11 Materials

11.1 Density

The density of a substance is defined as its mass per unit volume.

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

Measuring Density

- **Regular solids** - measure its mass using a **top pan balance**, then measure its dimensions using a **vernier caliper** and calculate its volume.
- **Liquid** - measure the mass of an empty **measuring cylinder** and measure the volume of the liquid. Measure the mass of a cylinder with liquid and calculate the mass of the liquid.
- **Irregular solid** - measure the mass of the object, and **immerse the object** in a liquid. The increase in liquid level is the volume of the object.

11.2 Springs

The **tension** is equal and opposite to the force needed to stretch the string.

Hooke's law states that the force needed to stretch a string is directly proportional to the extension of the string from its natural length.

$$F = k\Delta L$$

- k is the **string constant**, the greater the value of k the stiffer the string. The unit of k is Nm^{-1}.
  - The graph of F against ΔL is a straight line of gradient k through the origin.
- ΔL is the **extension from its natural length** L.

If a string is stretched beyond its **elastic limit**, it **does not regain its original length** when the force applied to it is removed.

- Where **springs in parallel**, the **effective spring constant** is

$$k = k_P + k_Q$$

- Where **spring in series**

$$\frac{1}{k} = \frac{1}{k_P} + \frac{1}{k_Q}$$

Elastic Potential Energy

Elastic potential energy is energy **stored in a stretched spring**, if the spring is released, the elastic energy will be **transferred into kinetic energy** of the spring. The work done to stretch a spring by extension ΔL from its unstretched length is $\frac{1}{2}F\Delta L$.

So the elastic potential energy stored in a stretched spring is

$$E_p = \frac{1}{2}F\Delta L = \frac{1}{2}k\Delta L^2$$

11.3 Deformation of Solids

The **elasticity** of a solid material is its ability to regain its shape after it has been deformed or distorted once the forces that deformed it have been released.

- **Tensile deformations** stretch an object.
- **Compressive deformations** compresses an object.

A **tensile-extension graph** shows how easily different materials stretch.

- A **steel spring** gives a straight line, showing it obeys Hooke's law.
- A **rubber band** at first extends easily, then becomes very difficult to stretch further when it becomes fully stretched.
- A **polythene strip** stretches easily after its initial stiffness is overcome. After extending a little it becomes difficult to stretch again.

For a wire of length L and cross section A under tension.

- **Tensile stress** $\sigma = \dfrac{T}{A}$, the unit of stress is the **pascal** equal to 1Nm^{-2}.
- **Tensile strain** $\epsilon = \dfrac{\Delta L}{L}$, tensile strain is a ratio and **has no unit**.

In a graph of tensile stress against tensile strain.

1. From 0 to the **limit of proportionality**, the tensile stress is proportional to the tensile strain.
2. Beyond that the line curves and continues beyond the **elastic limit**.
    - Beyond which the wire is permanently stretched and suffers **plastic deformation**.
3. And to the **yield point**, where the wire weakens temporarily.
4. A small increase in the tensile stress causes a large increase in tensile strain as the material of the wire undergoes **plastic flow**.
5. Beyond the **ultimate tensile stress**, the wire loses its strength, extends and **becomes narrower** at its weakest point.

6. Increase of tensile stress occurs due to the reduced area of cross section at this point until the wire breaks.

The **ultimate tensile stress** is the maximum tensile stress, sometimes called the breaking stress. The **strength** of a material is its ultimate tensile stress.

The **stiffness** of different materials can be compared using the gradient of the stress-strain line - it is equal to the **Young's modulus** of the material.

- **Brittle material** snaps without noticeable yield.
- **Ductile material** can be drawn into a wire.

11.4 More about Stress and Strain

- For a **metal wire**, the loading/unloading curves are the same provided the elastic limit is not exceeded.
  - Beyond the elastic limit, the unloading curve is **parallel to the loading curve** as the wire has a **permanent extension**.
- For a **rubber band**, the unloading curve is **below the loading curve** except at zero and maximum extensions.
  - The rubber band **remains elastic** so regains its initial length.
  - But has a low **limit of proportionality**.
- For a **polythene strip**, the strip does not return to its initial length - it has a **low limit of proportionality** and suffers **plastic deformation**.

Strain energy is the work done to deform an object. The work done is represented by the area under the loading curve.