Bulk Properties of Solids

Question Paper

Name: _____

Class: _____

Date: _____

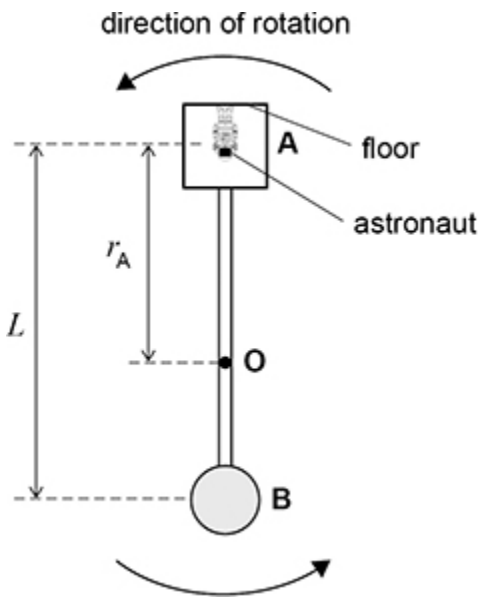
Time: **84 minutes**

Marks: **60 marks**

Comments:

1. **Figure 1** shows a rotating spacecraft that is proposed to carry astronauts to Mars.

Figure 1



The spacecraft consists of two parts **A** and **B** connected by a rigid cylindrical rod. When the spacecraft is travelling, **A** and **B** rotate at a constant angular speed about their common centre of mass **O**.

L is the distance between the centre of mass of **A** and the centre of mass of **B**. r_A is the distance from **O** to the centre of mass of **A**.

(a) As the spacecraft rotates, a force that imitates the effect of gravity acts on an astronaut who is in contact with the floor.

Explain why.

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(2)

(b) The forces exerted on **A** and **B** by the connecting rod have the same magnitude.

m_A is the mass of **A**
m_B is the mass of **B**

Show, by considering the centripetal forces acting on **A** and **B**, that r_A is given by

$$r_A = \frac{m_B L}{m_A + m_B}$$

(2)

(c) In this spacecraft $m_A < m_B$.

Deduce whether the centre of mass of **A** or the centre of mass of **B** rotates with a greater linear speed.

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(2)

The astronauts live in **A** and the cargo is stored in **B**.

When loaded,

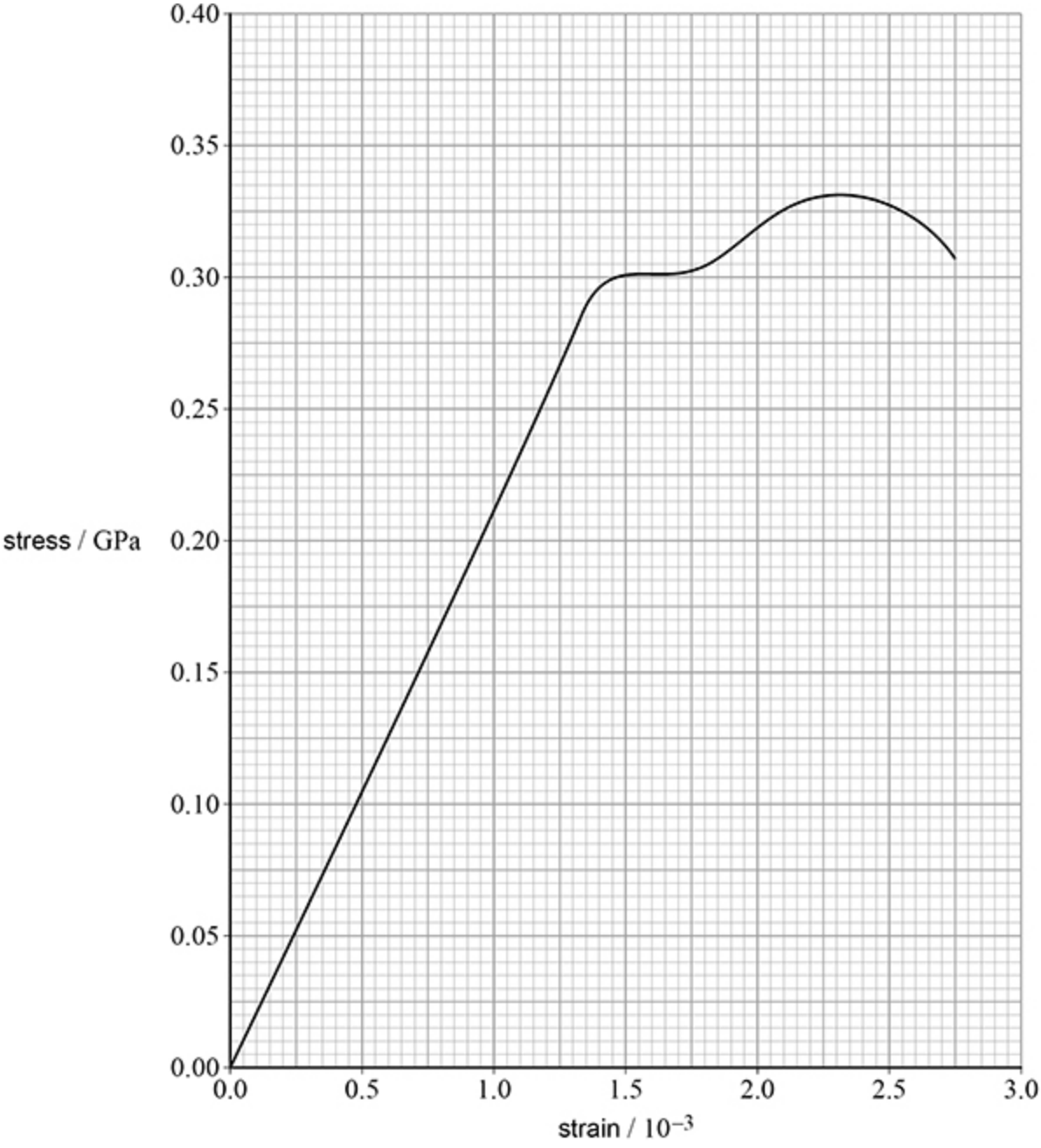
$m_A = 1.32 \times 10^6$ kg

$m_B = 3.30 \times 10^6$ kg.

The spacecraft imitates the gravity of Mars where $g = 3.7$ m s^{-2}.

Figure 2 shows a stress–strain curve for the metal used for the rigid rod.

Figure 2


stress / GPa
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
strain / 10^{-3}

(d) Suggest a suitable diameter for the rod.
Justify your answer.

diameter = _____ m

_____

_____

_____

_____

_____

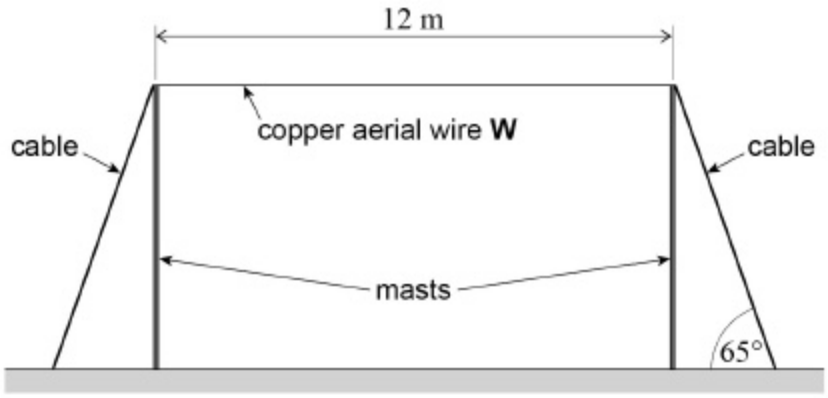
_____

(5)

(Total 11 marks)

2. **Figure 1** shows a structure that supports a horizontal copper aerial wire **W** used for transmitting radio signals.

Figure 1



The copper aerial wire is 12 m long and its area of cross-section is 1.6×10^{-5} m^2.
The tension in the copper aerial wire is 5.0×10^2 N.

Young modulus of copper = 1.2×10^{11} Pa

(a) Show that the extension produced in a 12 m length of the aerial wire when the tension is 5.0×10^2 N is less than 4 mm.

(2)

(b) The cables that support each mast are at an angle of 65° to the horizontal.

Calculate the tension in each supporting cable so that there is no resultant horizontal force on either mast.

tension = _____ N

(1)

(c) When wind blows, stationary waves can be formed on the aerial wire.

Explain how stationary waves are produced and why only waves of specific frequencies can form on the aerial wire.

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(4)

(d) Calculate the mass of a 1.0 m length of the aerial wire.

Density of copper = 8900 kg m^{-3}

mass = _____ kg

(1)

(e) Calculate the frequency of the wave when the third harmonic is formed on the aerial wire.

frequency = _____ Hz

(2)

(f) Sketch, on **Figure 2**, the standing wave on the wire when the third harmonic is formed.

Figure 2

(1)

(g) High winds produce large amplitudes of vibration of the aerial wire.

Explain why the wire may sag when the high wind stops.

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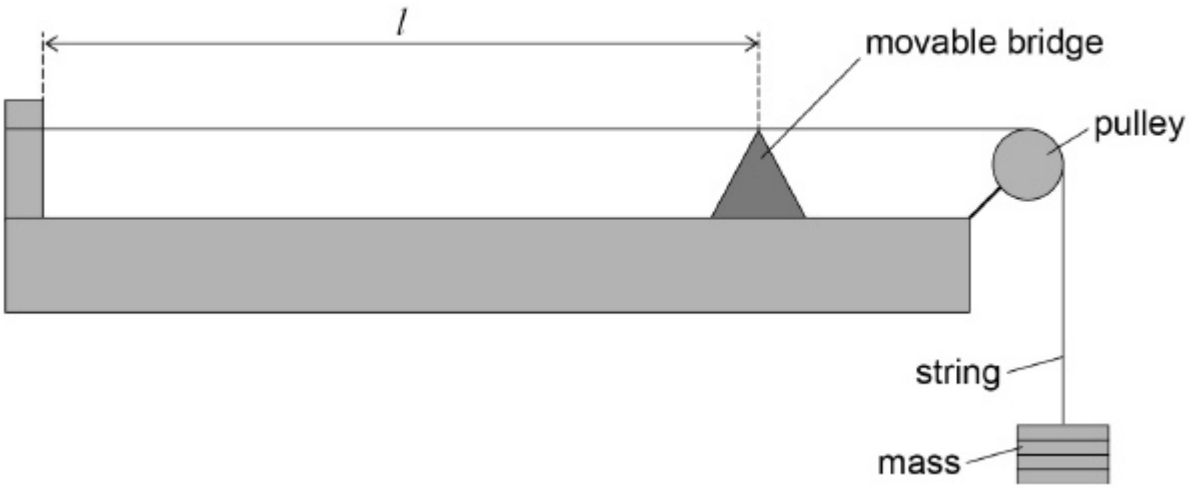
(2)

(Total 13 marks)

3. The diagram shows an arrangement used by a student to investigate vibrations in a stretched nylon string of fixed length l. He measures how the frequency f of first-harmonic vibrations for the string varies with the mass m suspended from it.



The table shows the results of the experiment.

m / kg	f / Hz
0.50	110
0.80	140
1.20	170

(a) Show that the data in the table are consistent with the relationship

$$f \propto \sqrt{T}$$

where T is the tension in the nylon string.

(2)

(b) The nylon string used has a density of 1150 kg m^{-3} and a uniform diameter of 5.0×10^{-4} m.

Determine the length l of the string used.

l = _____ m

(3)

(c) The student uses the relationship in question (a) to predict frequencies for tensions that are much larger than those used in the original experiment.

Explain how the actual frequencies produced would be different from those that the student predicts.

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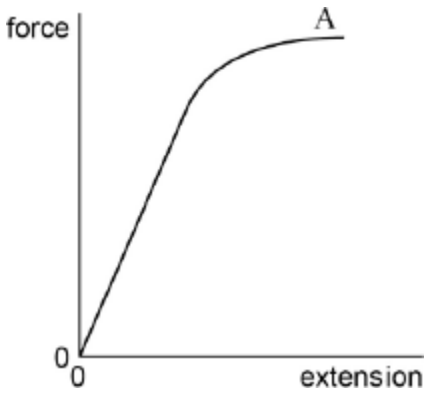
(2)

(Total 7 marks)

4. A student adds a series of masses to a vertical metal wire of circular cross–section and measures the extension of the wire produced. The figure below is a force-extension graph of the data.



(a) Mark on the figure the point P, the limit beyond which Hooke's law is no longer obeyed.

(1)

(b) Outline how the student can use these results and other measurements to determine the Young modulus of the wire.

_____

_____

_____

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(3)

(c) When the wire has been extended to A, the masses are removed one by one and the extension re-measured.

Draw, on the figure above, the shape of the graph that the student will obtain.

(1)

(d) Explain why the graph has the shape you have drawn.

_____

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_____

(2)

(e) The metal wire is used to make a cable of diameter 6.0 mm. The Young modulus of metal of the cable is 2.0×10^{11} Pa.

Calculate the force necessary to produce a strain of 0.20% in the cable.

force = _____ kN

(3)

(f) The cable is used in a crane to lift a mass of 600 kg.

Determine the maximum acceleration with which the mass can be lifted if the strain in the cable is not to exceed 0.20%.

acceleration = _____ m s^{-2}

(3)

(g) An engineer redesigns the crane to lift a 1200 kg load at the same maximum acceleration.

Discuss the changes that could be made to the cable of the crane to achieve this, without exceeding 0.20% strain.

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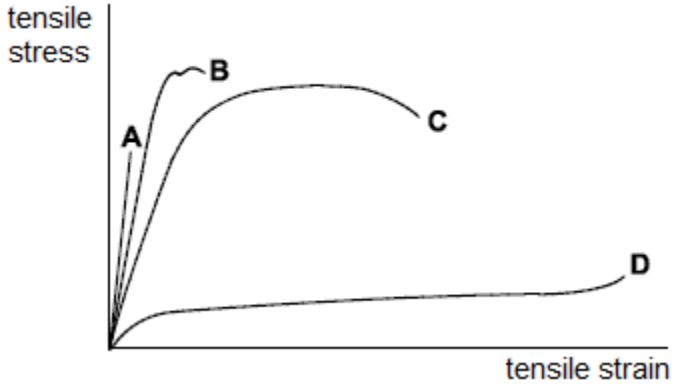
(3)

(Total 16 marks)

5. The diagram below shows the tensile stress–tensile strain graphs for four materials, **A**, **B**, **C** and **D**, up to their breaking stress.



(a) State what is meant by tensile stress and tensile strain.

tensile stress _____

_____

_____

tensile strain _____

_____

_____

(2)

(b) Identify a property of material **A** using evidence from the graph to support your choice.

property _____

evidence _____

_____

_____

_____

(2)

(c) A cylindrical specimen of material **A** under test has a diameter of 1.5×10^{-4} m and a breaking stress of 1.3 GPa.

Calculate the tensile force acting on the specimen at its breaking point.

tensile force = _____ N

(3)

(d) Discuss which of the four materials shown on the graph is most suitable for each of the following applications:

- the cable supporting a lift in a tall building
- a rope or cable attached to a person doing a bungee jump.

For each application, you should discuss the reason for your choice and why you rejected the other materials.

(6)

(Total 13 marks)