Physics Module Outlines and Learning Ladders

Module Outline 01: Introduction to Physics

Essential Standard

Students will understand the nature and scope of physics, apply the scientific method to investigations, perform accurate measurements using SI units, use mathematical tools to solve problems, and work with vectors both graphically and analytically.

Section 1: Scope of Physics

Learning Objectives - I can...

- Define physics and describe what physics studies, distinguishing it from other sciences.
- Identify the major branches of physics (mechanics, thermodynamics, waves/optics, electromagnetism, modern physics, astrophysics) and give examples of what each branch studies.
- Explain how physics connects to other sciences and everyday life, providing specific real-world examples.

Section 2: The Scientific Method

Learning Objectives - I can...

- Describe the steps of the scientific method (observation, hypothesis, experiment, analysis, conclusion) and explain the purpose of each step.
- Develop testable hypotheses based on observations and distinguish between hypotheses, theories, and scientific laws.
- Design simple experiments to test hypotheses, identifying independent variables, dependent variables, and controlled variables.

Section 3: Scientific Measurement and Math Tools

Learning Objectives - I can...

- Perform accurate scientific measurements using appropriate SI units (meter, kilogram, second, etc.) and metric prefixes (kilo-, centi-, milli-, etc.).
- Convert between different units using conversion factors and dimensional analysis.
- Express measurements using scientific notation and apply rules for significant figures in calculations.

Section 4: Vectors and Vector Components

Learning Objectives - I can...

- Distinguish between scalar quantities (magnitude only) and vector quantities (magnitude and direction), providing examples of each.
- Represent vectors graphically using arrows with proper scale, showing both magnitude and direction.
- Resolve vectors into perpendicular components (x and y) using trigonometric functions (sine, cosine, tangent).

Section 5: Vector Addition

Learning Objectives - I can...

- Add vectors graphically using the tip-to-tail (head-to-tail) method and the parallelogram method.
- Add vectors analytically by first resolving them into components, then adding corresponding components.
- Calculate the magnitude and direction of the resultant vector from its components using the Pythagorean theorem and inverse tangent.

LEARNING LADDER 01: INTRODUCTION TO PHYSICS

This learning ladder contains 10 rungs aligned with the 8 Science Practices. The bottom 7 rungs represent essential learning that average students should master. The top 3 rungs represent extended learning for advanced students.

Rung	I Can Statement	Science Practice	Level
10	I can design and propose solutions to complex physics problems that require multi-step vector analysis, dimensional analysis, and integration of multiple mathematical techniques.	6. Constructing Explanations & Designing Solutions	Extended
9	I can engage in argument from evidence to support claims about measurement accuracy, experimental design, and the importance of the scientific method in physics.	7. Engaging in Argument from Evidence	Extended
8	I can obtain, evaluate, and communicate information about historical developments in physics and how physics connects to other scientific disciplines.	8. Obtaining, Evaluating & Communicating Information	Extended
7	I can add vectors using graphical methods (tip-to-tail and parallelogram methods) and verify results using analytical methods.	5. Using Mathematics & Computational Thinking	Essential
6	I can resolve vectors into components using trigonometry and apply these skills to solve two-dimensional problems.	5. Using Mathematics & Computational Thinking	Essential
5	I can use mathematical and computational thinking to solve physics problems using algebra, trigonometry, and graphing techniques.	5. Using Mathematics & Computational Thinking	Essential
4	I can analyze and interpret data using significant figures, scientific notation, and proper unit conversions.	4. Analyzing & Interpreting Data	Essential
3	I can perform accurate scientific measurements using appropriate tools and units, including metric prefixes and SI base units.	3. Planning & Carrying Out Investigations	Essential
2	I can develop and use models to represent the scientific method, including forming hypotheses, designing experiments, and drawing conclusions.	2. Developing & Using Models	Essential
1	I can ask questions about the scope of physics and identify what physics studies versus other sciences.	1. Asking Questions & Defining Problems	Essential

Progress Tracking

Students self-assess on each rung using the following scale:
Not Yet: I need more instruction and practice
Getting There: I understand most of it but need more practice
Got It!: I can do this independently

Assessment Methods

Rung 1: Class discussions, questioning, and student-generated questions about physics scope
Rung 2: Scientific method flowcharts, hypothesis-testing plans, experimental design proposals
Rung 3: Laboratory measurement tasks, proper tool selection, unit identification
Rung 4: Data analysis problems with significant figures, scientific notation exercises, unit conversion calculations
Rung 5: Multi-step algebraic problem solving, graphing and interpretation tasks, trigonometric applications
Rung 6: Vector component resolution problems, two-dimensional motion calculations
Rung 7: Graphical vector addition exercises, analytical verification of graphical results
Rung 8: Research presentations on physics history, written summaries connecting physics to other sciences
Rung 9: Written arguments with experimental evidence, debate on measurement techniques and precision
Rung 10: Complex problem-solving project requiring integration of all Module 1 skills

Module Outline 02: Motion in One-Dimension

Essential Standard

Students will master the fundamental concepts of one-dimensional motion by analyzing position, displacement, velocity, and acceleration. They will use mathematical representations, graphical analysis, and kinematic equations to describe and predict the motion of objects moving in a straight line, including objects in free fall under constant gravitational acceleration.

Section 2.1: Position, Displacement, and Distance

Learning Objectives - I can...

- Define position, displacement, and distance and explain the difference between these quantities.
- Use a coordinate system to describe the position of an object along a straight line.
- Calculate displacement and distance traveled for objects moving in one dimension.
- Distinguish between scalar quantities (distance) and vector quantities (displacement).

Section 2.2: Velocity and Speed

Learning Objectives - I can...

- Define average velocity and average speed and explain how they differ.
- Calculate average velocity and average speed using displacement, distance, and time data.
- Define instantaneous velocity and explain how it relates to average velocity.
- Interpret velocity values including direction and sign conventions.

Section 2.3: Acceleration

Learning Objectives - I can...

- Define average acceleration and instantaneous acceleration.
- Calculate average acceleration using changes in velocity and time intervals.
- Explain what it means for an object to have positive, negative, or zero acceleration.
- Describe the motion of objects under constant (uniform) acceleration.

Section 2.4: Kinematic Equations and Free Fall

Learning Objectives - I can...

- Apply the kinematic equations to solve problems involving constant acceleration.
- Analyze free fall motion and calculate displacement, velocity, and time for falling objects.
- Explain why all objects fall at the same rate in the absence of air resistance.
- Select the appropriate kinematic equation based on known and unknown variables.

Section 2.5: Graphical Analysis of Motion

Learning Objectives - I can...

- Create and interpret position vs. time graphs for objects in motion.
- Create and interpret velocity vs. time graphs for objects in motion.
- Determine velocity from the slope of a position vs. time graph.
- Determine acceleration from the slope of a velocity vs. time graph and displacement from the area under a velocity vs. time graph.

LEARNING LADDER 02: MOTION IN ONE-DIMENSION

This learning ladder contains 10 rungs aligned with the 8 Science Practices. The bottom 7 rungs represent essential learning that average students should master. The top 3 rungs represent extended learning for advanced students.

Rung	I Can Statement	Science Practice	Level
10	I can design and test solutions to real-world problems involving motion (such as optimizing braking distance or projectile launch angle) using kinematic principles.	6. Constructing Explanations & Designing Solutions	Extended
9	I can analyze complex motion scenarios involving multiple stages of acceleration and use mathematical reasoning to predict final position and velocity.	5. Using Mathematics & Computational Thinking	Extended
8	I can obtain, evaluate, and communicate information about motion using multiple representations including graphs, equations, diagrams, and written descriptions.	8. Obtaining, Evaluating & Communicating Information	Extended
7	I can analyze experimental data and use evidence to determine whether motion is uniform (constant velocity) or uniformly accelerated (constant acceleration).	7. Engaging in Argument from Evidence	Essential
6	I can construct explanations for why objects in free fall accelerate at the same rate regardless of mass, and predict motion under constant acceleration.	6. Constructing Explanations & Designing Solutions	Essential
5	I can use mathematics to calculate displacement, average velocity, instantaneous velocity, average acceleration, and final velocity using kinematic equations.	5. Using Mathematics & Computational Thinking	Essential
4	I can analyze position vs. time and velocity vs. time graphs to determine displacement, velocity, and acceleration of moving objects.	4. Analyzing & Interpreting Data	Essential
3	I can plan and carry out investigations to collect position and time data for moving objects using measurement tools and technology.	3. Planning & Carrying Out Investigations	Essential
2	I can create and use models (position vs. time graphs and velocity vs. time graphs) to represent the motion of objects moving in one dimension.	2. Developing & Using Models	Essential
1	I can ask questions about how objects move and identify variables that affect motion such as position, velocity, and acceleration.	1. Asking Questions & Defining Problems	Essential

Progress Tracking

Students self-assess on each rung using the following scale:
Not Yet: I need more instruction and practice
Getting There: I understand most of it but need more practice
Got It!: I can do this independently

Assessment Methods

Rung 1: Class discussions, questioning, and student-generated questions about motion
Rung 2: Creation and interpretation of position vs. time and velocity vs. time graphs
Rung 3: Laboratory investigation planning documents and data collection procedures
Rung 4: Graph analysis problems determining displacement, velocity, and acceleration from graphical data
Rung 5: Multi-step calculation problems using kinematic equations in various contexts
Rung 6: Written explanations of free fall motion and predictions for uniformly accelerated motion
Rung 7: Data analysis to classify motion types with evidence-based arguments
Rung 8: Communication project presenting motion analysis using multiple representations
Rung 9: Complex multi-stage motion problems requiring synthesis of multiple concepts
Rung 10: Engineering design project applying kinematic principles to solve real-world problems

Module Outline 03: Forces and Newton's Laws of Motion

Essential Standard

Students will understand and apply Newton's three laws of motion to analyze forces acting on objects, predict motion in various situations including inclined planes and projectile motion, calculate friction and gravitational forces, and use free-body diagrams to solve complex force problems.

Section 3.1: Weight and Gravitational Force

Learning Objectives - I can...

- Define weight as the gravitational force acting on an object and explain how it differs from mass.
- Calculate weight using the equation $W = mg$ and convert between mass and weight.
- Explain how weight changes with location (on different planets or at different altitudes) while mass remains constant.
- Use free-body diagrams to represent the weight force acting on objects.

Section 3.2: Friction

Learning Objectives - I can...

- Describe friction as a force that opposes motion between surfaces in contact.
- Distinguish between static friction and kinetic friction and explain when each type acts.
- Calculate friction forces using the coefficient of friction and the normal force ($f = \mu N$).
- Analyze factors that affect friction, including surface texture and the normal force.

Section 3.3: Connecting Newton's First and Second Laws

Learning Objectives - I can...

- State Newton's First Law of Motion and explain the concept of inertia.
- Apply Newton's Second Law ($F = ma$) to calculate net force, mass, or acceleration in various scenarios.
- Create and analyze free-body diagrams to determine the net force acting on an object.
- Solve multi-step problems involving multiple forces, including weight, friction, applied forces, and tension.

Section 3.4: Newton's Third Law

Learning Objectives - I can...

- State Newton's Third Law and identify action-reaction force pairs in various situations.
- Explain why action-reaction pairs do not cancel each other out despite being equal in magnitude and opposite in direction.
- Apply Newton's Third Law to analyze interactions between objects, including collisions and propulsion.

Section 3.5: Gravitational Force and Inclined Planes

Learning Objectives - I can...

- Resolve the weight force into components parallel and perpendicular to an inclined plane using trigonometry.
- Analyze forces on inclined planes, including the normal force, friction, and weight components.
- Calculate the acceleration of objects sliding down inclined planes with and without friction.
- Apply Newton's Second Law to solve problems involving objects on inclined planes in multiple scenarios.

LEARNING LADDER 03: FORCES AND NEWTON'S LAWS OF MOTION

This learning ladder contains 10 rungs aligned with the 8 Science Practices. The bottom 7 rungs represent essential learning that average students should master. The top 3 rungs represent extended learning for advanced students.

Rung	I Can Statement	Science Practice	Level
10	I can design and test solutions to engineering challenges that apply Newton's laws, such as optimizing projectile trajectories, minimizing friction in mechanical systems, or maximizing safety in collisions.	6. Constructing Explanations & Designing Solutions	Extended
9	I can engage in argument from evidence by analyzing data from projectile motion experiments to support claims about the independence of horizontal and vertical motion components.	7. Engaging in Argument from Evidence	Extended
8	I can obtain, evaluate, and communicate information about how Newton's laws apply to complex real-world systems such as car safety features, rocket propulsion, and athletic performance.	8. Obtaining, Evaluating & Communicating Information	Extended
7	I can plan and conduct investigations to determine how changing force, mass, or angle affects the motion of objects on inclined planes and in projectile motion.	3. Planning & Carrying Out Investigations	Essential
6	I can apply Newton's Third Law to identify action-reaction force pairs and explain how these paired forces affect the motion of interacting objects.	6. Constructing Explanations & Designing Solutions	Essential
5	I can analyze friction forces and calculate the coefficient of friction between surfaces using experimental data.	4. Analyzing & Interpreting Data	Essential
4	I can use Newton's Second Law ($F = ma$) to calculate the net force, mass, or acceleration of an object in various situations.	5. Using Mathematics & Computational Thinking	Essential
3	I can apply Newton's First Law to explain why objects at rest stay at rest and objects in motion stay in motion unless acted upon by an unbalanced force.	6. Constructing Explanations & Designing Solutions	Essential
2	I can create free-body diagrams to model the forces acting on an object and use these models to predict motion.	2. Developing & Using Models	Essential
1	I can ask questions about forces and motion, identifying what causes objects to start moving, stop moving, or change direction.	1. Asking Questions & Defining Problems	Essential

Progress Tracking

Students self-assess on each rung using the following scale:

Not Yet: I need more instruction and practice
Getting There: I understand most of it but need more practice
Got It!: I can do this independently

Assessment Methods

Rung 1: Class discussions, questioning, and student-generated questions about forces and motion
Rung 2: Free-body diagram construction, force vector identification, model-based predictions
Rung 3: Explanatory responses, concept application scenarios, real-world situation analysis
Rung 4: Multi-step calculation problems using Newton's Second Law in various contexts
Rung 5: Laboratory friction investigations, data analysis, coefficient of friction calculations
Rung 6: Action-reaction pair identification, force diagram analysis, conceptual explanations
Rung 7: Laboratory investigations on inclined planes and projectile motion, experimental design and data collection
Rung 8: Research presentations on real-world applications, written analysis of complex systems using Newton's laws
Rung 9: Written argument with experimental evidence, data-driven claims about projectile motion independence
Rung 10: Engineering design project, prototype testing, optimization analysis with justification

Module Outline 04: Conservation Laws

Essential Standard

Students will apply the laws of conservation of momentum and conservation of energy to analyze and predict the outcomes of collisions and energy transformations in physical systems. Students will use mathematical reasoning and problem-solving skills to calculate momentum, impulse, kinetic energy, and potential energy in various scenarios.

Section 4.1: Momentum and Impulse

Learning Objectives - I can...

- Define momentum and explain why it depends on both mass and velocity
- Calculate the momentum of moving objects using the formula $p = mv$
- Explain impulse as the change in momentum and relate it to force and time
- Apply the impulse-momentum theorem to solve problems involving forces acting over time

Section 4.2: Conservation of Momentum in One Dimension

Learning Objectives - I can...

- State the law of conservation of momentum and identify when it applies
- Apply conservation of momentum to predict final velocities after one-dimensional collisions
- Solve collision problems involving two objects moving along a straight line
- Explain why momentum is conserved even when kinetic energy is not

Section 4.3: Elastic and Inelastic Collisions

Learning Objectives - I can...

- Distinguish between elastic and inelastic collisions based on kinetic energy conservation
- Identify perfectly inelastic collisions where objects stick together after impact
- Calculate the final velocity in perfectly inelastic collisions
- Analyze kinetic energy before and after collisions to determine the type of collision

Section 4.4: Potential Energy

Learning Objectives - I can...

- Define gravitational potential energy and explain its relationship to height
- Calculate gravitational potential energy using the formula $PE = mgh$
- Explain how potential energy depends on an object's position in a gravitational field

Section 4.5: Kinetic Energy and Conservation of Energy

Learning Objectives - I can...

- Define kinetic energy and calculate it using the formula $KE = \frac{1}{2}mv^2$
- State the law of conservation of energy and identify when it applies
- Apply conservation of energy to solve problems involving transformations between kinetic and potential energy
- Analyze energy transformations in roller coasters, pendulums, and falling objects

LEARNING LADDER 04: CONSERVATION LAWS

This learning ladder contains 10 rungs aligned with the 8 Science Practices. The bottom 7 rungs represent essential learning that average students should master. The top 3 rungs represent extended learning for advanced students.

Rung	I Can Statement	Science Practice	Level
10	I can use evidence from multiple investigations and data analysis to engage in scientific arguments about whether energy is truly conserved in real-world scenarios where friction and air resistance are present.	7. Engaging in Argument from Evidence	Extended
9	I can obtain, evaluate, and communicate information about how conservation laws apply to real-world systems such as vehicle safety features, sports equipment design, and renewable energy technologies.	8. Obtaining, Evaluating & Communicating Information	Extended
8	I can plan and conduct investigations to test conservation laws by measuring momentum and energy before and after collisions in laboratory experiments.	3. Planning & Carrying Out Investigations	Extended
7	I can use the law of conservation of energy to solve problems involving objects moving between different heights and speeds.	6. Constructing Explanations & Designing Solutions	Essential
6	I can calculate gravitational potential energy and kinetic energy and explain how energy transforms between these forms.	5. Using Mathematics & Computational Thinking	Essential
5	I can distinguish between elastic and inelastic collisions by analyzing kinetic energy before and after the collision.	4. Analyzing & Interpreting Data	Essential
4	I can apply the law of conservation of momentum to predict the final velocities of objects after one-dimensional collisions.	5. Using Mathematics & Computational Thinking	Essential
3	I can calculate momentum and impulse using mathematical formulas and explain how forces change an object's momentum over time.	5. Using Mathematics & Computational Thinking	Essential
2	I can create and use models (diagrams, charts, graphs) to represent momentum and energy in physical systems before and after collisions.	2. Developing & Using Models	Essential
1	I can ask questions about how momentum and energy are conserved in everyday collisions and interactions.	1. Asking Questions & Defining Problems	Essential

Progress Tracking

Students self-assess on each rung using the following scale:
Not Yet: I need more instruction and practice
Getting There: I understand most of it but need more practice
Got It!: I can do this independently

Assessment Methods

Rung 1: Class discussions, questioning, and student-generated questions about conservation in everyday situations
Rung 2: Labeled diagrams, before-and-after collision models, energy bar charts, and momentum vector diagrams
Rung 3: Calculation problems involving momentum and impulse formulas, including multi-step problems
Rung 4: Problem sets applying conservation of momentum to one-dimensional collision scenarios
Rung 5: Data analysis activities comparing kinetic energy before and after collisions, identification of collision types
Rung 6: Calculation problems involving potential energy, kinetic energy, and energy transformations
Rung 7: Multi-step problem solving using conservation of energy with height and velocity changes
Rung 8: Laboratory investigations with data collection, analysis, and error assessment for momentum and energy conservation
Rung 9: Research project on real-world applications with presentation of findings
Rung 10: Written scientific argument with evidence from investigations addressing energy conservation in non-ideal systems

Module Outline 05: Harmonic Motion, Waves, and Sound

Essential Standard

Students will understand the fundamental principles of simple harmonic motion and waves, apply mathematical relationships to analyze wave properties, and explain how sound waves are produced and perceived.

Section 1: Simple Harmonic Motion

Learning Objectives - I can...

- Identify and describe examples of repeating motion in everyday life and explain what causes objects to oscillate.
- Create and use models (diagrams and graphs) to represent the motion of objects undergoing simple harmonic motion, including mass-spring systems and pendulums.
- Apply mathematical relationships ($T = 2\pi\sqrt{(m/k)}$ and $T = 2\pi\sqrt{(L/g)}$) to calculate period and frequency in oscillating systems.

Section 2: Transverse and Longitudinal Waves

Learning Objectives - I can...

- Distinguish between transverse and longitudinal waves by analyzing how particles move relative to the direction of wave travel and provide real-world examples of each type.
- Define wavelength, frequency, period, and amplitude, and explain how these properties describe wave characteristics.
- Use the wave equation ($v = f\lambda$) to calculate wave speed, frequency, or wavelength in various media.

Section 3: Wave Behavior and Properties

Learning Objectives - I can...

- Describe how waves reflect, refract, and diffract when encountering boundaries or obstacles.
- Analyze wave interference patterns and explain how constructive and destructive interference affect the resulting amplitude.
- Plan and conduct investigations to explore wave phenomena such as reflection, refraction, diffraction, and interference.

Section 4: Sound Waves

Learning Objectives - I can...

- Construct explanations for how sound waves are produced, transmitted through different media, and how frequency relates to pitch and amplitude relates to loudness.
- Calculate the speed of sound in various media and compare values across different materials and temperatures.
- Apply the Doppler effect to explain frequency shifts in moving sound sources and predict how relative motion affects perceived pitch.

Section 5: Real-World Applications and Engineering Design

Learning Objectives - I can...

- Obtain, evaluate, and communicate information about real-world applications of sound waves (ultrasound, sonar, musical instruments, noise cancellation) and explain the physics principles involved.
- Design and propose solutions to real-world problems using principles of harmonic motion, wave interference, or sound propagation.
- Use evidence from investigations and mathematical analysis to justify design decisions and explain why certain models are appropriate for specific phenomena.

LEARNING LADDER 05: HARMONIC MOTION, WAVES, AND SOUND

This learning ladder contains 10 rungs aligned with the 8 Science Practices. The bottom 7 rungs represent essential learning that average students should master. The top 3 rungs represent extended learning for advanced students.

Rung	I Can Statement	Science Practice	Level
10	I can design and propose solutions to real-world problems using principles of harmonic motion, wave interference, or sound propagation, evaluating multiple design options and justifying my choices with scientific reasoning.	6. Constructing Explanations & Designing Solutions	Extended
9	I can use evidence from investigations and mathematical analysis to argue why certain models (such as the wave model of sound) are more appropriate than others for explaining specific phenomena.	7. Engaging in Argument from Evidence	Extended
8	I can obtain, evaluate, and communicate information about real-world applications of sound waves (ultrasound, sonar, musical instruments, noise cancellation) and explain the physics principles involved.	8. Obtaining, Evaluating & Communicating Information	Extended
7	I can analyze data from wave interference patterns to determine whether constructive or destructive interference occurred and explain the resulting amplitude changes.	4. Analyzing & Interpreting Data	Essential
6	I can construct explanations for how sound waves are produced, transmitted through different media, and how frequency relates to pitch and amplitude relates to loudness.	6. Constructing Explanations & Designing Solutions	Essential
5	I can plan and conduct investigations to explore how waves reflect, refract, diffract, and interfere with one another, collecting data on wave patterns.	3. Planning & Carrying Out Investigations	Essential
4	I can use mathematics to calculate wave speed, frequency, wavelength, period, and amplitude using the wave equation ($v = f\lambda$) and related formulas.	5. Using Mathematics & Computational Thinking	Essential
3	I can distinguish between transverse and longitudinal waves by analyzing how particles move relative to the direction of wave travel and provide real-world examples of each type.	4. Analyzing & Interpreting Data	Essential
2	I can create and use models (diagrams, graphs) to represent the motion of objects undergoing simple harmonic motion, including mass-spring systems and pendulums.	2. Developing & Using Models	Essential
1	I can identify and describe examples of repeating motion in everyday life and ask questions about what causes objects to oscillate.	1. Asking Questions & Defining Problems	Essential

Progress Tracking

Students self-assess on each rung using the following scale:
Not Yet: I need more instruction and practice
Getting There: I understand most of it but need more practice
Got It!: I can do this independently

Assessment Methods

Rung 1: Class discussions, questioning, and student-generated questions about oscillatory motion in everyday contexts
Rung 2: Labeled diagrams, motion graphs (position vs. time), and physical/computer models of mass-spring and pendulum systems
Rung 3: Wave type identification tasks, comparative diagrams showing particle motion, and real-world application matching activities
Rung 4: Multi-step calculation problems using the wave equation and related formulas ($v = f\lambda$, $f = 1/T$, etc.)
Rung 5: Laboratory investigations of wave reflection, refraction, diffraction, and interference with data collection and analysis
Rung 6: Short-answer explanations of sound wave production and transmission; pitch and loudness relationship problems
Rung 7: Analysis of interference pattern data; identification and explanation of constructive and destructive interference from experimental or simulated results
Rung 8: Research project or presentation on real-world sound applications with explanation of underlying physics principles
Rung 9: Written argument with experimental evidence and mathematical reasoning supporting choice of wave model for specific phenomena
Rung 10: Engineering design project proposing solutions to real-world problems; includes prototype testing, data analysis, and design justification

Module Outline 06: Optics

Essential Standard

Students will understand how light behaves when it interacts with mirrors and lenses, apply mathematical relationships to predict image formation, and explain real-world applications of optical principles in technology and everyday life.

Section 1: Reflection and the Law of Reflection

Learning Objectives - I can...

- Ask questions about how light behaves when it interacts with mirrors and reflective surfaces.
- Create diagrams and ray models to show how light travels in straight lines and how reflection occurs at surfaces.
- Describe the law of reflection and apply it to predict how light reflects from plane mirrors with accuracy.

Section 2: Refraction and Snell's Law

Learning Objectives - I can...

- Explain how light bends when it passes between different materials and why this phenomenon occurs.
- Apply Snell's Law to calculate angles of refraction and predict light bending at interfaces between different media.
- Relate refractive index to the optical density of materials and explain how this affects light propagation.

Section 3: Total Internal Reflection

Learning Objectives - I can...

- Investigate the conditions under which total internal reflection occurs and determine critical angles.
- Apply the critical angle concept to explain total internal reflection and recognize real-world applications.
- Explain how fiber optics technology uses total internal reflection to transmit data and light signals.

Section 4: Mirrors and Image Formation

Learning Objectives - I can...

- Determine the properties and behavior of images formed by plane mirrors, concave mirrors, and convex mirrors.
- Use ray diagrams to predict where images will form in curved mirror systems.
- Apply the mirror equation to calculate image distance, magnification, and other image properties for different mirror types.

Section 5: Lenses and Optical Instruments

Learning Objectives - I can...

- Use lens equations and ray diagrams to determine where images form in converging (convex) and diverging (concave) lenses.
- Compare the properties of lenses to mirrors and explain the similarities and differences in their operation.
- Evaluate and communicate how optical instruments (cameras, telescopes, microscopes) use mirrors and lenses to enhance vision and capture images.

Section 6: Real-World Applications and Engineering Design

Learning Objectives - I can...

- Analyze experimental data and use evidence to argue for the most appropriate model (ray or wave) to explain specific optical phenomena.
- Design and test an optical device (periscope, simple telescope, or laser system) that applies multiple optics principles.
- Use mathematical and scientific reasoning to justify design decisions and optimize optical systems for real-world problem solving.

LEARNING LADDER 06: OPTICS

This learning ladder contains 10 rungs aligned with the 8 Science Practices. The bottom 7 rungs represent essential learning that average students should master. The top 3 rungs represent extended learning for advanced students.

Rung	I Can Statement	Science Practice	Level
10	I can design and test an optical device (periscope, simple telescope, or laser system) that applies multiple optics principles to solve a real-world problem.	6. Constructing Explanations & Designing Solutions	Extended
9	I can analyze experimental data and use evidence to argue for the most appropriate model (ray or wave) to explain specific optical phenomena.	7. Engaging in Argument from Evidence	Extended
8	I can evaluate and communicate how optical instruments (cameras, telescopes, microscopes) use mirrors and lenses to enhance human vision.	8. Obtaining, Evaluating & Communicating Information	Extended
7	I can investigate total internal reflection and determine the critical angle at which it occurs between two media.	3. Planning & Carrying Out Investigations	Essential
6	I can use lens equations and ray diagrams to determine where images form in converging (convex) and diverging (concave) lenses.	5. Using Mathematics & Computational Thinking	Essential
5	I can determine the properties and behavior of images formed by plane mirrors, concave mirrors, and convex mirrors.	4. Analyzing & Interpreting Data	Essential
4	I can explain refraction using Snell's Law and predict how light bends when passing between different materials.	5. Using Mathematics & Computational Thinking	Essential
3	I can describe the law of reflection and apply it to predict how light reflects from plane mirrors.	6. Constructing Explanations	Essential
2	I can create diagrams and models to show how light travels in straight lines and how reflection occurs at surfaces.	2. Developing & Using Models	Essential
1	I can ask questions about how light behaves when it interacts with mirrors and lenses.	1. Asking Questions & Defining Problems	Essential

Progress Tracking

Students self-assess on each rung using the following scale:
Not Yet: I need more instruction and practice
Getting There: I understand most of it but need more practice
Got It!: I can do this independently

Assessment Methods

Rung 1: Class discussions, questioning, and student-generated questions
Rung 2: Labeled diagrams, ray diagrams, and model representations
Rung 3: Short-answer explanations and application problems
Rung 4: Multi-step calculation problems using Snell's Law
Rung 5: Image identification and mirror equation calculations
Rung 6: Lens equation calculations and ray diagram analysis
Rung 7: Laboratory investigation of critical angle and total internal reflection
Rung 8: Research project on optical instruments and technology
Rung 9: Written argument with experimental evidence supporting optical model choice
Rung 10: Engineering design project and prototype testing

Module Outline 07: Introduction to Electricity

Essential Standard

Students will understand the fundamental principles of electricity, including electric charge, force, fields, and current, and apply these concepts to analyze simple circuits and energy transfer.

Section 1: Electric Charge and Electric Force

Learning Objectives - I can...

- Define electric charge and distinguish between positive and negative charges, explaining how they differ at the atomic level.
- Explain how electric force acts between charged objects and describe the relationship between the magnitude of charge and the strength of the force.
- Apply Coulomb's Law to calculate the electric force between two point charges and predict how changes in charge or distance affect the force.

Section 2: Electric Fields and Voltage

Learning Objectives - I can...

- Visualize and describe electric fields around charged objects and compare field line patterns for different charge configurations (single charge, dipole, and parallel plates).
- Define electric potential and voltage, explaining the relationship between them and how they describe the work done on moving charges.
- Predict how changes in charge distribution affect the electric potential and field strength at various locations.

Section 3: Current, Power Sources, and Measurement

Learning Objectives - I can...

- Define electric current in terms of charge flow, explain conventional current direction, and measure current accurately using an ammeter in a circuit.
- Describe how chemical cells and solar cells generate voltage through energy conversion, and explain the differences between these two types of power sources.
- Use ammeters and voltmeters correctly in circuits to measure current and voltage, and interpret circuit measurements to determine circuit behavior.

Section 4: Ohm's Law and Circuit Analysis

Learning Objectives - I can...

- State Ohm's Law and explain the relationship between voltage, current, and resistance in a circuit.
- Apply Ohm's Law to calculate unknown values of voltage, current, or resistance in simple circuits.
- Analyze circuit diagrams, distinguish between series and parallel circuit configurations, and predict how changes to one component affect current and voltage throughout the circuit.

Section 5: Energy, Efficiency, and Circuit Design

Learning Objectives - I can...

- Calculate electrical power dissipated in resistive devices and determine energy consumption and efficiency in electrical systems.
- Compare the advantages and limitations of different electricity sources (chemical, solar, and others) in terms of efficiency and environmental impact.
- Design, build, and test simple circuits to solve practical problems, and justify design decisions based on circuit principles and efficiency goals.

LEARNING LADDER 07: INTRODUCTION TO ELECTRICITY

This learning ladder contains 10 rungs aligned with the 8 Science Practices. The bottom 7 rungs represent essential learning that average students should master. The top 3 rungs represent extended learning for advanced students.

Rung	I Can Statement	Science Practice	Level
10	I can construct evidence-based arguments about the advantages and limitations of different electricity sources, and evaluate energy efficiency in electrical devices.	7. Engaging in Argument from Evidence	Extended
9	I can compare chemical and solar cells, explain how they generate voltage, and design an experiment to test cell efficiency.	1. Asking Questions & Defining Problems	Extended
8	I can analyze circuit diagrams, distinguish between series and parallel configurations, and predict how changes to one component affect the entire circuit.	4. Analyzing & Interpreting Data	Extended
7	I can apply Ohm's Law to calculate voltage, current, and resistance in simple circuits and explain the relationships between them.	5. Using Mathematics & Computational Thinking	Essential
6	I can define electric current, describe conventional current flow, and measure current using an ammeter.	3. Planning & Carrying Out Investigations	Essential
5	I can define voltage and explain how it relates to electric potential and work done on charges.	2. Developing & Using Models	Essential
4	I can visualize and describe electric fields around charged objects and compare field patterns for different configurations.	2. Developing & Using Models	Essential
3	I can apply Coulomb's Law to calculate the electric force between two charged objects.	5. Using Mathematics & Computational Thinking	Essential
2	I can explain how electric force acts between charged objects and describe the relationship between charge and force.	2. Developing & Using Models	Essential
1	I can define electric charge and distinguish between positive and negative charges.	2. Developing & Using Models	Essential

Progress Tracking

Students self-assess on each rung using the following scale:
Not Yet: I need more instruction and practice
Getting There: I understand most of it but need more practice
Got It!: I can do this independently

Assessment Methods

Rung 1: Concept mapping and explanation of charge properties
Rung 2: Diagrams showing force interactions and relationship analysis
Rung 3: Multi-step calculation problems using Coulomb's Law
Rung 4: Field line diagrams and comparative analysis of field patterns
Rung 5: Short-answer explanations and voltage-related calculations
Rung 6: Laboratory investigation of current measurement with ammeters
Rung 7: Ohm's Law application problems and circuit analysis
Rung 8: Circuit diagram analysis and prediction tasks
Rung 9: Research project on cell types and experimental efficiency testing
Rung 10: Written argument with evidence supporting energy source choices

Module Outline 08: Electric Circuits

Essential Standard

Students will understand how electric circuits transfer and consume energy, analyze circuit behavior using circuit models and mathematical relationships, and apply these concepts to design and troubleshoot electrical systems.

8.1 Energy Transfer in Electric Circuits

Learning Objectives - I can...

- Define electric charge, voltage, current, and resistance, and explain how they relate to energy transfer in circuits.
- Explain how chemical and solar cells generate voltage and provide energy to circuits.
- Calculate electrical power and energy consumption using appropriate formulas and explain energy transformations in circuits.

8.2 Measuring and Analyzing Circuit Behavior

Learning Objectives - I can...

- Measure voltage, current, and resistance in circuits using a multimeter and correctly interpret the measurements.
- Apply Ohm's Law to predict and calculate circuit values and explain the relationship between voltage, current, and resistance.
- Use circuit data to analyze circuit behavior and predict how changes affect circuit performance.

8.3 Series and Parallel Circuits

Learning Objectives - I can...

- Distinguish between series and parallel circuits by analyzing circuit diagrams and component configurations.
- Predict how voltage and current distribute across components in series and parallel circuits.
- Build and test series and parallel circuits to verify circuit behavior and explain the advantages of each configuration.

8.4 Complex Circuit Analysis

Learning Objectives - I can...

- Identify and analyze combined series-parallel circuits using circuit diagrams and mathematical relationships.
- Calculate equivalent resistance, total current, and voltage distribution in complex circuits.
- Design circuits to meet specific requirements and justify design choices based on circuit principles.

8.5 Capacitors and Practical Applications

Learning Objectives - I can...

- Explain how capacitors store and release electrical energy and describe their function in circuits.
- Evaluate energy efficiency in electrical systems and compare advantages and limitations of different electricity sources.
- Construct evidence-based arguments about the practical applications of circuits in real-world technology and renewable energy systems.

LEARNING LADDER 08: ELECTRIC CIRCUITS

This learning ladder contains 10 rungs aligned with the 8 Science Practices. The bottom 7 rungs represent essential learning that average students should master. The top 3 rungs represent extended learning for advanced students.

Rung	I Can Statement	Science Practice	Level
10	I can construct evidence-based arguments about energy efficiency in electrical systems and evaluate real-world applications.	7. Engaging in Argument from Evidence	Extended
9	I can design and test a circuit using capacitors and explain how they store and release electrical energy.	1. Asking Questions & Defining Problems	Extended
8	I can analyze complex circuit diagrams with series-parallel combinations and calculate circuit values.	4. Analyzing & Interpreting Data	Extended
7	I can calculate power and energy consumption in circuits and explain the practical applications of electrical systems.	5. Using Mathematics & Computational Thinking	Essential
6	I can design and build a simple circuit to accomplish a specific task and explain how it works.	6. Constructing Explanations & Designing Solutions	Essential
5	I can predict how changes to voltage, current, or resistance affect energy transfer in a circuit.	4. Analyzing & Interpreting Data	Essential
4	I can distinguish between series and parallel circuits and analyze how components are connected.	2. Developing & Using Models	Essential
3	I can apply Ohm's Law to calculate voltage, current, and resistance in simple circuits.	5. Using Mathematics & Computational Thinking	Essential
2	I can measure voltage, current, and resistance in a circuit using appropriate tools.	3. Planning & Carrying Out Investigations	Essential
1	I can define electric charge and explain how it relates to voltage, current, and energy in circuits.	2. Developing & Using Models	Essential

Progress Tracking

Students self-assess on each rung using the following scale:
Not Yet: I need more instruction and practice
Getting There: I understand most of it but need more practice
Got It!: I can do this independently

Assessment Methods

Rung 1: Diagrams and explanations of charge and energy relationships
Rung 2: Laboratory investigation measuring circuit values with meters
Rung 3: Multi-step calculation problems using Ohm's Law
Rung 4: Circuit diagrams and comparative analysis of series versus parallel
Rung 5: Data analysis and predictions of circuit behavior
Rung 6: Design and construction of a functional circuit with explanation
Rung 7: Power and energy calculations and real-world applications
Rung 8: Complex circuit analysis with series-parallel combinations
Rung 9: Experimental design with capacitors and energy testing
Rung 10: Written argument with evidence supporting circuit choices and efficiency

Physics Vocabulary and Formulas Reference

Complete Guide - All 8 Modules

Table of Contents

Module 8: Electric Circuits

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	$\% \text{ error} = \frac{\|\text{Exp} - \text{Theo}\|}{\text{Theo}} \times 100\%$	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)	$d = \|x_f - x_i\|$	d = distance (m), x_f = final position (m), x_i = initial position (m)
Total Distance (Multiple Segments)	$d_{total} = d_1 + d_2 + d_3 + \ldots$	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/s².

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/s²)

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/s²), 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/s²), 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 $\mathrm{kg \cdot m/s^2}$.

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·m²/s².

FORMULAS

Formula Name	Formula	Variables and Units
Gravitational Potential Energy	$PE = mgh$	PE = potential energy (J), m = mass (kg), g = 9.8 m/s² (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/s²
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	$e = 1.60 \times 10^{-19}\ \mathrm{C}$	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)	$P = I^2R$	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)