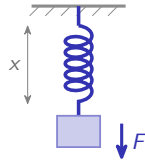


Deformation of Solids

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

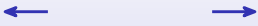
Forces and deformation

Forces that change shape

A force along the length changes the shape –
deformation 形变:

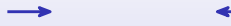
Tensile 拉伸

stretches → **extension** 伸长量 x



Compressive 压缩

squeezes → 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

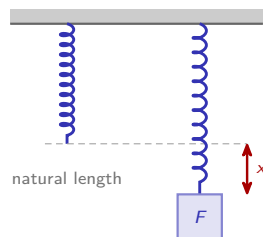
Hooke's law

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

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

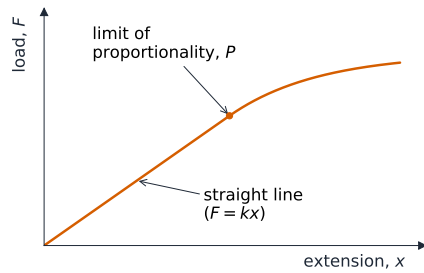
2.0 N stretches a spring 4.0 cm

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



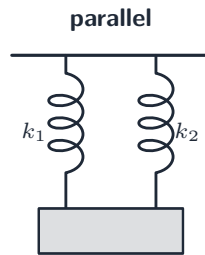
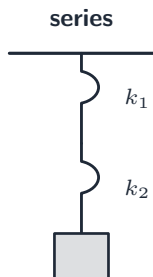
The load–extension graph

- gradient of F vs $x = k$
- straight only up to the **limit of proportionality** 比例极限 P
- beyond P the line curves



Springs in series and parallel

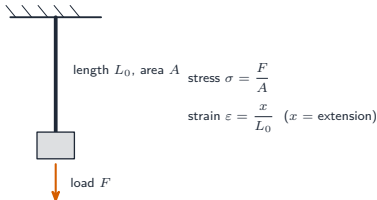
- **series** 串联: $\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}$ (softer)
- **parallel** 并联: $k = k_1 + k_2$ (stiffer)



3

Stress, strain, Young modulus

Stress, strain and the Young modulus



■ **stress** 应力 $\sigma = \frac{F}{A}$ (Pa)

■ **strain** 应变 $\epsilon = \frac{x}{L_0}$ (no unit)

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

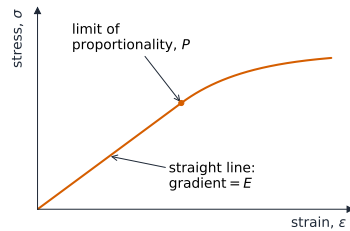
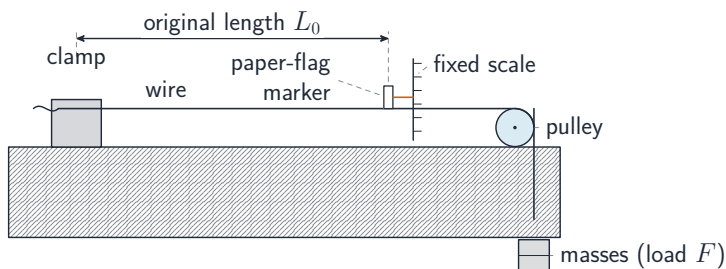
E is a **material** property; $k = EA/L_0$ also depends on size.

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

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

$$= 2.0 \times 10^{11} \text{ Pa.}$$

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

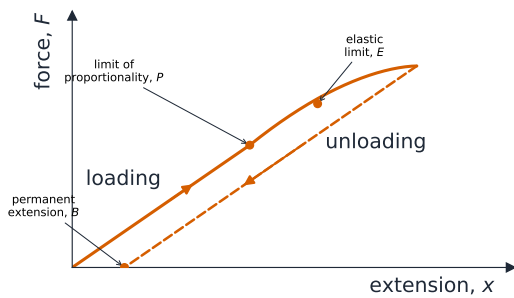
- 3 add loads; plot F vs x
- 4 $E = \text{gradient} \times L_0/A$

Long + thin $\Rightarrow$ a big, measurable extension.

Elastic vs plastic

- └ Elastic vs plastic

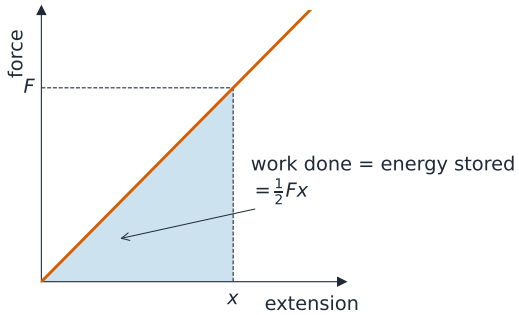
Elastic and plastic behaviour



- 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

Energy stored

Energy stored in a stretched material



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

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

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

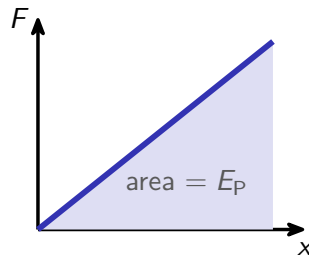
$$E_P = \frac{1}{2}(50)(0.20)^2 = 1.0 \text{ J}$$

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: $\frac{1}{2}kx^2 = \frac{1}{2}mv^2 (+mgh)$.



6

Recap

Topic 6 – key takeaways

1 Hooke's law

$F = kx$ up to the limit of proportionality

2 Young modulus

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

3 Elastic / plastic

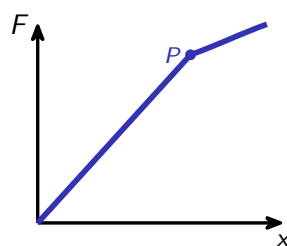
plastic leaves a permanent extension

4 Stored energy

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

Check yourself

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



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