Set 4 Heat

Q1

Calculate how much heat:
[a] 28.6 kg of ice at 0.00 °C absorbs while it melts completely;
[b] 423 g of steam at 100.0 °C releases when it condenses to water at the same temperature;
[c] 4.58 g of silver absorbs as it boils.

(a)	$Q = m\,L_f = 28.6\text{ kg} \times 3.34 \times 10^5\text{ J kg}^{-1} = 9.55\text{ MJ}$
(b)	$Q = m\,L_v = 0.423\text{ kg} \times 2.26 \times 10^6\text{ J kg}^{-1} = 956\text{ kJ}$
(c)	$Q = m\,L_v = 0.00458\text{ kg} \times 2.35 \times 10^6\text{ J kg}^{-1} = 10.8\text{ kJ}$

Q2

Metallurgists sometimes refine pure cadmium metal by boiling the metal to a gas and then condensing it back to the liquid. A metallurgist measures that 208 g of cadmium releases 1.85×10^4 J of heat when it condenses at its boiling point. Calculate the latent heat of vaporisation of cadmium.

$$L_v = \frac{Q}{m} = \frac{1.85 \times 10^4 \text{ J}}{0.208 \text{ kg}} = 8.89 \times 10^4 \text{ J kg}^{-1}$$

Q3

A technician freezes some ethanol by removing 9.53×10^4 J of heat energy from it at its melting point. What mass of ethanol is she freezing?

$$m = \frac{Q}{L_f} = \frac{9.53 \times 10^4 \text{ J}}{1.05 \times 10^5 \text{ J kg}^{-1}} = 0.908 \text{ kg or } 908 \text{ g}$$

Q4

In different parts of a car air conditioner, a liquid changes to a gas, and a gas changes to a liquid.
[a] Which of these changes causes the cooling?
[b] Describe how the air conditioner removes heat from the car's cabin.

(a)	The latent heat absorbed when a liquid changes to a gas does the cooling.
(b)	The air conditioner actually removes heat from warm air. It then blows the cooled air into the car's cabin and the cooled air removes heat from the interior mainly by conduction. The cooling process involves compressing refrigerant gas, which heats up as it compresses. The hot compressed gas is fan-cooled and it condenses to liquid. The now cool liquid then has the pressure taken off and it partly evaporates. This cools the remaining liquid. Warm air is cooled by the cool refrigerant liquid.

Q5

If you hold your hand in the steam escaping from the spout of a boiling kettle you can receive a severe burn. A splash of water from the same boiling kettle will not burn you as severely. Explain this observation.

If equal masses of water are involved in the two incidents, more heat will be transferred to your hand by the steam because as well as transferring heat by cooling from 100°C, it also releases heat as it condenses on your hand (latent heat of vaporisation).

Q6

Mario has painfully discovered that if he carelessly touches a hot clothes iron he gets a serious burn. He knows that he should test if his iron is hot by tapping its surface gently with a wet finger. Explain why his testing method stops him from getting burnt.

The heat energy from the iron is principally used to vaporise the water rather than to raise the temperature of Mario's finger.

Q7

The instructions for a practical test state you should put two mugs of equal mass, both at room temperature and each with a flat base of equal size, onto a large block of ice. The ice has a temperature of 0 ºC. You must then put the ice and mugs into a thermally insulated box. One mug is made of glass and one of pewter, an alloy of lead and tin.

[a] The mugs will sink into the ice. Explain why.

[b] Give one reason why the glass might sink faster than the pewter.

[c] Give one reason why the pewter might sink faster than the glass.

(a)	The mugs are both warmer than the ice and since heat energy always travels from 'hot to cold', they will transfer energy to their respective blocks of ice. As a result, the ice will absorb this released energy and begin a change of state phase (since it is already at 0 °C) and begin melting.
(b)	As the glass cools from room temperature to 0 °C, it releases heat energy at a greater rate (since it has a higher specific heat capacity) than the pewter and therefore melts the ice more quickly.
(c)	Since pewter is an alloy of lead and tin, two metals and therefore good conductors of heat, this mug would conduct heat through its base at a greater rate than the glass mug. It may therefore sink faster.

Q8

In the Australian Alps, snow often covers the ground in winter. At such times visitors often notice there is no snow on the ground near the edges of large lakes. Explain what would cause this lack of snow.

The lake has a large heat capacity due to the high specific heat capacity of water. This means that it cools down much more slowly than the surrounding earth. Heat energy flows from the relatively warmer lake to melt any nearby snow.

Q9

In hot conditions, a person may, through perspiration, lose up to 4.00 L of water every hour. The latent heat of vaporisation of water at skin temperature (33 ºC) is 2.42×10^6 J kg^{-1}.

[a] If a person evaporates 4.00 L of water through perspiration, how much heat energy does the person lose? Assume the evaporating perspiration does not absorb heat from anywhere else.

[b] By how much would a 55.0 kg girl's temperature rise if the 4.00 L of perspiration did not evaporate from her skin? Assume that her body produces heat at a constant rate and she loses heat in no other way.

(a)	Since 4.00 L of water has mass 4.00 kg: $Q = m L_v = (4\text{ kg})(2.42 \times 10^6\text{ J kg}^{-1}) = 9.68\text{ MJ}$
(b)	$\Delta T = \dfrac{Q}{mc} = \dfrac{9.86 \times 10^6\text{ J}}{(55\text{ kg})(3.5 \times 10^3\text{ J kg}^{-1}\text{ K}^{-1})} = 50.3\,°\text{C}$

Q9 continued

[c] Why does the cooling effect of an electric fan depend on you perspiring?
[d] Explain why swimmers often feel colder when they get out of the water, even if the temperature of the air and the water is the same.

(c)	Air movement over your skin helps to evaporate perspiration from your skin. The latent heat needed for this phase change comes from your body. The combination of evaporation and forced convection cools you down.
(d)	When out of the water, air movement (or movement of the swimmer) results in significant amounts of water being evaporated from the swimmer's skin. The energy to do this is largely drawn from the swimmers body, thus cooling the swimmer.

Q10

In Melbourne, a huge shopping centre was built around an old 'shot tower'. Hot lead globules were poured from the top of the tower and fell into a large pool of water at the foot of the tower. The surface tension of the liquid lead pulled it into the shape having the smallest surface area, a sphere. In this way spherical lead shot was made; hence the name 'shot tower'.

[a] How tall must the tower be to allow 6.00 s of free fall?

[b] If they wanted to make iron ball bearings by the same method and iron melts at 560 ºC, how would the tower design change? State any assumptions you make.

[c] Identify one assumption you made which is probably in error and would result in a different tower height for the iron ball bearing scenario.

Q10 continued

(a)	$s = ut + \frac{1}{2}gt^2$ since u = zero, then: $s = \frac{1}{2}(9.8\ m\ s^{-2})(6\ s)^2 = 176\ m$
(b)	L_f for iron = $2.76 \times 10^5\ J\ kg^{-1}$ and L_f for lead = $2.5 \times 10^4\ J\ kg^{-1}$ So the value for iron is 11 times greater than that of lead, which means that in order for iron to begin the solidification process it must lose 11 times the amount of energy per kilogram. This means that the tower would have to be a lot taller if iron ball bearings were to be made in this way. This assumes that the surrounding air will take away the heat from the bearings and that the iron will lose heat at a steady rate, that the air temperature will be constant and that the air pressure exerted around the ball bearing and the surface tension forces are sufficient to maintain the spherical shape, particularly at the higher altitude. It also assumes that the iron ball bearing will keep accelerating until it hits the ground.
(c)	Since air at higher altitude is likely to be much cooler than air nearer the ground, the rate of loss of heat from the iron ball bearings would probably be greater initially so the tower could perhaps be made a little shorter. This is further reinforced by the fact that since iron has a higher melting point than lead, it does not have to cool down as much to begin solidifying. Finally, and maybe most significantly, since the tower would have to be much taller, the iron bearings would almost certainly reach their terminal velocity well before they hit the pool of water. This means they would take longer to fall through the air which is additional evidence that a smaller tower than that suggested above would do the job.

Q11

Many anglers make fishing sinkers by pouring molten lead into a mould. Max decided to melt 55.0 g of lead and use it to cast a sinker. Calculate:

[a] how much heat the lead released when it cooled from 427 ºC to its freezing point of 327 ºC;

[b] how much heat the lead released as it froze;

[c] how much heat the lead, initially at its freezing point of 327 ºC, released as it cooled to 21.5 ºC;

[d] the total amount of heat released.

(a)	$Q = m\,c_{liquid}\,\Delta T = (0.055\ kg)(105\ J\ kg^{-1}\ K^{-1})(427\ ^{\circ}C - 327\ ^{\circ}C) = 578\ J$
(b)	$Q = m\,L_f = (0.055\ kg)(2.5 \times 10^4\ J\ kg^{-1}) = 1.38\ kJ$
(c)	$Q = m\,c_{solid}\,\Delta T = (0.055\ kg)(130\ J\ kg^{-1}\ K^{-1})(327\ ^{\circ}C - 21.5\ ^{\circ}C) = 2.18\ kJ$
(d)	$Q_{total} = 578\ J + 1380\ J + 2180\ J = 4140\ J$ (or 4.14 kJ)

Q12

An immersion heater can supply heat at the rate of 48.0 J s^{-1}.
[a] How long will it take to heat 12.5 g of water, originally at 26.5 °C, to its boiling point?
[b] How long will it take to boil away 12.5 g of water at its boiling point?
[c] How long can the heater be left on in 12.5 g of water without boiling the container dry?

(a)	Heat needed, $Q = m\,c\,\Delta T = (0.0125\text{ kg})(4180\text{ J kg}^{-1}\text{ K}^{-1})(100\text{ °C} - 26.5\text{ °C}) = 3840\text{ J}$ $\text{time taken } t = \frac{Q}{P} = \frac{3840\text{ J}}{48\text{ J s}^{-1}} = 80\text{ s}$
(b)	Heat needed, $Q = m\,L_v = (0.0125\text{ kg})(2.26 \times 10^6\text{ J kg}^{-1}) = 28.3\text{ kJ}$ $\text{time taken } t = \frac{Q}{P} = \frac{28\,300\text{ J}}{48\text{ J s}^{-1}} = 590\text{ s}$
(c)	total time = 80s + 590s = 670 s (or 11 mins 10 s)

Q13

You are an energy consultant and a client wants to know how well their refrigerator is operating. You put 2.15 kg of water at 21.5 °C into the refrigerator's freezer compartment. You measure that it takes 2.00 h to freeze all that water into ice at its freezing point. Calculate at what rate (in joules per second) the refrigerator is removing heat from the freezer compartment.

(a)	$Q = m\, c_{liquid}\, \Delta T = (0.055\ \text{kg})(105\ \text{J kg}^{-1}\ \text{K}^{-1})(427\ ^{\circ}\text{C} - 327\ ^{\circ}\text{C}) = 578\ \text{J}$
(b)	$Q = m\, L_f = (0.055\ \text{kg})(2.5 \times 10^4\ \text{J kg}^{-1}) = 1.38\ \text{kJ}$
(c)	$Q = m\, c_{solid}\, \Delta T = (0.055\ \text{kg})(130\ \text{J kg}^{-1}\ \text{K}^{-1})(327\ ^{\circ}\text{C} - 21.5\ ^{\circ}\text{C}) = 2.18\ \text{kJ}$
(d)	$Q_{total} = 578\ \text{J} + 1380\ \text{J} + 2180\ \text{J} = 4140\ \text{J}$ (or 4.14 kJ)

Q14

To cook spaghetti, you first boil the water and then add spaghetti to the boiling water. Describe and explain what happens to the boiling water when you add a large amount of spaghetti.

The colder spaghetti will absorb some of the heat energy from the water, thereby decreasing the temperature of the water.

Q15

Steamers are vessels you can use to cook food in. Food in the steamer gains heat as the steam condenses on it. A boiler supplies steam at 105 ºC to a steamer at the rate of 455 g $min^{-1.}$ Calculate the rate (in $J\ s^{-1}$) at which the steam supplies heat to the food if the steam cools, then condenses to water at 100.0 ºC.

Heat supplied per second as steam cools:

$Q = m\ c\ \Delta T = (0.455kg \div 60s) \times 2010 J kg^{-1} K^{-1} \times (105^{\circ}C - 100^{\circ}C) = 76.2\ J\ s^{-1}$

Heat supplied per second as steam condenses:

$Q = m \times L_v = (0.455kg \div 60s) \times 2.26 \times 10^6\ J\ kg^{-1} = 17.14\ kJ\ s^{-1}$

Total heat supplied per second, $P = 76.2 + 17.14 \times 10^3 = 1.72 \times 10^4\ J\ s^{-1}$

Q16

A foundry operator finds that it takes 55.6 MJ of heat to heat a 286 kg mass of an alloy steel from 22.0 ºC to 452 ºC.
[a] Calculate the specific heat capacity of that steel.
[b] If the foundry worker cools the steel by pouring water onto it, the water will heat up to its boiling point, then it will boil. What minimum mass of water, initially at 22.0 ºC, would cool the hot steel down to 100 ºC?
[c] What assumptions have you made in calculating the answer to [b] above?

(a)	$C = Q \div (m \times \Delta T) = 55.6 \times 10^6\ J \div [286kg \times (452\,^{\circ}C - 22\,^{\circ}C)] = 452\ Jkg^{-1}K^{-1}$
(b)	Total heat taken away by water, $Q = m \times C \times \Delta T + m \times L_v$ so, $55.6 \times 10^6\ J = [m \times 4180 \times (100\,^{\circ}C - 22\,^{\circ}C)] + (m \times 2.26 \times 10^6\ J\ kg^{-1})$ gives $m_{min} = 21.5$ kg
(c)	The steel does not lose heat any other way, eg. by radiation, or by heating the air around it.

Q17

Ice blocks of total mass 23.2 g were taken from a freezer at -10 °C and placed in an empty glass.

[a] Calculate the quantity of heat that must be absorbed to convert them to water at 10 °C.

[b] Explain clearly where this heat has come from.

(a)	Heat absorbed to warm ice, $Q = m\,c\,\Delta T = 0.0232\ \text{kg} \times 2100\ \text{J kg}^{-1}\ \text{K}^{-1} \times 10\ ^{\circ}\text{C} = 0.49\ \text{kJ}$ Heat absorbed to melt ice, $Q = m\,L_f = 0.0232\ \text{kg} \times 3.34 \times 10^5\ \text{J kg}^{-1} = 7.75\ \text{kJ}$ Heat absorbed to warm water, $Q = m\,c\,\Delta T = 0.0232\ \text{kg} \times 4180\ \text{J kg}^{-1}\ \text{K}^{-1} \times 10\ ^{\circ}\text{C} = 0.97\ \text{kJ}$ Total amount of heat required = 0.49 kJ + 7.75 kJ + 0.97 kJ = 9.21 kJ
(b)	The energy comes from the surrounding air and the actual glass itself.

Q18

You find you have let a 12.0 kg stainless steel barbecue plate become much too hot for normal cooking. You decide to cool the plate from 395 ºC to 185 ºC by spraying water onto the plate.
[a] Calculate the mass of water at 20.0 ºC you will need, assuming all the water evaporates to steam at 100.0 ºC.
[b] What mass of ice at 0.00 ºC would have the same effect?

(a)

Heat to be removed form the BBQ = m x C x ΔT = 12kg x 445$Jkg^{-1}K^{-1}$ x (395 °C - 185 °C)] = 1.12 M J

so, total heat to taken away by water, Q = 1.12 MJ = m x C x ΔT + m x L_v

so, 1.12 x 10^6 J = [m x 4180 x (100 °C - 20 °C)] + (m x 2.26 x 10^6 J kg^{-1})

gives m = 0.432 kg (or 432 g)

(b)

Total heat to taken away by ice, Q = 1.12 MJ = (m x L_f) + (m x C x ΔT) + (m x L_v)

so, 1.12 x 10^6 J = (m x 3.34 x 10^5 J kg^{-1}) + [m x 4180 x (100 °C - 20 °C)] + (m x 2.26 x 10^6 J kg^{-1})

gives m = 0.383 kg (or 383 g)

Q19

You want to make a cool drink from some 19.7 ºC tap water by adding ice.
Calculate the mass of ice at -11.3 ºC you need to cool 195 g of such tap water in a 215 g glass to a temperature of 3.60 ºC.
Neglect any heat that your drink would gain from its surroundings.

heat lost by water + heat lost by glass = heat gained by ice

heat lost by water + heat lost by glass = $(m_{water} \times C_{water} \times \Delta T_{water}) + (m_{glass} \times C_{glass} \times \Delta T_{glass})$

$= [0.195\text{kg} \times 4180 \times (19.7\,^{\circ}\text{C} - 3.6\,^{\circ}\text{C})] + [0.215\text{kg} \times 670 \times (19.7\,^{\circ}\text{C} - 3.6\,^{\circ}\text{C})] = 15.4\ \text{kJ}$

so, heat gained by ice = 15.4 kJ = $(m_{ice} \times C_{ice} \times \Delta T_{ice}) + (m_{ice} \times L_f) + (m_{ice/water} \times C_{water} \times \Delta T_{water})$

therefore, $15400\ \text{J} = (m_{ice} \times 2100 \times 11.3\,^{\circ}\text{C}) + (m_{ice} \times 3.34 \times 10^{5}\ \text{J kg}^{-1}) + (m_{ice/water} \times 4180 \times 3.6\,^{\circ}\text{C})$

gives $m_{ice} = 0.0414$ kg (or 41.4 g)

Q20

A maintenance worker uses steam to defrost a small freezer that contains 1.50 kg of ice at 0.00 °C. Calculate the mass of dry steam at 100 °C he needs to convert all the ice to water at 24.5 °C. Assume the heat absorbed by the freezer's plastic lining is negligible.

heat lost by steam/water + heat gained by ice/water = 0

$$(m_{steam} \times L_v) + (m_{steam/water} \times c_{water} \times \Delta T_{water}) = (m_{ice} \times L_f) + (m_{water} \times c_{water} \times \Delta T_{water})$$

$$(m_{steam} \times 2.26 \times 10^6 \text{ J kg}^{-1}) + [m_{steam/water} \times 4180 \text{ J kg}^{-1} \text{ K}^{-1} \times (100 \text{ °C} - 24.5 \text{ °C})] =$$

$$(1.5 \text{ kg} \times 3.34 \times 10^5 \text{ J kg}^{-1}) + [1.5 \text{ kg} \times 4180 \text{ J kg}^{-1} \text{ K}^{-1} \times (24.5 \text{ °C} - 0 \text{ °C})]$$

gives m_{steam} = 0.254 kg (or 254 g)