EDO UNIVERSITY IYAMHO, EDO STATE
Department of Physics

PHY 111: General Physics I (3 Units)

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General overview of lecture: The course introduces some fundamental concepts measurements, rectilinear motion, vector space, kinematics and dynamics, work, energy and power, conservation laws, momentum and conservation of momentum, elastic properties of material, surface tension, adhesion, cohesion, capillarity, projectile motion, pressure, newton's law of gravitation, satellite, escape velocity. circular motion, periodic motion, velocity and acceleration of a sinusoidal oscillation, force oscillation, resonance, propagation and behaviour of waves, types, classes and properties of waves, temperature, heat, gas laws, thermodynamics laws and the kinetic theory of gases.

Prerequisite: The students are expected to have a preliminary knowledge and background in ordinary level Physics and Mathematics.

Learning outcomes: At the completion of this course, students are expected to:
- ✓ Define the basic concept of Physics in connection to introductory mechanics, thermal and properties of matter.
- ✓ Understand basic unit of quantities in Physics
- ✓ Understand some basic problem solving approaches in Physics in connection to introductory mechanics, thermal and properties of matter.
- ✓ Apply physics problem solving concepts to Physics problems in connection to introductory mechanics, thermal and properties of matter.
- ✓ Formulate Physics problems in connection to introductory mechanics, thermal and properties of matter.

Assignments: Assignments: We expect to have some homework assignments throughout the course in addition to a mid-term test and a final examination. Term papers may also be given at the beginning of the class and submission will be on the due date. Home works in the form of individual assignments and group assignments would be organized and structured as preparation for the midterm and final examination which are meant to be a studying material for both examinations.

Grading: This is a core course for all Physics major students and required for all student in the faculties of Sciences, Engineering and Medical Sciences. The grades will be distributed as:

continuous assessments (test, assignments, group work etc.) 30%, final examination 70%, total score 100%

Textbook: The recommended textbook for this class are:

Title: Physics for Scientists and Engineers with Modern Physics
Authors: Serway, R.A. and Jewett. J.W
Publisher: Physical Sciences: Mary Finch, 9th Edition
Year: 2014

Title: College Physics
Author: Young, H. D
Publisher: Pearson Education, Inc. 9th Edition
Year: 2012

Title: First Course in Fundamental Physics
Editors: Osemeikhan J.E.A and Asokhia M.B
Publisher: Aniko Nigeria Publishing Inc. 1st Edition
Year: 2005

Relevant URL

- ✓ http://hyperphysics.phy-astr.gsu.edu
- ✓ http://www.physicstutorials.org

Main Lecture: Below is a description of the contents. We may change the order to accommodate the materials you need for the course.

Measurement

The study of Physics is mainly through experimental observations, this due to the fact that it is a Science of observation on our environment. There are basically three aspect of experimental observation; measurement, uncertainty and correlation.

Measurement is the quantification of observation. Measurement of physical quantities takes place by means of a comparison with a standard. The whole system of measurement is based upon three basic notions; space (quantified through length), time (quantified through reoccurrence) and matter (through mass). For example: a meter stick, a weight of 1 kilogram, etc.

As a result of measuring device limitations, which introduces some elements of uncertainty into the measurement and such uncertainty when known are referred to error which can either be added or subtracted from the observed measured value as the case may be.

Correlation is the degree of regularity in a relationship between different measured quantities.

Metric Prefixes

Power of ten	Prefix	Abbreviation	Pronunciation
10^{-24}	yocto-	y	*yoc*-toe
10^{-21}	zepto-	z	*zep*-toe
10^{-18}	atto-	a	*at*-toe
10^{-15}	femto-	f	*fem*-toe
10^{-12}	pico-	p	*pee*-koe
10^{-9}	nano-	n	*nan*-oe
10^{-6}	micro-	μ	*my*-crow
10^{-3}	milli-	m	*mil*-i
10^{-2}	centi-	c	*cen*-ti
10^{3}	kilo-	k	*kil*-oe
10^{6}	mega-	M	*meg*-a
10^{9}	giga-	G	*jig*-a or *gig*-a
10^{12}	tera-	T	*ter*-a
10^{15}	peta-	P	*pet*-a
10^{18}	exa-	E	*ex*-a
10^{21}	zetta-	Z	*zet*-a
10^{24}	yotta-	Y	*yot*-a

Greek Alphabets

Upper Case Letter	Lower Case Letter	Greek Letter Name	English Equivalent
Α	α	Alpha	a
Β	β	Beta	b
Γ	γ	Gamma	g
Δ	δ	Delta	d
Ε	ε	Epsilon	e
Ζ	ζ	Zeta	z
Η	η	Eta	h
Θ	θ	Theta	th
Ι	ι	Iota	i
Κ	κ	Kappa	k
Λ	λ	Lambda	l
Μ	μ	Mu	m

Upper Case Letter	Lower Case Letter	Greek Letter Name	English Equivalent
Ν	ν	Nu	n
Ξ	ξ	Xi	x
Ο	ο	Omicron	o
Π	π	Pi	p
Ρ	ρ	Rho	r
Σ	σ,ς *	Sigma	s
Τ	τ	Tau	t
Υ	υ	Upsilon	u
Φ	φ	Phi	ph
Χ	χ	Chi	ch
Ψ	ψ	Psi	ps
Ω	ω	Omega	o

Fundamental and Derived Units

All laws in Physics are expressed in terms of physical quantities and these quantities are divided into two; fundamental and derived quantities.

Those physical quantities which are independent to each other are called fundamental quantities and their units are called fundamental units.

S/N	Fundamental Quantities	Fundamental Units	Symbol
1	Length	Metre	M
2	Mass	Kilogram	Kg
3	Time	Second	S
4	Temperature	Kelvin	K
5	Amount of Substance	Mole	Mole
6	Electric Current	Ampere	A
7	Luminous Intensity	Candela	Cd

Supplementary Fundamental Units

Radian and steradian are two supplementary fundamental units. It measures plane angle and solid angle respectively.

S/N	Supplementary Fundamental Quantities	Supplementary Unit	Symbol
1	Plane angle	Radian	rad
2	Solid angle	Steradian	Sr

Those physical quantities whose defining operators are based on other physical quantities are called derived quantities and their units are called derived units. e.g. velocity, acceleration, force, work, etc.

Systems of Units

A system of units is the complete set of units, both fundamental and derived, for all kinds of physical quantities. The common systems of units which are used in mechanics are given below:

1. CGS System In this system, the unit of length is centimetre, the unit of mass is gram and

the unit of time is second.

2. FPS System In this system, the unit of length is foot, the unit of mass is pound and the unit of time is second.

3. MKS System In this system, the unit of length is metre, the unit of mass is kilogram and the unit of time is second.

4. SI System This system contains seven fundamental units and two supplementary fundamental units.

Relationship between Some Mechanical SI Unit and Commonly Used Units

S/N	Physical Quantity	Unit
1	Length	(a) 1 micrometre = 10^{-6} m (b) 1 angstrom =10^{-10} m
2	Mass	1 metric ton = 10^{3} kg (b) 1 pound = 0.4537 kg (c) 1 amu = 1.66 x10^{-23} kg
3	Volume	
4	Force	(a) 1 dyne = 10^{-5} N (b) 1 kgf = 9.81 N
5	Pressure	(a) 1 $kgfm^{2}$ = $9.81Nm^{-2}$ (b) 1 mm of Hg = 133 Nm^{-2} (c) 1 pascal = 1 Nm^{-2}

		(d) 1 atmosphere pressure = 76 cm of Hg = 1.01 x 10^5pascal
6	Work and energy	(a) 1 erg =10^{-7} J (b) 1 kgf-m = 9.81 J (c) 1 kWh = 3.6 x 10^6 J (d) 1 eV = 1.6 x 10^{-19} J
7	Power	1 horse power = 746 W

Some Practical Units

1. 1 fermi =10^{-15} m
2. 1 X-ray unit = 10^{-13} m
3. 1 astronomical unit = 1.49 x 10^{11} m (average distance between sun and earth)
4. 1 light year = 9.46 x 10^{15} m
5. 1 parsec = 3.08 x 10^{16} m = 3.26 light year

Some Approximate Masses

Object	Kilogram
Our galaxy	2 x 10^{41}
Sun	2 x 10^{30}
Moon	7 x 10^{22}
Asteroid Eros	5 x 10^{15}

Dimensions

Dimensions of any physical quantity are those powers which are raised on fundamental units to express its unit. The expression which shows how and which of the base quantities represent the dimensions of a physical quantity, is called the dimensional formula.

Having the same units on both sides of an equation does not guarantee that the equation is correct. But having different units on the two sides of an equation certainly guarantees that it is wrong. Units obey the same algebraic rules as numbers, so they can serve as one diagnostic tool to check your problem solutions. To express the dimensions of basic quantities in mechanics, we use the abbreviation L, M and T for length, mass and time respectively.

S/N	Physical Quantity	Dimensional Formula	MKS Unit
1	Area	L^2	m^2
2	Volume	L^3	m^3
3	Velocity	LT^{-1}	ms^{-1}
4	Acceleration	LT^{-2}	ms^{-2}
5	Force	MLT^{-2}	Newton (N)
6	Work or energy	ML^2T^{-2}	Joule (J)
7	Power	ML^2T^{-3}	Js^{-1} or watt
8	Pressure or stress	$ML^{-1}T^{-2}$	Nm^{-2}
9	Linear momentum or Impulse	MLT^{-1}	$kgms^{-1}$
10	Density	ML^{-3}	kgm^{-3}
11	Strain	Dimensionless	Unit less
12	Modulus of elasticity	$ML^{-1}T^{-2}$	Nm^{-2}
13	Surface tension	MT^{-2}	Nm^{-1}
14	Velocity gradient	T^{-1}	s^{-1}
15	Coefficient of viscosity	$ML^{-1}T^{-1}$	$kgm^{-1}s^{-1}$
16	Gravitational constant	$M^{-1}L^3T^{-2}$	Nm^2kg^{-2}
17	Moment of inertia	ML^2	kgm^2
18	Angular velocity	T^{-1}	rad/s
19	Angular acceleration	T^{-2}	rad/s^2
20	Angular momentum	ML^2T^{-1}	kgm^2s^{-1}

Homogeneity Principle

If the dimensions of left hand side of an equation are equal to the dimensions of right hand side of the equation, then the equation is dimensionally correct. This is known as *homogeneity principle.*

Mathematically [LHS] = [RHS]

Example

The displacement of a particle moving under uniform acceleration is some function of the elapsed time and the acceleration. Suppose we write this displacement

$s = ka^m t^n$

Where k is a dimensionless constant; show by dimensional analysis that this expression is satisfied if $m = 1$ and $n = 2$. Can this analysis give the value of k?

Applications of Dimensions

- ✓ To check the accuracy of physical equations or to test the validity of an equation
- ✓ To change a physical quantity from one system of units to another system of units
- ✓ To obtain a relation between different physical quantities
- ✓ To establish formula
- ✓ To find the dimension of constants in a given relation
- ✓ To provide partial solution for physical problems whose direct solution cannot be achieved by the stated methods

Limitation of Dimensions

- ✓ It does not give information about the dimension constant
- ✓ It gives no information whether a physical quantity is scalar or vector
- ✓ It cannot be used to derive formulae containing trigonometric function, exponential functions logarithmic function etc.

Examples/Assignment [1]

Newton's law of universal gravitation is given by $F = \frac{GMm}{r^2}$

Where F is the gravitational force, M and m are masses, and r is a length. Derive the SI unit of the proportionality constant G? Note: Force is has the SI unit kgm/s^2 (Newton).

Motion in a Straight Line

The world and everything in it moves. Even seemingly stationary things, such as a roadway, move with earth's rotation, earth's orbit around the sun, the sun's orbit around the center of the Milky Way Galaxy, and that galaxy's migration relative to other galaxies.

Motion is the change in position of body with reference to time; motion is said to take place when there is a relative displacement with time of a body in place with respect to a reference. There are difference kinds of motion; linear/translational, oscillatory, rotational, circular, random and relative. The branch of Physics that study the motion of a body is known as Mechanics.

The classification and comparison of motions (called *Kinematics*) is often challenging. The study of motion which does not involve force is called *Kinematics* while involving force is called *Dynamics*

Position, Distance and Displacement

The position of an object in space or on a plane is the point at which the object can be located with reference to a given point.

Distance is the measure of the separation between two points. The displacement of a particle is defined as its change in position in a specified direction, while without specified direction is term *Distance*. As a body moves from an initial position x_i to a final position x_f its displacement is given by $x_f - x_i$. Therefore, the displacement, or change in position, of the particle as:

$$s = \sqrt{\Delta x + \Delta y + \Delta z} \tag{1}$$

Where, $\Delta x = x_f - x_i, \Delta y = y_f - y_i, \Delta z = z_f - z_i$

Displacement is an example of a vector quantity. Many other physical quantities, including velocity and acceleration, also are vectors. In general, a vector is a physical quantity that requires the specification of both direction and magnitude. By contrast, a scalar is a quantity that has magnitude and no direction.

Speed, Velocity and Acceleration

An object that changes its position has a non-zero velocity. The average velocity $\overline{v_x}$ of a particle is defined as the particle's displacement Δx divided by the time interval Δt during which that displacement occurred:

$$\overline{v_x} = \frac{\Delta x}{\Delta t} \tag{2}$$

The subscript *x* indicates motion along the *x*-axis.

In everyday usage, the terms *speed* and *velocity* are interchangeable. The average speed of a particle, a scalar quantity, is defined as the total distance traveled divided by the total time it takes to travel that distance:

$$Average\,speed = \frac{Total\;dis\tan ce}{Time\;Taken} \tag{3}$$

Instantaneous Velocity and Speed

Instantaneous velocity v_x equals the limiting value of the ratio $\Delta x / \Delta t$ as Δt approaches zero

$$v_x \equiv \lim_{x \to 0} \frac{\Delta x}{\Delta t} \tag{4}$$

In calculus notation, this limit is called the *derivative* of *x* with respect to *t*, written *dx*/*dt:*

$$v_x \equiv \lim_{x \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt} \tag{5}$$

The instantaneous velocity can be positive, negative, or zero. The instantaneous speed of a particle is defined as the magnitude of its velocity. As with average speed, instantaneous speed has no direction associated with it and hence carries no algebraic sign

Acceleration

The average acceleration of the particle is defined as the change in velocity Δv_x divided by the time interval Δt during which that change occurred:

$$\overline{a_x} \equiv \frac{\Delta v_x}{\Delta t} = \frac{v_{xf} - v_{xi}}{t_f - t_i} \qquad (6)$$

In some situations, the value of the average acceleration may be different over different time intervals. It is therefore useful to define the *Instantaneous Acceleration* as the limit of the average acceleration as Δt approaches zero. Instantaneous acceleration is given as:

$$a_x \equiv \lim_{x \to 0} \frac{\Delta v_x}{\Delta t} = \frac{dv_x}{dt} \qquad (7)$$

That is, the instantaneous acceleration equals the derivative of the velocity with respect to time, which by definition is the slope of the velocity–time graph.

One-Dimensional Motion with Constant Acceleration

If the acceleration of a particle varies in time, its motion can be complex and difficult to analyze. However, a very common and simple type of one-dimensional motion is that in which the acceleration is constant. When this is the case, the average acceleration over any time interval equals the instantaneous acceleration at any instant within the interval, and the velocity changes at the same rate throughout the motion.

If we replace $\overline{a_x}$ by a_x in Equation 5 and take t_i=0 and t_f to be any later time t, we find that

$$a_x = \frac{v_{xf} - v_{xi}}{t}$$

or

$$v_{xf} = v_{xi} + a_x t \qquad (8)$$

Because velocity at constant acceleration varies linearly in time according to Equation 7, we can express the average velocity in any time interval as the arithmetic mean of the initial velocity v_{xi} and the final velocity v_{xf} :

$$\overline{v_x} = \frac{v_{xi} + v_{xf}}{2} \qquad (9)$$

We can now use Equations 1, 2, and 9 to obtain the displacement of any object as a function of time

$$x_f - x_i = \bar{v}_x t = \frac{1}{2}\left(v_{xi} + v_{xf}\right)t \qquad (10)$$

We can obtain another useful expression for displacement at constant acceleration by substituting Equation 8 into Equation 10:

$$x_f - x_i = \frac{1}{2}\left(v_{xi} + v_{xi} + a_x t\right)t$$
$$x_f - x_i = v_{xi}t + \frac{1}{2}a_x t^2 \qquad (11)$$

We can check the validity of Equation 11 by moving the x_i term to the right-hand side of the equation and differentiating the equation with respect to time

$$v_{xf} = \frac{dx_f}{dt} = \frac{d}{dt}\left(x_i + v_{xi}t + \frac{1}{2}a_x t^2\right) = v_{xi} + a_x t \qquad (12)$$

Finally, we can obtain an expression for the final velocity that does not contain a time interval by substituting the value of t from Equation 8 into Equation 10:

$$x_f - x_i = \frac{1}{2}\left(v_{xi} + v_{xf}\right)\left(\frac{v_{xf} - v_{xi}}{a_x}\right) = \frac{v_{xf}^{\ 2} - v_{xi}^{\ 2}}{2a_x}$$

$$v_{xf}^{\ 2} = v_{xi}^{\ 2} + 2a_x\left(x_f - x_i\right) \qquad (13)$$

Examples/Assignment [2]

1. Calculate the distance that is required to stop a car moving at 106km/hr, if the reaction time of the driver is 0.1s.
2. The brakes of a certain car can produce an acceleration of 6m/s^2. How long does it take the car to come to stop from a velocity of 30m/s, how far does the car travel during the time the brakes are applied?
3. A bike moving at 54km/hr slow down uniformly to 18km/hr after the gradual application of brake. Find the time takes to cover 50m and the rate of change of its velocity (and define it appropriately).
4. A car starting from rest moves for 30s. Find the final velocity attained after covering a distance of 40m.
5. A Toyota Jeep moves from rest with uniform acceleration until it attain 108km/hr after 15s. Calculate its acceleration.
6. Show the necessary equations of a motion in a straight line.

Motion under Gravity

The motion of objects in space is generally influenced by the action of the earth's gravity and air resistance. If the air resistance is neglected, objects tend to have accelerated motion (if falling at a given height) or decelerated motion (if projected upward in the air).

The equations of motion under gravity are:

$$v = u \pm gt$$
$$h = ut \pm \frac{1}{2}gt^2 \qquad (14)$$
$$v^2 = u^2 \pm 2gh$$

Acceleration of Free Fall due to Gravity

Free fall objects have accelerated motion due to the action of the earth's gravity on them. No matter the difference in mass, such objects fall with the acceleration and at the same time. If the air resistance is neglected, g can be determined by simple pendulum experiment or by free fall method.

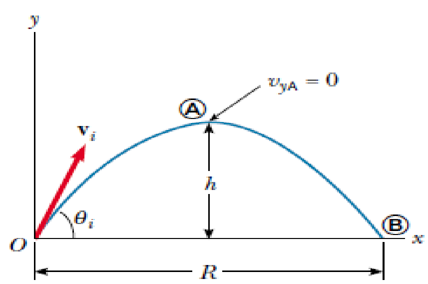
Projectile Motion

Projectile motion is the superposition of two motions:

- ✓ Constant- velocity motion in the horizontal direction and
- ✓ Free-fall motion in the vertical direction.

Except for *t*, the time of flight, the horizontal and vertical components of a projectile's motion are completely independent of each other.

Time of Flight, Horizontal Range and Maximum Height of a Projectile



Time of Flight

From the diagram,

$$v_{yf} = v_{yi} + a_y t$$
$$0 = v_i \sin\theta_i - gt_A$$
$$t_A = \frac{v_i \sin\theta}{g}$$

But,

$$T = \frac{2t_A}{g}$$

$$T = \frac{2v_1 \sin\theta}{g} \qquad (15)$$

Maximum Height

The Maximum height reach for a projectile is given as

$$h = \frac{v_i^2 \sin^2 \theta_i}{2g} \qquad (16)$$

Range

The range *R* is the horizontal distance that the projectile travels in twice the time it takes to reach its peak.

Range of projectile is given as

$$R = \frac{v_i^2 \sin 2\theta_i}{g} \qquad (17)$$

For a maximum value of *Range R* (at *45^0*) is given as:

$$R_{\max} = \frac{u^2}{g} \qquad (18)$$

Since sin $90^0 = 1$

Trajectory – Parabolic Path

The shape of the trajectory can be found by combining the Eqns for vertical and horizontal velocity. Taking the vertical displacement as ***y*** and the horizontal displacement as ***x***:

$$x = ut\cos\theta$$

$$y = ut\sin\theta - \frac{1}{2}gt^2 \qquad (19)$$

This gives:

$$y = x\tan\theta - \frac{gx^2}{2u^2\cos^2\theta} \qquad (20)$$

For a given angle of projection and projection velocity:

$$y = Bx - Cx^2 \qquad (21)$$

Where *B* and *C* are constant, Eqn (21) is the ***Equation of Parabola***

Examples/Assignment [3]

1. An object is projected at an elevation angle of 60^0 with an initial velocity of 100m/s. Calculate the time of flight, maximum height and the range.
2. A stone is projected at an angle of 60^0 to the horizontal with velocity of 30m/s. Calculate the highest point reached, the range, the time taken for the flight and the height of the stone at the instant that the path makes an angle of 30^0 with the horizontal.

The Laws of Motion

According to Isaac Newton, there are three basic laws of motion, which deal with forces and masses which were formulated about three centuries ago.

The Concept of Force

Everyone has a basic understanding of the concept of force from everyday experience. When you push your empty dinner plate away, you exert a force on it. Similarly, you exert a force on a ball when you throw or kick it. If the net force exerted on an object is zero, then the acceleration of the object is zero and its velocity remains constant.

Newton's First Law and Inertial Frames: In the absence of external forces, an object at rest remains at rest and an object in motion continues in motion with a constant velocity (that is, with a constant speed in a straight line).

In simpler terms, we can say that when no force acts on an object, the acceleration of the object is zero. If nothing acts to change the object's motion, then its velocity does not change.

This implies that an object continues in its state of rest or of uniform motion in a straight line unless a net external force act on it to change that state. From the first law, we conclude that any *isolated object* (one that does not interact with its environment that is closed system) is either at rest or moving with constant velocity. The tendency of a body to resist any attempt to change its present position is called the inertia of the body.

Mass

Mass is an inherent property of an object and is independent of the object's surroundings and of the method used to measure it; it is the quantity of matter contained in a body. Also, mass is a scalar quantity and thus obeys the rules of ordinary arithmetic

Newton's Second Law: The rate of change of momentum, Δp of an object is directly proportional to the applied force, and this change takes place in the direction of the force. This implies also that the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. Thus, we can relate mass, m and force, f through the following mathematical statement of Newton's second law;

$$F \infty \frac{\Delta p}{t} \Rightarrow F = k\frac{\Delta p}{t} = F\frac{\Delta p}{t} \qquad (22)$$

Choosing the unit to be such that the constant of proportionality is unity and *momentum is product of the mass and velocity (kgms^{-1}).*

$$\frac{\Delta p}{t} \Rightarrow \frac{mv - mu}{t} = \frac{m(v-u)}{t} \qquad (23)$$

Impulse $= F \times t = \Delta p$

Recall that, $a = \frac{v-u}{t}$

$$\therefore F = ma \qquad (24)$$

Force therefore, is that which change or tend to change the state of rest or of uniform motion in a straight. There are two types of force: Contact force and field force.

Contact force: Force that acts on bodies that are in contact. The basic types are; frictional, tensional and normal/reactional force.

Field force: Force that acts on bodies that are not in contact. The basic types are; electrical, magnetic, gravitational, etc.

The Force of Gravity and Weight

The attractive force exerted by the earth on an object is called the force of gravity *Fg*. This force is directed toward the center of the earth and its magnitude is called the weight, *W* of the object. The force acting on an object due to gravitational pull is known as the weight of the object.

Hence, $W = mg$ (25a)

A freely falling object experiences an acceleration *g* acting toward the centre of the earth. Applying Newton's second law to a freely falling object of mass *m*, with *a* = *g* and, we obtain $F = F_g$

$$F_g = mg \qquad (25b)$$

Principle of Conservation of Linear Momentum

This principle states that if no external forces act on a system of colliding bodies, the total momentum of the bodies in a given direction before collision is the same as the total momentum after collision in the direction.

Types of Collisions

There are two types of collision: Elastic Collision and Inelastic Collision

Elastic Collision: Both momentum and total kinetic energy are conserved and if there is a rebound after collision.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2 \qquad (26a)$$

$$\frac{1}{2}m_1u_1 + \frac{1}{2}m_2u_2 = \frac{1}{2}m_1v_1 + \frac{1}{2}m_2v_2 \qquad (26b)$$

Inelastic Collision: Only the momentum is conserved, while the kinetic energy is not conserved in which the bodies stick together and move with a common velocity after collision.

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v \quad (27a)$$

$$\frac{1}{2}m_1u_2 + \frac{1}{2}m_2u_2 = \frac{1}{2}(m_1 + m_2)v^2 \quad (27b)$$

Note: p is negative if motion is in opposite direction (from right to left).

Newton's Third Law: To every action there is an equal and opposite reaction. This implies that, if one body exerts a certain force on a second body, the second body exerts an equal and opposite force on the first *(If two objects interact, the force F_{12} exerted by object 1 on object 2 is equal in magnitude to and opposite in direction to the force F_{21} exerted by object 2 on object 1: $F_{12} = F_{21}$).* Newton's third law states the relationship between the forces resulting from the interaction between two or more objects; its shows that forces always occur in pairs.

Application of Newton's Third Law

- ✓ Jet engines and rockets: The working principles behind the operation of the jet engines and rockets are derived from Newton's third law.
- ✓ Recoil of a gun: When a bullet is shot out of a gun, the person firing experiences a backward impact/force known as recoil force, while the force propelling the bullet out of the gun is known as propulsive force.

Since, force is proportional to change of momentum; then by the Newton's third law, the momentum of the bullet would be equal and opposite to that of the gun:

$$m_bv_p = m_gv_r$$

$$\therefore v_r = \frac{m_bv_p}{m_g} \quad (28)$$

Where $\boldsymbol{m_b}$, $\boldsymbol{m_g}$, $\boldsymbol{v_p}$ and $\boldsymbol{v_r}$ are the mass of the bullet, mass of the gun, propulsive velocity and recoil velocity respectively.

Examples/Assignment [4]

1. A Toyota Jeep with mass 1.8×10^3kg is travelling eastbound at 15m/s, while a Benz Jeep with mass 9×10^2kg is travelling westbound at -15m/s. These cars collide head on and become entangled. Calculate the velocity of the entangled jeeps after collision, the change in velocity of each jeep and the change in kinetic energy of the system consisting of both Jeeps.
2. A car of mass 1200kg travelling at 10m/s collides with a stationary car of mass 1000kg. If the cars stick together. Find their combined velocity. Hence, show the kind of collision of the cars by comparing the kinetic energy before and after collision.
3. An arrow travelling at 150m/s of mass 0.004kg is shot at a fixed target. Calculate the distance before it was brought to rest after 0.02s and the average retarding force exerted on the arrow head.

Vector and Scalar Quantities

Measureable physical quantities in Physics may also be classified as scalar and vector.

Scalar Quantity: is specified by a single value with an appropriate unit (magnitude) and has no specified direction. Examples of scalar quantities are volume, mass, time intervals etc. The rules of ordinary arithmetic are used to manipulate scalar quantities, since they do not have direction associated in space.

Vector quantity: has both magnitude and direction. Examples of vector quantities are velocity, acceleration and displacement etc. The number of components needed to specify the vector depends on the geometry of the space which can be represented by lines.

Some Properties of Vectors

Two vectors *A* and *B* may be defined to be equal if they have the same magnitude and point in the same direction. That is, $A = B$ only if $A=B$ and if *A* and *B* point in the same direction along parallel lines.

Addition of Vectors: The rules for adding vectors are conveniently described by geometric methods. To add vector *B* to vector *A*, first draw vector A, with its magnitude represented by a convenient scale, on graph paper and then draw vector B to the same scale with its tail starting from the tip of *A*. The resultant vector $R = A + B$ is the vector drawn from the tail of *A* to the tip of *B*. This procedure is known as the triangle method of addition.

Negative of a Vector: The negative of the vector A is defined as the vector that when added to A gives zero for the vector sum. That is, $A + (-A) = 0$. The vectors A and -A have the same magnitude but point in opposite directions.

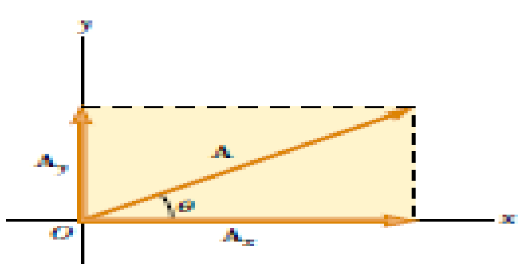
Subtraction of Vectors: The operation of vector subtraction makes use of the definition of the negative of a vector. We define the operation $A - B$ as vector $-B$ added to vector *A*:

$$A - B = A + (-B) \qquad (29)$$

Components of a Vector and Unit Vectors

This is the method of adding vectors that makes use of the projections of vectors along the coordinate axes. These projections are called the components of the vector. Any vector can be completely described by its components.

Consider the diagram below



$$A_x = ACos\,\theta$$
$$A_y = ASin\theta \quad (30)$$

These components form two sides of a right triangle with a hypotenuse of length A. Thus, it follows that the magnitude and direction of A are related to its components through the expressions.

$$A = \sqrt{A_x{}^2 + A_y{}^2}$$
$$\theta = \tan^{-1}\left(\frac{A_y}{A_x}\right) \quad (31)$$

Note: The signs of the components *Ax* and *Ay* depend on the angle θ

Relative Motion and Velocity

Motions in general are relative; this is why we should always choose a reference frame with respect to which we can specify the motion. The earth is usually frame of reference chosen at rest even though the earth is moving through space. The motion of a body relative to another is the vector difference between the motions of the bodies

The relative velocity is a comparative velocity between two moving bodies with reference to a point. If the velocity of a body *A* is V_a and that of the second body *B* is V_b. Then;

The relative velocity of A to B, if both bodies are moving in the same direction = $V_a - V_b$.

If both bodies are moving in opposite direction = $V_b + V_a$.

Examples/Assignment [5]

1. A Toyota Jeep moving with a velocity of 65m/s travels in opposite direction to a Benz Jeep with a velocity of 80m/s. Find the relative velocity of the Benz Jeep to the Toyota Jeep.
2. $\overrightarrow{F_1} = 3\hat{i} - \hat{j} - 4\hat{k}, \overrightarrow{F_2} = -4\hat{i} + 4\hat{j} - 3\hat{k}, \overrightarrow{F_3} = 3\hat{i} + 2\hat{j} - \hat{k}\ and\ \overrightarrow{F_4} = 2\hat{i} - 2\hat{j} - 3\hat{k}$ are forces acting on an object. Calculate the magnitude of the equilibrant of the forces.
3. Two aero plane, *X* and *Y* moving in space have position vectors $3\hat{i} + 4\hat{j} + 7\hat{k}\ and\ -\hat{i} + 2\hat{j} + 3\hat{k}$ respectively, in what direction should the pilot of *X* look to see *Y*.

Work, Energy and Power

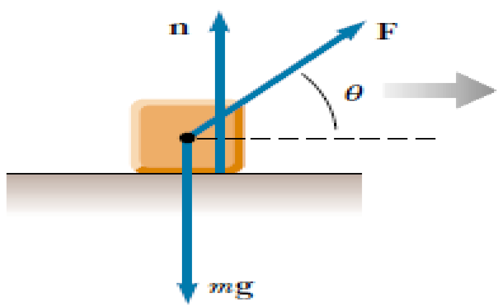
The work W done on an object by an agent exerting a constant force on the object is the product of the component of the force in the direction of the displacement and the magnitude of the displacement.

$$W = Fd \cos \theta \tag{32}$$

If an applied force F acts along the direction of the displacement, then $\theta = 0$ and $\cos\theta = 1$. In this case, Equation 19 gives

$$W = F.d \tag{33}$$

Work is a scalar quantity, and its units are force multiplied by length. Therefore, the SI unit of work is the newton meter (Nm). This combination of units is used so frequently that it has been given a name of its own: the joule (J).



Energy

Energy is the ability to do work.

Types of Energy

- ✓ Mechanical Energy
- ✓ Solar Energy
- ✓ Nuclear Energy
- ✓ Chemical Energy
- ✓ Heat Energy
- ✓ Sound Energy etc

We shall limit to mechanical (which may be in the form of energy kinetic or potential energy)

Kinetic Energy: energy by virtue of motion of a body, it is stored in a body when the velocity changes, given by:

$$K.E = \frac{1}{2}mv^2 \tag{34}$$

Potential Energy: energy by virtue of the position or level of a body, given by:

$$P.E = mgh \qquad (35)$$

Principle Conservation and Transformation of Energy

Although energy may be transformed from one form to another, the total energy in a closed or isolated system is always constant. Mechanical energy is conserved when the energy changes by virtue of the position of a body and when in motion, this can be illustrated when a body is dropped from a given height.

Power

The time rate of doing work is called power. If an external force is applied to an object (which we assume acts as a particle), and if the work done by this force in the time interval *t* is *W*, then the average power expended during this interval is defined as

$$P = \frac{W}{\Delta t} \Rightarrow \frac{Fs}{t} = Fv \qquad (36)$$

Note: 1 horse power (h.p) = 746 W

Examples/Assignment [6]

1. Calculate the work done in moving a body along a straight line from (3, 2, -1) to (2, -1, 4) in a force field given by $\overrightarrow{F_4} = 4\hat{i} - 3\hat{j} + 2\hat{k}$.
2. A young guy uses a horizontal force of 200N to push a crate up a ramp of 8m long at 20^0 above the horizontal. How much work does the guy perform and if he takes 12s to push the crate up the ramp, what is his power output in h.p.

The Law of Gravity

Newton's Law of Universal Gravitation: Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

If the particles have masses m_1 and m_2 and are separated by a distance *r*, the magnitude of this gravitational force is

$$F \infty m_1 m_2 \text{ and } F \infty \frac{1}{r^2}$$

$$\Rightarrow F_g = G\frac{m_1 m_2}{r^2} \qquad (37)$$

Where *G* is a constant, called the *universal gravitational constant* $G = 6.673 \times 10^{-11}\, Nm^2 kg^{-2}$

The Gravitational Field

The gravitational field is a region in which every object on the earth surface is pulled by the earth's gravity or is attracted towards it. It is at a point in space equals the gravitational force experienced by a *test particle* placed at that point divided by the mass of the test particle.

$$g = \frac{F_g}{m} = \frac{Gm_e}{R^2_e} \tag{38}$$

Gravitational Potential Energy

The gravitational potential at a point on the earth's surface is the work done in moving a unit mass of a body from infinity to that point.

The gravitational potential energy associated with any pair of particles of masses m_1 and m_2 separated by a distance r is given as:

$$U = -\frac{Gm_1m_2}{r} \tag{39}$$

Escape Velocity

Is the velocity required for a body of mass, m to just escape from the gravitational influence of the earth; it can be derived from:

$$K.\mathrm{E} + \mathrm{P.E} = \frac{1}{2}mv^2 - \frac{Gm_e m}{R_e} \Rightarrow \frac{1}{2}mv^2 - \frac{Gm_e m}{R_e} = 0 \quad \Rightarrow \frac{1}{2}mv^2 = \frac{Gm_e m}{R_e} \tag{40}$$

$$v_e = \sqrt{\frac{2GM_e}{R_e}} \Rightarrow 11.2kms^{-1} \tag{41}$$

Where, mass of the earth, $m_e = 5.98\times10^{-24}\ kg$, Radius of the earth, $R_e = 6.38\times10^{6}\ kg$

Kepler's Law

Kepler's laws of planetary motion was derived by the German astronomer Johannes Kepler a German, whose analysis of the observations of the 16th-century Danish astronomer Tycho Brahe enabled him to announce his first two laws in the year 1609 and a third law nearly a decade later, in 1618. Kepler himself never numbered these laws or specially distinguished them from his other discoveries.

The laws describe the motions of the planets in the solar system and they are used in astronomy and classical physics. Kepler's three laws of planetary motion can be stated as follows:

1. All planets move about the sun in elliptical orbits, having the sun as one of the foci.
2. A radius vector joining any planet to the sun sweeps out equal areas in equal lengths of time; this implies that all line drawn from the sun to any planet sweeps out equal areas in equal intervals.
3. The squares of the orbital (sidereal) periods (of revolution) of the planets are directly proportional to the cubes of their mean (average) distances from the planet to the sun.

$$m_p a = \frac{m_p v^2}{r} = \frac{G m_s m_p}{r^2} \qquad (42)$$

Where, $v = \frac{2\pi r}{T}$

$$\therefore \frac{G m_s}{r^2} = \frac{\left(\frac{2\pi r}{T}\right)^2}{r} \qquad (43)$$

$$T^2 = \left(\frac{4\pi^2}{G m_s}\right) r^3 = k_s r^3 \qquad (44)$$

Eqn. (44) is the Kepler's 3rd Law.

Note: Mass of the earth, $m_e = 5.98\times10^{-24}\ kg$, Radius of the earth, $R_e = 6.38\times10^{6}\ kg$, $T = 5.98\times10^{7}\ s$, near distance for the sun = $1.496\times10^{11}\ m$

$m_s = \frac{4\pi^2}{G k_s}$ (Mass of the sun)

$$\Rightarrow k_s = \frac{4\pi^2}{G m_s} = 2.97\times10^{-19}\, s^2 m^{-3} \qquad (45)$$

The relevance of Kepler's laws extends to the motions of natural and artificial satellites as well as to unpowered spacecraft in orbit in stellar systems or near planets. As formulated by Kepler, the laws do not, of course, take into account the gravitational interactions (as perturbing effects) of the various planets on each other. The general problem of accurately predicting the motions of more than two bodies under their mutual attractions is quite complicated; analytical solutions of the three-body problem are unobtainable except for some special cases. It may be noted that Kepler's laws apply not only to gravitational but also to all other inverse-square-law forces and, if due allowance is made for relativistic and quantum effects, to the electromagnetic forces within the atom.

Examples/Assignment [7]

1. A satellite is expected to circle round the earth in an orbit 40000km from the surface. Calculate the velocity of the satellite in its orbit, its period and the acceleration due to gravity at that instant (take the radius of the earth = 6400km).
2. Calculate the escape velocity from the earth for a 5000kg spacecraft, and determine the kinetic energy it must have at the earth's surface in order to escape the earth's gravitational field.

Escape velocity from the surfaces of the planets, moons and sun

Body	$v_{esc}(km/s)$
Mercury	4.3
Venus	10.3
Earth	11.2
Moon	2.3
Mars	5.0
Jupiter	60
Saturn	36
Uranus	22
Neptune	24
Pluto	1.1
Sun	618