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 **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
- η = 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**.

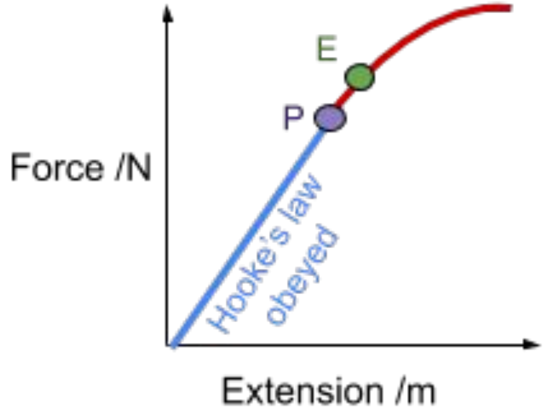
Note that Stoke’s Law **only** applies to small spherical objects travelling at low speeds in **laminar**, or **non-turbulent**, flow.

Hooke's Law

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

Force = kΔL *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

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

but...

$$Work\ Done = Energy\ Stored$$

so...

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

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

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.

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

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:

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