

Heating and cooling curves mixed calculations

AQA GCSE Combined Science Trilogy 8464 and Separate Physics 8463 | Foundation and Higher | Paper 1

Worked answers | Both qualifications and both tiers | 30 parts | 53 marks

Specification points covered

4.3.1.2 / 6.3.1.2: physical changes of state and conservation of mass

4.3.2.1 / 6.3.2.1: internal energy and particle energy changes

4.3.2.2 / 6.3.2.2: temperature changes and specific heat capacity

4.3.2.3 / 6.3.2.3: latent heat and heating or cooling curves

4.1.1.4 / 6.1.1.4: power; 4.1.2.1 / 6.1.2.1: energy accounting

A mountain rescue station tests a system that turns stored ice into warm water. You will use heating and cooling curves to check the energy budget, then choose insulation to keep the water usable overnight.

Original PhysicsUK practice, not an official AQA resource. Both qualifications and both tiers; one common route. 30 parts, 53 marks. Accept equivalent physics and consistent follow-through. Use the supplied approximate latent heat for the internally consistent model, not a memorised alternative value.

1 Choosing the energy model

A sealed sample contains 300 g of ice at -40°C . Its first stage is warming the ice to 0°C without melting.

1(a) Define the internal energy of the sample. **[1 mark]**

Answer / mark points: The total kinetic energy and potential energy of all the sample's particles. [1]
Both kinds of energy and all particles are required.

1(b) The sealed 300 g sample later melts completely. State the mass of the liquid water. **[1 mark]**

Answer / mark points: 300 g (0.300 kg). [1] Mass is conserved; it is not lost during melting.

1(c) For the first stage from -40°C to 0°C , choose $E = mc\Delta\theta$ or $E = mL$ and justify your choice. **[2 marks]**

Answer / mark points: $E = mc\Delta\theta$. [1]
The temperature changes while the sample remains solid; there is no change of state in this stage.
[1] $E = mL$ is not a formula for warming a solid.



2 Heating the rescue water

Figure 1 shows an idealised test of the 300 g sample. A constant 210 W is transferred to the sample. Ignore energy transferred to the container or surroundings. The sample has a uniform temperature.

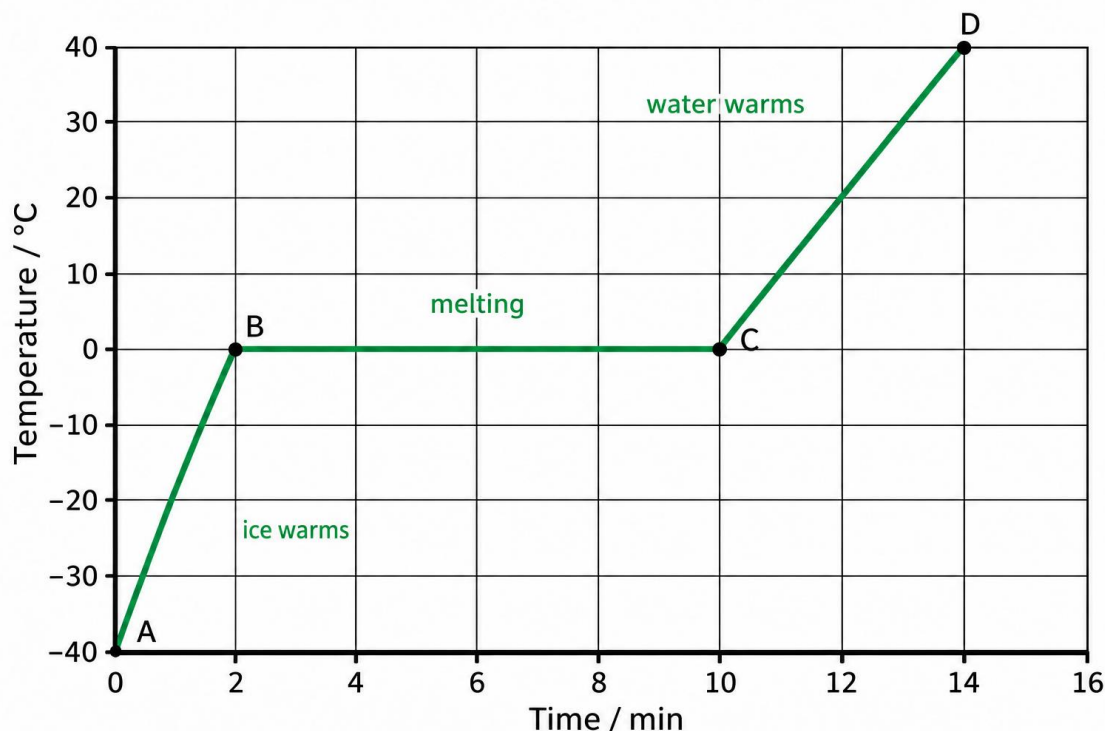


Figure 1

2(a) State what happens to the sample during each section AB, BC and CD. **[3 marks]**

Answer / mark points: AB: the solid ice warms. [1]
 BC: the ice melts; solid and liquid coexist during the plateau. [1]
 CD: the liquid water warms. [1] Do not call CD boiling.

2(b) Read the sample's temperature at 12 minutes. **[1 mark]**

Answer / mark points: 20°C. [1] Read the rising CD section.

2(c) Use the graph to find how long melting takes. Give the duration in minutes and in seconds. **[2 marks]**

Answer / mark points: 10 – 2 = 8 minutes. [1]
 8 × 60 = 480 s. [1] Ten minutes is the finishing time, not the melting duration.

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2 Heating the rescue water continued

Use Figure 1 and the model data on page 1. The sample mass is 0.300 kg.

2(d) Calculate the energy transferred to warm the 300 g of ice from -40°C to 0°C in AB. **[1 mark]**

Answer / mark points: $m = 0.300 \text{ kg}$; $\Delta\theta = 0 - (-40) = 40^{\circ}\text{C}$. $E = 0.300 \times 2100 \times 40 = 25200 \text{ J}$. [1]

2(e) Calculate the energy transferred to melt all the ice during BC. **[1 mark]**

Answer / mark points: $E = mL = 0.300 \times 336000 = 100800 \text{ J}$. [1] Use latent heat, not specific heat capacity.

2(f) Calculate the energy transferred to warm the water from 0°C to 40°C in CD. **[1 mark]**

Answer / mark points: $E = mc\Delta\theta = 0.300 \times 4200 \times 40 = 50400 \text{ J}$. [1]

2(g) Add the three stage energies to find the total energy. Use 210 W to calculate the total heating time in seconds and check it against the graph. **[2 marks]**

Answer / mark points: Total $E = 25200 + 100800 + 50400 = 176400 \text{ J}$. [1]
Time = $E/P = 176400/210 = 840 \text{ s} = 14 \text{ minutes}$, agreeing with D. [1]

2(h) At 6 minutes the heater has been on continuously since A. Calculate the mass of ice that has melted. Show how you account for the energy used to warm the ice first. **[3 marks]**

Answer / mark points: Input $E = 210 \times (6 \times 60) = 75600 \text{ J}$. [1]
Energy for melting = $75600 - 25200 = 50400 \text{ J}$. [1]
Melted mass = $50400/336000 = 0.150 \text{ kg}$ (150 g). [1] The remaining 150 g is ice; both are at 0°C .

2(i) A trainee says that no energy is transferred during BC because the line is horizontal. Explain why this is wrong, using particle energies. **[3 marks]**

Answer / mark points: Energy is still transferred to the sample, so its internal energy increases. [1]
The energy increases particle potential energy as the ice melts. [1]
The average particle kinetic energy does not increase, so the temperature stays constant. [1] Do not say particles stop moving or that the temperature is used up.



3 Planning different batches

These are separate trials. Use each question's stated mass, state and temperature. The same material values apply; ignore the container and surroundings.

3(a) A fresh 600 g batch starts as ice at 0°C. Calculate the total energy needed to melt it completely and then warm the water to 20°C. **[2 marks]**

Answer / mark points: Melting: $0.600 \times 336000 = 201600$ J; warming: $0.600 \times 4200 \times 20 = 50400$ J. [1 for both stage energies]
Total = 252000 J. [1] No below-zero ice-warming stage is needed.

3(b) Calculate the time for that 252000 J transfer if the useful heating power is 210 W. **[1 mark]**

Answer / mark points: $t = E/P = 252000/210 = 1200$ s (20 minutes). [1]

3(c) A different 600 g ice sample at 0°C receives only 168000 J. Calculate the mass melted and state what remains at the end. **[2 marks]**

Answer / mark points: Melted mass = $168000/336000 = 0.500$ kg (500 g). [1]
100 g of ice remains with 500 g of liquid water, all at 0°C. [1] There is not enough energy to melt all 600 g.

3(d) A 300 g portion of liquid water cools from 40°C to 20°C. Calculate the energy it transfers to the surroundings. **[1 mark]**

Answer / mark points: $E = 0.300 \times 4200 \times (40 - 20) = 25200$ J transferred out. [1] Give the positive magnitude of the released energy.

3(e) A separate 200 g portion of water starts at 10°C and gains 25200 J. Calculate its final temperature. It remains liquid. **[2 marks]**

Answer / mark points: $\Delta\theta = E/(mc) = 25200/(0.200 \times 4200) = 30^\circ\text{C}$. [1]
Final temperature = $10 + 30 = 40^\circ\text{C}$. [1] The calculated 30°C is a temperature rise, not the final temperature.



4 Cooling and freezing

Figure 2 is a separate controlled cooling test on 300 g of water initially at 40°C. A cooling unit removes energy FROM THE SAMPLE at a constant 210 W. This is not its electrical input power or a natural cooling curve.

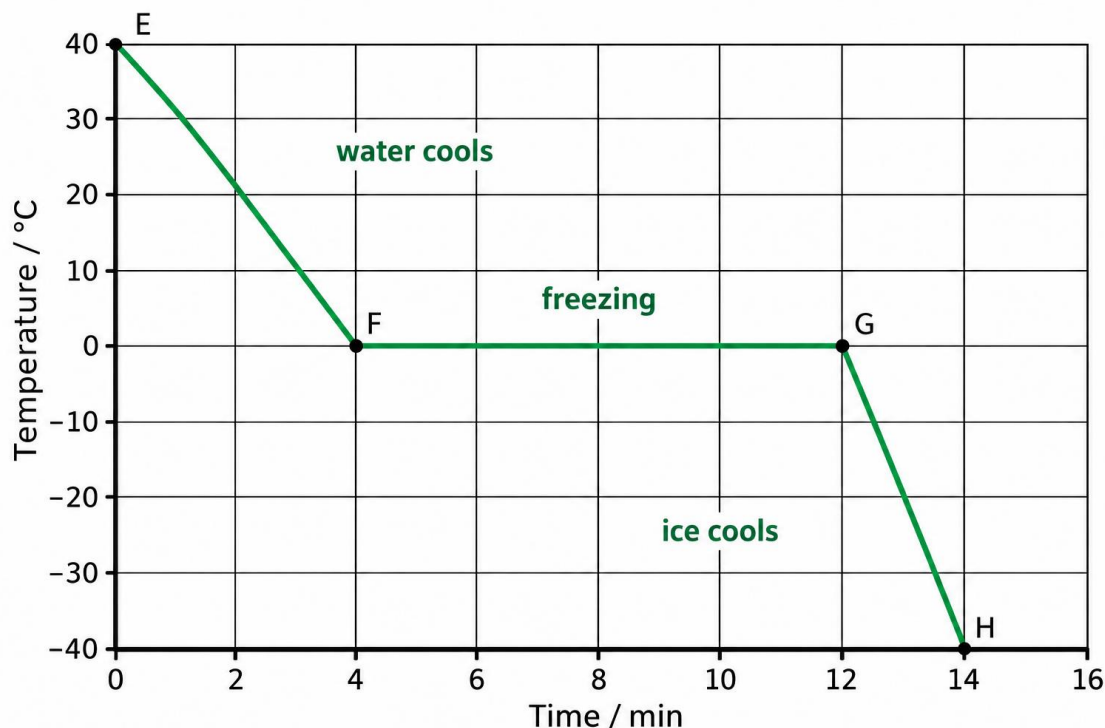


Figure 2

4(a) Read the temperature after 2 minutes of controlled cooling. **[1 mark]**

Answer / mark points: 20°C. [1] The sample is still liquid water.

4(b) Name the change of state during FG and use the graph to find its duration. **[2 marks]**

Answer / mark points: Freezing (liquid to solid). [1]
 12 – 4 = 8 minutes. [1] Do not use the total time from E.

4(c) During FG energy leaves the sample but its temperature stays constant. Explain this in terms of particle potential and kinetic energies. **[2 marks]**

Answer / mark points: Particle potential energy decreases as the water freezes. [1]
 Average particle kinetic energy stays the same, so the temperature stays constant. [1] Energy is released to the surroundings; it does not disappear.

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4 Cooling and freezing continued

Use Figure 2 for (d)–(f), then compare the warming sections of Figure 1 in (g).

4(d) Calculate the energy removed from the 300 g of water as it cools from 40°C to 0°C in EF. **[1 mark]**

Answer / mark points: $E = 0.300 \times 4200 \times 40 = 50400 \text{ J}$. [1]

4(e) Calculate the energy released when all the water freezes in FG. Use the 210 W removal rate to calculate the freezing time in seconds. **[2 marks]**

Answer / mark points: $E = 0.300 \times 336000 = 100800 \text{ J}$. [1]
 $t = 100800/210 = 480 \text{ s}$. [1] It agrees with the 8-minute plateau.

4(f) At 8 minutes on Figure 2, calculate the mass that has frozen since F and state the mass still liquid. **[2 marks]**

Answer / mark points: Freezing has lasted $8 - 4 = 4$ minutes = 240 s. Energy released = $210 \times 240 = 50400 \text{ J}$. Frozen mass = $50400/336000 = 0.150 \text{ kg}$. [1]
 Liquid mass = $0.300 - 0.150 = 0.150 \text{ kg}$. [1] Both phases are at 0°C.

4(g) Return to Figure 1. AB warms by 40°C in 2 minutes; CD warms by 40°C in 4 minutes. Explain the different rates despite the same sample mass and constant 210 W heating power. **[2 marks]**

Answer / mark points: Water has twice the specific heat capacity of ice: 4200 compared with 2100 J kg⁻¹ °C⁻¹. [1]
 It therefore needs twice the energy for the same mass and temperature rise; at the same power the rise takes twice as long. [1] A steeper line alone does not mean more energy per second.

5 Real heating and overnight storage

The real station heater has a constant electrical input power of 250 W. It takes 16 minutes to turn the same 300 g of ice at -40°C into water at 40°C. The sample's required energy gain is 176400 J. No water is lost.

5(a) Calculate the electrical energy supplied by the real 250 W heater in 16 minutes. **[2 marks]**

Answer / mark points: $t = 16 \times 60 = 960 \text{ s}$. [1]
 $E = Pt = 250 \times 960 = 240000 \text{ J}$. [1]



5 Real heating and overnight storage continued

Continue the real test: electrical input 250 W for 16 minutes; the sample gains 176400 J.

5(b) Calculate the difference between the electrical energy supplied and the sample's energy gain. Suggest where this energy is transferred. **[2 marks]**

Answer / mark points: Difference = $240000 - 176400 = 63600$ J. [1]
Energy heats the container and/or is transferred to the surroundings. [1] It is not destroyed.

5(c) Calculate the mean rate of energy transfer into the sample during these 16 minutes. Explain why using 250 W as the sample's heating power would underestimate the time. **[2 marks]**

Answer / mark points: Mean sample power = $176400/960 = 183.75$ W (about 184 W). [1]
Some electrical energy heats the container/surroundings, so the net sample heating power is below 250 W; using 250 W predicts a shorter time. [1]

5(d) For overnight storage, 300 g of water starts at 40°C and must stay at or above 5°C. Calculate the energy it can lose before reaching 5°C. **[1 mark]**

Answer / mark points: $E = 0.300 \times 4200 \times (40 - 5) = 44100$ J. [1]

5(e) Two insulation jackets are tested for 3.0 hours. Their mean energy-loss rates over this period are A: 3.0 W and B: 5.0 W. Calculate the energy lost with each and choose which keeps the water at or above 5°C. Justify your choice. **[3 marks]**

Answer / mark points: 3.0 hours = 10800 s. Jacket A: $E = 3.0 \times 10800 = 32400$ J. [1]
Jacket B: $E = 5.0 \times 10800 = 54000$ J. [1]
Choose A: 32400 J is below the 44100 J allowance; B exceeds it. [1] Rates are supplied period averages.

5(f) For jacket B, a pupil uses $E = mc\Delta\theta$ for all 54000 J and predicts liquid water at -2.9°C. Explain the mistake and state the final temperature and phases for this model. **[2 marks]**

Answer / mark points: Cooling to 0°C releases only 50400 J; the remaining 3600 J is released by freezing some water, not by cooling liquid below 0°C. [1]
The final temperature is 0°C with a mixture of ice and liquid water. [1] Do not continue a single-state $mc\Delta\theta$ calculation through a phase change.

Review and improve

Check that pupils distinguish energy transfer from temperature change, and sample heating power from electrical input power. Timing is estimated and untrials.

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