Bulk Matter Properties: Elasticity

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What is Bulk Matter?

Bulk, as the name indicates is basically matter when its made of large amounts molecules or particles.

When particles are in bulk, they behave differently than when they are by their own. Particles on their own behave quantum-mechanically while bulk matter can be accurately described by using classical physics.

When studying properties of bulk matter, we are focused on how it responds to force, thus we study its dynamics: thermodyanmics, aerodynamics, elastic & fluid dynamics.

Elasticity

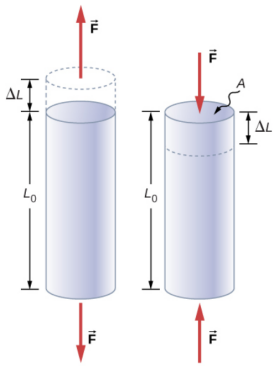
Rigid Bodies - Bodies That Can't Be Deformed Under

We have discussed rigid bodies vastly in the previous units, and how they behave under force. Force has a rotational effect on rigid bodies and the rotation depends on the geometry of the bodies and how massive they are. Matter we see everyday can be rigid or able to be deformed.

When matter is acted upon by a force, it can get deformed(change their shapes/orientation). Deformation is experienced by objects under the action of external forces — for example, this may be squashing, squeezing, ripping, twisting, shearing, or pulling the objects apart. To describe deformations, we use the terms **stress** and **strain**.

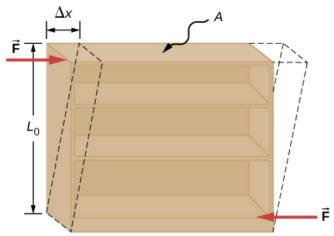
Stress describes the magnitude of forces that cause deformation while strain describes the degree of deformation. Depending on the nature of the matter being deformed and the nature of the deformation, we can have different types of deformation:

Tensile/Compressive - deformation along the length



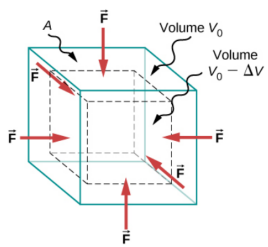
This is deforming an linear object about its axis.

Shear - deformation by changing the orientation



deforms the object's orientation.

Bulk - this is volumetric and hence changes volumes all over.



Stress & Strain

Stress is like pressure, it is the impact causing force acting over an area. Tensile/compressive stress $= \frac{F_\perp}{A}$

Strain is the degree of deformation or the percentage length change: Tensile Strain $= \frac{\Delta L}{L_0}$

For the other types of deformation, stress will still be the impact causing force we saw above($\frac{F_\perp}{A}$)
However, for Shear and Bulk deformations, the strain is different because the deformations are along different dimensions:
$Strain_{shear} = \frac{\Delta x}{L_0}$ - measures the orientational change(degree)
$Strain_{bulk} = \frac{\Delta V}{V_0}$ - measures the volumetric change - whether it be expansion or compression

Food for thought

What are the units of stress? What about strain?

Why can't Young's Modulus and Shear Modulus apply to fluids?

Moduli

The quantities that relate stress and strain are called Elastic Moduli.

Tensile Deformation - for tensile deformation, we have a quantity called the **Young's Modulus**(Y)(*why is it called Young's?*) and $Y = \dfrac{\text{tensile stress}}{\text{tensile strain}} = \dfrac{\frac{F_\perp}{A}}{\frac{\Delta L}{L_0}} = \dfrac{F_\perp L_0}{A\Delta L}$

Shear Deformation - for shear deformation, we have a quantity called the **Young's Modulus**(Y) and

$S = \dfrac{\text{shear stress}}{\text{shear strain}} = \dfrac{\frac{F_\parallel}{A}}{\frac{\Delta x}{L_0}} = \dfrac{F_\parallel L_0}{A\Delta x}$

Bulk Deformation - for bulk deformation, we have a quantity called the **Bulk's Modulus**(Y) and

$B = \dfrac{\text{bulk stress (pressure)}}{\text{bulk strain}} = \dfrac{\frac{F_\perp}{A}}{\frac{\Delta V}{V_0}} = \dfrac{F_\perp V_0}{A\Delta V} = \dfrac{PV_0}{\Delta V}$

The reciprocal of the bulk modulus is called compressibility.

Compressibility(k), as we defined earlier, is a quantity that tells us how compressible a fluid is.

$$k = \frac{1}{B} = \frac{\frac{\Delta V}{V_0}}{P}$$

Compressibility is a quantity we use solely for fluids. It describes the change in the volume of a fluid per unit increase in pressure. *Fluids characterized by a large compressibility are relatively easy to compress*. Bulk Deformation is specially important in real life applications.

A material is called solid (rather than -perfect fluid) if it can support a shearing force over the time scale of some natural process. The biggest difference between shearing and compressive(tensile) forces is that shearing forces are directed parallel, rather than perpendicular(as with tensile), to the material surface on which they act.

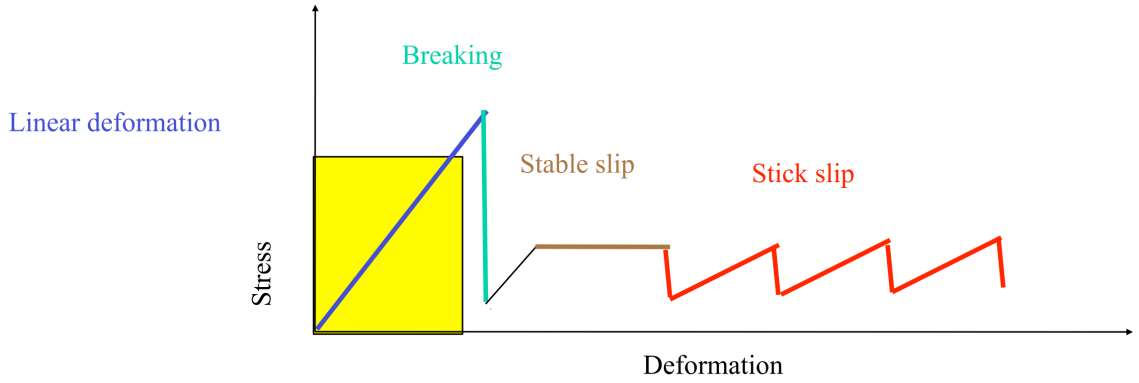
Elasticity and Plasticity

Elasticity is the tendency of solid objects and materials to return to their original shape after the external forces (load) causing a deformation are removed.

An object is **elastic** when it comes back to its original size and shape when the load is no longer present. *Physical reasons for elastic behavior vary among materials and depend on the microscopic structure of the material.*

The two parameters that determine the elasticity of a material are its **elastic modulus** and its **elastic limit**. If an object's elastic modulus is high, it is usually hard to deform.

The elastic limit is the stress value beyond which the material no longer behaves elastically but becomes permanently deformed.



The linearity limit (or the proportionality limit) is the largest stress value beyond which stress is no longer proportional to strain. Beyond the linearity limit, the relation between stress and strain is no longer linear. When stress becomes larger than the linearity limit but still within the elasticity limit, behavior is still elastic, but the relation between stress and strain becomes nonlinear.