Exam Practise 7: Heat

Q and A

Q1

Sam pours 550 g of water at 32 °C into a 210-g aluminum can with an initial temperature of 15 °C. Find the final temperature of the system, assuming no heat is exchanged with the surroundings. (You fill in the missing values)

$$Q_w = m_w c_w (T - T_w)$$

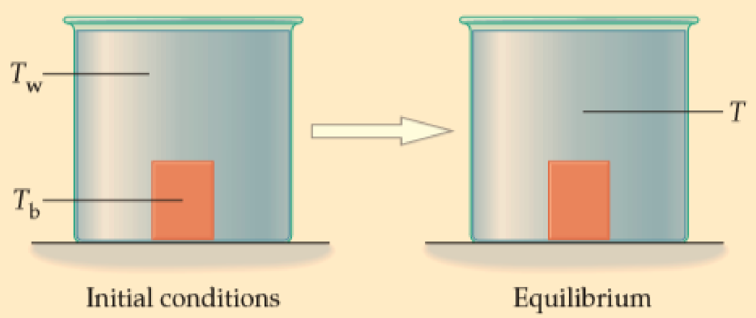
$$Q_a = m_a c_a (T - T_a)$$

$$Q_w + Q_a = 0$$

$$T = 31\ °C$$

Q2

- A 0.50-kg block of metal with an initial temperature of 54.5 °C is dropped into a container holding 1.1 kg of water at 20.0 °C. If the final temperature of the block–water system is 21.4 °C, what is the specific heat of the metal? Assume the container can be ignored, and that no heat is exchanged with the surroundings.



$$Q_{\text{block}} = m_b c_b (T - T_b)$$

$$Q_{\text{water}} = m_w c_w (T - T_w)$$

$$Q_{\text{block}} + Q_{\text{water}} = m_b c_b (T - T_b) + m_w c_w (T - T_w) = 0$$

$$c_b = \frac{m_w c_w (T - T_w)}{m_b (T_b - T)}$$

$$c_b = \frac{(1.1\ \text{kg})[4186\ \text{J}/(\text{kg}\cdot\text{K})](21.4\ °\text{C} - 20.0\ °\text{C})}{(0.50\ \text{kg})(54.5\ °\text{C} - 21.4\ °\text{C})}$$

$$= 390\ \text{J}/(\text{kg}\cdot\text{K})$$

Q3

- A hot water tank contains 135 L of water. Initially the water is at 20°C. Calculate the amount of energy that must be transferred to the water to raise the temperature to 70°C.

- 1 L of water = 1 kg
- Volume = 135 L so mass of water = 135 kg
- ΔT = final temperature − initial temperature
- $\Delta T = 70 - 20 = 50°C$
- From the table of specific heat capacities on page 10, cwater = 4200 J kg−1 K−1. Use the equation $Q = mc\Delta T$.
- $Q = mc\Delta T = 135 \times 4200 \times 50 = 28\,350\,000$ J = 28 MJ

Q4

- How much energy must be removed from 2.5 L of water at 0°C to produce a block of ice at 0°C? Express your answer in kJ.

- Calculate the mass of water involved.
- 1 L of water = 1 kg, so 2.5 L = 2.5 kg
- Find the latent heat of fusion for water.
- Lfusion = 3.34 × 105 J kg−1
- Use the equation Q = mLfusion.
- Q = mLfusion = 2.5 × 3.34 × 105 = 8.35 × 105 J Convert to kJ. Q = 8.35 × 102 kJ

Q5

- 50 mL of water is heated from a room temperature of 20˚C to its boiling point at 100˚C. It is boiled at this temperature until it is completely evaporated. How much energy in total was required to raise the temperature and boil the water?

- 50 mL of water = 0.05 kg
- Find the specific heat capacity of water c = 4200 J kg−1 K−1
- Q = mcΔT to calculate the heat energy required to change the temperature of water from 20˚C to 100˚C.
- $Q = mc\Delta T = 0.05 \times 4200 \times (100 - 20) = 16\,800$ J
- Find the specific latent heat of vaporisation of water.
- Lvapour = 22.5 × 105 J kg−1
- Use the equation Q = mLvapour to calculate the latent heat required to boil water.
- Q = mLvapour = 0.05 × 22.5 × 105 = 112 500 J
- Total Q = 16 800 + 112 500 = 129 300 J (or 1.29 × 105 J)

Q6

(a) Lead has a specific heat capacity of 130 J kg^{-1} K^{-1}. Explain what is meant by this statement.

It takes 130 J of energy to raise the temperature of a mass of 1 kg of lead by 1 K , without changing its state.
[1 mark]

(b) Lead of mass 0.75 kg is heated from 21 ºC to its melting point and continues to be heated until it has all melted.

Calculate how much energy is supplied to the lead.
melting point of lead = 327.5 ºC
specific latent heat of fusion of lead = 23 000 J kg^{-1}

$Q = mc\Delta T + ml$
$Q = 0.75 \times 130 \times (327.5 - 21) + 0.75 \times 23000$
$Q = 29884 + 17250$
$Q = 47134$
$Q = 4.7 \times 10^{4}$ J

Q7

- A bicycle and its rider have a total mass of 95 kg. The bicycle is travelling along a horizontal road at a constant speed of $8.0 ms^{-1}$.
- (a) Calculate the kinetic energy of the bicycle and rider.
- $E_k = ½mv^2$
- $E_k = ½ \times 95 \times 8.02$
- $E_k = 3040$ J
- (b) The brakes are applied until the bicycle and rider come to rest. During braking, 60% of the kinetic energy of the bicycle and rider is converted to thermal energy in the brake blocks. The brake blocks have a total mass of 0.12 kg and the material from which they are made has a specific heat capacity of $1200 \text{ J kg}^{-1} \text{ K}^{-1}$.
- (i) Calculate the maximum rise in temperature of the brake blocks.
- 60% of the KE = 0.60 x 3040 = 1824 (J)
- $\Delta Q = mc\Delta T$
- $1824 = 0.12 \times 1200 \times \Delta T$
- $\Delta T = 13$ K (12.7 K)
- (ii) State an assumption you have made in part (b)(i).
- No heat is lost to the surroundings

Q8

Calculate the quantity of heat energy required to raise the temperature of a mass of 810 g of aluminium from 20 °C to 75 °C. The specific heat capacity of aluminium is 910 J kg^{-1} K^{-1}.

$$\text{Heat energy required} = m \times c \times \Delta T$$
$$= \frac{810}{1000} \times 910 \times (75 - 20)$$
$$= \mathbf{4.1 \times 10^4\ J}$$

Q9

A mass of 0.30 kg of water at 95 °C is mixed with 0.50 kg of water at 20 °C. Calculate the final temperature of the water, given that the specific heat capacity of water is 4200 J kg^{-1} K^{-1}.

heat energy lost by hot water = heat energy gained by cold water

$$(m \times c \times \Delta T_1) = (M \times c \times \Delta T_2)$$

$$0.30 \times 4200 \times (95 - T) = 0.50 \times 4200 \times (T - 20)$$

where θ is the final temperature of the water.

$$1260 \times (95 - \Delta T) = 2100 \times (\Delta T - 20)$$

$$119700 - 1260\,T = 2100\,T - 42000$$

$$161700 = 3360\,T$$

$$\theta = \mathbf{48\,°C}$$

Q10

A mass of 12 g of ice at 0 °C is placed in a drink of mass 210 g at 25 °C. Calculate the final temperature of the drink, given that the specific latent heat of fusion of ice is 334 kJ kg^{-1} and that the specific heat capacity of water and the drink is 4.2 kJ kg^{-1} K^{-1}.

energy lost by drink = energy gained by melting ice + energy gained by ice water

$$(m \times c \times \Delta T_1) = (M \times L_f) + (M \times c \times \Delta T_2)$$

$$M \times c \times \Delta T_2 = \frac{12}{1000} \times 4.2 \times 1000 \times (T - 0)$$

$$= 50.4T$$

$$\frac{210}{1000} \times 4.2 \times 1000 \times (25 - T) = \frac{12}{1000} \times 334 \times 1000 + 50.4T$$

where T is the final temperature of the drink. Simplifying,

$$22050 - 882T = 4008 + 50.4T$$

$$18\,042 = 932.4T$$

$$\mathbf{T = 19\,°C}$$

Q11

A hot water tank contains 135 litres of water. The water is initially at 20°C.

a Calculate the amount of energy that must be transferred to the water to raise the temperature to 70°C.

b Calculate the time this will take when a 5 kW electric water heater is used.

a Volume = 135 litres; hence, mass = 135 kg

$\Delta T = 70° - 20° = 50°C$

and from Table 6.2, $c = 4200\ \mathrm{J\,kg^{-1}\,K^{-1}}$ for water.

$\Delta Q = cm\,\Delta T$

$\Delta Q = 4200 \times 135 \times 50$

$\Delta Q = 28\,350\,000$ joule = 28 MJ

b Recall that power (P) = energy/time.

Rearranging: time = E/P

$$= \frac{28\,350\,000}{5000}$$

= 5670 seconds = 94.5 minutes

Q12

The hot water tap of a bath delivers water at 80°C. Ten litres of hot water is added to a bath containing 30 litres of water at 20°C. Ignoring energy losses to the surrounding environment, what will be the final temperature of the bath water?

Heat energy gained by the cold water = heat energy lost by the hot water.
In terms of the final temperature of the mixture:

$$cm(80 - T) = cm(T - 20)$$

Note that the specific heat of water will cancel out as it appears on both sides of the equation.

So, $10(80 - T) = 30(T - 20)$

Expanding: $800 - 10T = 30T - 600$

Rearranging: $800 + 600 = 30T + 10T$

and $1400 = 40T$

Hence $T = 35°\text{C}$

Q13

50 grams of iron is heated over a flame for several minutes. It is then plunged into a closed container containing 1.0 litre of cool water, originally at 15°C. After the temperatures equalise, the water is now found to be at 17°C. If no water changed state to become steam and there were no losses to the surrounding environment, what was the temperature of the iron just prior to being immersed in the water?

Mass of iron = 50 g = 0.050 kg, mass of water = 1.0 kg

From Table 6.2, c for iron = 440 J kg^{-1} K^{-1}, c for water = 4200 J kg^{-1} K^{-1}.

Energy lost by iron = energy gained by water

$$cm\,\Delta T = cm\,\Delta T$$

$$440 \times 0.05 \times (T - 17) = 4200 \times 1 \times (17 - 15)$$

$$22T - 374 = 8400$$

$$22T = 8774$$

and $$T = \frac{8774}{22} = 399°\text{C} \ (\sim 400°\text{C}).$$

Q14

How much energy has to be removed from 2.5 kg of water at 10°C to produce a block of ice at 0°C? Express your answer in kilojoules.

$m = 2.5$ kg and, from Table 6.3, $L_f = 3.34 \times 10^5$ J kg^{-1}, $c = 4200$ J kg^{-1} K^{-1}.

Cooling the water to 0°C:

$$\Delta Q = cm\,\Delta T$$

$$\Delta Q = 4200 \times 2.5 \times 10 = 105\,000 \text{ J} = 105 \text{ kJ}$$

Freezing the water at 0°C to create ice at 0°C:

$$\Delta Q = m \times L_f$$

$$\Delta Q = 2.5 \times 3.34 \times 10^5 = 835\,000 \text{ J} = 835 \text{ kJ}$$

Total energy required = 105 kJ + 835 kJ = 940 kJ

Q15

Calculate the heat required to convert 5 kg of ice at −20°C into steam at 100°C.

a Warming of ice from −20°C to 0°C: specific heat
$\Delta T = 20°C$, $c = 2100\ J\ kg^{-1}\ K^{-1}$ for ice
$\Delta Q = cm\ \Delta T$
$\Delta Q = 2100 \times 5 \times 20$
$= 2.1 \times 10^5\ J = 0.21\ MJ$

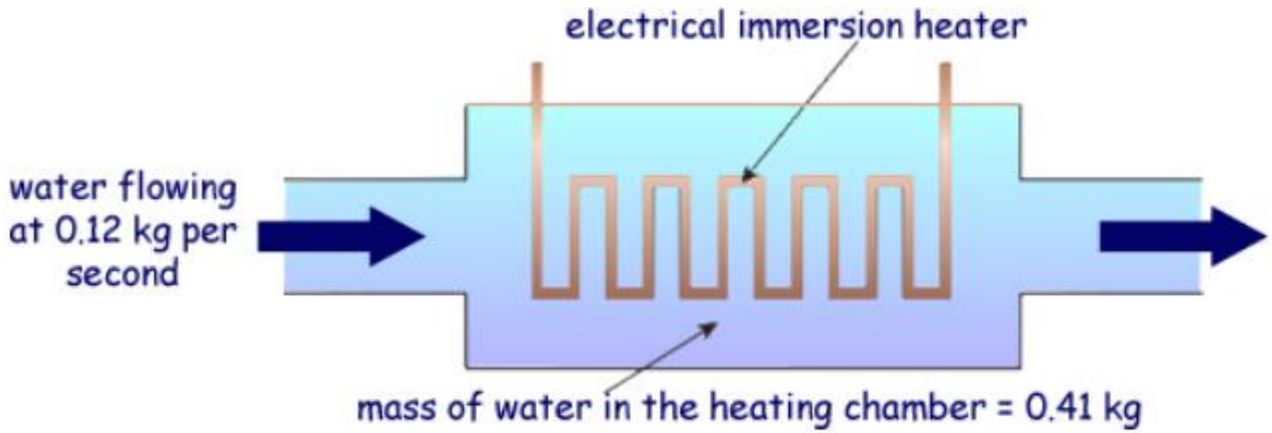
b Melting the ice: latent heat of fusion
$\Delta Q = mL_f$, $L_f = 3.34 \times 10^5\ J\ kg^{-1}$ for ice
$\Delta Q = 3.34 \times 10^5 \times 5$
$= 1.67 \times 10^6\ J = 1.67\ MJ$

c Warming the water from 0°C to 100°C: specific heat
$\Delta T = 100°C$, $c = 4200\ J\ kg^{-1}\ K^{-1}$ for water
$\Delta Q = cm\ \Delta T$
$\Delta Q = 4200 \times 5 \times 100$
$= 2.1 \times 10^6\ J = 2.1\ MJ$

d Evaporating the water: latent heat of vaporisation
$\Delta Q = mL_v$, $L_v = 22.5 \times 10^5\ J\ kg^{-1}$ for water
$\Delta Q = 22.5 \times 105 \times 5$
$= 11.25 \times 10^6\ J = 11.25\ MJ$

Q16

- An electrical immersion heater supplies 8.5 kJ of energy every second. Water flows through the heater at a rate of 0.12 kg s^{-1} as shown in the diagram.



- (a) Assuming all the energy is transferred to the water, calculate the rise in temperature of the water (in kelvin) as it flows through the heater, given that the specific heat capacity of water = 4200 J $kg^{-1}K^{-1}$
- Q = mc
- therefore = Q/mc
- in one second:
- = 8500/(0.12 x 4200) = 16.9 K
- = 17 K
- Here we are assuming that the heat energy goes to the water that flows through the heater - common mistake is to use 0.41 kg instead of the 0.12kg

Q16 continued

- (b) The water suddenly stops flowing at the instant when its average temperature is 26° C. The mass of water trapped in the heater is 0.41 kg. Calculate the number of seconds it takes for the water to reach 100° C if the immersion heater continues supplying energy at the same rate.
- = (100 - 26) = 74° C. = 74K
- Q = mc = 0.41 x 4200 x 74 J
- The heater supplies energy at 8500 J/s
- Therefore time = 0.41 x 4200 x 74/8500 = 15 seconds

Q17

- The specific latent heat of vaporisation of water is 2.26 MJ kg−1. Calculate the energy needed to change 2.0 g of water into steam at 100 °C.

- m = 2.0 g = 0.002 kg and L = 2.26 MJ kg−1

- E = mL

$$\text{energy} = 0.002 \times 2.26 \times 10^6 = 4520\ \text{J}$$

Q18

- A tray containing 0.20 kg of water at 20 °C is placed in a freezer.
- (a) The temperature of the water drops to 0 °C in 10 minutes.
- *(specific heat capacity of water = 4200 J kg $^{-1}$ K $^{-1}$)*

- Calculate:
- (i) the energy lost by the water as it cools to 0 °C,
- $\Delta Q = mc\Delta\theta$
- energy lost by water = $0.20 \times 4200 \times 20$
- $= 1.7 \times 10^4$ J [1.68×10^4 J]

- (ii) the average rate at which the water is losing energy, in J s^{-1}.
- rate of loss of energy = $(1.68 \times 10^4)/(10 \times 60) = 28$W

Q18 continued

- (b)
- (i) Estimate the time taken for the water at 0 °C to turn completely into ice.
- *(specific latent heat of fusion of water = 3.3×10^{5} J kg^{-1})*
- $\Delta Q = ml = Pt$
- $28 \times t = 0.20 \times 3.3 \times 10^5$
- $t = 2.4 \times 10^3$ s (2.36×10^3 s)

- (ii) State any assumptions you make.
- That there is a constant rate of heat loss
- That the ice remains at 0°C

Q19

- (a) A 2.0kW heater is used to heat a room from 5 °C to 20 °C. The mass of air in the room is 30 kg. Under these conditions the specific heat capacity of air = 1000 J $kg^{-1}K^{-1}$.
- Calculate
- (i) the gain in thermal energy of the air,
- $\Delta Q = mc\Delta T$
- $\Delta Q = 30 \times 1000 \times 15$
- $\Delta Q = 4.5 \times 10^5 J$
- (ii) the minimum time required to heat the room.
- P × t = 4.5 x 105
- t = 45 x 105/2000 = 225 s
- (b) State and explain one reason why the actual time taken to heat the room is longer than the value calculated in part (a)(ii).
- Heat is lost to surroundings or other objects in room or to heater itself therefore more (thermal) energy is required from heater [or because convection currents cause uneven heating or rate of heat transfer decreases as temperature increases]

Q20

- (a) Calculate the energy released when 1.5 kg of water at 18 °C cools to 0 °C and then freezes to form ice, also at 0 °C.
- *specific heat capacity of water = 4200 J kg^{-1} K^{-1}*
- *specific latent heat of fusion of ice = 3.4 × 10^{5} J kg^{-1}*
- (4 marks)
- **Water cooling to zero**
- $\Delta Q = mc\Delta\theta$
- $\Delta Q_1 = 1.5 \times 4200 \times 18$
- $\Delta Q_1 = 1.1 \times 10^5$ (J)
- **Ice forming**
- $\Delta Q_2 = 1.5 \times 3.4 \times 10^5 = 5.1 \times 10^5$ (J)
- ---------------------------
- total energy released = $1.1 \times 10^5 + 5.1 \times 10^5$
- total energy released = 6.2×10^5 J

Q20 continued

- (b) Explain why it is more effective to cool cans of drinks by placing them in a bucket full of melting ice rather than in a bucket of water at an initial temperature of 0 °C.

- Ice requires an input of latent heat energy to melt. The ice therefore takes this energy from the drink until it has all melted. This cools the cans before a heat exchange between the drink and melted ice begins. Water at 0 ºC would exchange heat with the cans but only cool them to an intermediate temperature - the ice would cool them to almost zero degrees.

Q21

- 4.00 kg of water initially at 85.0°C is mixed with 3.00 kg of water initially at 25.0°C. What is the final temperature of the water once thermal equilibrium is reached?

$$\Delta Q_{\text{hot}} = \Delta Q_{\text{cold}}$$
$$m_{\text{hot}} c \Delta T_{\text{hot}} = m_{\text{cold}} c \Delta T_{\text{cold}}$$

$$m_{\text{hot}} \Delta T_{\text{hot}} = m_{\text{cold}} \Delta T_{\text{cold}}$$

$$4.00 \times (85.0 - T) = 3.00 \times (T - 25.0)$$
$$340 - 4.00T = 3.00T - 75.0$$
$$340 + 75.0 = 3.00T + 4.00T$$
$$415 = 7.00T$$
$$T = \frac{415}{7.00}$$
$$T = 59.3^{\circ}\text{C}$$

Q22

- A 75.0 g piece of copper is heated over a flame for several minutes. The copper is then plunged into an insulated, closed container containing 0.500 L of cool water, originally at 20.0°C. When thermal equilibrium is reached, the temperature of the water is found to be 22.0°C. If no water changes state to become steam and there are no other energy losses, then what was the temperature of the copper just before it was immersed in the water?
- Mass of copper = 75.0 g = 0.0750 kg $c_{copper} = 390\ \mathrm{J\,kg^{-1}\,K^{-1}}$

  Mass of water = 0.500 kg (1.00 L of water = 1.00 kg) $c_{water} = 4180\ \mathrm{J\,kg^{-1}\,K^{-1}}$

$$\Delta Q_{copper} = \Delta Q_{water}$$
$$m_c c_c \Delta T_c = m_w c_w \Delta T_w$$

$$m_c c_c \Delta T_c = m_w c_w \Delta T_w$$
$$0.0750 \times 390 \times (T_c - 22.0) = 0.500 \times 4180 \times (22.0 - 20.0)$$
$$29.25T_c - 643.5 = 4180$$
$$29.25T_c = 4823.5$$
$$T_{copper} = \frac{4823.5}{29.25}$$
$$T_{copper} = 165^\circ\mathrm{C}$$

Q23

- Calculate the heat energy that must be lost, in J, to convert 5.00 kg of water vapour at 140.0°C into solid ice at 0.00°C.

Step 1: Steam at 140.0°C to steam at 100.0°C
Step 2: Steam at 100.0°C to water at 100.0°C
Step 3: Water at 100.0°C to water at 0.00°C
Step 4: Water at 0.00°C to ice at 0.00°C

$$c_{\text{steam}} = 2000\ \text{J kg}^{-1}\,\text{K}^{-1}$$
$$c_{\text{water}} = 4180\ \text{J kg}^{-1}\,\text{K}^{-1}$$
$$L_{\text{fusion}} = 3.34 \times 10^5\ \text{J kg}^{-1}$$
$$L_{\text{vapour}} = 22.5 \times 10^5\ \text{J kg}^{-1}$$

Step 1: Cooling the steam

$$\begin{aligned} Q_1 &= mc\Delta T \\ &= 5.00 \times 2000 \times 40.0 \\ &= 4.00 \times 10^5\ \text{J} \end{aligned}$$

Step 2: Condensing the steam

$$\begin{aligned} Q_2 &= mL_{\text{vapour}} \\ &= 5.00 \times 22.5 \times 10^5 \\ &= 1.125 \times 10^7\ \text{J} \end{aligned}$$

Step 3: Cooling the water

$$\begin{aligned} Q_3 &= mc\Delta T \\ &= 5.00 \times 4180 \times 100.0 \\ &= 2.09 \times 10^6\ \text{J} \end{aligned}$$

Step 4: Freezing the water

$$\begin{aligned} Q_4 &= mL_{\text{fusion}} \\ &= 5.00 \times 3.34 \times 10^5 \\ &= 1.67 \times 10^6\ \text{J} \end{aligned}$$

$$\begin{aligned} Q_T &= Q_1 + Q_2 + Q_3 + Q_4 \\ &= (4.00 \times 10^5) + (1.125 \times 10^7) + (2.09 \times 10^6) + (1.67 \times 10^6) \\ &= 1.54 \times 10^7\ \text{J} \end{aligned}$$