UNIVERSITY COLLEGE – YANBU

Lecture Material

for

Preparatory Physical Science (PHSC 001)

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Reference Textbook
Conceptual Physical Science by P. Hewitt, J. Suchocki and L. Hewitt,
3rd Edition, Pearson Addison-Wesley (2004)
ISBN: 0-321-10663-6

Module 1- Mechanics

1. SPEED AND VELOCITY

Speed is defined as the distance covered per unit time. The speed of any moving object is given by

$$Speed = \frac{distance\ covered}{travel\ time}$$

Mathematically we can write as $v = \frac{d}{t}$

where v is the speed
d is the distance covered
t is the travel time.

The SI unit of speed is "m/s" or "km/h".

Example:

What is the average speed of a car that travels 180 miles in 4 hours?

$$Speed = \frac{distance\ covered}{travel\ time}$$

$$= \frac{180\ miles}{4\ hours} = 45\ miles / hour$$

In the above example, the calculated speed is the average speed. The speed of the car at a particular instant might be different than the average speed.

Instantaneous speed is how fast a body is traveling at one particular instant. In other words this is the magnitude of velocity at a particular instant.

Average speed is characteristic of an entire trip, that is

$$Average\ speed = Total\ distance\ covered / Total\ time$$

Remember
A **vector quantity** has both a magnitude and a direction. For example: displacement, velocity, acceleration, and force.
A **scalar quantity** has a magnitude only. For example: distance, speed, mass, and volume.

Velocity of an object tells us both the magnitude and the direction of the travel. Therefore, it is a vector quantity. On the other hand speed is a scalar quantity because it only tells us the magnitude.

Constant speed – means steady speed, not changing
Constant velocity – means both speed and direction, are constant. For example, a car moving

2. LAWS OF MOTION

What is inertia?

Definition of Inertia
Inertia is the tendency of an object to remain at rest if it's already at rest, or to keep moving if it's already moving. In other words, inertia is a property of matter that *resists* changes in motion.

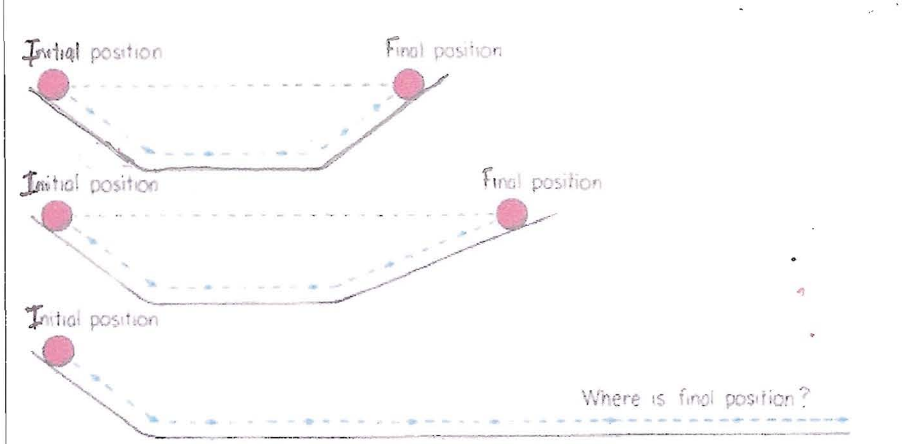
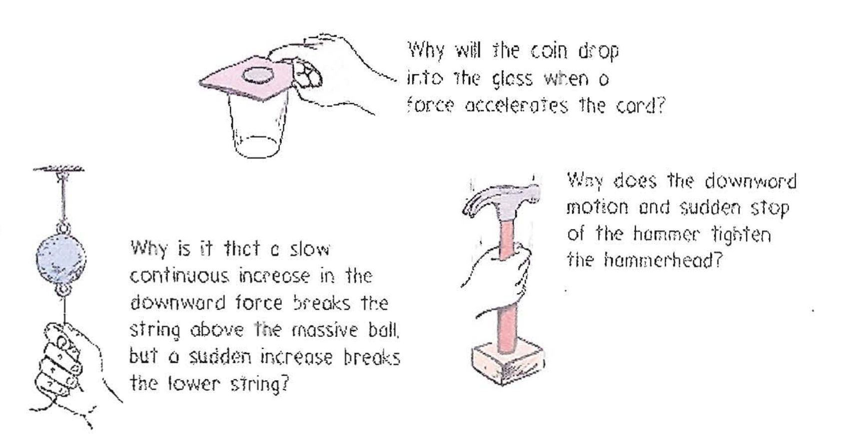


Figure: *Gravity increases the speed of the ball that rolls down (left) on the inclined plane while it decreases the speed when the ball rolls up (right) on the inclined plane. The ball moving horizontally would move forever in the absence of any frictional or opposing forces.*

Inertia is Mass

Mass is a measure of inertia. The more mass an object has, the more inertia it will have. Mass is measured in kilograms (kg).

Three Examples of Inertia



NEWTON'S FIRST LAW OF MOTION – LAW OF INERTIA

Newton's First Law - also called "the law of inertia".

Definition

If no (net) force acts on an object, then it continues its state of rest or its state of motion in a straight line at constant speed.

Recall that inertia is the property of a body that resists changes in motion.

ACCELERATION

The rate of change of velocity is defined as "acceleration". We can write the acceleration as

$$Acceleration = \frac{change\ in\ velocity}{time\ interval}$$

Mathematically we can write as $$a = \frac{\Delta v}{\Delta t}$$

where a is the acceleration

Δv is the change in velocity $= v_{final} - v_{initial}$

Δt is the time interval.

The SI unit of acceleration is "m/s^2".

Example: A car accelerates in a straight line from *50 km/hour* to 70 *km/hour* in 5 *sec*. What is its acceleration?

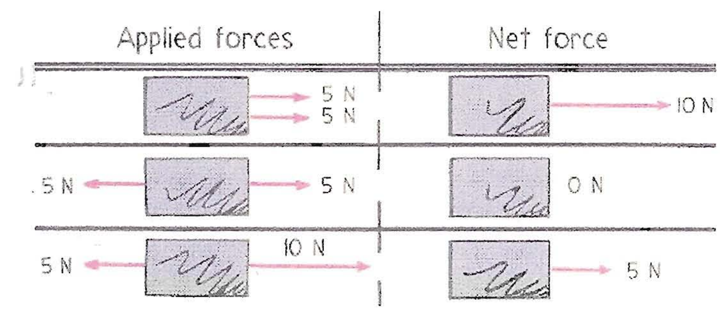
$$Acceleration = \frac{change\ in\ velocity}{time\ interval} \Rightarrow \frac{\Delta V = (70-50)\frac{km}{hr}}{5s} \simeq 20\frac{km}{hr}\left(\frac{1000m}{km}\right)\left(\frac{1\ hr}{3{,}600s}\right) = 5.6\frac{m}{s}$$

$$\frac{5.6\ m/s}{5\ sec} = 1.11\frac{m}{s^2}$$

FORCE AND NET FORCE

A **force** is a **push** or a **pull** on an object.

The "**net force**" on any object is the combination of all forces acting on that object.



To find a "net force" forces need to be added or subtracted. One can choose the forces in one direction as (+) and the forces in the opposite direction as (-).

Remember – A force also has both magnitude and direction. Therefore force is also a vector quantity.

Like any vector quantity, force is represented by an arrow. The length of the arrow gives the magnitude of the force and the direction of the arrow indicates the direction of that force.

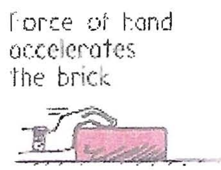
The force is measured in Newtons (*N*).

NEWTON'S SECOND LAW OF MOTION

The acceleration produced by a net force is directly proportional to the net force and inversely proportional to the mass of the object. Mathematically this law can be expressed as $a = \frac{F}{m}$

where
- a is the acceleration
- F is the net force acting on the object
- m is the mass of the object

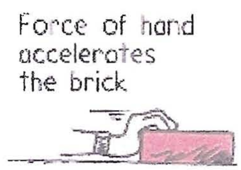
Acceleration (a) is directly proportional to net force (F)



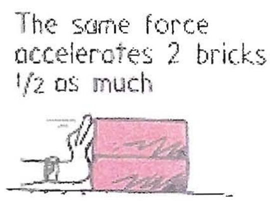
$a = F/m$

$2a = 2F/m$

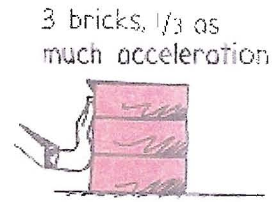
Acceleration (a) is inversely proportional to mass (m)



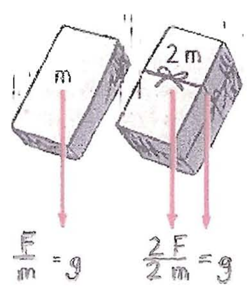
$a = F/m$



$a/2 = F/2m$



$a/3 = F/3m$



Remember:

Gravitational force (weight) is proportional to mass. Double the mass and the gravitational force will also be doubled which means ratio of weight to mass is always the same.

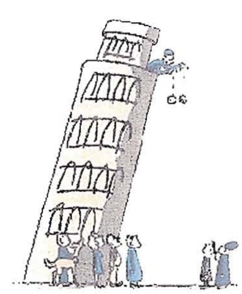
$$(F/m = mg/m = g)$$

FREE FALL MOTION

An object in free fall (only the force of gravity is acting on the object) near the surface of the earth has an acceleration of $9.8\ m/s^2$ (nearly $10\ m/s^2$). **Acceleration due to gravity** is represented by "g" and is given by

$$g \cong 10\ m/s^2$$

Galileo's famous experiment proved that the objects with different mass fall to the ground at the same time. Acceleration due to gravity (g) is independent of mass



MASS AND WEIGHT

Remember "mass" and "weight" are different.

- Mass is a measure of an object's inertia
- Weight (W) is a measure of the amount of gravitational force acting on an object having a mass (m).
- Mathematically weight is defined as

$$W = mg \quad (where \ \ g \cong 10 \ m/s^2)$$

- Mass and weight are directly proportional to one another.
- Mass is measured in grams, kilograms, etc.
- Weight is measured in pounds, Newtons, etc.

Example:

A cube of butter has a mass of about 0.1 kg. Find its weight.

$$W = mg \ = 0.1 \times 10 \ = 1 \ N$$

EQUILIBRIUM

a) Equilibrium for objects at rest

An object is in mechanical equilibrium when the sum of all forces (the net force) acting on it is zero. Mathematically we can write as

$$\sum F = 0$$

To find the vector sum one can choose the upward forces as (+) and the downward forces as (-) or the forces in one direction as (+) and the forces in the opposite direction as (-), or the action forces as (+) and the reaction forces as (-).

Example:

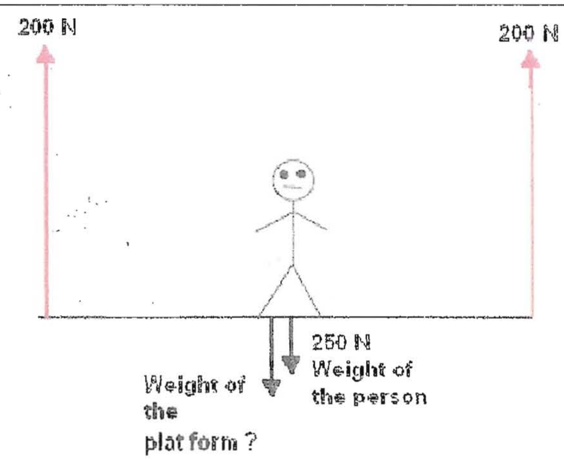
What is the weight of the platform if it is to be in equilibrium?

Weight of the platform "W" can be calculated as follows:

$$\sum F = 0$$

$$200 \ N + 200 \ N - 250 \ N - W = 0$$

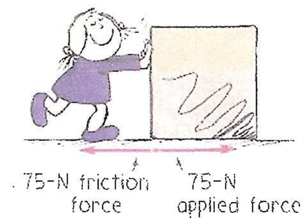
$$W = 150 \ N$$



b) **Equilibrium for moving objects**

Moving objects can also be in equilibrium provided that the net force is zero.

This is the case when an object moves with constant speed.



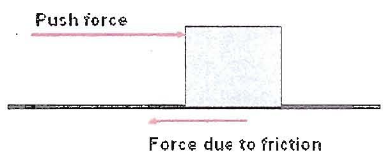
Forces are in balance, so block is in equilibrium, and therefore it is moving at a constant speed.

Static Equilibrium - The objects at rest are in the static equilibrium.

Dynamic equilibrium - The objects moving at a constant velocity are in the dynamic equilibrium.

FRICTION

The force of friction always acts in a direction to oppose motion.



If you push horizontally on a crate and it slides across the floor. The friction force acting on the crate will oppose the motion.

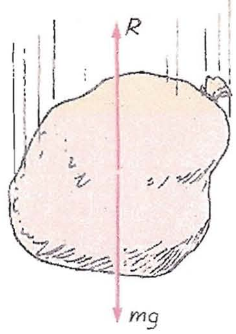
NEWTON'S THIRD LAW OF MOTION

A force is an interaction between two bodies. There will always be a pair of forces involved. For example, if you push on a wall with your hand, you will feel that the wall is pushing on your hand. This is essentially Newton's 3rd law.

Definition of Newton's Third Law

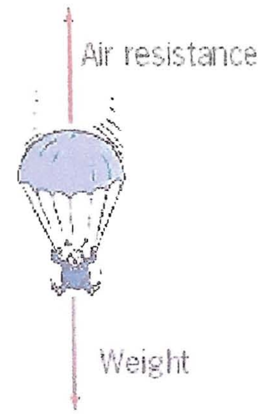
Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first. (**Action/reaction forces act in pairs**).

Terminal Speed

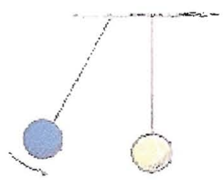


Air resistance increases (R) as the speed increases. Eventually, the force R of air resistance becomes equal to the force exerted by the earth, and the object reaches equilibrium.

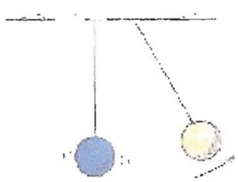
$$R = mg$$



Newton's Third Law of Motion - Action-Reaction Pair Example

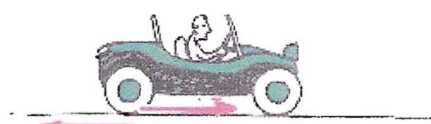


Grey ball moves because the black ball exerts a force on it. (Action)

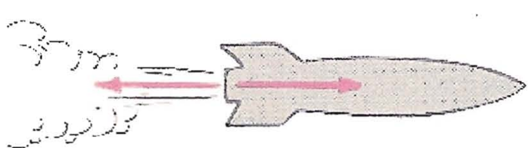


Black ball stops because the grey ball exerts a force on it. (Reaction)

More Action-Reaction Pair Examples



Action: tire pushes on road Reaction: road pushes on tire



Action: rocket pushes on gas Reaction: gas pushes on rocket

3. MOMENTUM AND IMPULSE

Definition of Momentum

Momentum is the product of mass (m) and velocity (v). In equation form we can write

$$\text{Momentum} = \text{mass} \times \text{velocity} \qquad M = m\,v$$

Example 1: Consider an oil tanker moving at 0.5 m/s. Calculate its momentum (magnitude only) if the mass of the tanker is 9.0×10^3 kg.

Solution: $M = mv = (9.0 \times 10^3 \text{ kg}) \times (0.5 \text{ m/s}) = 4.5 \times 10^3 \text{ kg m/s}$

Example 2: Assume a car of 3000 kg mass is also moving on the same road. How fast this car has to travel in order to have the same momentum as the oil tanker?

Solution: $4.5 \times 10^3 \text{ kg m/s} = 3000 \text{ kg} \times v$
Therefore $v = 4.5 \times 10^3 / 3000 = 1.5 \text{ m/s}$

Example 3: A person falls from a height of $10\ m$. This fall takes 1.4 seconds. What is his momentum (magnitude only) just before he hits the ground if his mass is $50\ kg$?

Solution: To determine the momentum first we need to calculate his speed just before he hit the ground which can be calculated as

$$v = g\,t = (10 \text{ m/s}^2)(1.4 s) = 14 \text{ m/s}$$

Therefore his momentum is $M = mv = (50kg)(14m/s) = 700 \text{ kg.m/s}$

Definition of Impulse

A change in momentum is called *impulse*. An impulse is the product of a force (F) and the time interval (t) for which that force acts. In equation form we can write

$$\text{Impulse} = \text{force} \times \text{time interval} = F\,t$$

Example: Assume the wall exerts a force of $100\ N$. If the contact time is $0.1\ s$ then the impulse is

$F\,t = 10 \text{ N.s}$

Impulses and Contact Time

Consider the example shown in the figure. When a truck hits a mountain of soft sand it will hit with a less force when compared with a direct hit against a concrete wall.

However, either way, the change in momentum will be the same.

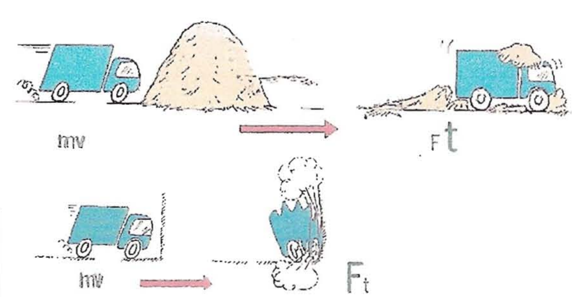


Figure: The force F will be less if one can spread impulse out over a longer time.

CONSERVATION OF MOMENTUM

In the absence of an external force, the momentum of a system remains constant. No momentum is gained and no momentum is lost.

Momentum before = 0,
Momentum after = 0
After firing, the opposite momenta cancel.

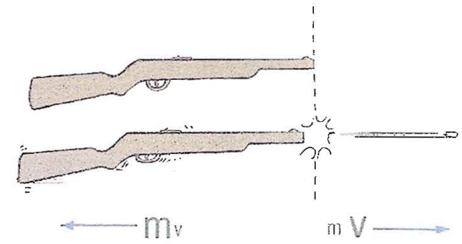


Figure: Conservation of momentum

COLLISIONS

The total momentum before a collision equals the total momentum after a collision

Example: Consider two identical trains with mass m. Train 1 moves with speed v toward train 2 which is at rest. If the trains stick together after the collision what is the speed of the combination?

Solution:
Set the momentum before the collision equal to the momentum after the collision and solve for the final speed:
$mv = 2mv_f$

Therefore $v_f = v/2$

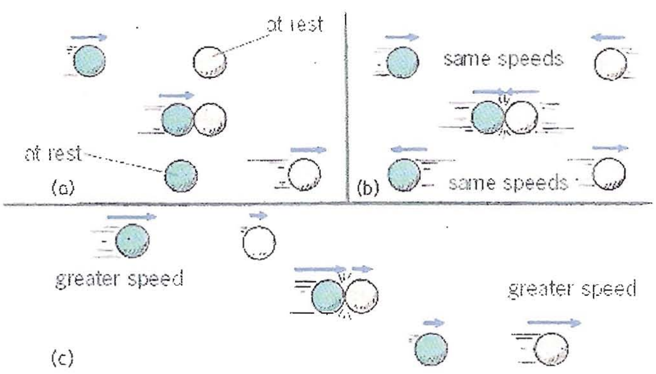
Momentum before the collision:
$m_1v_1+m_2v_2 = mv + m(0) = mv$

Momentum after the collision:
$m_1v_1+m_2v_2 = mv_f + mv_f = 2mv_f$

ELASTIC COLLISIONS

In *elastic* collisions no permanent deformation occurs; objects elastically rebound from each other.

In head-on elastic collisions between equal masses, velocities are exchanged.



INELASTIC COLLISIONS

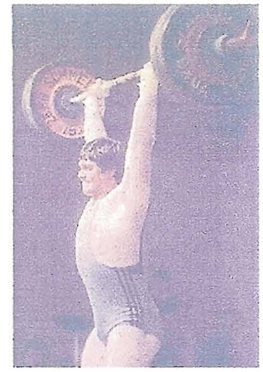
In *inelastic* collisions permanent deformation occurs and heat is generated. However, momentum remains conserved.

Inelastic collisions -- as between the arm and wooden plates -- the wooden plates are broken and permanent deformation takes place.

The kinetic energy of the swinging arm is converted into heat and chemical energy (to break the bonds between atoms in the wood).

4. WORK AND ENERGY

WORK



Work is the product of force and distance. In equation form we can define work as

$$Work = Force \times Distance$$
$$W = Fd$$

If $F = 2000\ N$ and $d = 2.5$ meters, then the work is

$$W = 2000\ N \times 2.5\ m$$
$$= 5000\ N\text{-}m$$

Alternative unit of work is *Joule* $1\ N\text{-}m = 1\ joule\ (J)$

Remember

If the wall doesn't move, the man does no work. Because the distance is 0. ($W = Fd$)

ENERGY

Consider the example of bow and the arrow as shown in the figure. Work is done on the bow. The work done is stored in the bow and string as *elastic potential energy*. After release, the arrow is said to have *kinetic energy*/

$$Kinetic\ energy = \frac{1}{2}mv^2$$

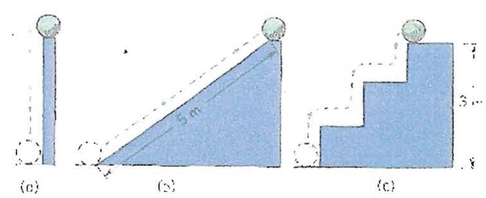
An object has kinetic energy due to its motion.

Energy is measured in the same units (joules) as work.

Example:
A car of mass 1000 kg travels at 30 m/s(70 mph), how much kinetic energy does it have?

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(1000kg)(30m/s)^2 = 450{,}000\ J$$

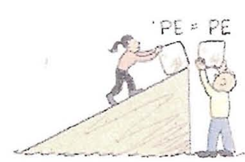
WORK AND POTENTIAL ENERGY



The work done on the ball gives the ball *gravitational potential* energy.

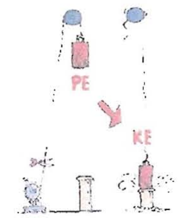
Gravitational potential energy = *mgh*

Both blocks acquire the same gravitational potential energy *mgh*.



The same work is done on each block. What matters is the final elevation, not the path followed.

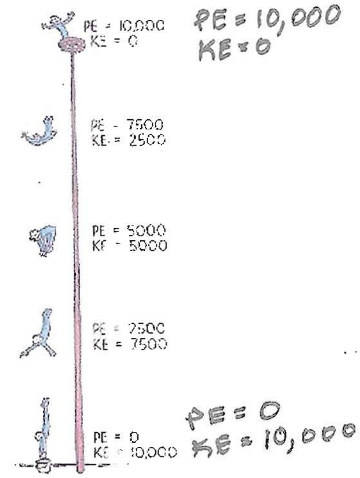
ENERGY TRANSFORMATION



The work done in lifting the mass gave the mass gravitational potential energy.

Potential energy then becomes kinetic energy. Kinetic energy then does work to push stake into ground.

ENERGY CONSERVATION



Energy cannot be created or destroyed; it may be transformed from one form into another but the total amount of energy never changes.

From the Figure one can see that the total energy is the sum of both types of energy.

POWER

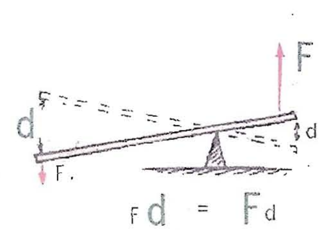
The time rate of doing work is defined as power.

Power = Work/ Time

Mathematically $P=W/t$

The unit of power is watt. 1 joule / second = 1 watt

MACHINES



A machine is a device for multiplying forces or simply changing the direction of forces. All machines employ conservation of energy.
The simplest example of machine is lever.

Work Out = Work In

Small force applied over large distance is the same as large force applied over a small distance.

5. Newton's Law of Universal Gravitation

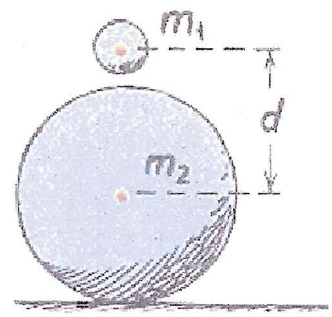
Newton determined that the force of gravity between two objects depends directly on the product of their masses and inversely to the distance between their centers squared. This law is called Newton's law of universal gravitation. Mathematically this law can be written as

$$F = \frac{Gm_1m_2}{d^2}$$

Where m_1 and m_2 are the masses of the two objects and d is the distance between them. G is called the universal gravitational constant and its value is given by

$G = 6.67 \times 10^{-11}\ N.m^2/kg^2$

The two objects involved here do not have to be in contact.



Calculating the Mass of the Earth

Assume that there is an object of one kilogram mass ($m_1 = 1kg$) lying on the surface of the earth. The weight of this object will be exactly equal to the force of gravity F between this object and the earth. We can find the mass of earth M with the help of Newton's law of gravitation.

Mass of the given object $(m_1) = 1kg$
Weight of one kilogram object $(F) = 9.8\ N$
Distance between the two objects m_1 and M, d is equal to the radius of earth $= 6.4 \times 10^6\ m$
$G = 6.67 \times 10^{-11}\ N.m^2/kg^2$

Applying Newton's law of universal gravitation in the present case, we get

$F = G\ m_1 M / d^2$
$9.8 = (6.67 \times 10^{-11})(1)\ M / (6.4 \times 10^6)^2$,

Solving for M we obtain

$M = 6 \times 10^{24}\ kg$ (which is the calculated mass of earth)

Summary of Terms

- **Inertia** The tendency of things to resist changes in motion.
- **Law of inertia (Newton's first law)** Every material object continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.
- **Mass** The quantity of matter in an object. More specifically, it is the measurement of the inertia or sluggishness that an object exhibits in response to any effort made to start it, stop it, deflect it, or change in any way its state of
- **Weight** The gravitational force exerted on an object by the nearest most-massive body (locally, by the Earth).
- **Kilogram** The fundamental SI unit of mass. One kilogram (symbol kg) is this amount of mass in 1 liter (L) of water at 4°C.
- **Newton** The SI unit of force. One newton (symbol N) is the force that will give an object of mass 1 kg an acceleration of 1 m/s^2.
- **Newton's second law** The acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force, and is inversely proportional to the mass of the object.

- **Momentum** The product of the mass of an object and its velocity.
- **Impulse** The product of the force acting on an object and the time during which it acts.
- **Relationship** between impulse and momentum: Impulse is equal to the change in the momentum of the object that the impulse acts on. In symbol notation,

$$Ft = \Delta mv$$

- **Conservation of momentum** When no external net force acts on an object or a system of objects, no change of momentum takes place. Hence, the momentum before an event involving only internal forces is equal to the momentum after the event:

$$mv_{\text{(before event)}} = mv_{\text{(after event)}}$$

- **Elastic collision** A collision in which colliding objects rebound without lasting deformation or the generation of heat.
- **Inelastic collision** A collision in which the colliding objects become distorted, generate heat, and possibly stick together.
- **Work** The product of the force and the distance through which the force moves:

$$W = Fd$$

- **Energy** The property of a system that enables it to do work.

- **Potential energy** The stored energy that a body possesses because of its position.
- **Kinetic energy** Energy of motion, described by the relationship

$$\text{Kinetic energy} = \frac{1}{2}mv^2$$

- **Conservation of energy** Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes. In an ideal machine, where no energy is transformed into heat, $\text{work}_{\text{input}} = \text{work}_{\text{output}}$ and $(Fd)_{\text{input}} = (Fd)_{\text{output}}$.
- **Power** The time rate of work:

$$\text{Power} = \frac{\text{work done}}{\text{time interval}}$$

- **Law of universal gravitation** Every body in the universe attracts every other body with a force that, for two bodies, is directly proportional to the product of their masses and inversely proportional to the square of the distance separating them:

$$F = \frac{Gm_1m_2}{d^2}$$