

Stress, strain and Young modulus worksheet

AQA AS and A level Physics 7407 and 7408

35–40 minutes independent work and 15–20 minutes review 36 marks

Specification points covered

3.4.2.1 Selected bulk properties of solids: tensile stress and strain, Hooke's law, elastic strain energy and stress–strain curves.

3.4.2.2 The Young modulus: calculations, stress–strain gradients and a simple measurement method; Required practical 4.

3.1.2 Selected measurement skills: percentage uncertainties and their combination, including powers.

1 The precision inspection platform

A precision inspection platform hangs from two identical vertical steel rods (Figure 1). The platform and payload have a combined mass of 24.0 kg. Their centre of mass is midway between the rods. The platform is horizontal and at rest, with no other support. Ignore the rods' weights. Take $g = 9.81 \text{ m s}^{-2}$.

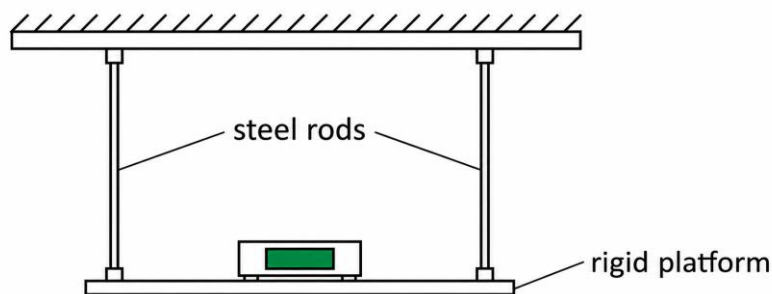


Figure 1 Not to scale

1(a) State what is meant by tensile stress and tensile strain in one of the rods. [2 marks]

1(b) Determine the tensile force in each rod. Explain why the two forces are equal. [2 marks]



1 Rod measurements

Table 1

Quantity for each original rod	Value
Original length L	0.800 m
Diameter d	1.00 mm
Measured extension ΔL at full load	0.600 mm

1(c) Use Table 1 to calculate the tensile stress in each rod. [2 marks]

1(d) Calculate the tensile strain in each rod. [1 mark]

1(e) Determine the Young modulus of the steel. [1 mark]

1(f) The maximum permitted working stress is 200 MPa. For accurate inspection, neither rod may extend by more than 0.500 mm. A technician says that meeting the working-stress limit is sufficient to approve the rods. Evaluate this claim using your results. [2 marks]

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2 Choosing a rod design

The engineer considers alternative rods for the same 24.0 kg combined load. Use $E = 2.00 \times 10^{11}$ Pa for steel. All proposed materials obey Hooke's law under the stated loads. The extension limit remains 0.500 mm.

2(a) Both rods are made 1.60 m long, with their diameter, material and tensile force unchanged. Predict the new extension of each rod and justify your prediction using the Young modulus relationship. **[2 marks]**

2(b) Instead, both original rods are replaced by steel rods of length 0.800 m and diameter 1.20 mm. Determine the extension of each replacement rod. **[1 mark]**

2(c) Determine the minimum diameter of a steel rod of length 0.800 m that meets the 0.500 mm extension limit under the same tensile force. Give a suitable diameter to three significant figures. **[2 marks]**

2(d) An alloy has a Young modulus of 8.00×10^{10} Pa and a breaking stress of 900 MPa. The steel has a breaking stress of 700 MPa. Calculate the extension if both original rods are replaced by alloy rods of the same original dimensions. Explain whether the larger breaking stress makes the alloy a better choice for maintaining alignment. **[2 marks]**

2(e) For the two 1.20 mm diameter steel rods in 2(b), calculate the total elastic strain energy stored at full load, relative to their unstretched states. **[2 marks]**

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3 Checking the supplier data

The laboratory tests a fresh specimen from the same batch of steel. Figure 2 shows its loading curve. Laboratory test stresses can exceed the permitted working stress for the platform.

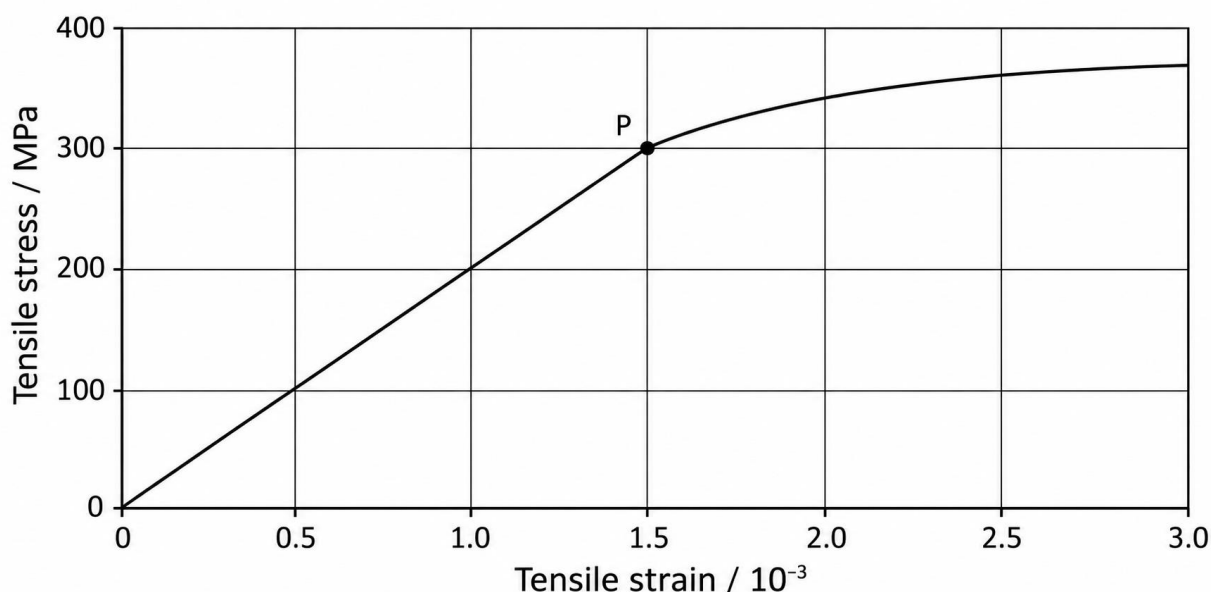


Figure 2 Loading curve

3(a) Determine the Young modulus from Figure 2. Show clearly which graph values you use. **[2 marks]**

3(b) Point P is at the end of the straight section. A technician labels P as the elastic limit. Explain why this loading graph alone does not justify that label. **[2 marks]**

3(c) The laboratory compares the elastic strain energy stored per unit volume. Starting from $W = \frac{1}{2}F\Delta L$, show that $W/(AL) = \frac{1}{2}\sigma\epsilon$, where σ is tensile stress and ϵ is tensile strain. Use Figure 2 to calculate this energy per unit volume at a strain of 1.00×10^{-3} . **[3 marks]**

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4 Confirming the material experimentally

Before approving the rods, the laboratory checks the steel using a long thin test wire from the same batch. Table 2 gives one set of measurements and their absolute uncertainties. The force and extension are measured from the same small-preload reference.

Table 2

Quantity	Measured value	Absolute uncertainty
Diameter d	0.400 mm	± 0.002 mm
Original gauge length L	1.200 m	± 0.001 m
Added tensile force F	30.0 N	± 0.2 N
Extension ΔL	1.44 mm	± 0.04 mm

4(a) Calculate the percentage uncertainty in the cross-sectional area of the test wire. Explain why it is not equal to the percentage uncertainty in its diameter. **[2 marks]**

4(b) Use $E = FL/(A\Delta L)$ and the uncertainties in Table 2 to calculate the maximum percentage uncertainty in the measured Young modulus. **[2 marks]**



