

Springs, wires and the stiffness of materials

Physics grades 11-12 (A Level · IB · Class 11-12) · Worksheet

Name: _____ Date: _____ Class: _____

These problems practise Hooke's law, energy stored in springs and wires, stress, strain and the Young modulus. They suit A Level, IB physics and Class 11-12 students and include reading force-extension and stress-strain graphs. Always convert millimetres and square millimetres to metres first.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** A Level 3.4.2

Problem 1 Hooke's law in words (easy)

Aarav in Pune writes notes on springs.

1. State Hooke's law.
2. State the unit of the force constant k .
3. Describe the shape of the force-extension graph for a spring obeying Hooke's law.

Problem 2 Finding k (easy)

A force of 6.0 N extends a spring by 0.030 m.

1. Calculate the force constant.
2. Calculate the force needed for an extension of 0.045 m.
3. Calculate the extension produced by 15 N.

Problem 3 Stress in a wire (easy)

A wire of cross-sectional area 2.0 mm² carries a load of 500 N.

1. Convert the area to m².
2. Calculate the stress in Pa.
3. Express the stress in MPa.

Problem 4 Strain of a cable (easy)

A steel cable 3.00 m long stretches by 1.5 mm under load.

1. Convert the extension to metres.
2. Calculate the strain.
3. Express the strain as a percentage.

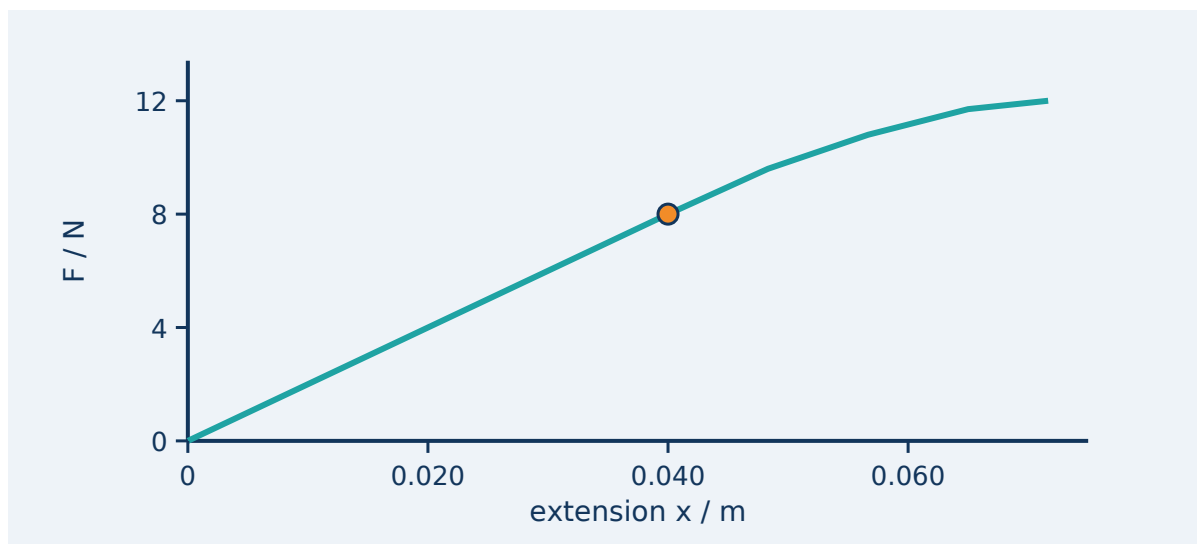
Problem 5 Young modulus from stress and strain (easy)

A material has a stress of 1.0×10^8 Pa when the strain is 5.0×10^{-4} .

1. Write the definition of the Young modulus.
2. Calculate the Young modulus.
3. Express your answer in GPa and say which material it suggests.

Problem 6 Reading a force-extension graph (easy)

Kofi in Accra tests a spring in the school lab.



Force against extension for a spring.

1. State the force at the limit of proportionality.
2. Calculate the force constant of the spring.
3. Calculate the energy stored at a force of 6.0 N.

Problem 7 Elastic or plastic? (easy)

Chiamaka in Lagos stretches a copper wire beyond its elastic limit and then removes the load.

1. State what happens to the length of the wire when the load is removed.
2. Define elastic deformation and plastic deformation.
3. Name one ductile material and one brittle material.

Problem 8 Copper wire stretch (medium)

Emma in Leeds hangs a load of 30 N from a copper wire of length 1.80 m and diameter 0.50 mm. The Young modulus of copper is 1.2×10^{11} Pa.

1. Calculate the cross-sectional area.
2. Calculate the stress and the strain.
3. Calculate the extension in mm.

Problem 9 Two wires compared (medium)

Wire A (length L , diameter d) extends by 4.0 mm under a load. Wire B is made of the same material, is twice as long and has twice the diameter. The same load is applied.

1. Explain how the extension depends on L and d .
2. Calculate the extension of B.
3. Predict the extension if B had half the diameter of A and the same length.

Problem 10 Catapult (medium)

Diego in Texas stretches a catapult band of force constant 120 N/m by 0.15 m and fires a 0.20 kg pebble. Assume all the stored energy becomes kinetic energy of the pebble.

1. Calculate the force needed to hold the band at this extension.
2. Calculate the stored energy.
3. Calculate the speed of the pebble.

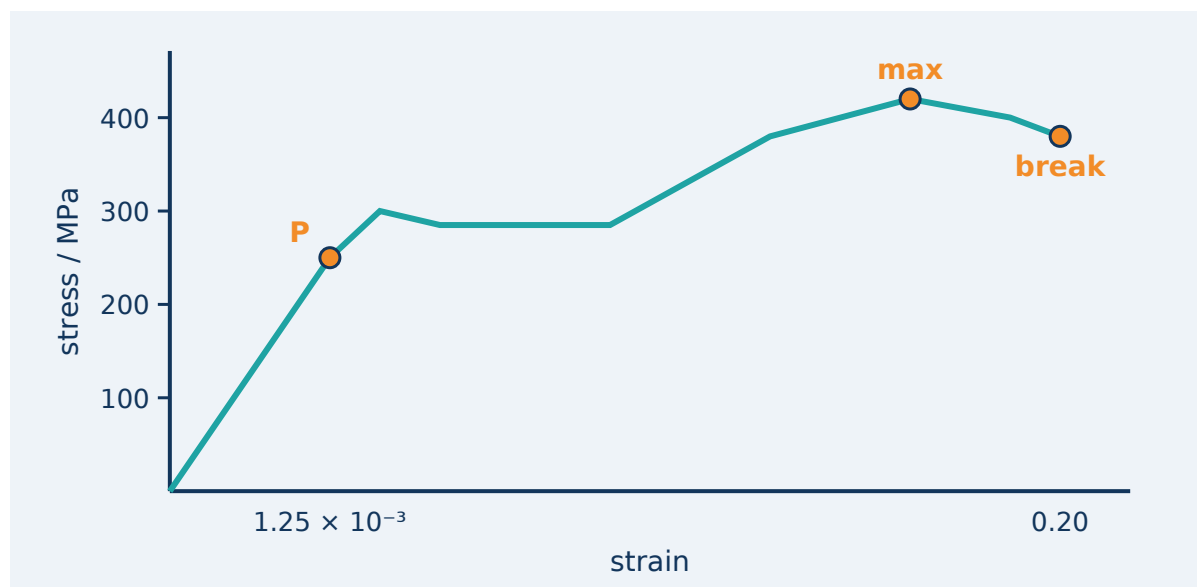
Problem 11 Energy stored in a wire (medium)

A wire of length 2.0 m and cross-sectional area $1.0 \times 10^{-6} \text{ m}^2$ stretches by 1.0 mm under a load of 200 N .

1. Calculate the elastic energy stored.
2. Calculate the volume of the wire.
3. Calculate the energy stored per unit volume and check it with $\frac{1}{2}\sigma\epsilon$.

Problem 12 Reading a stress-strain graph (medium)

Mei in Singapore tests a metal wire and obtains the graph. At the limit of proportionality P the strain is 1.25×10^{-3} .



Stress against strain for a metal wire.

1. Read the stress at P and the ultimate tensile stress.
2. Calculate the Young modulus.
3. State the breaking stress and explain why it is lower than the ultimate tensile stress.

Problem 13 Rubber band behaviour (medium)

A rubber band is stretched by increasing the load, and then the load is removed gradually. The unloading curve of force against extension lies below the loading curve.

1. State whether rubber obeys Hooke's law.
2. Explain what the area between the two curves represents.
3. Explain why a rubber band feels warm after repeated stretching.

Problem 14 Same stress, different strain (medium)

A stress of 100 MPa is applied to three rods of steel, aluminium and nylon with Young moduli of 200 GPa, 70 GPa and 3.0 GPa.

1. Calculate the strain in each rod.
2. State which rod is the stiffest.
3. State which rod extends most and by what factor compared with steel.

Problem 15 Crane cable (medium)

A crane cable has cross-sectional area 4.0 cm^2 . The breaking stress of its steel is $4.0 \times 10^8 \text{ Pa}$. Engineers use a safety factor of 4, so the working load is a quarter of the breaking load. Take $g = 9.81 \text{ m/s}^2$.

1. Convert the area to m^2 .
2. Calculate the breaking load.
3. Calculate the greatest safe mass.

Problem 16 Steel and copper in parallel (hard)

A steel wire and a copper wire have the same length (1.0 m) and cross-sectional area ($1.0 \times 10^{-6} \text{ m}^2$). They hang side by side and share a total load of 800 N, so both extend by the same amount. $E_{\text{steel}} = 200 \text{ GPa}$, $E_{\text{copper}} = 120 \text{ GPa}$.

1. Explain why the forces in the two wires are in the ratio of their Young moduli.
2. Calculate the force in each wire.
3. Calculate the common extension.

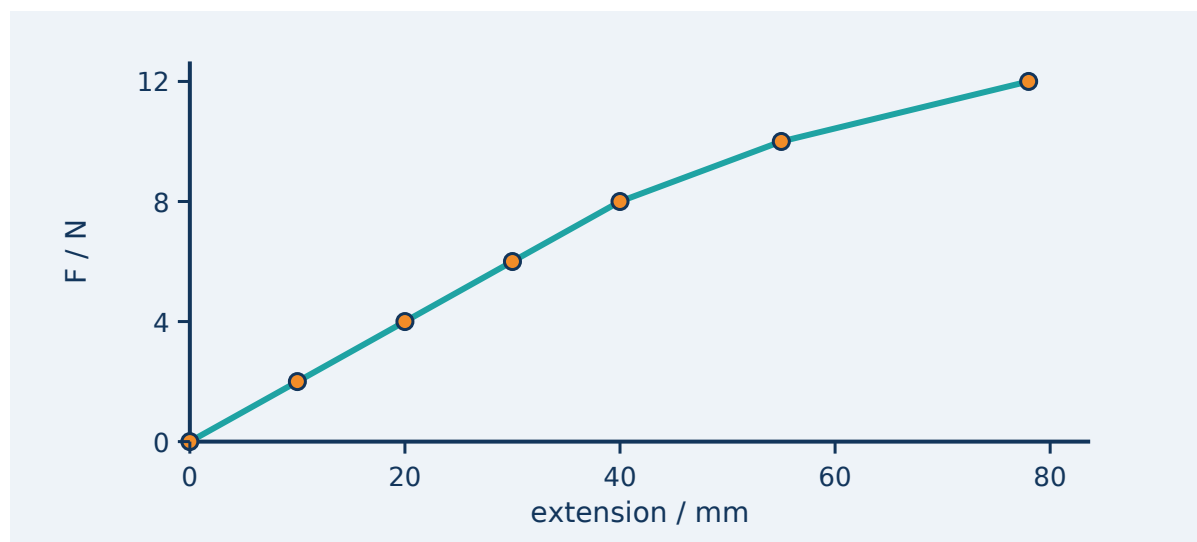
Problem 17 Sudden loading (hard)

A 10 kg mass is attached to the end of a steel wire ($L = 1.5 \text{ m}$, $A = 1.0 \text{ mm}^2$, $E = 2.0 \times 10^{11} \text{ Pa}$) that is just taut. The mass is released and falls until it first stops momentarily. Take $g = 9.81 \text{ m/s}^2$.

1. Calculate the force constant of the wire.
2. Calculate the extension when the mass hangs at rest.
3. Use energy conservation to show that the maximum extension is twice this, and calculate the maximum stress.

Problem 18 Polymer strip data (hard)

A student loads a polymer strip and plots the graph.



Force against extension for a polymer strip.

1. Identify the limit of proportionality and calculate k for the straight part.
2. Calculate the work done between 0 and 8 N using $\frac{1}{2}Fx$.
3. Estimate the total work done up to 12 N, using trapezia for the curved part.

Problem 19 Young modulus from a gradient (hard)

Bilal in Lahore plots force against extension for a wire of length 2.4 m and diameter 0.90 mm. The gradient is 1.86×10^4 N/m. The uncertainty in the diameter is ± 0.01 mm and in the length ± 2 mm.

1. Show that $E = \text{gradient} \times L \div A$.
2. Calculate the Young modulus.
3. Calculate the percentage uncertainty in E and identify the largest source.

Problem 20 Evaluate the claims (hard)

A student writes: "A thicker wire has a bigger Young modulus because it is stronger. For my copper wire, 1.2 mm extension on 2.0 m gives a strain of 0.6."

1. Explain why the first claim is wrong.
2. Identify and correct the error in the strain calculation.
3. State which quantity does depend on thickness.