# Edexcel Physics A-level

## Topic 4: Materials

Key Points

# Density

**Density** is defined as the **mass per unit volume** of an object. As an equation this is:

$$\rho = \frac{m}{V}$$

Consequently, the unit for density is $\mathbf{kgm^{-3}}$

Calculating the volume of an object in order to find its density, can be done in two main ways:

1. For **regular shapes**, you can measure the dimensions required and then apply a **standard formula** for the volume of the given shape
2. For **irregular shapes**, you need to use a **submersion** method, where you measure the volume of water that is displaced when the object is submerged into a beaker of water

# Floating and Sinking

An object in a **fluid** will experience two main forces:

1. Weight
2. Upthrust

Whether an object floats or sinks, depends on the **balance** between these two forces. If the weight **exceeds** the upthrust, the object will sink.

The weight of the object can be calculated using W = mg, whereas the magnitude of the **upthrust** acting on an object is governed by **Archimedes' Principle**:

*'When a body is fully or partially submerged in a fluid, it experiences an upthrust equal to the weight of the fluid it has displaced'*

This means that an object that is **denser** than the fluid it is placed in will always **sink** since the weight of the fluid it displaces will always be **less** than the weight of the object itself.

# Stoke's Law

An ball moving through a fluid will always experience a **drag force**. This force resists the motion of the object. The **magnitude** of this force on the ball can be calculated using Stoke's Law:

$$F = 6\pi\eta rv$$

Where:

- r = the radius of the ball
- $\eta$ = viscosity of the fluid
- v = velocity of the ball

**Viscosity** is a quantity that depends on the **surface** of the ball and the **liquid** that it is moving through. It is also **temperature dependant**.

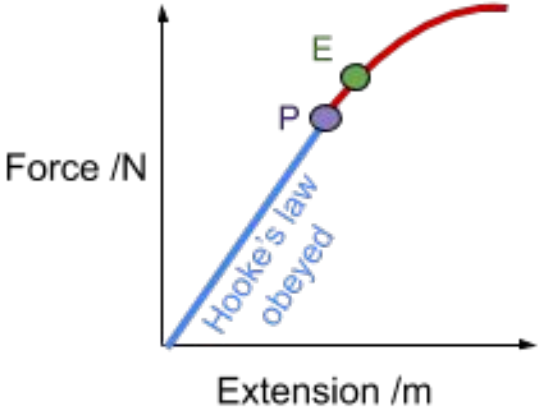
Note that Stoke's Law **only** applies to small spherical objects travelling at low speeds in **laminar**, or **non-turbulent**, flow.

# Hooke's Law

Hooke's law says that the force applied is **directly proportional** to the extension.

*Force =* $k\Delta L$ *Force = Spring Constant x Change in Length*

The **limit of proportionality (P)** is the point beyond which Hooke's law no longer applies. The **elastic limit (E)** is the maximum stress that can be applied without plastic deformation which is where the object does not return to its original shape.




**Elastic Deformation**: Material returns to its original shape and has no permanent extension. Energy is stored as elastic strain energy e.g. an elastic band

**Plastic Deformation**: Material is permanently stretched because the atoms have physically moved relative to one another. Energy is used to deform it and dissipated as heat e.g polythene

# Stress and Strain

**Tensile Stress** is the force applied per unit cross-sectional area, measured in **Pa** or $Nm^{-2}$
**Tensile Strain** is the ratio of extension to original length. It has **no unit.**

$$Stress = \frac{F}{A} \qquad Strain = \frac{\Delta L}{L}$$

If enough stress is applied to a material it can fracture. This is called the **breaking stress**. The **maximum stress** it can withhold, without fracturing, is called the **ultimate tensile stress**.

A **brittle** material fractures without showing any plastic behaviour (shows very little extension). A **ductile** material can be stretched into long wires and stays permanently stretched. The strength of a material is its ultimate tensile stress.

# Energy Stored

If Hooke's Law is obeyed, the energy stored in the object is the **area** under its force-extension graph

$$Work\ Done = \tfrac{1}{2} F \Delta L$$

but...

$$Work\ Done = Energy\ Stored$$

so...

$$E = \tfrac{1}{2} F \Delta L$$

$$E = \tfrac{1}{2} k \ (\Delta L)^2$$

The energy in a spring can be transformed into **kinetic** and **gravitational potential** energy.

# Young Modulus

Up to the **limit of proportionality**, the stress and strain are directly proportional to each other. If you divide stress by strain, you get the **Young Modulus**, which is the measure of the stiffness of a material.

$$\textit{Young Modulus} = \frac{\textit{Tensile Stress}}{\textit{Tensile Strain}} = \frac{F\,L}{A\,\Delta L}$$

The **gradient** of a stress-strain graph is the young modulus.
The **area** under the graph is the 'strain energy per unit volume' and therefore:

$$\textit{Energy per unit Volume} = \tfrac{1}{2} \times \textit{Stress} \times \textit{Strain}$$