Name: **Index No:**

Date: **Class:**

Assignment 10: Thermal properties of matter

1. A student wants to investigate the relationship between the amount of energy absorbed by water and its subsequent increase in temperature. He observed that a certain amount of water absorbed 10.0 kJ and its temperature increased by 5.0 °C. He then concluded that "the specific heat capacity of water is 2000 J $^{o}C^{-1}$ ". However, he found in a textbook that the correct value for the specific heat capacity of water to be 4200 J kg^{-1} $^{o}C^{-1}$.

   (a) Explain why the student's conclusion is incorrect. [1]

   He did not account for the mass of water in his calculation of the specific heat capacity. [1]

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   (b) State the name of the quantity the student had calculated instead. Give the correct unit for this quantity. [1]

   Heat capacity. J $^{o}C^{-1}$ or J /°C [1]

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   (c) Determine the mass of water the student used, in kg. [1]

   $Q = mc(\Delta\theta)$
   10 000 J = m (4200 J kg^{-1} $^{o}C^{-1}$)(5.0 °C)
   m = <u>0.48 kg</u> (to 2 s.f.) [1]

2. A chef pours 2.00 × 10^2 g of water at a temperature of 15.0 °C into a hot aluminium saucepan with a mass of 2.50 × 10^2 g and a temperature of 120.0 °C.

   Determine the temperature, θ, of the water and the saucepan when thermal equilibrium is reached. Assume no energy is transferred to or from the surroundings.

   Take the specific heat capacity of water = 4 200 J/(kg K) and the specific heat capacity of aluminium = 0.900 kJ/(kg K). [2]

   Q gained by water = Q lost by saucepan

   $m_w c_w (\Delta\theta_w) = m_s c_s (\Delta\theta_s)$
   (0.200 kg) (4200 J/(kg K)) (θ – 15.0 °C) = (0.250 kg) (900 J/(kg K)) (120.0 °C – θ) [1]
   θ = <u>37.2 °C</u> (to 3 s.f.) [1] [accept 37 °C]

   <u>Note:</u>
   Value of θ calculated is in °C, which is consistent with the temperatures given in the question.
   There is no need to convert temperatures in °C to K even though s.h.c. is given in J/(kg K).
   Second mark will not be awarded if 37.2 K is written instead of 37.2 °C.

3. When a lead ball is dropped vertically on a hard surface, it is deformed upon impact.

Assuming all the energy in the kinetic store is transferred to the internal store in the ball upon impact, from what height, h, above the surface, must the ball be dropped to raise its temperature by 1.0 °C?

Take the specific heat capacity of lead = 130 J/(kg K) and the gravitational acceleration, g = 10 m/s². Neglect air resistance. [2]

K.E. of ball just before impact = Q gained to raise its temperature (i.e. increase internal energy)

$\cancel{m}\, g\, (\Delta h) = \cancel{m}\, c\, (\Delta \theta)$

(10 m/s²)(Δh) = (130 J/(kg K))(1.0 °C) [1]

Δh = 13 m (to 2 s.f.) [1]

4. A lead bullet of mass 3.00×10^{-3} kg is fired horizontally from a gun such that it hits a steel plate. The speed of the bullet just before impact is 4.00×10^{2} m s^{-1}. Upon hitting the plate, 18 % of the energy in the kinetic store is transferred to the internal store of the bullet.

If the specific heat capacity of the bullet is 130 J kg^{-1} K^{-1}, calculate the rise in temperature of the bullet immediately after impact. [3]

K.E. = ½ (3.00×10^{-3} kg)(4.00×10^{2} m s^{-1})^2 [1]
= 240 J

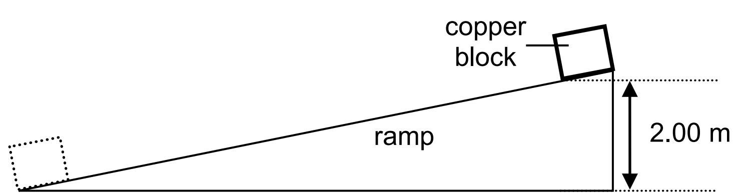
Energy gained upon impact = 18/100 X 240 J [1]
= 43.2 J

$Q = mc(\Delta\theta)$

43.2 J = (3.00×10^{-3} kg)(130 J kg^{-1} K^{-1})($\Delta\theta$)

$\Delta\theta$ = 110 °C (to 2 s.f.) [1] [accept 110 K. Note: use symbol $\Delta\theta$, not θ.]

5. A 1.00 kg copper block is placed at the top of a ramp as shown in the diagram below.



When released from rest, the block slides down the rough ramp and reaches the bottom with a speed of 3.50 m s^{-1}. Take gravitational acceleration, g = 10 m s^{-2}.

(a) Calculate the amount of energy transferred to the internal store of the block-ramp-earth system, due to work done against friction, when the block reaches the bottom of the ramp. [2]

$K.E._{initial} + G.P.E._{initial} = K.E._{final} + G.P.E._{final} + W_{against\ friction}$

0 + (1.00)(10)(2.00) = ½ (1.00)(3.50)² + 0 + $W_{against\ friction}$ [1]

$W_{against\ friction}$ = 13.875
= 13.9 J (to 3 s.f.) [1]

(b) Assume 75 % of the energy calculated in (a) is transferred to the internal store of the block. Determine the specific heat capacity of copper, if the temperature of the block increases by 0.027 °C, [2]

$Q = mc(\Delta\theta)$

0.75 x 13.875 J = (1.00 kg)(c)(0.027 °C) [1]

c = 3.9×10^{2} J kg^{-1} K^{-1} (to 2 s.f.) [1]

(c) Explain the change in the motion of the atoms in the copper block as its temperature increased. [2]

As the block's temperature increased, the **average** kinetic energy of its atoms increased. [1]

The atoms vibrated **more** vigorously about their mean (fixed) positions. [1]

[reject: 'move faster'; use 'energy', not 'thermal energy']

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6. Wet clothes dry faster when they are placed outdoors in the sun on a hot, windy day as compared to when placed indoors without any wind.

(a) Explain, in terms of molecules, how the hot outdoor environment allows the wet clothes to dry faster. [2]

On a hot day, the temperature of water in the wet clothes placed outdoors is higher, thus the **average** kinetic energy of the water molecules increases. [1]

More molecules near surface of wet clothes have sufficient energy to overcome intermolecular forces (attraction) and escape into the air, thus increasing the rate of evaporation of water. [1]

[Intention of question is to explain evaporation, in terms of molecules, thus explanation of 'water evaporates faster' or 'rate of evaporation increases' is rejected.

reject: water molecules evaporate faster; temperature of water molecules increases]

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(b) Explain, in terms of molecules, how the windy outdoor environment allows the wet clothes to dry faster. [2]

On a windy day, (water) vapour molecules formed by evaporation (of water) near surface of wet clothes are carried away at a faster rate. [1]

More molecules escape into air, without colliding into other gaseous molecules (or without bouncing back into water), thus increasing the rate of evaporation of water. [1]

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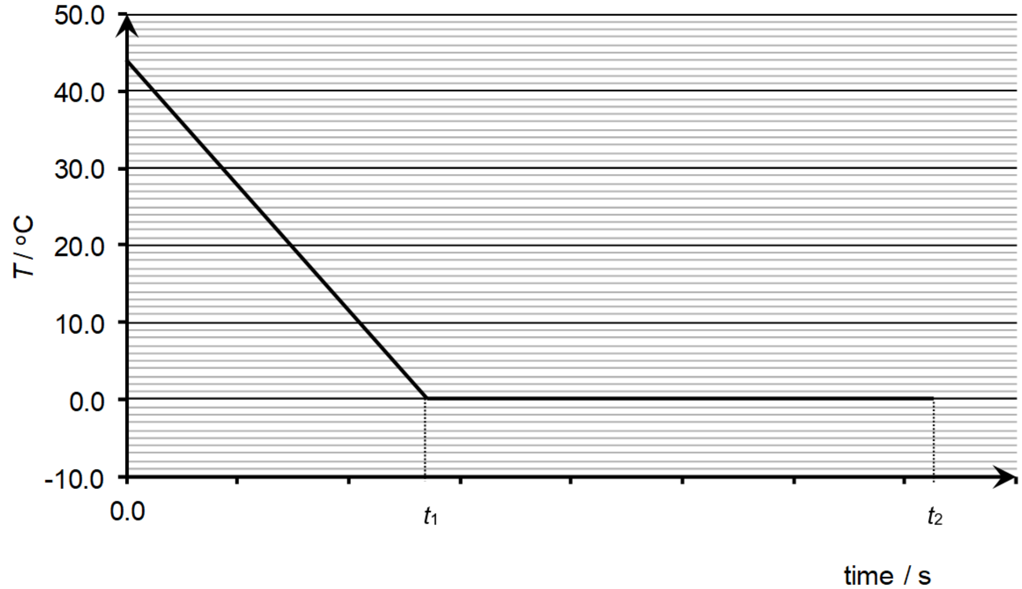
7. The diagram shows a graph of temperature, T, against time for 15.0 g of water when it was placed in a freezer. The water is initially at 44.0 °C.



(a) Calculate the amount of energy removed from the water in t_2 s.

Take the specific heat capacity of water, c_{water} = 4200 J kg^{-1} K^{-1} and the specific latent heat of fusion of ice, l_f = 336 kJ kg^{-1}. Assume the water became entirely frozen in t_2 s. [3]

Q removed to change water temperature from 44.0 °C to 0 °C = $m\,c\,(\Delta\theta)$
= (0.0150 kg)(4200 J kg^{-1} K^{-1})(44.0 °C – 0 °C) [1]
= 2772 J

Q required to change water at 0 °C to ice at 0 °C = $m\,l_f$
= (0.0150 kg)(336 × 10^3 kJ kg^{-1}) [1]
= 5040 J

Total Q removed = 2772 + 5040 = 7812 J
= <u>7800 J</u> (to 2 s.f.) [1][accept: 7810 J]

(b) Given the freezer removed energy at a constant rate of 220 J s^{-1}, determine the value of t_1 and t_2. [3]

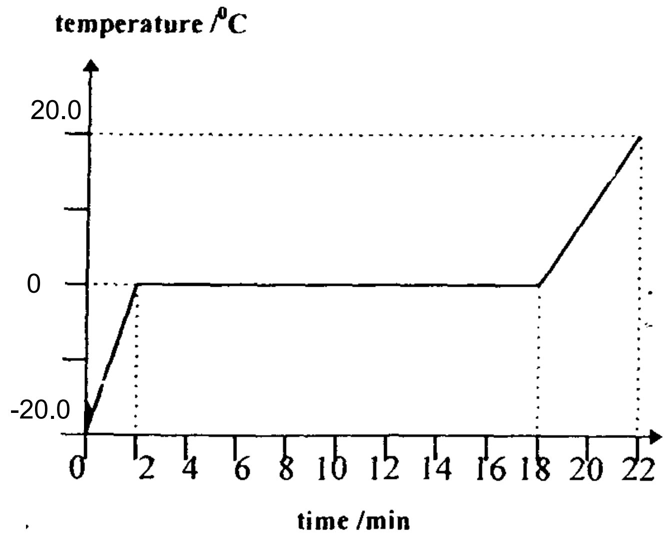
t_1 = 2772 / 220
= 12.6 s = <u>13 s</u> (to 2 s.f.) [1]

$t_2 - t_1$ = 5040 / 220 = 22.909 s [1]

t_2 = 35.5 s = <u>36 s</u> (to 2 s.f.) [1]

t_2 = 7812 / 220 [1]
= 35.5 s
= 36 s (to 2 s.f.) [1]

8. 0.20 kg of ice at -20.0 °C is put in an insulated calorimeter of negligible heat capacity. Energy is supplied at a constant rate by an immersion heater. The temperature is taken at two-minute intervals as shown in the diagram below. Take the specific heat capacity of water = 4200 J/(kg K).



(a) "The *melting point* of pure ice is 0 °C." Define *melting point*. [1]

Melting point is the constant temperature at which pure ice changes from a solid to a liquid. In this case, it is at 0 °C.

[Note: Apply to context where necessary.]

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(b) Calculate the power of the immersion heater. [2]

Q supplied by heater = Q gained by water (Given: calorimeter has negligible heat capacity)

$P\,(\Delta t) = m\,c\,(\Delta\theta)$

$P\,[(22 - 18) \times 60] = (0.20 \text{ kg})(4200 \text{ J/(kg K)})(20.0\ ^{\circ}\text{C})$ [1]

$P = \underline{70 \text{ W}}$ (to 2 s.f.) [1]

(c) Determine the following quantities.
(i) specific heat capacity of ice [2]
(ii) specific latent heat of fusion of ice [2]

(i) Q supplied by heater = Q gained by ice to increase its temperature

$P\,(\Delta t) = m\,c\,(\Delta\theta)$

$(70 \text{ W})\,[(2 - 0) \times 60] = (0.20 \text{ kg})\,(c)\,(0\ ^{\circ}\text{C} - (-20.0\ ^{\circ}\text{C}))$ [1]

$c = \underline{2100 \text{ J/(kg K)}}$ (to 2 s.f.) [1]

(ii) Q supplied by heater = Q gained by ice to melt

$P\,(\Delta t) = m\,l_f$

$(70 \text{ W})\,[(18 - 2) \times 60] = (0.20 \text{ kg})\,l_f$ [1]

$l_f = \underline{340\ 000 \text{ J/kg}}$ (to 2.s.f.) [1]

(d) Explain, in terms of molecules, why the temperature of the ice did not increase between 2 min and 18 min even though energy was supplied. [2]

Energy transferred to the ice increases average intermolecular distance between molecules (does work to overcome intermolecular forces between molecules) and increases their potential energy. [1]

Since the **average** kinetic energy of the molecules remains constant, the temperature of the substance did not increase. [1]

[reject: energy absorbed to break bonds]

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(e) Suggest why the slope of the graph between –20 °C and 0 °C is greater than that between 0 °C and 20 °C. [1]

Ice has a lower specific heat capacity than water. [1]

Since the power of the heater remained constant throughout, to bring about the same temperature increment of 20 °C, the time taken by ice will be half that of water as specific heat capacity of ice (2100 J/(kg K)) is half that of specific heat capacity of water (4200 J/(kg K)).

Mathematically, $P\,(\Delta t) = m\,c\,(\Delta\theta)$ => $P = m\,c\,[(\Delta\theta)/(\Delta t)]$ gradient of graph

Since P and m are constants, a smaller c gives a steeper slope.

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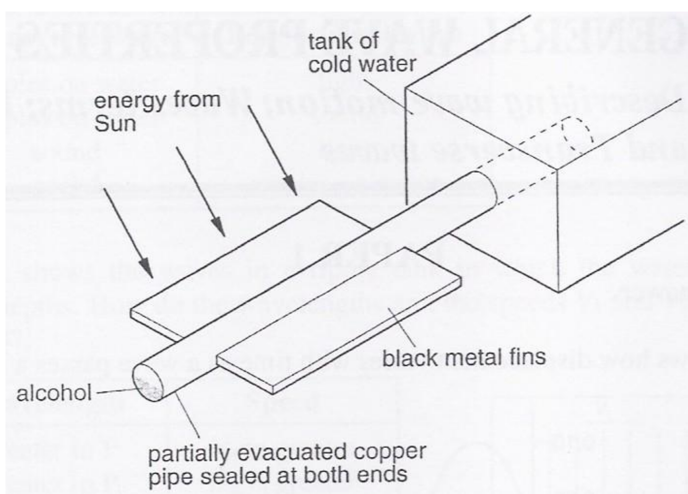
9. The diagram shows parts of a heat pipe. The specific latent heat of vaporisation of alcohol is 840 J g^{-1}.



(a) State what is meant by "The specific latent heat of vaporisation of alcohol is 840 J g^{-1}.". [2]

840 J of energy is required to change a unit mass (or 1 g) of alcohol between its liquid and gaseous states [1] at a constant temperature. [1]

[reject: 840 J per gram or 840 J/g stated in answer]

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(b) In one minute, 25.0 g of alcohol condenses at the end of the heat pipe in the water tank.

Calculate the maximum rise in temperature that this produces in 0.500 kg of cold water.

The specific heat capacity of water is 4.2 J g^{-1} K^{-1}. Neglect any change in the temperature of the alcohol. [2]

Q gained by water = Q released by alcohol when it condenses

$m\,c\,(\Delta\theta) = m\,l_v$

(500 g)(4.2 J g^{-1} K^{-1}) ($\Delta\theta$) = (25.0 g) (840 J g^{-1}) [1]

$\Delta\theta$ = 10 K [1]

10. Some data on the thermal properties of water are shown below.

Specific heat capacity of ice, c_{ice} = 2100 J kg^{-1} K^{-1}
Specific heat capacity of water, c_{water} = 4200 J kg^{-1} K^{-1}
Specific heat capacity of steam, c_{steam} = 2000 J kg^{-1} K^{-1}
Specific latent heat of fusion of ice, l_f = 336 kJ kg^{-1}
Specific latent heat of vaporisation of water, l_v = 2260 kJ kg^{-1}

(a) A student claimed that "a burn caused by 100 g of water at 100 °C is worse than a burn caused by 100 g of steam at 100 °C as the specific heat capacity of steam is lower than the specific heat capacity of water. As such, water can transfer more energy to the skin for 1 °C change in temperature than steam at 100 °C, causing more severe burns."

Comment on the validity of the student's claim. Support your answer with calculations. [2]

Q transferred by 100 g of water for a unit Δ in temperature = (0.100 kg)(4200 J kg^{-1} K^{-1})(1 °C)
= 420 J

Q released by 100 g steam to condense to 100 g water at 100 °C = (0.100 kg)(2260 kJ kg^{-1})
= 226 kJ [1]

Claim is not valid. Steam causes more severe burns as more energy is transferred to the skin (due to latent heat released) when it condenses. [1]

[wrong calculations: (0.100 kg)(2000 J kg^{-1} K^{-1})(1 °C); (0.100 kg)(4200 J kg^{-1} K^{-1})(100 °C);
(0.100 kg)(2000 J kg^{-1} K^{-1})(100 °C)]

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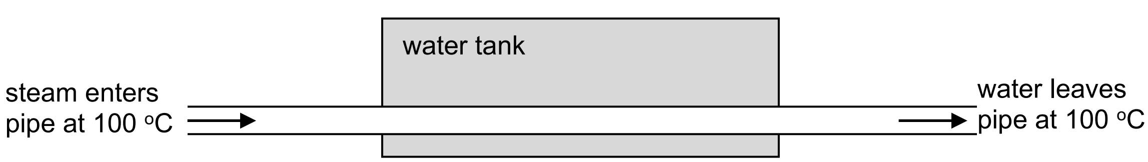
(b) Steam is used as a heating agent in cold climates. In a water heater, steam at 100 °C is passed through a pipe. The pipe runs through a tank of water containing 50.0 kg of water at 5.0 °C. The steam condenses and leaves the pipe as water at 100 °C. The cross-sectional view of the tank is shown below.



(i) Calculate the amount of energy required to raise the temperature of the water in the tank to 40.0 °C. [1]

Q required = $m\,c\,(\Delta\theta)$
= (50.0 kg)(4200 J kg^{-1} K^{-1})(40.0 °C - 5.0 °C)
= 7400 kJ (2 s.f.) [1]

(ii) Hence, determine the mass of steam required, in kg, to bring about the temperature change in the water in (b)(i). [2]

Q released by steam when it condenses = Q gained by water

m (2260 kJ kg^{-1}) = 7350 kJ [1]

m = 3.3 kg (to 2 s.f.) [1]

(iii) State the assumption needed for the calculation in (b)(ii) to be valid. [1]

No energy is transferred to the surroundings. [1]
(That is, the pipe and the tank has negligible heat capacities.)

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(iv) Determine the flow rate of steam in the pipe, in kg s^{-1}, if the water in the tank took 13 s to reach 40.0 ^{o}C. [2]

$$\text{Flow rate of steam} = \frac{\text{mass of steam needed to increase water temperature to 40.0 }^{o}\text{C}}{\text{time taken for change}}$$

= 3.2522 kg / 13 s [1]

= 0.25 kg s^{-1} (to 2 s.f.) [1]