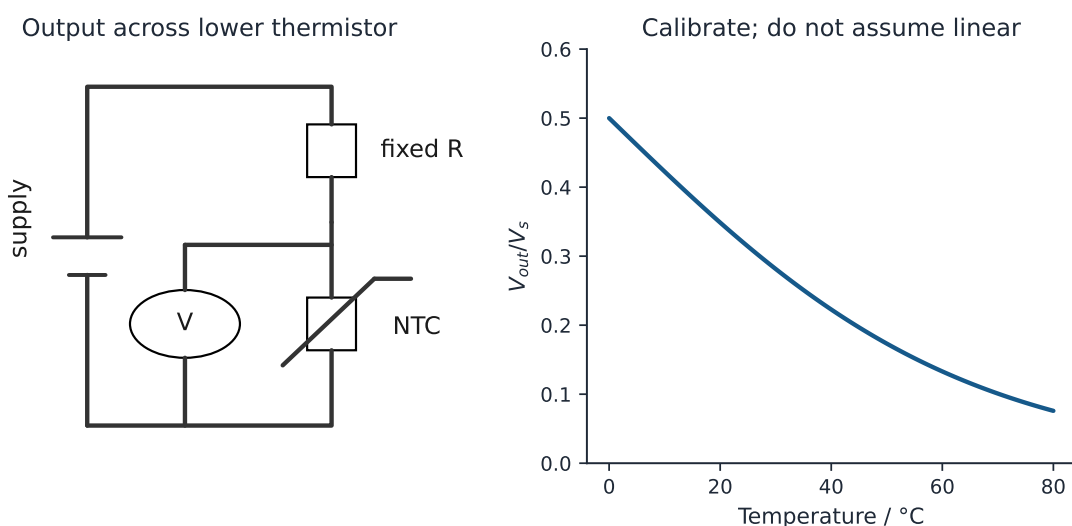
day and input needed to boil water are different quantities; state what a particular comparison actually establishes.

■ CP12: calibrate a thermostat

A **thermistor** has resistance that changes with temperature. The usual negative-temperature-coefficient (NTC) thermistor decreases in resistance when heated. In a **potential divider** :

$$V_{\text{out}} = V_s \frac{R_{\text{lower}}}{R_{\text{upper}} + R_{\text{lower}}}$$

With the thermistor as the lower resistor and output measured across it, warming reduces output voltage. Swapping resistor positions reverses that trend. A thermostat switches at a chosen output threshold; the divider alone is not a complete switching device.



For core practical 12, place the thermistor and a reference thermometer close together in a stirred water bath. Keep electrical contacts dry and insulated. At several temperatures across the intended range, wait for thermal equilibrium and record temperature and divider voltage. Keep supply voltage and fixed resistance unchanged. Use a high-input-resistance voltmeter to reduce loading. Plot output against temperature and interpolate the voltage for the chosen switching temperature. Repeat readings or compare warming/cooling to reveal lag. Do not assume a linear calibration without evidence. Use low-voltage electricity and take care with hot water.

■ CP13: measure latent heat

Supply measured electrical power to a material during its phase change. Measure mass melted or evaporated over a timed interval after conditions stabilise. A balance measures mass change; do not confuse collected liquid volume with mass. Without loss correction, $L = VIt/\Delta m$ assumes all supplied energy causes the phase change.

A useful correction is to compare two powers at the same steady phase-change temperature. If heat-loss power is approximately unchanged, subtracting the two mea-

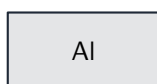
measurements removes it:

$$L = \frac{P_2 - P_1}{\dot{m}_2 - \dot{m}_1}$$

State that constant-loss assumption. A control measurement of melting without the heater is another possible correction in a suitable ice experiment. Reduce heat loss with insulation where safe; avoid splashing, hot surfaces and unsafe mains connections.

2 Practice

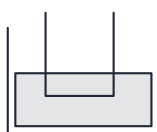
2.1 A 0.25 kg aluminium block warms from 20 to 50 °C. Its specific heat capacity is 900 J kg⁻¹ K⁻¹. Calculate the energy increase. Explain why its temperature is not a measure of its total internal energy. [4]



0.25 kg; 20 to 50 °C

2.2 A heater supplies 24 W for 300 s while ice melts at 0 °C. The mass melted is 0.020 kg. Calculate an uncorrected latent heat and explain how heat loss to surroundings affects it. [4]

24 W; 300 s



ice at 0 °C

[4]

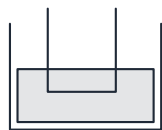
lower NTC

[7]

0.15 kg ice

3.2 In a steady boiling experiment, powers 40 and 60 W give mass-loss rates 1.2×10^{-5} and $2.1 \times 10^{-5} \text{ kg s}^{-1}$. Derive a heat-loss-corrected expression for latent heat, calculate it, and state the assumption enabling subtraction. [5]

40 W / 60 W



steady boiling

3.3 Design a calibration for the thermistor divider of 2.3 to switch a thermostat at 45°C . Include an independent temperature measurement, equilibrium, controls, processing, one loading error and safety. Explain why two end-point readings alone may not be enough. [6]

thermistor

thermometer



Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

2.1 The known mass and temperature rise require sensible heating.

$$\Delta E = mc\Delta\theta = (0.25 \text{ kg})(900 \text{ J kg}^{-1} \text{ K}^{-1})(50 - 20) \text{ K} = 6750 \text{ J}$$

Energy. Temperature relates to average random kinetic energy; total internal energy also depends on amount and intermolecular potential energy/state.

2.2 At constant temperature, use phase-change energy.

$$L = \frac{Pt}{\Delta m} = \frac{(24 \text{ W})(300 \text{ s})}{0.020 \text{ kg}} = 3.6 \times 10^5 \text{ J kg}^{-1}$$

Value. If some heater energy escapes to surroundings, less causes melting; assigning all input to melting overestimates L . This assumes net loss, not extra melting caused by warm surroundings.

2.3 Output is across the lower resistor, so use the divider relation.

$$V_{out,c} = V_s \frac{R_c}{R + R_c} = 6.0 \text{ V} \frac{4.0 \text{ k}\Omega}{(2.0 + 4.0) \text{ k}\Omega} = 4.0 \text{ V}$$

Cold value.

$$V_{out,w} = V_s \frac{R_w}{R + R_w} = 6.0 \text{ V} \frac{1.0 \text{ k}\Omega}{(2.0 + 1.0) \text{ k}\Omega} = 2.0 \text{ V}$$

Warm value. Warming reduces lower resistance and its share of supply voltage.

3.1 Melting and warming the resulting water are separate stores.

$$E_u = mL_f + mc_w\Delta\theta$$

$$E_u = (0.15 \text{ kg})(3.3 \times 10^5 \text{ J kg}^{-1}) + (0.15 \text{ kg})(4200 \text{ J kg}^{-1} \text{ K}^{-1})(20 \text{ K}) = 62100 \text{ J}$$

Useful energy.

$$E_{in} = Pt = (200 \text{ W})(400 \text{ s}) = 80000 \text{ J}$$

Input energy.

$$\eta = \frac{E_u}{E_{in}} = \frac{62100 \text{ J}}{80000 \text{ J}} = 0.776 = 77.6\%$$

Efficiency.

$$P_{loss} = \frac{E_{in} - E_u}{t} = \frac{(80000 - 62100) \text{ J}}{400 \text{ s}} = 44.8 \text{ W}$$

Loss power. Energy during melting changes molecular arrangement/potential energy, without raising average random kinetic energy/temperature during the ideal phase change.

3.2 At either steady power, $P = L\dot{m} + P_{loss}$. Subtract to eliminate the same loss power.

$$L = \frac{P_2 - P_1}{\dot{m}_2 - \dot{m}_1} = \frac{(60 - 40) \text{ W}}{(2.1 - 1.2) \times 10^{-5} \text{ kg s}^{-1}} = 2.22 \times 10^6 \text{ J kg}^{-1}$$

Numerical value and unit. Heat-loss power must be approximately unchanged at the two steady boiling conditions.

3.3 Place an independent thermometer beside the thermistor in a stirred water bath. Record multiple temperatures and outputs, waiting for equilibrium each time. Keep supply and fixed resistance unchanged. Plot a calibration and interpolate output at $45\text{ }^{\circ}\text{C}$; the NTC relation may curve, so end points alone do not establish the switching voltage. Use a high-input-resistance voltmeter to avoid loading. Keep contacts dry/insulated and use low voltage with hot-water precautions.