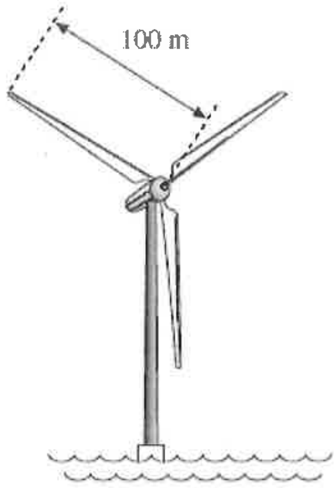
Work, Energy and Power

Conservation of energy, forms of energy

57 minutes

56 marks

Q1. It has been predicted that in the future large offshore wind turbines may have a power output ten times that of the largest ones currently in use. These turbines could have a blade length of 100 m or more. A turbine such as this is shown in the diagram below.



(a) At a wind speed of 11 m s^{-1} the volume of air passing through the blades each second is 3.5×10^5 m^3.

(i) Show that the mass of air that would pass through the blades each second is about 4×10^5 kg.

The density of air is 1.2 kg m^{-3}

(2)

(ii) Calculate the kinetic energy of the air that would enter the turbine each second.

answer = ... J

(2)

(iii) It has been predicted that the turbine would produce an electrical power output of 10 MW in these wind conditions. Calculate the percentage efficiency of the turbine in converting this kinetic energy into electrical energy.

answer = ... %

(2)

(b) State **one** advantage and **one** disadvantage of wind power in comparison to fossil fuel.

Advantage ....

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Disadvantage ....

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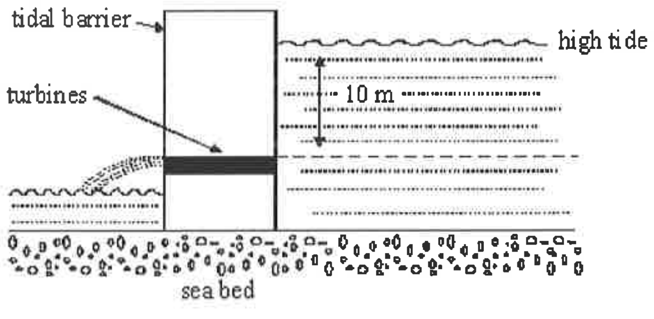
(2)
(Total 8 marks)

Q2. Tidal power could make a significant contribution to UK energy requirements. This question is about a tidal power station which traps sea water behind a tidal barrier at high tide and then releases the water through turbines 10.0 m below the high tide mark.



(i) Calculate the mass of sea water covering an area of 120 km^2 and depth 10.0 m.

density of sea water = 1100 kg m^{-3}

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(ii) Calculate the maximum loss of potential energy of the sea water in part (i) when it is released through the turbines.

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(iii) The potential energy of the sea water released through the turbines, calculated in part (ii), is lost over a period of 6.0 hours. Estimate the average power output of the power station over this time period. Assume the power station efficiency is 40%.

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(Total 7 marks)

Q3. The figure below shows apparatus that can be used to investigate energy changes.

The trolley and the mass are joined by an inextensible string. In an experiment to investigate energy changes, the trolley is initially held at rest, and is then released so that the mass falls vertically to the ground.

You may be awarded marks for the quality of written communication in your answer.

(a) (i) State the energy changes of the falling mass.

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(ii) Describe the energy changes that take place in this system.

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(4)

(b) State what measurements would need to be made to investigate the *conservation of energy*.

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(2)

(c) Describe how the measurements in part (b) would be used to investigate the conservation of energy.

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(4)
(Total 10 marks)

Q4. (a) Explain why a raindrop falling vertically through still air reaches a constant velocity. You may be awarded marks for the quality of written communication in your answer.

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(4)

(b) A raindrop falls at a constant vertical velocity of 1.8 m s^{-1} in still air. The mass of the raindrop is 7.2×10^{-9} kg.

Calculate

(i) the kinetic energy of the raindrop,

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(ii) the work done on the raindrop as it falls through a vertical distance of 4.5 m.

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(4)

(c) The raindrop in part (b) now falls through air in which a horizontal wind is blowing. If the velocity of the wind is 1.4 m s^{-1}, use a scale diagram or calculation to determine the magnitude and direction of the resultant velocity of the raindrop.

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(3)
(Total 11 marks)

Q5. A packing case is being lifted vertically at a constant speed by a cable attached to a crane. The packing case has a mass of 640 kg.

(a) With reference to one of Newton's laws of motion, explain why the tension, T, in the cable must be equal to the weight of the packing case.

You may be awarded marks for the quality of written communication in your answer.

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(3)

(b) The packing case is lifted through a vertical height of 8.0 m in 4.5 s.

Calculate

(i) the work done on the packing case,

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(ii) the power output of the crane in this situation.

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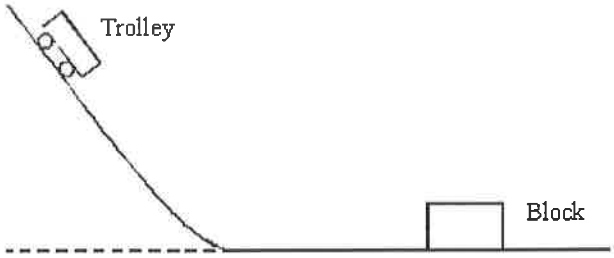
(3)
(Total 6 marks)

Q6. The diagram represents an experiment that can be used to investigate stopping distances for a moving trolley.



The trolley is placed on the raised section of the track. When released it moves down the track and then travels along the horizontal section before colliding with the block. The trolley and block join and move together after the collision. The distance they move is measured.

(a) State the main energy changes taking place

(i) as the trolley descends,

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(ii) after the collision, as the trolley and block move together.

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(2)

(b) Describe how the speed of the trolley, just before it collides with the block may be measured experimentally.

You may be awarded marks for the quality of written communication in your answer.

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(3)

(c) State and explain how the speed of the trolley, prior to impact could be varied.

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(2)
(Total 7 marks)

Q7. A skydiver of mass 70 kg, jumps from a stationary balloon and reaches a speed of 45 m s^{-1} after falling a distance of 150 m.

(a) Calculate the skydiver's

(i) loss of gravitational potential energy,

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(ii) gain in kinetic energy.

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(4)

(b) The difference between the loss of gravitational potential energy and the gain in kinetic energy is equal to the work done against air resistance. Use this fact to calculate

(i) the work done against air resistance,

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(ii) the average force due to air resistance acting on the skydiver.

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(3)
(Total 7 marks)

Materials

Density, Hooke's law, Young modulus

174 minutes

174 marks

Q1. A uniform wooden beam of mass 35.0 kg and length 5.52 m is supported by two identical vertical steel cables **A** and **B** attached at either end, as shown in **Figure 1**.

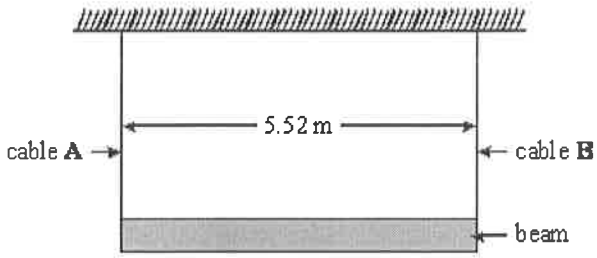

Figure 1

(a) Calculate

(i) the weight of the beam,

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(ii) the tension in each cable.

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(2)

(b) Each unstretched cable has a diameter of 8.26 mm and a length 2.50 m. Calculate the extension of each cable when supporting the beam.

The Young modulus for steel = 2.10×10^{11} Pa

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(4)

(c) An object of mass 20.0 kg is hung from the beam 1.00 m from cable **A**, as shown in **Figure 2**.

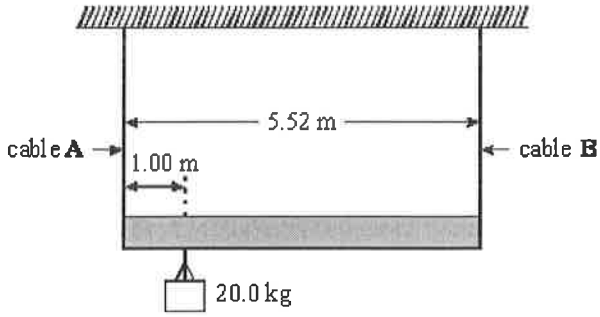

Figure 2

(i) Show that the new tension in cable **A** is 332 N.

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(ii) Calculate the new tension in cable **B**.

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(6)
(Total 12 marks)

Q2. A material in the form of a wire, 3.0 m long and cross-sectional area = 2.8×10^{-7} m^2 is suspended from a support so that it hangs vertically. Different masses may be suspended from its lower end. The table shows the extension of the wire when it is subjected to an increasing load and then a decreasing load.

load/N	0	24	52	70	82	88	94	101	71	50	16	0
extension/mm	0	2.2	4.6	6.4	7.4	8.2	9.6	13.0	10.2	8.0	4.8	3.2

(a) Plot a graph of load (on *y* axis) against extension (on *x* axis) both for increasing and decreasing loads.

(Allow one sheet of graph paper)

(4)

(b) Explain what the shape of the graph tells us about the behaviour of the material in the wire. You may be awarded marks for the quality of written communication in your answer.

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(4)

(c) Using the graph, determine a value of the Young modulus for the material of the wire.

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(3)

(d) State how the graph can be used to estimate the energy stored during the loading process.

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(1)
(Total 12 marks)

Q3. (a) Define the *density* of a material.

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(1)

(b) Brass, an alloy of copper and zinc, consists of 70% **by volume** of copper and 30% **by volume** of zinc.

density of copper $= 8.9 \times 10^3$ kg m^{-3}
density of zinc $= 7.1 \times 10^3$ kg m^{-3}

(i) Determine the mass of copper and the mass of zinc required to make a rod of brass of volume 0.80×10^{-3} m^3.

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(ii) Calculate the density of brass.

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(4)
(Total 5 marks)

Q4. (a) When a *tensile stress* is applied to a wire, a *tensile strain* is produced in the wire. State the meaning of

tensile stress, ...

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tensile strain. ....

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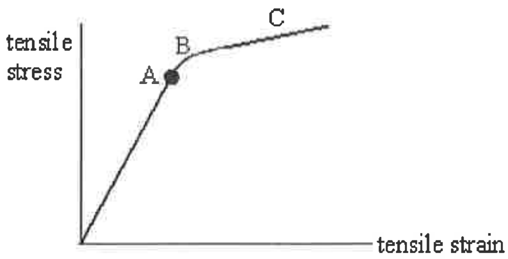
(2)

(b) A long thin line metallic wire is suspended from a fixed support and hangs vertically. Weights are added to increase the load on the free end of the wire until the wire breaks. The graph below shows how the tensile strain in the wire increases as the tensile stress increases.



With reference to the graph, describe the behaviour of the wire as the load on the free end is increased. To assist with your answer refer to the point A, and regions B and C.

You may be awarded marks for the quality of written communication in your answer.

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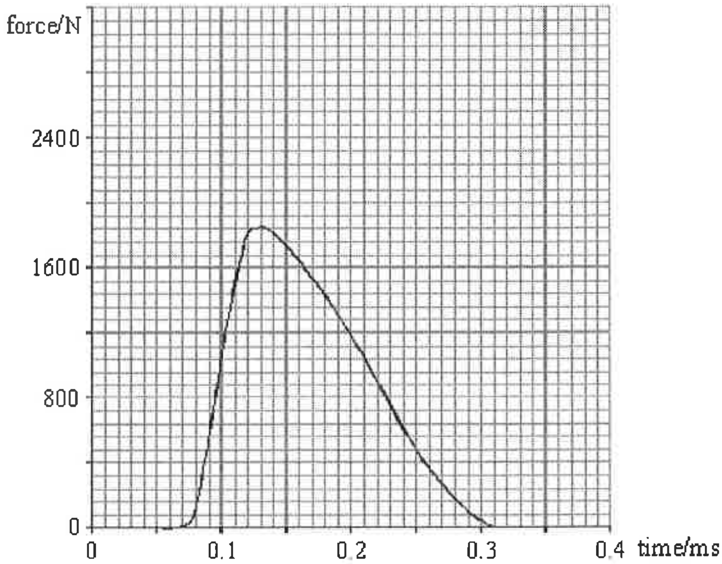
(5)
(Total 7 marks)

Q5. The diagram below shows how the impact force on the heel of a runner's foot varies with time during an impact when the runner is wearing cushioned sports shoes.



(a) Estimate the maximum stress on the cartilage pad in the knee joint as a result of this force acting on the cartilage pad over a contact area of 550 mm^2.

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(4)

(b) On the diagram above, sketch the graph of force against time you would expect to see if a sports shoe with less cushioning had been used.

(3)
(Total 7 marks)

Q6. (a) State *Hooke's law* for a material in the form of a wire.

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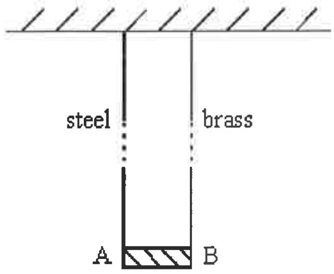
(2)

(b) A rigid bar AB of negligible mass, is suspended horizontally from two long, vertical wires as shown in the diagram. One wire is made of steel and the other of brass. The wires are fixed at their upper end to a rigid horizontal surface. Each wire is 2.5 m long but they have different cross-sectional areas.



When a mass of 16 kg is suspended from the centre of AB, the bar remains horizontal.

the Young modulus for steel = 2.0×10^{11} Pa

the Young modulus for brass = 1.0×10^{11} Pa

(i) What is the tension in each wire?

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(ii) If the cross-sectional area of the steel wire is 2.8×10^{-7} m^2, calculate the extension of the steel wire.

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(iii) Calculate the cross-sectional area of the brass wire.

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(iv) Calculate the energy stored in the steel wire.

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(7)

(c) The brass wire is replaced by a steel wire of the same dimensions as the brass wire. The same mass is suspended from the midpoint of AB.

(i) Which end of the bar is lower?

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(ii) Calculate the vertical distance between the ends of the bar.

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(2)
(Total 11 marks)

Q7. (a) When determining the Young modulus for the material of a wire, a *tensile stress* is applied to the wire and the *tensile strain* is measured.

(i) State the meaning of

tensile stress ....

....

tensile strain ....

....

(ii) Define the Young modulus ....

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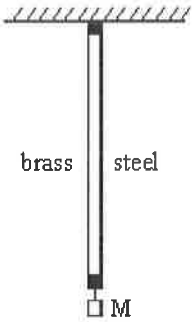
(3)

(b) The diagram below shows two wires, one made of steel and the other of brass, firmly clamped together at their ends. The wires have the same unstretched length and the same cross-sectional area.
One of the clamped ends is fixed to a horizontal support and a mass M is suspended from the other end, so that the wires hang vertically.



(i) Since the wires are clamped together the extension of each wire will be the same. If E_S is the Young modulus for steel and E_B the Young modulus for brass, show that

$$\frac{E_S}{E_B} = \frac{F_S}{F_B},$$

where F_S and F_B are the respective forces in the steel and brass wire.

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(ii) The mass M produces a total force of 15 N. Show that the magnitude of the force $F_S = 10$ N.

the Young modulus for steel = 2.0×10^{11} Pa
the Young modulus for brass = 1.0×10^{11} Pa

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(iii) The cross-sectional area of each wire is 1.4×10^{-6} m^2 and the unstretched length is 1.5 m. Determine the extension produced in either wire.

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(6)
(Total 9 marks)

Q8. (a) State *Hooke's law* for a material in the form of a wire and state the conditions under which this law applies.

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(2)

(b) A length of steel wire and a length of brass wire are joined together. This combination is suspended from a fixed support and a force of 80 N is applied at the bottom end, as shown in the figure below.

Each wire has a cross-sectional area of 2.4×10^{-6} m^2.

length of the steel wire = 0.80 m
length of the brass wire = 1.40 m
the Young modulus for steel = 2.0×10^{11} Pa
the Young modulus for brass = 1.0×10^{11} Pa

(i) Calculate the total extension produced when the force of 80 N is applied.

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(ii) Show that the mass of the combination wire = 4.4×10^{-2} kg.

density of steel = 7.9×10^3 kg m^{-3}
density of brass = 8.5×10^3 kg m^{-3}

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(7)

(c) A single brass wire has the same mass and the same cross-sectional area as the combination wire described in part (b). Calculate its length.

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(2)
(Total 11 marks)

Q9. (a) When a *tensile stress* is applied to a wire, a *tensile strain* is produced in the wire. State the meaning of

tensile stress, ...

....

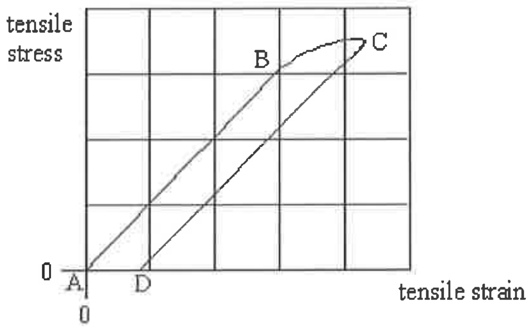
tensile strain. ....

....

(2)

(b) A long, thin metal wire is suspended from a fixed support and hangs vertically. Masses are suspended from its lower end.

As the load on the lower end is increased from zero to a certain value, and then decreased again to zero, the variation of the resulting tensile strain with the applied tensile stress is shown in the graph.



(i) Describe the behaviour of the wire during this process. Refer to the points A, B, C and D in your answer.
You may be awarded marks for the quality of written communication in your answer.

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(ii) State, with a reason, whether the material of the wire is ductile or brittle.

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(iii) What does AD represent?

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(iv) State how the Young modulus for the material may be obtained from the graph.

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(v) State how the energy per unit volume stored in the wire during the loading process may be estimated from the graph.

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(9)

(c) The wire described in part (b) has an unstretched length of 3.0 m and cross-sectional area 2.8×10^{-7} m^2. At a certain stage between the points A and B on the graph, the wire supports a load of 75 N. Calculate the extension produced in the wire by this load.
the Young modulus for the material of the wire = 2.1×10^{11} Pa

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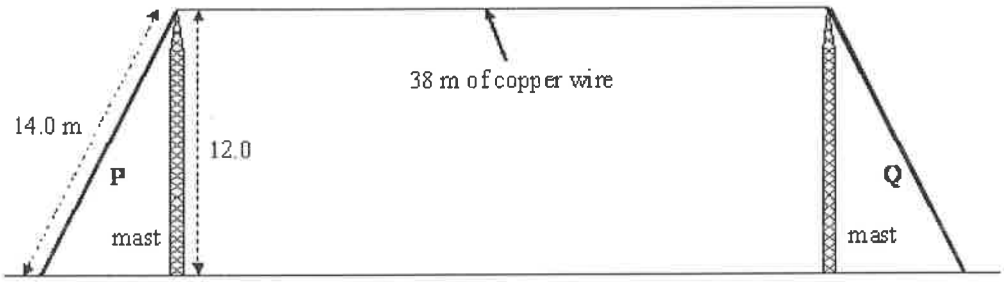
(2)
(Total 13 marks)

Q10. An aerial system consists of a horizontal copper wire of length 38 m supported between two masts, as shown in the figure below. The wire transmits electromagnetic waves when an alternating potential is applied to it at one end.



(a) The wavelength of the radiation transmitted from the wire is twice the length of the copper wire. Calculate the frequency of the transmitted radiation.

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(1)

(b) The ends of the copper wire are fixed to masts of height 12.0 m. The masts are held in a vertical position by cables, labelled **P** and **Q**, as shown in the figure above.

(i) **P** has a length of 14.0 m and the tension in it is 110 N. Calculate the tension in the copper wire.

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(ii) The copper wire has a diameter of 4.0 mm. Calculate the stress in the copper wire.

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(iii) Discuss whether the wire is in danger of breaking if it is stretched further due to movement of the top of the masts in strong winds.

breaking stress of copper = 3.0×10^8 Pa

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(7)
(Total 8 marks)

Q11. (a) (i) Describe the behaviour of a wire that obeys Hooke's law.

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(ii) Explain what is meant by the elastic limit of the wire.

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(iii) Define the Young modulus of a material and state the unit in which it is measured.

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(5)

(b) A student is required to carry out an experiment and draw a suitable graph in order to obtain a value for the Young modulus of a material in the form of a wire.
A long, uniform wire is suspended vertically and a weight, sufficient to make the wire taut, is fixed to the free end. The student increases the load gradually by adding known weights. As each weight is added, the extension of the wire is measured accurately.

(i) What other quantities must be measured before the value of the Young modulus can be obtained?

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(ii) Explain how the student may obtain a value of the Young modulus.

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(iii) How would a value for the elastic energy stored in the wire be found from the results?

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(6)
(Total 11 marks)

Q12. (a) (i) Describe the behaviour of a wire that obeys Hooke's law.

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(ii) Explain what is meant by the elastic limit of the wire.

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(iii) Define the Young modulus of a material and state the unit in which it is measured.

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(5)

(b) A student is required to carry out an experiment and draw a suitable graph in order to obtain a value for the Young modulus of a material in the form of a wire. A long, uniform wire is suspended vertically and a weight, sufficient to make the wire taut, is fixed to the free end. The student increases the load gradually by adding known weights. As each weight is added, the extension of the wire is measured accurately.

(i) What other quantities must be measured before the value of the Young modulus can be obtained?

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(ii) Explain how the student may obtain a value of the Young modulus.

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(iii) How would a value for the elastic energy stored in the wire be found from the results?

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(6)
(Total 11 marks)

Q13. (a) State Hooke's law.

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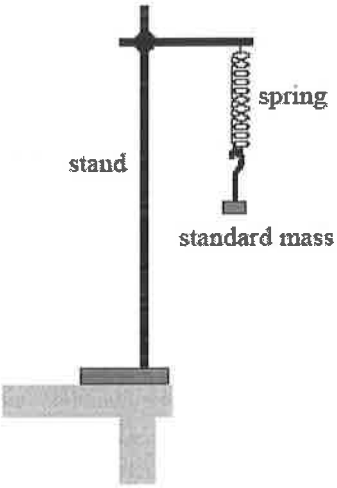
(2)

(b) A student is asked to measure the mass of a rock sample using a steel spring, standard masses and a metre rule. She measured the unstretched length of the spring and then set up the arrangement shown in the diagram below.



(i) Describe how you would use this arrangement to measure the mass of the rock sample. State the measurements you would make and explain how you would use the measurements to find the mass of the rock sample.
The quality of your written communication will be assessed in this question.

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(6)

(ii) State and explain **one** modification you could make to the arrangement in the diagram above to make it more stable.

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(2)
(Total 10 marks)

Q14. (a) Describe how to obtain, accurately by experiment, the data to determine the Young modulus of a metal wire.

A space is provided for a labelled diagram.

The quality of your written answer will be assessed in this question.

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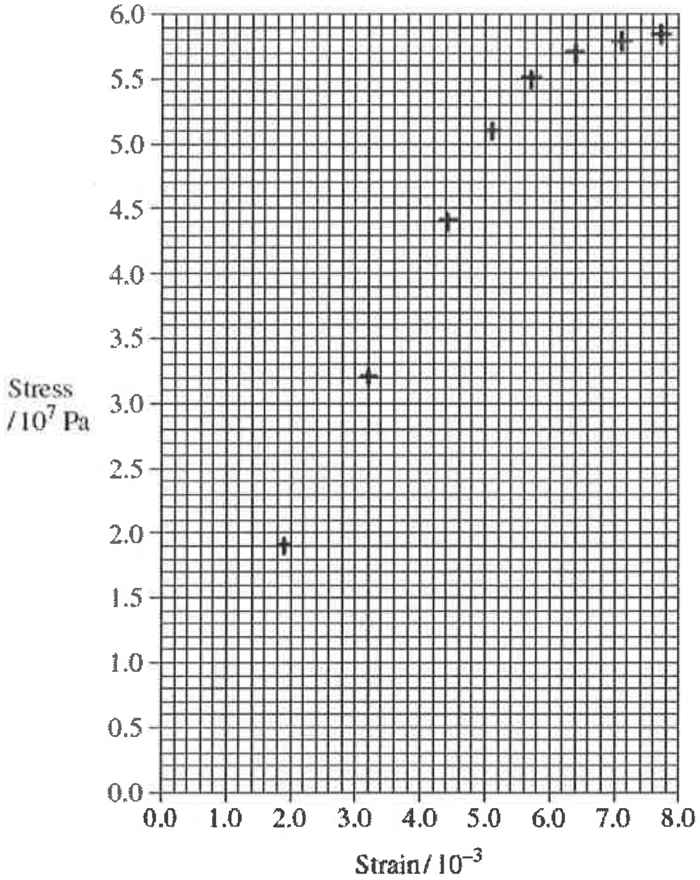
(6)

(b) The diagram below is a plot of some results from an experiment in which a metal wire was stretched.



(i) Draw a best-fit line using the data points.

(1)

(ii) Use your line to find the Young modulus of the metal, stating an appropriate unit.

answer = ...

(4)

(c) After reaching a strain of 7.7×10^{-3}, the wire is to be unloaded. On the diagram above, sketch the line you would expect to obtain for this.

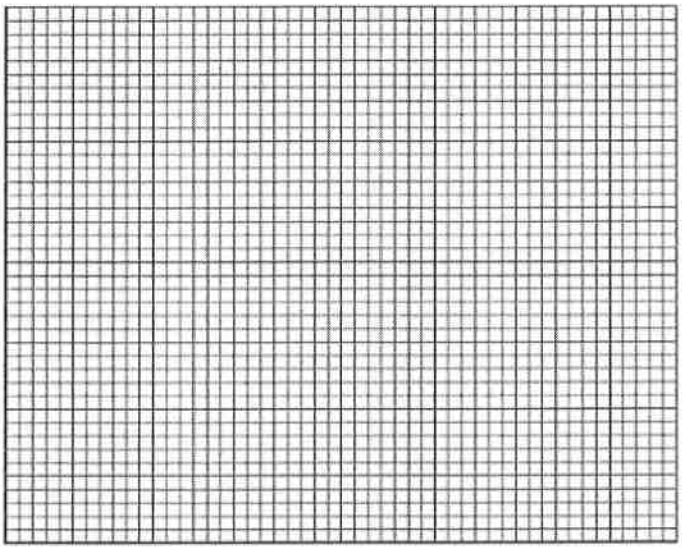
(1)
(Total 12 marks)

Q15. The table below shows the results of an experiment where a force was applied to a sample of metal.

(a) On the axes below, plot a graph of stress against strain using the data in the table.

Strain / 10^{-3}	0	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
Stress / 10^8 Pa	0	0.90	2.15	3.15	3.35	3.20	3.30	3.50	3.60	3.60	3.50

stress / 10^8 Pa



strain / 10^{-3}

(3)

(b) Use your graph to find the Young modulus of the metal.

answer = ... Pa

(2)

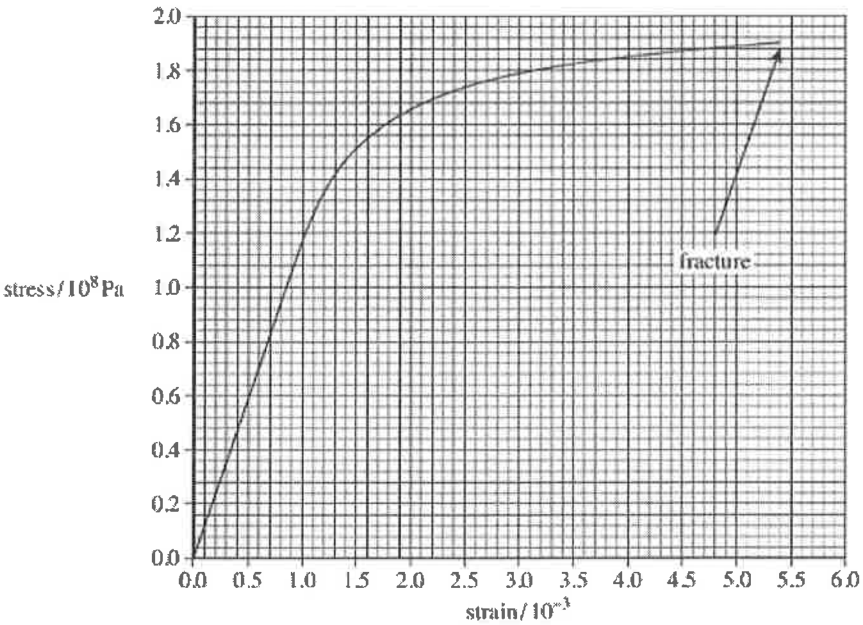
(c) A 3.0 m length of steel rod is going to be used in the construction of a bridge. The tension in the rod will be 10 kN and the rod must extend by no more than 1.0mm. Calculate the minimum cross-sectional area required for the rod.

Young modulus of steel = 1.90×10^{11} Pa

answer = ... m^2

(3)
(Total 8 marks)

Q16. The figure below shows a stress-strain graph for a copper wire.



(a) Define tensile strain.

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(1)

(b) State the breaking stress of this copper wire.

answer = ... Pa

(1)

(c) Mark on the figure above a point on the line where you consider plastic deformation may start.
Label this point **A**.

(1)

(d) Use the graph to calculate the Young modulus of copper. State an appropriate unit for your answer.

answer = ...

(3)

(e) The area under the line in a stress-strain graph represents the work done per unit volume to stretch the wire.

(i) Use the graph to find the work done per unit volume in stretching the wire to a strain of 3.0×10^{-3}.

answer = ...J m^{-3}

(2)

(ii) Calculate the work done to stretch a 0.015 kg sample of this wire to a strain of 3.0×10^{-3}.

The density of copper = 8960 kg m^{-3}.

answer = ...J

(2)

(f) A certain material has a Young modulus greater than copper and undergoes brittle fracture at a stress of 176 MPa.

On the figure above draw a line showing the possible variation of stress with strain for this material.

(2)
(Total 12 marks)

Q17. (a) Describe an experiment to accurately determine the spring constant *k* of a spring that is thought to reach its limit of proportionality when the load is about 20 N.

Include details of the necessary measurements and calculations and describe how you would reduce uncertainty in your measurements. A space is provided for a labelled diagram should you wish to include one.

The quality of your written communication will be assessed in this question.

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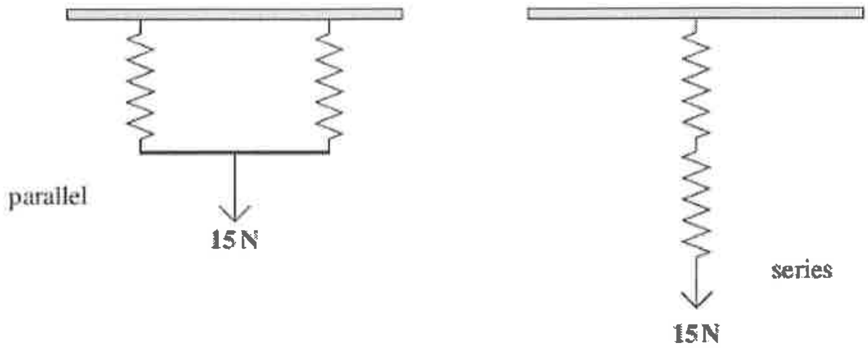
(6)

(b) Two identical springs, each having a spring constant of 85 Nm^{-1}, are shown arranged in parallel and series in the figure below.



A load of 15 N is attached to each arrangement.

(i) Calculate the extension for the parallel arrangement when the load is midway between the lower ends of the springs.

answer = ... m

(2)

(ii) Calculate the extension for the series arrangement.

answer = ... m

(2)

(iii) Calculate the energy stored in the parallel arrangement.

answer = ... J

(2)

(iv) Without further calculation, discuss whether the energy stored in the series arrangement is less, or greater, or the same as in the parallel arrangement.

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(3)
(Total 15 marks)

Optics

Refection, refraction, total internal reflection

55 minutes

55 marks

Q1. **Figure 1** shows a cross-section through a rectangular light-emitting diode (LED). When current passes through the LED, light is emitted from the semiconductor material at P and passes through the transparent material and into the air at Q.

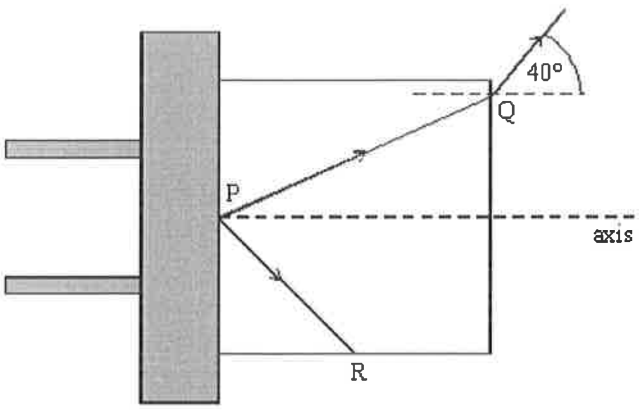

Figure 1

(a) (i) The refractive index of the transparent material of the LED is 1.5. Calculate the critical angle of this material when the LED is in air.

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(ii) **Figure 1** shows a light ray PQ incident on the surface at Q. Calculate the angle of incidence of this light ray at Q if the angle of refraction is 40°.

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(iii) **Figure 1** also shows a second light ray PR incident at R at an angle of incidence of 45°. Use **Figure 1** to explain why this light ray cannot escape into the air.

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(7)

(b) The LED in part (a) is used to send pulses of light down two straight optical fibres of the same refractive index as the transparent material of the LED. The fibres are placed end-on with the LED, as shown in **Figure 2**. Optical fibre 1 is positioned at Q and the other at S directly opposite P.

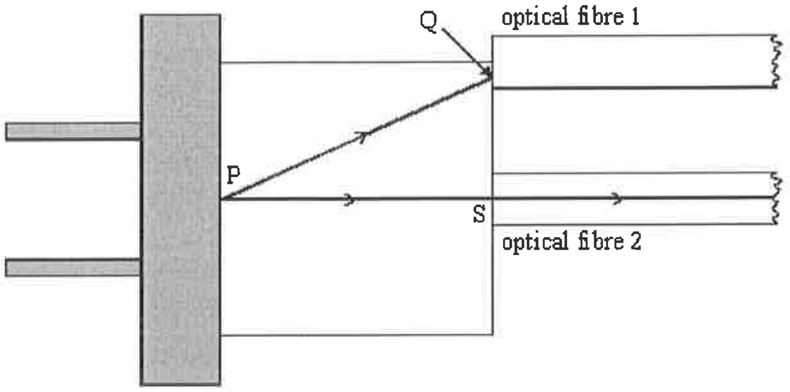

Figure 2

(i) Continue the path of the light ray PQ into and along the optical fibre.

(ii) Compare the times taken for pulses of light to travel along the same length of each fibre.

Give a reason for your answer.

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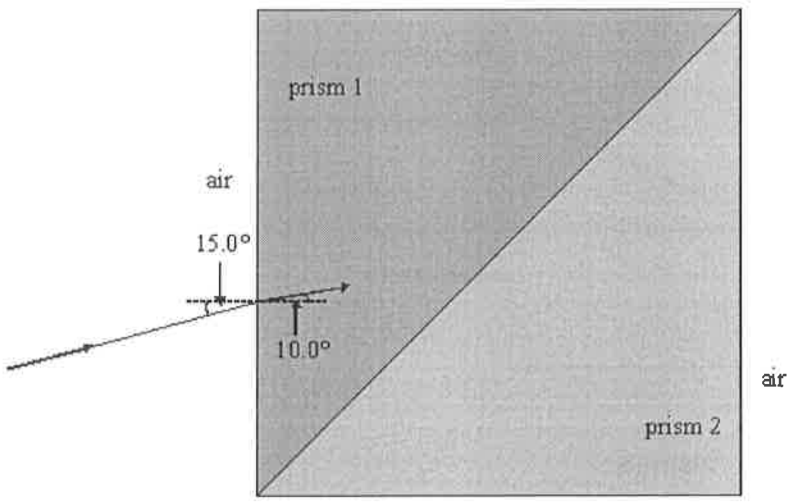
(3)
(Total 10 marks)

Q2. A ray of light passes from air into a glass prism as shown in **Figure 1**.

Figure 1



(a) Confirm, by calculation, that the refractive index of the glass from which the prism was made is 1.49.

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(1)

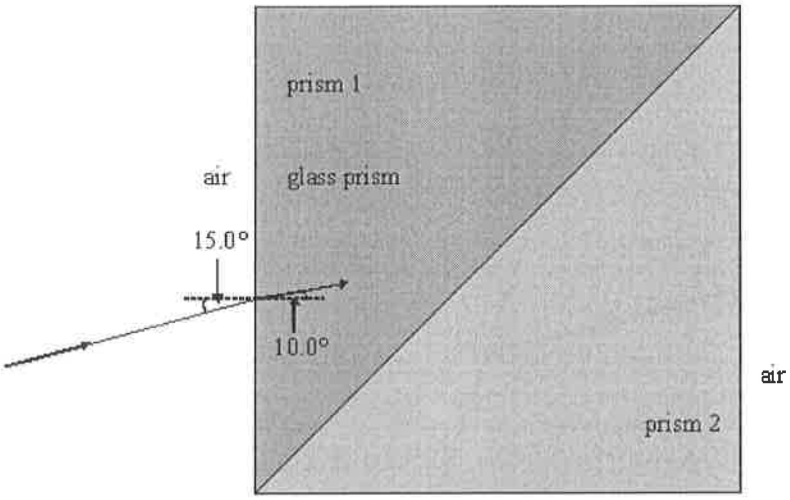
(b) On **Figure 1**, draw the continuation of the path of the ray of light until it emerges back into the air. Write on **Figure 1** the values of the angles between the ray and any normals you have drawn.

the critical angle from glass to air is less than 45°

(2)

(c) A second prism, prism 2, made from transparent material of refractive index 1.37 is placed firmly against the original prism, prism 1, to form a cube as shown in **Figure 2**.

Figure 2



(i) The ray strikes the boundary between the prisms. Calculate the angle of refraction of the ray in prism 2.

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(ii) Calculate the speed of light in prism 2.

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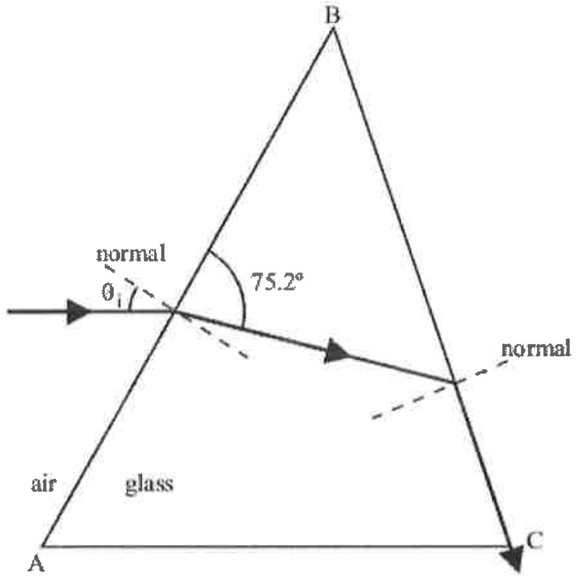
(iii) Draw a path the ray could follow to emerge from prism 2 into the air.

(7)
(Total 10 marks)

Q3. The diagram shows a ray of light passing from air into a glass prism at an angle of incidence θ_i. The light emerges from face BC as shown.

refractive index of the glass = 1.55



(a) (i) Mark the critical angle along the path of the ray with the symbol θ_c.

(ii) Calculate the critical angle, θ_c.

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(3)

(b) For the ray shown calculate the angle of incidence, θ_i.

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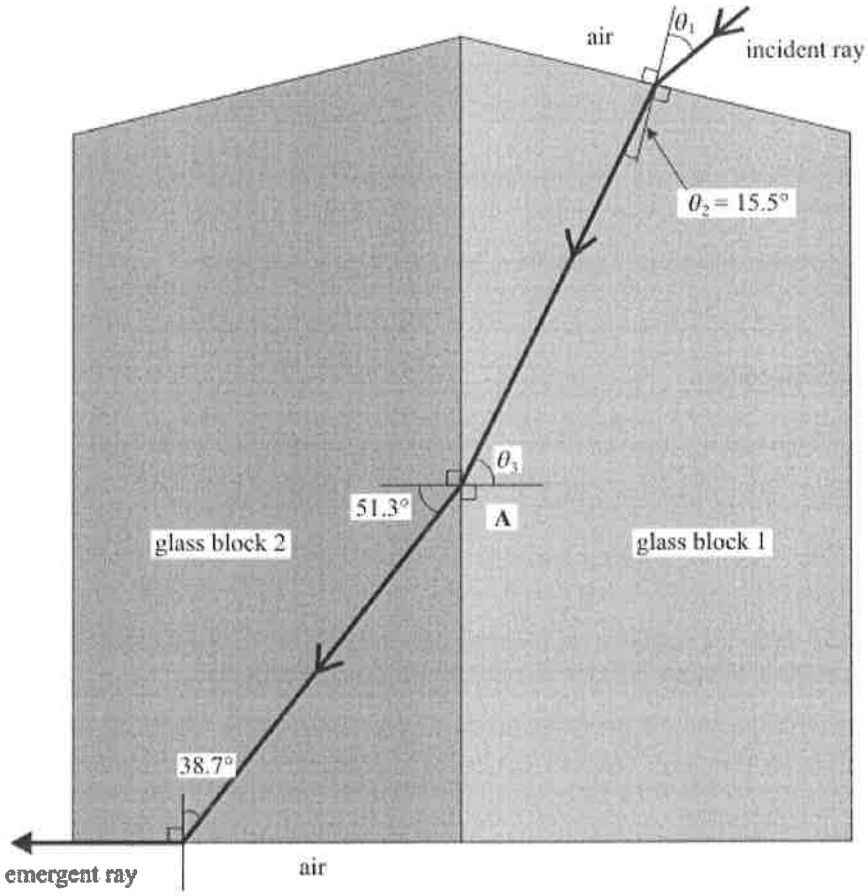
(2)

(c) Without further calculations draw the path of another ray of light incident at the same point on the prism but with a smaller angle of incidence. The path should show the ray emerging from the prism into the air.

(3)
(Total 8 marks)

Q4. The figure below shows a ray of light passing from air into glass at the top face of glass block 1 and emerging along the bottom face of glass block 2.

refractive index of the glass in block 1 = 1.45



(a) Calculate

(i) the incident angle θ_1,

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....

....

(ii) the refractive index of the glass in block 2,

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....

(iii) the angle θ_3 by considering the refraction at point **A**.

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(7)

(b) In which of the two blocks of glass will the speed of light be greater?

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Explain your reasoning.

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....

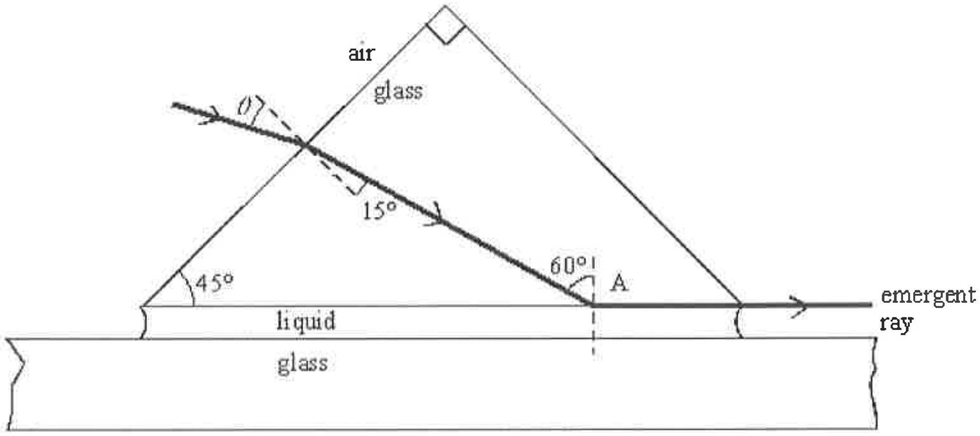
(2)

(c) Using a ruler, draw the path of a ray partially reflected at **A** on the figure above. Continue the ray to show it emerging into the air. No calculations are expected.

(2)
(Total 11 marks)

Q5. The diagram, which is not to scale, shows the cross-section of a 45° right angled glass prism supported by a film of liquid on a glass table. A ray of monochromatic light is incident on the prism at an angle of incidence θ and emerges along the glass - liquid boundary as shown.

refractive index of glass = 1.5



(a) Calculate the speed of light in the glass.

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(2)

(b) Determine

(i) the angle of incidence, θ,

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(ii) the refractive index of the liquid.

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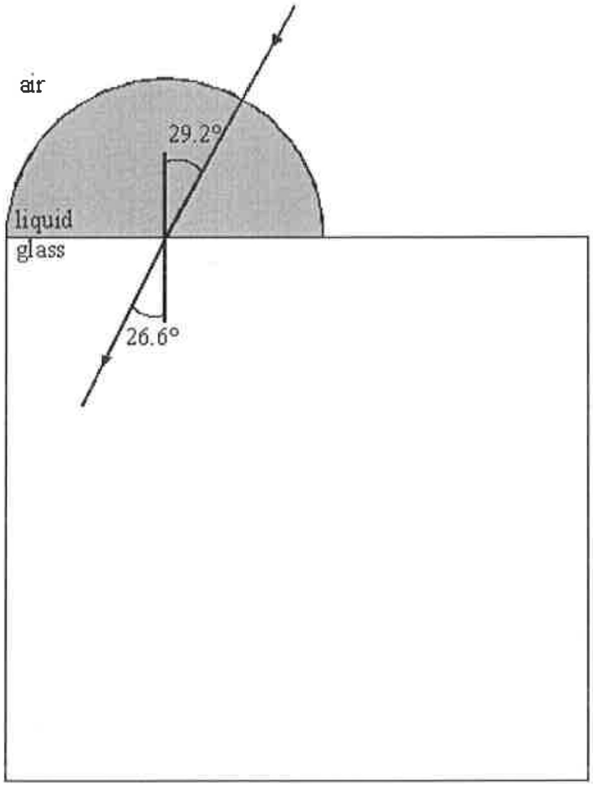
(5)

(c) The liquid is now changed to one with a lower refractive index. Draw a possible path for the ray beyond the point A and into the air.

(2)
(Total 9 marks)

Q6. The diagram below shows a liquid droplet placed on a cube of glass. A ray of light from air, incident normally on to the droplet, continues in a straight line and is refracted at the liquid to glass boundary as shown.
refractive index of the glass = 1.45



(a) Calculate the speed of light

(i) in the glass,

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(ii) in the liquid droplet.

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(3)

(b) Calculate the refractive index of the liquid.

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(2)

(c) On the diagram above, complete the path of the ray showing it emerge from the glass cube into the air.
No further calculations are required.

(2)
(Total 7 marks)