11 Electric Circuits

Content Area:	**Science**
Course(s):	**AP Physics C**
Time Period:	**Semester 2**
Length:	**3 weeks**
Status:	**Published**

Standards

SCI.HS-PS3-1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
	Using Mathematics and Computational Thinking
SCI.HS.PS3.A	Definitions of Energy
SCI.HS.PS3.B	Conservation of Energy and Energy Transfer
	Systems and System Models
SCI.HS-PS3-3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
	Constructing Explanations and Designing Solutions

AP Physics C Learning Objectives

Note: Learning Objectives are taken verbatim from the AP Physics C - Mechanics Course and Exam Description. The verb "describe" could refer to a variety of different methods of expression (e.g. words, diagrams, graphs, mathematical expressions), as appropriate.

Describe the movement of electric charges through a medium.

Describe the behavior of a circuit.

Describe the resistance of an object using physical properties of that object.

Describe the electrical characteristics of elements of a circuit.

Describe the transfer of energy into, out of, or within an electric circuit, in terms of power.

Describe the equivalent resistance of multiple resistors connected in a circuit.

Describe a circuit with resistive wires and a battery with internal resistance.

Describe the measurement of current and potential difference in a circuit.

Describe a circuit or elements of a circuit by applying Kirchhoff's loop rule.

Describe a circuit or elements of a circuit by applying Kirchhoff's junction rule.

Describe the equivalent capacitance of multiple capacitors.

Describe the behavior of a circuit containing combinations of resistors and capacitors.

Enduring Understandings

Fields predict and describe interactions.

Conservation laws constrain interactions.

The rate of charge through a conductor depends on the physical characteristics of the conductor.

There are electrical devices that convert electrical potential energy into other forms of energy.

Total energy and charge are conserved in a circuit containing resistors and a source of energy.

Total energy and charge are conserved in a circuit that includes resistors, capacitors, and a source of energy.

Essential Questions

How does a house's wiring design account for a flipped circuit breaker to cause electricity to go off in some rooms but stay on in other rooms?

Why do warming bulbs take several minutes to shine brightly?

Why does the electric company charge by kilowatt-hour instead of electrons used?

How does touching a conductor to a capacitor before removing it from a circuit protect you?

Knowledge and Skills

Topic 11.1 Electric Current

Knowledge:

- Current is the rate at which charge passes through a cross-sectional area of a wire.
- Current within a conductor consists of charge carriers traveling through the conductor with an average drift velocity.
- Electric charge moves in a circuit in response to an electric potential difference, sometimes referred to as electromotive force, or emf.
- If the current is zero in a section of wire, the net motion of charge carriers in the wire is also zero, although individual charge carriers will not have zero speed.
- Current density is the flow of charge per unit area.
- Current density is related to the motion of the charge carriers within a conductor.
- Current density is a vector quantity.

- A potential difference across a conductor creates an electric field within the conductor that is proportional to the resistivity of the conductor and the current density.
- If a function of current density is given, the total current can be determined by integrating the current density over the area.
- Although current is a scalar quantity, it does have a direction. Because its direction is relative to the current carrier and not space, current does not obey the laws of vector addition and has no vector components.
- The direction of conventional current is chosen to be the direction in which positive charge would move.
- In common circuits, the current is actually due to the movement of electrons (negative charge carriers).

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 11.2 Simple Circuits
Knowledge:

- A circuit is composed of electrical loops, which can include wires, batteries, resistors, lightbulbs, capacitors, inductors, switches, ammeters, and voltmeters.
- A closed electrical loop is a closed path through which charges may flow.
- A closed circuit is one in which charges would be able to flow.
- An open circuit is one in which charges would not be able to flow.
- A short circuit is one in which charges would be able to flow with no change in potential difference.
- A single circuit element may be part of multiple electrical loops.
- Circuit schematics are representations used to describe and analyze electric circuits.
- The properties of an electric circuit are dependent on the physical arrangement of its constituent elements.
- Circuit elements have common symbols that are used to create schematic diagrams. Variable elements are indicated by a diagonal strikethrough arrow across the standard symbol for that element.

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 11.3 Resistance, Resistivity, and Ohm's Law
Knowledge:

- Resistance is a measure of the degree to which an object opposes the movement of electric charge.

- The resistance of a resistor with uniform geometry is proportional to its resistivity and length and is inversely proportional to its cross-sectional area.
- Resistivity is a fundamental property of a material that depends on its atomic and molecular structure and quantifies how strongly the material opposes the motion of electric charge.
- The resistivity of a conductor typically increases with temperature.
- The total resistance of a resistor with uniform geometry, but that is made of a material whose resistivity varies along the length of the resistor, is given by .
- Ohm's law relates current, resistance, and potential difference across a conductive element of a circuit.
- Materials that obey Ohm's law have constant resistance for all currents and are called ohmic materials.
- The resistivity of an ohmic material is constant regardless of temperature.
- Resistors can also convert electrical energy to thermal energy, which may change the temperature of both the resistor and the resistor's environment.
- The resistance of an ohmic circuit element can be determined from the slope of a graph of the current in the element as a function of the potential difference across the element.

Skills:

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Calculate or estimate an unknown quantity with units from known quantities by selecting and following a logical computational pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 11.4 Electric Power
Knowledge:

- The rate at which energy is transferred, converted, or dissipated by a circuit element depends on the current through the element and the electric potential difference across it.
- The brightness of a lightbulb increases with power, so power can be used to qualitatively predict the brightness of lightbulbs in a circuit.

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Calculate or estimate an unknown quantity with units from known quantities by selecting and following a logical computational pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 11.5 Compound Direct Current Circuits
Knowledge:

- Circuit elements may be connected in series and/or in parallel.
- A series connection is one in which any charge passing through one circuit element must proceed through all elements in that connection and has no other path available. The current in each element in series must be the same.
- A parallel connection is one in which charges may pass through one of two or more paths. Across each

path, the potential difference is the same.
- A collection of resistors in a circuit may be analyzed as though it were a single resistor with an equivalent resistance.
- The equivalent resistance of a set of resistors in series is the sum of the individual resistances.
- The inverse of the equivalent resistance of a set of resistors connected in parallel is equal to the sum of the inverses of the individual resistances.
- When resistors are connected in parallel, the number of paths available to charges increases, and the equivalent resistance of the group of resistors decreases.
- Ideal batteries have negligible internal resistance. Ideal wires have negligible resistance.
- The resistance of wires that are good conductors may normally be neglected, because their resistance is much smaller than that of other elements of a circuit.
- The resistance of wires may only be neglected if the circuit contains other elements that do have resistance.
- The potential difference a battery would supply if it were ideal is the potential difference measured across the terminals when there is no current in the battery and is sometimes referred to as its emf.
- The internal resistance of a nonideal battery may be treated as the resistance of a resistor in series with an ideal battery and the remainder of the circuit.
- When there is current in a nonideal battery with internal resistance r, the potential difference across the terminals of the battery is reduced relative to the potential difference when there is no current in the battery.
- Ammeters are used to measure current at a specific point in a circuit.
- Ammeters must be connected in series with the element in which current is being measured.
- Ideal ammeters have zero resistance so that they do not affect the current in the element that they are in series with.
- Voltmeters are used to measure electric potential difference between two points in a circuit.
- Voltmeters must be connected in parallel with the element across which potential difference is being measured.
- Ideal voltmeters have infinite resistance so that no charge flows through them.
- Nonideal ammeters and voltmeters will change the properties of the circuit being measured.

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 11.6 Kirchhoff's Loop Rule
Knowledge:

- Energy changes in simple electrical circuits may be represented in terms of charges moving through electric potential differences within circuit elements.
- Kirchhoff’s loop rule is a consequence of the conservation of energy.
- Kirchhoff’s loop rule states that the sum of potential differences across all circuit elements in a single closed loop must equal zero.
- The values of electric potential at points in a circuit can be represented by a graph of electric potential

as a function of position within a loop.

Skills:

- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 11.7 Kirchhoff's Junction Rule
Knowledge:

- Kirchhoff's junction rule is a consequence of the conservation of electric charge.
- Kirchhoff's junction rule states that the total amount of charge entering a junction per unit time must equal the total amount of charge exiting that junction per unit time.

Skills:

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Calculate or estimate an unknown quantity with units from known quantities by selecting and following a logical computational pathway.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 11.8 Resistor-Capacitor (RC) Circuits
Knowledge:

- A collection of capacitors in a circuit may be analyzed as though it was a single capacitor with an equivalent capacitance.
- The inverse of the equivalent capacitance of a set of capacitors connected in series is equal to the sum of the inverses of the individual capacitances.
- The equivalent capacitance of a set of capacitors in series is less than the capacitance of the smallest capacitor.
- The equivalent capacitance of a set of capacitors in parallel is the sum of the individual capacitances.
- As a result of conservation of charge, each of the capacitors in series must have the same magnitude of charge on each plate.
- The charge on a capacitor or the current in a resistor in an RC circuit can be described by a fundamental differential equation derived from Kirchhoff's loop rule.
- The time constant is a significant feature of an RC circuit.
- The time constant of an RC circuit is a measure of how quickly the capacitor will charge or discharge and is defined as .
- For a charging capacitor, the time constant represents the time required for the capacitor's charge to increase from zero to approximately 63 percent of its final asymptotic value.
- For a discharging capacitor, the time constant represents the time required for the capacitor's charge to decrease from fully charged to approximately 37 percent of its initial value.
- The potential difference across a capacitor and the current in the branch of the circuit containing the capacitor each change over time as the capacitor charges and discharges, but both will reach a steady

state after a long time interval.
- Immediately after being placed in a circuit, an uncharged capacitor acts like a wire, and charge can easily flow to or from the plates of the capacitor.
- As a capacitor charges, changes to the potential difference across the capacitor affect the charge on the plates of the capacitor, the current in the circuit branch in which the capacitor is located, and the electric potential energy stored in the capacitor.
- The potential difference across a capacitor, the current in the circuit branch in which the capacitor is located, and the electric potential energy stored in the capacitor all change with respect to time and asymptotically approach steady state conditions.
- After a long time, a charging capacitor approaches a state of being fully charged, reaching a maximum potential difference at which there is zero current in the circuit branch in which the capacitor is located.
- Immediately after a charged capacitor begins discharging, the amount of charge on the capacitor and the energy stored in the capacitor begin to decrease.
- As a capacitor discharges, the amount of charge on the capacitor, the potential difference across the capacitor, and the current in the circuit branch in which the capacitor is located all decrease until a steady state is reached.
- After either charging or discharging for times much greater than the time constant, the capacitor and the relevant circuit branch may be modeled using steady-state conditions.

Skills:

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Transfer Goals

Whether or not they're aware, students interact with electric circuits regularly through charging their phones, powering up their laptops, or simply switching on a light. Unit 11 serves to illuminate how, and why, simple electronic devices such as lightbulbs and household wiring function by exploring the nature and importance of electric currents, circuits, and resistance. Through activities and lab investigations, students will have opportunities to relate knowledge across the course by using the electrical components they learned about in Unit 10 and will come to discover in Unit 11 to create, modify, and analyze circuits. Students will also analyze the relationships that exist between current, resistance, and power, in addition to exploring and applying Ohm's Law and Kirchhoff's Rules.

Assessments

https://docs.google.com/document/d/1wR7bQF-8AQoRrt0g4C3hKja0yjwDjC9_BiAmONWbTcI/edit?usp=sharing

Modifications

https://docs.google.com/document/d/1ODqaPP69YkcFiyG72fIT8XsUIe3K1VSG7nxuc4CpCec/edit?usp=sharing