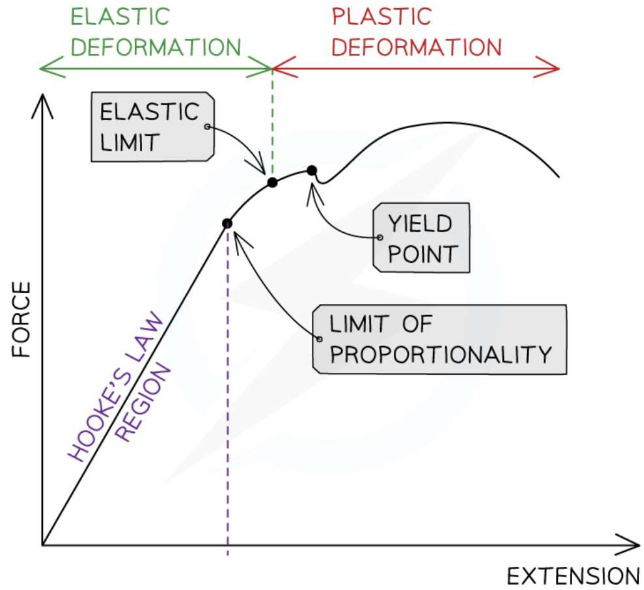
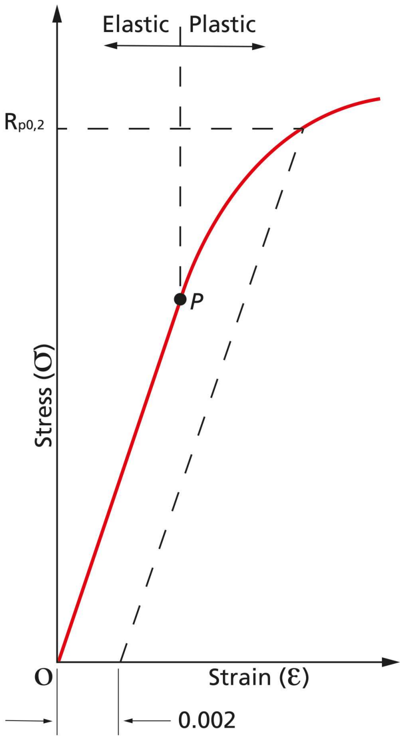
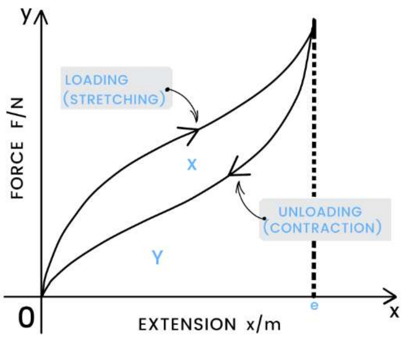
3.4.2 Materials

3.4.2.1 Bulk properties of solids

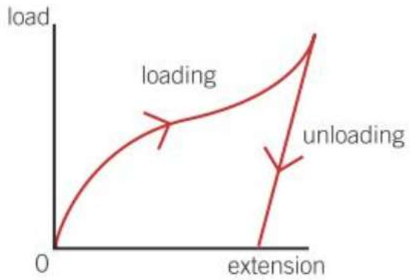
- Density
    - Mass per unit volume
    - $\rho = \dfrac{m}{V}$
- Hooke's law
    - The extension of the material is directly proportional to the load applied up to the limit of proportionality
    - $F = k\Delta L = \text{spring constant (stiffness)} \times \text{extension}$
- Springs combined together
    - Springs in parallel
        - $k = k_1 + k_2 + \cdots + k_n$
    - Springs in series
        - $\dfrac{1}{k} = \dfrac{1}{k_1} + \dfrac{1}{k_2} + \cdots + \dfrac{1}{k_n}$
- Energy transfer in springs
    - Hung vertically and stretched: KE → elastic strain energy
    - Force removed: elastic strain energy → KE → GPE
- Force-extension graph
    - 

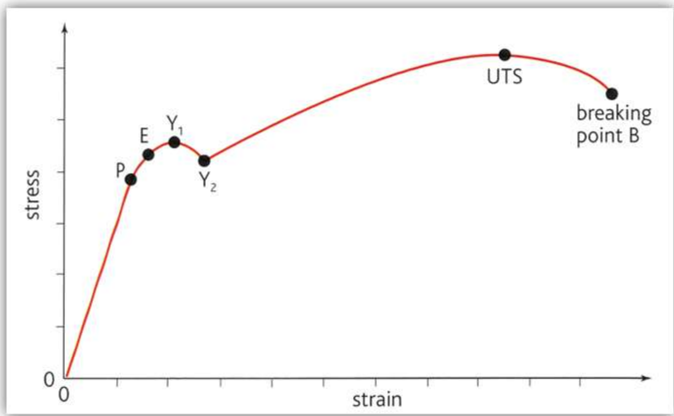
    - Limit of proportionality: the point beyond which Hooke's Law is no longer true
    - Elastic limit: the point beyond which the material will be permanently deformed, right after limit of proportionality
    - Brittle materials: extend very little before it breaks / fractures at a low extension
    - Plastic materials: experience a large amount of extension as the load is increased, especially after the elastic limit
- Types of stretches
    - Elastic
        - Material **returns to original shape** once force is removed
        - All the work done is stored as elastic strain energy
    - Plastic
        - Material **does not return to original shape** once force is removed
        - Work is done to move atoms apart so energy is not stored as elastic strain energy but dissipated as heat
- Types of deformation
    - Tensile deformation
        - Deformation that **stretches** an object

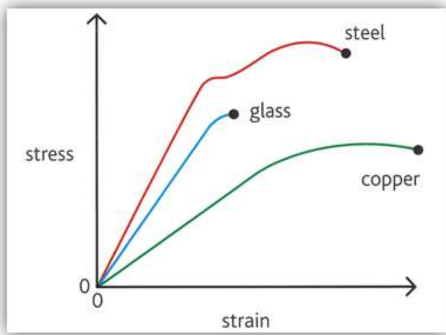
- Compressive deformation
  - Deformation that **compresses** an object
- Strain energy
  - The area under the force-extension graph = work done to stretch the energy = strain energy
- Elastic strain energy in springs
  - $E_p = \frac{1}{2}F\Delta L = \frac{1}{2}k(\Delta L)^2 = \text{area under force-extension graph}$
- Loading & unloading materials
  - **Area between loading and unloading lines = work done to permanently deform the material**
  - Plastic deformation
    - When a material is stretched beyond its elastic limit it will not return to its original length after the load is removed (permanent extension / deformation)
  - Metal wire
    - Loading (the proportional part) + unloading curves are the same straight line
    - Gradient of the unloading line remains the same because the stiffness only changes with material
    - 

  - Extension of elastic materials graph e.g. seatbelts
    - Loading and unloading curves are not linear & not the same
    - During unloading the change in length is greater for a given change in tension
    - Returns to the original length when unloaded
    - 

  - Extension of plastic materials graph
    - The loading curve is not linear
    - During unloading the change in length is greater for a given change in tension
    - Does not return to its original strength

- 

- Stress-strain curves
  - 

  - Before limit of proportionality (P)
    - **Gradient = Young modulus of the material**
    - Tensile stress ∝ tensile strain
    - The material obeys Hooke's law
  - Elastic Limit (E)
    - Up to this point the material returns to its original length when the load acting on it is completely removed
    - Beyond this limit the material doesn't return to its original position and a plastic deformation starts to appear in it
  - Yield point (Y_1 and Y_2)
    - The stress at which the material starts to deform plastically
    - After the yield point is passed, **plastic deformation occurs**
    - 2 yield points: upper (Y_1) + lower yield point (Y_2)
      - At the upper yield point the wire weakens temporarily
      - At the lower yield point a small increase in stress causes a large increase in strain and the wire undergoes plastic flow
  - Ultimate tensile stress (UTS)
    - The maximum stress a material can withstand
    - After UTS the wire loses its strength, extends and **becomes narrower at its weakest point**
    - **Plastic deformation stops**
  - Fracture / breaking point (B)
    - The point in the stress-strain curve at which the material breaks / fractures
- Stress / strain curve for different materials
  - 

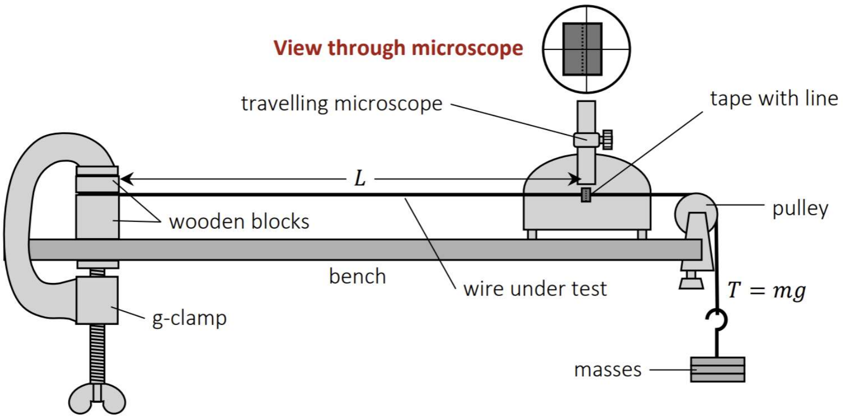
  - Brittle materials (e.g. glass) snap without noticeable yield

- Ductile materials can be drawn into a wire (e.g. copper)

3.4.2.2 The Young modulus

- Tensile strain
    - Extension per unit length
    - $\sigma = \dfrac{F}{A}$
- Tensile stress
    - The force per unit cross-sectional area
    - $\varepsilon = \dfrac{\Delta L}{L}$
- Young modulus
    - $E = \dfrac{\text{tensile stress}}{\text{tensile strain}} = \dfrac{FL}{A\Delta L}$
    - Unit = Pascal (Pa)
    - Measures the **stiffness of the material** (higher Young modulus = stiffer material)
    * Young modulus is specific to the material and **doesn't change**
    * Young modulus = gradient of the straight line part of the stress strain graph

Required practical 4 - determining the Young modulus

- Method
    - Measure the initial length of wire with a ruler
    - Measure the initial diameter of wire with a micrometer
        - Measure in several places and take mean
        - Diameter is very small so it cannot be measured by a ruler but only with a micrometer
    - Mark a cross onto the wire with a tape
    - Align the travelling microscope with the cross
        - Extension can be very small so a microscope is needed
    - Add load and align the travelling microscope with the cross again
    - Read off the extension of the wire
    - Repeat for a range of loads
    - Repeat up to the limit of proportionality / elastic limit
    - Repeat the experiment 2 more times for each value of load and calculate mean extension
    - Calculate tensile stress and strain for each load value
    - Plot a graph of stress against strain
    - Young modulus = gradient of the linear part of the graph
    - 

- Measurements
    - Length of the wire between clamp and mark (metre rule)
    - Diameter of the wire (micrometer, measure several positions + mean taken)
    - Extension of wire for a known mass (by moving travelling microscope and checking the scale)
    - Repeat readings for increasing load