WINTER SEMESTER

Survey of Physics - Winter

Electricity, Magnetism & Electromagnetism

A 10-Week Course · Physics Literacy for Kids

COURSE INFORMATION	
Duration: 10 Weeks	Level: Middle / Early High School
Sessions: 1 hour per week	Format: Live Zoom + Pre-recorded Video
Resources: Workbooks, PhET simulations, AI-generated notes	Prerequisites: Survey of Physics — Fall Semester
Assessment: Kahoot, Blooket, Google Form quizzes	End-of-Course: Student project presentation

Course Description

This course introduces students to the fundamental concepts of electricity and magnetism — from electric charge and Coulomb's Law through circuits and capacitors, and all the way to the elegant unification of electricity and magnetism through electromagnetism and Faraday's Law of induction. Students explore these ideas through hands-on experiments, PhET simulations, and real-world applications. The course builds both conceptual understanding and basic quantitative skills, and is designed as the winter semester of the Survey of Physics, following the mechanics foundation built in the fall.

Course Objectives

By the end of this course, students will:

- Understand the fundamental principles of electric charge, electric fields, and electric potential
- Explain how voltage drives current through a circuit and apply Ohm's Law to solve problems
- Build and analyze series and parallel circuits, and understand how capacitors store energy
- Understand how magnets work and how magnetic fields interact with moving charges
- Explain how electricity and magnetism interact to create electromagnetism
- Perform hands-on experiments and build devices that demonstrate these principles
- Connect everything learned to everyday technology — motors, generators, wireless charging, and more

Week-by-Week Curriculum

Winter Semester — Weeks 1–10

Electricity, Magnetism & Electromagnetism

We begin with the invisible world of electric charge — what it is, how it behaves, and how to map it. Students then build real circuits, explore energy storage in capacitors, discover the world of magnetism, and finish by uncovering one of the most elegant discoveries in all of physics: that electricity creates magnetism, and magnetism creates electricity.

Week 1: Introduction to Electricity

Topics & Concepts	Activity & Experiment	Key Figures	Key Equation / Formula
Electric charges: positive and negative Protons, electrons, and the atomic origin of charge Conservation of charge — never created or destroyed Charging by friction, conduction, and induction Conductors vs. insulators — why materials behave differently Polarization — how a neutral object is attracted to a charged one Everyday examples: lightning rods, grounding, static cling	Build a simple electroscope from a glass jar, aluminum foil strips, and a wire — detect and measure charge without touching Static electricity experiments: rub a balloon on hair, attract paper scraps, and a thin stream of water Material sorting activity: test household materials (plastic, metal, rubber, wood) with a charged balloon to classify conductors and insulators PhET 'Balloons and Static Electricity' — visualize charge transfer in real time Discussion: Why does your hair stick to a plastic comb on a dry winter day?	Benjamin Franklin (named + and −, 1752) Charles-Augustin de Coulomb J.J. Thomson (electron, 1897) Lord Kelvin (electrostatic induction) Robert Millikan (measured e, 1909)	$q = ne$ (charge is quantized) $e = 1.6 \times 10^{-19}$ C Conservation of charge: Q_initial = Q_final Conductors: free electrons Insulators: bound electrons

Week 2: Electric Fields and Forces

Topics & Concepts	Activity & Experiment	Key Figures	Key Equation / Formula
What an electric field is and why physicists use it Electric field lines — direction, density, and what they represent Coulomb's Law: the force between two charges depends on their sizes and distance Comparing electric force to gravity — same inverse-square law, but vastly stronger The electric field around a single charge, two opposite charges, and two like charges Uniform electric fields between parallel plates	PhET 'Charges and Fields' — place charges, visualize field lines, sketch and interpret the patterns Create an electric field map: use a charged balloon near small paper scraps arranged on a flat surface to see the field pattern Parallel plate exploration: set up a parallel plate configuration in the simulation and explore the uniform field between the plates Quantitative problems: calculate the electric force between two known charges at different distances Discussion: Why do electric field lines never cross each other?	Charles-Augustin de Coulomb (1784) Michael Faraday (field concept) Carl Friedrich Gauss (Gauss's Law) Joseph Priestley (noticed inverse-square pattern, 1767)	Coulomb's Law: $F = kq_1q_2 / r^2$ $k = 8.99 \times 10^9$ N·m²/C² Electric field: $E = F/q = kQ/r^2$ (field at distance r from Q) Field lines: direction = force on a + test charge

Week 3: Introduction to Electric Potential

Topics & Concepts	Activity & Experiment	Key Figures	Key Equation / Formula
Electric potential energy — energy stored in a charge arrangement Electric potential (voltage) — potential energy per unit charge Equipotential lines — surfaces where the voltage is the same everywhere Relationship between field lines and equipotential lines (always perpendicular) Voltage as the 'pressure' that drives current through a circuit	PhET 'Charges and Fields' equipotential mapping — trace equipotential lines around charge arrangements, sketch and compare to field lines Voltage analogy: use the water-in-pipes model to build intuition — voltage = water pressure, current = flow rate Quantitative practice: calculate the electric potential at a point near a known charge	Alessandro Volta (battery and voltage unit, 1800) James Clerk Maxwell (mathematical framework) Georg Simon Ohm (voltage-current relationship) Carl Friedrich Gauss	Electric potential: $V = kQ / r$ (from a point charge Q) Potential energy: $PE = qV$ Voltage: volts (V = J/C) Field lines ⊥ equipotential lines $E = -\Delta V/\Delta r$

Quantitative: calculating electric potential from charge and distance	Discussion: What does it mean for two points in space to be at the same potential? Discussion: if voltage is electric pressure, what causes current to flow from high to low potential?		

Week 4: Electric Circuits — Part 1

Topics & Concepts	Activity & Experiment	Key Figures	Key Equation / Formula
What an electric circuit is and the role of each component Key components: battery (voltage source), wires (conductors), resistors, light bulbs, switches Electric current — the flow of charge; measured in amperes Resistance — opposition to current flow; measured in ohms Ohm's Law: $V = IR$ — the fundamental circuit relationship Reading and drawing circuit diagrams using standard symbols Electric power: $P = IV$	Hands-on circuit build: connect a battery, wires, and a light bulb to make the simplest possible working circuit Circuit diagram activity: learn standard symbols and draw the circuit just built PhET 'Circuit Construction Kit (DC)' — build virtual circuits, observe current flow, add a voltmeter and ammeter to measure V and I Ohm's Law problems: calculate voltage, current, or resistance given the other two in real-world scenarios Interactive simulation: use an online circuit simulator to try more complex configurations Discussion: why does a higher voltage battery make the bulb glow brighter?	Alessandro Volta (battery, 1800) Georg Simon Ohm (Ohm's Law, 1827) André-Marie Ampère (current unit) James Prescott Joule (power, heat from current)	Ohm's Law: $V = IR$ Current: $I = Q/t$ Amperes ($A = C/s$) Resistance: ohms (Ω) Power: $P = IV = I^2R = V^2/R$ Units: watts (W)

Week 5: Electric Circuits — Part 2: Series and Parallel

Topics & Concepts	Activity & Experiment	Key Figures	Key Equation / Formula
Series circuits — current is the same everywhere; voltage divides across components	Hands-on series circuit: wire two bulbs in series, observe brightness, then remove one bulb and	Gustav Kirchhoff (circuit laws, 1845)	Series: I same throughout $V_T = V_1 + V_2 + \ldots$ $R_T = R_1 + R_2 + \ldots$

Total resistance in series: $R\_T = R_1 + R_2 + R_3$ ... Parallel circuits — voltage is the same across each branch; current divides Total resistance in parallel: $1/R\_T = 1/R_1 + 1/R_2 + \ldots$ What happens when one component fails in each type (the Christmas lights problem) Why homes are wired in parallel — practical and safety reasons Kirchhoff's Voltage Law and Current Law (conceptual introduction)	observe what happens to the other Hands-on parallel circuit: wire two bulbs in parallel, compare brightness to series, remove one — does the other go out? Measure brightness of bulbs in series vs. parallel to observe how circuit arrangement affects each bulb PhET 'Circuit Construction Kit' — compare series and parallel side by side with virtual ammeter and voltmeter Practice: calculate total resistance, current, and voltage drops for both circuit types Homework: draw circuit diagrams for both types; record and explain your observations	Georg Simon Ohm Thomas Edison (early series lighting limitations) George Westinghouse (parallel AC distribution)	Parallel: V same across each branch $I\_T = I_1 + I_2 + \ldots$ $1/R\_T = 1/R_1 + 1/R_2 + \ldots$ Kirchhoff's Laws: KVL + KCL

Week 6: Introduction to Capacitors

Topics & Concepts	Activity & Experiment	Key Figures	Key Equation / Formula
What a capacitor is and how it stores charge on two conducting plates Capacitance $C = Q/V$ — how much charge stored per volt The role of the dielectric material between the plates and how it increases capacitance How plate area, plate separation, and dielectric affect capacitance Capacitors in series vs. parallel — how total capacitance changes in each case Energy stored in a capacitor: $U = ½CV^2$ Real-world applications: camera flashes, defibrillators,	Build a simple capacitor: layer aluminum foil and plastic wrap to form a parallel-plate capacitor and measure it PhET 'Capacitor Lab: Basics' — adjust plate size, separation, and dielectric material; observe how charge and energy stored change Series vs. parallel capacitor problems: practice calculating equivalent capacitance for combinations Discussion: how does a camera flash store and release energy so quickly? How does a defibrillator deliver a controlled shock?	Ewald Georg von Kleist (Leyden jar, 1745) Alessandro Volta Michael Faraday (dielectric research; the farad is named after him) James Clerk Maxwell	Capacitance: $C = Q/V$ Units: farads (F) Energy stored: $U = ½CV^2$ Series: $1/C\_T = \Sigma\ 1/C_i$ Parallel: $C\_T = \Sigma\ C_i$ Parallel plate: $C = \varepsilon_0 \kappa A/d$

touchscreens, power supplies	Discussion: how does a touchscreen know exactly where your finger is?		

Week 7: Introduction to Magnetism

Topics & Concepts	Activity & Experiment	Key Figures	Key Equation / Formula
Permanent magnets — north and south poles, attraction and repulsion Magnetic field lines — direction, density, and what they represent Earth as a giant magnet — why compasses work and why magnetic north ≠ geographic north Magnetic domains — why some materials are magnetic and others are not The fundamental difference from electric fields: no magnetic monopoles exist Comparing magnetic force to electric force — similarities and key differences	Iron filings lab: sprinkle iron filings around bar magnets and horseshoe magnets to reveal field line patterns — sketch and interpret the results Compass activity: use a compass to systematically map the magnetic field around a bar magnet; compare pattern to a diagram of Earth's field Magnet sorting: test which household objects are attracted to a magnet (steel vs. aluminum vs. copper vs. plastic) Discussion: if you cut a magnet in half, do you get a separate north and south pole? Test it! Discussion: what is inside the Earth that creates its magnetic field? Why does it flip every few hundred thousand years?	William Gilbert (Earth as magnet, 1600) Hans Christian Ørsted (electricity-magnetism link, 1820) Pierre Curie (magnetic domains and Curie temperature) André-Marie Ampère (magnetic force between wires)	Magnetic field: B Units: tesla (T) Field lines: N→S outside S→N inside magnet No magnetic monopoles: $\nabla \cdot B = 0$ (Gauss's Law for Magnetism) Earth: B ≈ 25–65 μT at surface

Week 8: Magnetic Forces and Fields

Topics & Concepts	Activity & Experiment	Key Figures	Key Equation / Formula
A moving charge in a magnetic field experiences a force — the Lorentz force The right-hand rule — determining the direction of magnetic force on a moving charge	Build an electromagnet: wrap insulated wire around an iron nail, connect to a battery, pick up paper clips — test how coil number and battery voltage affect lifting strength	Hendrik Lorentz (Lorentz force, 1895) Hans Christian Ørsted (1820) André-Marie Ampère (force between wires)	Lorentz force: $F = qv \times B$ $F = qvB \sin\theta$ Force on a wire: $F = BIL \sin\theta$ Right-hand rule:

Force on a current-carrying wire placed in a magnetic field Building an electromagnet — turning the magnetic field on and off with a switch Factors that affect electromagnet strength: number of coils, current magnitude, core material Applications: electric motors, speakers, MRI machines, maglev trains, particle accelerators	Right-hand rule practice: work through a set of diagrams to determine force direction for various combinations of charge velocity and magnetic field orientation Visualize magnetic forces: hold a small compass near a current-carrying wire and observe the needle deflect as current turns on and off PhET 'Magnets and Electromagnets' — explore how current and coil number affect the magnetic field strength and direction Discussion: how does a speaker use magnetic force to convert an electrical signal into sound waves?	Joseph Henry (powerful electromagnets, 1830s)	thumb = v (or I direction) fingers curl with B field palm pushes = direction of F

Week 9: Electricity and Magnetism Combined — Electromagnetism

Topics & Concepts	Activity & Experiment	Key Figures	Key Equation / Formula
Ørsted's discovery (1820): a current-carrying wire creates a magnetic field around it The magnetic field around a straight wire and around a coil (solenoid) Solenoids — how winding wire into a coil amplifies and concentrates the magnetic field Ampère's Law: the quantitative relationship between current and magnetic field How a simple electric motor works: force on a current-carrying loop in a magnetic field produces rotation The deep symmetry: current creates a magnetic field (this week); changing	Hold a compass near a wire connected to a battery — watch the needle deflect when current flows; discuss what Ørsted saw in 1820 Solenoid exploration: use PhET 'Faraday's Electromagnetic Lab' — visualize the field inside a solenoid as a function of coil number and current Build a simple DC motor: a battery, a small wire coil, two permanent magnets, and a safety pin frame — observe rotation and discuss which forces cause it Discussion: How does an MRI machine use an electromagnet? Why does it need to be	Hans Christian Ørsted (1820) André-Marie Ampère (Ampère's Law, 1826) Michael Faraday (electromagnetic induction) Nikola Tesla (AC motor, 1888) James Clerk Maxwell (unified theory, 1865)	B around a straight wire: $B = \mu_0 I / (2\pi r)$ Solenoid field: $B = \mu_0 n I$ (n = turns per meter) Ampère's Law: $\oint B \cdot dl = \mu_0 I\_enclosed$ Motor: current loop in B field → torque → rotation

magnetic field creates current (next week)	50,000× stronger than Earth's magnetic field? Discussion: a motor and a generator use the same components — what is the only key difference between them?		

Week 10: Electromagnetic Induction — Magnetism Creates Electricity

Topics & Concepts	Activity & Experiment	Key Figures	Key Equation / Formula
Faraday's discovery (1831): a changing magnetic field creates (induces) an electric current Magnetic flux — the total amount of magnetic field passing through a loop Faraday's Law of Induction: induced EMF is proportional to rate of change of flux Lenz's Law — the induced current always opposes the change that caused it Factors that affect induced current: speed of magnet motion, field strength, number of coils in the wire Real-world applications: AC generators, transformers, wireless charging, induction cooktops, regenerative braking Full-circle synthesis: Ørsted showed electricity → magnetism; Faraday showed magnetism → electricity	Magnet-through-coil experiment: push a strong magnet through a coil of wire connected to a galvanometer — observe induced current; try faster, slower, reversed direction, and more coils to see how each changes the reading PhET 'Faraday's Electromagnetic Lab' — explore induction with a bar magnet and coil interactively; adjust speed and coil size Lenz's Law demonstration: drop a magnet through a copper tube — observe it fall much more slowly than expected; explain using Lenz's Law Discussion: how does a wireless phone charger work without any physical connection between the charger and the phone? End-of-course review: trace the full arc — from static charge (Week 1) → electric field → voltage → circuits → magnetism → electromagnetism → induction (Week 10)	Michael Faraday (induction, 1831) Joseph Henry (independent discovery, USA, 1831) Heinrich Lenz (Lenz's Law, 1834) James Clerk Maxwell (unified E&M, 1865) Nikola Tesla (AC generator and transformer)	Faraday's Law: $EMF = -N \cdot \Delta\Phi/\Delta t$ Magnetic flux: $\Phi = BA \cos\theta$ (B through area A at angle θ) Lenz's Law: The induced current opposes the change that caused it Generator: mechanical → electrical Motor: electrical → mechanical

Resources & Materials

PhET Simulations (all free at phet.colorado.edu)

- Balloons and Static Electricity — Week 1: visualize charge transfer between objects
- Charges and Fields — Weeks 2–3: map electric fields and trace equipotential lines
- Capacitor Lab: Basics — Week 6: explore how plate size, separation, and dielectric affect capacitance
- Circuit Construction Kit (DC) — Weeks 4–5: build and analyze virtual circuits with meters
- Magnets and Electromagnets — Weeks 7–8: explore how current creates a magnetic field
- Faraday's Electromagnetic Lab — Weeks 9–10: solenoid fields and electromagnetic induction

Hands-On Materials

- Balloons, wool or hair, aluminum foil strips, glass jar (electroscope build — Week 1)
- 9V battery or AA battery pack, insulated wire, light bulbs, switches, resistors (Weeks 4–5)
- Iron nail, ~3 meters of thin insulated wire, paper clips (electromagnet build — Week 8)
- Strong bar magnet, iron filings, compass (Weeks 7–8)
- Copper tube ~30 cm long, strong rare-earth magnet (Lenz's Law demo — Week 10)
- Wire coil (50–100 turns) connected to a galvanometer or multimeter (induction lab — Week 10)

"The special theory of relativity owes its origins to Maxwell's equations of the electromagnetic field." — Albert Einstein