



# PHYSICS



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## WHAT IS PHYSICS ALL ABOUT?

Physics seeks to understand the natural phenomena that occur in our universe; a description of a natural phenomenon uses many specific terms, definitions and mathematical equations.  
**Solving Problems in Physics**  
In physics, we use the SI units (International System) for data and calculations.

Base Quantity	Symbol	Unit
Length	$L, x$	Meter - m
Mass	$m, M$	Kilogram - kg
Temperature	$T$	Kelvin - K
Time	$t$	Second - s
Electric Current	$I$	Ampere - A (C/s)

Other physical quantities are derived from these basic units. Prefixes denote fractions or multiples of units; many variable symbols are Greek letters.  
**Math Skills:** Many physical concepts are only understood with the use of algebra, statistics, trigonometry and calculus.

## CLASSICAL MECHANICS

**A. Classical or Newtonian Mechanics:** The position of a body is given by an equation of motion with position, velocity and acceleration as variables; mass is the measure of the amount of matter; the standard unit for mass is kg,  $1 \text{ kg} = 1000 \text{ g}$ ; Inertia is a property of matter, and as such, it occupies space.

1. Motion along a straight line is called rectilinear; the equation of motion describes the position of the particle and velocity for elapsed time,  $t$ .

a. **Velocity ( $v$ ):** The rate of change of the displacement

$$(x) \text{ with time } (t): v = \frac{dx}{dt} = \frac{dx}{dt}$$

b. **Acceleration ( $a$ ):** The rate of change of the velocity with time:  $a = \frac{dv}{dt} = \frac{dv}{dt}$

$a$  &  $v$  are vectors, with magnitude and direction

c. **Speed** is the absolute value of the velocity; scalar with the same units as velocity.

2. **Equations of Motion for One Dimension (1-D)**

Equations of motion describe the future position ( $x$ ) and velocity ( $v$ ) of a body in terms of the initial velocity ( $v_0$ ), position ( $x_0$ ) and acceleration ( $a$ )

a. For constant acceleration, the position is related to the time and acceleration by the following equation of motion:  $x(t) = x_0 + v_0 t + \frac{1}{2} a t^2$

b. For constant acceleration, the velocity vs. time is given by the following:  $v(t) = v_0 + a t$

c. If the acceleration is a function of time, the equation must be solved using  $a = a(t)$

**B. Motion in Two Dimensions (2-D)**

1. For bodies moving along a straight line, derive  $x$ - and  $y$ -equations of motion

$$x = v_{0x} t + \frac{1}{2} a_x t^2$$

$$y = v_{0y} t + \frac{1}{2} a_y t^2$$



2. For a rotating body, use polar coordinates, an angle variable,  $\theta$ , and  $r$ , a radial distance from the rotational center

Polar:  $(r, \theta)$   
 $r = r \cos \theta$   
 $r^2 = x^2 + y^2$

**C. Motion in Three Dimensions (3-D)**

1. **Cartesian System:** Equations of motion with  $x$ ,  $y$  and  $z$  components

2. **Spherical Coordinates:** Equations of motion based on two angles ( $\theta$  and  $\phi$ ) and  $r$ , the radial distance from the origin.



**D. Newton's Laws of Motion**  
Newton's Laws are the core principles for describing the motion of classical objects in response to forces. The SI unit of force is the Newton, N;  $1 \text{ N} = 1 \text{ kg m/s}^2$ , the cgs unit is the dyne;  $1 \text{ dyne} = 1 \text{ g cm/s}^2$

$x = r \sin \theta \cos \phi$   
 $y = r \sin \theta \sin \phi$   
 $z = r \cos \theta$   
 $r^2 = x^2 + y^2 + z^2$

- Newton's 1st Law:** A body remains at rest or in motion unless influenced by a force
- Newton's 2nd Law:** Force and acceleration determine the motion of a body and predict future position and velocity:  $F = m a$  OR  $\Sigma F = m a$
- Newton's 3rd Law:** Every action is countered by an opposing action

### E. Types of Forces

1. A body force acts on the entire body, with the force acting at the center of mass

a. A gravitational force,  $F_g$ , pulls an object toward the center of the Earth:  $F_g = m g$

b. Weight =  $F_g$ ; gravitational force

c. Mass is a measure of the quantity of material, independent of  $g$  and other forces.

2. Surface forces act on the body's surface

a. **Friction,  $F_f$ ,** is proportional to the force normal to the part of the body in contact with a surface.  
 $F_f = F_N = \mu F_N$

i. **Static friction** resists the movement of a body

ii. **Dynamic friction** slows the motion of a body

For an object on a horizontal plane:  
 $F_f = \mu F_N = \mu m g$   
 Net force =  $F_f + F_g$



### F. Circular Motion

1. Motion along a circular path uses polar coordinates:  $(r, \theta)$

2. **Key Variables:**

$r$	Meter	The distance from the rotation center (center of mass)
$\theta$	Radian	The angle between $r$ and the ( $x$ ) axis
$\omega$	Radian/second	The angular velocity
$\alpha$	Radian/second <sup>2</sup>	The angular acceleration
$s$	Meter	The circular motion arc $s = r\theta$ ( $\theta$ in rad)



3. **Tangential acceleration & velocity:**  
 $v_t = r \omega$ ,  $a_t = r \alpha$ ;  $v$  and  $a$  along the path of the motion are

4. **Centripetal acceleration:**  $a_c = \frac{v^2}{r}$ ;  $a$  is directed toward the rotational center

a. The centripetal force keeps the body in circular motion with a tangential acceleration and velocity

### G. Kinetic Energy & Work

1. **Kinetic energy,  $K$ :** Kinetic energy is the energy of motion; mass,  $m$  and velocity,  $v$ ;  $K = \frac{1}{2} m v^2$

The SI energy unit is the Joule (J);  $1 \text{ J} = 1 \text{ kg m}^2/\text{s}^2$

2. **Momentum,  $p$ :** Momentum is a property of motion, defined as the product of mass and velocity:  $p = m v$

3. **Work ( $W$ ):** Work is a force acting on a body moving a distance; for a general force,  $F$ , and a body moving a path,  $s$ :  $W = \int F ds$

For a constant force, work is the scalar product of the two vectors: force,  $F$ , and path,  $r$ :  
 $W = F d \cos(\theta) = F \cdot r$



Maximum work:  $W = F r$

No work:  $W = 0$

4. **Power ( $P$ ):** energy expended per unit time:  
 $P = \frac{dW}{dt} = \frac{dW}{dt}$

$$Work = \int P(t) dt$$

The SI unit for power is the Watt (W):

$$1 \text{ W} = 1 \text{ Joule/second} = 1 \text{ J/s}$$

Work for a constant output of power:

$$W = P \Delta t$$

### H. Potential Energy & Energy Conservation

1. The total energy of a body,  $E$ , is the sum of kinetic,  $K$ , & potential energy,  $U$ :  $E = K + \Sigma U$

2. **Potential energy** arises from the interaction with a potential from an external force

Potential energy is energy of position;  $U(r)$ ; the form of  $U$  depends on the force generating the potential:

Gravitational:  $U(h) = m g h$

Electrostatic:  $U(r_{12}) = \frac{q_1 q_2}{r_{12}}$

If there are no other forces acting on the system,  $E$  is constant and the system is called **conservative**

### I. Collisions & Linear Momentum

1. **Types of Collisions:**

a. **Elastic:** conserve energy

b. **Inelastic:** energy is lost as heat or deformation



2. **Relative Motion & Frames of Reference:** A body moves with velocity  $v$  in frame  $S$ ; in frame  $S'$  the velocity is  $v'$ ; if  $V_s$  is the velocity of frame  $S'$  relative to  $S$ , therefore:  $v = V_s + v'$

3. **Elastic Collision:**

Conserve Kinetic Energy:  $\Sigma \frac{1}{2} m v^2 = \Sigma \frac{1}{2} m v'^2$

Conserve Momentum:  $\Sigma m v_i = \Sigma m v_f$

4. **Impulse** is a force acting over time

$$Impulse = F \Delta t \text{ or } \int F(t) dt$$

Impulse is also the momentum change:  $p_{fin} - p_{ini}$

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# Active Physics Study Guide

**Tom M. Apostol, Dave A. Campbell, T.  
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