MOORESTOWN TOWNSHIP PUBLIC SCHOOLS
MOORESTOWN, NEW JERSEY

Moorestown High School
Science Department

AP Physics C: Electricity & Magnetism
Grade 12

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Contents

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Course Description and Fundamental Concepts

AP Physics C Electricity and Magnetism picks up where AP Physics C Mechanics leaves off, continuing an introduction to the main principles of engineering-level physics at the freshman college level. Physics C provides a systematic introduction to the main principles of Physics and emphasizes the development of problem solving ability. Strong emphasis is placed on solving a variety of challenging problems, with fundamental calculus use being introduced. The subject matter covers Electricity, Circuits, Magnetism, Fields, and Induction. The laboratory components of the course offer many experiences dealing with both simple and advanced topics. Upon completion of the course students will be prepared to take the AP Physics C Electricity & Magnetism test offered by the College Board.

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New Jersey Student Learning Standards (NJSLS)

Subject/Content Standards *Include grade appropriate subject/content standards that will be addressed*

Standard #	Standard Description
HS-PS2-2	Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
HS-PS2-4	Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
HS-PS2-5	Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
HS-PS2-6	Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
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.
HS-PS3-2	Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
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.
HS-PS3-5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.
HS-PS4-1	Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
HS-PS4-5	Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

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HS-ETS1-1	Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
HS-ETS1-2	Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
HS-ETS1-3	Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.
HS-ETS1-4	Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

English Companion Standards
List grade-level appropriate companion standards for History, Social Studies, Science and Technical Subjects (CTE/Arts) 6-12. English Companion Standards are required in these subject/content areas.

Unit Addressed	Standard #	Standard Description
1,2,3,4,5	*RST.11-12.1*	*Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.*
2,3,5	*RST.11-12.7*	*Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.*
1,2,3,4,5	*WHST.9-12.9*	*Draw evidence from informational texts to support analysis, reflection, and research.*

Career Awareness, Exploration, Preparation, and Training (Standard 9.2)
List appropriate units below for which standards will be addressed

By Grade 12

Unit Addressed	Core Idea	Standard / Description
3,5	There are strategies to improve one's professional value and marketability.	***9.2.12.CAP.1***: *Analyze unemployment rates for workers with different levels of education and how the economic, social, and political conditions of a time period are affected by a recession.*

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		9.2.12.CAP.2: *Develop college and career readiness skills by participating in opportunities such as structured learning experiences, apprenticeships, and dual enrollment programs.* ***9.2.12.CAP.3***: *Investigate how continuing education contributes to one's career and personal growth.*
3,5	Career planning requires purposeful planning based on research, self-knowledge, and informed choices.	***9.2.12.CAP.4***: *Evaluate different careers and develop various plans (e.g., costs of public, private, training schools) and timetables for achieving them, including educational/training requirements, costs, loans, and debt repayment.* ***9.2.12.CAP.5***: *Assess and modify a personal plan to support current interests and postsecondary plans.* ***9.2.12.CAP.6***: *Identify transferable skills in career choices and design alternative career plans based on those skills.* ***9.2.12.CAP.7***: *Use online resources to examine licensing, certification, and credentialing requirements at the local, state, and national levels to maintain compliance with industry requirements in areas of career interest.* ***9.2.12.CAP.8***: *Determine job entrance criteria (e.g., education credentials, math/writing/reading comprehension tests, drug tests) used by employers in various industry sectors.* ***9.2.12.CAP.9***: *Locate information on working papers, what is required to obtain them, and who must sign them.* ***9.2.12.CAP.10***: *Identify strategies for reducing overall costs of postsecondary education (e.g., tuition assistance, loans, grants, scholarships, and student loans).* ***9.2.12.CAP.11***: *Demonstrate an understanding of Free Application for Federal Student Aid (FAFSA) requirements to apply for postsecondary education.*
3,5	An individual's income and benefit needs and financial plan can change over time.	***9.2.12.CAP.12***: *Explain how compulsory government programs (e.g., Social Security, Medicare) provide insurance against some loss of income and benefits to eligible recipients.* ***9.2.12.CAP.13***: *Analyze how the economic, social, and political conditions of a time period can affect the labor market.*

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3,5	Securing an income involves an understanding of the costs and time in preparing for a career field, interview and negotiation skills, job searches, resume development, prior experience, and vesting and retirement plans.	***9.2.12.CAP.14***: *Analyze and critique various sources of income and available resources (e.g., financial assets, property, and transfer payments) and how they may substitute for earned income.*
5	Understanding income involves an analysis of payroll taxes, deductions and earned benefits.	***9.2.12.CAP.15***: *Demonstrate how exemptions, deductions, and deferred income (e.g., retirement or medical) can reduce taxable income.* ***9.2.12.CAP.16***: *Explain why taxes are withheld from income and the relationship of federal, state, and local taxes (e.g., property, income, excise, and sales) and how the money collected is used by local, county, state, and federal governments.* ***9.2.12.CAP.17***: *Analyze the impact of the collective bargaining process on benefits, income, and fair labor practice.* ***9.2.12.CAP.18***: *Differentiate between taxable and nontaxable income from various forms of employment (e.g., cash business, tips, tax filing and withholding).* ***9.2.12.CAP.19***: *Explain the purpose of payroll deductions and why fees for various benefits (e.g., medical benefits) are taken out of pay, including the cost of employee benefits to employers and self-employment income.* ***9.2.12.CAP.20***: *Analyze a Federal and State Income Tax Return.*
3	There are ways to assess a business's feasibility and risk and to align it with an individual's financial goals.	***9.2.12.CAP.21***: *Explain low-cost and low-risk ways to start a business.* ***9.2.12.CAP.22***: *Compare risk and reward potential and use the comparison to decide whether starting a business is feasible.* ***9.2.12.CAP.23***: *Identify different ways to obtain capital for starting a business*

Life Literacies and Key Skills (Standard 9.4)
List appropriate units below for which standards will be addressed

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By Grade 12		
Unit Addressed	**Core Idea**	**Standard / Description**
1,2,3,4,5	**Creativity and Innovation**: With a growth mindset, failure is an important part of success.	***9.4.12.CI.1***: *Demonstrate the ability to reflect, analyze, and use creative skills and ideas (e.g., 1.1.12prof.CR3a).*
3,5	**Creativity and Innovation**: Innovative ideas or innovation can lead to career opportunities.	***9.4.12.CI.2:*** *Identify career pathways that highlight personal talents, skills, and abilities (e.g., 1.4.12prof.CR2b, 2.2.12.LF.8).* ***9.4.12.CI.3:*** *Investigate new challenges and opportunities for personal growth, advancement, and transition (e.g., 2.1.12.PGD.1).*
1,2,3,4,5	**Critical Thinking and Problem-solving:** Collaboration with individuals with diverse experiences can aid in the problem-solving process, particularly for global issues where diverse solutions are needed.	***9.4.12.CT.1:*** *Identify problem-solving strategies used in the development of an innovative product or practice (e.g., 1.1.12acc.C1b, 2.2.12.PF.3).* ***9.4.12.CT.2:*** *Explain the potential benefits of collaborating to enhance critical thinking and problem solving (e.g., 1.3E.12profCR3.a).* ***9.4.12.CT.3:*** *Enlist input from a variety of stakeholders (e.g., community members, experts in the field) to design a service learning activity that addresses a local or global issue (e.g., environmental justice).* ***9.4.12.CT.4:*** *Participate in online strategy and planning sessions for course-based, school-based, or other projects and determine the strategies that contribute to effective outcomes.*
5	**Digital Citizenship:** Laws govern the use of intellectual property and there are legal consequences to utilizing or sharing another's original works without permission or appropriate credit.	***9.4.12.DC.1***: *Explain the beneficial and harmful effects that intellectual property laws can have on the creation and sharing of content (e.g., 6.1.12.CivicsPR.16.a).* ***9.4.12.DC.2***: *Compare and contrast international differences in copyright laws and ethics*

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3	**Digital Citizenship:** Laws govern many aspects of computing, such as privacy, data, property, information, and identity. These laws can have beneficial and harmful effects, such as expediting or delaying advancements in computing and protecting or infringing upon people's rights.	***9.4.12.DC.3***: *Evaluate the social and economic implications of privacy in the context of safety, law, or ethics (e.g., 6.3.12.HistoryCA.1).* ***9.4.12.DC.4***: *Explain the privacy concerns related to the collection of data (e.g., cookies) and generation of data through automated processes that may not be evident to users (e.g., 8.1.12.NI.3).* ***9.4.12.DC.5***: *Debate laws and regulations that impact the development and use of software.*
3	**Digital Citizenship:** Cultivating online reputations for employers and academia requires separating private and professional digital identities.	***9.4.12.DC.6***: *Select information to post online that positively impacts personal image and future college and career opportunities.*
3,5	**Digital Citizenship:** Digital communities influence many aspects of society, especially the workforce. The increased connectivity between people in different cultures and different career fields have changed the nature, content, and responsibilities of many careers.	***9.4.12.DC.7***: *Evaluate the influence of digital communities on the nature, content and responsibilities of careers, and other aspects of society (e.g., 6.1.12.CivicsPD.16.a).*
3,5	**Digital Citizenship:** Network connectivity and computing capability extended to objects, sensors and everyday items not normally considered computers allows these devices to generate, exchange, and consume data with minimal human intervention. Technologies such as Artificial Intelligence (AI) and blockchain can help minimize the effect of climate change.	***9.4.12.DC.8***: *Explain how increased network connectivity and computing capabilities of everyday objects allow for innovative technological approaches to climate protection.*
3,5	**Global and Cultural Awareness:** Solutions to the problems faced by a global society require the contribution of individuals with different points of view and experiences.	***9.4.12.GCA.1:*** *Collaborate with individuals to analyze a variety of potential solutions to climate change effects and determine why some solutions (e.g., political. economic, cultural) may work better than others (e.g., SL.11-12.1., HS-ETS1-1, HS-ETS1-2, HS-ETS1-4, 6.3.12.GeoGI.1, 7.1.IH.IPERS.6, 7.1.IL.IPERS.7, 8.2.12.ETW.3).*

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3,5	**Information and Media Literacy:** Advanced search techniques can be used with digital and media resources to locate information and to check the credibility and the expertise of sources to answer questions, solve problems, and inform the decision-making.	***9.4.12.IML.1:*** *Compare search browsers and recognize features that allow for filtering of information.* ***9.4.12.IML.2:*** *Evaluate digital sources for timeliness, accuracy, perspective, credibility of the source, and relevance of information, in media, data, or other resources (e.g., NJSLSA.W8, Social Studies Practice: Gathering and Evaluating Sources.*
1,2,3,4,5	**Information and Media Literacy:** Digital tools such as artificial intelligence, image enhancement and analysis, and sophisticated computer modeling and simulation create new types of information that may have profound effects on society. These new types of information must be evaluated carefully	***9.4.12.IML.3****: Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions (e.g., S-ID.B.6a., 8.1.12.DA.5, 7.1.IH.IPRET.8)* ***9.4.12.IML.4****: Assess and critique the appropriateness and impact of existing data visualizations for an intended audience (e.g., S-ID.B.6b, HS-LS2-4).*
5	**Information and Media Literacy:** In order for members of our society to participate productively, information needs to be shared accurately and ethically.	***9.4.12.IML.5****: Evaluate, synthesize, and apply information on climate change from various sources appropriately (e.g., 2.1.12.CHSS.6, S.IC.B.4, S.IC.B.6, 8.1.12.DA.1, 6.1.12.GeoHE.14.a, 7.1.AL.PRSNT.2).* ***9.4.12.IML.6****: Use various types of media to produce and store information on climate change for different purposes and audiences with sensitivity to cultural, gender, and age diversity (e.g., NJSLSA.SL5).*
4	**Information and Media Literacy:** Accurate information may help in making valuable and ethical choices.	***9.4.12.IML.7****: Develop an argument to support a claim regarding a current workplace or societal/ethical issue such as climate change (e.g., NJSLSA.W1, 7.1.AL.PRSNT.4).*
5	**Information and Media Literacy:** Media have embedded values and points of view.	***9.4.12.IML.8****: Evaluate media sources for point of view, bias, and motivations (e.g., NJSLSA.R6, 7.1.AL.IPRET.6).* ***9.4.12.IML.9****: Analyze the decisions creators make to reveal explicit and implicit messages within information and media (e.g., 1.5.12acc.C2a, 7.1.IL.IPRET.4).*

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1,2,3,4,5	**Technology Literacy:** Digital tools differ in features, capacities, and styles. Knowledge of different digital tools is helpful in selecting the best tool for a given task.	***9.4.12.TL.1**: Assess digital tools based on features such as accessibility options, capacities, and utility for accomplishing a specific task (e.g., W.11-12.6.).* ***9.4.12.TL.2**: Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.*
1,2,3,4,5	**Technology Literacy:** Collaborative digital tools can be used to access, record and share different viewpoints and to collect and tabulate the views of groups of people.	***9.4.12.TL.3**: Analyze the effectiveness of the process and quality of collaborative environments.* ***9.4.12.TL.4**: Collaborate in online learning communities or social networks or virtual worlds to analyze and propose a resolution to a real-world problem (e.g., 7.1.AL.IPERS.6).*

Interdisciplinary Connections (2020 NJSLS)
List any other content standards addressed as well as appropriate units. All arts integration connections may be listed within this chart.

Visual & Performing Arts Integration (Standard 1)
List appropriate units below for which standards (1.1 through 1.5) may be addressed

Unit Addressed	Artistic Process	Anchor Standard
1,2,3,4,54	**Creating**	*Anchor Standard 1: Generating and conceptualizing ideas.* *Anchor Standard 2: Organizing and developing ideas.* *Anchor Standard 3: Refining and completing products.*
	Connecting	*Anchor Standard 10: Synthesizing and relating knowledge and personal experiences to create products.* *Anchor Standard 11: Relating artistic ideas and works within societal, cultural, and historical contexts to deepen understanding.*
	Performing/ Presenting/ Producing	*Anchor Standard 4: Selecting, analyzing, and interpreting work.* *Anchor Standard 5: Developing and refining techniques and models or steps needed to create products.* *Anchor Standard 6: Conveying meaning through art.*
	Responding	*Anchor Standard 7: Perceiving and analyzing products.* *Anchor Standard 8: Applying criteria to evaluate products.* *Anchor Standard 9: Interpreting intent and meaning.*

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Unit Addressed	**Content / Standard #**	**Standard Description**
1,2,3,4,5	*Math / MP.4*	*Model with mathematics.*
1,2,3,4,5	*Math / HSN-Q.A.1*	*Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays*
1,2,3,4,5	*Math / HSN-Q.A.2*	*Define appropriate quantities for the purpose of descriptive modeling.*
1,2,3,45	*Math / HSN-Q.A.3*	*Choose a level of accuracy appropriate to limitations on measurement when reporting quantities*
1,2,3,4,5	*Math / HSA-SSE.A.1*	*Interpret expressions that represent a quantity in terms of its context.*
1,2,3,4,5	*Math / HSA-SSE.B.3*	*Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression*
1,2,3,4,5	*Math / HSA-CED.A.1*	*Create equations and inequalities in one variable and use them to solve problems.*
1,2,3,4,5	*Math / HSA-CED.A.2*	*Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales*
1,2,3,4,5	*Math / HSA-CED.A.4*	*Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.*
1,2,3,4,5	*Math / HSF-IF.C.7*	*Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases.*
1,2,3,4,5	*Math / HSS-ID.A.1*	*Represent data with plots on the real number line (dot plots, histograms, and box plots).*

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Pacing Guide (All Dates are approximate based on the school calendar)

Unit/ Topic	Month (w/Approx number of Teaching Days)
Introduction to Dot and Cross Products, and Calculus Introduction	**September** (~19 days)
Review Kinematics, Newton's Laws, Circular Motion Energy and Momentum	**October** (~19 days)
Unit 1 - Electrostatics	**November** (~16 days)
Unit 2 - Conductors, Capacitors and Dielectrics	**December** (~15 days)
Unit 3 - Electric Circuits	**January** (~18 days)
Unit 4 - Magnetic Fields	**February** (~18 days)
Unit 5 - Electromagnetism	**March** (~15-20 days)
AP Review	**April** (~15-20 days)
AP Review/AP Test/Final Exam/Lab Work	**May** (~18 days)
Lab Work/Project	**June** (~15 days)

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[Units Scope and Sequence](#)

Unit : Introduction to Dot and Cross Products, and Calculus Introduction

Learning Goals: What do I want my students to learn?

Standards

NJSLS -

HS-PS2-4
Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

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.

HS-ETS1-2
Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-4
Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

NJSLS - Career Awareness, Exploration, Preparation, and Training
NJSLS - Life Literacies and Key Skills
NJSLS - Interdisciplinary Standards

Fundamental Concepts / Big Ideas

- The concept of a dot product and why we use them
- The concept of a cross product and why we use them
- The process of differentiation and what the result represents
- The process of Integration and what it represents

Learning Objectives

Students will be able to…

- Take a dot product of two quantities and explain the meaning of the result
- Take a cross product of two quantities and explain the meaning of the result
- Take the derivative, using the power rule, and explain the result
- Take an integral using the power rule, and explain the result

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Units

Unit : Review of Mechanics/AP Physics 1

Learning Goals: What do I want my students to learn?

Standards

NJSLS -

HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration

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.

HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

NJSLS - Career Awareness, Exploration, Preparation, and Training
NJSLS - Life Literacies and Key Skills
NJSLS - Interdisciplinary Standards

Fundamental Concepts / Big Ideas

- Motion of an object can be described in terms of position, velocity and acceleration.
- When an object is in free fall the equations of kinematics can describe its motion.
- Motion in horizontal and vertical directions are independent of each other.
- Some quantities are vectors and must be added as such.
- Calculus can be used to find and instantaneous rate of change
- Calculus can be applied to find the area of nonlinear functions
- Acceleration can be predicted by Newton's Second Law
- Work is a form of energy
- The total work done equals the change in kinetic energy
- Total energy is always conserved but can change forms
- Linear momentum is conserved for an object or system if the net external force is zero
- Impulse is equivalent to the change in momentum

Learning Objectives

Students will be able to…

- Define kinematics variables
- Derive equations of kinematics
- Solve problems using equations of kinematics in both one and two dimensions
- Recognize and solve free fall problems

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- Construct and interpret graphs of motion
- Apply calculus to compute and instantaneous rate or an area
- Recognize when it is appropriate to apply calculus vs. algebra
- Apply Newton's Second Law to a single body or system and calculate the acceleration
- Identify the centripetal force for objects in uniform circular motion
- Apply Newton's Second Law for situations where the object is in circular motion
- Recognize when it is appropriate to apply a derivative vs. an integral
- Calculate the work done by a force
- Apply the work-energy theorem to given situations
- Identify when only conservative forces act
- Analyze one dimensional elastic and inelastic collisions and solve for an unknown
- Analyze two dimensional elastic and inelastic collisions and solve for an unknown
- Read and interpret force vs. time graphs and use the graph to solve for an unknown

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Unit 1: Electrostatics

Learning Goals: What do I want my students to learn?
Standards

NJSLS -
HS-PS2-2
Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

HS-PS2-4
Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

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.

HS-PS3-2
Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).

HS-PS3-5
Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

HS-ETS1-4.
Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

NJSLS - Career Awareness, Exploration, Preparation, and Training
NJSLS - Life Literacies and Key Skills
NJSLS - Interdisciplinary Standards

Fundamental Concepts / Big Ideas

- Charge and Coulomb's Law
- Electric field and electric potential (including point charges)
- Gauss's Law
- Fields and potentials of other charge distributions

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Learning Objectives

Students will be able to…
● Describe the types of charge and the attraction and repulsion of charges.
● Describe polarization and induced charges.
● Calculate the magnitude and direction of the force on a positive or negative charge due to other specified point charges.
● Analyze the motion of a particle of specified charge and mass under the influence of an electrostatic force.
● Define it in terms of the force on a test charge.
● Describe and calculate the electric field of a single point charge.
● Calculate the magnitude and direction of the electric field produced by two or more point charges.
● Calculate the magnitude and direction of the force on a positive or negative charge placed in a specified field.
● Interpret an electric field diagram.
● Analyze the motion of a particle of specified charge and mass in a uniform electric field.
● Determine the electric potential in the vicinity of one or more point charges.
● Calculate the electrical work done on a charge or use conservation of energy to determine the speed of a charge that moves through a specified potential difference.
● Determine the direction and approximate magnitude of the electric field at various positions given a sketch of equipotentials.
● Calculate the potential difference between two points in a uniform electric field, and state which point is at the higher potential.
● Calculate how much work is required to move a test charge from one location to another in the field of fixed point charges.
● Calculate the electrostatic potential energy of a system of two or more point charges, and calculate how much work is required to establish the charge system.
● Use integration to determine electric potential difference between two points on a line, given electric field strength as a function of position along that line.
● State the general relationship between field and potential, and define and apply the concept of a conservative electric field.
● Calculate the flux of an electric field through an arbitrary surface or of a field uniform in magnitude over a Gaussian surface and perpendicular to it.
● Calculate the flux of the electric field through a rectangle when the field is perpendicular to the rectangle and a function of one coordinate only.
● State and apply the relationship between flux and lines of force.
● State the law in integral form, and apply it qualitatively to relate flux and electric charge for a specified surface.
● Apply the law, along with symmetry arguments, to determine the electric field for a planar, spherical or cylindrically symmetric charge distribution.
● Apply the law to determine the charge density or total charge on a
● surface in terms of the electric field near the surface.
● Use the principle of superposition to calculate by integration:
    o The electric field of a straight, uniformly charged wire.
    o The electric field and potential on the axis of a thin ring of charge, or at the center of a circular arc of charge.
    o The electric potential on the axis of a uniformly charged disk.
● Identify situations in which the direction of the electric field produced by a charge distribution can be deduced from symmetry considerations.
● Describe qualitatively the patterns and variation with distance of the electric field of:
    o Oppositely-charged parallel plates.

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- A long, uniformly-charged wire, or thin cylindrical or spherical shell.
- Use superposition to determine the fields of parallel charged planes, coaxial cylinders or concentric spheres.
- Derive expressions for electric potential as a function of position in the above cases.

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Units

Unit 2: Conductors, Capacitors, Dielectrics

Learning Goals: What do I want my students to learn?

Standards

NJSLS -

HS-PS2-4
Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

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.

HS-PS3-2
Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).

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.

HS-PS3-5
Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

HS-ETS1-2
Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-4
Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

NJSLS - Career Awareness, Exploration, Preparation, and Training
NJSLS - Life Literacies and Key Skills
NJSLS - Interdisciplinary Standards

Fundamental Concepts / Big Ideas

- Electrostatics with conductors
- Capacitors, how and why they store a given amount of charge
- Dielectrics and how they affect the charge stored
- Why and what amounts of energy a capacitor can store

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Learning Objectives
Students will be able to… ● Explain the mechanics responsible for the absence of electric field inside a conductor, and know that all excess charge must reside on the surface of the conductor. ● Explain why a conductor must be an equipotential, and apply this principle in analyzing what happens when conductors are connected by wires. ● Show that all excess charge on a conductor must reside on its surface and that the field outside the conductor must be perpendicular to the surface. ● Describe and sketch a graph of the electric field and potential inside and outside a charged conducting sphere. ● Describe the process of charging by induction. ● Explain why a neutral conductor is attracted to a charged object. ● Explain why there can be no electric field in a charge-free region completely surrounded by a single conductor, and recognize consequences of this result. ● Explain why the electric field outside a closed conducting surface cannot depend on the precise location of charge in the space enclosed by the conductor, and identify consequences of this result. ● Relate stored charge and voltage for a capacitor. ● Relate voltage, charge and stored energy for a capacitor. ● Recognize situations in which energy stored in a capacitor is converted to other forms. ● Describe the electric field inside the capacitor, and relate the strength of this field to the potential difference between the plates and the plate separation. ● Relate the electric field to the density of the charge on the plates. ● Derive an expression for the capacitance of a parallel-plate capacitor. ● Determine how changes in dimension will affect the value of the capacitance. ● Derive and apply expressions for the energy stored in a parallel-plate capacitor and for the energy density in the field between the plates. ● Analyze situations in which capacitor plates are moved apart or moved closer together, or in which a conducting slab is inserted between capacitor plates, either with a battery connected between the plates or with the charge on the plates held fixed. ● Describe the electric field inside cylindrical and spherical capacitors. ● Derive an expression for the capacitance of cylindrical and spherical capacitors. ● Describe how the insertion of a dielectric between the plates of a charged parallel-plate capacitor affects its capacitance and the field strength and voltage between the plates. ● Analyze situations in which a dielectric slab is inserted between the plates of a capacitor.

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Units

Unit 3: Electric Circuits

Learning Goals: What do I want my students to learn?
Standards

NJSLS -

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.

HS-PS3-2
Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).

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.

HS-PS3-5
Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

HS-ETS1-1
Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-4
Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

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NJSLS - Interdisciplinary Standards

Fundamental Concepts / Big Ideas

- Current, resistance, power and their relationships
- Steady-state direct current circuits with batteries and resistors only
- Capacitors in circuits

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Learning Objectives
Students will be able to… ● Write expressions to describe the time dependence of the stored charge orRelate current and voltage for a resistor. ● Write the relationship between electric field strength and current density in a conductor, and describe, in terms of the drift velocity of electrons, why such a relationship is plausible. ● Describe how the resistance of a resistor depends upon its length and cross-sectional area, and apply this result in comparing current flow in resistors of different material or different geometry. ● Derive an expression for the resistance of a resistor of uniform cross-section in terms of its dimensions and the resistivity of the material from which it is constructed. ● Derive expressions that relate the current, voltage and resistance to the rate at which heat is produced when current passes through a resistor. ● Apply the relationships for the rate of heat production in a resistor. ● Identify on a circuit diagram whether resistors are in series or in parallel. ● Determine the ratio of the voltages across resistors connected in series or the ratio of the currents through resistors connected in parallel. ● Calculate the equivalent resistance of a network of resistors that can be broken down into series and parallel combinations. ● Calculate the voltage, current and power dissipation for any resistor in such a network of resistors connected to a single power supply. ● Design a simple series-parallel circuit that produces a given current through and potential difference across one specified component, and draw a diagram for the circuit using conventional symbols. ● Calculate the terminal voltage of a battery of specified emf and internal resistance from which a known current is flowing. ● Calculate the rate at which a battery is supplying energy to a circuit or is being charged up by a circuit. ● Determine a single unknown current, voltage or resistance. ● Set up and solve simultaneous equations to determine two unknown currents. ● State whether the resistance of voltmeters and ammeters is high or low. ● Identify or show correct methods of connecting meters into circuits in order to measure voltage or current. ● Assess qualitatively the effect of finite meter resistance on a circuit into which these meters are connected. ● Understand the $t = 0$ and steady-state behavior of capacitors connected in series or in parallel. ● Calculate the equivalent capacitance of a series or parallel combination. ● Describe how stored charge is divided between capacitors connected in parallel. ● Determine the ratio of voltages for capacitors connected in series. ● Calculate the voltage or stored charge, under steady-state conditions, for a capacitor connected to a circuit consisting of a battery and resistors. ● Understand the discharging or charging of a capacitor through a resistor. ● Calculate and interpret the time constant of the circuit. ● Sketch or identify graphs of stored charge or voltage for the capacitor, or of current or voltage for the resistor, and indicate on the graph the significance of the time constant. ● voltage for the capacitor, or of the current or voltage for the resistor. ● Analyze the behavior of circuits containing several capacitors and resistors, including analyzing or sketching graphs that correctly indicate how voltages and currents vary with time.

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Units

Unit 4: Magnetic Fields
Learning Goals: What do I want my students to learn?
Standards
NJSLS - *HS-PS2-2* *Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.* *HS-PS2-4* *Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.* *HS-PS2-5* *Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.* *HS-PS2-6* *Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* *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.* *HS-PS3-2* *Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).* *HS-PS3-5* *Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.* *HS-ETS1-4* *Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.* *NJSLS - Career Awareness, Exploration, Preparation, and Training* *NJSLS - Life Literacies and Key Skills* *NJSLS - Interdisciplinary Standards*

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Fundamental Concepts / Big Ideas
• Forces on moving charges in magnetic fields • Forces on current-carrying wires in magnetic fields • Fields of long current-carrying wires • Biot-Savart Law and Ampere's Law

Learning Objectives
Students will be able to… • Calculate the magnitude and direction of the force in terms of • $\vec{q}$, $\vec{v}$, and $\vec{B}$,and explain why the magnetic force can perform no work. • Deduce the direction of a magnetic field from information about the forces experienced by charged particles moving through that field. • Describe the paths of charged particles moving in uniform magnetic fields. • Derive and apply the formula for the radius of the circular path of a charge that moves perpendicular to a uniform magnetic field. • Describe under what conditions particles will move with constant velocity through crossed electric and magnetic fields. • Calculate the magnitude and direction of the force on a straight segment of current-carrying wire in a uniform magnetic field. • Indicate the direction of magnetic forces on a current-carrying loop of wire in a magnetic field, and determine how the loop will tend to rotate as a consequence of these forces. • Calculate the magnitude and direction of the torque experienced by a rectangular loop of wire carrying a current in a magnetic field. • Calculate the magnitude and direction of the field at a point in the vicinity of such a wire. • Use superposition to determine the magnetic field produced by two long wires. • Calculate the force of attraction or repulsion between two long current-carrying wires. • Deduce the magnitude and direction of the contribution to the magnetic field made by a short straight segment of current-carrying wire. • Derive and apply the expression for the magnitude of $\vec{B}$ on the axis of a circular loop of current. • State Ampere's Law precisely. • Use Ampere's law, plus symmetry arguments and the right-hand rule, to relate magnetic field strength to current for planar or cylindrical symmetries. • Apply the superposition principle so they can determine the magnetic field produced by combinations of the configurations listed above.

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Units

Unit 5: Electromagnetism

Learning Goals: What do I want my students to learn?
Standards
[NJSLS](#) - *HS-PS2-5* *Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.* *HS-PS2-6* *Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* *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.* *HS-PS3-2* *Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).* *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.* *HS-PS3-5* *Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.* *HS-PS4-1* *Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.* *HS-PS4-5* *Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.* *HS-ETS1-1* *Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.* *HS-ETS1-2*

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Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-4
Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

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Fundamental Concepts / Big Ideas

- Electromagnetic induction (including Faraday's law and Lenz's law)
- Inductance (including LR and LC circuits)
- Maxwell's equations

Learning Objectives

Students will be able to…

- Calculate the flux of a uniform magnetic field through a loop of arbitrary orientation.
- Use integration to calculate the flux of a non-uniform magnetic field, whose magnitude is a function of one coordinate, through a rectangular loop perpendicular to the field.
- Recognize situations in which changing flux through a loop will cause an induced emf or current in the loop.
- Calculate the magnitude and direction of the induced emf and current in a loop of wire or a conducting bar under the following conditions:
  - The magnitude of a related quantity such as magnetic field or area of the loop is changing at a constant rate.
  - The magnitude of a related quantity such as magnetic field or area of the loop is a specified non-linear function of time.
- Analyze the forces that act on induced currents so they can determine the mechanical consequences of those forces.
- Calculate the magnitude and sense of the emf in an inductor through which a specified changing current is flowing.
- Derive and apply the expression for the self-inductance of a long solenoid.
- Apply Kirchhoff's rules to a simple LR series circuit to obtain a differential equation for the current as a function of time.
- Solve the differential equation obtained in the LR series circuit for the current as a function of time through the battery, using separation of variables.
- Calculate the initial transient currents and final steady state currents through any part of a simple series and parallel circuit containing an inductor and one or more resistors.
- Sketch graphs of the current through or voltage across the resistors or inductor in a simple series and parallel circuit.
- Calculate the rate of change of current in the inductor as a function of time.
- Calculate the energy stored in an inductor that has a steady current flowing through it.
- Be familiar with Maxwell's equations and associate each equation with its implications.

Please contact the Content Supervisor for any questions.

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