Solids

Name _____ Date _____

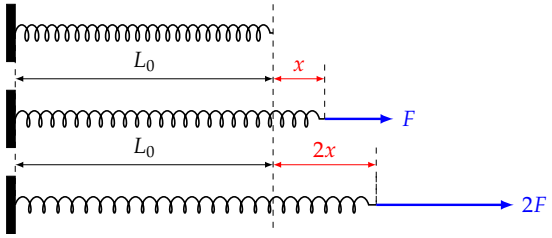
By the end of this topic I can…

- use Hooke's law, spring constant and elastic potential energy
- combine springs in series and in parallel
- define stress, strain and the Young modulus and use them
- interpret stress–strain graphs for metals, brittle materials, polymers and rubber

Springs

Hooke's law

Hooke's law: the extension of a spring is directly _____ to the load applied, provided the _____ is not exceeded:

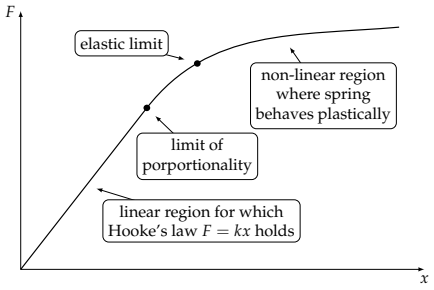


• k is the _____ (unit _____); a large k means a _____ spring

• Hooke's law holds for _____ as well as extension

• **limit of proportionality**: beyond this point F is no longer proportional to x

• **elastic limit**: beyond this point the spring does not return to its original length; it shows _____

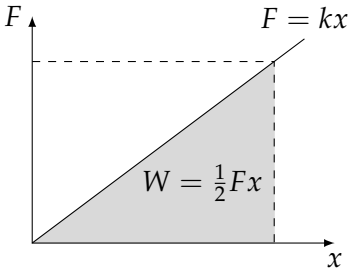


Example 7.1 A spring has a natural length of 20.0 cm. When a mass of 250 g is suspended from the spring, the new length of the spring is 26.0 cm. Find the spring constant.

Example 7.2 A spring has a spring constant of 270 N m^{-1}. A mass of 1.2 kg is hung from the spring. When the mass is released from a position where the spring has an extension of 5.0 cm, what is the acceleration of the mass?

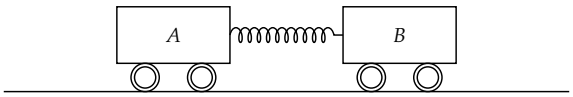
Elastic potential energy

The force varies as the spring is stretched, so the work done is the _____:



Example 7.3 A steel spring has a spring constant of 20 N cm^{-1}. How much work is needed to stretch it from an extension of 3.0 cm to an extension of 5.0 cm?

Example 7.4 A trolley of 400 g can travel freely along a horizontal surface. It is pushed against a spring buffer. Suppose the spring is initially compressed by 5.0 cm under a 20 N force. When the trolley is released, it accelerates until it becomes detached. What is the trolley's final speed?



Example 7.5 The same spring (compressed 5.0 cm by a 20 N force) is set between two trolleys A and B of masses 400 g and 600 g. After release, what are their final speeds?

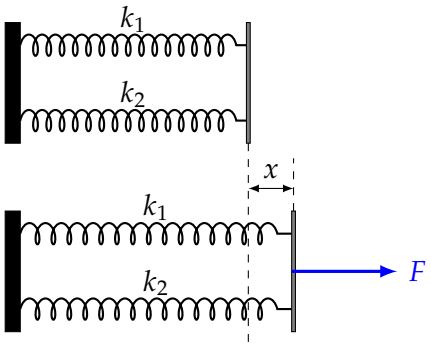
Combinations of springs

Parallel: same _____, forces add:

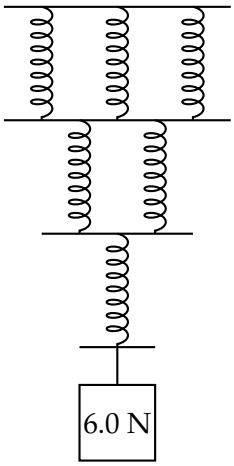
Series: same _____, extensions add:

• parallel springs are _____ than any one spring; series springs are _____

Example 7.6 (a) A spring with $k_1 = 20\ \text{N cm}^{-1}$ is connected in series with a second spring with $k_2 = 30\ \text{N cm}^{-1}$. When a force of 60 N is applied, what is the total extension of the combination? (b) The same two springs are now connected in parallel. When a force of 50 N is applied on the combination, what is the extension?



Example 7.7 A set of identical springs are set up as shown. Each individual spring extends by 1.0 cm under a load of 1.0 N. Assume the limit of proportionality is not exceeded, what is the total extension for this combination when a load of 6.0 N is applied?



Stress, strain and the Young modulus

Tensile stress is the

_____:

$[\sigma] =$ _____

Tensile strain is the

_____:

_____

Example 7.8 A copper wire has a cross-sectional area of 1.5×10^{-6} m^2. The breaking stress of the wire is 2.0×10^8 Pa. Find the breaking force.

The **Young modulus** is the ratio of _____ to _____ (below the limit of proportionality):

$[E] =$ _____

- the Young modulus is a property of the _____, independent of its shape or size
- rearranging gives the spring constant of a wire:

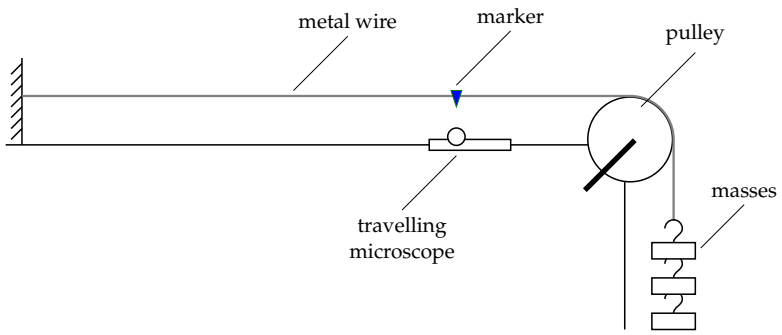
Example 7.9 A 200 N tensile force is applied on a steel wire of 1.5 m, the wire extends by 5.0 mm. The diameter of the cross section is 0.60 mm. What is the Young modulus of the steel wire?

Example 7.10 A copper wire of length 2.0 m is under a stress of 7.8×10^7 Pa. Given that the Young modulus of copper is 1.2×10^{11} Pa, what is (a) the strain of the wire, (b) the extension of the wire?

Example 7.11 Several blocks of steel are used to support a bridge. Each block has a height of 30 cm and a cross section of 15 cm $\times$ 15 cm. The steel block is designed to compress 2.0 mm when the maximum load is applied. Given that the Young modulus of steel is 2.1×10^{11} Pa, what is the maximum load that can be supported by one block?

Example 7.12 Two metal wires A and B are of the same length and they extend by the same amount under the same load. Given that Young modulus of wire A is twice of B, what is the ratio of their diameters?

Measuring the Young modulus

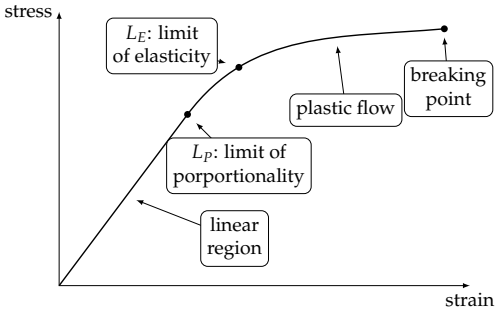


• measure the original length L with a _____, the diameter d with a _____ (several places), so $A = \frac{1}{4}\pi d^2$

• add masses m in steps, giving $F = mg$; measure the extension x at the marker

• plot _____: the _____ of the straight section is the _____

Stress–strain graphs



• up to the limit of proportionality, stress is _____ to strain

• **ductile** materials show _____ before breaking; **brittle** materials break with _____

• the _____ a stress–strain graph is the _____ (work done per unit volume)

• a wire stretched beyond its elastic limit shows _____ when unloaded; the area between the loading and unloading curves is the _____

Metals and polymers

• **metals:** positive ions in a sea of delocalised electrons; plastic deformation occurs as _____ move through the lattice

• **work hardening** and **alloying** stop dislocations moving, so the metal has a higher yield stress but is _____

• **polymers:** long chains; the chains _____ (large strain for small stress), then become taut and stiff

• **rubber:** the loading and unloading curves differ (_____); the area between them is the energy dissipated as _____

Practice questions

Question 7.1 A spring of force constant 500 N m^{-1} stretches to a length of 30 cm when a 40 N weight hangs from it. Find its natural length.

Question 7.2 Two springs have $k_1 = 8.0$ N cm^{-1} and $k_2 = 12$ N cm^{-1}. Find the total extension under a load of 60 N when they are connected (a) in parallel, (b) in series.

Question 7.3 A 100 N weight compresses a spring by 2.0 cm. Assuming Hooke's law, how much energy is stored in the spring?

Question 7.4 A 160 g trolley is pushed against a spring buffer of force constant 90 N m^{-1}, compressing it by 7.0 cm, then released from rest on a frictionless track. Find (a) the initial acceleration, (b) the final speed.

Question 7.5 A cable of diameter 1.5 mm carries a tension of 200 N. Find the stress in the cable.

Question 7.6 A wire of natural length 1.8 m and diameter 0.70 mm hangs from a ceiling. A 6.5 kg mass on its lower end extends it by 2.7 mm. Find (a) the strain, (b) the Young modulus.

Question 7.7 A wire of diameter 0.50 mm and Young modulus 0.18 TPa is lengthened by 0.20% by a force F. Find (a) the stress, (b) F.

Question 7.8 Rods A and B of the same diameter are joined end to end and hang vertically. Rod B is twice as long as A but has half the Young modulus. What is the ratio of the extension of A to the extension of B?