

## 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

$$\begin{aligned} \text{Polar: } (r, \theta) \\ r &= r \cos \theta \\ r^2 &= x^2 + y^2 \end{aligned}$$

### 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;  $1 \text{ dyne} = 1 \text{ g cm/s}^2$

- 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:

$$F_f = \mu F_N = \mu m g$$

$$\text{Net force} = F_A - F_f$$



### 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:

$$v_t = r \omega; a_t = r \alpha; v \text{ and } a \text{ along the path of the motion arc}$$

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,  $r$ :

$$W = F d \cos(\theta) = F \cdot r$$



4. **Power ( $P$ ):** energy expended per unit time:

$$P = \frac{dW}{dt} = \frac{dW}{dt}$$

$$\text{Work} = \int P(t) dt$$

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:

Gravitation:  $U(h) = mgh$

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**

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

$$\text{Conserve Momentum: } \Sigma m v_i = \Sigma m v_f$$

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

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

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



# Active Physics Study Guide

**Mansoor Khan MBBS, RDMS, RDCS**



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## Table of Contents Active Physics Study Guide

1. Understanding the eBook Active Physics Study Guide
  - The Rise of Digital Reading Active Physics Study Guide
  - Advantages of eBooks Over Traditional Books
2. Identifying Active Physics Study Guide
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Active Physics Study Guide
  - User-Friendly Interface
4. Exploring eBook Recommendations from Active Physics Study Guide
  - Personalized Recommendations
  - Active Physics Study Guide User Reviews and Ratings
  - Active Physics Study Guide and Bestseller Lists
5. Accessing Active Physics Study Guide Free and Paid eBooks
  - Active Physics Study Guide Public Domain eBooks
  - Active Physics Study Guide eBook Subscription Services
  - Active Physics Study Guide Budget-Friendly Options
6. Navigating Active Physics Study Guide eBook Formats
  - ePub, PDF, MOBI, and More
  - Active Physics Study Guide Compatibility with Devices
  - Active Physics Study Guide Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Active Physics Study Guide
  - Highlighting and Note-Taking Active Physics Study Guide
  - Interactive Elements Active Physics Study Guide
8. Staying Engaged with Active Physics Study Guide

- Joining Online Reading Communities
- Participating in Virtual Book Clubs
- Following Authors and Publishers Active Physics Study Guide
- 9. Balancing eBooks and Physical Books Active Physics Study Guide
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Active Physics Study Guide
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Active Physics Study Guide
  - Setting Reading Goals Active Physics Study Guide
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Active Physics Study Guide
  - Fact-Checking eBook Content of Active Physics Study Guide
  - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
- 14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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