

Physics Chapter 4: Materials

Strength – describes how much force can be applied without breaking the material.

Stiffness – a measure of the difficulty of changing the shape of an object, e.g. by applying a tensile force for the difficulty to get the material to stretch. The stiffer a material is the smaller the extension will be under a tensile force. A stiff material will have a high gradient up to point P on the graph.

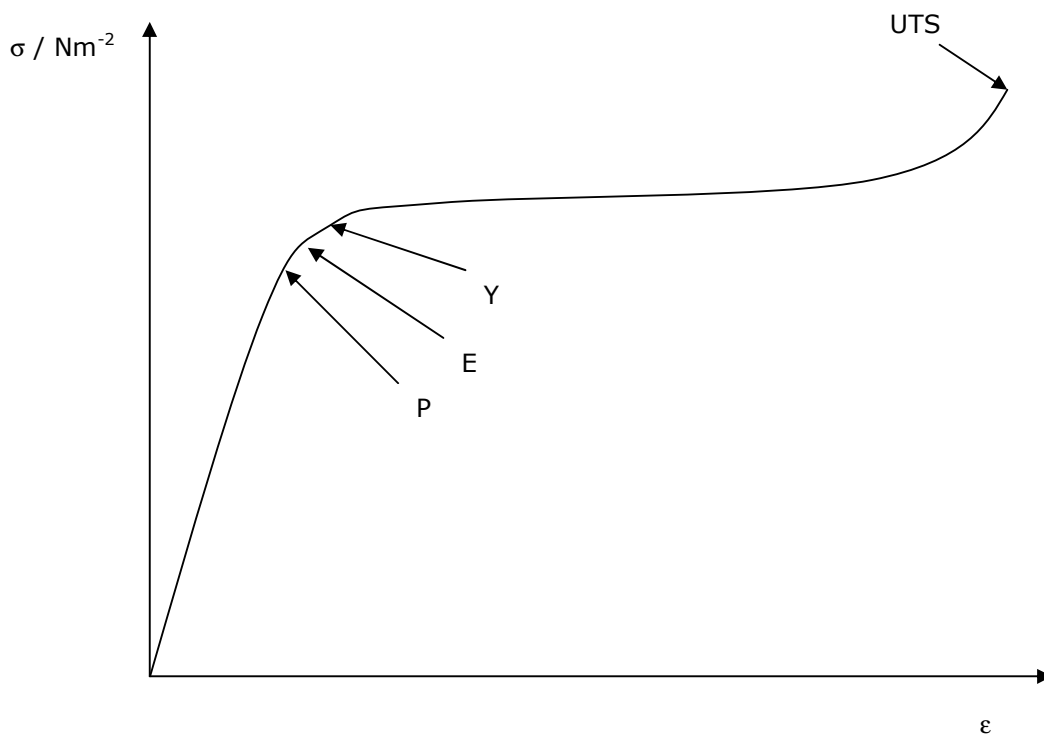
Brittle – a brittle material will suffer no plastic deformation (stretching) before breaking

Tough – energy absorbed after yield point before breaking, a large strain value at the ultimate tensile strength.

Stress, $\sigma = \text{Force} / \text{Area}$ Stress is measured in Nm^{-2}

Strain, $\epsilon = \text{Extension} / \text{Original length}$ Strain is measured as a percentage.

Common stress-strain plots



P: The limit of proportionality, up to this point $\sigma \propto \epsilon$.

E: Elastic limit

Y: Yield point (ϵ increases rapidly here)

UTS: Ultimate tensile strength (after here the material breaks)

Often P, E and Y will take the same value.

For a typical ductile metal, copper, for example the distance from Y to the UTS is long. This means that the material is tough.

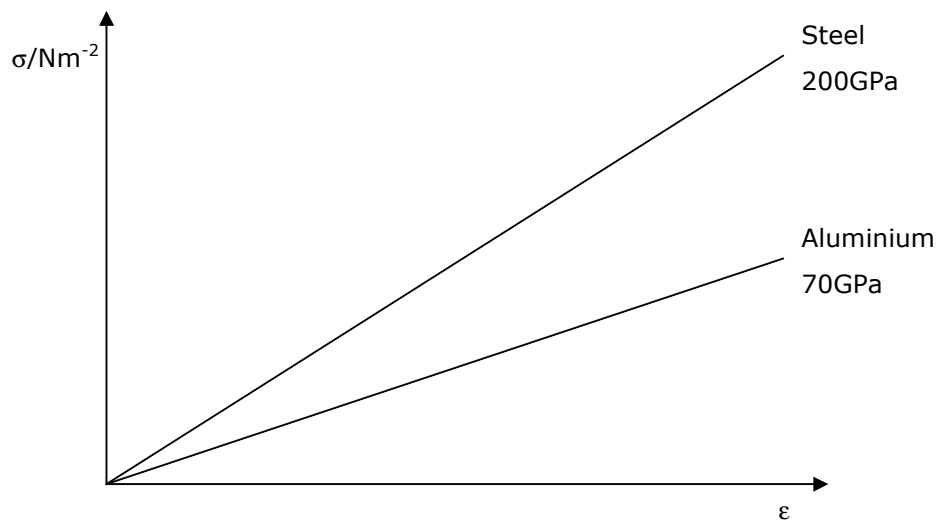
Young Modulus, $E = \sigma / \epsilon$

Young Modulus is measured in GPa, giga-Pascals.

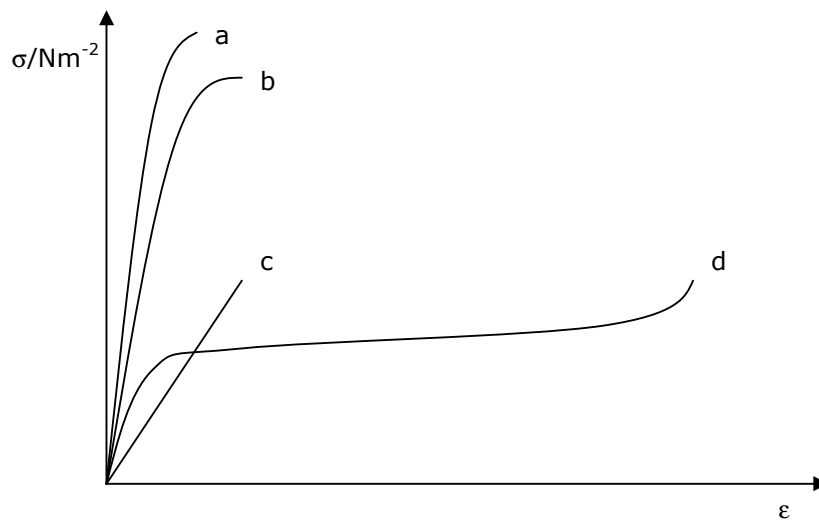
Typical values include:

Material	Young Modulus value (GPa)
Silver	82.4
Copper	129.9
Nickel	199.5
Tungsten	411.0
Tungsten Carbide	~530

Another typical stress-strain plot:



These materials are brittle as they experience no plastic deformation.



- a: ceramic – high UTS
- b: steel – high UTS

c: glass – brittle

d: copper – stiff (high young modulus), ductile, tough, lower UTS

The area under a force-extension plot represents the work done in stretching the material.

The area under a stress-strain plot represents the work done per unit volume to stretch it.

Optical properties

Is light a wave?

Light has 5 characteristics typical of waves:

- Refraction [Chapter 4]
- Reflection [Chapter 4]
- Diffraction [Chapter 6]
- Interference (Superposition) [Chapter 6]
- Polarisation [Chapters 1, 3]

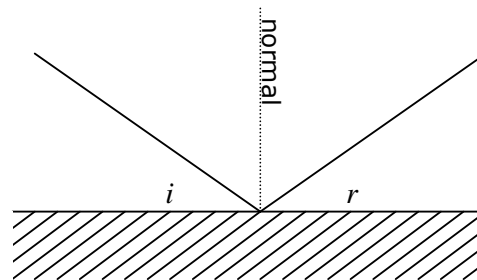
Light is part of the electromagnetic spectrum.

In a vacuum the speed of light is quoted as being $3.0 \times 10^8 \text{ m s}^{-1}$, although it is slightly less than this.

In Chapter 7 observations that suggest light is a particle will be studied.

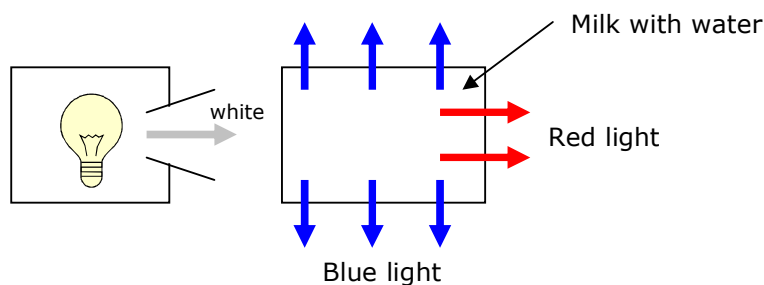
Photons are 'packets of light.'

Reflection



Regular reflection: flat/mirrored surface

Diffuse reflection: rough surface such as a table-top.



Refraction is an abrupt and instantaneous change of direction and speed.

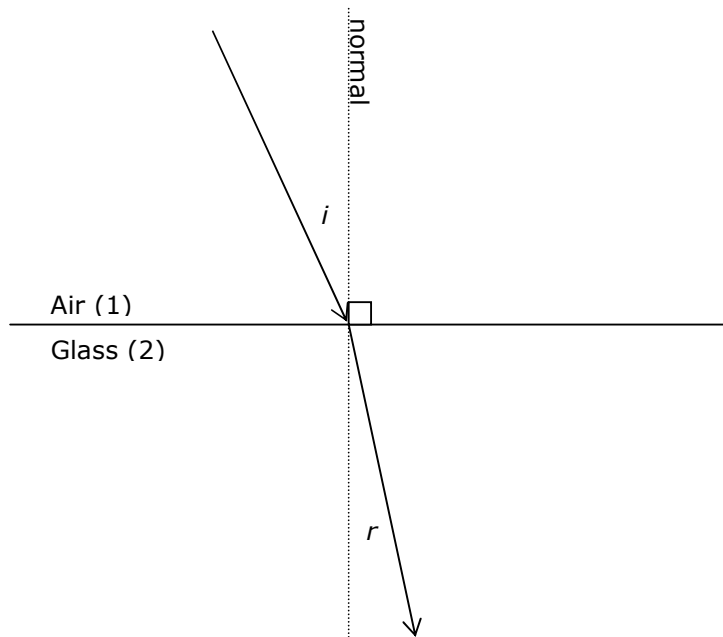
Refractive Index

Waves are transmitted at different speeds in different materials.

$$v = f \lambda$$

In refraction v decreases, f remains constant and λ decreases.

In glass the speed of light is $\sim 2.0 \times 10^8 \text{ m s}^{-1}$



Snell's law states that:

$$\frac{\sin i}{\sin r} = \text{constant}$$

This constant is called n , the refractive index.

We write it in the form: ${}_1n_2$, where 1 is the first medium and 2 is the second medium, that the light is travelling into.

To work out the refractive index for ${}_2n_1$ we use the reciprocal of ${}_1n_2$.

So:

$${}_1n_2 = \frac{1}{{}_2n_1}$$

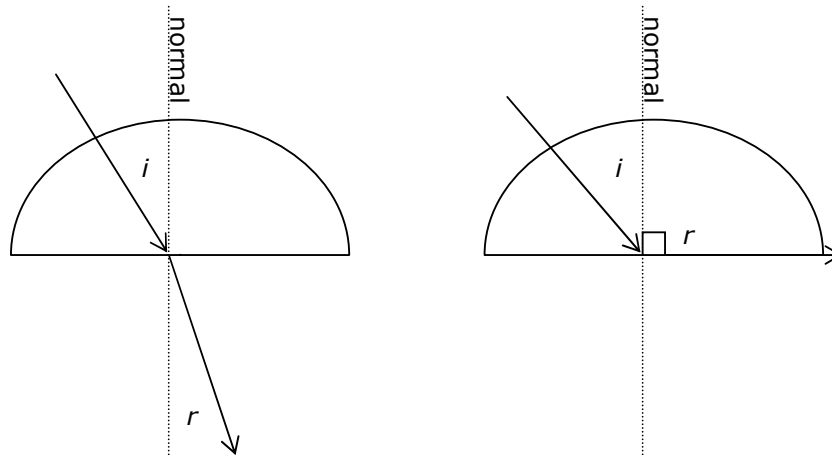
The absolute refractive index quotes values from a vacuum to a medium:

$${}_{\text{vacuum}}n_{\text{medium}} = \frac{c}{c_{\text{medium}}}$$

At 589nm Yellow Na, the absolute refractive index for the following materials:

Material	Absolute refractive index
Crown glass	1.53
Ice	1.31
Diamond	2.42
Air	1.0003

As λ varies n varies, i.e.: blue light will deviate more due to dispersion.



At one value of i , r is 90° . The value of i for which this is true is called the critical angle of refraction. Here total internal refraction happens. The value of i for which this is true will vary, for glass this is true for $\sim 42^\circ$.

A final point about Snell's law:

$$\begin{aligned} \text{light} n_{\text{heavy}} & n > 1 \\ \text{heavy} n_{\text{light}} & n < 1 \end{aligned}$$

Resistance

In a wire in a loop and a kettle the electrical energy is converted to other forms.

$$\text{Resistance, } R = \frac{\text{Voltage, } V}{\text{Current, } I}$$

Resistance is the opposition to current flow. It is not a force, but a mechanism by which energy is converted from electrical energy to other forms (primarily heat).

$$\text{Power, } P = I^2 * R$$

Power is the rate at which energy is transferred.

Conductance is the inverse of Resistance:

$$\text{Conductance, } G = \frac{\text{Current, } I}{\text{Voltage, } V}$$

We measure this in S , Siemens. (*Advancing Physics: p99*)

The Resistance of a sample depends on:

- Material resistivity, ρ
- Areas of cross-section, A
- Length of sample, l
- (*Temperature, T*)

So the following equation can be formed:

$$R = \frac{\rho l}{A}$$

(Where T remains constant)

As conductance is the reciprocal of Resistance, we can say:

$$G = \frac{\rho A}{l}$$

(Where T remains constant)

The conductance, ρ , of a material can be found in various listings. σ , the conductivity of a material is the inverse of ρ .