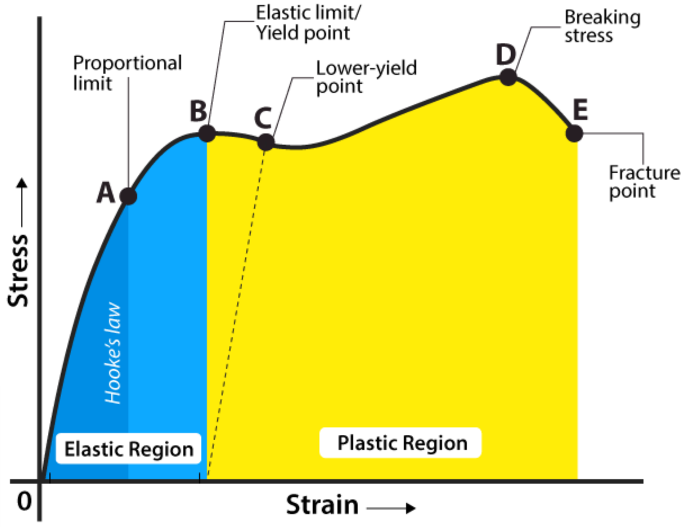
“Properties of Matter”



Chapter 6

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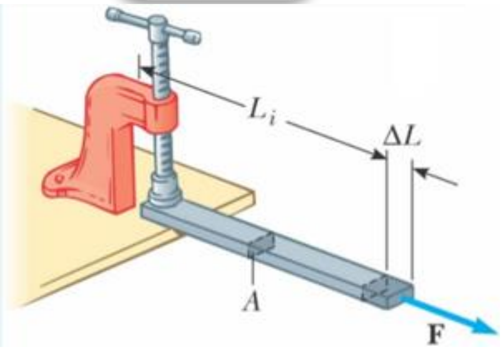
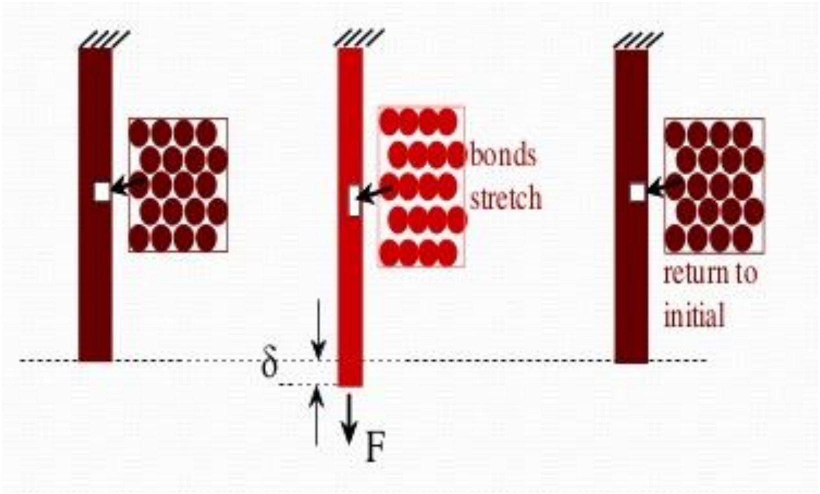


6-1 An introduction to Elasticity in physics

Elasticity is that property of a body by which it experiences a change in size or shape whenever a deforming force acts on the body. When the force is removed the body returns to its original size and shape. Most people are familiar with the stretching of a rubber band.



Objects deform when pushed, pulled, and twisted. **Elasticity** is the measure of the amount that the object can return to its original shape after these external forces and pressures stop. Bodies, which can recover completely their original condition, on the removal of the deforming forces, are said to be **perfectly elastic**.

On the other hand, bodies, which do not show any tendency to recover their original condition, are said to be **plastic**.

The opposite of elasticity is **plasticity**; when something is stretched, and it stays stretched, the material is said to be plastic. When energy goes into changing the shape of some material and it stays changed, that is said to be *plastic deformation*.

Most materials have an amount of force or pressure for which they deform elastically. If more force or pressure is applied, then they have plastic deformation. Materials that have a fair amount of plastic deformation before breaking are said to be **ductile**. Materials that can't stretch or bend much without breaking are said to be **brittle**. Copper is quite ductile, which is part of why it is used for wires (most metals are ductile (but copper especially so). Glass and ceramics are often brittle; they will break rather than bend!

Figure: A spring wire is an example of elasticity, since it returns to its original shape, after being pulled and pushed on.

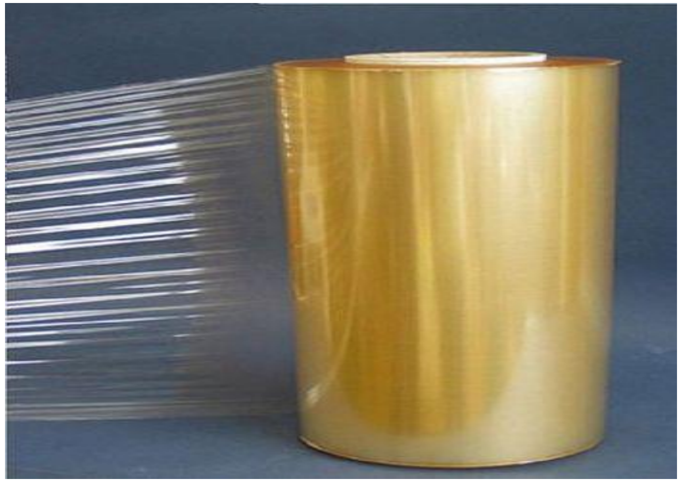
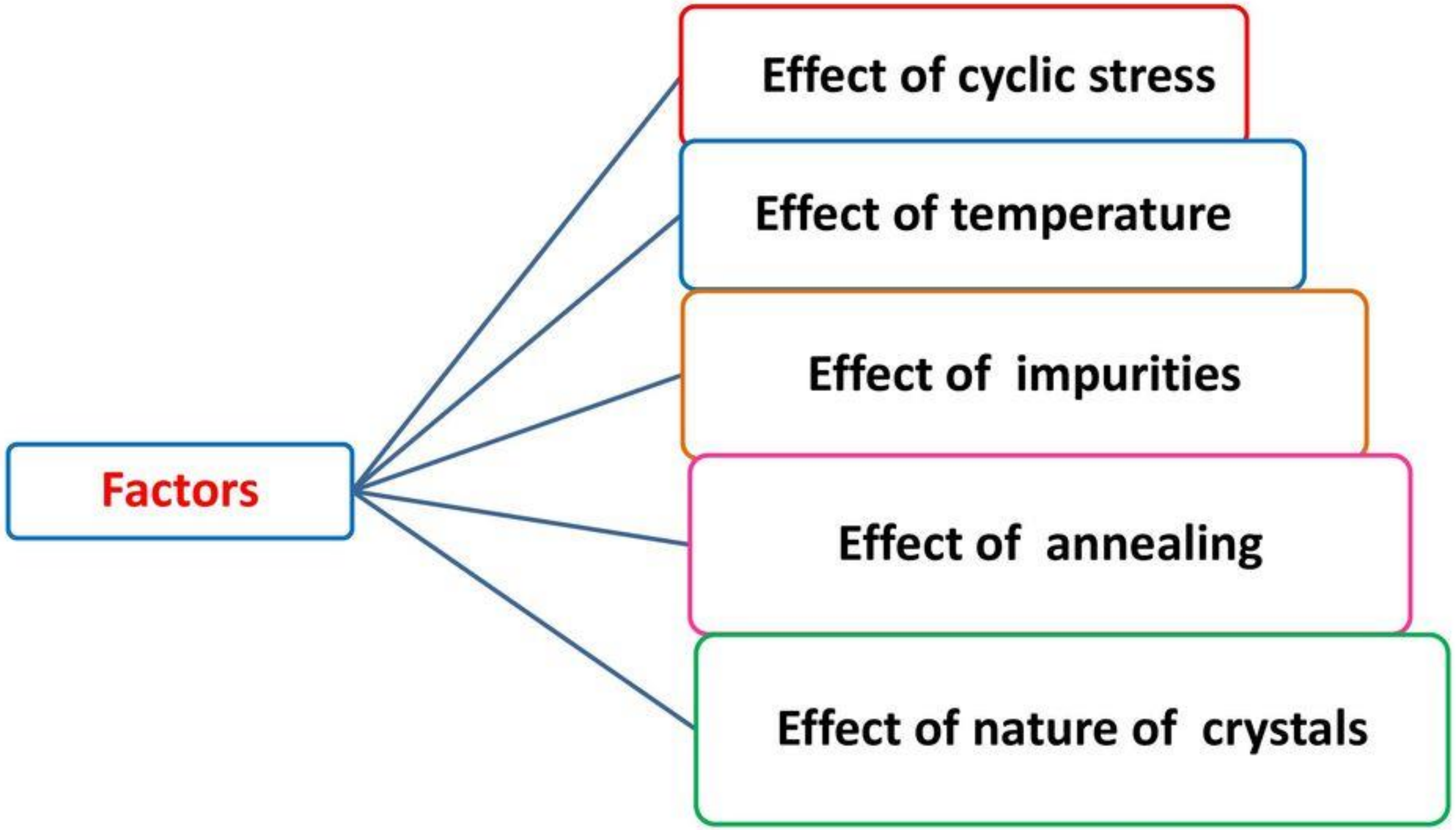


Figure : Plastic wrap is an example of plasticity. After stretched—it stays stretched.

Factors Affecting Elasticity



Body loses its elastic property even within elastic limit, due to elastic fatigue.

Apart from elastic fatigue, some materials will have change in their property due to these factors

There are basically five factors that affect the elasticity of a spring:

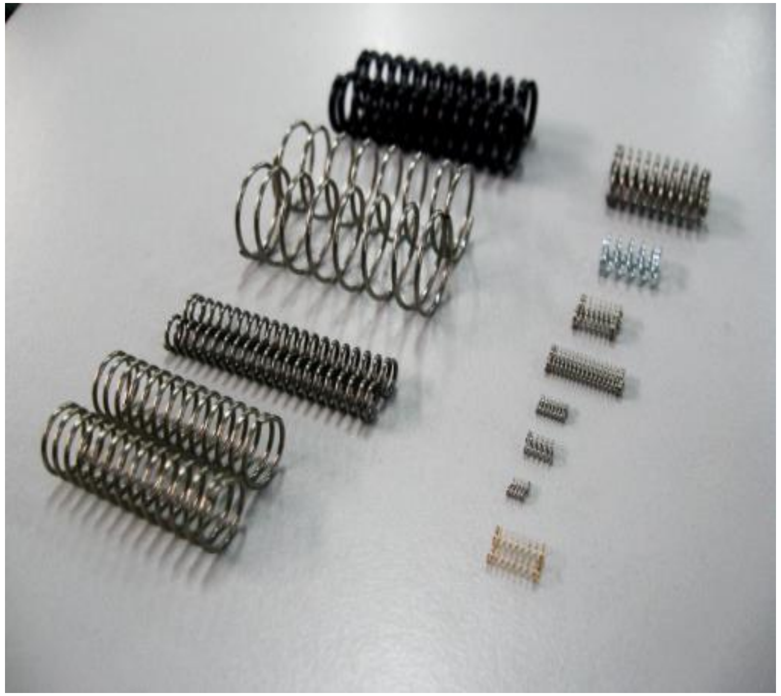
1. Length of spring – A shorter spring is a stiffer spring.

2. Thickness of spring wire – A spring with a thicker wire is a stiffer spring.

3. Diameter of coils of spring – A spring with a smaller diameter of coils is a stiffer spring.

4. Material of spring – Springs made of different materials have different stiffness (e.g. steel wire is stiffer than copper wire)

5. Arrangement of springs – Springs that are arranged in parallel to each other are stiffer then those arranged in series.



6-2 The Atomic Nature of Elasticity

The explanation of the elastic property of solids is found in an atomic description of a solid. Most solids are composed of a very large number of atoms or molecules arranged in a fixed pattern called the **lattice structure of a solid** and shown schematically in figure. These atoms or molecules are held in their positions by electrical forces. The electrical force between the molecules is attractive and tends to pull the molecules together. Thus, the solid resists being pulled apart.

Any one molecule has an attractive force pulling it to the right and an equal attractive force pulling it to the left. There are also equal attractive forces pulling the molecule up and down, and in and out. A repulsive force between the molecules also tends to repel the molecules if they get too close together. *This is why solids are difficult to compress.*

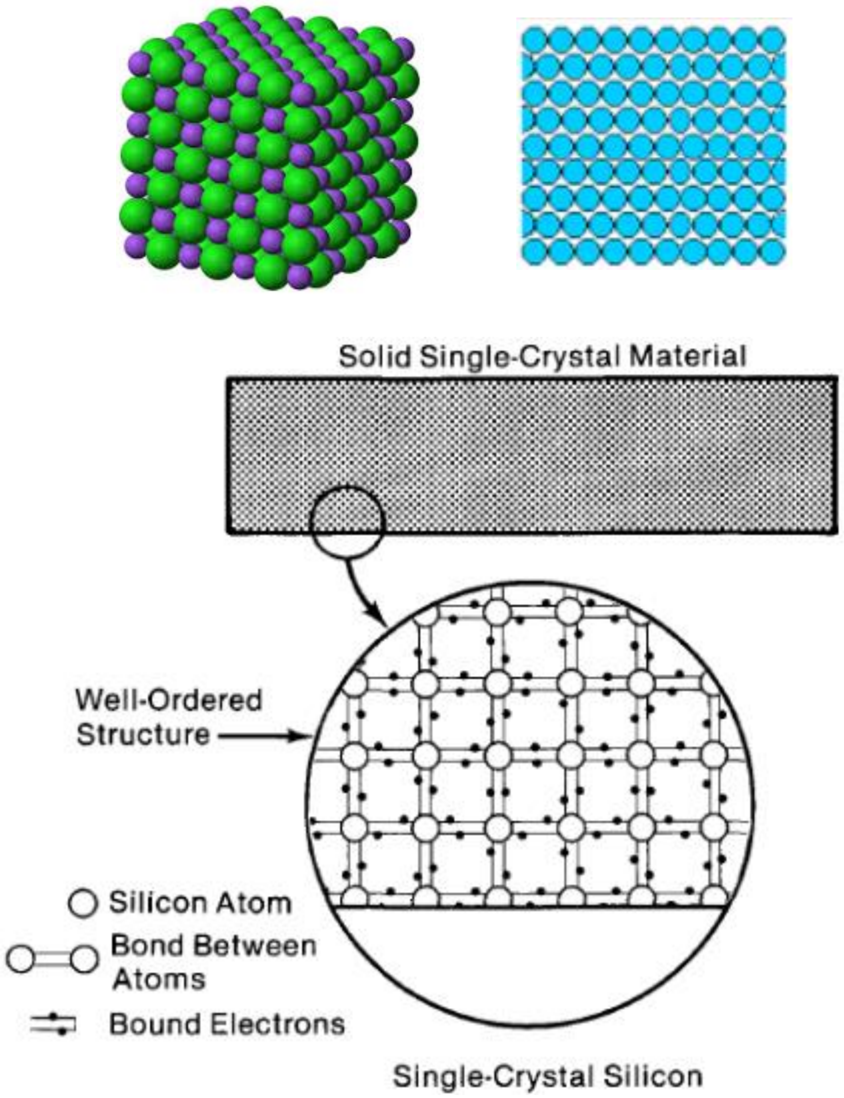
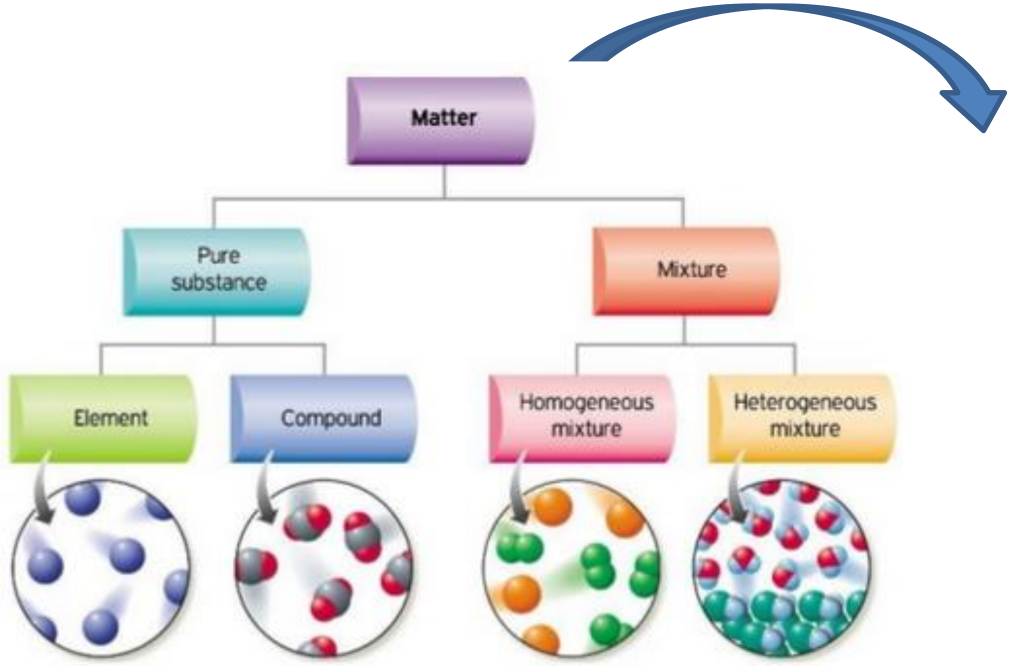


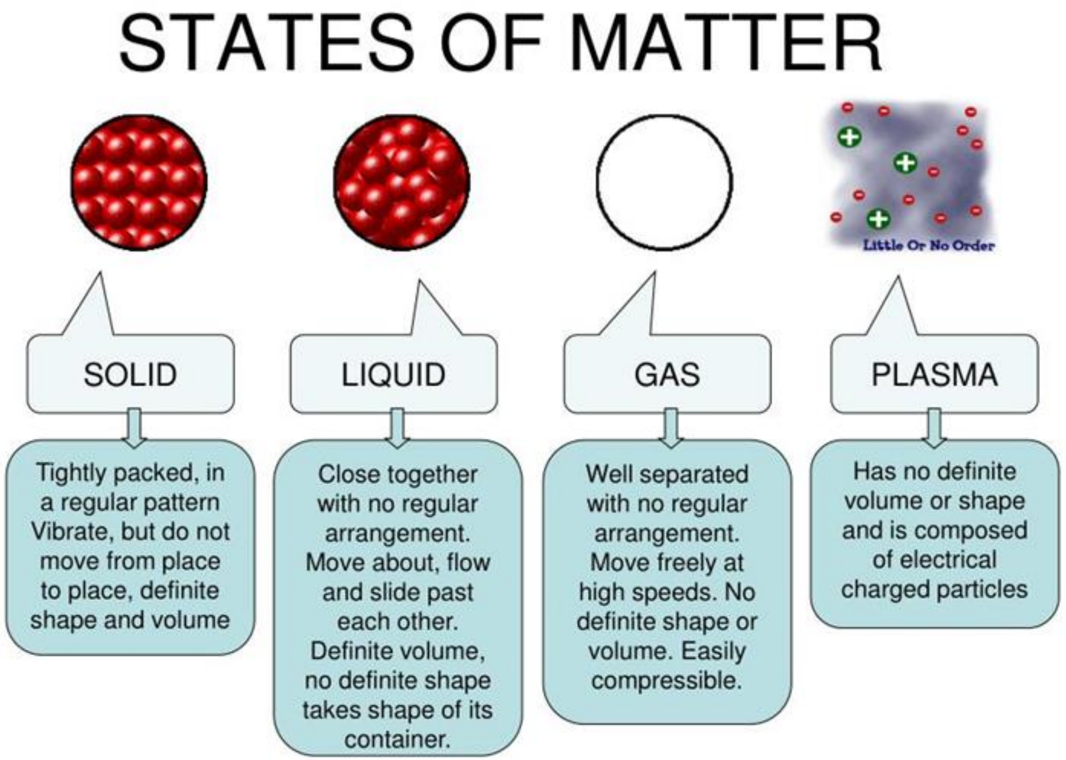
Figure: Lattice structure of a solid & actual pictures of atoms

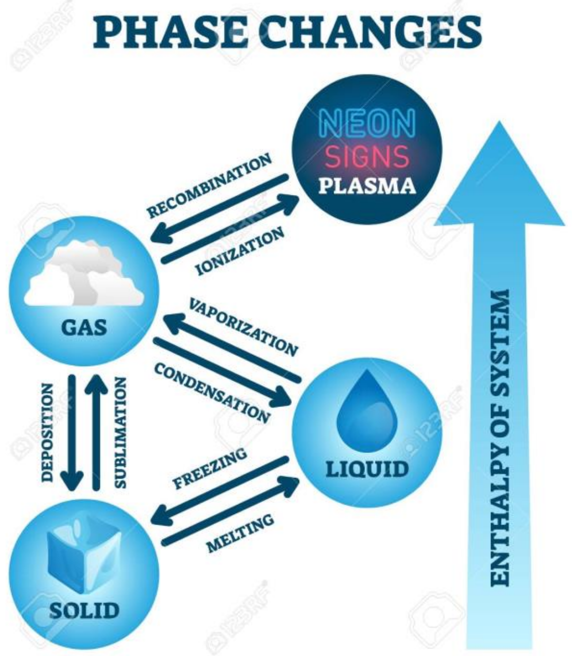
Classification of Matter:

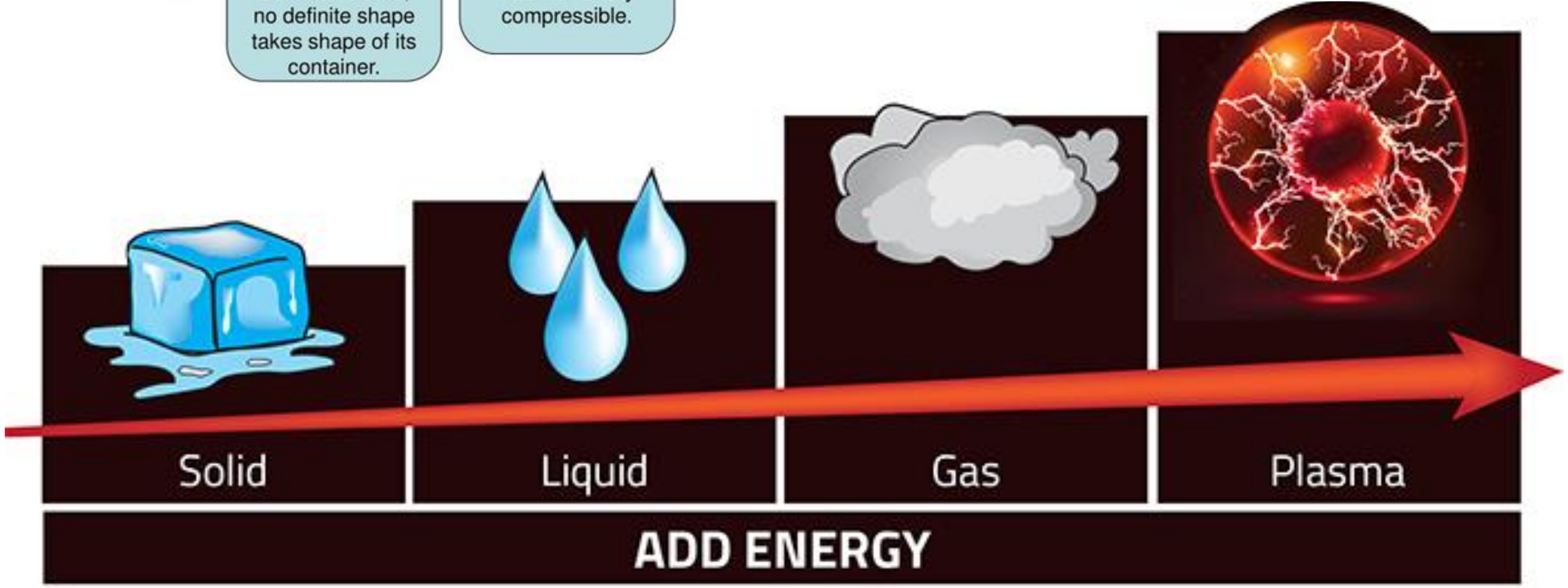
A pure **substance** consists only of one element or one compound.
A **mixture** is a combination of two or more substances.
Substances are composed of pure elements or chemically bonded elements, whereas mixtures are composed of non-bonded substances.



Matter is anything that has **mass** and **volume**. Matter is composed of atoms, which are then composed of "elementary particles": protons, neutrons, and electrons.


STATES OF MATTER
Little Or No Order
SOLID
LIQUID
GAS
PLASMA
Tightly packed, in a regular pattern Vibrate, but do not move from place to place, definite shape and volume
Close together with no regular arrangement. Move about, flow and slide past each other. Definite volume, no definite shape takes shape of its container.
Well separated with no regular arrangement. Move freely at high speeds. No definite shape or volume. Easily compressible.
Has no definite volume or shape and is composed of electrical charged particles


PHASE CHANGES
NEON
SIGNS
PLASMA
RECOMBINATION
IONIZATION
GAS
VAPORIZATION
CONDENSATION
LIQUID
DEPOSITION
SUBLIMATION
FREEZING
MELTING
SOLID
ENTHALPY OF SYSTEM


Solid
Liquid
Gas
Plasma
ADD ENERGY

6-3 Stress and Strain

As a result of the deforming forces applied to a body, forces of reaction come into play internally in it, due to the relative displacement of its molecules, tending to restore it to its original Condition. The restoring or recovering force per unit area set up inside the body is called **stress**, and is measured by the deforming force applied per unit area of the body, until its elastic limit has been reached. In mechanics, it is a measure of the average amount of force exerted per unit area od a surface within a deformable body on which internal forces act. The internal forces are produced between the particles in the body as a reaction to external forces applied on the body.

Stress is measured by the force applied per unit area which produce or tend to produce deformation in a body.

Kinds of stress:

1- Tensile Stress

2- Compressive Stress

3- Shearing Stress

4- Torsion Stress

The change produced in the dimensions of a body under a system of forces or couples, in equilibrium, is called **strain**, and is measured by the change per unit length (linear strain), per unit volume, (volume strain), or the angular deformation, (shear strain, or simply, shear) according as the change takes place in length, volume or shape of the body. Thus, being just a ratio, (or an angle) it is a dimensionless quantity, having no units.

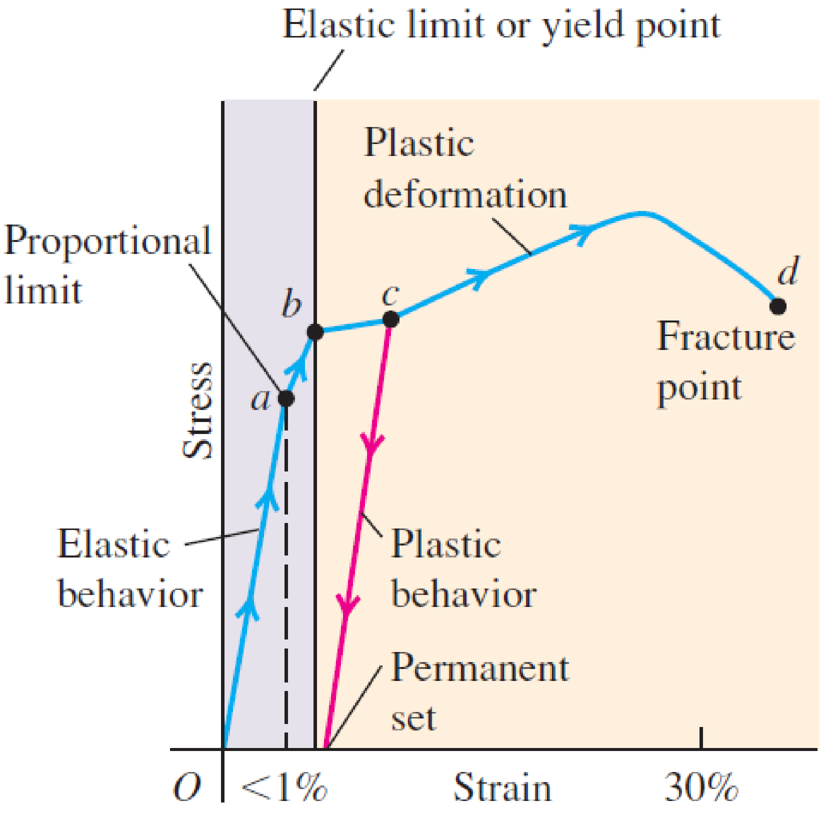
Strain is the fractional change in dimensions of a body produced by a system of stress (F/A) in equilibrium (The effect produced on an object by stress is called strain).

Kinds of strain:

1- Tensile Strain
2- Compressive Strain
3- Shearing Strain
4- Volume Strain

6-4 Elastic Limit & Hook's Law

Figure shows a typical stress-strain graph for a metal such as copper or soft iron. The strain is shown as the *percent elongation;* the horizontal scale is not uniform beyond the first portion of the curve, up to a strain of less than 1%. The first portion is a straight line, indicating Hooke's law behavior with stress directly proportional to strain. This straight-line portion ends at point *a*; *the stress at this point is called the proportional limit*.



From *a to b, stress and strain are no longer proportional, and Hooke's law is not obeyed. If the load is gradually removed, starting at any point between O and b, the curve is retraced until the material returns to its original length. The deformation* is *reversible, and the forces are conservative; the energy put into the* material to cause the deformation is recovered when the stress is removed. In region *Ob we say that the material shows elastic behavior. Point b, the end of this* region, is called the *yield point; the stress at the yield point is called the **elastic limit**.*

When we increase the stress beyond point b, the strain continues to increase. But now when we remove the load at some point beyond b, say c, the material does not come back to its original length. Instead, it follows the red line in Figure. The length at zero stress is now greater than the original length; the material has undergone an irreversible deformation and has acquired what we call a permanent set. Further increase of load beyond c produces a large increase in strain for a relatively small increase in stress, until a point d is reached at which fracture takes place. The behavior of the material from b to d is called **plastic flow** or plastic deformation. A plastic deformation is irreversible; when the stress is removed, the material does not return to its original state.

The stress required to cause actual fracture of a material is called the **breaking stress**, the ultimate strength, or (for tensile stress) the tensile strength. Two materials, such as two types of steel, may have very similar elastic constants but vastly different breaking stresses. Table gives typical values of breaking stress for several materials in tension. The conversion factor may help put these numbers in perspective.

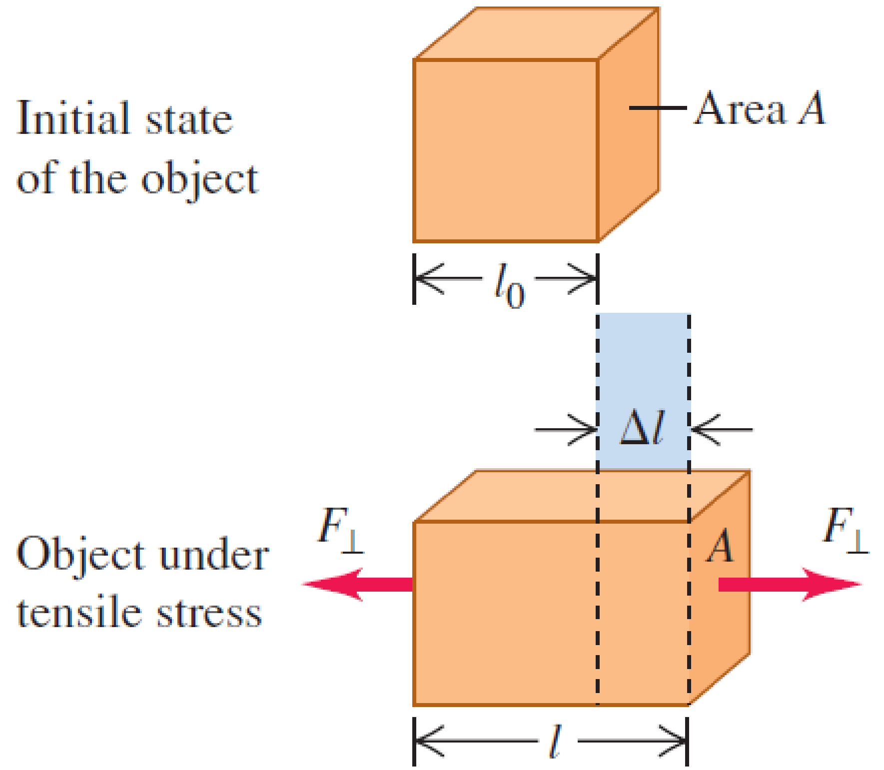
Material	Breaking Stress (Pa or N/m^2)
Aluminum	2.2×10^8
Brass	4.7×10^8
Glass	10×10^8
Iron	3.0×10^8
Phosphor bronze	5.6×10^8
Steel	$5–20 \times 10^8$

6-5 Tensile and Compressive Stress and Strain

The simplest elastic behavior to understand is the stretching of a bar, rod, or wire when its ends are pulled. Figure shows an object that initially has uniform cross-section area and length. We then apply forces of equal magnitude but opposite directions at the ends and we say that the object is in **tension.**

We define the tensile stress at the cross section as the ratio of the force to the cross-sectional area*:*

$$\textbf{Tensile Stress} = \frac{\mathbf{F}}{\mathbf{A}}$$



(Tensile stress is tensile force per unit area) The SI unit of stress is the pascal (abbreviated **Pa**):

1 pascal = 1 Pa = 1 $N.m^{-2}$

The units of stress are the same as those of *pressure*

The object shown in Figure stretches to a length when under tension. The elongation does not occur only at the ends; every part of the bar stretches in the same proportion. The **tensile strain of the object is equal to the** fractional change in length, which is the ratio of the elongation to the original length

$$\text{Tensile Strain} = \frac{\Delta l}{l}$$

(Tensile strain is fractional change in length). Experiment shows that for sufficiently small tensile stress, stress and strain are proportional. The corresponding elastic modulus is called **Young's modulus**, denoted by **Y:**

$$Y = \frac{\text{Tensile Stress}}{\text{Tensile Strain}} = \frac{F/A}{\Delta l/l_o} = \frac{F\,l_o}{A\,\Delta l}$$

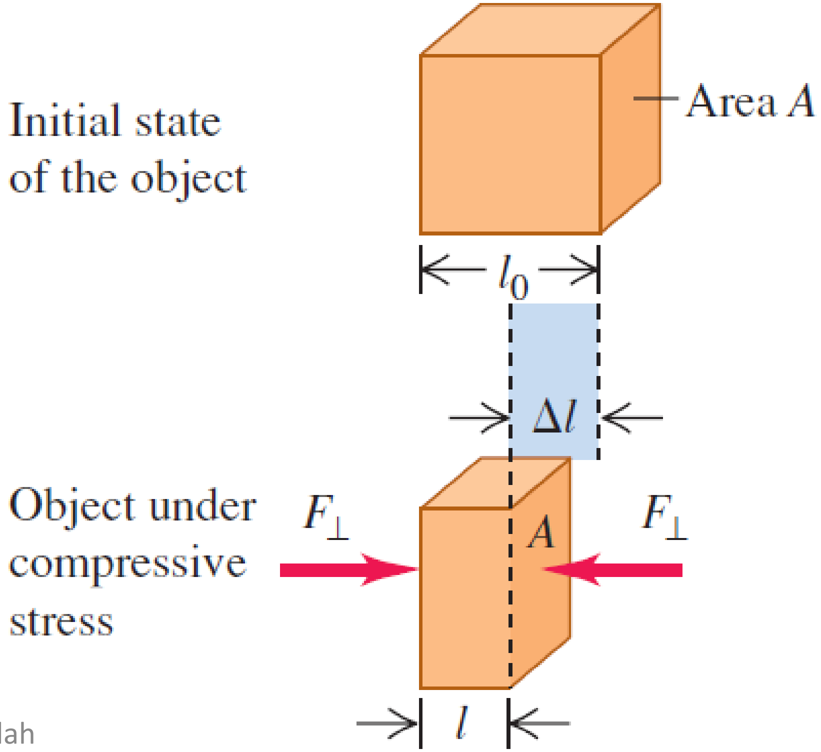
Some typical values are listed in the next Table (this table also gives values of two other elastic moduli that we will discuss later in this chapter)

Table **Approximate Elastic Moduli**

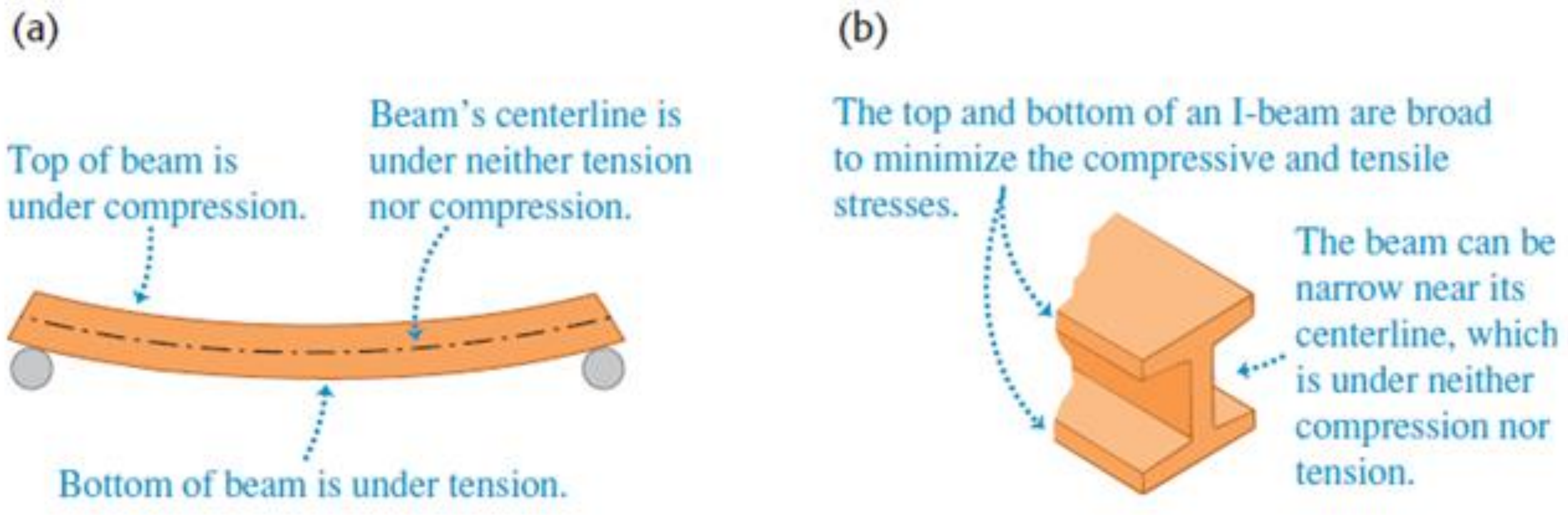
Material	Young's Modulus, Y (Pa)	Bulk Modulus, B (Pa)	Shear Modulus, S (Pa)
Aluminum	7.0×10^{10}	7.5×10^{10}	2.5×10^{10}
Brass	9.0×10^{10}	6.0×10^{10}	3.5×10^{10}
Copper	11×10^{10}	14×10^{10}	4.4×10^{10}
Crown glass	6.0×10^{10}	5.0×10^{10}	2.5×10^{10}
Iron	21×10^{10}	16×10^{10}	7.7×10^{10}
Lead	1.6×10^{10}	4.1×10^{10}	0.6×10^{10}
Nickel	21×10^{10}	17×10^{10}	7.8×10^{10}
Steel	20×10^{10}	16×10^{10}	7.5×10^{10}

When the forces on the ends of a bar are pushes rather than pulls as in figure, the bar is in compression and the stress is a compressive stress. The compressive strain of an object in compression is defined in the same way as the tensile strain, but has the opposite direction.

Hooke's law and the previous equation are valid for compression as well as tension if the compressive stress is not too great. For many materials, Young's modulus has the same value for both tensile and compressive stresses.



(a). To minimize the stress and hence the bending strain, the top and bottom of the beam are given a large cross sectional area. There is neither compression nor tension along the centerline of the beam, so this part can have a small cross section; this helps to keep the weight of the bar to a minimum and further helps to reduce the stress. The result is an **I-beam** of the familiar shape used in building construction (b).



We shall discuss the deformation of solids in terms of the concepts of *stress* and *strain*. **Stress** is a quantity that is proportional to the force causing a deformation; more specifically, stress is the external force acting on an object per unit cross-sectional area. The result of a stress is **strain**, which is a measure of the degree of deformation. It is found that, for sufficiently small stresses, **strain is proportional to stress;** the constant of proportionality depends on the material being deformed and on the nature of the deformation. We call this proportionality constant the **elastic modulus**. The elastic modulus is therefore defined as the ratio of the stress to the resulting strain:

$$\text{Elastic modulus} \equiv \frac{\text{stress}}{\text{strain}}$$

The elastic modulus in general relates what is done to a solid object (a force is applied) to how that object responds (it deforms to some extent).

We consider three types of deformation and define an elastic modulus for each:

1. **Young's modulus**, which measures the resistance of a solid to a change in its length
2. **Shear modulus**, which measures the resistance to motion of the planes within a solid parallel to each other
3. **Bulk modulus**, which measures the resistance of solids or liquids to changes in their volume

6-6 Shear Stress and Strain

An object under shear stress. Forces are applied tangent to opposite surfaces of the object (in contrast to the situation in Figure, in which the forces act perpendicular to the surfaces). The deformation *x is exaggerated for clarity.*

One part of the ribbon is being pushed up while an adjacent part is being pushed down, producing a deformation of the ribbon. Figure shows a body being deformed by a shear stress. In the figure, forces of equal magnitude but opposite direction act *tangent to the surfaces of opposite ends of* the object. We define the shear stress as the force acting tangent to the surface divided by the area *A on which it acts:*

$$\text{Shear Stress} = \frac{F}{A}$$

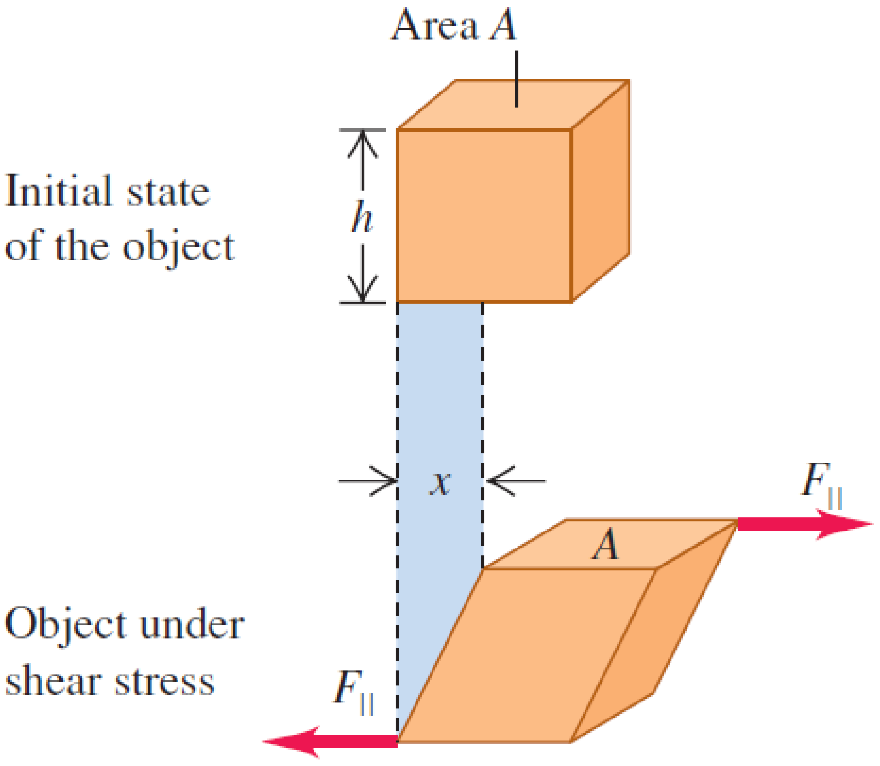


Figure shows that one face of the object under shear stress is displaced by a distance x relative to the opposite face. We define **shear strain as the ratio of** the displacement **x** to the transverse dimension **h**:

$$\text{Shear Strain} = \frac{x}{h}$$

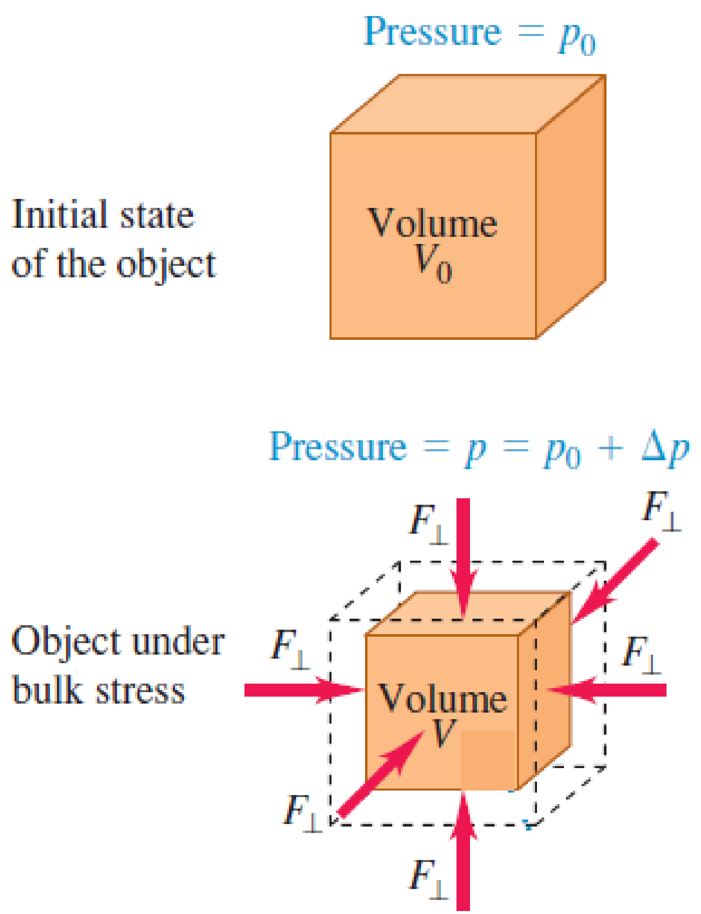
If the forces are small enough that Hooke's law is obeyed, the shear strain is *proportional to the shear stress. The corresponding elastic modulus (ratio of* shear stress to shear strain) is called the **shear modulus, denoted by *S:***

$$S = \frac{\text{Shear Stress}}{\text{Shear Strain}} = \frac{F/A}{x/h} = \frac{F\,h}{A\,x}$$

The previous Table gives several values of shear modulus. For a given material, *S is* usually one-third to one-half as large as Young's modulus *Y for tensile stress.* Keep in mind that the concepts of shear stress, shear strain, and shear modulus apply to ***solid materials*** *only. The reason is that shear refers to deforming an* object that has a definite shape. This concept doesn't apply to gases and liquids, which do not have definite shapes.

6-7 Bulk Stress and Strain

The stress is a uniform pressure on all sides, and the resulting deformation is a volume change. We use the terms **bulk stress** (or volume stress) and **bulk strain** (or volume strain) to describe these quantities.



If an object is immersed in a fluid (liquid or gas) at rest, the fluid exerts a force on any part of the object's surface; this force is *perpendicular to the surface.* (If we tried to make the fluid exert a force parallel to the surface, the fluid would slip sideways to counteract the effort.) The force per unit area that the fluid exerts on the surface of an immersed object is called the pressure *p in* the fluid:

$$P = \frac{F}{A}$$

Note:

The pressure in a fluid increases with depth.

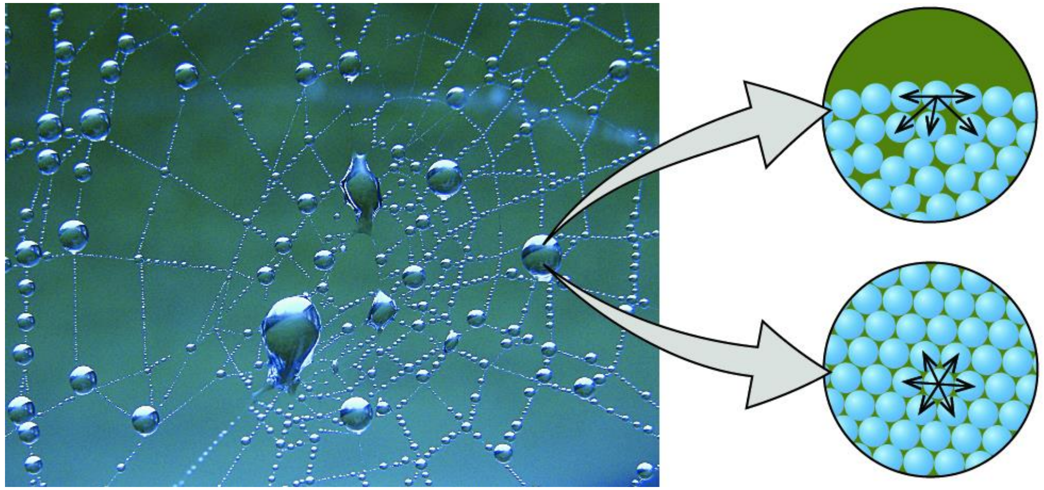
1 atmosphere = 1 atm = 1.013 * 105 Pa.

Unlike force, pressure has no intrinsic direction (Scalar quantity)

6.1 Cohesion and Adhesion Forces

The force of attraction between molecules of the same substance is sometimes called **cohesion**. Cohesion forces are intermolecular forces since these forces can be found between the molecules of the same substance. These cohesion forces can be found in solid and liquid matter. The atoms or particles in solids and liquids are held together by these forces. Hydrogen bonding and Van Der Waal forces are types of cohesion forces.

A good example for the presence of cohesion forces can be found regarding water. The force attraction between water molecules is a type of cohesive force since it is a hydrogen bonding. A water droplet is formed due to this force. The effects of cohesion include surface tension, meniscus, and capillary action.



Adhesion is the attraction force between molecules of different kinds. In other words, adhesion forces occur between different molecules. Adhesion forces include electrostatic forces between two different molecules. For example, a strong adhesive force causes a liquid to spread over a solid surface. One of the major applications of adhesion in nature is the water transportation through xylem vessels. Here, the adhesion forces between the water molecules and the cell wall components help the water to move through xylem tube.

Capillary action and the meniscus are effects of adhesion. Capillary action is the movement of a liquid through a small tube against gravity. This occurs with the help of both adhesion and cohesion. The attraction force between liquid molecules and the tube wall is the adhesion here. In meniscus, the curvature of the liquid surface is helped by adhesion forces that act between the wall of the container and the liquid. The edges of the liquid are held by adhesion.