Properties of Matter

Chapter One

PHYSICAL QUANTITIES

Quantitative versus Qualitative

A physical quantity is one that can be measured and consists of a magnitude and unit. Are classified into two types: Base quantities and Derived quantities

- **Base quantity** is like the brick – the basic building block of a house
- **Derived quantity** is like the house that was build up from a collection of bricks (basic quantity)

SI Units – International System of Units

Base Quantities	Name of Unit	Symbol of Unit
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

Derived Quantity	Relation with Base and Derived Quantities	Special Name
area	length × width	
volume	length × width × height	
density	mass ÷ volume	
speed	distance ÷ time	
acceleration	change in velocity ÷ time	
force	mass × acceleration	newton (N)
pressure	force ÷ area	pascal (Pa)
work	force × distance	joule (J)
power	work ÷ time	watt (W)

Prefixes

Prefixes simplify the writing of very large or very small quantities

Prefix	Abbreviation	Power
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}

Scalars and Vectors

Scalar quantities are quantities that have magnitude only.

Vector quantities are quantities that have both magnitude and direction

Examples of scalars and vectors

Scalars	Vectors
Distance	Displacement
Speed	Velocity
Mass	Weight
Time	Acceleration
Pressure	Force
Energy	Momentum
Volume	
Density	

Dimensional Analysis

Engineering and science, dimensional analysis is the analysis of the relationships between different physical quantities by identifying their base quantities (such as length, mass, time, electric charge) and units of measure (such as miles vs. kilometers, or pounds vs. kilo-grams) tracking these dimensions as calculations or comparisons are performed.

The importance of dimensional analysis

- To check the correctness of the form of the equation
- To derive a relation between the physical quantities but it can't have the values of the constants.

- To determine the proper units for some particular terms in an equation.

Dimension of basic and derived units

Basic Units	
Length	$[L]$
Time	$[T]$
Mass	$[M]$
Temperature	$[°K]$
Angle	dimensionless

Derived Units	
Velocity	$[L][T^{-1}]$
Acceleration	$[L][T^{-2}]$
Force	$[M][L][T^{-2}]$
Frequency	$[T^{-1}]$
Density	$[M][L^{-3}]$
Volume	$[L^{3}]$
Pressure	$[M][L^{-1}][T^{-2}]$
Work	$[M][L^{2}][T^{-1}]$

Examples

Example (1-1):

Show that the following equation is dimensionally correct:

$$X = v_o t + \frac{1}{2} a t^2$$

Where (v_o) is velocity and (a) is acceleration

Solution:

$$Dim[LHS] = [L]$$

$$Dim[RHS] = \left[\frac{L}{T}\right][T] + \frac{1}{2}\left[\frac{L}{T^2}\right][T]^2$$

$$= [L] + \frac{1}{2}[L] = \frac{3}{2}[L]$$

$$Dim[LHS] = Dim[RHS]$$

The equation is dimensionally correct (ignore constants)

Example (1-2):

Show that the following equation is dimensionally correct:

$$v = v\mathrm{o} + \mathrm{at}$$

where (v_o) is velocity and (a) is acceleration

Solution:

$$Dim[LHS] = \left[\frac{L}{T}\right]$$

$$Dim[RHS] = \left[\frac{L}{T}\right] + \left[\frac{L}{T^2}\right][T]$$

$$= \left[\frac{L}{T}\right] + \left[\frac{L}{T}\right] = 2\left[\frac{L}{T}\right]$$

$$Dim[LHS] = Dim[RHS]$$

The equation is dimensionally correct (ignore constants)

Example (1-3):

The period (p) of a simple pendulum is the time for one complete swing. How does (p) depend on mass (m) of the bob, the length (L) of the string, and the acceleration due to gravity (g)?

Solution:

Let $p \propto m^a L^b g^c$

$$p = km^a L^b g^c$$

$$Dim[LHS] = Dim[RHS]$$

$$[T] = [M]^a [L]^b \left[\frac{L}{T^2}\right]^c$$

$$[T] = [M]^a [L]^{b+C} [T]^{-2c}$$

$$\therefore\ a = 0$$

$$\therefore\ -2c = 1 \Rightarrow c = -0.5$$

$$\therefore\ b + c = 0 \Rightarrow b = 0.5$$

$$p = kL^{0.5} g^{-0.5} = k\sqrt{\frac{L}{g}}$$

Example (1-4):

Newton's second law states that acceleration is proportional to the force acting on an object and is inversely proportional to the object mass. What are the dimensions of force?

Solution:

The acceleration → $[a] = \frac{[L]}{T^2}$,

The mass m → $[m] = [M]$

$$a \propto Fm^{-1} \Rightarrow a = \frac{kF}{m}$$

$$\therefore F = \frac{ma}{k} \Rightarrow [F] = [m][a] = [M][L][T]^{-2}$$

Example (1-5):

The wave length λ of a wave depends on the speed (v) of the wave and its frequency (f). Decide which of the following equations is correct: $\lambda = vf$ or $\lambda = v/f$.

Solution:

$$\lambda = v^a f^b$$

$$Dim[LHS] = Dim[RHS]$$

$$[L] = \left[\frac{L}{T}\right]^a \left[\frac{1}{T}\right]^b$$

$$[L] = [L]^a[T]^{-a-b}$$

$$\therefore \ a = 1$$

$$-a - b = 0 \Rightarrow \ \therefore b = -1$$

$$\lambda = v^1 f^{-1} = \frac{v}{f}$$

$\therefore$ The correct relation is $\lambda = {}^{v}/_{f}$

$$Dim[RHS] = [L]$$

From equation (1):

$$Dim[RHS] = \left[\frac{L}{T}\right]\left[\frac{1}{T}\right] = \left[\frac{L}{T^2}\right] \neq Dim[LHS] \Rightarrow Uncorrect$$

From equation (2):

$$Dim[RHS] = {}^{\left[\frac{L}{T}\right]}\Big/_{\left[\frac{1}{T}\right]} = [L] = Dim[LHS] \Rightarrow Correct$$

$\therefore$ The correct relation is $\lambda = {}^{v}/_{f}$

Example (1-6):

Suppose a sphere of Radius (R) is pulled at constant speed (v) through a fluid viscosity η. The force (F) that is required to pull the sphere through the fluid depends on v, R and η, (F = $(const)$). Find the dimensions of η.

Solution:

$$Dim[LHS] = Dim[RHS]$$

$$[v] = \left[\frac{L}{T}\right] \ ,$$

$$[F] = \frac{[M][L]}{T^2}, \qquad [\eta] = ???$$

$$F = (const)vR\eta$$

$$\therefore\ \eta = \frac{F}{(const)vR} \Rightarrow [\eta] = \frac{[F]}{[v][R]}$$

$$[\eta] = \frac{[M][L]}{[T^2]} \frac{1}{\left[\frac{L}{T}\right][L]}$$

$$\therefore\ [\eta] = \frac{[M]}{[L][T]}$$

Chapter Two

STATES AND BEHAVIOR OF MATTER

Introduction to matter

Matter is anything, such as a solid, liquid or gas, that has **weight** (mass) and occupies space. For anything to occupy space, it must have **volume**. Thinking about it, everything on earth has weight and takes up space, and that means everything on earth is matter.

Properties of Matter

The basic properties of matter are it is made up of mass and it has a volume occupying space. The properties of matter can be divided into two categories:

- **Extensive properties** – It is that property which depends on the quantity of matter in a body. For example **mass**, **volume**, **calories** etc.
- **Intrinsic properties** – It is that property which is independent of the quantity of matter present in the body. It rather depends on the type of matter the substance is made up of. For example **density**, **hardness**, **melting point**, **boiling point**, color etc.

Classification of Matter

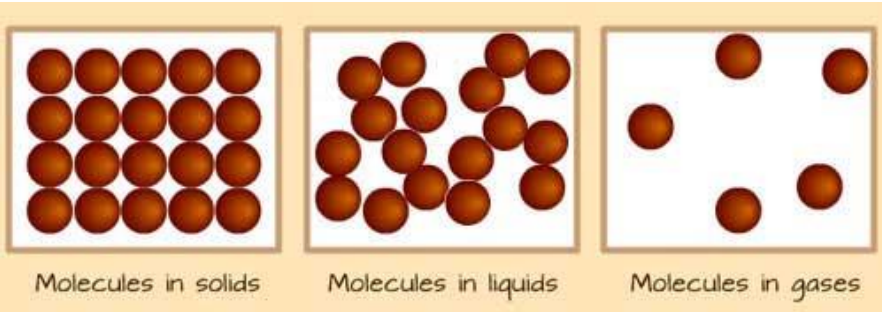
Matter can be classified into three different types namely:

- **Elements** – It is made up of atoms or molecules of a similar kind. Atom is the smallest particle of matter, for example, neon and when two or more atoms are chemically bonded they form molecules, for example, oxygen. Elements cannot be broken down into simpler particles either by physical or by chemical means.
- **Compounds** – It is made up of atoms or molecules of dissimilar elements chemically bonded together. Compounds can be broken down into simpler particles by chemical means and the properties of the broken part are completely different from its parent compound. A compound made up of elements always maintains a fixed ratio. For example two molecules of hydrogen react with one molecule of oxygen to form two molecules of water.
- **Mixtures** – It is made up of two or more different types of elements or compounds which are bonded as well as could be separated by physical means. Every part of it retains its individual properties. It could further be divided into two types:
    - **Heterogeneous Mixtures** – Composition of matter is not uniform throughout. **E.g.** Gravel, soil etc.
    - **Homogeneous Mixtures (solutions)** – Composition of matter is uniform throughout. **E.g.** Tea, Kool Aid etc.

States of Matter

There are mainly three states of matter-Solid, Liquid and Gas. Solids, liquids and gases are all made up of very tiny stuff that the naked eye cannot see, called atoms, molecules and/or ions.

The illustration below is an idea of how atoms, molecules and ions in matter look like under a microscope.



In this lesson, we shall look at Solids, Liquids and Gases, which are known as the three states of matter.

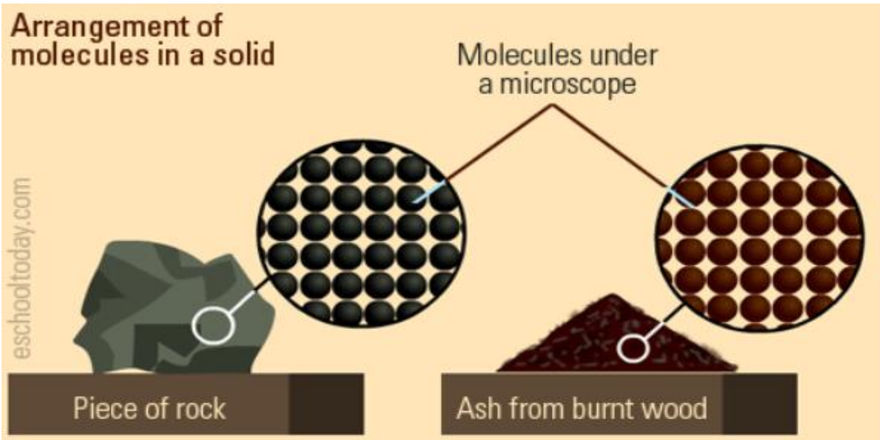
NOTE

Plasma is considered to be the fourth state of matter. It is hot ionized gas having almost an equal number of negatively charged electrons and positively charged ions. It is highly affected by both electrical and magnetic field. For example, noble gases are used as glowing tubes my ionizing it with the help of electricity.

Solids

Solids are simply hard substances, and they are hard because of how their molecules are packed together. Examples include rock, chalk, sugar, a piece of wood, plastic, steel or nail. They are all solids at room temperature. They can come in all sizes, shapes and forms. Think of ice cubes as an example. They are solids when frozen. They change into liquid at room temperature. What about ashes? Is that solid too? Yes, ashes are tiny solid particles that fall off when something burns— like wood ash in the fireplace.

In the diagram below, see how similar the arrangement of molecules are in the piece of rock and wood ash.



Characteristic of particles (molecules) in a solid.

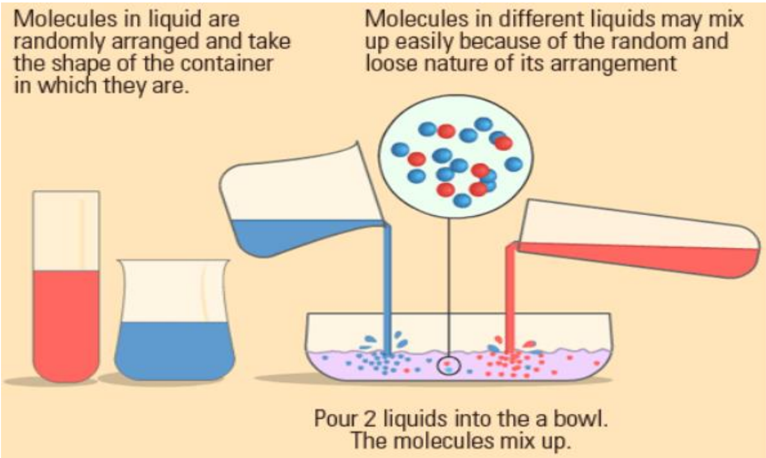
- The particles are close together (that's why they cannot be squashed or compressed.
- The particles cannot move freely from place to place (this is why they have a fixed shape). The particles are arranged in a regular, distinct pattern.
- The particles are held together by strong forces called bonds (This is why solids do ***not*** flow like water. Their particles are only able to vibrate in their position and cannot move from place to place.)
- The particles can vibrate in a fixed position

Different solids behave slightly differently because they have different properties such as 'STRENGTH'. This makes solids useful for different things. Look at a pencil eraser—it is solid, but can slightly change shape because the strength of its bonds is slightly weaker than that in a piece of diamond.

Liquid

The particles in liquids are not as closely bonded, arranged and fixed in place as in solids. The particles in liquid can flow freely and can mix with particles from other liquids. Liquids have their atoms close together, so they are not very easy to ***compress***.

Liquids, unlike gases are pulled by gravity to the bottom of the container holding it. They take the shape of the container holding it. You can pour a volume of liquid from one container to the other — it can change shape but the volume will be the same.



Characteristic of particles in liquids:

The particles are:

- Close together, but not as packed as in solids. (They cannot be compressed or squashed)
- Arranged in a random way.

- move around each other (They flow and take the shape of their container because their particles can move over each other)
- The bonds in a liquid are strong enough to keep the particles close together, but weak enough to let them move around each other.

Gases

Gas is everywhere, and it surrounds us. The air around us is a kind of gas. The atmosphere surrounding the earth is a gas too. Helium, Oxygen, Carbon dioxide and water vapour are all gases. The particles in gases are very different from that of solids and liquids. In gases, the particles are far apart from each other and arranged in a random way.

The particles also move quickly in all directions. Gases can fill up any container of any shape and size. Gases can be compressed or squashed because the molecules are far from each other. When gas is compressed, the gas molecules move from an area of high pressure to low pressure.

Vapour is also a gas. Gases that are liquid at room temperature, like water, can be classified as vapour. This means they are usually liquid, but can vaporize (turn into gas) under certain conditions.

NOTE

Compressing something means forcing the atoms in it closer together. When you compress an object, you force the atoms closer together.

Comparisons between the three State of Matter

Properties	Solid	Liquid	Gas
Shape	Solids have a definite shape	Liquids do not have a definite shape. It takes up the shape of the container in which it is kept	Gas does not have a definite shape. It takes up the shape of the entire space kept in
Volume	Solids have a definite Volume	Liquids have a definite volume	Gas do not have a definite volume
Effect of rise in temperature	With the rise in temperature there is small expansion. On reaching the melting point solids change into liquids and at	With the rise in temperature there is small expansion. On reaching the vaporization point liquid changes to	With the rise in temperature there is large expansion. On reaching the deposition point gas changes to

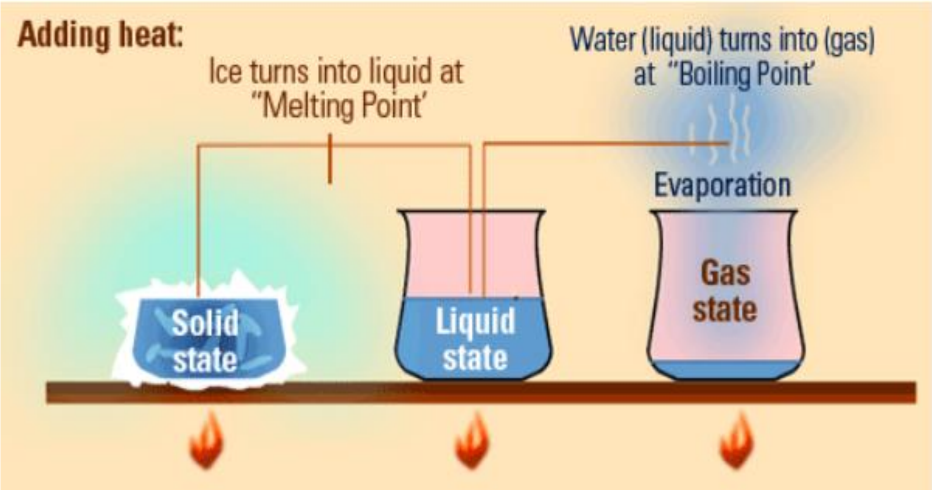
Properties	Solid	Liquid	Gas
	sublimation directly changes from solid to gas	gas and at freezing point liquid changes to solid state	solids and at condensation point gas changes to liquid state
Kinetic energy	Low	More kinetic energy compared to solids	Highest
Malleability	Malleable	Non malleable	Non malleable
Ductility	Ductile	Non ductile	Non ductile
Compressible	Cannot be compressed into smaller volume with increase in pressure	Cannot be compressed into smaller volume with increase in pressure	Can be compressed into smaller volume with increase in pressure
Inter-molecular space	The molecules are closely packed having very less	The intermolecular space is larger in liquids compared to	The intermolecular space is largest in gas compared to that of solids

Properties	Solid	Liquid	Gas
	intermolecular space	that of solids	
Inter-molecular attraction	Strong intermolecular forces of attraction holding the molecules firmly in position	Weak intermolecular forces of attraction as a result of which the molecules freely slide over each other, hence making it viscous in nature	Weakest intermolecular forces of attraction as a result of which the molecules are free to move in any direction
Example	Gold, silver etc	Water, oil etc	Oxygen, hydrogen etc

The Changing state of Matter

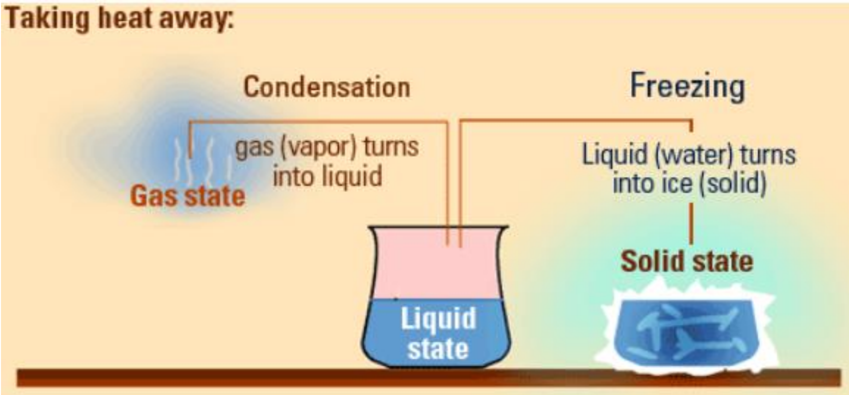
Matter cannot be created or destroyed, but can change from one state to the other with the application or removal of heat (temperature). Each time matter changes state, it is simply the movement of molecules in them speeding up or slowing down.

Let us use water as an example. At room temperature, water is a liquid, and the molecules in it move slowly. When you apply heat (or raise the temperature) the molecules move faster and faster. With more heat, the liquid state will change to gas, because the molecules would be moving so fast and taking up space everywhere.



The scientific term for water turning into gas (vapour) as a result of heat application is evaporation (to evaporate). Water evaporates when it reaches boiling point.

When you reduce the heat and bring down the temperature in the gas, the molecules in the vapour slow down and gradually turn back into liquid. The scientific term for gas turning into liquid as a result of heat loss is condensation (to condense).



If you take away all the heat (put it in a freezer), the molecules will be extremely slow and move very little. They will hold to each other, turning the water into a solid (ice). The point at which water turns into ice is called 'Freezing point'.

Now, take the ice (solid) from the freezer, and place it in room temperature. Soon the ice begins to melt. The point at which solids melt into liquid is known as melting point.

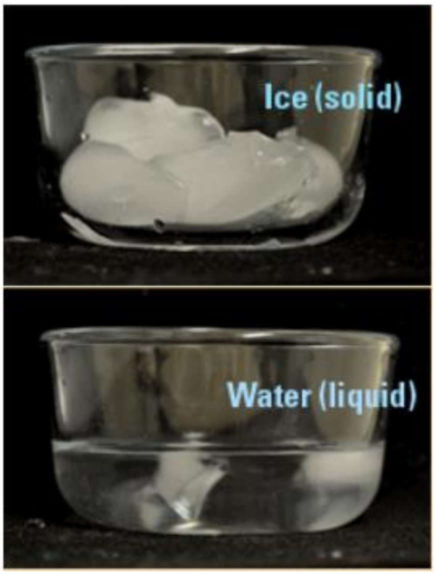
Physical Change

In a physical change, the internal make-up of the object (molecules) stays the same, even after the change — only its form changes. The resulting element can be reversed into the object before. Changes that can be reversed are called a ***Reversible Change.***

In a physical change, ***the state, shape or size*** of the object is changed. ***Pressure, temperature or motion*** can bring about a physical change.

Change in state:

Put some water into a plastic cup and place it in the freezer. After sometime the water changes into ice, right?



The water moved from a liquid state to a solid state. With a bit of heat energy, the ice will melt back into water. Note that the stuff that water is made up of, hydrogen oxygen, did not change, but its' state changed from liquid to ice and back to liquid.

Change in shape: Take a sheet of paper and crush it in your hands. Notice how the shape changed from a sheet into a small ball in your hands? This physical change resulted from the pressure you applied to it.

Change in size: If the piece of paper is ripped apart, there is going to be a change in its size too.

Sometimes physical change can involve a change in color too, even though we don't like to use color change in explaining a physical change. This is because applying paint or color to an object technically means adding another matter to it. Real change in color will be a result of a chemical change.

NOTE

In a physical change, no new kinds of particles are produced even though the particles can move closer together or farther apart, or they may mix with particles of other substances.

DID YOU KNOW...

When you put sugar in water, it dissolves. It is a physical change because the sugar particles mix with the water particles, but molecule make-up does not change. The process can be reversed by evaporating the water and collecting the sugar.

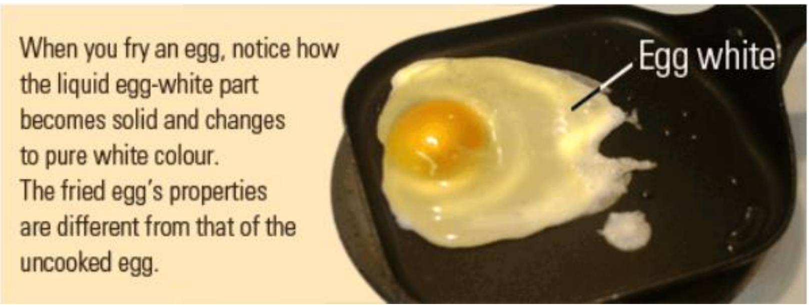
Chemical Change

Every day we experience chemical changes in many things around us. Think of a rotten orange, fried egg, rusted nail and even poop! — all these things involved an object (matter) going through a process that can never be reversed. A chemical process (reaction) caused that kind of change.

We say there us a ***chemical change*** in a matter when the internal make-up (molecules) of the object changes. Unlike a physical change, chemical changes cannot be reversed. Changes that cannot be reversed are called ***Non-reversible Change***.

There are usually one or more new substances formed or created from that change. You can tell there is chemical change when it produces a ***gas, light, smell, fire (heat) or color change.*** A chemical change may also be accompanied by the formation of a solid in the form of a precipitate, and in some cases, accompanied by a gain or loss of energy.

A good example is the change that occurs when you fry an egg:



Here is another example:

Think of the dry wood in the fireplace. When we light the wood up, it burns gently and after a while, it turns into ashes. As it burns, it produces heat, light and smoke which escapes through the chimney. The heat, light, fire and smoke are all good characteristics of a chemical reaction, which result in a completely ***new*** matter—ashes.

Note that the ashes from the burning wood have an entirely new molecular composition. It can never be turned back into wood again.

Here are 10 common examples of Chemical Change you can find in your home:

- Baking cakes
- Rusting nails or metals or aluminium
- Burning wood/log or lighting a match
- Exploding Fireworks
- Ripening and rotting bananas
- Digesting food in your tummy
- Mixing an acid with a base, producing water and a salt
- Baking turkey or grilling chicken
- Changing color of autumn leaves
- Milk going/gone bad...

NOTE

When we eat, our bodies digest the food and converts sugars into energy, proteins into body cells and so on. When we breathe, our lungs absorb Oxygen from the air we breathe in, and uses the oxygen to enrich our blood. All these activities in our bodies are chemical activities. Their end results cannot be reversed.

Chapter Three

MASS, VOLUME AND DENSITY

Mass

Mass is a measure of the amount of material an object is made of. It is measured in kilograms.

Weight is the force of gravity on an object. It is measured in Newtons.

Basis for Comparison	Mass	Weight
Meaning	Mass refers to the quantity of matter contained in a body.	Weight implies the force acted upon the object due to the pull of gravity.
What is it?	It is the measure of inertia.	It is the measure of force.
Location	It remains same, irrespective of the location.	It varies as per the location.
Physical Quantity	Scalar Quantity	Vector Quantity
Zero	It can never be zero.	When no gravity acts upon the body, it can be zero.
SI unit	Kilogram	Newtons
Measurement	Ordinary balance is used in measurement.	Spring balance is used in measurement.

Examples

Example (3-1):

The strength of gravity at the Earth's surface is 10 newtons per kilogram. Calculate the weight of a car with a mass of 1500 kg.

Solution:

Weight = Mass × Gravity

Hence: Weight = 1500 × 10 = 15000 newtons

Example (3-2):

The strength of gravity on the Moon is 1.6 newtons per kilogram. If an astronaut's mass is 80 kg on Earth, what would it be on the Moon?

Solution:

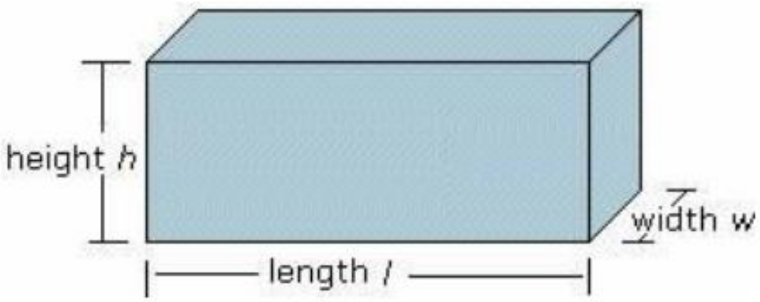
Mass is independent of location, so the astronaut's mass on the Moon is the same as the astronaut's mass on the Earth.

Hence: Astronaut's mass on the Moon = Astronaut's mass on the Earth = 80 kg

Volume

Measurement of the amount of space an object takes up

• Measured in milliliters (ml) or cm^3



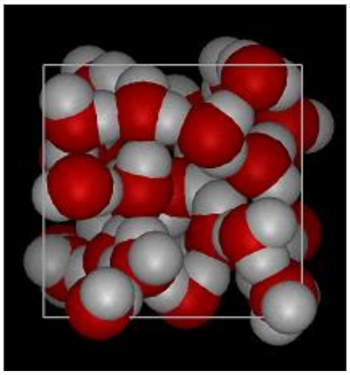
Which do you think would have the greater volume? The greater mass? Why?

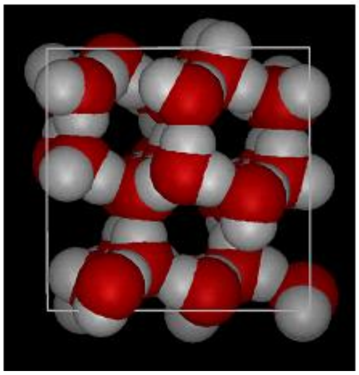
1 kg of feathers

1 kg of rocks

Density

Density is defined as mass per unit volume. It is a measure of how tightly packed and how heavy the molecules are in an object. Density is the amount of matter within a certain volume.

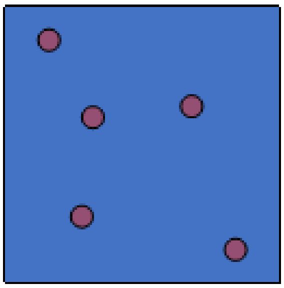


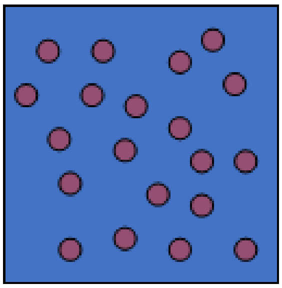


Which one is more dense?

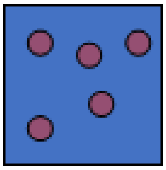
Demonstration: People in a square, How about this:

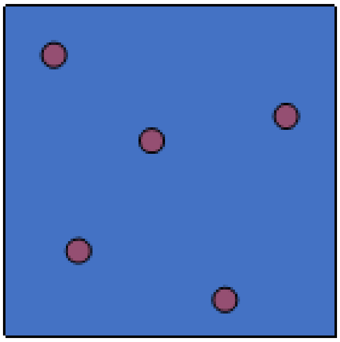
Which square is more dense?





Which one is more dense? Now which one is more dense?





To find the density Divide $Density = \frac{Mass\ g}{Volume\ c^3}$

Example (3-3):

If the mass of an object is 35 grams and it takes up 7 cm^3 of space, calculate the density Set up your density problems like this: Given: Mass = 35 grams Unknown: Density (g/cm^3) Volume = 7 cm^3

Formula: D = M / V

Solution:

$D = 35g/7\ cm^3$ $D = 5\ g/cm^3$

Let's try some density problems together, Work on these problems with your neighbor

1) Frank has a paper clip. It has a mass of 9g and a volume of $3cm^3$. What is its density?

2) Frank also has an eraser. It has a mass of 3g, and a volume of $1cm^3$. What is its density?

3) Jack has a rock. The rock has a mass of 6g and a volume of 3cm3. What is the density of the rock?

4) Jill has a gel pen. The gel pen has a mass of 8g and a volume of $2cm^3$. What is the density of the rock?

Ways to Affect Density

Change Mass AND Keep Volume Same

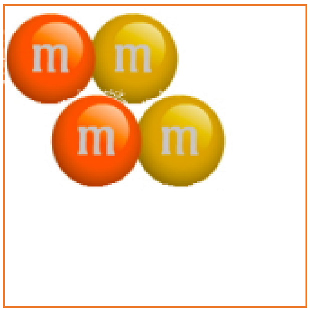
Increase the mass → increase density

Decrease the mass → decrease in density

Which container has more density?

A

B

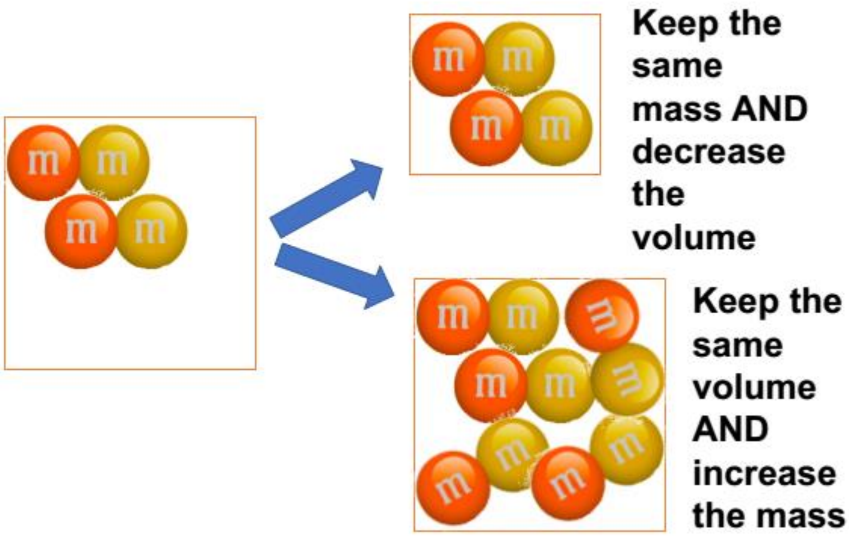


A

B

In your notebook illustrate the answer to the following question:

What 2 ways will INCREASE density?



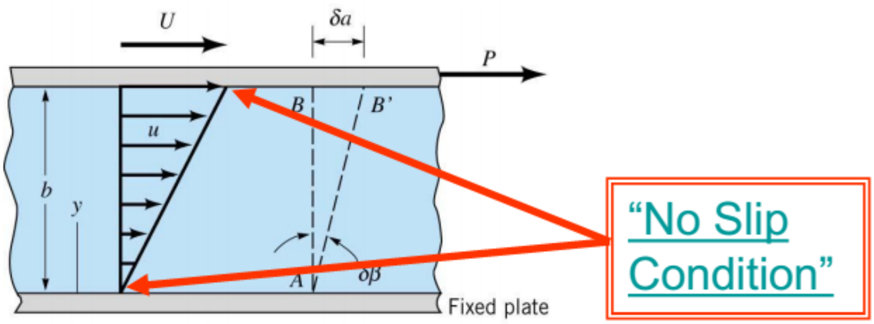
Chapter Four

VISCOSITY

The viscosity is measure of the "fluidity" of the fluid which is not captured simply by density or specific weight. A fluid cannot resist a shear and under shear begins to flow. The shearing stress and shearing strain can be related with a relationship of the following form for common fluids such as water, air, oil, and gasoline:

$$\tau = \mu \frac{du}{dy}$$

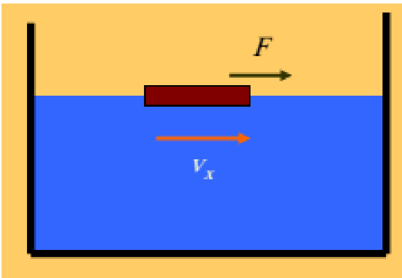
μ is the absolute viscosity or dynamics viscosity of the fluid, u is the velocity of the fluid and y is the vertical coordinate as shown in the schematic below:



We feel resistance if we walk into a lake. This means the existence of a force of friction in water. It is notable that this force differs from a liquid to another; there are liquids of high friction force and others of low friction force. Forces of friction of these liquids are known as viscosity of liquids or fluids. If the force is high the liquid or fluid is said to be highly viscous and vice versa.

Fluid Resistance

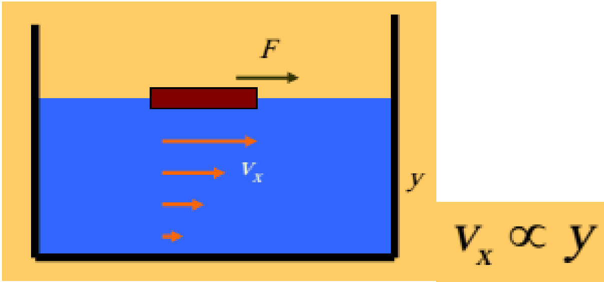
- An object moving through or on a fluid meets resistance.
- Force causes the fluid to move.
- The velocity is proportional to the force.



$$V_x \propto F$$

Velocity Gradient

- The resistance tends to keep the fluid in place.
    - Law of inertia
- The fluid moves most near the object and least farther away.
- This is a velocity *gradient.*



Coefficient of viscosity and Newton's formula:

Newton coined a term to denote friction force among layers of the liquid, besides a term referring to coefficient of viscosity. He confirmed this through scientific experiments. He stated that the friction force (F) relied on the surface area of the liquid (A) besides velocity of the flowing of the liquid (V) and it is indirectly proportionate to distance x its measure at the static layer; the one next to the wall of the tube through which the liquid runs. This is mathematically expressed as follows:

$$f \propto -A.V.\frac{1}{X}$$

Or

$$f = \eta.V.\frac{1}{X}$$

The previous negative sign reveals that direction of the friction force is opposite to that of the velocity of the liquid's flowing. The constant of this ratio (η) is known as coefficient of viscosity. It depends on the nature of the liquid. In case of the previous equation, it is possible to place V/X as dV/dX in which case the quantity dV/dX is known as velocity gradient.

Newton's formula is expressed in this following way:

$$f = \ -\eta . A . \ \frac{dV}{dX}$$

Or $$\eta = -A \ \frac{F}{dV \mid dX}$$

Accordingly, the coefficient of viscosity may be defined as the friction force needed for keeping velocity gradient equal to a unit in a surface area of a unit, too.

If this force is equal to a unit, the coefficient of viscosity is also equal to a unit. In this case, it is called poise, named after scientist Poiseuille. Viscosity in liquids is similar to friction forces among solid bodies as both.

Motion in a viscous medium:

Scientist Stocks investigated motions of metal balls inside viscous media and coined a term expressing the friction force produced by viscosity of the medium. Supposing that the diameter of the ball is (r) and it moves with a velocity (V) in a medium whose viscosity coefficient is (η), this force is expressed by the following relation:

$$F = \ 6\pi V r\eta$$

This law is known as Stocks law. This may be concluded by the theory of dimensions. Supposing that there is a ball of a radius (r) is dropped into a liquid whose coefficient of viscosity is (η), density o and density of the metal ball is 8 &o, at the beginning of dropping, velocity of the ball will be irregular, but it gets regular later. It is called terminal velocity, then. At this moment, acceleration of the forces influencing them is zero. In other words, the three forces are:

1- Weight of the ball downward

2- Force of pushing the liquid onto the ball upward.

3- Stocks force due to upward viscosity

Weight of the ball is

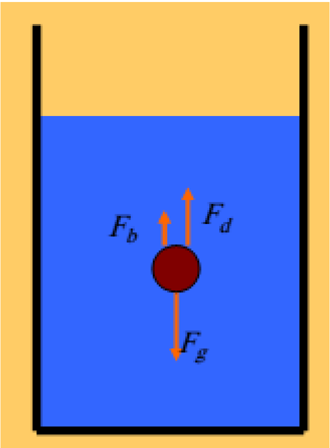
$$4/3\pi r^3\delta.g$$

Were (g) is Earth gravity, force of pushing the liquid is

$$4/3\pi r^3\delta.g$$

stocks force is

$$6\pi Vr\eta$$



and at the terminal velocity, the following equation may be written:

Weight of the ball force of pushing on the ball + Stocks force.

This expression is written mathematically as follows:

$$4/3\pi r^3\delta.g = 4/3\pi r^3\delta.g + 6\pi Vr\eta$$

Or $$6\pi V r \eta = 4/3\pi r^3 . g\,(\delta - \sigma)$$

Or $$V = \frac{(2r^2\, g)}{9\eta}\,(\delta - \sigma)$$

This illustrates that terminal velocity is directly proportionate with its square radius, taking into account difference between the densities of the ball and liquid. The terminal velocity is also indirectly proportionate with coefficient of viscosity.

Chapter Five

SURFACE TENSION

At the interface between a liquid and a gas or two immiscible liquids, forces develop forming an analogous “skin” or “membrane” stretched over the fluid mass which can support weight.

This “skin” is due to an imbalance of cohesive forces. The interior of the fluid is in balance as molecules of the like fluid are attracting each other while on the interface there is a net inward pulling force.

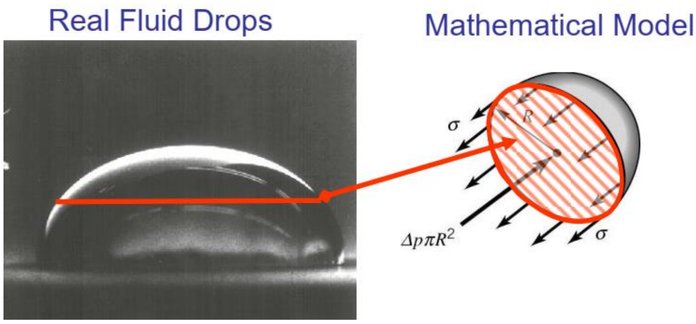
Surface tension is the intensity of the molecular attraction per unit length along any line in the surface.

Surface tension is a property of the liquid type, the temperature, and the other fluid at the interface.

This membrane can be “broken” with a surfactant which reduces the surface tension.

Liquid Drop

The pressure inside a drop of fluid can be calculated using a free-body diagram:



R is the radius of the droplet, s is the surface tension, Dp is the pressure difference between the inside and outside pressure.

The force developed around the edge due to surface tension along the line:

$$F_{surface} = 2\pi R\sigma$$ Applied to Circumference

This force is balanced by the pressure difference Δp:

$$F_{pressure} = \Delta p \pi R^2$$ Applied to Area

Now, equating the Surface Tension Force to the Pressure Force, we can estimate:

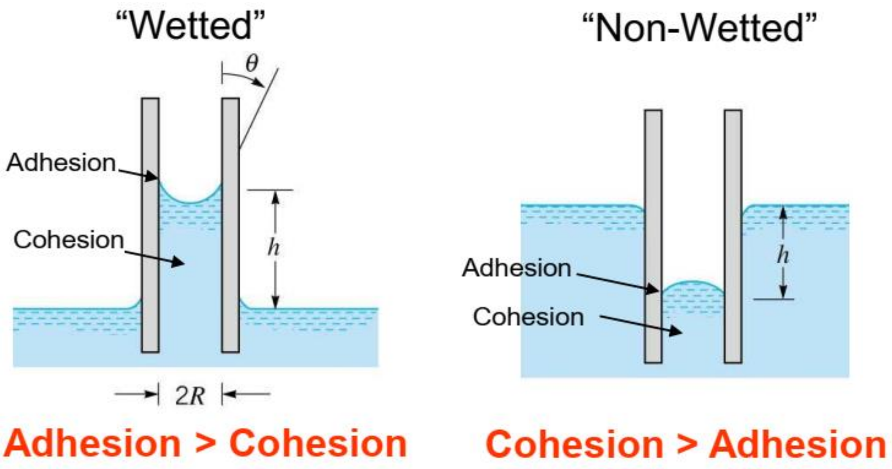
$$\Delta p = p_i - p_e$$

$$\Delta p = \frac{2\delta}{R}$$

This indicates that the internal pressure in the droplet is greater that the external pressure since the right hand side is entirely positive.

Capillary Action

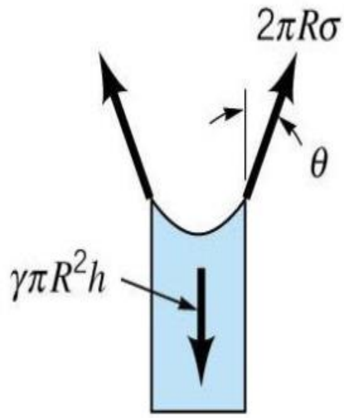
Capillary action in small tubes which involve a liquid-gas-solid interface is caused by surface tension. The fluid is either drawn up the tube or pushed down.



h is the height, R is the radius of the tube, q is the angle of contact.

"Wetted" "Non-Wetted" The weight of the fluid is balanced with the vertical force caused by surface tension.

Free Body Diagram for Capillary Action for a Wetted Surface:



$$F_{surface} = 2\pi R\sigma \cos\theta$$

$$W = \gamma\pi R^2 h$$

Equating the two and solving for h:

$$h = \frac{2\sigma \cos\theta}{\gamma R}$$

For clean glass in contact with water, ϴ ≈ 0°, and thus as R decreases, h increases, giving a higher rise.

For a clean glass in contact with Mercury, ϴ ≈ 130°, and thus h is negative or there is a push down of the fluid.

NOTE

Surface tension is apparent in many practical problems such as movement of liquid through soil and other porous media, flow of thin films, formation of drops and bubbles, and the breakup of liquid jets.

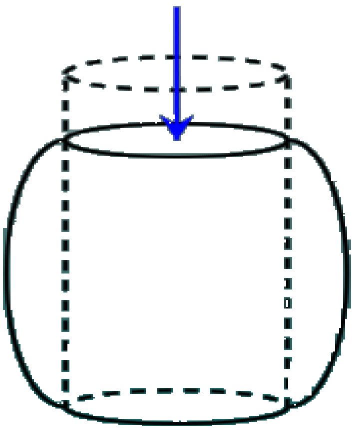
Chapter Six

ELASTICITY

Deformation

Deformation refers to any changes in the shape or size of an object due to:

– An applied force (the deformation energy in this case is transferred through work)
– A change in temperature (the deformation energy in this case is transferred through heat).



Compressive stress results in deformation which shortens the object but also expands it outwards.

Elastic Deformation versus Plastic Deformation

Elastic Deformation	Plastic Deformation
Elastic deformation is the deformation that disappears upon the removal of the external forces, causing the alteration and the stress associated with it	Plastic deformation is the permanent deformation or change in shape of a solid body without fracture under the action of a sustained force
Reversible	Irreversible
Non- permanent; the substance can resume the initial state back	Permanent; the substance stays unchanged after removing the stress
Causes the chemical bonds of the substance to undergo stretching and bending	Causes some of the chemical bonds of the substance to undergo breakage
Atoms do not slip pass on each other	Atoms slip pass on each other

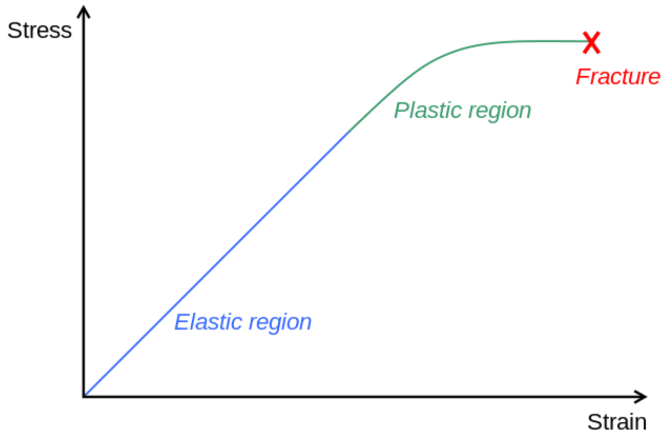


Diagram of a stress–strain curve, showing the relationship between stress (force applied) and strain (deformation) of a ductile metal.

Elastic Properties of Matter

An **elastic body** is one that returns to its original shape after a deformation.

- Golf Ball
- Rubber Band
- Soccer Ball

An **inelastic body** is one that does **not** return to its original shape after a deformation.

- Dough or Bread
- Clay
- Inelastic Ball

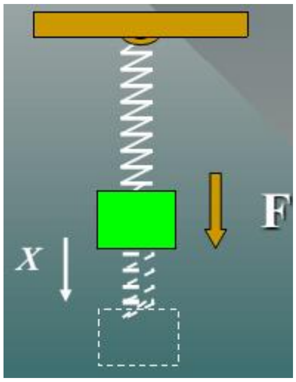
Elastic or Inelastic?

An elastic collision loses no energy. The deformation on collision is fully restored.

In an inelastic collision, energy is lost and the deformation may be permanent.

An Elastic Spring

A spring is an example of an elastic body that can be deformed by stretching.

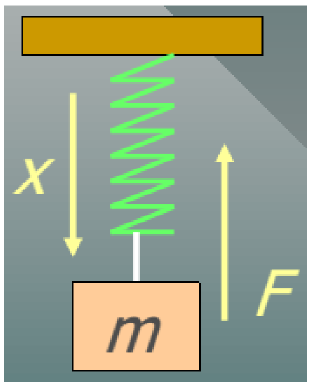


A **restoring force**, ***F***, acts in the direction opposite the displacement of the oscillating body.

$$F = -kx$$

Hooke's Law

When a spring is stretched, there is a restoring force that is proportional to the displacement.



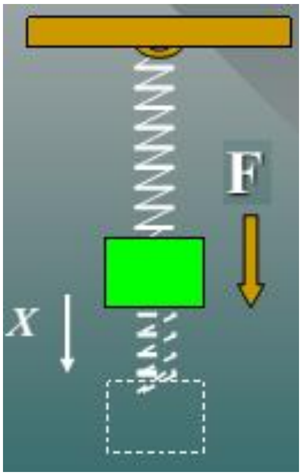
$$F = -kx$$

The spring constant k is a property of the spring given by:

$$k = \frac{\Delta F}{\Delta x}$$

The spring constant k is a measure of the elasticity of the spring.

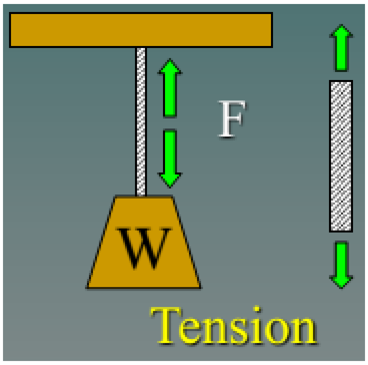
Stress and Strain



Stress refers to the cause of a deformation, and strain refers to the effect of the deformation.

The downward force F causes the displacement x. Thus, the stress is the force; the strain is the elongation.

Types of Stress

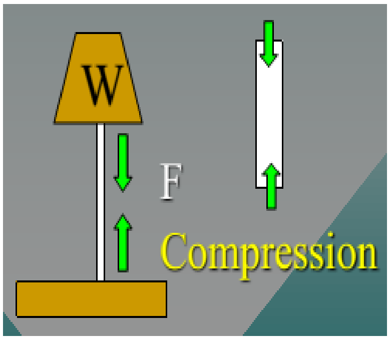


A tensile stress occurs when equal and opposite forces is directed away from each other.

A compressive stress occurs when equal and opposite forces is directed toward each other.

Summary of Definitions

Stress is the ratio of an applied force F to the area A over which it acts:



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

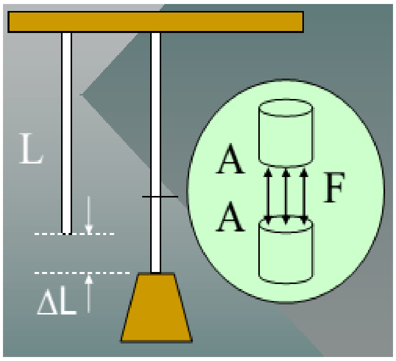
$$Unite: Pa = \frac{N}{m^2} \quad or \quad \frac{1b}{in^2}$$

Strain is the relative change in the dimensions or shape of a body as the result of an applied stress:

Examples: Change in length per unit length; change in volume per unit volume.

Longitudinal Stress and Strain

For wires, rods, and bars, there is a longitudinal stress F/A that produces a change in length per unit length. In such cases:



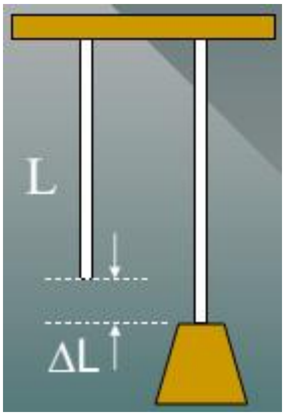
$$Stress = \frac{F}{A}$$

$$Strain = \frac{\Delta L}{L}$$

Example 1.

A steel wire 10 m long and 2 mm in diameter is attached to the ceiling and a 200-N weight is attached to the end. What is the applied stress?

First find area of wire:



$$A = \frac{\pi D^2}{4} = \frac{\pi (0.002m)^2}{4}$$

$$= 3.14x10^{-6}m^2$$

$$Stress = \frac{F}{A} = \frac{200\ N}{3.14 \times 10^{-6} m^2}$$

$$= 6.37 \times 10^7 Pa$$

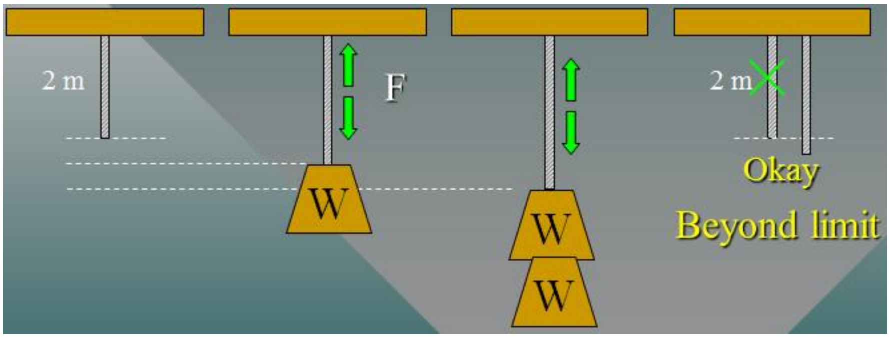
Example 1 (Cont.)

A 10 m steel wire stretches 3.08 mm due to the 200 N load. What is the longitudinal strain? Given: L = 10 m; ΔL = 3.08 mm

$$Longitudinal\ Strain = \frac{\Delta L}{L} = \frac{0.00308\ m}{10\ m} = 3.08 \times 10^{-4}$$

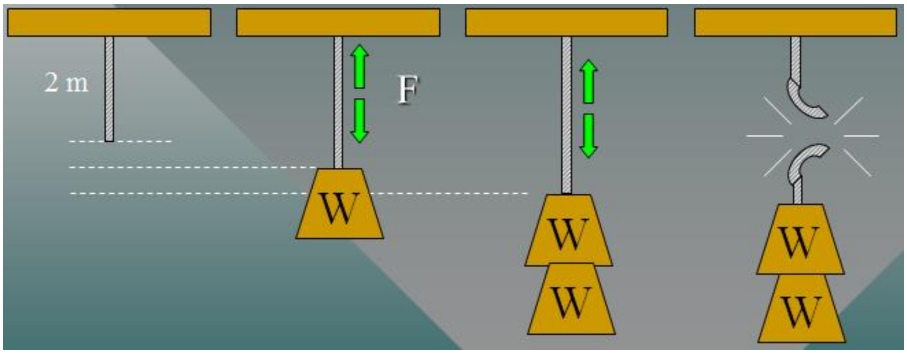
The Elastic Limit

The elastic limit is the maximum stress a body can experience without becoming permanently deformed.



If the stress exceeds the elastic limit, the final length will be longer than the original 2 m.

The ultimate strength is the greatest stress a body can experience without breaking or rupturing.



If the stress exceeds the ultimate strength, the string breaks!

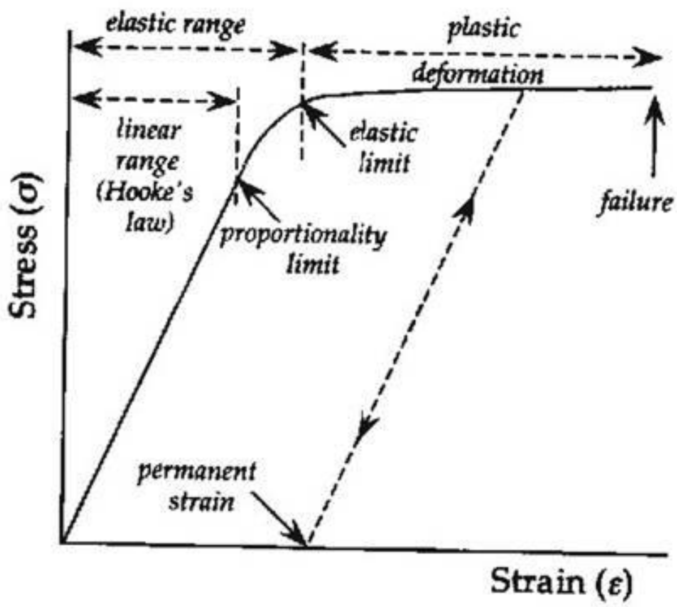
Elastic Limit Definition

Elastic limit is the maximum stress within which the body regains its original condition when the deforming force is removed.

The stress strain curve

In the case of crystalline material or metals the stress-strain curve will be linear for small deformations. The relationship between stress and strain is given by Hooke's law.

The stress beyond the elastic limit the relation is not linear. Beyond the elastic limit the materials undergo plastic deformation.



Example 2.

The elastic limit for steel is 2.48 x 10^8 Pa. What is the maximum weight that can be supported without exceeding the elastic limit?

$$\text{Recall: } A = 3.14 \times 10^{-6}\, m^2$$

$$Stress = \frac{F}{A} = 2.48 \times 10^8\ Pa$$

$$F = (2.48 \times 10^8\, Pa)\, A$$

$$F = (2.48 \times 10^8\, Pa)(3.14 \times 10^{-6}\, m^2) = 779\, N$$

Example 2(Cont.)

The ultimate strength for steel is 4089 x 108 Pa. What is the maxi- mum weight that can be supported without breaking the wire?

$$\text{Recall: } A = 3.14 \times 10^{-6}\, m^2$$

$$Stress = \frac{F}{A} = 4.89 \times 10^8\ Pa$$

$$F = (4.89 \times 10^8\, Pa)\, A$$

$$F = (4.89 \times 10^8\, Pa)(3.14 \times 10^{-6}\, m^2) = 1536\, N$$

The Modulus of Elasticity

Provided that the elastic limit is not exceeded, an elastic deformation (strain) is directly proportional to the magnitude of the applied force per unit area (stress).

$$Modulus\ of\ Elasticity = \frac{stress}{strain}$$

Example 3.

In our previous example, the stress applied to the steel wire was 6.37 x 10^7 Pa and the strain was 3.08 x 10^{-4}. Find the modulus of elasticity for steel.

$$Modulus = \frac{stress}{strain} = \frac{6.37 \times 10^7}{3.08 \times 10^{-4}} = 207 \times 10^9 Pa$$

This longitudinal modulus of elasticity is called Young's Modulus and is denoted by the symbol Y

Young's Modulus

For materials whose length is much greater than the width or thickness, we are concerned with the longitudinal modulus of elasticity, or Young's Modulus (Y).

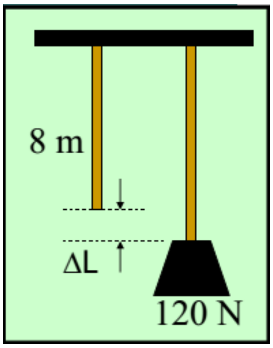
$$Young's\ Modulus = \frac{longitudinal\ stress}{longitudinal\ strain}$$

$$Y = \frac{F/A}{\Delta L/L} = \frac{FL}{A\Delta L}$$

$$Unite: Pa \quad or \quad \frac{1b}{in^2}$$

Example 4:

Young's modulus for brass is 8.96 x 10^{11} Pa. A 120 N weight is attached to an 8 m length of brass wire; find the increase in length. The diameter is 1.5 mm.



First find area of wire:

$$A = \frac{\pi D^2}{4} = \frac{\pi(0.0015\,m)^2}{4}$$

$$= 1.77 \times 10^{-6}\,m^2$$

Y = 8.96 x 10^{11} Pa; F = 120 N; L = 8 m; A = 1.77 x 10^{-6} m^2; F = 120 N; ΔL = ???

$$Y = \frac{FL}{A\Delta L} \Rightarrow \Delta L = \frac{FL}{AY}$$

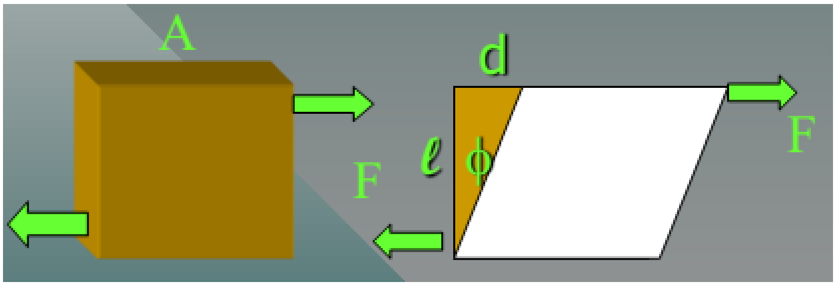
$$\Delta L = \frac{FL}{AY} = \frac{(120\,N)(8.00\,m)}{(1.77 \times 10^{-6} m^2)(8.96 \times 10^{11} Pa)}$$

Increase in length:

$$\Delta L = 0.605 \text{ mm}$$

Shear Modulus

A shearing stress alters only the shape of the body, leaving the volume unchanged. For example, consider equal and opposite shearing forces F acting on the cube below:



The shearing force F produces a shearing angle ϕ. The angle ϕ is the strain and the stress is given by F/A as before.

Calculating Shear Modulus

Stress is force per unit area:

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

The strain is the angle expressed in radians:

$$Strain = \phi = \frac{d}{l}$$

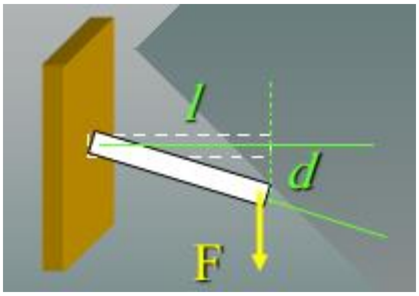
The shear modulus S is defined as the ratio of the shearing stress F/A to the shearing strain ϕ:

$$S = \frac{F/A}{\phi}$$

The shear modulus Units are in Pascals.

Example 5.

A steel stud ($S = 8.27 \times 10^{10}$ Pa) 1 cm in diameter projects 4 cm from the wall. A 36,000 N shearing force is applied to the end. What is the defection d of the stud?



First find area of wire:

$$A = \frac{\pi D^2}{4} = \frac{\pi (0.01\, m)^2}{4}$$

$$= 7.85 \times 10^{-5}\, m^2$$

F = 36000 N; l = 0.04 m; A = 7.85×10^{-5} m^2; d = ???

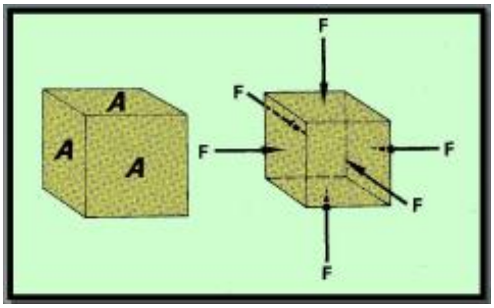
$$S = \frac{F/A}{\phi} = \frac{F/A}{d/l} = \frac{Fl}{Ad} \Rightarrow d = \frac{Fl}{AS}$$

$$d = \frac{Fl}{AY} = \frac{(36000\, N)(0.04\, m)}{(7.85 \times 10^{-5} m^2)(8.27 \times 10^{10} Pa)}$$

$$= 0.222\, mm$$

Volume Elasticity

Not all deformations are linear. Sometimes an applied stress F/A results in a decrease of volume. In such cases, there is a bulk modulus B of elasticity.



$$B = \frac{Volume\ stress}{Volume\ strain}$$

$$= \frac{-F/A}{\Delta V/V}$$

The bulk modulus is negative because of decrease in V.

The Bulk Modulus

$$B = \frac{-F/A}{\Delta V/V}$$

Since F/A is generally pressure P, we may write:

$$B = \frac{-P}{\Delta V/V} = \frac{PV}{\Delta V}$$

Units remain in Pascals (Pa); since the strain is unitless.

Example 7.

A hydrostatic press contains 5 liters of oil. Find the decrease in volume of the oil if it is subjected to a pressure of 3000 kPa. (Assume that B = 1700 MPa.)

$$B = \frac{-P}{\Delta V / V} = \frac{PV}{\Delta V}$$

$$B = \frac{-P}{\Delta V / V} = \frac{-PV}{\Delta V}$$

$$\Delta V = \frac{-PV}{\mathrm{B}} = \frac{-(3 \times 10^6 Pa)(5\ L)}{(1.70 \times 10^9 Pa)}$$

Decrease in V in milliliters (mL);

$$\Delta V = -8.82\ mL$$