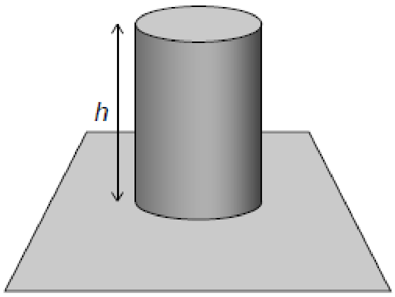
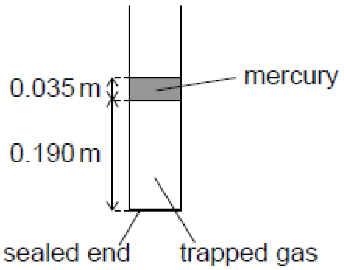
Thermal-practice-1-shortA *[211 marks]*

1a. A solid cylinder of height h and density ρ rests on a flat surface. *[2 marks]*



Show that the pressure p_c exerted by the cylinder on the surface is given by $p_c = \rho g h$.

A tube of constant circular cross-section, sealed at one end, contains an ideal gas trapped by a cylinder of mercury of length 0.035 m. The whole arrangement is in the Earth's atmosphere. The density of mercury is 1.36×10^4 kg m^{-3}.



When the mercury is above the gas column the length of the gas column is 0.190 m.

1b. Show that $(p_o + p_m) \times 0.190 = \frac{nRT}{A}$ where *[2 marks]*

p_o = atmospheric pressure

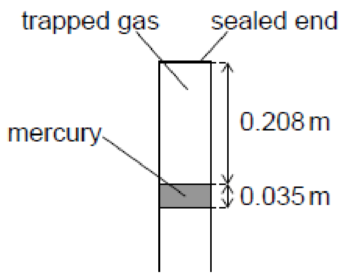
p_m = pressure due to the mercury column

T = temperature of the trapped gas

n = number of moles of the trapped gas

A = cross-sectional area of the tube.

The tube is slowly rotated until the gas column is above the mercury.



The length of the gas column is now 0.208 m. The temperature of the trapped gas does not change during the process.

1c. Determine the atmospheric pressure. Give a suitable unit for your answer. *[4 marks]*

1d. Outline why the gas particles in the tube hit the mercury surface less often after the tube has been rotated. *[1 mark]*

A container of volume 3.2 × 10-6 m^3 is filled with helium gas at a pressure of 5.1 × 10^5 Pa and temperature 320 K. Assume that this sample of helium gas behaves as an ideal gas.

2a. The molar mass of helium is 4.0 g mol^{-1}. Show that the mass of a helium atom is 6.6 × 10^{-27} kg. *[1 mark]*

2b. Estimate the average speed of the helium atoms in the container. *[2 marks]*

2c. Show that the number of helium atoms in the container is about 4 × 10^{20}. *[2 marks]*

A helium atom has a volume of 4.9 × 10^{-31} m^3.

2d. Calculate the ratio $\frac{\text{total volume of helium atoms}}{\text{volume of helium gas}}$. *[1 mark]*

2e. Explain, using your answer to (d)(i) and with reference to the kinetic model, why this sample of helium can be assumed to be an ideal gas. *[2 marks]*

Liquid oxygen at its boiling point is stored in an insulated tank. Gaseous oxygen is produced from the tank when required using an electrical heater placed in the liquid.

The following data are available.

Mass of 1.0 mol of oxygen = 32 g

Specific latent heat of vaporization of oxygen = 2.1×10^5 J kg^{-1}

3a. Distinguish between the internal energy of the oxygen at the boiling point when it is in its liquid phase and when it is in its gas phase. *[2 marks]*

An oxygen flow rate of 0.25 mol s^{-1} is needed.

3b. Calculate, in kW, the heater power required. *[2 marks]*

3c. Calculate the volume of the oxygen produced in one second when it is allowed to expand to a pressure of 0.11 MPa and to reach a temperature of 260 K. *[1 mark]*

3d. State **one** assumption of the kinetic model of an ideal gas that does not apply to oxygen. *[1 mark]*

A closed box of fixed volume 0.15 m^3 contains 3.0 mol of an ideal monatomic gas. The temperature of the gas is 290 K.

4a. Calculate the pressure of the gas. *[1 mark]*

When the gas is supplied with 0.86 kJ of energy, its temperature increases by 23 K. The specific heat capacity of the gas is 3.1 kJ kg^{-1} K^{-1}.

4b. Calculate, in kg, the mass of the gas. *[1 mark]*

4c. Calculate the average kinetic energy of the particles of the gas. *[1 mark]*

4d. Explain, with reference to the kinetic model of an ideal gas, how an increase in temperature of the gas leads to an increase in pressure. *[3 marks]*

An ideal monatomic gas is kept in a container of volume 2.1×10^{-4} m^3, temperature 310 K and pressure 5.3×10^5 Pa.

5a. State what is meant by an ideal gas. *[1 mark]*

5b. Calculate the number of atoms in the gas. *[1 mark]*

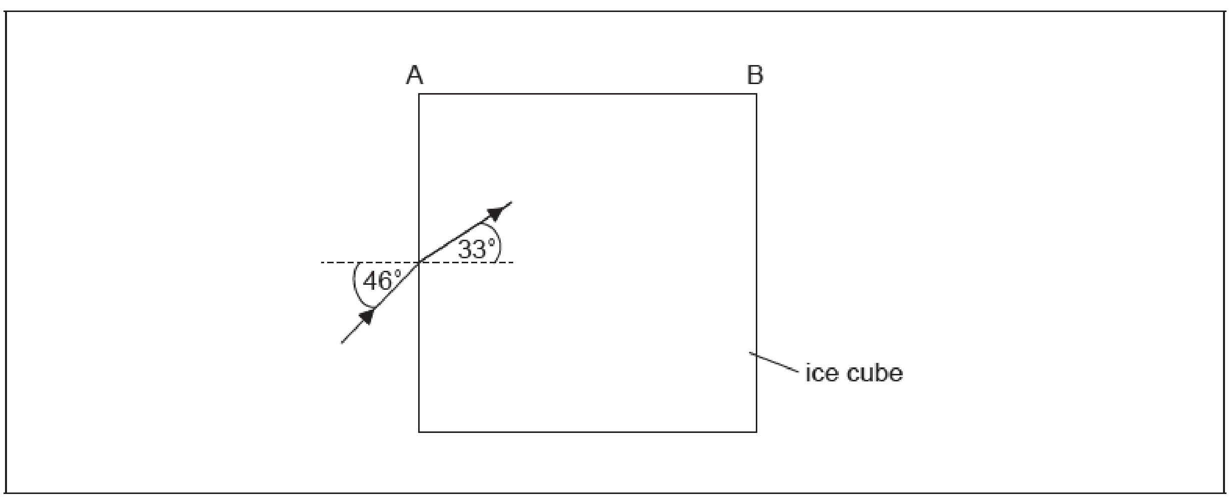
5c. Calculate, in J, the internal energy of the gas. *[2 marks]*

The volume of the gas in (a) is increased to 6.8×10^{-4} m^3 at constant temperature.

5d. Calculate, in Pa, the new pressure of the gas. *[1 mark]*

5e. Explain, in terms of molecular motion, this change in pressure. *[2 marks]*

A large cube is formed from ice. A light ray is incident from a vacuum at an angle of 46˚ to the normal on one surface of the cube. The light ray is parallel to the plane of one of the sides of the cube. The angle of refraction inside the cube is 33˚.



6a. Calculate the speed of light inside the ice cube. *[2 marks]*

6b. Show that no light emerges from side AB. *[3 marks]*

6c. Sketch, on the diagram, the subsequent path of the light ray. *[2 marks]*

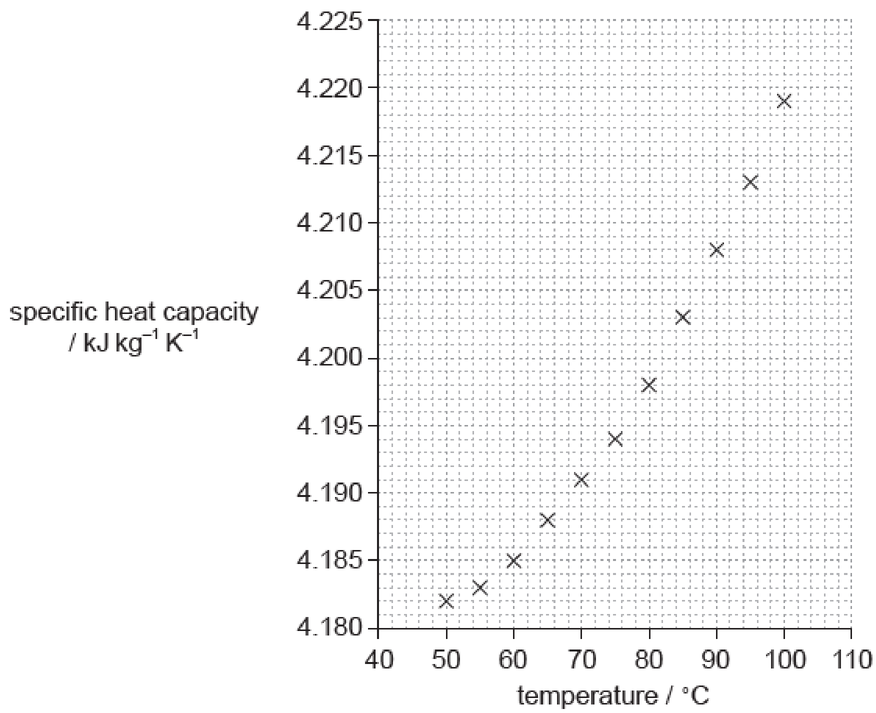
Each side of the ice cube is 0.75 m in length. The initial temperature of the ice cube is –20 °C.

6d. Determine the energy required to melt all of the ice from –20 °C to water at a temperature of 0 °C. *[4 marks]*

Specific latent heat of fusion of ice = 330 kJ kg^{-1}
Specific heat capacity of ice = 2.1 kJ kg^{-1} k^{-1}
Density of ice = 920 kg m^{-3}

6e. Outline the difference between the molecular structure of a solid and a liquid. *[1 mark]*

In an experiment, data were collected on the variation of specific heat capacity of water with temperature. The graph of the plotted data is shown.



7a. Draw the line of best-fit for the data. *[1 mark]*

7b. Determine the gradient of the line at a temperature of 80 °C. *[3 marks]*

7c. State the unit for the quantity represented by the gradient in your answer to (b)(i). *[1 mark]*

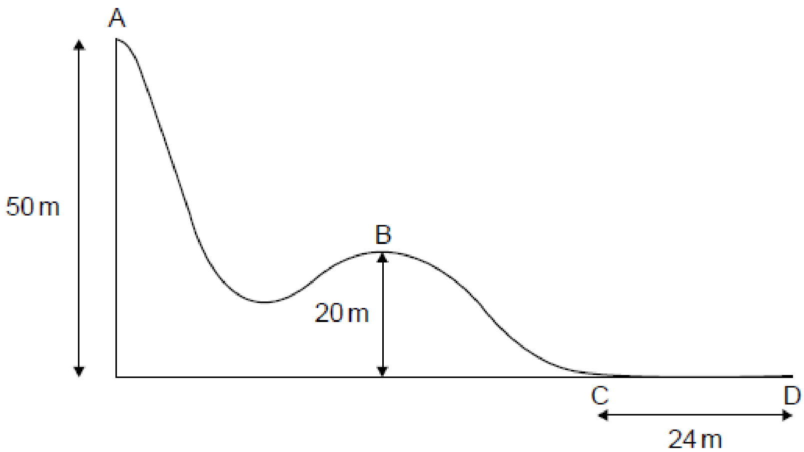
The uncertainty in the values for specific heat capacity is 5%.

Water of mass (100 ± 2) g is heated from (75.0 ± 0.5) °C to (85.0 ± 0.5) °C.

7d. Calculate the energy required to raise the temperature of the water from 75 °C to 85 °C. *[1 mark]*

7e. Using an appropriate error calculation, justify the number of significant figures that should be used for your answer to (c)(i). *[3 marks]*

The diagram below shows part of a downhill ski course which starts at point A, 50 m above level ground. Point B is 20 m above level ground.



A skier of mass 65 kg starts from rest at point A and during the ski course some of the gravitational potential energy transferred to kinetic energy.

8a. From A to B, 24 % of the gravitational potential energy transferred to kinetic energy. Show that the velocity at B is 12 m s^{-1}. *[2 marks]*

8b. Some of the gravitational potential energy transferred into internal energy of the skis, slightly increasing their temperature. Distinguish between internal energy and temperature. *[2 marks]*

8c. The dot on the following diagram represents the skier as she passes point B. *[2 marks]*
Draw and label the vertical forces acting on the skier.

8d. The hill at point B has a circular shape with a radius of 20 m. Determine whether the skier will lose contact with the ground at point B. *[3 marks]*

8e. The skier reaches point C with a speed of 8.2 m s^{-1}. She stops after a distance of 24 m at point D. *[3 marks]*

Determine the coefficient of dynamic friction between the base of the skis and the snow. Assume that the frictional force is constant and that air resistance can be neglected.

At the side of the course flexible safety nets are used. Another skier of mass 76 kg falls normally into the safety net with speed 9.6 m s^{-1}.

8f. Calculate the impulse required from the net to stop the skier and state an appropriate unit for your answer. *[2 marks]*

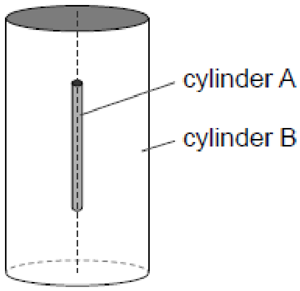
8g. Explain, with reference to change in momentum, why a flexible safety net is less likely to harm the skier than a rigid barrier. *[2 marks]*

The first scientists to identify alpha particles by a direct method were Rutherford and Royds. They knew that radium-226 ($^{226}_{86}\mathrm{Ra}$) decays by alpha emission to form a nuclide known as radon (Rn).

9a. Write down the missing values in the nuclear equation for this decay. *[1 mark]*

$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{\dots\dots}_{86}\mathrm{Rn} + {}^{\dots\dots}_{2}\alpha$$

9b. Rutherford and Royds put some pure radium-226 in a small closed cylinder A. Cylinder A is fixed in the centre of a larger closed cylinder B. *[1 mark]*



At the start of the experiment all the air was removed from cylinder B. The alpha particles combined with electrons as they moved through the wall of cylinder A to form helium gas in cylinder B.

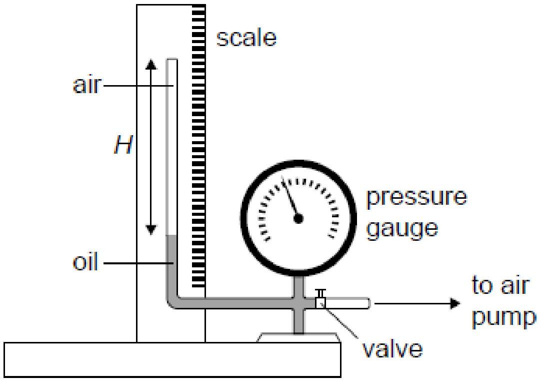
The wall of cylinder A is made from glass. Outline why this glass wall had to be very thin.

9c. Rutherford and Royds expected 2.7×10^{15} alpha particles to be emitted during the experiment. The experiment was carried out at a temperature of 18 °C. The volume of cylinder B was 1.3×10^{-5} m^3 and the volume of cylinder A was negligible. Calculate the pressure of the helium gas that was collected in cylinder B. *[3 marks]*

9d. Rutherford and Royds identified the helium gas in cylinder B by observing its emission spectrum. Outline, with reference to atomic energy levels, how an emission spectrum is formed. *[3 marks]*

9e. The work was first reported in a peer-reviewed scientific journal. Outline why Rutherford and Royds chose to publish their work in this way. *[1 mark]*

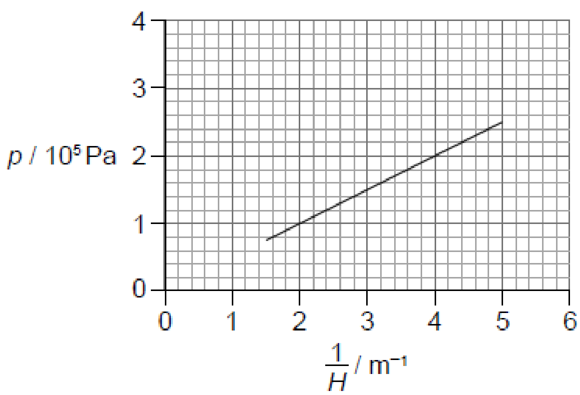
The equipment shown in the diagram was used by a student to investigate the variation with volume, of the pressure *p* of air, at constant temperature. The air was trapped in a tube of constant cross-sectional area above a column of oil.



The pump forces oil to move up the tube decreasing the volume of the trapped air.

10a. The student measured the height *H* of the air column and the corresponding air pressure *p*. After each reduction in the volume the student waited for some time before measuring the pressure. Outline why this was necessary. *[1 mark]*

10b. The following graph of *p* versus $\frac{1}{H}$ was obtained. Error bars were negligibly small. *[3 marks]*



The equation of the line of best fit is $p = a + \frac{b}{H}$.

Determine the value of *b* including an appropriate unit.

10c. Outline how the results of this experiment are consistent with the ideal gas law at constant temperature. *[2 marks]*

10d. The cross-sectional area of the tube is $1.3 \times 10^{-3}\ m^2$ and the temperature of air is 300 K. Estimate the number of moles of air in the tube. *[2 marks]*

10e. The equation in (b) may be used to predict the pressure of the air at extremely large values of $\frac{1}{H}$. Suggest why this will be an unreliable estimate of the pressure. *[2 marks]*

11a. Define *internal energy.* *[2 marks]*

11b. 0.46 mole of an ideal monatomic gas is trapped in a cylinder. The gas has a volume of 21 m^3 and a pressure of 1.4 Pa. *[4 marks]*

(i) State how the internal energy of an ideal gas differs from that of a real gas.

(ii) Determine, in kelvin, the temperature of the gas in the cylinder.

(iii) The kinetic theory of ideal gases is one example of a scientific model. Identify **one** reason why scientists find such models useful.

In an experiment to determine the specific latent heat of fusion of ice, an ice cube is dropped into water that is contained in a well-insulated calorimeter of negligible specific heat capacity. The following data are available.

Mass of ice cube = 25g
Mass of water = 350g
Initial temperature of ice cube = 0˚C
Initial temperature of water = 18˚C
Final temperature of water = 12˚C
Specific heat capacity of water = 4200$Jkg^{-1}K^{-1}$

12a. Using the data, estimate the specific latent heat of fusion of ice. *[4 marks]*

12b. The experiment is repeated using the same mass of crushed ice. *[2 marks]*

Suggest the effect, if any, of crushing the ice on

(i) the final temperature of the water.

(ii) the time it takes the water to reach its final temperature.

This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about thermal physics.

Part 1 Energy resources

Electricity can be generated using nuclear fission, by burning fossil fuels or using pump storage hydroelectric schemes.

13a. Outline which of the three generation methods above is renewable. *[2 marks]*

In a nuclear reactor, outline the purpose of the

13b. heat exchanger. *[1 mark]*

13c. moderator. *[2 marks]*

Fission of one uranium-235 nucleus releases 203 MeV.

13d. Determine the maximum amount of energy, in joule, released by 1.0 g of uranium-235 as a result of fission. *[3 marks]*

13e. Describe the main principles of the operation of a pump storage hydroelectric scheme. *[3 marks]*

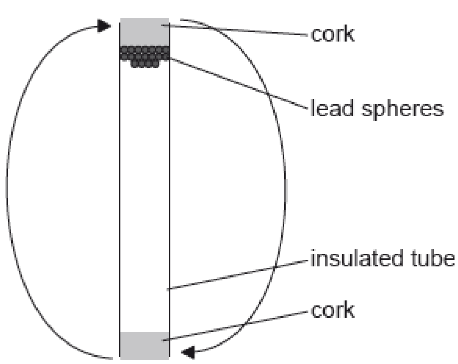
13f. A hydroelectric scheme has an efficiency of 92%. Water stored in the dam falls through an average height of 57 m. Determine the rate of flow of water, in $\mathrm{kg\,s^{-1}}$, required to generate an electrical output power of 4.5 MW. *[3 marks]*

This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about thermal physics.

Part 2 Thermal physics

13g. Distinguish between specific heat capacity and specific latent heat. *[2 marks]*

A mass of 0.22 kg of lead spheres is placed in a well-insulated tube. The tube is turned upside down several times so that the spheres fall through an average height of 0.45 m each time the tube is turned. The temperature of the spheres is found to increase by 8 °C.



13h. Discuss the changes to the energy of the lead spheres. *[2 marks]*

13i. The specific heat capacity of lead is $1.3 \times 10^{2}\ \mathrm{J\,kg^{-1}K^{-1}}$. Deduce the number of times that the tube is turned upside down. *[4 marks]*

This question is about thermal properties of matter.

14a. Explain, in terms of the energy of its molecules, why the temperature of a pure substance does not change during melting. *[3 marks]*

14b. Three ice cubes at a temperature of 0°C are dropped into a container of water at a temperature of 22°C. The mass of each ice cube is 25 g and the mass of the water is 330 g. The ice melts, so that the temperature of the water decreases. The thermal capacity of the container is negligible. *[4 marks]*

The following data are available.

Specific latent heat of fusion of ice $= 3.3 \times 10^{5}$ J kg^{-1}

Specific heat capacity of water $= 4.2 \times 10^{3}$ J kg^{-1} K^{-1}

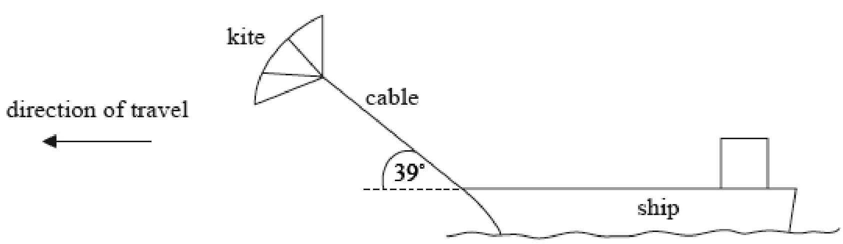
Calculate the final temperature of the water when all of the ice has melted. Assume that no thermal energy is exchanged between the water and the surroundings.

This question is in **two** parts. **Part 1** is about the motion of a ship. **Part 2** is about melting ice.

Part 1 Motion of a ship

15a. Outline the meaning of work. *[2 marks]*

Some cargo ships use kites working together with the ship's engines to move the vessel.



The tension in the cable that connects the kite to the ship is 250 kN. The kite is pulling the ship at an angle of 39° to the horizontal. The ship travels at a steady speed of $8.5\ \mathrm{m\,s^{-1}}$ when the ship's engines operate with a power output of 2.7 MW.

15b. Calculate the work done on the ship by the kite when the ship travels a distance of 1.0 km. *[2 marks]*

15c. Show that, when the ship is travelling at a speed of $8.5\ \mathrm{m\,s^{-1}}$, the kite provides about 40% of the total power required by the ship. *[4 marks]*

15d. The kite is taken down and no longer produces a force on the ship. The resistive force F that opposes the motion of the ship is related to the speed v of the ship by *[3 marks]*

$$F = kv^2$$

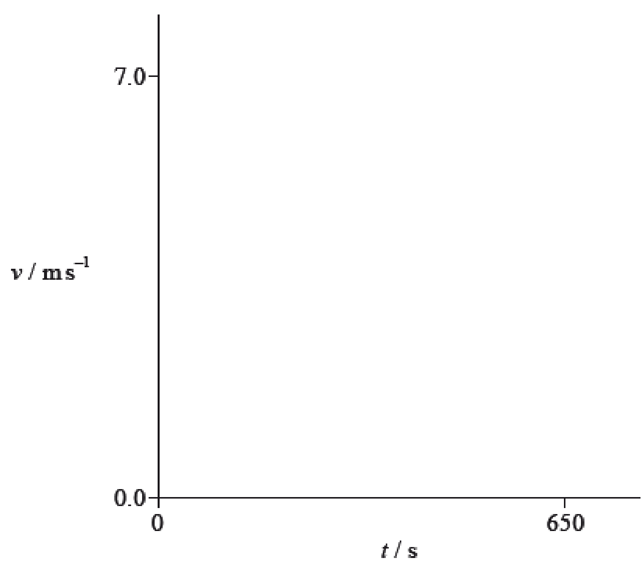
where k is a constant.

Show that, if the power output of the engines remains at 2.7 MW, the speed of the ship will decrease to about $7\ \mathrm{m\,s^{-1}}$. Assume that k is independent of whether the kite is in use or not.

The ship's engines are switched off and the ship comes to rest from a speed of $7\ \mathrm{m\,s^{-1}}$ in a time of 650 s.

15e. Estimate the distance that the ship takes to stop. Assume that the acceleration is uniform. *[2 marks]*

15f. It is unlikely that the acceleration of the ship will be uniform given that the resistive force acting on the ship depends on the speed of the ship. Using the axes, sketch a graph to show how the speed v varies with time t after the ship's engines are switched off. *[2 marks]*



Part 2 Melting ice

15g. Describe, with reference to molecular behaviour, the process of melting ice. *[2 marks]*

A container of negligible mass, isolated from its surroundings, contains 0.150 kg of ice at a temperature of –18.7 °C. An electric heater supplies energy at a rate of 125 W.

15h. After a time interval of 45.0 s all of the ice has reached a temperature of 0 °C without any melting. Calculate the specific heat capacity of ice. *[2 marks]*

15i. The following data are available. *[3 marks]*

Specific heat capacity of water $= 4200\ \mathrm{J\,kg^{-1}K^{-1}}$

Specific latent heat of fusion of ice $= 3.30 \times 10^5\ \mathrm{J\,kg^{-1}}$

Determine the final temperature of the water when the heater supplies energy for a further 600 s.

15j. The whole of the experiment in (f)(i) and (f)(ii) is repeated with a container of negligible mass that is not isolated from the surroundings. *[3 marks]*
The temperature of the surroundings is 18 °C. Comment on the final temperature of the water in (f)(ii).

This question is about energy.

At its melting temperature, molten zinc is poured into an iron mould. The molten zinc becomes a solid without changing temperature.

16a. Outline why a given mass of molten zinc has a greater internal energy than the same mass of solid zinc at the same temperature. *[3 marks]*

16b. Molten zinc cools in an iron mould. *[4 marks]*

The temperature of the iron mould was 20° C before the molten zinc, at its melting temperature, was poured into it. The final temperature of the iron mould and the solidified zinc is 89° C.

The following data are available.

Mass of iron mould $= 12\ \mathrm{kg}$

Mass of zinc $= 1.5\ \mathrm{kg}$

Specific heat capacity of iron $= 440\ \mathrm{J\,kg^{-1}K^{-1}}$

Specific latent heat of fusion of zinc $= 113\ \mathrm{kJ\,kg^{-1}}$

Melting temperature of zinc $= 420\ ^\circ\mathrm{C}$

Using the data, determine the specific heat capacity of zinc.

This question is about the use of energy resources.

17a. State the difference between renewable and non-renewable energy sources. *[1 mark]*

Electrical energy is obtained from tidal energy at La Rance in France.

Water flows into a river basin from the sea for six hours and then flows from the basin back to the sea for another six hours. The water flows through turbines and generates energy during both flows.

The following data are available.

Area of river basin $= 22\ \mathrm{km}^2$

Change in water level of basin over six hours $= 6.0\ \mathrm{m}$

Density of water $= 1000\ \mathrm{kg\,m^{-3}}$

17b. (i) The basin empties over a six hour period. Show that about $6000\ \mathrm{m}^3$ of water flows through the turbines every second. *[10 marks]*

(ii) Show that the average power that the water can supply over the six hour period is about 0.2 GW.

(iii) La Rance tidal power station has an energy output of $5.4 \times 10^8\ \mathrm{kW\,h}$ per year. Calculate the overall efficiency of the power station. Assume that the water can supply 0.2 GW at all times.

Energy resources such as La Rance tidal power station could replace the use of

fossil fuels. This may result in an increase in the average albedo of Earth.

(iv) State **two** reasons why the albedo of Earth must be given as an average value.

Nuclear reactors are used to generate energy. In a particular nuclear reactor, neutrons collide elastically with carbon-12 nuclei $\left({}^{12}_{6}\mathrm{C}\right)$ that act as the moderator of the reactor. A neutron with an initial speed of $9.8 \times 10^{6}\ \mathrm{m\,s^{-1}}$ collides head-on with a stationary carbon-12 nucleus. Immediately after the collision the carbon-12 nucleus has a speed of $1.5 \times 10^{6}\ \mathrm{m\,s^{-1}}$.

17c. (i) State the principle of conservation of momentum. *[10 marks]*

(ii) Show that the speed of the neutron immediately after the collision is about $8.0 \times 10^{6}\ \mathrm{m\,s^{-1}}$.

(iii) Show that the fractional change in energy of the neutron as a result of the collision

is about 0.3.

(iv) Estimate the minimum number of collisions required for the neutron to reduce its initial energy by a factor of 10^{6}.

(v) Outline why the reduction in energy is necessary for this type of reactor to function.

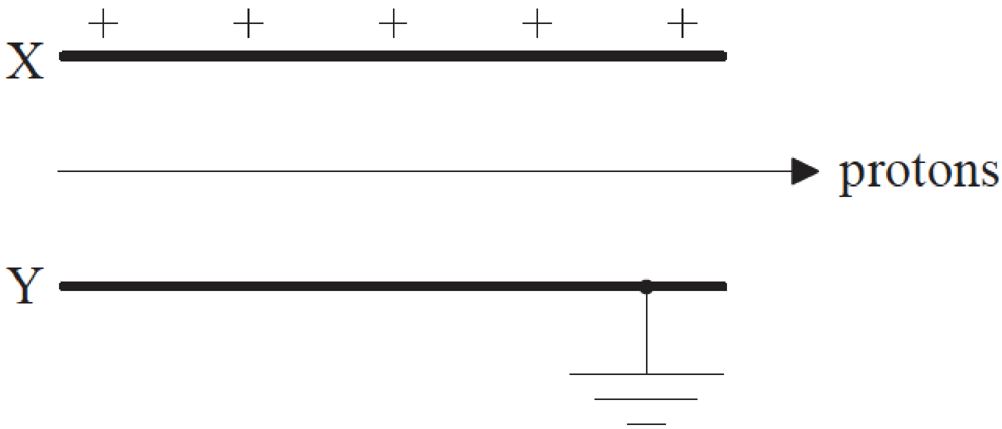
This question is in **two** parts. **Part 1** is about electric fields and radioactive decay. **Part 2** is about change of phase.

Part 1 Electric fields and radioactive decay

18a. Define *electric field strength*. *[2 marks]*

18b. A simple model of the proton is that of a sphere of radius 1.0×10^{-15}m with charge concentrated at the centre of the sphere. Estimate the magnitude of the field strength at the surface of the proton. *[2 marks]*

18c. Protons travelling with a speed of $3.9\times10^{6}ms^{-1}$ enter the region between two charged parallel plates X and Y. Plate X is positively charged and plate Y is connected to earth. *[4 marks]*



A uniform magnetic field also exists in the region between the plates. The direction of the field is such that the protons pass between the plates without deflection.

(i) State the direction of the magnetic field.

(ii) The magnitude of the magnetic field strength is 2.3×10^{-4}T. Determine the magnitude of the electric field strength between the plates, stating an appropriate unit for your answer.

18d. Protons can be produced by the bombardment of nitrogen-14 nuclei with alpha particles. The nuclear reaction equation for this process is given below. *[1 mark]*

$$^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow \mathrm{X} + {}^{1}_{1}\mathrm{H}$$

Identify the proton number and nucleon number for the nucleus X.

18e. The following data are available for the reaction in (d). *[3 marks]*

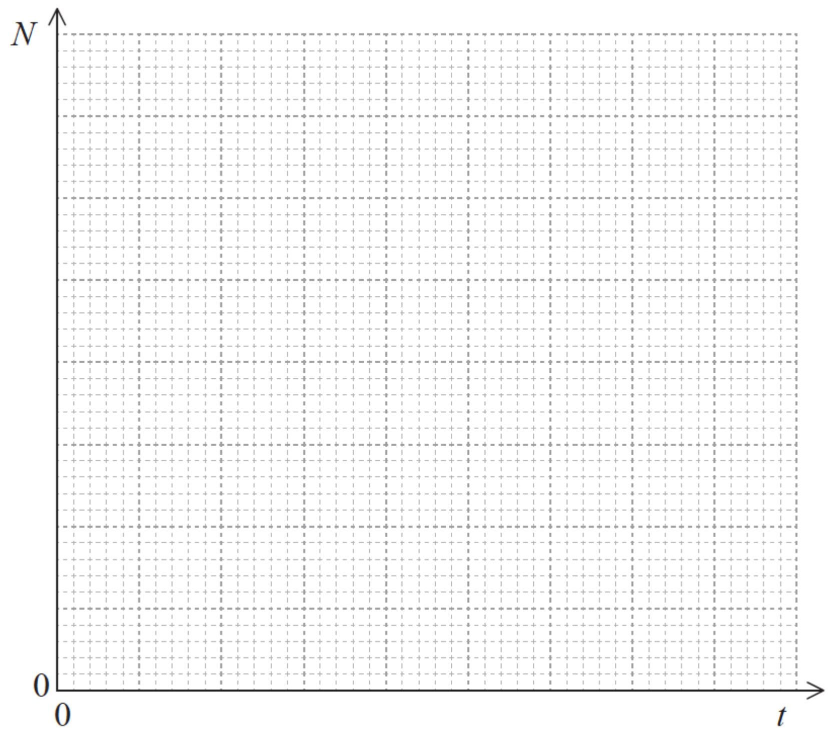
Rest mass of nitrogen-14 nucleus =14.0031 u
Rest mass of alpha particle =4.0026 u
Rest mass of X nucleus =16.9991 u
Rest mass of proton =1.0073 u

Show that the minimum kinetic energy that the alpha particle must have in order for the reaction to take place is about 0.7 Me V.

18f. A nucleus of another isotope of the element X in (d) decays with a half-life $T_{\frac{1}{2}}$ to a nucleus of an isotope of fluorine-19 (F-19). *[5 marks]*

(i) Define the terms *isotope* and *half-life*.

(ii) Using the axes below, sketch a graph to show how the number of atoms N in a sample of X varies with time t, from t=0 to $t = 3T_{\frac{1}{2}}$. There are N_0 atoms in the sample at t=0.



Part 2 Change of phase

18g. Water at constant pressure boils at constant temperature. Outline, in terms of the energy of the molecules, the reason for this. *[2 marks]*

18h. In an experiment to measure the specific latent heat of vaporization of water, steam at 100°C was passed into water in an insulated container. *[4 marks]*
The following data are available.

Initial mass of water in container = 0.300kg
Final mass of water in container = 0.312kg
Initial temperature of water in container = 15.2°C
Final temperature of water in container = 34.6°C
Specific heat capacity of water = 4.18×10^{3} $Jkg^{-1}K^{-1}$

Show that the data give a value of about 1.8×10^{6} Jkg^{-1} for the specific latent heat of vaporization L of water.

18i. Explain why, other than measurement or calculation error, the accepted value of L is greater than that given in (h). *[2 marks]*