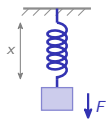


Deformation of Solids

AS Physics ■ Topic 6

A-Level Physics



Deformation of Solids

What we will cover

- 1 Forces and deformation
- 2 Hooke's law
- 3 Stress, strain & Young modulus
- 4 Elastic vs plastic
- 5 Energy stored
- 6 Recap



1 Forces and deformation

Deformation of Solids
└ Forces and deformation

Forces that change shape

A force along the length changes the shape – **deformation** 形变. Two one-dimensional cases:

Tensile 拉伸

stretches → **extension** 伸长量 x



Compressive 压缩

squeezes → a **compression** 压缩, a negative x



Tensile testing machine

The applied force is the **load** 负载; the shape change is measured from the natural length.

2 Hooke's law

Deformation of Solids
└ Hooke's law

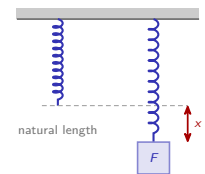
Hooke's law

Extension is **proportional** to load (at small extensions):

$$F = kx, \quad k = \frac{F}{x}, \quad [k] = \text{N m}^{-1}.$$

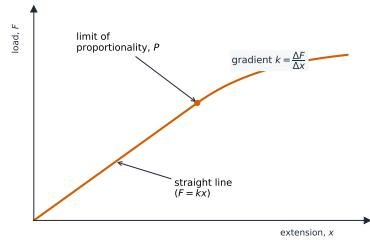
2.0 N stretches a spring 4.0 cm

$$k = \frac{2.0}{0.040} = 50 \text{ N m}^{-1}$$



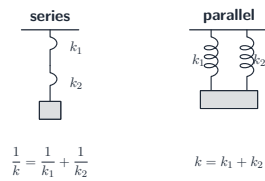
The load–extension graph

- gradient of F vs $x = k$
- straight only up to the **limit of proportionality** 比例极限 P
- beyond P the line curves – the material may stay **elastic** 弹性 a little further, then turns **plastic** 塑性
- plotting *length* L instead of x ? The gradient still gives k , since $L = L_0 + F/k$



Springs in series and parallel

- **series** 串联 – the **same load** passes through both and the extensions **add**:
 $\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}$ (softer)
- **parallel** 并联 – each takes **half the load** and the extensions are **equal**: $k = k_1 + k_2$ (stiffer)



3

Stress, strain, Young modulus

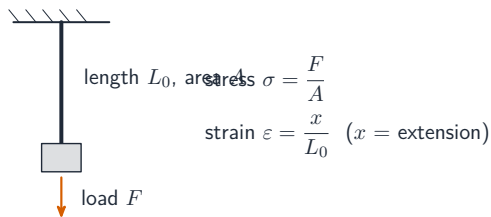
Stress, strain and the Young modulus

- **stress** 应力 $\sigma = \frac{F}{A}$ (Pa)
- **strain** 应变 $\varepsilon = \frac{x}{L_0}$ (no unit)

$$E = \frac{\sigma}{\varepsilon} = \frac{FL_0}{Ax}$$

E is a **material** property; $k = EA/L_0$ also depends on size.

Stress, strain and the Young modulus, in detail



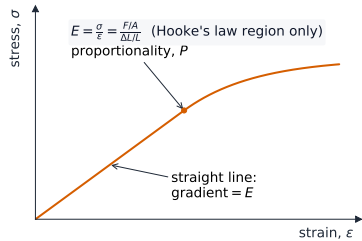
Stress is the load per cross-sectional area; strain is the extension per original length

Worked example – the Young modulus

Steel wire: $L_0 = 2.0$ m, $A = 1.5 \times 10^{-7}$ m², $x = 1.0$ mm **under** 15 N

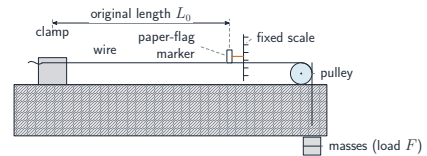
$$E = \frac{FL_0}{Ax} = \frac{15 \times 2.0}{(1.5 \times 10^{-7})(1.0 \times 10^{-3})} = 2.0 \times 10^{11} \text{ Pa.}$$

Worked example – the Young modulus, in detail



A stress-strain graph, straight up to the limit of proportionality P

Measuring E for a wire

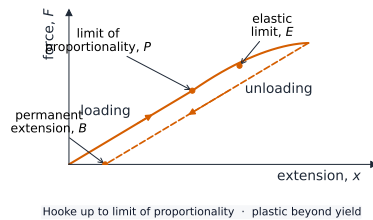


- 1 long thin wire over a pulley 滑轮
- 2 $A = \pi d^2/4$ from a micrometer 螺旋测微器
- 3 add loads; plot F vs x
- 4 $E = \text{gradient} \times L_0/A$

Long & thin gives a measurable extension; repeating and measuring the **diameter** 直径 in several places cuts **random error** 随机误差.

4 Elastic vs plastic

Elastic and plastic behaviour



- 1 straight, Hooke obeyed (to P)
- 2 **elastic** 弹性: returns to first length (to the **elastic limit** 弹性极限)
- 3 **plastic** 塑性: a permanent extension stays

5 Energy stored

Energy stored in a stretched material

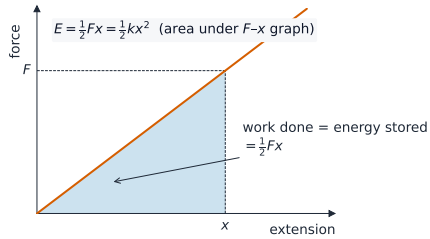
Work done = **area** under the F - x graph. For a Hooke material:

$$E_P = \frac{1}{2}Fx = \frac{1}{2}kx^2 = \frac{F^2}{2k}$$

$$k = 50 \text{ N m}^{-1}, x = 0.20 \text{ m}$$

$$E_P = \frac{1}{2}(50)(0.20)^2 = 1.0 \text{ J}$$

Energy stored in a stretched material, in detail



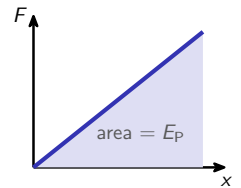
Work done = area under the F - x graph.

Comparing and releasing stored energy

Using $E_p = \frac{1}{2}Fx$:

- same F , **softer** spring $\rightarrow$ bigger $x \rightarrow$ more energy
- same x , **stiffer** spring $\rightarrow$ bigger $F \rightarrow$ more energy

Released onto a mass, the **elastic potential energy** 弹性势能 becomes **kinetic energy** 动能: $\frac{1}{2}kx^2 = \frac{1}{2}mv^2$ (+ mgh if it rises).



Exam tips

- Hooke's law** ($F = kx$) holds only up to the limit of proportionality.
- Stress** = F/A , **strain** = x/L , **Young modulus** = **stress/strain** (gradient of the straight part of the stress-strain graph) – watch the units (Pa).
- Energy stored = **area under the force-extension graph** = $\frac{1}{2}Fx$ in the elastic region.
- Distinguish **elastic** (returns to shape) from **plastic** (permanent) deformation.

6 Recap

Topic 6 – key takeaways

1 Hooke's law

$F = kx$ up to the limit of proportionality

2 Young modulus

$E = \sigma/\epsilon = FL_0/Ax$, a material property

3 Elastic / plastic

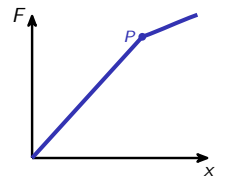
plastic leaves a permanent extension

4 Stored energy

area under F - x : $\frac{1}{2}kx^2$

Check yourself

- Unit of the spring constant k ?
- Does the Young modulus depend on the wire's shape?
- Energy in a spring, $k = 200$, $x = 0.10$ m?
- What stays after a plastic deformation?



Answers 1. N m^{-1} 2. no (material only) 3. $\frac{1}{2}kx^2 = 1.0$ J 4. a permanent extension