Physics Vocabulary and Formulas Reference

Complete Guide - All 8 Modules

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Module 1. Introduction to Physics

1.1 Scope of Physics

VOCABULARY

Physics
The branch of science that studies matter, energy, and the interactions between them.

Matter
Anything that has mass and takes up space.

Energy
The ability to do work or cause a change.

Force
A push or pull on an object.

Motion
How an object's position changes over time.

Mechanics
The study of motion and forces.

Thermodynamics
The study of heat, temperature, and energy transfer.

Waves
How energy travels through waves.

Optics
The study of light and vision.

Electromagnetism
The study of electric charges and magnetic fields.

FORMULAS

Quantity	Formula	Variables
Density	$\rho = \frac{m}{V}$	ρ = density, m = mass, V = volume
Celsius to Fahrenheit	$T_F = \frac{9}{5}T_C + 32$	Temperature conversion
Fahrenheit to Celsius	$T_C = \frac{5}{9}(T_F - 32)$	Temperature conversion
Distance	$d = vt$	d = distance, v = velocity, t = time

1.2 Scientific Method

VOCABULARY

Scientific Method

A systematic approach to investigating questions and solving problems.

Observation

Using your senses to gather information about the world.

Qualitative

Descriptive observations (e.g., "the liquid is blue").

Quantitative

Numerical observations (e.g., "the temperature is 25°C").

Scientific Question

A question that can be answered through investigation and experimentation.

Hypothesis

A testable prediction or proposed explanation for an observation.

Experiment

A controlled procedure designed to test a hypothesis.

Independent Variable

The variable you deliberately change or manipulate.

Dependent Variable

The variable you observe or measure that responds to changes.

Control Group

The group not exposed to the experimental variable; used for comparison.

Theory

A well-tested explanation supported by extensive evidence from many experiments.

Scientific Law

A statement describing a consistent pattern in nature, often expressed mathematically.

FORMULAS - GEOMETRY FOR LAB WORK

Shape	Formula	Variables
Area of Rectangle	$A = lw$	A = area, l = length, w = width
Area of Circle	$A = \pi r^2$	A = area, r = radius
Perimeter of Rectangle	$P = 2l + 2w$	P = perimeter
Volume of Rectangular Solid	$V = lwh$	V = volume, h = height

1.3 Scientific Measurement and Math Tools

VOCABULARY

SI Units

The standardized system of measurement.

Meter

SI unit of length.

Kilogram

SI unit of mass.

Second

SI unit of time.

Significant Figures

The digits in a number meaningful to its precision.

Scientific Notation

A method of expressing numbers as a coefficient times a power of 10.

Precision

How closely repeated measurements agree with each other.

Accuracy

How close a measurement is to the true or accepted value.

FORMULAS

Quantity	Formula	Variables
Percent Error	$\% \text{ error} = \frac{\lvert \text{Exp} - \text{Theo} \rvert}{\text{Theo}} \times 100\%$	Compare experimental to theoretical

1.4 Vectors and Vector Components

VOCABULARY

Scalar

A quantity that has only magnitude (size). Examples: mass, time, temperature, speed, energy, volume.

Vector

A quantity that has both magnitude and direction. Examples: displacement, velocity, acceleration, force, momentum.

Components

Perpendicular parts of a vector that add up to give the original vector.

Magnitude

The size or length of a vector.

FORMULAS

Formula Name	Formula	Variables and Units
X-Component	$A_x = A\cos(\theta)$	A = magnitude of vector (any units) A_x = x-component (same units as A) θ = angle from positive x-axis (degrees or radians)
Y-Component	$A_y = A\sin(\theta)$	A = magnitude of vector (any units) A_y = y-component (same units as A) θ = angle from positive x-axis (degrees or radians)
Magnitude from Components	$A = \sqrt{A_x^2 + A_y^2}$	A = magnitude of vector A_x = x-component A_y = y-component
Direction from Components	$\theta = \tan^{-1}\left(\frac{A_y}{A_x}\right)$	θ = angle from positive x-axis A_x = x-component A_y = y-component (Check quadrant for correct angle!)

1.5 Vector Addition

VOCABULARY

Resultant Vector

The vector sum of two or more vectors.

Tip-to-Tail Method

Graphical method: place vectors head-to-tail, resultant goes from first tail to last head.

Parallelogram Method

Graphical method: place vectors tail-to-tail, resultant is the diagonal.

Analytical Method

Mathematical method using components to add vectors precisely.

Component Addition

Adding corresponding components of vectors: $R_x = A_x + B_x$, etc.

Commutative

Property where order doesn't matter: $\mathbf{A} + \mathbf{B} = \mathbf{B} + \mathbf{A}$.

FORMULAS

Formula Name	Formula	Description
Resultant X-Component	$R_x = A_x + B_x$	Adding x-components of all vectors
Resultant Y-Component	$R_y = A_y + B_y$	Adding y-components of all vectors
Resultant Magnitude	$R = \sqrt{R_x^2 + R_y^2}$	Finding size of resultant from components
Resultant Direction	$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$	Finding angle of resultant
Vector Components	$A_x = A\cos\theta, A_y = A\sin\theta$	Breaking vectors into components first

Module 2. Motion in One-Dimension

2.1 Position, Displacement, and Distance

VOCABULARY

Position

The location of an object relative to a chosen reference point (origin), measured in meters (m). Can be positive or negative depending on which side of the origin the object is located.

Displacement

The change in position of an object; a vector quantity with both magnitude and direction. Calculated as $\Delta x = x_f - x_i$.

Distance

The total length of the path traveled by an object, regardless of direction; a scalar quantity with magnitude only, always positive or zero.

Coordinate System

A reference frame with an origin and positive direction used to specify locations of objects in space.

Origin

The reference point (position zero) in a coordinate system, from which all positions are measured.

Vector Quantity

A physical quantity that has both magnitude and direction. Examples include displacement, velocity, acceleration, and force.

Scalar Quantity

A physical quantity that has magnitude but no direction. Examples include distance, speed, time, mass, and temperature.

Delta (Δ)

Greek letter meaning "change in"; used to indicate the difference between final and initial values of a quantity.

Magnitude

The size or amount of a quantity, without regard to direction.

One-Dimensional Motion

Motion along a straight line in one direction or its opposite.

FORMULAS

Formula Name	Formula	Variables and Units
Displacement	$\Delta x = x_f - x_i$	Δx = displacement (m), x_f = final position (m), x_i = initial position (m)
Distance (Straight Path)	$d = \lvert x_f - x_i \rvert$	d = distance (m), x_f = final position (m), x_i = initial position (m)
Total Distance (Multiple Segments)	$d_{total} = d_1 + d_2 + d_3 + ...$	d_{total} = total distance (m), d_1, d_2, d_3 = segment distances (m)

2.2 Velocity and Speed

VOCABULARY

Average Velocity (v_avg or $\bar{v}$)

The displacement divided by the time interval during which the displacement occurred; a vector quantity measured in meters per second (m/s).

Average Speed (s_avg)

The total distance traveled divided by the time interval; a scalar quantity measured in meters per second (m/s), always positive or zero.

Instantaneous Velocity (v)

The velocity of an object at a specific instant in time; the limit of average velocity as the time interval approaches zero.

Units of Velocity

SI unit is meters per second (m/s); other common units include kilometers per hour (km/h), miles per hour (mph), and feet per second (ft/s).

Positive Velocity

Motion in the positive direction (often right, forward, or upward in the chosen coordinate system).

Negative Velocity

Motion in the negative direction (often left, backward, or downward); does NOT mean the object is slowing down.

Zero Velocity

No motion; the object is at rest.

FORMULAS

Formula Name	Formula	Variables and Units
Average Velocity	$v_{avg} = \frac{\Delta x}{\Delta t}$	v_{avg} = average velocity (m/s), Δx = displacement (m), Δt = time interval (s)
Average Velocity (Alternate)	$v_{avg} = \frac{x_f - x_i}{t_f - t_i}$	x_f = final position (m), x_i = initial position (m), t_f = final time (s), t_i = initial time (s)
Average Speed	$s_{avg} = \frac{d}{\Delta t}$	s_{avg} = average speed (m/s), d = total distance (m), Δt = time interval (s)

2.3 Acceleration

VOCABULARY

Acceleration

The rate of change of velocity with respect to time; a vector quantity with SI units of m/s^2.

Average Acceleration

The change in velocity divided by the time interval during which the change occurs.

Instantaneous Acceleration

The acceleration at a specific moment in time.

Uniform Acceleration

Acceleration that remains constant in magnitude and direction over time.

Positive Acceleration

Acceleration in the positive direction; can mean speeding up or slowing down depending on velocity direction.

Negative Acceleration

Acceleration in the negative direction; can mean speeding up or slowing down depending on velocity direction.

Zero Acceleration

No change in velocity; indicates constant velocity (including possibly zero velocity).

Meters per Second Squared (m/s^2)

The SI unit of acceleration.

FORMULAS

Formula Name	Formula	Variables and Units
Average Acceleration	$a_{avg} = \frac{\Delta v}{\Delta t}$	a_{avg} = average acceleration (m/s^2), Δv = change in velocity (m/s), Δt = time interval (s)
Average Acceleration (Expanded Form)	$a = \frac{v_f - v_i}{t_f - t_i}$	v_f = final velocity (m/s), v_i = initial velocity (m/s), t_f = final time (s), t_i = initial time (s)
Final Velocity with Constant Acceleration	$v_f = v_i + a \cdot \Delta t$	v_f = final velocity (m/s), v_i = initial velocity (m/s), a = acceleration (m/s^2), Δt = time interval (s)

2.4 Kinematic Equations and Free Fall

VOCABULARY

Kinematic Equations

Four equations that describe motion with constant acceleration, relating position, velocity, acceleration, and time.

Free Fall

Motion under the influence of gravity alone, with no other forces acting.

Gravitational Acceleration (g)

The acceleration due to gravity near Earth's surface, approximately 9.8 m/s^2.

Constant Acceleration

Acceleration that does not change in magnitude or direction during the motion.

Symmetric Motion

Projectile motion where an object returns to its starting height, with equal times and speeds going up and coming down.

Terminal Velocity

The constant velocity reached when air resistance equals gravitational force, causing acceleration to become zero.

FORMULAS

Formula Name	Formula	When to Use
Final Velocity	$v_f = v_i + at$	When you don't know or need displacement
Displacement	$\Delta x = v_i t + \frac{1}{2}at^2$	When you don't know or need final velocity
Velocity-Displacement Relation	$v_f^2 = v_i^2 + 2a\Delta x$	When you don't know or need time
Displacement (Average Velocity Form)	$\Delta x = \frac{1}{2}(v_i + v_f)t$	When you don't know or need acceleration
Gravitational Acceleration	$g = 9.8\ \mathrm{m/s}^2$	For free fall problems (use $a = -g$ if up is positive)

2.5 Graphical Analysis of Motion

VOCABULARY

Position vs. Time Graph (x-t graph)

A graph showing an object's position on the vertical axis and time on the horizontal axis; slope equals velocity.

Velocity vs. Time Graph (v-t graph)

A graph showing an object's velocity on the vertical axis and time on the horizontal axis; slope equals acceleration, area equals displacement.

Slope

The rate of change of the vertical variable with respect to the horizontal variable; calculated as rise over run.

Tangent Line

A straight line that touches a curve at exactly one point; used to find instantaneous slope of curved graphs.

Area Under Curve

The region between a graph line and the horizontal axis; for v-t graphs, this area equals displacement.

Rise

The vertical change between two points on a graph (Δy).

Run

The horizontal change between two points on a graph (Δx).

Graphical Analysis

The process of extracting quantitative information from graphs using slopes, areas, and other geometric properties.

FORMULAS

Relationship	Formula	Description
Slope Formula	$m = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1}$	General formula for calculating slope from two points
Velocity from x-t Graph	$v = \frac{\Delta x}{\Delta t}$	Slope of position vs. time graph equals velocity
Acceleration from v-t Graph	$a = \frac{\Delta v}{\Delta t}$	Slope of velocity vs. time graph equals acceleration
Displacement from v-t Graph	$\Delta x = \text{area under curve}$	Area under velocity vs. time graph equals displacement
Area of Rectangle	$A = b \times h$	For constant velocity: base = time, height = velocity
Area of Triangle	$A = \frac{1}{2}bh$	For uniform acceleration from rest
Area of Trapezoid	$A = \frac{1}{2}(b_1 + b_2)h$	For uniform acceleration (not from rest)

Module 3. Forces and Newton's Laws of Motion

3.1 Weight and Gravitational Force

VOCABULARY

Weight

The gravitational force acting on an object, measured in newtons (N).

Mass

The amount of matter in an object, measured in kilograms (kg); an intrinsic property that doesn't change with location.

Force

A push or pull on an object, measured in newtons (N); a vector quantity with magnitude and direction.

Acceleration due to gravity (g)

The rate at which objects accelerate in free fall; approximately $9.8\ \mathrm{m/s^2}$ on Earth's surface.

Newton (N)

The SI unit of force; one newton equals one $kg \cdot m/s^2$.

Free-body diagram

A simplified drawing showing an object and all forces acting on it, represented as arrows.

Gravitational field strength

The acceleration due to gravity at a particular location; varies depending on the mass and radius of the celestial body.

Vector quantity

A quantity that has both magnitude and direction (e.g., force, weight, velocity).

Scalar quantity

A quantity that has only magnitude, no direction (e.g., mass, temperature, time).

FORMULAS

Formula Name	Formula	Variables and Units
Weight	$W = mg$	W = weight (N), m = mass (kg), g = acceleration due to gravity (m/s²)
Rearranged for mass	$m = \frac{W}{g}$	m = mass (kg), W = weight (N), g = acceleration due to gravity (m/s²)
Rearranged for g	$g = \frac{W}{m}$	g = acceleration due to gravity (m/s²), W = weight (N), m = mass (kg)

3.2 Friction

VOCABULARY

Friction
A force that opposes relative motion between two surfaces in contact.

Static friction
Friction force between surfaces not sliding relative to each other; prevents motion from starting.

Kinetic friction
Friction force between surfaces sliding relative to each other; opposes ongoing motion.

Coefficient of friction (μ)
Dimensionless number representing friction between two surfaces; depends on materials and conditions.

Normal force (N)
Perpendicular contact force exerted by a surface on an object.

Coefficient of static friction (μ_s)
The ratio of maximum static friction to normal force.

Coefficient of kinetic friction (μ_k)

The ratio of kinetic friction to normal force.

FORMULAS

Formula Name	Formula	Variables and Units
Weight	$W = mg$	W = weight (N), m = mass (kg), g = acceleration due to gravity (m/s²)
Maximum Static Friction	$f_s \leq \mu_s N$	f_s = static friction force (N), μ_s = coefficient of static friction (no units), N = normal force (N)
Kinetic Friction	$f_k = \mu_k N$	f_k = kinetic friction force (N), μ_k = coefficient of kinetic friction (no units), N = normal force (N)
Normal Force (horizontal surface)	$N = mg$	N = normal force (N), m = mass (kg), g = acceleration due to gravity (m/s²)

3.3 Connecting Newton's First and Second Laws

VOCABULARY

Newton's First Law

Objects maintain constant velocity unless acted upon by unbalanced force; Law of Inertia.

Inertia

The tendency of objects to resist changes in motion; measured by mass.

Net force

The vector sum of all forces acting on an object.

Equilibrium

The state when net force is zero and acceleration is zero.

Balanced forces

Forces that sum to zero; object in equilibrium.

Unbalanced forces

Forces that don't sum to zero; object accelerates.

Newton's Second Law

Net force equals mass times acceleration: $F_{net} = ma$.

Tension

Pulling force transmitted through a rope, string, or cable.

Free-body diagram

Diagram showing all forces acting on a single object.

FORMULAS

Formula Name	Formula	Variables and Units
Newton's Second Law	$F_{net} = ma$	F_{net} = net force (N), m = mass (kg), a = acceleration (m/s²)
Weight	$W = mg$	W = weight (N), m = mass (kg), g = 9.8 m/s²
Friction	$f = \mu N$	f = friction force (N), μ = coefficient of friction, N = normal force (N)
Net Force (1D)	$F_{net} = \sum F$	Sum of all forces (N); add forces with proper signs (+ and −)

3.4 Newton's Third Law

VOCABULARY

Newton's Third Law

For every action force, there is an equal and opposite reaction force; forces occur in pairs.

Action-reaction pair

Two forces equal in magnitude, opposite in direction, acting on different objects.

Action force

One force in an interaction pair (the label is arbitrary—either can be called "action").

Reaction force

The other force in an interaction pair (paired with the "action").

Recoil

Backward motion of a device that expels a projectile, caused by Newton's Third Law.

Propulsion

Motion achieved by pushing something in the opposite direction (Newton's Third Law).

Momentum

The product of mass and velocity; quantity of motion ($p = mv$).

FORMULAS

Formula Name	Formula	Variables and Units
Newton's Third Law	$F_{AB} = -F_{BA}$	F_{AB} = force of A on B (N), F_{BA} = force of B on A (N); negative sign indicates opposite directions
Newton's Second Law	$F_{net} = ma$	F_{net} = net force (N), m = mass (kg), a = acceleration (m/s²)
Momentum	$p = mv$	p = momentum (kg·m/s), m = mass (kg), v = velocity (m/s)

3.5 Gravitational Force and Inclined Planes

VOCABULARY

Inclined plane

A flat surface set at an angle to the horizontal; a ramp.

Angle of incline (θ)

The angle between the inclined surface and the horizontal.

Parallel component

The part of weight acting along the ramp surface; $W_{\parallel} = mg\sin\theta$.

Perpendicular component

The part of weight acting perpendicular to the ramp; $W_{\perp} = mg\cos\theta$.

Component resolution

Breaking a vector into perpendicular parts using trigonometry.

Normal force (on incline)

Force perpendicular to ramp surface; equals $mg\cos\theta$ on incline.

FORMULAS

Formula Name	Formula	Variables and Units
Parallel Component	$W_{\parallel} = mg\sin\theta$	$W_{\parallel}$ = component parallel to ramp (N), m = mass (kg), g = 9.8 m/s², θ = angle of incline (degrees)
Perpendicular Component	$W_{\perp} = mg\cos\theta$	$W_{\perp}$ = component perpendicular to ramp (N), m = mass (kg), g = 9.8 m/s², θ = angle of incline (degrees)
Normal Force on Incline	$N = mg\cos\theta$	N = normal force (N), m = mass (kg), g = 9.8 m/s², θ = angle (degrees)
Friction on Incline	$f = \mu N$	f = friction force (N), μ = coefficient of friction, N = normal force (N)
Acceleration (frictionless)	$a = g\sin\theta$	a = acceleration down ramp (m/s²), g = 9.8 m/s², θ = angle (degrees)

Module 4. Conservation Laws

4.1 Momentum and Impulse

VOCABULARY

Momentum

The product of an object's mass and velocity ($p = mv$); a vector quantity that measures an object's motion.

Impulse

The change in momentum of an object; also equal to the product of force and time interval ($J = F\Delta t$).

Impulse-Momentum Theorem

The principle stating that impulse equals the change in momentum: $F\Delta t = \Delta p$.

Vector Quantity

A physical quantity that has both magnitude and direction (like momentum, velocity, and force).

Change in Momentum

The difference between final and initial momentum: $\Delta p = p_f - p_i = mv_f - mv_i$.

Average Force

The constant force that would produce the same impulse as a varying force over a given time interval.

Newton-second (N·s)

The SI unit of impulse, equivalent to kg·m/s.

Kilogram-meter per second (kg·m/s)

The SI unit of momentum.

FORMULAS

Formula Name	Formula	Variables and Units
Momentum	$p = mv$	p = momentum (kg·m/s), m = mass (kg), v = velocity (m/s)
Impulse	$J = F\Delta t$	J = impulse (N·s or kg·m/s), F = average force (N), Δt = time interval (s)
Change in Momentum	$\Delta p = mv_f - mv_i$	Δp = change in momentum (kg·m/s), m = mass (kg), v_f = final velocity (m/s), v_i = initial velocity (m/s)
Impulse-Momentum Theorem	$F\Delta t = \Delta p$	Force × time interval equals change in momentum

4.2 Conservation of Momentum in One Dimension

VOCABULARY

Conservation of Momentum

The principle that total momentum in an isolated system remains constant before and after a collision or interaction.

Isolated System

A system in which no net external force acts; only internal forces between objects within the system are present.

Internal Forces

Forces that objects within a system exert on each other; these do not change the total momentum of the system.

External Forces

Forces acting on the system from outside; these can change the total momentum of the system.

One-Dimensional Collision

A collision where all motion occurs along a single straight line.

Recoil

The backward motion of an object when it expels or releases another object (like a gun firing a bullet).

Total Momentum

The vector sum of the momenta of all objects in a system.

FORMULAS

Formula Name	Formula	Variables and Units
Conservation of Momentum (General)	$p_{\text{before}} = p_{\text{after}}$	p = momentum (kg·m/s)
Conservation of Momentum (Two Objects)	$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$	m_1, m_2 = masses (kg), v_{1i}, v_{2i} = initial velocities (m/s), v_{1f}, v_{2f} = final velocities (m/s)
Explosion from Rest	$m_1 v_{1f} + m_2 v_{2f} = 0$	Two objects separate in opposite directions; total momentum is zero

4.3 Elastic and Inelastic Collisions

VOCABULARY

Elastic Collision

A collision in which both momentum and kinetic energy are conserved; objects bounce apart.

Inelastic Collision

A collision in which momentum is conserved but kinetic energy is not; some KE is converted to other forms.

Perfectly Inelastic Collision

A collision in which objects stick together after impact, moving with a common final velocity; maximum KE loss.

Kinetic Energy

Energy of motion, calculated as $KE = \frac{1}{2}mv^2$.

Energy Transformation

The conversion of energy from one form to another (e.g., kinetic to thermal).

Deformation Energy

Energy used to permanently change the shape of an object during a collision.

Coefficient of Restitution

A measure of how "bouncy" a collision is; ranges from 0 (perfectly inelastic) to 1 (perfectly elastic).

FORMULAS

Formula Name	Formula	Variables and Units
Kinetic Energy	$$KE = \frac{1}{2}mv^2$$	KE = kinetic energy (J), m = mass (kg), v = speed (m/s)
Elastic Collision (Momentum)	$$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$$	Momentum is conserved
Elastic Collision (KE)	$$\frac{1}{2}m_1v_{1i}^2 + \frac{1}{2}m_2v_{2i}^2 = \frac{1}{2}m_1v_{1f}^2 + \frac{1}{2}m_2v_{2f}^2$$	Kinetic energy is conserved
Perfectly Inelastic Collision	$$m_1v_{1i} + m_2v_{2i} = (m_1 + m_2)v_f$$	Objects stick together with common final velocity

4.4 Potential Energy

VOCABULARY

Potential Energy

Energy stored in a system due to the position or configuration of objects.

Gravitational Potential Energy

Energy stored due to an object's position in a gravitational field; calculated as $PE = mgh$.

Reference Point

The chosen location where potential energy is defined as zero ($h = 0$).

Height (h)

Vertical distance above the reference point.

Gravitational Field

The region around a massive object where gravitational force is exerted.

Work

Energy transferred when a force moves an object; equal to $F \cdot d$ when force and displacement are in the same direction.

Joule (J)

The SI unit of energy; 1 J = 1 kg·m^2/s^2.

FORMULAS

Formula Name	Formula	Variables and Units
Gravitational Potential Energy	$PE = mgh$	PE = potential energy (J), m = mass (kg), g = 9.8 m/s^2 (on Earth), h = height (m)
Change in Potential Energy	$\Delta PE = mg\Delta h$	ΔPE = change in PE (J), Δh = change in height (m)
Weight	$W = mg$	W = weight/gravitational force (N), m = mass (kg), g = 9.8 m/s^2
Work	$W = F \cdot d$	W = work (J), F = force (N), d = displacement (m)

4.5 Kinetic Energy and Conservation of Energy

VOCABULARY

Kinetic Energy

Energy of motion; $KE = \frac{1}{2}mv^2$.

Conservation of Energy

Energy cannot be created or destroyed, only transformed between forms.

Mechanical Energy

Sum of kinetic and potential energy in a system.

Energy Transformation

The conversion of energy from one form to another.

Isolated System

A system with no external forces doing work; mechanical energy is conserved.

FORMULAS

Formula Name	Formula	Variables and Units
Kinetic Energy	$KE = \frac{1}{2}mv^2$	KE = kinetic energy (J), m = mass (kg), v = speed (m/s)
Potential Energy	$PE = mgh$	PE = potential energy (J), m = mass (kg), g = 9.8 m/s², h = height (m)
Conservation of Mechanical Energy	$PE_i + KE_i = PE_f + KE_f$	Subscript i = initial, subscript f = final; all energies in joules (J)
Total Mechanical Energy	$E = PE + KE$	E = total mechanical energy (J)
Energy Conservation	$E_{\text{total}} = PE + KE = \text{constant}$	Total mechanical energy remains constant in isolated systems

Module 5. Harmonic Motion, Waves, and Sound

5.1 Introduction to Simple Harmonic Motion

VOCABULARY

Oscillation

Repeating motion around a central position.

Simple Harmonic Motion (SHM)

The repetitive back-and-forth movement of an object through an equilibrium position, where the restoring force is directly proportional to the displacement from equilibrium.

Equilibrium Position

The central resting position where the net force on an object is zero and the object would remain at rest if not disturbed.

Displacement

The distance and direction of an object from its equilibrium position, measured in meters (m).

Restoring Force

The force that acts to bring an oscillating object back toward its equilibrium position; it always points toward equilibrium.

Periodic Motion

Motion that repeats in a regular cycle.

Amplitude (A)

The maximum displacement from equilibrium position, measured in meters (m). This represents how far the object moves from center to its farthest point.

Period (T)

The time required for one complete cycle of motion, measured in seconds (s). One complete cycle means going from a starting point, through all positions, and back to the starting point moving in the same direction.

Frequency (f)

The number of complete cycles per second, measured in hertz (Hz) or cycles per second (1 Hz = 1 cycle/s).

Hooke's Law

The principle that the restoring force of a spring is proportional to its displacement: $F = -kx$.

Spring Constant (k)

A measure of a spring's stiffness, measured in newtons per meter (N/m). A larger spring constant means a stiffer spring that requires more force to stretch or compress.

Simple Pendulum

A mass (called a bob) suspended from a fixed point by a string or rod of negligible mass; exhibits simple harmonic motion for small angles.

FORMULAS

Formula Name	Formula	Variables and Units
Frequency-Period Relationship	$f = \frac{1}{T}$	f = frequency (Hz), T = period (s)
Hooke's Law	$F = -kx$	F = restoring force (N), k = spring constant (N/m), x = displacement (m)
Period of Mass-Spring System	$T = 2\pi\sqrt{\frac{m}{k}}$	T = period (s), m = mass (kg), k = spring constant (N/m)
Period of Simple Pendulum	$T = 2\pi\sqrt{\frac{L}{g}}$	T = period (s), L = length (m), g = 9.8 m/s^2

5.2 Transverse Waves

VOCABULARY

Wave

A disturbance that transfers energy from one place to another without permanently transferring matter.

Transverse Wave

A wave in which the particles of the medium move perpendicular (at right angles) to the direction of wave propagation.

Medium

The material substance through which a wave travels. For mechanical waves, a medium is required; electromagnetic waves can travel through empty space.

Propagation

The movement or spreading of a wave through space or a medium.

Crest

The highest point of a wave above the equilibrium position; represents maximum positive displacement.

Trough

The lowest point of a wave below the equilibrium position; represents maximum negative displacement.

Wavelength (λ)

The distance between two consecutive corresponding points on a wave, such as crest to crest or trough to trough, measured in meters (m). Represented by the Greek letter lambda (λ).

Wave Speed

The speed at which the wave pattern travels through the medium, measured in meters per second (m/s).

Electromagnetic Wave

A transverse wave consisting of oscillating electric and magnetic fields that can travel through empty space; includes visible light, radio waves, and X-rays.

FORMULAS

Equation Name	Formula	Variables and Units
Frequency-Period Relationship	$f = \frac{1}{T}$	f = frequency (Hz), T = period (s)
Wave Equation	$v = f\lambda$	v = wave speed (m/s), f = frequency (Hz), λ = wavelength (m)
Wave Speed (Alternative)	$v = \frac{\lambda}{T}$	v = wave speed (m/s), λ = wavelength (m), T = period (s)

5.3 Longitudinal Waves

VOCABULARY

Longitudinal Wave

A wave in which particles oscillate parallel to the direction of wave propagation.

Compression

A region in a longitudinal wave where particles are pushed closer together than normal, creating higher density and higher pressure.

Rarefaction

A region in a longitudinal wave where particles are pulled farther apart than normal, creating lower density and lower pressure.

Sound Wave

A longitudinal wave of pressure variations that travels through a medium by creating compressions and rarefactions.

Mechanical Wave

A wave that requires a physical medium (matter) to travel through; cannot propagate through a vacuum.

Ultrasound

Sound waves with frequencies above the range of human hearing (above 20,000 Hz); used in medical imaging and other applications.

Infrasound

Sound waves with frequencies below the range of human hearing (below 20 Hz); produced by earthquakes, ocean waves, and large animals.

FORMULAS

Equation Name	Formula	Variables and Units
Wave Equation	$v = f\lambda$	v = wave speed (m/s), f = frequency (Hz), λ = wavelength (m)
Frequency-Period Relationship	$f = \frac{1}{T}$	f = frequency (Hz), T = period (s)
Distance from Echo Time	$d = vt$	d = distance (m), v = wave speed (m/s), t = time (s)

5.4 Wave Properties and Behavior

VOCABULARY

Reflection

The bouncing back of a wave when it strikes a boundary or obstacle.

Incident Wave

The wave traveling toward a surface or boundary.

Reflected Wave

The wave bouncing back from a surface or boundary.

Normal Line

A line perpendicular to a surface, used as a reference for measuring angles of incidence and reflection.

Angle of Incidence

The angle between the incident wave and the normal line to a surface.

Angle of Reflection

The angle between the reflected wave and the normal line to a surface.

Law of Reflection

The principle that the angle of incidence equals the angle of reflection, both measured from the normal line to a surface.

Specular Reflection

Reflection from a smooth surface where all reflected rays are parallel to each other.

Diffuse Reflection

Reflection from a rough surface where reflected rays scatter in many different directions.

Refraction

The bending of a wave as it passes from one medium to another due to a change in wave speed.

Index of Refraction (n)

A dimensionless number that describes how much a medium slows down light or other waves compared to vacuum; higher values mean slower wave speed.

Snell's Law

The mathematical relationship between angles and indices of refraction when a wave enters a different medium: $n_1 \sin \theta_1 = n_2 \sin \theta_2$.

Diffraction

The spreading of a wave around obstacles and through openings; more pronounced when wavelength is large compared to the obstacle size.

Diffraction Pattern

The pattern of wave intensity created when a wave spreads around an obstacle or through an opening.

Interference

The combination of two or more waves that interact and produce a new wave pattern; can result in reinforcement (constructive) or cancellation (destructive).

Superposition

The principle that when two waves overlap, the resultant displacement at any point is the sum of the displacements from each wave.

Constructive Interference

Occurs when waves arrive with crests aligned with crests (in phase); amplitudes add, producing a larger combined amplitude.

Destructive Interference

Occurs when waves arrive with crests aligned with troughs (out of phase by 180 degrees); amplitudes subtract, potentially resulting in zero amplitude.

Phase

The position of a wave relative to a reference point; determines whether waves arriving at the same point interfere constructively or destructively.

Standing Wave

A wave pattern that appears to stand still rather than propagate, formed when incident and reflected waves interfere at specific frequencies.

Node

A point of zero amplitude in a standing wave where destructive interference always occurs; particles at nodes do not move.

Antinode

A point of maximum amplitude in a standing wave where constructive interference occurs; particles at antinodes oscillate with maximum displacement.

FORMULAS

Equation Name	Formula	Variables and Units
Law of Reflection	$\theta_i = \theta_r$	θ_i = angle of incidence (degrees), θ_r = angle of reflection (degrees)
Snell's Law	$n_1 \sin\theta_1 = n_2 \sin\theta_2$	n = index of refraction (unitless), θ = angle from normal (degrees)
Constructive Interference	Path difference = $n\lambda$	n = 0, 1, 2, 3... (integer), λ = wavelength (m)
Destructive Interference	Path difference = $(n + \frac{1}{2})\lambda$	n = 0, 1, 2, 3... (integer), λ = wavelength (m)

5.5 Sound Waves

VOCABULARY

Sound

A longitudinal mechanical wave consisting of pressure variations that travel through a medium.

Pitch

The perceived highness or lowness of a sound; directly related to frequency (high frequency = high pitch).

Loudness

The perceived intensity of sound; related to amplitude and the amount of energy the wave carries.

Timbre

The quality or color of a sound that distinguishes different sources; related to the combination of frequencies (harmonics) present.

Audible Range

The range of sound frequencies detectable by humans, approximately 20 Hz to 20,000 Hz (20 kHz); varies with age.

Doppler Effect

The change in observed frequency of a wave when the source and observer are moving relative to each other; frequency increases when approaching and decreases when receding.

Harmonic

A frequency component of a complex sound that is a whole-number multiple of the fundamental frequency; contributes to the timbre of an instrument.

Fundamental Frequency

The lowest frequency at which an object vibrates naturally; determines the basic pitch of the sound produced by an instrument.

Intensity

The power per unit area carried by a wave, measured in watts per square meter (W/m^2); related to how loud a sound is perceived.

Decibel (dB)

A logarithmic unit used to measure sound intensity and loudness; based on a reference level (threshold of hearing at 0 dB).

FORMULAS

Equation Name	Formula	Variables and Units
Wave Equation	$v = f\lambda$	v = wave speed (m/s), f = frequency (Hz), λ = wavelength (m)
Speed of Sound in Air	$v = 331 + 0.6T$	v = speed (m/s), T = temperature ($^\circ$C)
Doppler Effect (Moving Source)	$f_{obs} = f_{source}\left(\frac{v_{sound}}{v_{sound} \mp v_{source}}\right)$	f = frequency (Hz), v = speed (m/s); use $-$ for approaching, $+$ for receding
Fundamental Frequency (String)	$f_1 = \frac{v}{2L}$	f_1 = fundamental frequency (Hz), v = wave speed on string (m/s), L = string length (m)

Module 6. Optics

6.1 Reflection and the Law of Reflection

VOCABULARY

Light
A form of electromagnetic energy that travels through space and allows us to see objects.

Ray
A straight line with an arrow that represents the direction light is traveling.

Speed of Light (c)
The speed at which light travels through empty space, approximately 3×10^8 m/s.

Ray Model
A simplified way of representing light as straight lines (rays) traveling in specific directions.

Reflection
The bouncing of light off a surface when light strikes it.

Reflecting Surface
The surface off which light bounces.

Normal
An imaginary line perpendicular (at a 90-degree angle) to the reflecting surface at the point where light hits it.

Angle of Incidence (θ_1)
The angle between the incoming light ray and the normal.

Angle of Reflection (θ_2)
The angle between the reflected light ray and the normal.

Incident Ray
The light ray traveling toward the reflecting surface.

Reflected Ray

The light ray bouncing away from the reflecting surface.

Law of Reflection

The principle that the angle of incidence equals the angle of reflection, both measured from the normal line.

Ray Diagram

A diagram showing the path of light rays, used to solve reflection problems.

Specular Reflection

Reflection from a smooth, shiny surface like a mirror where all light rays reflect in the same direction, creating a clear reflection.

Diffuse Reflection

Reflection from a rough, bumpy surface where light rays scatter in many different directions and no clear reflection is visible.

FORMULAS

Concept	Equation/Definition	Variables
Law of Reflection	$\theta_1 = \theta_2$	θ_1 = angle of incidence (degrees), θ_2 = angle of reflection (degrees)
Angle Conversion	$\theta_{normal} = 90^\circ - \theta_{surface}$	θ_normal = angle from normal, θ_surface = angle from surface

6.2 Refraction and Snell's Law

VOCABULARY

Refraction

The bending of light when it passes from one material to another due to a change in wave speed.

Optical Density

A property of a material related to its refractive index; high optical density means light travels slowly through it.

Refractive Index (n)

A dimensionless number that describes how much a medium slows down light compared to vacuum; $n = c/v$.

Snell's Law

The mathematical relationship between angles of incidence and refraction and refractive indices: $n_1 \sin\theta_1 = n_2 \sin\theta_2$.

Interface

The boundary between two different materials through which light passes.

FORMULAS

Equation Name	Formula	Variables and Units
Refractive Index	$n = \frac{c}{v}$	c = speed of light in vacuum (3×10^8 m/s), v = speed of light in material (m/s)
Snell's Law	$n_1 \sin\theta_1 = n_2 \sin\theta_2$	n = refractive index (unitless), θ = angle from normal (degrees)

6.3 Total Internal Reflection

VOCABULARY

Critical Angle (θc)

The angle of incidence at which the angle of refraction becomes 90°. Beyond this angle, total internal reflection occurs.

Total Internal Reflection

The complete reflection of light back into a more optically dense material when light hits the interface with a less dense material at an angle greater than the critical angle.

FORMULAS

Equation Name	Formula	Variables and Units
Critical Angle	$\sin\theta_c = \frac{n_2}{n_1}$	θc = critical angle (degrees), n_1 = denser material, n_2 = less dense material
Critical Angle (Alternative)	$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$	Same as above

6.4 Mirrors: Plane, Concave, and Convex

VOCABULARY

Plane Mirror

A flat, reflective surface that produces virtual, upright images of the same size as the object.

Virtual Image

An image formed at a location where light does not actually travel; appears behind a mirror.

Upright

Image orientation property where the image is right-side up (not inverted).

Same Size

Image property where the image is the same size as the object.

Curved Mirrors

Mirrors whose surfaces are part of a sphere; includes concave and convex mirrors.

Concave Mirrors

Curved mirrors that curve inward (like a spoon); also called converging mirrors because they bring light rays together.

Convex Mirrors

Curved mirrors that curve outward (like the back of a spoon); also called diverging mirrors because they spread light rays apart.

Focal Point (F)

The point where parallel light rays converge after reflection from a concave mirror.

Center of Curvature (C)

The center of the sphere of which a curved mirror is a part.

Focal Length (f)

The distance from a mirror to its focal point; for a curved mirror, $f = R/2$ where R is radius of curvature.

FORMULAS

Formula Name	Formula	Variables and Units
Mirror Equation	$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$	f = focal length, d_o = object distance, d_i = image distance
Magnification	$M = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$	M = magnification, h_o = object height, h_i = image height
Focal Length and Radius	$f = \frac{R}{2}$	f = focal length, R = radius of curvature

6.5 Lenses: Double Convex and Double Concave

VOCABULARY

Double Convex Lenses

Lenses that are thicker in the middle and thinner at the edges; also called converging lenses because they bend light rays toward each other.

Converging Lenses

Lenses that bend light rays toward each other, causing them to converge at a focal point; have positive focal length.

Double Concave Lenses

Lenses that are thinner in the middle and thicker at the edges; also called diverging lenses because they bend light rays away from each other.

Diverging Lenses

Lenses that bend light rays away from each other, causing them to diverge; have negative focal length and always produce virtual images.

FORMULAS

Formula Name	Formula	Variables and Units
Lens Equation	$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$	f = focal length, d_o = object distance, d_i = image distance
Magnification (Lenses)	$M = \frac{d_i}{d_o} = \frac{h_i}{h_o}$	M = magnification, h_o = object height, h_i = image height

Module 7. Intro to Electricity

7.1 Electric Charge and Electric Force

VOCABULARY

Static electricity

Electric charge at rest; the buildup of charge on objects.

Electric charge

A fundamental property of matter that causes objects to experience force in an electromagnetic field.

Positive charge

Electric charge carried by protons; has charge of +e.

Negative charge

Electric charge carried by electrons; has charge of −e.

Elementary charge

The magnitude of charge on a single proton or electron; $e = 1.60 \times 10^{-19}$ C.

Coulomb (C)

The SI unit of electric charge.

Coulomb's Law

The equation describing the electric force between two point charges: $F_e = k\frac{|q_1 q_2|}{r^2}$.

Point charge

An idealized charged object treated as a single point in space.

Law of Electric Charges

Like charges repel; opposite charges attract.

Repulsion

The force pushing two like charges apart.

Attraction

The force pulling two opposite charges together.

FORMULAS

Formula Name	Formula	Variables and Units
Coulomb's Law	$F_e = k\frac{\lvert q_1 q_2 \rvert}{r^2}$	F_e = electric force (N), $k = 8.99 \times 10^9$ N·m²/C², q_1, q_2 = charges (C), r = distance (m)
Elementary Charge	$e = 1.60 \times 10^{-19}$ C	e = magnitude of charge on proton or electron (C)

7.2 Electric Fields and Voltage

VOCABULARY

Electric field

The region around a charged object where electric force is exerted on other charges.

Electric field lines

Lines that show the direction and strength of the electric field; always point away from positive charges and toward negative charges.

Dipole

A pair of equal and opposite charges separated by a distance.

Uniform electric field

An electric field with the same strength and direction at every point.

Electric potential energy

Energy stored due to the position of a charge in an electric field.

Voltage

The potential difference per unit charge; energy per coulomb; measured in volts (V).

Volt (V)

The SI unit of voltage; 1 V = 1 J/C.

Potential difference

The difference in electric potential between two points; voltage between two points.

FORMULAS

Formula Name	Formula	Variables and Units
Electric Field Strength	$E = \frac{F_e}{q}$	E = electric field (N/C or V/m), F_e = electric force (N), q = charge (C)
Force from Electric Field	$F_e = qE$	F_e = electric force (N), q = charge (C), E = electric field (N/C)
Electric Potential (Voltage)	$V = \frac{U_e}{q}$	V = voltage (V), U_e = electric potential energy (J), q = charge (C)
Work and Voltage	$W = qV$	W = work done (J), q = charge (C), V = voltage difference (V)
Field-Voltage Relationship (Uniform Field)	$E = \frac{V}{d}$	E = electric field (V/m), V = voltage difference (V), d = distance (m)

7.3 Current, Power Sources, and Measurement

VOCABULARY

Electric current

The flow of electric charge through a conductor; measured in amperes (A).

Ampere (A)

The SI unit of electric current; 1 A = 1 C/s.

Drift velocity

The average velocity of charge carriers (electrons) moving through a conductor.

Conventional current

The flow of positive charge (opposite to electron flow direction).

Power source

A device that provides electrical energy (e.g., battery, solar cell).

Chemical cell

A device that converts chemical energy into electrical energy through a chemical reaction.

Electrodes

The terminals of a power source where current enters or leaves.

Electrolyte

A substance in a chemical cell that allows ions to move and conduct current.

Photoelectric effect

The emission of electrons from a material when light shines on it.

Voltmeter

An instrument that measures voltage between two points.

Ammeter

An instrument that measures electric current.

Multimeter

A device that can measure voltage, current, and resistance.

FORMULAS

Formula Name	Formula	Variables and Units
Electric Current	$I = \frac{Q}{t}$	I = current (A), Q = charge (C), t = time (s)
Charge from Current	$Q = I \cdot t$	Q = charge (C), I = current (A), t = time (s)
Electrical Energy	$E = QV$	E = energy (J), Q = charge (C), V = voltage (V)

7.4 Ohm's Law and Circuit Analysis

VOCABULARY

Resistance

Opposition to the flow of electric current; measured in ohms (Ω).

Ohm (Ω)

The SI unit of electrical resistance; 1 Ω = 1 V/A.

Ohm's Law

The relationship stating that voltage equals current times resistance: $V = IR$.

Series circuit

A circuit in which components are connected one after another in a single path.

Parallel circuit

A circuit in which components are connected along multiple paths.

Insulator

A material with very high resistance that does not conduct electricity well.

Conductor

A material with low resistance that conducts electricity easily (e.g., copper, aluminum).

FORMULAS

Formula Name	Formula	Variables and Units
Ohm's Law	$V = IR$	V = voltage (V), I = current (A), R = resistance (Ω)
Ohm's Law (solving for I)	$I = \frac{V}{R}$	I = current (A), V = voltage (V), R = resistance (Ω)
Ohm's Law (solving for R)	$R = \frac{V}{I}$	R = resistance (Ω), V = voltage (V), I = current (A)
Series Resistance	$R_{\text{total}} = R_1 + R_2 + R_3 + \cdots$	All resistances in ohms (Ω)
Parallel Resistance	$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$	All resistances in ohms (Ω)
Two Resistors in Parallel	$R_{\text{total}} = \frac{R_1 \times R_2}{R_1 + R_2}$	All resistances in ohms (Ω)

7.5 Energy, Efficiency, and Circuit Design

VOCABULARY

Electrical power

The rate at which electrical energy is transferred; measured in watts (W).

Watt (W)

The SI unit of power; 1 W = 1 J/s.

Kilowatt (kW)

1000 watts; used for larger power quantities.

Electrical energy

Energy transferred by electric current; measured in joules (J) or kilowatt-hours (kWh).

Kilowatt-hour (kWh)

A unit of energy equal to 1000 watts × 3600 seconds; commonly used for household electricity billing.

Efficiency

The ratio of useful energy output to total energy input; expressed as a percentage.

Solar cell

A device that converts light energy directly into electrical energy using the photoelectric effect.

FORMULAS

Formula Name	Formula	Variables and Units
Electrical Power	$P = IV$	P = power (W), I = current (A), V = voltage (V)
Power (using resistance)	$P = I^2R$	P = power (W), I = current (A), R = resistance (Ω)
Power (using voltage)	$P = \frac{V^2}{R}$	P = power (W), V = voltage (V), R = resistance (Ω)
Electrical Energy	$E = Pt$	E = energy (J or kWh), P = power (W or kW), t = time (s or h)
Cost of Electricity	$\text{Cost} = \text{Energy (kWh)} \times \text{Price per kWh}$	Energy in kWh, Price in $/kWh
Efficiency	$\eta = \frac{\text{Useful Energy Out}}{\text{Total Energy In}} \times 100\%$	η = efficiency (%), expressed as percentage

Module 8. Electric Circuits

8.1 Energy Transfer in Electric Circuits

VOCABULARY

Electric charge

A fundamental property of matter; measured in coulombs (C).

Electric current

The flow of electric charge through a conductor; measured in amperes (A).

Voltage

The potential difference that drives electric current; measured in volts (V).

Resistance

Opposition to the flow of electric current; measured in ohms (Ω).

Chemical cells and batteries

Devices that convert chemical energy into electrical energy to power circuits.

Solar cells

Devices that convert light energy directly into electrical energy.

Electrical power

The rate at which electrical energy is transferred; measured in watts (W).

Electrical energy

Energy transferred by electric current; measured in joules (J) or kilowatt-hours (kWh).

FORMULAS

Formula Name	Formula	Variables and Units
Electric Current	$I = \frac{Q}{t}$	I = current (A), Q = charge (C), t = time (s)
Voltage	$V = \frac{E}{Q}$	V = voltage (V), E = energy (J), Q = charge (C)
Electrical Power	$P = IV$	P = power (W), I = current (A), V = voltage (V)
Power (Resistance Form)	$P = I^2 R$	P = power (W), I = current (A), R = resistance (Ω)
Power (Voltage Form)	$P = \frac{V^2}{R}$	P = power (W), V = voltage (V), R = resistance (Ω)
Electrical Energy	$E = Pt$	E = energy (J), P = power (W), t = time (s)

8.2 Measuring and Analyzing Circuit Behavior

VOCABULARY

Multimeter

An instrument that can measure voltage, current, and resistance in circuits.

Ohmic materials

Materials that obey Ohm's Law; resistance remains constant over a range of voltages.

Resistance measurement

The process of using an ohmmeter to determine the resistance of a component or circuit.

FORMULAS

Formula Name	Formula	Variables and Units
Ohm's Law (Standard Form)	$V = IR$	V = voltage (V), I = current (A), R = resistance (Ω)
Ohm's Law (Current Form)	$I = \frac{V}{R}$	I = current (A), V = voltage (V), R = resistance (Ω)
Ohm's Law (Resistance Form)	$R = \frac{V}{I}$	R = resistance (Ω), V = voltage (V), I = current (A)

8.3 Series and Parallel Circuits

VOCABULARY

Series circuit

A circuit in which components are connected one after another in a single path; current is same everywhere.

Parallel circuit

A circuit in which components are connected along multiple paths; voltage is same across all branches.

FORMULAS

Circuit Type	Formula	Description
Series Current	$I_{\text{total}} = I_1 = I_2 = I_3$	Current is same everywhere in series circuit
Series Voltage	$V_{\text{total}} = V_1 + V_2 + V_3$	Voltages add up in series circuit
Series Resistance	$R_{\text{total}} = R_1 + R_2 + R_3$	Resistances add directly in series
Parallel Voltage	$V_1 = V_2 = V_3$	Voltage is same across all branches in parallel
Parallel Current	$I_{\text{total}} = I_1 + I_2 + I_3$	Currents add up in parallel circuit
Parallel Resistance	$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$	Reciprocals add in parallel

8.4 Complex Circuit Analysis

VOCABULARY

Complex circuits

Circuits that combine series and parallel sections; requires systematic analysis using equivalent resistance.

FORMULAS

Quantity	Formula	When to Use
Equivalent Resistance (Series)	$R_{\text{eq}} = R_1 + R_2 + R_3$	For components in series
Equivalent Resistance (Parallel)	$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$	For components in parallel
Total Current	$I_{\text{total}} = \frac{V}{R_{\text{total}}}$	After finding equivalent resistance
Voltage Drop (Series)	$V = IR$	For individual components in series
Branch Current (Parallel)	$I = \frac{V}{R}$	For individual branches in parallel
Power in Component	$P = IV = I^2R = \frac{V^2}{R}$	To verify component safety limits

8.5 Capacitors and Practical Applications

VOCABULARY

Capacitor

A device that stores electrical energy in an electric field between two plates.

Capacitance

The ability of a capacitor to store charge; measured in farads (F).

Farad (F)

The SI unit of capacitance; 1 F = 1 C/V.

Time constant

The time it takes for a capacitor to charge to 63% (or discharge to 37%) of its final value; $\tau = RC$.

FORMULAS

Quantity	Formula	Variables and Units
Capacitance	$C = \frac{Q}{V}$	C = capacitance (F), Q = charge (C), V = voltage (V)
Energy Stored	$E = \frac{1}{2}CV^2$	E = energy (J), C = capacitance (F), V = voltage (V)
Energy (Alternative)	$E = \frac{1}{2}QV$	E = energy (J), Q = charge (C), V = voltage (V)
Time Constant	$\tau = RC$	τ = time constant (s), R = resistance (Ω), C = capacitance (F)