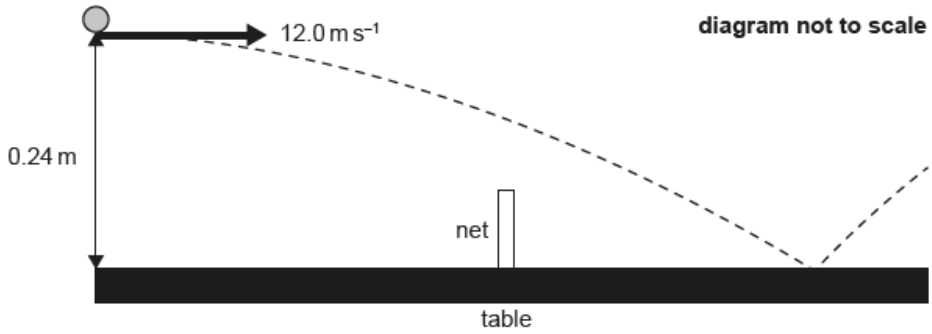
Red [most common] *[154 marks]*

Two players are playing table tennis. Player A hits the ball at a height of 0.24 m above the edge of the table, measured from the top of the table to the bottom of the ball. The initial speed of the ball is 12.0 m s^{-1} horizontally. Assume that air resistance is negligible.



1a. Show that the time taken for the ball to reach the surface of the table is about 0.2 s. *[1 mark]*

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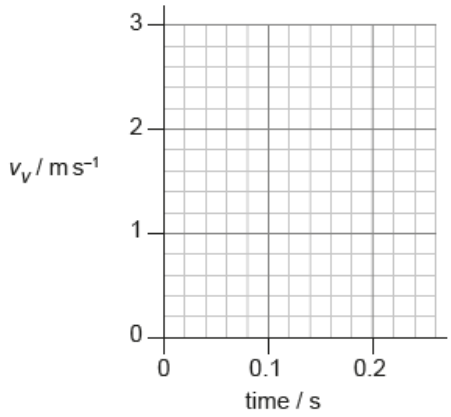
1b. Sketch, on the axes, a graph showing the variation with time of the vertical component of velocity v_V of the ball until it reaches the table surface. Take g to be $+10\,\text{m s}^{-2}$. *[2 marks]*



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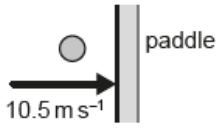
1c. The net is stretched across the middle of the table. The table has a length of 2.74 m and the net has a height of 15.0 cm. *[3 marks]*

Show that the ball will go over the net.

The ball bounces and then reaches a peak height of 0.18 m above the table with a horizontal speed of 10.5 m s^{-1}. The mass of the ball is 2.7 g.

1d. Determine the kinetic energy of the ball immediately after the bounce. *[2 marks]*

1e. Player B intercepts the ball when it is at its peak height. Player B holds a paddle (racket) stationary and vertical. The ball is in contact with the paddle for 0.010 s. Assume the collision is elastic. *[3 marks]*



Calculate the average force exerted by the ball on the paddle. State your answer to an appropriate number of significant figures.

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A girl rides a bicycle that is powered by an electric motor. A battery transfers energy to the electric motor. The emf of the battery is 16 V and it can deliver a charge of 43 kC when discharging completely from a full charge.

The maximum speed of the girl on a horizontal road is 7.0 m s^{-1} with energy from the battery alone. The maximum distance that the girl can travel under these conditions is 20 km.

2a. Show that the time taken for the battery to discharge is about 3×10^3 s. *[1 mark]*

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2b. Deduce that the average power output of the battery is about 240 W. *[2 marks]*

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2c. Friction and air resistance act on the bicycle and the girl when they move. Assume that all the energy is transferred from the battery to the electric motor. Determine the total average resistive force that acts on the bicycle and the girl. *[2 marks]*

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The bicycle and the girl have a total mass of 66 kg. The girl rides up a slope that is at an angle of 3.0° to the horizontal.

2d. Calculate the component of weight for the bicycle and girl acting down the slope. *[1 mark]*

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2e. The battery continues to give an output power of 240 W. Assume that the resistive forces are the same as in (a)(iii). *[2 marks]*

Calculate the maximum speed of the bicycle and the girl up the slope.

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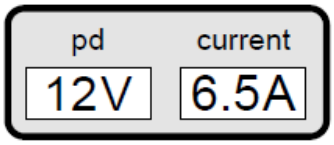
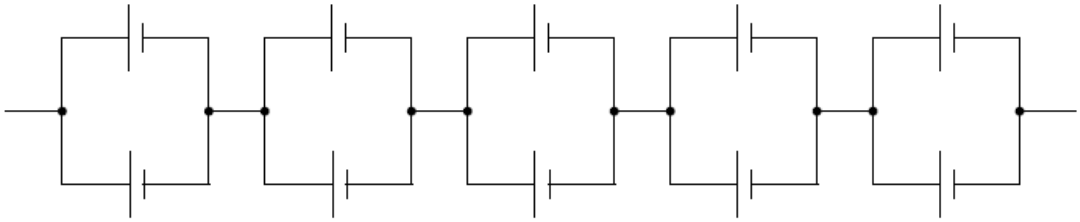
2f. On another journey up the slope, the girl carries an additional mass. Explain whether carrying this mass will change the maximum distance that the bicycle can travel along the slope. *[2 marks]*

The bicycle has a meter that displays the current and the terminal potential difference (pd) for the battery when the motor is running. The diagram shows the meter readings at one instant. The emf of the cell is 16 V.



2g. Determine the internal resistance of the battery. *[2 marks]*

The battery is made from an arrangement of 10 identical cells as shown.



2h. Calculate the emf of **one** cell. *[1 mark]*

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2i. Calculate the internal resistance of **one** cell. *[2 marks]*

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2j. Calculate the internal resistance of **one** cell. *[2 marks]*

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2k. Calculate the emf of **one** cell. *[1 mark]*

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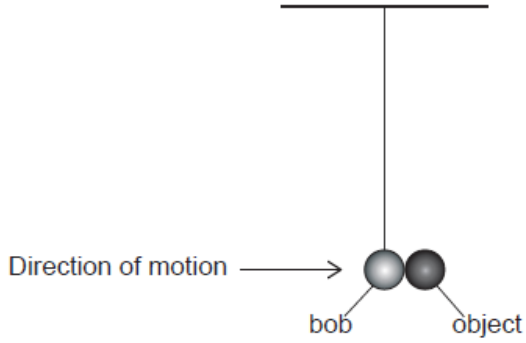
A small metal pendulum bob of mass 75 g is suspended at rest from a fixed point with a length of thread of negligible mass. Air resistance is negligible. The bob is then displaced to the left.

At time $t = 0$ the bob is moving horizontally to the right at 0.8 m s^{-1}. It collides with a small stationary object also of mass 75 g. Both objects then move together with motion that is simple harmonic.



3a. Calculate the speed of the combined masses immediately after the collision. *[1 mark]*

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3b. Show that the collision is inelastic. *[3 marks]*

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3c. Describe the changes in gravitational potential energy of the oscillating system from $t = 0$ as it oscillates through one cycle of its motion. *[1 mark]*

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4a. Define *impulse*. *[1 mark]*

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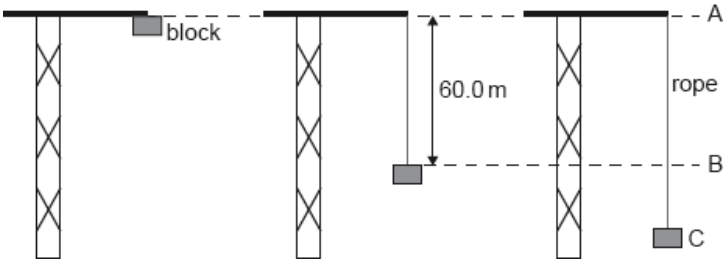
A chicken's egg of mass 58 g is dropped onto grass from a height of 1.1 m. Assume that air resistance is negligible and that the egg does not bounce or break.

4b. Show that the kinetic energy of the egg just before impact is about 0.6 J. *[1 mark]*

4c. The egg comes to rest in a time of 55 ms. Determine the magnitude of the average decelerating force that the ground exerts on the egg. *[4 marks]*

4d. Explain why the egg is likely to break when dropped onto concrete from the same height. *[2 marks]*

An elastic climbing rope is tested by fixing one end of the rope to the top of a crane. The other end of the rope is connected to a block which is initially at position A. The block is released from rest. The mass of the rope is negligible.



The unextended length of the rope is 60.0 m. From position A to position B, the block falls freely.

5a. At position B the rope starts to extend. Calculate the speed of the block at position B. *[2 marks]*

At position C the speed of the block reaches zero. The time taken for the block to fall between B and C is 0.759 s. The mass of the block is 80.0 kg.

5b. Determine the magnitude of the average resultant force acting on the block between B and C. *[2 marks]*

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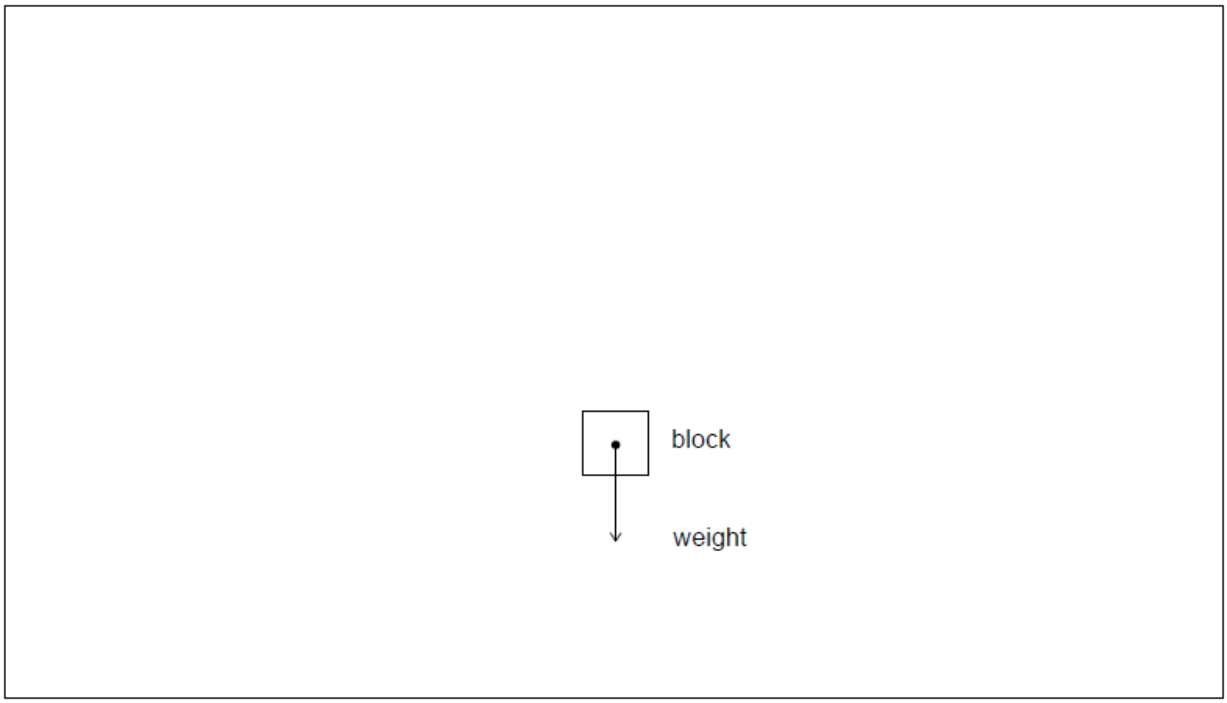
5c. Sketch on the diagram the average resultant force acting on the block between B and C. The arrow on the diagram represents the weight of the block. *[2 marks]*



5d. Calculate the magnitude of the average force exerted by the rope on the block between B and C. *[2 marks]*

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For the rope and block, describe the energy changes that take place

5e. between A and B. *[1 mark]*

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5f. between B and C. *[1 mark]*

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5g. The length reached by the rope at C is 77.4 m. Suggest how energy considerations could be used to determine the elastic constant of the rope. *[2 marks]*

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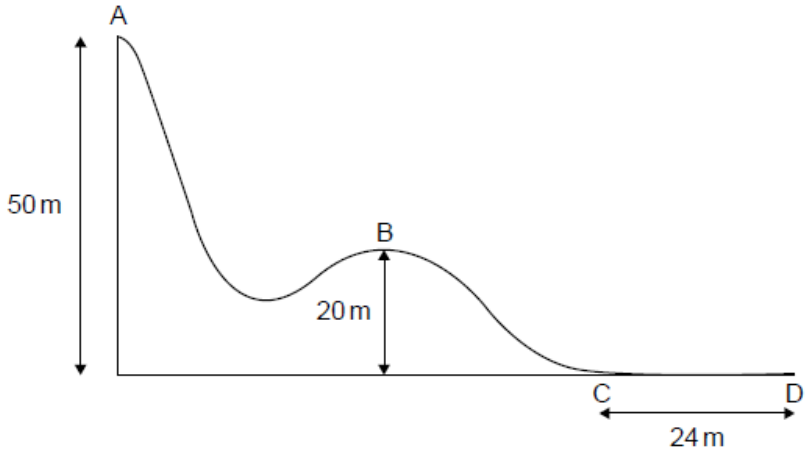
The diagram below shows part of a downhill ski course which starts at point A, 50 m above level ground. Point B is 20 m above level ground.



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.

6a. 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]*

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6b. 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]*

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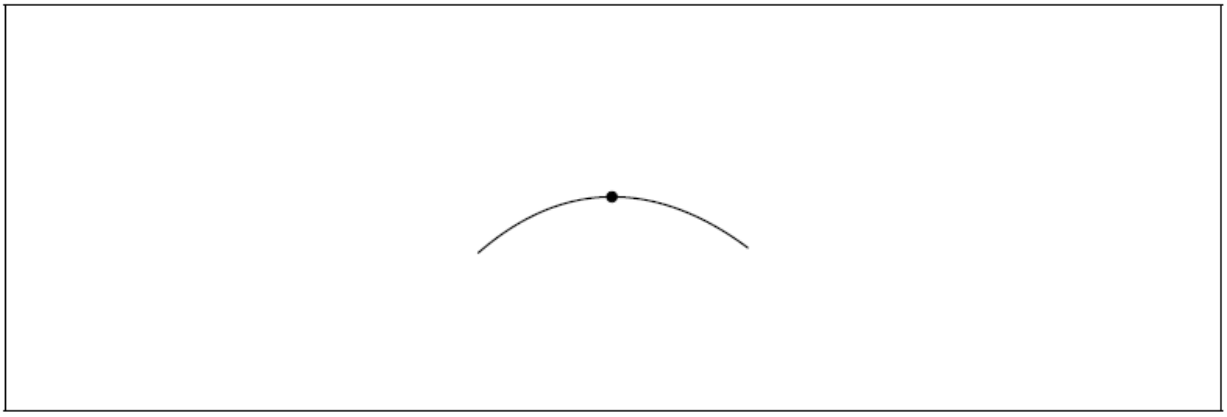
6c. The dot on the following diagram represents the skier as she passes point B. *[2 marks]*
Draw and label the vertical forces acting on the skier.



6d. 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]*

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6e. 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.

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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}.

6f. Calculate the impulse required from the net to stop the skier and state an appropriate unit for your answer. *[2 marks]*

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6g. 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]*

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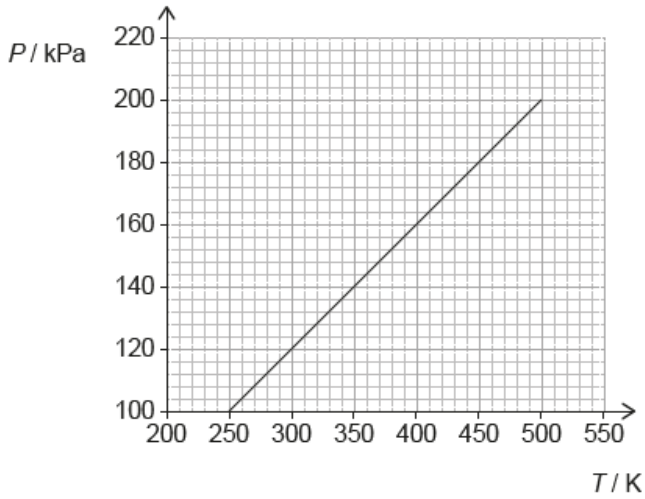
The graph shows the variation with temperature T of the pressure P of a fixed mass of helium gas trapped in a container with a fixed volume of $1.0 \times 10^{-3}\,m^3$.



7a. Deduce whether helium behaves as an ideal gas over the temperature range 250 K to 500 K. *[2 marks]*

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7b. Helium has a molar mass of 4.0 g. Calculate the mass of gas in the container. *[2 marks]*

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7c. A second container, of the same volume as the original container, contains twice as many helium atoms. The graph of the variation of P with T is determined for the gas in the second container. *[2 marks]*

Predict how the graph for the second container will differ from the graph for the first container.

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The air in a kitchen has pressure 1.0×10^5 Pa and temperature 22°C. A refrigerator of internal volume 0.36 m^3 is installed in the kitchen.

8a. With the door open the air in the refrigerator is initially at the same temperature and pressure as the air in the kitchen. Calculate the number of molecules of air in the refrigerator. *[2 marks]*

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The refrigerator door is closed. The air in the refrigerator is cooled to 5.0°C and the number of air molecules in the refrigerator stays the same.

8b. Determine the pressure of the air inside the refrigerator. *[2 marks]*

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8c. The door of the refrigerator has an area of 0.72 m^2. Show that the minimum force needed to open the refrigerator door is about 4 kN. *[2 marks]*

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8d. Comment on the magnitude of the force in (b)(ii). *[2 marks]*

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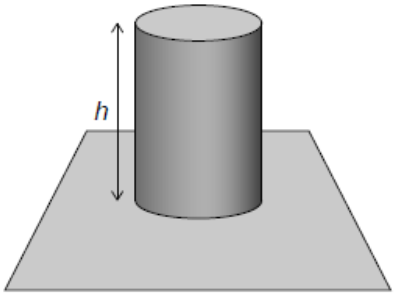
9a. A solid cylinder of height h and density ρ rests on a flat surface. *[2 marks]*



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

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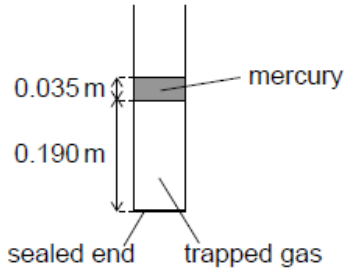
A tube of constant circular cross-section, sealed at one end, contains an ideal gas trapped by a cylinder of mercury of length 0.035 m. The whole arrangement is in the Earth's atmosphere. The density of mercury is 1.36×10^4 kg m^{-3}.



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

9b. 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.

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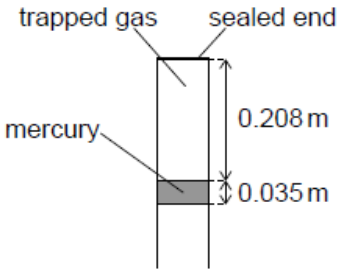
The tube is slowly rotated until the gas column is above the mercury.

diagram not to scale



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

9c. Determine the atmospheric pressure. Give a suitable unit for your answer. *[4 marks]*

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9d. Outline why the gas particles in the tube hit the mercury surface less often after the tube has been rotated. *[1 mark]*

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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.

10a. 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]*

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10b. Estimate the average speed of the helium atoms in the container. *[2 marks]*

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

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

10d. Calculate the ratio $\frac{\text{total volume of helium atoms}}{\text{volume of helium gas}}$. *[1 mark]*

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10e. 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]*

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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}

11a. 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]*

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

11b. Calculate, in kW, the heater power required. *[2 marks]*

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11c. 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 –13 °C. *[2 marks]*

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11d. State **one** assumption of the kinetic model of an ideal gas that does not apply to oxygen. *[1 mark]*

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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.

12a. State what is meant by an ideal gas. *[1 mark]*

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12b. Calculate the number of atoms in the gas. *[1 mark]*

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12c. Calculate, in J, the internal energy of the gas. *[2 marks]*

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

12d. Calculate, in Pa, the new pressure of the gas. *[1 mark]*

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12e. Explain, in terms of molecular motion, this change in pressure. *[2 marks]*

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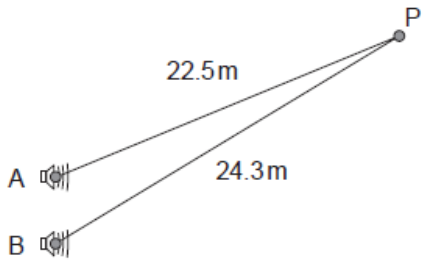
Two loudspeakers, A and B, are driven in phase and with the same amplitude at a frequency of $850\ \text{Hz}$. Point P is located $22.5\ \text{m}$ from A and $24.3\ \text{m}$ from B. The speed of sound is $340\ \text{m s}^{-1}$.



13a. Deduce that a minimum intensity of sound is heard at P. *[4 marks]*

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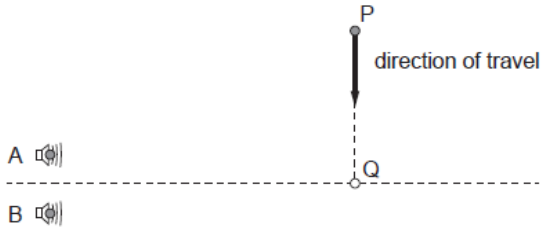
13b. A microphone moves along the line from P to Q. PQ is normal to the line midway between the loudspeakers. *[2 marks]*



The intensity of sound is detected by the microphone. Predict the variation of detected intensity as the microphone moves from P to Q.

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13c. When both loudspeakers are operating, the intensity of sound recorded at Q is I_0. Loudspeaker B is now disconnected. Loudspeaker A continues to emit sound with unchanged amplitude and frequency. The intensity of sound recorded at Q changes to I_A. *[2 marks]*

Estimate $\frac{I_A}{I_0}$.

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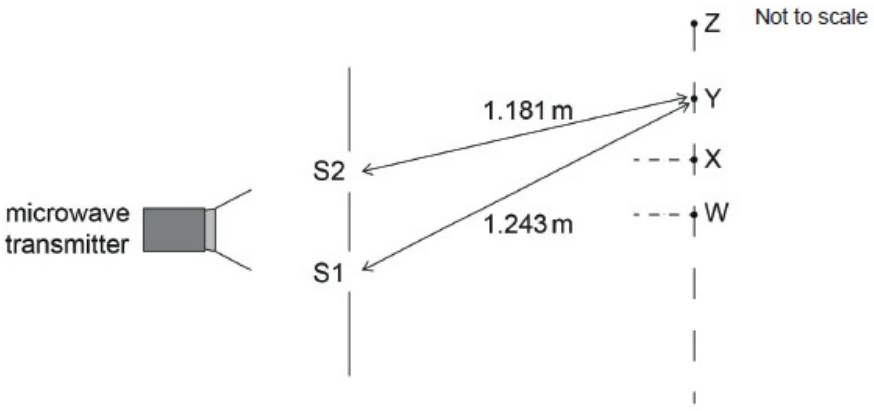
A beam of microwaves is incident normally on a pair of identical narrow slits S1 and S2.



When a microwave receiver is initially placed at W which is equidistant from the slits, a maximum in intensity is observed. The receiver is then moved towards Z along a line parallel to the slits. Intensity maxima are observed at X and Y with one minimum between them. W, X and Y are consecutive maxima.

14a. Explain why intensity maxima are observed at X and Y. *[2 marks]*

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14b. The distance from S1 to Y is 1.243 m and the distance from S2 to Y is 1.181 m. *[3 marks]*

Determine the frequency of the microwaves.

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14c. Outline **one** reason why the maxima observed at W, X and Y will have different intensities from each other. *[1 mark]*

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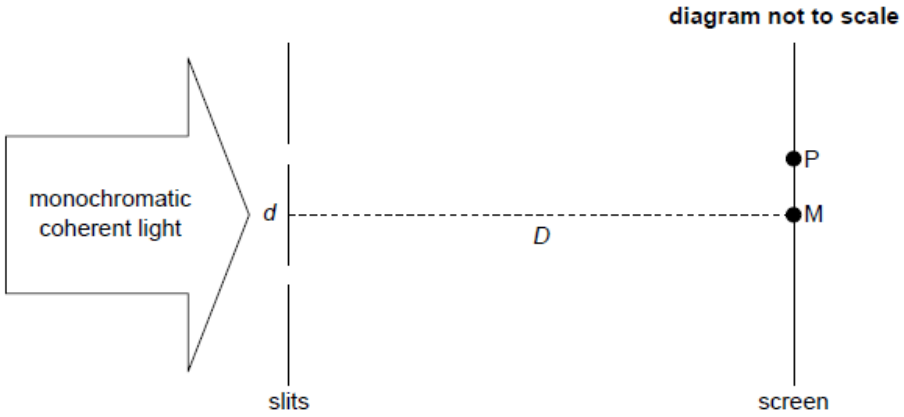
Monochromatic coherent light is incident on two parallel slits of negligible width a distance *d* apart. A screen is placed a distance *D* from the slits. Point M is directly opposite the midpoint of the slits.



Initially the lower slit is covered and the intensity of light at M due to the upper slit alone is 22 W m^{-2}. The lower slit is now uncovered.

15a. Deduce, in W m^{-2}, the intensity at M. *[3 marks]*

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15b. P is the first maximum of intensity on **one** side of M. The following data are available. *[2 marks]*

$d = 0.12$ mm

$D = 1.5$ m

Distance MP = 7.0 mm

Calculate, in nm, the wavelength λ of the light.

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The width of each slit is increased to 0.030 mm. *D*, *d* and λ remain the same.

15c. Suggest why, after this change, the intensity at P will be less than that at M. *[1 mark]*

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15d. Show that, due to single slit diffraction, the intensity at a point on the screen a distance of 28 mm from M is zero. *[2 marks]*

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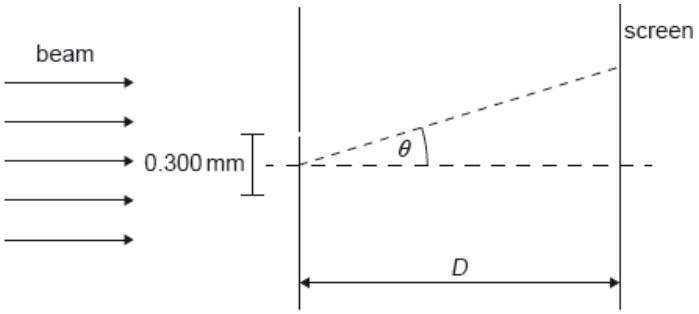
A beam of coherent monochromatic light from a distant galaxy is used in an optics experiment on Earth.

The beam is incident normally on a double slit. The distance between the slits is 0.300 mm. A screen is at a distance D from the slits. The diffraction angle θ is labelled.



16a. A series of dark and bright fringes appears on the screen. Explain how a dark fringe is formed. *[3 marks]*

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16b. The wavelength of the beam as observed on Earth is 633.0 nm. The separation between a dark and a bright fringe on the screen is 4.50 mm. Calculate D. *[2 marks]*

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The air between the slits and the screen is replaced with water. The refractive index of water is 1.33.

16c. Calculate the wavelength of the light in water. *[1 mark]*

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16d. State **two** ways in which the intensity pattern on the screen changes. *[2 marks]*

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17a. Outline what is meant by the principle of superposition of waves. *[2 marks]*

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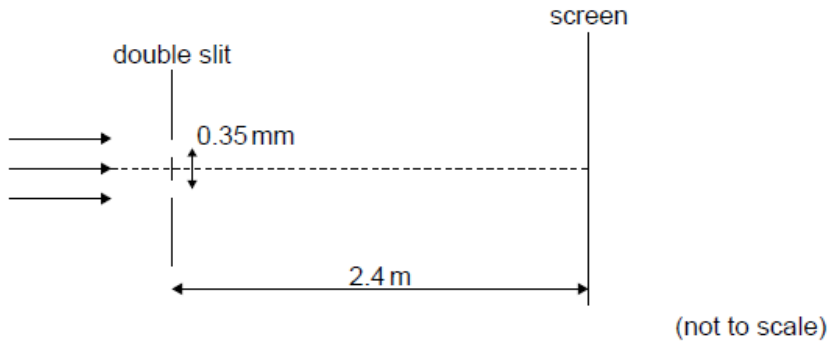
17b. Red laser light is incident on a double slit with a slit separation of 0.35 mm. *[3 marks]*

A double-slit interference pattern is observed on a screen 2.4 m from the slits.
The distance between successive maxima on the screen is 4.7 mm.



(not to scale)

Calculate the wavelength of the light. Give your answer to an appropriate number of significant figures.

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17c. Explain the change to the appearance of the interference pattern when the red-light laser is replaced by one that emits green light. *[2 marks]*

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17d. One of the slits is now covered. *[2 marks]*

Describe the appearance of the pattern on the screen.

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