## Contents

1. Introduction
2. Kinematics
3. Uniform Motion
4. Uniform Acceleration
5. Newton's Laws of Motion
6. Uniform Circular motion
7. Newton's Canon Experiment
8. Centrifugal Force
9. How a Cream separator separates the cream from milk?
10. What is the role of centrifugal forces in Uranium Enrichment process?
11. Centrifugal Force and curved path
12. Projectile Motion
13. How target is aimed through the sights or lens in a gun?
14. What is the physics involved in achieving the maximum range when throwing the javelin or disk?
15. Force
16. Linear Momentum and Impulse
17. Law of Conservation of Linear Momentum
18. Why rockets are designed multi-stage?
19. Fundamental Forces
20. Gravitational Force & Graviton
21. Applications of Acceleration due to Gravity:
22. Why strange feeling in the stomach while descending on a lift?
23. Weak Force & Bosons
24. Electromagnetic Forces
25. Nuclear Forces
26. Frictional Forces
27. Applications of Frictional Force
28. Why radial tyres are better than ordinary tyres?
29. Why is it easier to pull than to push a lawn roller?
30. Will driving on an ice covered road require less fuel due to reduced friction?
31. Comparing disc brake and drum brakes. Which is Better?
32. Torque
33. Why handles in doors / quern are placed at a distance from Hinge?
34. Couple
35. Work Power and Energy
36. Work
37. Power:
38. Why Horse only as unit of Power? Why not bulls or oxen?
39. Energy
40. Kinetic Energy
41. Potential Energy:
42. Elasticity
43. Poisson Ratio
44. Why Cork is used as stopper in wine bottles and why not Rubber?
45. Pressure
46. Why they keep wooden sleepers below the rail Tracks?
47. Pressure in water or other liquids
48. Why they make the bottoms of Dam walls thicker than the top?
49. Pascal's Law
50. Hydraulic Press

## Introduction

We all know that anything that has space and mass is called matter. Physics is a natural science that involves the study of matter and its motion through space-time. In Physics we also study the basic concepts like energy and force. Physics helps us to understand, how the universe in general behaves.

Physics is based upon two principal thrusts viz. **Unification** and **Reduction**. **Unification** tries to unify the fundamental forces of nature through Universal Laws such as Laws of Gravitation. **Reduction** refers to the derivation of properties of bigger and complex systems from the properties of simple and small systems. Physics deals with a wide variety of systems, yet certain theories are used by all physicists. The branches of Physics include Acoustics, Atomic Physics, Biophysics, Cryogenics, Electrodynamics, Fluid Dynamics, Geophysics, Health Physics, Mechanics, Molecular Physics, Nuclear Physics, Optics, particle Physics, Plasma Physics, Quantum Physics, Solid State Physics, Thermodynamics etc.

Then, there are new major fields have come up over the period of time such as **Condensed matter physics**, **Astrophysics** and **Physical cosmology**. Condensed matter physics is the field of physics that deals with the macroscopic physical properties of matter, that includes important concepts such as **superfluid** and the **Bose–Einstein condensate** etc. Astrophysics and astronomy are the application of the theories and methods of physics to the study of stellar structure, stellar evolution, the origin of the solar system, and related problems of cosmology.

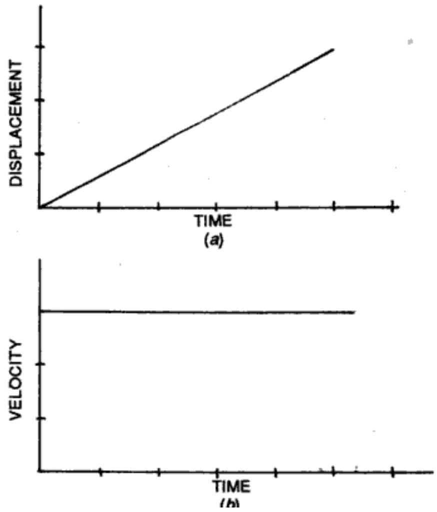
As an aspirant to the UPSC IAS Examination, we are more concerned with the applied part of the Physics, that helps us understand the basic laws and their role in our everyday life. Applied Physics is a general term for physics which is intended for a particular technological or practical use. Apart from that we also need to take a look at the **latest developments** in the field and contribution of some modern Physicists. We also need to take a broad look at some ***unresolved*** issues of Physics such as **Quantum gravity**, **Cosmic inflation**, Concepts related to **Future of the universe** such as **Big Freeze, Fundamental Particles** such as **neutrinos**, **Existence of the Universe**, **Dark matter** and **Dark energy**, **Shape of the Universe**, **Ultra-high-energy cosmic rays** etc.

## Kinematics

We begin our study with the general laws of Kinematics. We understand that a body is said to be in the state of rest if it's position with respect to a fixed observer **does not change** with time. However, when the length or direction or both of the **line joining** the body and the fixed observer changes with time, the body is said to be in motion. Kinematics describes the motion of a moving body without being concerned to the reasons of the movement. So, the Kinematics explains, how the body is moving and NOT why the Body is moving.

### Uniform Motion

Motion is a change in position of an object with respect to time. Change in action is the result of an unbalanced force. Motion is typically described in terms of velocity, acceleration, displacement and time. The change in the position is known as Displacement. Displacement is the length of the path covered by any object in a particular direction. Velocity is the rate of change of displacement with time, so it will be the ratio of displacement to time. If during the motion, velocity (v) of the body remains constant, the body will describe equal displacements (s) in equal intervals of time (t) and this will be called the Uniform Motion. The The s-t graph for such a motion will be a straight line that is inclined at certain angle with the time axis. The v-t graph will be a straight line parallel to the time axis.




The acceleration (a), as we all know is the rate of change of velocity with time. Its SI unit is meter per sq. second. In the above example,

$$s=vt$$

since a=0,

### Uniform Acceleration

The displacement, velocity and acceleration are having particular directions, they are called vector quantities. When the velocity increases uniformly with time, the acceleration is constant and the body will describe "unequal" displacements in "equal" intervels of time. Acceraation is also a vector quantity. It can be represented as follows:

Acceleration = Change in velocity ÷ Time

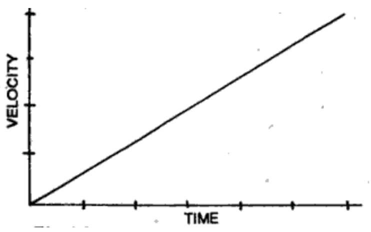
If u is the initial velocity and v is the final velocity, acceleration will be:

a= (v-u)÷t

Using the above equation, we can find the final velocity as follows:

v=u+ at

The time velocity graph in **Uniform Acceleration** will be as follows:




The displacement in this case shall be expressed as follows:

s= $\left(\frac{v+u}{2}\right) t$

so,

s= ut +$\frac{1}{2}$ at$^2$ and s =vt -$\frac{1}{2}$ at$^2$

so, v$^2$=u$^2$ +2as

The above formulae can be used for solving simple numerical problems such as follows:

*A ball is thrown up with initial velocity of 49 m/s, how much time will it take to reach the maximum height.*
*Here u=49*
*V=0*
*a= -9.8 m/s$^2$*
t=(v-u)/a = (0-49)/9.8 = 5 seconds.
And using the formula v$^2$=u$^2$ +2as
We can write that:
02=49$^2$+2(-9.8)s
2x9.8xS=49$^2$
S= $\frac{\mathbf{49x49}}{\mathbf{2x\ 9.8}}$ =122.5 meters is the displacement (means height) attained by the ball.

The formulae are written as follows:

| Starting from rest means u=0 | Starting from an initial velocity u |
|---|---|
| $v = at$ | $v = u + at$ |
| $s = \frac{1}{2}at^2$ | $s = ut + \frac{1}{2}at^2$ |
| $v^2 = 2as$ | $v^2 = u^2 + 2as$ |

## Newton's Laws of Motion

Newton's three laws of motion sum up the basic principles of motion. Before we move ahead, we need to take a look at these laws.

**Newton's First law:** *Every object* ***continues in its state*** *of rest or of uniform motion in a straight line if no net force acts upon it.*

This is the classic law which we all have studied in our school days and reminds us of "momentum". When a passenger in a fast moving bus falls forward when it stops suddenly, it reminds us of the first law of Newton. Similarly a person getting down from a moving bus has to run a little so that he can 'maintain' the momentum for a while. Here we have to note that "Momentum" is the product of mass and velocity. It is shown as below:

**Momentum=mass x velocity**

**Newton's Second Law:** *The rate of change of momentum of a body is proportional to the applied force and takes place in the direction of the force.*

The above law leads to an implication that force is proportional to the product of mass and acceleration. This means that

**F=m x a**

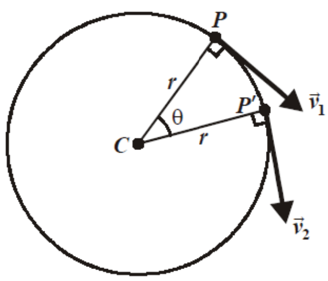
Where F=Force
M= mass and
a= Acceleration
This means that if same force applies on two products of mass X and 2X, then the acceleration produced in case of X will be twice of that in case of 2X.
**Newton's Third Law:** *To every action there is an equal and opposite reaction.*
The above law implies that if a body A exerts a force on body B, then body B exerts an equal and opposite force on A.
The above law is of very interest and rocket science and astronomy. A rocket contains the fuel which burns to produce a high velocity blast of the hot gases. The large force generated by the chemical reaction, propels out the hot gases through the tail nozzle with very high velocity, leading to a reaction in equal and opposite direction that propels the rocket forward.

## Uniform Circular motion

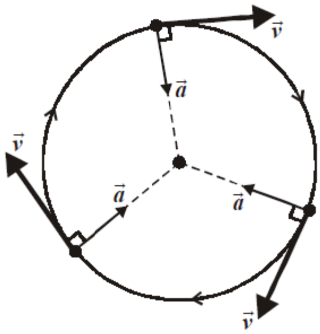
If a body describes the motion in a circular path, it is known as Circular motion. The third law of Newton also applies to the circular motion. When we whirl a stone around by a string, we note that

1. Velocity of the body is tangential at every point of the track so , its direction changes every point.
2. Our hand exerts an inner pull to keep it moving around in a curve. It is called Centripetal force. Centripetal Force means "seeking centre" and is the inward force required to keep a particle moving in circular path.

The velocity of the particle is constant in magnitude but changes in direction as shown in the figure. In this




figure, the object moves from P to P'. The velocity at P is $v_1$ , a vector tangent to the curve at P. The velocity at P' is $v_2$ , a vector tangent to the curve at P'. Here we note that as the speed of the particle is constant, the vectors $v_1$ and $v_2$ are equal in magnitude, but their directions are different.
Now we know that acceleration is the **rate of change of velocity over time**, this means that there is an acceleration in the body. The direction of this acceleration denoted by $\vec{a}$ is instantaneously along a radius inward toward the centre of the circle. This is shown by the following figure:




The above radial acceleration is called the "centripetal acceleration" and its value is shown as the following:

$$\vec{a} = \frac{v^2}{r}$$

Where v is the velocity of the particle or object and r is the radius or length of the string in above case. We here have to note that acceleration resulting from a change in direction of a velocity is just as real and just as much acceleration in every sense as that arising from a change in magnitude of a velocity. The velocity, being a vector, can change in direction as well as magnitude. If a physical quantity is a vector, its directional aspects cannot be ignored, for their effects will prove to be every bit as important and real as those produced by changes in magnitude.

We note that when the object moves from P to P', there is a change in the angle Θ. The rate of change of angle in time is called the angular velocity. Thus angular velocity is the vector quantity which specifies the angular speed of an object and the axis about which the object is rotating. The SI unit of angular velocity is radians per second, however we can used other units such as degrees per second, revolutions per second, revolutions per minute, degrees per hour, etc. Angular velocity is usually represented by the symbol omega (ω)

The ω is expressed by the following formula:

$$\omega = \frac{v}{r}$$

So, we can write that v=ωr

Thus we arrive at the following formula

$$\vec{a} = \frac{v^2}{r} = \frac{\omega^2 r^2}{r} = \omega^2 r$$

We have studied above that

**F=m x a**

**So,**

$$F = m\omega^2 r \text{ or } m\frac{v^2}{r}$$

The core principle of arriving at above formula is to understand that an object would like to move in a straight line but the above force would be required to keep it departing from the straight motion. The above force is responsible for the circular motion and is known as "centripetal force".

Here we take an example. We suppose that the mass of the object is 5kg and it moves at a constant speed of 6 meters per second in a circular path of radius 2 meters. Then the centripetal force would be:

$$F = m\omega^2 r \text{ or } m\frac{v^2}{r} = 5x\frac{6^2}{2} = 90 \text{ Newton}$$

**Now we take this simple Numerical Question:**

We suppose that we have a string which can be broken if we exert a force of 1500 Newton. If we attach an object with mass 8.3 kilogram at one of its end and whirl it horizontal direction in a circle of 80 cm, then what should be the maximum speed it can have, so that the string does not break.

The above equation will be arranged as follows:

$F = m\omega^2 r \text{ or } m\frac{v^2}{r}$

$1500 = 8.3 \text{ x } \frac{v^2}{0.8}$

So

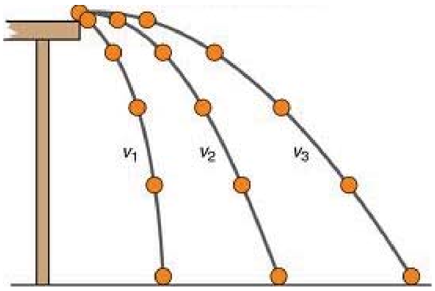
$v^2 = \frac{1500 \, x \, 0.8}{8.3} \approx 144$

*v = 12 meter per second.*

- ✓ The above description was taught to us in our school days to explain why a bucket carrying water is, when rotated in a vertical circle does not fall downward when the bucket is at highest point. This is because the necessary "centripetal" force is provided by the motion.
- ✓ When moon revolves around the earth, centripetal force is provided by gravitational force of Earth on moon. Similar is with artificial satellites, because as they move around the earth, the force of attraction of earth on the satellite provides necessary centripetal force.

## Newton's Canon Experiment

Now, we take another example. When we throw a stone with some speed in the horizontal direction, it will follow a curved path and fall on the ground. When we throw the stone with a greater speed, it will follow a curved path that is even bigger than the previous one. Thus, greater is the speed, greater is the radius of the curved path as shown below:




Now, if we have such a powerful device to throw this stone with such a tremendous speed that radius of the curved path it follows becomes little bigger than the radius of earth, we cannot expect it to return to earth. Rather, it will keep on revolving around the earth. This is how the artificial satellites work. They are projected with such a speed that the "radius" of their curved path is "greater" than the radius of earth.

Here we need to note that

- ✍ Gravitational pull of earth would provide the necessary centripetal force that is needed to keep it in its particular orbit

Here, we should not that speed of the satellite is carefully chosen so that it provides necessary force to keep it revolving. Here we note that:

**F** (Gravitational) = **F** (centripetal)

$$\text{So } m\frac{v^2}{r} = mg$$

$$\therefore$$

$$v^2 = rg$$

$$V = \sqrt{rg}$$

From the above formula, we don't find **m** , which means that the speed of an artificial satellite does NOT depend upon its mass. This implies that at a particular distance from earth, all objects would move at same speed of revolution.

But the above formula says that v is dependent upon r. The above formula now we derive again as follows:

**F** (Gravitational) = **F** (centripetal)

$$\frac{GMm}{r^2} = m\frac{v^2}{r}$$

In the above formula, G is the universal gravitational constant and M is the mass of earth. We arrive at v as follows:

$$m\frac{v^2}{r} = \frac{GMm}{r^2}$$

$$v = \sqrt{\frac{GM}{r}}$$

Here we come to two conclusions:

- v is dependent upon r because **V=** $\sqrt{rg}$
- **v is inversely proportional to r because** $v = \sqrt{GM/r}$

Here we conclude that higher the orbit is, lower is its speed. When we whirl a small string with an small object tied at one of its and also allow to get it rolled around our finger, we find that the smaller the radius of the circle is, higher is its speed.

- So, when a satellite moved from higher orbit to lower orbit, its speed increases.

Now, most of us know that g= 9.8 square meters per second and radius of earth is 6.4 x $10^6$ meters, we conclude that

V = $\sqrt{rg}$ **=**$\sqrt{6.4\ x\ 10^6\ x9.8}$ **= 7.9 x $10^3$ meters per second = 7.9 kilometers per second**

Thus, if we throw the satellite of a speed lesser than 7900 meters per second or 28500 kilometers per hour, it will simply fall on earth. But the speed higher than this will produce an elliptical orbit. However if this speed is more than 11.2 kilometers per second , it will escape the earth's gravitation field and will never come back.

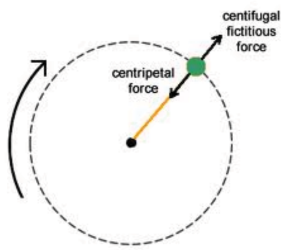
This value of 11.2 kilometers per second is known as escape velocity and it explains why we have the gaseous atmosphere which does not go away from earth. On moon the escape velocity is 1.9 kilometers per second and molecules of any gas formed on moon would have velocity more than this value and that is why moon has not gaseous atmosphere.

Launching a satellite needs tremendous forces, because providing it an speed of 28500 kilometers per second is not an easy task.

## Centrifugal Force

Whenever a body is accelerated, as per the third law of Newton, a reaction is also produced which is equal in magnitude but opposite in direction. The centrifugal force is supposed to act on a body that is moving in a circle, and is **equal and opposite in direction** to the centripetal force. Please note that while centripetal force is a real force, centrifugal force is NOT a real force but Centripetal force is a Real force. When we whirl a stone attached to one end of an elastic string, we see that the string elongates, which shows that the string is pulled at both ends by forces, acting in opposite directions. If the string is NOT sufficiently strong, it will break apart.

The force is called fictitious because it is an apparent force that acts on all masses in a non-inertial frame of reference.




Here we take an example of a vehicle that moves in a circular path. When the vehicle is undergoing circular motion, it constantly accelerates toward the axis of rotation, which is called the centripetal acceleration- provided by a centripetal force. In accordance with Newton's Third Law of Motion, the vehicle exerts an equal and opposite force, which is called the reactive centrifugal force. It is directed away from the center of rotation. Concept of centrifugal force is applied in rotating devices such as centrifuges, centrifugal pumps, centrifugal governors, centrifugal clutches, etc., as well as in centrifugal railways, planetary orbits, banked curves, etc.

**How a Cream separator separates the cream from milk?**

Centrifuge, a machine that **separates liquids of different densities**. It can also **separate liquids from solids that are held in suspension.** Cream separator is used to break down whole milk into cream and skim milk. The liquid to be separated is placed in a container that is rotated at high speed. Because of centrifugal force, the heavier materials are thrown out farther from the center of rotation than are the lighter materials, thus separating them.

Centrifuges are also widely used in medical, chemical, and biological laboratories and have many industrial uses.

**What is the role of centrifugal forces in Uranium Enrichment process?**

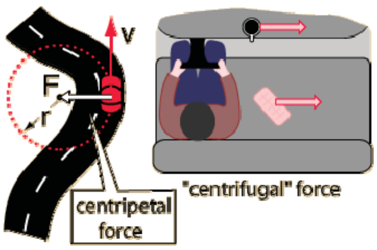
We should know that the processed Uranium ore is **Uranium Oxide**, which has two isotopes of uranium viz. U-235 and U-238. We need U-235 to make a bomb or use in nuclear power plant. But more than 99% part is U-238 in the uranium oxide. So, U-235 is needed to be separated from U-238, or its concentration is needed to be increased.

The process of concentrating the U-235 is called enrichment and the centrifuges play a major role in the Uranium Enrichment Process.

The fundamental principle behind the Uranium Enrichment by centrifuges is that **U-235 weighs slightly less than U-238.** This difference in weight is used to separate them. First Uranium is made to react with **hydrofluoric acid (HF)**, an extremely powerful acid and the result is **Uranium Hexafluoride ($UF_6$)** or **Hex**. In **Hex,** we have the **Uranium in Gaseous form**. This gas is put in the centrifuge and is made to spin at a huge speed such as 1 lakh rpm. The centrifuge creates a very powerful centrifugal force and, as we read, that U-238 atoms are slightly heavier than the U-235 atoms, they tend to move out toward the walls of the centrifuge.

The U-235 atoms tend to stay more toward the center of the centrifuge. The Hex is extracted from the center of the centrifuge, which has now greater concentration of U-235. It is placed in another centrifuge and this follows for not hundreds but for thousands times, in a huge chain of centrifuges. Finally we get the Uranium Hexafluoride gas, which has higher concentration of U-235 atoms. The Hex is now made to **react with Calcium**. Calcium reacts with the Fluoride and creates salt leaving Pure Uranium behind.

## Centrifugal Force and curved path




Please note that the inward acceleration necessary for a vehicle to go around the level curve is partly supplied by the friction on the tires and partly by the banked curve, which supplies the inward component of acceleration. The driver of a car on a curve is in a rotating reference frame and he could invoke a "centrifugal" force to explain why his water bottle that is placed on a seat beside him tends to slide sideways.

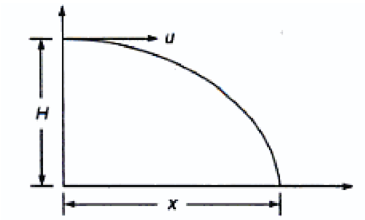
As shown in the diagram, when a car moved on a curved path, both centripetal and centrifugal forces work. The car moving in a curved path is experiencing a **centripetal acceleration** $v^2/r$, and so an object of mass m on the seat will require a force $mv^2/r$ toward the center of the circle to stay at the same spot on the seat. From the reference frame of a person in the car, there seems to be an outward centrifugal force $mv^2/r$ acting to move the mass radially outward.

## Projectile Motion

When a body is thrown horizontally from a certain height, it covers horizontal distance because of the horizontal velocity given to the body at the lime of throwing it. This horizontal velocity remains constant because there is no force working on the body in the horizontal direction. But at the same time the body also covers a vertical height die to acceleration it is experiencing due to earth's gravitation force. Please note that these two motions are independent of each other.

Now, we consider that the velocity of this body is u and it is thrown from a height H from the ground. If the distance x is covered by it time t is the taken by it to reach the ground, then H is directly proportional to the square of x i.e. $H \propto x^2$

We can prove this as follows:




In this picture, we need to focus on two types of motion of the body. In the vertical motion H will be given by:

$$H = o + \frac{1}{2} gt^2$$

$$\boxed{H = \frac{1}{2} gt^2}$$

While in the Horizontal direction, H will be given by

x =ut

so

t=x/u

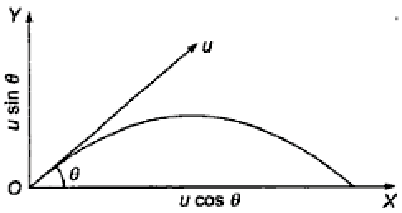
When we put the value of t in above equation, we get $H = \frac{1}{2} g \frac{x^2}{u^2}$

All other things for the body are constant, so

$$H \propto x^2$$

When H is directly proportional to $x^2$, it gives us a message that the motion is parabolic.

When we project a body from ground with certain initial velocity u, and making an angle $\theta$ with horizontal direction, the body will describe two dimensional motion with a path that is parabolic. This path is called trajectory and the body is called projectile. In this situation, **u cos $\theta$** and **u sin $\theta$** will be components of its velocity in horizontal and vertical directions, respectively as shown in the following diagram:




We derive the following from the above equations:

$$v = u - gt$$

$$o = u \sin \theta - gt$$

$$gt = u \sin \theta$$

$$t = \frac{u \sin \theta}{g}$$

Since, the body will take some time t to reach the ground from its highest point: then

$$(T) = t + t = 2t$$

$$T = \frac{2u \sin\theta}{g}$$

If H is the maximum height attained by the body, during this motion, then we derive :

$$o = u^2 \sin^2\theta - 2\,gH$$

$$H = \frac{u^2 \sin^2\theta}{2g}$$

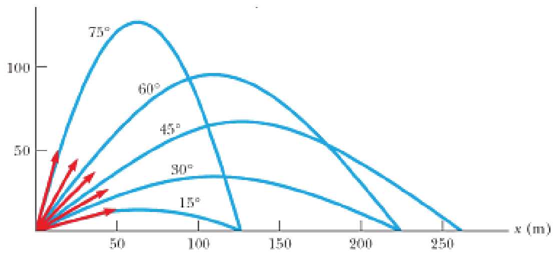
$$R = u\cos\theta \times T$$

$$= u\cos\theta \times \frac{2u\sin\theta}{g}$$

$$R = \frac{u^2 \sin 2\theta}{g}$$

Thus, we arrive at different formulae to calculate the Height H and Range R of that object. You don't have to cram these formulae , as we don't expect a numerical question. Here are some important points about this motion:

1. We have just now seen that $R = \frac{u^2 \sin 2\theta}{g}$ . So to get the maximum range the value of Sin2$\theta$ should be 1. Here we have to know that when, Sin2$\theta$ = 1, the value of 2$\theta$= 90°. This means that if the projectile is launched at an angle of $\theta$ =45°, the Range would be maximum. So, maximum range is attained at an angle 45°.
2. At the angle of 45°, the above equation will become R=$u^2$/g. This means that if we throw this body with an initial speed of u, the maximum range it can attain is R=$u^2$/g, where g is 9.8 m/$s^2$. Obviously we throw it at 45°.
3. When we discuss the equation $H = \frac{u^2 \sin^2\theta}{2g}$ , we can show that the to achieve maximum height, the value of sin$^2\theta$ should be 1. If $\theta$ is 90°, then sin$^2\theta$ =1. So, the **maximum height can obtained at 90°**.
4. The time of flight is given by the equation $T = \frac{2u\sin\theta}{g}$ . So, if the **value of $\theta$ is 90°, the time of flight would be maximum**.
5. There can be **two angles of projections** are possible for same horizontal range. The angles are x and 90-x. This means that projectile sent at 30°will have the same range as that of 60°.
6. As we increase the angle of projection ,the range first increases, becomes maximum at 45° and then decreases as shown below:




7. The **Horizontal component** of the velocity of the projectile remains constant through out the time of flight. The vertical component of the velocity becomes zero at highest point.
8. If a hunter aims his gun at a moneky sitting on a tree and fires, the bullet will not hit the monkey, because bullets moves under the influence of gravity. So, the aim should be a bit upwardly fixed.

**How target is aimed through the sights or lens in a gun?**

Please note that the sights on the rifle ( either the `fore sight & rear sight' or the optical ie `telescopic sight') are so arranged that when the rifle is correctly aimed , the sights point at the target but the rifle barrel points slightly upwards to cater for the bullet drop due to gravity. This upward angle is determined by various factors like the range (distance) at which the target is placed, the velocity of the bullet, the ballistics of the bullet to name a few. Hence every gun needs to be `zeroed' for a particular range, so that the bullet hits the spot at which the gun is aimed.

9. The time of the flight does not depend upon the mass of the object. It means that if a canon throws two bombs of 30 and 50 kilograms with same velocity and same angle, they will fall at ground at the same time, provided we take air resistance as zero.

**What is the physics involved in achieving the maximum range when throwing the javelin or disk?**

The physics involved in achieving the maximum range and the forces acting on the javelin those of projectile motion. We know that air resistance and gravity are the primary forces working against the javelin in flight. The air resistance is very small, because a javelin is designed to be aerodynamic. Gravity is working to pull the javelin back towards the ground. The Gravity does not affect the javelin's horizontal motion directly as the Horizontal component of the velocity remains constant but the javelin is more likely to land sooner if it is launched at an angle that is very close to the ground, or conversely, an angle that is too close to vertical. So, as we studied above, optimum release angle for any thrown object is 45 °, or exactly halfway from the horizontal to the vertical. Please note that javelin rotates about its long axis as it travels through the air, which helps to keep it stable in flight, akin to rifling in the barrel of a gun that causes the bullet to spin.

## Force

- ✓ Force is any influence that causes a free body to undergo a change in speed, a change in direction, or a change in shape.
- ✓ So, Forces are defined by the first law of Newton.
- ✓ The Forces are measured by the second law of Newton where F=ma. So, if m is 1 kg and a is 1 $m/s^2$, then F=1 N. Newton (N) is the SI unit of Force.
- ✓ The CGS unit of Force is Dyne. **1N** is equal to **$10^5$ Dyne**.
- ✓ Another unit of Force is kg-wt. 1 kg-wt is 9.8N.

## Linear Momentum and Impulse

The product of mass of a moving object and its velocity is called Momentum or Linear Momentum. Since, velocity is a vector quantity, Linear Momentum is also a vector quantity. It is express as

P=mv

The unit is kg.meter.second$^{-1}$

- ✓ The core funda is that momentum depends upon mass & velocity of the object.
- ✓ Higher is the mass, higher is the momentum. So, a truck has more momentum than a car and crushes it instantly, if it rams into it.
- ✓ A bullet has though very small mass, but has huge momentum due to its huge velocity and that is why is able to kill somebody even at a distance, or make holes in the walls.
- ✓ During fielding in cricket, the player has to move his hands in the direction of the ball, while taking a catch, just to avoid the injury because the ball has a huge momentum, due to its velocity.

If we apply a force on a body for a very small period of time, the product of that applied force and time will be known as Impulse. It is shown as follow:

$$J=F\,.\,\Delta t$$

The unit of Impulse is kg .ms-1

But Force x Time= Change in Momentum,

So huge change in momentum will impart an impulse. One example is that when a vehicle at a very high speed rams into a wall, it comes to rest suddenly. The Momentum thus becomes zero all of a sudden and a large impulse is applied to the wall. The result is either the car or the wall or both get damaged.

- ✓ The hammers which we use to insert a nail in depth work on the principle of Linear momentum and impulse.
- ✓ While boxing, the defender tried to move his face along the direction of the punch, thus increasing the contact time and decreasing the impulse.
- ✓ A Karate expert breaks a brick / slab mainly by bringing the hand to slab with a very high speed and thus decreasing the contact time, of course meditation helps him in doing so ☺

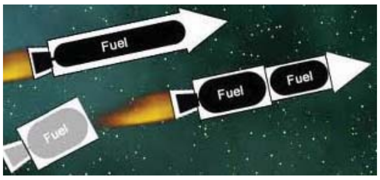
## Law of Conservation of Linear Momentum

This law says that under the mutual action and reaction of the two bodies, which are free from any external force, the algebraic sum of the linear momenta of them remains unchanged. For example, when a shot is fired from a cannon, the cannon recoils. The Shot+Cannon are at rest, and when the shot is fired with a velocity, canon also gains same momentum behind and thus total remains zero.

This also leads us to the law of conservation of kinetic energy in collisions. When two bodies collide with each other in such a way that the total kinetic energy remains conserved, it is elastic collision, otherwise inelastic.

### Why rockets are designed multi-stage?

Rockets are typical examples of Variable Mass system. It works as per the third law of Newton, as well as the law of conservation of linear momentum. In a rocket the hot gases keep on escaping, and thereby the mass of the system continuously decreases. The first stage of a rocket is largest in size weight, while the last stage is smallest in size and lightest in weight. We should note that the single stage rocket is incapable to put space satellites in the orbits or escape through the earth's gravitation field. The multistage rocket is designed so that with each progressive stage the momentum increases and velocity is also increased.




So, in a multistage rocket:

1. First stage is usually heaviest and biggest and often called the booster
2. Next few stages are successively smaller and are generally called sustainers.
3. Each stage is a complete vehicle in itself and carries its own propellant (either solid or liquid; both fuel and oxidizer),
4. Each stage has its own propulsion system, and has its own tankage and control system.

Once the fuel of a particular stage is burnt off, it is no longer useful in contributing additional kinetic energy to the succeeding stages. So, this useless weight is dropped off and it is possible to accelerate the payload to higher velocity than would be attainable if multiple staging were not used.

However, the disadvantage of the multistage rocket is that staging requires the vehicle to lift motors which are not being used until later, as well as making the entire rocket more complex and harder to build.

## Four Fundamental Forces of Nature

There are four types of the forces in the nature viz. Gravitational Force, Weak Force, Electromagnetic Force and Nuclear Force.

## Gravitational Force & Graviton

We should know that the Gravitational force is weakest among all existing forces and it is negligible for all the lighter and smaller bodies. But it becomes huge and operative with highly influence for large heavenly bodies. According to the law of universal gravitation, the attractive force (F) between two bodies is proportional to the product of their masses (m1 and m2), and inversely proportional to the square of the distance (r) between them:

$$F = G\frac{m_1 m_2}{r^2}$$

Where, G is the Gravitational Constant. The value of G as measured in **Torision Balance by** Cavendish is $6.67 \times 10^{-11}$ $Nm^2kg^{-2}$. So, if the bodes are of smaller mass, the above force is almost negligible.

The discovery of the fundamental forces of nature led to development of the special branch of Physics known as particle Physics. The scientists said that the forces arise from **exchange of particles**. They speak of two types of particles viz. the matter particles and the particles that carry forces. For example, the electromagnetic force is communicated via exchange of **Photons**. So for Gravitational force, a particle was theoretically hypothesized. This theoretical particle is called "Graviton". Since Gravitational Forces are extremely weak, the Graviton is yet to be observed. The scientists say that if Graviton exists, it must be massless (because the gravitational force has unlimited range) and must have a spin of 2. So, if a massless spin-2 particle is discovered, it must be the graviton. This is the only experimental verification left for existence of **Graviton.**

## Applications of Acceleration due to Gravity:

When a body is dropped freely and executes a free falling motion and comes near the Earth's surface, its velocity increases due to acceleration due to gravity.

If m is the mass of the object, the weight of the body due to gravity is mg. g is 9.8 $m/s^2$.

Now we again take the following formula:

$$F = G\frac{m_1 m_2}{r^2}$$

In the above formula we replace $m_1$ by Mass of Earth that is M , r by Radius of Earth R and $m_2$ by mass of an object. Then the Force due to gravity on this object is derived as follows:

$$F = G\frac{Mm}{R^2} = mg$$

Thus

$$G\frac{M}{R^2} = g$$

In other words, value of acceleration due to gravity g does not depend upon the mass of the object. So, if we neglect the air resistance and assume that two bodies with different masses fall from a definite height, they will reach the earth simultaneously. But when we throw a stone and a feather together, the stone reaches first because of the drag / buoyancy produced by air.

But the above formula says that value of g is dependent upon the radius of Earth. Since, earth is oblate in shape and its equatorial radius is 6,378.1370 km, while the polar radius is 6,356.7523 km, we can see that g is more at poles and less at equator.

- Thus, due to oblate shape of earth, same object will weigh maximum at Poles and minimum at equator.

Not only that, the rotational movement also has its impact on g. The earth's rotation causes the object to move away from its radius and so, the effective g is less than what it would have been if there were no rotation. We should not forget that an object placed on equator of earth moves 40,075 kilometers every day due to the rotational motion of earth.

But the impact of this rotation would be maximum at equator and zero at Poles. Consequently

- Due to rotation of earth, same object will weigh minimum at Equator and maximum at poles.

The combined impact of the above two impacts makes the value of g as well as weight of object vary at different latitude of earth.

Now, we can understand that if Earth stops rotating, the weight of a product placed on equator will increased substantially. Further, by simple formulae we can show that if Earth rotates at a speed 17 times of its normal speed, an object at Equator will feel a centrifugal force exactly equal to Earth's gravitation and will weigh zero at that point.

Since the value of g is inversely proportional to square of R, it will also decrease when the altitude is increased. Here we should note that g=0 at center of earth. From centre to surface, the value of g increases linearly and becomes maximum at surface of earth. After that it decreases and becomes zero at infinity. Since, at the centre of the earth; there is no gravity because the gravitational pull from all directions is equal, and cancels out. Thus if we drill a hole through the centre of the earth, the object will show a to and fro movement. This journey would take 90 minutes and will not need any energy.

Now we discuss the elevators.

- If a lift or elevator goes up with any acceleration **a** then the man sitting in it will realize a greater weight, expressed by mg+ma.
- If the elevator comes down with some acceleration , man sitting in will realize lesser weight, expressed by mg-ma.
- If the elevator falls freely because the rope of the lift broken, the person sitting in it will become weight less. Mg-ma=0
- If the elevator moves downward with such an acceleration that it is more than g then, the man on the lift will escape to the life of the roof.

**Why do we get a strange feeling in the stomach while descending on a lift or airplane or giant wheel?**

The feeling in our stomach is of weight. When we come down on a giant wheel, the negative acceleration stress occurs on body when the direction of acceleration is from feet to head, causing a slight displacement of the internal organs in the abdomen and chest and a rush of blood to the face accompanied by the feeling of congestion. At a certain rate of acceleration, these opposite forces balance each other out, making us feel a sensation of weightlessness, including our stomach. Because it is weightless, our stomach is not pressing down which makes us feel strange. If we are accelerating up a steep hill, the acceleration force and gravity are pulling in roughly the same direction, making you feel much heavier than normal.

## Weak Force & W and Z Bosons

The concept of **weak force** or **weak interaction** came into existence for the first time in **Yukawa's Meson Theory**, during explanation of the beta particle decay in radioactivity.

Weak force is responsible for the radioactive decay of subatomic particles and initiates the process known as hydrogen fusion in stars. Weak interactions affect all known fermions; that is, particles whose spin (a property of all particles) is a half-integer. The weak force is stronger than the gravitational force by $10^{36}$ times but is weaker than electromagnetic force by $10^{3}$ times.

Akin to the Graviton in gravitational force, the mediators of Weak forces are **W and Z Bosons**. The W and Z bosons are the elementary particles that mediate the weak interaction. They are expressed by **W+, W−**and Z.

- The W bosons have a positive and negative electric charge of 1 elementary charge respectively and are each other's antiparticle.
- The Z boson is electrically neutral and is its own antiparticle. All three of these particles are very short-lived with a half-life of about 3×10−25 s.
- Their discovery was a major success for what is now called the Standard Model of particle physics.

## Electromagnetic Forces

The electromagnetic force acts on all charged particles and provides the atomic and molecular bindings forces. These forces are charge dependent and can be attractive or repulsive.

As the name suggests, the electric and magnetic forces compose the electromagnetic forces, which exist by means of Photon or Quanta. If both the electric and magnetic force exist, then the force is called **Lorentz Force**. The **Lorentz Force** is expressed as follows:

$$\mathbf{F} = q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$$

Where:

- F is the force (in newtons)
- E is the electric field (in volts per metre)
- B is the magnetic field (in teslas)
- q is the electric charge of the particle (in coulombs)
- v is the instantaneous velocity of the particle (in metres per second)

## Nuclear Forces

Among all the forces found in nature, the Nuclear force is strongest of all. This force explains the existence within nucleus of proton-proton , proton-neutron and neutron-neutron, within a range of $10^{-15}$ meter. The Nuclear Force is primarily attractive, non-electrical, non-gravitational, and extremely strong and is spin dependent.

The Nuclear Force is also known as residual strong force. Nuclear force is now understood as a residual effect of the even more powerful strong force, or strong interaction, which is the attractive force that binds particles called quarks together, to form the nucleons themselves. This more powerful force is mediated by particles called gluons. Gluons hold quarks together with a force like that of electric charge, but of far greater power.

The concept of a nuclear force was first quantitatively constructed in 1934, shortly after the discovery of the neutron revealed that atomic nuclei were made of protons and neutrons, held together by an attractive force. The nuclear force at that time was conceived to be transmitted by particles called mesons, which were predicted in theory before being discovered in 1947. In the 1970's, further understanding revealed these mesons to be combinations of quarks and gluons, transmitted between nucleons that themselves were made of quarks and gluons. This new model allowed the strong forces that held nucleons together, to be felt in neighboring nucleons, as residual strong forces.

## Frictional Forces

When a body is set in motion on the floor, it eventually comes to rest. This is due to the opposing force that retards its motion called Frictional force. The frictional force is neither electromagnetic nor gravitational but occurs in pair. The frictional force on each body is opposite to its motion.

Frictional Force can be of several kind such as

1. Dry friction resists relative lateral motion of two solid surfaces in contact. Dry Friction can be **static** or **kinetic.**
2. Fluid friction describes the friction between layers within a viscous fluid that are moving relative to each other.
3. Lubricated friction is a case of fluid friction where a fluid separates two solid surfaces.
4. Skin friction is a part of drag, the force resisting the motion of a solid body through a fluid.
5. Internal friction is the force resisting motion between the elements making up a solid material while it undergoes deformation.
6. Rolling friction, when a body rolls on another body or a surface.

**Static Frictional Force:** If a body kept on any surface tries to move by means of a force applied on it, the body does not move, then the force is called static frictional force.

**Kinetic Frictional Force:** When a body on any surface is sliding or moving uniformly, then the force operative between the surfaces is called sliding or Kinetic Frictional force.

**Rolling Frictional Force:** When a body rolls on another body , then the force operating is called Rolling frictional force.

Please note that

**Static > Kinetic>Rolling**

- The frictional forces operative within the two surfaces Do not depend upon the contact area BUT depend upon the nature of the surfaces.
- The static force of friction is largest and the rolling force of friction is smallest.
- The friction can be reduced between two surfaces using a suitable oil or grease(lubricant)

## Applications of Frictional Force

- If the friction force does not exist on the road, the wheels of the vehicles start to slip and thus it is very much helpful in movement of vehicles.
- Due to friction all animals are able to move and stand.
- The friction forces cause loss in energy and damage in machines.
- The inner components generate a lot of heat due to frictional forces only.

### Why radial tyres are better than ordinary tyres?

We all know that the Tyres consist of layers of cord called `plies'. Plies are shaped on a form and impregnated with rubber. There are two ways to apply the plies on the bias and radially. In bias type (ordinary) tyres the plies are criss-crossed. One layer run diagonally one way and the other layer runs diagonally the other way. The arrangement makes a carcass that is strong in all directions because of the overlapping plies. However the plies tend to move against each other due to friction. This movement generates heat, especially at high speed. Also the tread tends to `squirm' or close-up as it meets the road. This increase tyre wears. Tyres with radial plies were introduced to remedy these problems. In radial tyres, all the plies run parallel to each other and are vertical to the tyre bead. Belts are applied on top of the plies to provide added strength paralleled to the bead. The radial tyre gives better fuel economy & lesser tyre wear.

Radial tyres give the impression that they have low inflation even though the air pressure is as recommended by the manufacturer. This is primarily because of the soft sidewalls. Radial tyres normally give twice as much mileage as cross-ply tyres and the difference in cost is not more than 30 per cent sometimes even less and gives a marginally harder ride but is safer at high speed. Please note that Radials make the steering a little harder than cross-ply tyres, but provide better braking performance.

The Force of Friction is proportional to the normal reaction which means that

$$F_{fr} \propto R$$

$$F_{fr} = \mu R,$$

This means that

$$F_{fr} = \mu mg$$

$\mu$ in the above equation is called the Coefficient of friction. We note from the above equation that Frictional force is directly proportional to the mass or weight of the body.

### Why is it easier to pull than to push a lawn roller?

It is our daily experience that it is easier to move a body by pulling it than by pushing it. A body moves only when the applied force on it is more than the frictional force. This frictional force is proportional to the weight of the body under which it acts. When we move a body shorter than us, such as a lawn mover, the force applied is not horizontal. When a force (F) is applied to a body at an angle `Ø', it is equivalent to applying a horizontal force of F CosØ and a vertical force of F SinØ. Where `Ø' is the angle of the line of action of the force to the horizontal. F CosØ is the horizontal component & F SinØ is called the vertical component. Now, when we push a body, the vertical component acts downward and adds up to the weight of the body. So, pushing a body by applying a force `F' at an angle `Ø' is equivalent to moving a body a body of weight mg + (F SinØ), with a horizontal force F CosØ. When we pull a body, the vertical component acts upward. So pulling a body of weight `mg' by applying the same forces `F' at an angle `Ø', is equivalent to moving a body of weight W — (F SinØ) with a horizontal force F CosØ. So it is possible to pull a body by applying a force less than that is required to push it.

### Will driving on an ice covered road require less fuel due to reduced friction?

This is a typical question, which can confuse us. We know that during acceleration the thrust (power) developed by the engine of a vehicle to propel itself is effective to the extent of the grip that the tyres of the vehicle have on the road surface over which it moves. This grip depends on the friction between the tyres and the road surface. The greater the friction the better is this grip. The better the grip, the greater the utilization of the thrust developed by the engine.

If there is lesser friction, there will be lesser grip, which means loss of thrust. The loss of thrust will be dissipitated as heat and wastage of fuel. This means driving on ice covered road burns more fuel, as the process becomes less efficient due to loss of grip. However, decrease in friction between the ice surface and the tyres will also reduce the requirement of fuel. Overall, we can say that if other conditions like the friction due to air, wind force are all the same, and that the ice-sheet is not uneven, fuel requirement could be lesser on an ice covered road due to reduction in the sliding friction. But the vehicle maneuverability becomes difficult on an ice surface due to reduced friction and thus, operations of braking/acceleration will be prompted more frequently, say even during the small-degree steering.

**Comparing disc brake and drum brakes. Which is Better?**

A brakes works on the principle of applying the frictional resistance to a moving machine component such as wheels to retard the machine's motion. Drum design was used on all four wheels, previously and now they have been replaced by Disk brakes. Disk brakes are usually made of cast iron or reinforced carbon. This is connected to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads (mounted on brake caliper) is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop.

In the drum brakes, components were housed in a round drum that rotated along with the wheel. Inside was a set of shoes that, when the brake pedal was pressed, would force the shoes against the drum and slow the wheel. Fluid was used to transfer the movement of the brake pedal into the movement of the brake shoes, while the shoes themselves were made of a heat-resistant friction material similar to that used on clutch plates. But the basic design of the drum brakes had a flaw. Brakes convert motion to heat, and if the brakes get too hot, they become less effective, a phenomenon known as brake fade. Under high braking conditions, like descending a steep hill with a heavy load or repeated high-speed slowdowns, drum brakes would often fade and lose effectiveness. This flaw has been substantially reduced due to the design of the disk brakes. The Disc brakes use a slim rotor and small caliper to halt wheel movement. Within the caliper are two break pads, one on each side of the rotor, that clamp together when the brake pedal is pressed. However, unlike drum brakes, which allow heat to build up inside the drum during heavy braking, the rotor used in disc brakes is fully exposed. This exposure works to constantly cool the rotor, greatly reducing its tendency to overheat or cause fading.

## Torque

Torque moment of force is the tendency of a force to rotate an object about an axis, fulcrum, or pivot. Just as a force is a push or a pull, a torque can be thought of as a twist. In other words, Torque is a measure of the turning force on an object such as a bolt or a flywheel. It is represented by τ. When it is called moment, it is commonly denoted M.

Please note that the magnitude of torque depends on three quantities: the force applied, the length of the lever arm , connecting the axis to the point of force application, and the angle between the force vector and the lever arm.

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$$
$$\tau = rF\sin\theta$$

Where:

- τ is the torque vector and τ is the magnitude of the torque,
- r is the displacement vector (a vector from the point from which torque is measured to the point where force is applied), and r is the length (or magnitude) of the lever arm vector,
- F is the force vector, and F is the magnitude of the force,
- × denotes the cross product,
- θ is the angle between the force vector and the lever arm vector.

Torque is a vector quantity and its SI unit is **Newton meter**.

### Why handles in doors are placed at a distance from Hinge?

In the above formula $\tau = \mathbf{r} \times \mathbf{F}$ , we see that for the equal forces as far as larger distance from the hinges of the door it would be applied more moment of the force (torque). That is why the handles are kept at greater distance from the hinges of the door.

The same principle applies when handle of the quern if kept distant from its pivot, so that it is easy to rotate. The same principle applies on the hand pumps whose handle is kept large.

## Couple

Two equal and opposite forces make a couple. Couple is the product of the force and couple arm.

Couple = Force x couple arm

$$\text{Couple} = F \times d$$

Thus the SI unit is Newton Meter. It is the couple that causes the rotation in a body.

## Work Power and Energy

**Work:**

In Physics , work is associated with some kind of movement. When we see an engine pulling the train, we call it a work. When we try to push a wall , we are applying force, wasting our energy but not able to do work. So, work is said to be done only when the force is able to produce a motion.

The Work is measured as product of the force and the distance moved in the direction of the force.

So,

$$W = F \times D$$

Since, work is dependent upon the distance moved in the direction of the force, it's a vector quantify and its SI Unit is **Joule**. One Joule is equal to the energy expended (or work done) in applying a force of one newton through a distance of one metre (1 newton metre or N·m), or in passing an electric current of one ampere through a resistance of one ohm for one second. 1 joule is equal to: (Don't cram these figures)

- $1\times10^{7}$ ergs (exactly)
- $6.24150974\times10^{18}$ eV (electronvolts)
- 0.2390 cal (thermochemical gram calories or small calories)
- $2.3901\times10^{-4}$ kcal (thermochemical kilocalories, kilogram calories, large calories or food calories)
- $9.4782\times10^{-4}$ BTU (British thermal unit)
- 0.7376 ft·lbf (foot-pounds force)
- 23.7 ft·pdl (foot-poundals)
- $2.7778\times10^{-7}$ kilowatt-hour
- $2.7778\times10^{-4}$ watt-hour
- $9.8692\times10^{-3}$ litre-atmosphere
- 11.1265 femtograms (mass-energy equivalence)
- $1\times10^{-44}$ foe (exactly)

## Power:

The formula of calculating work W = F x D does not talk about the time. The Power is rate of work done, which takes into account the time also taken in doing a particular work. So power is Work done / Time taken. Its unit is **Watt , which refers to Joule per second. One Watt is one joule per second** and it also measures the rate of energy conversion.

- The Power of Machines is expressed in Horse Powers. **1 Horse Power is equal to 746 watt.**

- Since, 1 watt is 1 joule / second, 1 watt-second would equal to 1 joule. So, 1 watt hour is equal to 3600 Joules. And 1 kilowatthour will be 3600x1000 = $3.6 \times 10^6$ joules.

**Why Horse only as unit of Power? Why not bulls or oxen?**

When the steam engine began to do the work of horses in the mines during the early 1800s, the mine owners began to ask how many horses an engine would replace. James Watt, who invented steam engines, figured out a mathematical way to equate horses to engine power. Thus the term horsepower was invented. Watt measured the capability of a big horse to pull a load and found it could pull a weight of 150-pounds while walking at 2.5 miles per hour. This works out to 33,000 foot-pounds per minute or 550 foot-pounds per second.

### Energy:

Energy is defined as the capacity to do work. Its unit is also Joule. The energy can be kinetic or mechanical or other forms such as heat, sound, wave, electric etc.

### Kinetic Energy

Kinetic energy is possessed by an object due to its motion. It is expressed by the following formula:

$$KE=\frac{1}{2}mv^2$$

m is the mass of the object and v is the speed. A moving bullet has kinetic energy.

In the above formula we see that

$$KE \propto v^2$$

This means that if we double the velocity of an object, its kinetic energy becomes 4 times. So a car travelling at a speed of 50 km per hour will have 4 times the Kinetic energy of a car that moves at 25 km per hour.

### Potential Energy:

The energy possessed by any object due to its position is called Potential Energy. It is one of the most common forms of energy and is described as follows:

$$PE=mgh$$

Where m is the mass of the object, g is acceleration due to gravity and h is the height of the object above surface of earth. So, a stone held at certain height above earth's surface has potential energy. A stretched spring, water at elevated level, all is example of potential energy.

*Energy can be neither created or destroyed , but it can be only transformed from one form into another.* This philosophical law of Physics is called Law of Conservation of energy. So conservation of energy refers to the conservation of the total energy of an isolated system over time and all other forms of energy (kinetic, potential, nuclear, chemical, thermal, etc.) in the system together.

### Elasticity

Elasticity is the physical property of a material that returns to its original shape after the stress that made it deform is removed. The relative amount of deformation is called the strain.

- A **perfectly elastic** body is that which recovers its original size and shape completely, when an external force is removed.
- A **perfectly plastic** body is that which fully maintains its altered shape and size when the external force is reduced.
- When a body suffers a change in its size or shape under the action of external forces, it is said to be deformed, and the corresponding fractional change is called the '**Strain'.** Strain is a ratio, and there is no unit of strain.

- When external deforming forces act on a body, the internal forces opposing the former are developed at each section of the body which is known as **Stress**. So, stress is measured as external forces per unit area and its unit would be Newton per square meter or Dyne/cm$^2$.
- Hookes law says that Stress is proportional to strain means : **Stress ∝ Strain**
- So Stress ÷ strain should be a **constant.** This constant is called **Modulus of Elasticity** or **Young's Modulus**. Young's modulus is a measure of the stiffness of an elastic material and is a quantity used to characterize materials. The unit of Young's Modulus will be same as that of Stress that is Newton per sq. meter.
- When a uniform pressure is applied all over the surface of the body, its volume changes. The change in the volume per unit volume of the body will be called the **Bulk Modulus**. The bulk modulus of a substance measures the substance's **resistance to uniform compression**. It is defined as the pressure increase needed to decrease the volume by a factor of 1/e. Its base unit is the Pascal. The converse of the Bulk Modulus is **compressibility**.
- When a body is sheared, the ratio of the tangential stress to the shearing strain is called **Rigidity Modulus** or **Shear Modulus.** Shear modulus is usually expressed in gigapascals or thousands of pounds per square inch. In metal alloys, the shear modulus is observed to be higher than in pure metals due to the presence of additional sources of resistance.

## Poisson Ratio

When two equal and opposite forces are applied to a body along a certain direction, the body extends along that direction, It the same time the body also contracts along the perpendicular direction.

In other words, when we apply a force on a wire to increase its length, it is found that its size change not only along the length but also in a direction perpendicular to it (breadth).

So, if the force produces an extension in its own direction, usually a contraction occurs in the lateral or perpendicular direction and vice-versa. The change in the direction along which the forces are applied per unit is called Longitudinal Strain. The change in lateral dimension per unit is called lateral strain. The Within elastic limit, the lateral strain is proportional to the longitudinal strain, thus the ratio of lateral strain to the longitudinal strain within the limit of elasticity is a constant for the material of a body and is called the Poisson's ratio. It is usually denoted by σ.

We consider wire of length L and diameter D. Under application of an external longitudinal force F, let I be the increase in the length and d the decrease in the diameter, then

$$\text{Longitudinal strain } \alpha = \frac{l}{L}$$

$$\text{Lateral strain } \beta = \frac{d}{D}$$

$$\text{Poisson's ratio} = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$$

$$\sigma = \frac{\beta}{\alpha} = \frac{\frac{d}{D}}{\frac{l}{L}}$$

Since σ is a ratio, it has no unit. Please note that theoretical value of σ varies from -1 to $\frac{1}{2}$, but the practical value lies between 0 and $\frac{1}{2}$. The Poisson Ratio of Cork is almost zero and that of Rubber is ½.

**Why Cork is used as stopper in wine bottles and why not Rubber?**

We all know that Cork is an impermeable, buoyant material, obtained from *Quercus suber* (the Cork Oak), which is endemic to southwest Europe and northwest Africa. Cork is known for its content suberin, which is a hydrophobic substance, and because of its impermeability, buoyancy, elasticity, and fire resistance, it is used in a variety of products, the most common of which is for wine stoppers. The Poisson ratio has very important role in this use of Cork. We should note that cork has a Poisson ratio of near zero. This means that, as the cork is inserted into the bottle, the upper part which is not yet inserted will not expand when the lower part is compressed. The Poisson ratio of Rubber is 1/2 , which means that as the rubber stopper is inserted into the bottle, the upper part which is not yet inserted will expand and it will require additional force to overcome the expansion of the upper part of the rubber stopper.

Poisson's effect has a considerable influence is in pressurized pipe flow. When the air or liquid inside a pipe is highly pressurized it exerts a uniform force on the inside of the pipe, resulting in a radial stress within the pipe material. Due to Poisson's effect, this radial stress will cause the pipe to slightly increase in diameter and decrease in length. The decrease in length, in particular, can have a noticeable effect upon the pipe joints, as the effect will accumulate for each section of pipe joined in series. A restrained joint may be pulled apart or otherwise prone to failure.

Similarly, in a geological timescale, excessive erosion or sedimentation of Earth's crust can either create or remove large vertical stresses upon the underlying rock. This rock will expand or contract in the vertical direction as a direct result of the applied stress, and it will also deform in the horizontal direction as a result of Poisson's effect. This change in strain in the horizontal direction can affect or form joints and dormant stresses in the rock.

## Pressure

Pressure is the force applies per area and its unit is Newton per square meter which is called Pascal. Pascal or Pa is also unit of Young's modulus and tensile strength, named after the French mathematician, physicist **Blaise Pascal**. It is a measure of force per unit area, defined as one newton per square metre. In everyday life, the Pascal is perhaps best known from meteorological barometric pressure reports. The kilopascal is commonly used on bicycle tire labels.

So, Pressure is represented by

$$\text{Pressure} = \frac{Force}{Area}$$

This Equation shows that Pressure is directly proportional to Force but inversely proportional to area.

If we keep two bricks one standing and one lying as shown this image, we can say that both are applying the same force on earth (weight) but more Pressure is applied by the brick that is standing as the contact area is less. This is the fundamental principle that a nail can easily inserted in a wall or board because its tip has such a small area that applies a large pressure.

**Why they keep wooden sleepers below the rail Tracks?**

The broad wooden sleepers are made up of variety of hardwoods such as oak, as they are not susceptible to wear. They are generally laid transverse to the rails, on which the rails are supported and fixed, to transfer the loads from rails to the track ballast and subgrade, and to hold the rails upright and to the correct gauge. The pressure part also plays very important role. The weight of Rail causes a force on rail tracks and the area of these tracks is very narrow that may lead to huge pressure on ground below, making them prone to be broken or displaced. But when the sleepers are placed, the area is increased and pressure is substantially decreased.

## Pressure in water or other liquids

The pressure under water is due to the weight of the water above a particular point. The pressure at any point in a liquid acts in all directions. The Pressure P at depth d in a liquid of density δ will be

$$P = d\delta g$$

Where, g is the acceleration due to gravity.

### Why they make the bottoms of Dam walls thicker than the top?

The above formula says that Pressure of liquids is directly proportional to acceleration due to gravity g and depth d of the liquid. Thus as more and more depth we reach, the pressure of the water will increase due to the weight of the water above that point. This is the reason that the bottoms of Dam walls are made thicker than the top. The same is the reason that the pressure in the water tap at ground level is much higher than that on floors above the ground.

Scuba divers must understand this. At a depth of 10 meters under water, pressure is twice the atmospheric pressure at sea level, and increases by about 100 kPa for each increase of 10 m depth

## Pascal's Law

Pascal's law or the Principle of transmission of fluid-pressure says that "pressure exerted anywhere in a confined incompressible fluid is transmitted equally in all directions throughout the fluid such that the pressure ratio (initial difference) remains the same.

$$\Delta P = \rho g(\Delta h)$$

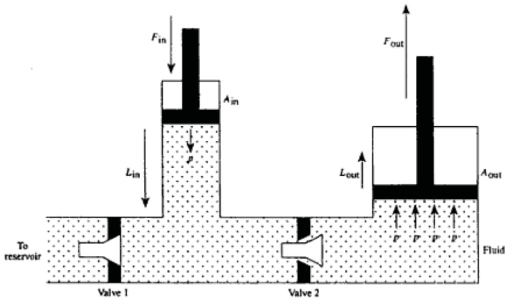
Where:

- ΔP is the hydrostatic pressure (given in pascals in the SI system), or the difference in pressure at two points within a fluid column, due to the weight of the fluid;
- ρ is the fluid density (in kilograms per cubic meter in the SI system);
- g is acceleration due to gravity (normally using the sea level acceleration due to Earth's gravity in metres per second squared);
- Δh is the height of fluid above the point of measurement, or the difference in elevation between the two points within the fluid column (in meters in SI).

The above principle applies in working of the siphon, working of the hydraulic press, Hydraulic Brakes and many other applications such as Hydraulic door closers.

## Hydraulic Press

A hydraulic press was invented by Joseph Bramah (he also invented flush toilet ☺) , so it is also called Bramah's Press in which hydraulic cylinder is used to generate a compressive force. It uses the hydraulic equivalent of a mechanical lever. It works on the Pascal's principle: the pressure throughout a closed system is constant. One part of the system is a piston acting as a pump, with a modest mechanical force acting on a small cross-sectional area; the other part is a piston with a larger area which generates a correspondingly large mechanical force.

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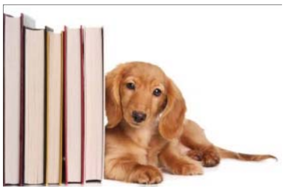

**To be continued in Everyday Physics -2**