Unit 2
Fields
Suggested Time: 47 Hours

Unit Overview

Introduction

Students have had experience with contact forces. Forces that exert influence through space without contact are more difficult to visualize. Historically, the notion of a field of influence which could be mapped and within which results are predictable went a long way in explaining and relating a wide range of different forces. The field remains one of the major unifying concepts of physics.

Focus and Context

We live in a world where the technological exploitation of our knowledge of electricity is expanding at an astonishing rate. Alexander Graham Bell would not recognize today's ultra-small digital phones. Maxwell could hardly have predicted that we would be cooking our dinner with radio waves. Plasma displays for computers are finding their way onto our walls as large, thin television screens. A space probe has been recently placed in orbit around an asteroid.

There is a rich context for the study of fields in everyday experience. It is important, however, to present also the historical context of the discovery and development in these areas. This historical context provides students with opportunities to explore the interconnectedness of science and technology. Students can improve their understanding of the concepts by reading and writing about their historical development.

When a force is applied to a mass by direct contact, it is not difficult to understand the event. When a magnet attracts a nail, or a plastic comb attracts a piece of paper, or a meteorite is pulled to Earth by gravity, an explanation is more challenging. When a force acts over a distance without obvious contact, what is the mechanism by which it acts?

Michael Faraday, in the mid-nineteenth century, first used the field concept to explain electric effects. In the early twentieth century, Albert Einstein used field principles to develop general relativity, his explanation of gravitation.

Field theory has provided a common lens through which to view phenomena that at first seemed unrelated. Beginning in the 1960s, physicists began to search in earnest for a unified field theory which would combine electromagnetism and gravitation as different aspects of a single field. The search continues.

Science Curriculum Links

This unit is an extension of forces, into the broader study of fields. The study of fields is essential for an understanding of structure in physics and chemistry. Students have studied electricity in Grade 9 (statics, current, voltage, resistance, generator, solar cell and circuits.

Curriculum Outcomes

STSE

Students will be expected to

Nature of Science and Technology

115-5 analyse why and how a particular technology was developed and improved over time

Relationships Between Science and Technology

116-4 analyse and describe examples where technologies were developed based on scientific understanding

116-6 describe and evaluate the design of technological solutions and the way they function, using scientific principles

Social and Environmental Contexts of Science and Technology

117-5 provide examples of how science and technology are an integral part of their lives and their community

117-7 identify and describe science- and technology-based careers related to the science they are studying

118-2 analyse from a variety of perspectives the risks and benefits to society and the environment of applying scientific knowledge or introducing a particular technology

118-4 evaluate the design of a technology and the way it functions on the basis of a variety of criteria that they have identified themselves

Skills

Students will be expected to

Initiating and Planning

212-2 define and delimit problems to facilitate investigation

212-3 design an experiment identifying and controlling major variables

212-4 state a prediction and a hypothesis based on available evidence and background information

212-6 design an experiment and identify specific variables

Performing and Recording

213-2 carry out procedures controlling the major variables and adapting or extending procedures where required

213-3 use instruments effectively and accurately for collecting data

213-4 estimate quantities

213-8 select and use apparatus and materials safely

Analysing and Interpreting

214-3 compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots

214-5 interpret patterns and trends in data, and infer or calculate linear and non-linear relationships among variables

Communication and Teamwork

215-1 communicate questions, ideas, and intentions, and receive, interpret, understand, support, and respond to the ideas of others

Knowledge

Students will be expected to

328-1 describe gravitational, electric, and magnetic fields as regions of space that affect mass and charge

328-2 describe gravitational, electric, and magnetic fields by illustrating the source and directions of the lines of force

328-3 describe electric fields in terms of like and unlike charges, and magnetic fields in terms of poles

328-4 compare Newton's universal law of gravitation and Coulomb's law, and apply both laws quantitatively

ACP-3 apply Ohm's Law to series, parallel, and combination circuits

328-5 analyse, qualitatively and quantitatively, the forces acting on a moving charge and on an electric current in a uniform magnetic field

328-6 describe the magnetic field produced by current in both a solenoid and a long, straight conductor

328-7 analyse, qualitatively and quantitatively, electromagnetic induction by both a changing magnetic flux and a moving conductor

ACP-4 describe and compare direct current and alternating current

Gravitational and Electric Fields

Outcomes

Students will be expected to

- describe gravitational fields as regions of space that affect mass, and illustrate the source and direction of the lines of force (328-1, 328-2)
  - explain what is meant by the term field
  - explain what is meant by a gravitational field
  - map a gravitational field, showing the field lines about a spherical object.
- explain the production of static electricity and its properties (308-13, 308-14, 308-15)
  - define electrostatic forces
  - describe the atom as the source of electrostatics
  - state the law of electric charges
  - describe the operation of an electroscope
  - demonstrate and explain charging by:
    (i) friction
    (ii) contact
    (iii) induction
  - state the SI unit of charge
  - calculate the number of excess electrons or protons on a body, given its net charge in Coulombs
  - calculate the charge on a body given the number of excess electrons or protons
  - discuss the nature of electrical discharge
  - distinguish between conductors and insulators

Elaborations—Strategies for Learning and Teaching

Teachers should point out to students that we use the field concept to explain how a force can act over a distance. This is different from the contact forces studied in unit 1.

The gravity field is a starting point to develop field theory because students live in it and can relate to a gravity field. Once this is done an excellent demonstration would be to move a pith ball around using a charged rod (or plastic pocket comb). Students can then move from the elementary explanation of "like charges repel" to their study of electric forces and fields.

Static electric charge should be explored both in the lab and in historical context. It is interesting for students to note that two types of charge and three conditions (positive, negative, and neutral) were identified before any explanation of the cause of the charge was proposed. It is pure chance that the type of charge identified traditionally as negative is, in fact, caused by an excess of negatively charged electrons.

The SI unit of charge is the Coulomb.

1 coulomb = 6.24×10^{18} electrons

e = charge on

one electron = 1.602×10^{-19}C (or one proton)

Millikan discovered that the number of elementary charges on a charged object is given by $N = \frac{q}{e}$, therefore, $q = Ne$ (see page 575 of the textbook).

Gravitational and Electric Fields

Suggested Assessment Strategies

Paper and Pencil

- Write a report, including diagrams, that indicate in steps how various charges can be placed on an electroscope by:
  - (a) contact
  - (b) induction (328-1)
- Explain why a comb, that has been rubbed through your hair, attracts small bits of paper, even though the paper is uncharged. (308-13, 308-14, 308-15)
- How can you determine the charge on a charged electroscope? (308-13, 308-14, 308-15)

Journal

- Students could address some of the following issues in their journals:
  - (i) what are some everyday experiences with static electricity?
  - (ii) how do fabric softener sheets remove static cling from clothing?
  - (iii) how does a photocopier or laser printer work?
  - (iv) how does an eleectrostatic air filter work?
  - (v) how does a swiffer™ cloth work?
  - (vi) how methods of charging are involved in the production of lightning. (308-13, 308-14, 308-15)

Resources/Notes

Concepts and Connections

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Gravitational and Electric Fields *(continued)*

Outcomes

Students will be expected to

- state a prediction based on available evidence (212-4)
- interpret patterns and trends in data, and infer relationships among variables (214-5)
- display evidence in a variety of formats, including diagrams, tables, and graphs (214-3)

Elaborations—Strategies for Learning and Teaching

The Laboratory outcomes 214-5, 214-3, 214-5, 214-16 and in part, 308-13, 308-14, 308-15 are addressed by completing *The Law of Electric Charges,* CORE LAB #4. Teachers should also add charging by contact and induction to this lab.

Gravitational and Electric Fields *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- Suppose you have two identical spheres and you put a charge of 4.0 microCoulombs on one sphere and nothing on the other. If you allow these spheres to touch, and then to separate again, what will be the charge on each sphere now? (212-4)

Performance

- Design a way to charge a person positively by induction using a Van der Graaf generator and an insulating stand. Demonstrate it in front of the class. (308-13, 308-14, 308-15)

Resources/Notes

Core Lab #4: *"The Law of Electric Charges*", **pages 587-588**

Gravitational and Electric Fields *(continued)*

Outcomes

Students will be expected to

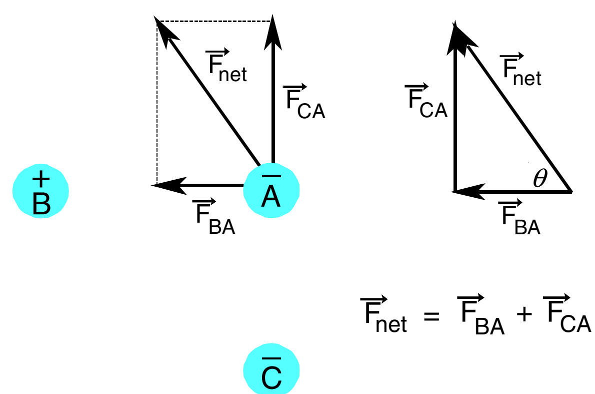
- compare Newton's Law of universal gravitation with Coulomb's Law, and apply both laws quantitatively (328-4)
  - state Coulomb's Law of electric force in sentence and in formula form
  - state the SI unit of charge
  - explain how the force between two charged particles depends on the values and types of the charges and their separation
  - given four of: distance separating two charged particles, charge on each, force between them, and Coulomb's constant, calculate the fifth quantity
  - calculate the electric force on a charged particle due to the presence of other charges when (i) all charges are on a common straight line, and (ii) when these other charges are on perpendicular lines that intersect at the first charged particle

Elaborations—Strategies for Learning and Teaching

There is a very useful table summarizing both laws on page 540 of the *Concepts and Connections* textbook.

Teachers should note that in the textbook page 543 under "The Vector Nature of Electric Forces between Charges" questions such as number 8 do not need to be covered. Coulomb's Law problems are limited to colinear and perpendicular vectors. For example: Calculate the electric force on a charged particle due to the presence of other charges when (i) all charges are on a common straight line, and (ii) when these other charges are on perpendicular lines that intersect at the first charged particle.

The diagram below illustrates the above example. The charges and distances are chosen in an arbitrary way. Read the forces like this: F_{xy} equals the force of x on y.



Where,

Q_A = -2.0 x 10^{-6}C, Q_B = +4.0 x 10^{-6}C, Q_C = -3.0 x 10^{-6}C

d_{BA} = distance between centres of B and A = 15.0 cm

d_{CA} = distance between centres of C and A = 10.0 cm

Teachers could ask, "What is the net force on A due to the presence of B and C?"

Because of the nature of the charges we know that B attracts A, and C repels A. First we find each of these forces and then add them using the Pythagorean theorem and trigonometry for the direction.

For charges that are perpendicular to one another (as shown above), students will only be asked to find the net force on the charge placed at the vertex of the right angle.

Gravitational and Electric Fields *(continued)*

Suggested Assessment Strategies

Performance

- We know that when we rub our heads with a balloon, the balloon becomes statically charged. Assuming that the balloon becomes negatively charged, the balloon must be stealing electrons from our hair. A simple experiment and some vector work can give us an idea of how many electrons we take from our heads.

  Students can use two balloons, two metre sticks, scale/balance, and 2.0 m of string. Blow up the two balloons so that they are approximately the same size. They can measure and record the mass of the balloon, then tie the two balloons together with a piece of string approximately 1.5×10^2 cm long. Drape them over one of the metre sticks or a bar which is at least one or two metres above the ground. Make sure the balloons are side by side and not touching any other objects. Measure and record the length from the centre of the balloon to the point where the string meets the bar. Take the two balloons and rub them vigorously on your head. Let the two balloons touch each other for a few seconds to ensure that both balloons have the same charge. Determine the distance between the centres of the balloons and the angle at the top of the string. You now have enough data to determine the number of electrons on each balloon.

  In your analysis, draw a free body diagram for one of the balloons showing vectors representing gravitational force, tension force, and electric repulsion force. Use Coulomb's Law to determine the amount of charge on each balloon and from the charge, determine the number of electrons. (212-2, 213-4, 214-5, 328-4)

Paper and Pencil

- Suppose that a friend has missed class for several days and was not present when Coulomb's Law was covered. Write a complete explanation of the Law and how to use it to solve problems. (328-4)

Resources/Notes

Concepts and Connections

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Gravitational and Electric Fields *(continued)*

Outcomes

Students will be expected to

- describe electric fields as regions of space that affect charges (like and unlike), and illustrate the source and direction of the lines of force (328-1, 328-2, 328-3)
  - explain what is meant by an electric field
  - explain the concept of the electrical test charge
  - explain and be able to draw electric fields lines for:
    (i) single point charges
    (ii) two point charges (opposite and alike)
    (iii) parallel plates
    (iv) single conductors
  - define equipotential lines

Elaborations—Strategies for Learning and Teaching

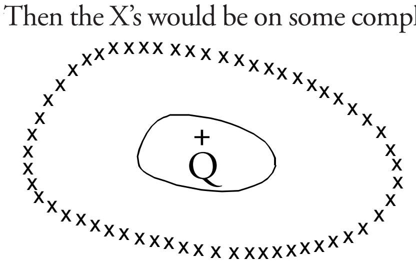
Students could explore and describe the field around various charged objects using a suspended pith ball. Many texts have pictures of grass seeds in oil used to display the electric field in much the same manner as iron filings show the magnetic field. Students should draw field diagrams which show the lines of force related to a positive test charge around single objects and between two objects. It might be useful to map the field in terms of equipotential lines, which indicate the inverse square nature of the field.

If a Van der Graaf generator is available, a graphite-coated Styrofoam ball suspended from a metre stick makes a good tool for exploring the field around a charged sphere. Students could model fields using Styrofoam balls and pipe cleaners.

Teachers should point out to students that force lines start on the positive object and end on the negative object. The lines are perpendicular to the surface of the object. Lines never cross. Students should also realize that the closeness of the lines of force indicate the strength of the field. Students will have to be cognizant of this when drawing the field around the pear-shaped conductor because the charge is denser at the pointed end.

A useful approach to equipotential lines is for students to imagine an object with a charge +Q. They could also imagine a small test charge +q an exremely long distance away from +Q that is unaffected by it, i.e., the potential energy of +q is zero. Now to bring the test charge towards the charged object, work must be done because there is a repulsion force between +Q and +q. Imagine that +Q can approach from any direction. This means you can lay +q down anywhere around +Q.

In the picture below the line of x's show some of the possible places where +q will be laid down so that one does exactly the same amount of work in bringing +q from a great distance to those points. Therefore, the electric potential energy gained by the test charge is the same at all points marked x. So, the line joining the x's is an equipotential line. (A good analogy is contour lines in geography.) Teachers should note that equipotential lines are perpendicular to the lines that represent the electric field around the object. Field lines are not shown in the picture below. As far as equipotential surfaces are concerned, it is important to think in three dimensions. For example, the picture below could be viewed as an onion. Then the X's would be on some complete layer of onion.



Note tht an understanding of equipotential lines is important in introducing electric potential difference later in the course.

Gravitational and Electric Fields *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- Draw diagrams to represent the fields around a point positive or negative charge, the region between two point positive charges, the region between two point negative charges, and the region between a point positive and a point negative charge. (328-2)
- Draw a diagram to represent the field between oppositely charged parallel plates.

Performance

- Make a poster showing similarities and differences between the electric and gravitational fields. (328-1, 328-2, 328-3, 328-4)

Resources/Notes

Concepts and Connections

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Gravitational and Electric Fields *(continued)*

Outcomes

Students will be expected to

- describe electric fields as regions of space that affect charges (like and unlike), and illustrate the source and direction of the lines of force (328-1, 328-2, 328-3) (**Cont'd**)
  - write an operational definition for electric field, and the SI unit in which it is measured
  - given the two of the electric field, the size of a positive test charge, and the electric force on it, calculate the third quantity
  - use the equation for the electric field in the region of single-charged particle or sphere
  - given three of: the charge of a particle or sphere, Coulomb's constant, the distance from the particle or sphere at which the field is specified, and the value of that field, calculate the fourth quantity

Elaborations—Strategies for Learning and Teaching

Students should state that the electric field (strength) at a particular point in the field is defined as the force per unit charge on a positive test charge placed at that point: $\vec{\varepsilon} = \frac{\vec{F}}{q}$ and if F is replaced with Coulomb's law then $\vec{E} = \frac{kq}{r^2}$.

Students should be able to do exercises similar to the folowing:

1. A charged Van der Graff generator creates a field around it. At a particular point in the field a test charge of 1.5×10^{-6} C experiences a force of 3.0×10^{-4} N. What is the magnitude of the electric field strength at that point?

Solution: $$\varepsilon = \frac{F}{q} = \frac{3.0\times10^{-4}N}{1.5\times10^{-6}C} = 2.0\times10^{2}\ N/C$$

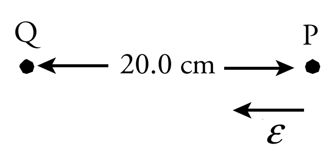
Students should be provided with exercises which give practice in calculating "F" and "q" when the other two terms are given.

2. Calculate the magnitude and direction of the electric field at a point P which is 20.0 cm to the right of a point charge Q = -2.5×10^{-6} C.

Solution: $$\varepsilon = k\frac{Q}{d^2} = \frac{9.0\times10^{9}\ N\cdot m^2/C^2 \times 2.5\times10^{-6}C}{(0.200m)^2}$$

$$\varepsilon = 5.6\times10^{5}\ N/C$$

The direction is toward the charge Q, or left.



In this example one can calculate the electic field strength without knowing the size of the test charge or the force exerted on it.

Gravitational and Electric Fields *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- Find the electric field strength 45 cm from a 6.0 μC charged object. (328-1, 328-2, 328-3)
- What is the electric field strength at a point where a -3.5 μC test charge experiences an electric force of 6.5×10^{-2}N? (328-1, 328-2, 328-3)
- Calculate the gravitational field strength (g); a) on the surface of Earth b) at one Earth radius above Earth's surface. (328-1, 328-2, 328-3)
- The electric field strength at a distance of 0.35 m from a charged object is 3.6×10^5 N/C. What is the electric field strength at a distance of 0.45 m from the same object? (328-1, 328-2, 328-3)
- Determine the electric field strength at point, P in the diagram below:

  ← 0.35m →← 0.35m →
  • P_x •
  70.0μC - 80.0μC

  (328-1, 328-2, 328-3)

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Gravitational and Electric Fields *(continued)*

Outcomes

Students will be expected to

- describe electric fields as regions of space that affect charges (like and unlike), and illustrate the source and direction of the lines of force (328-1, 328-2, 328-3) (**Cont'd**)
  - calculate the electric field at a point due to the presence of other charges when all charges are on a common straight line
  - extend the work-energy theorem to develop the concept of electric potential energy
  - use a reference point or level to define electrical potential

Elaborations—Strategies for Learning and Teaching

A representative example of this type of problem is #10 on page 555 of the *Concepts and Connections* textbook. It is very important that students understand the vector nature of electric fields, and therefore, apply vector principles for the direction of the electric field at a point.

The student should be able to express an understanding of the analogy in most textbooks which shows gravitational potential energy increasing as work is done to raise a weight above Earth. This analogy can be extended to explain that the electric potential energy of an electron increases when work is done on it to force it away from a positively charged region. (Note that it is equally correct to discuss the increase in electric potential energy of a positive charge that is forced away from a negatively charged region.) Students can therefore define electric potential energy as the total electrical energy (E_e) required to move charge from one region to another of higher potential.

This outcome uses the term electrical potential. The previous objective defines electric potential energy. Students should be able to distinguish these terms and understand the difference between them. Electric potential energy is the total energy (E_e) required to move charge from some low potential region to a higher potential region. Electrical potential is defined as the energy per unit charge required to raise that charge to a region of higher potential.

There are two differences between electrical potential and electric potential energy. They are: electric potential

(i) is electric potential energy per unit charge,

and (ii) is always with reference to a zero level of potential.

while electric potential energy is the total energy of the charge.

Put symbolically:

Electric Potential Energy = E_e/q (zero reference) $\left(v = E_e/q\right)$

and Change in Electric Potential = W $\left(\Delta E_e = W\right)$

Gravitational and Electric Fields *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- What is the electric field midway between charged objects of -3.2 μC and +4.7 μC that are placed 80.0 cm apart? (328-1, 328-2, 328-3)
- Distinguish between electric potential, electric potential energy and electric potential difference. (328-1, 328-2, 328-3)
- At what point between a -0.20 μC and a -0.50 μC point charge would the electric field strength be zero, given that the charges are 1.0 m apart? (328-1, 328-2, 328-3)

Journal

- Ask students to research the use of electric fields in television screens or computer monitors. (328-1, 328-2, 328-3)

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Gravitational and Electric Fields *(continued)*

Outcomes

Students will be expected to

- describe electric fields as regions of space that affect charges (like and unlike), and illustrate the source and direction of the lines of force (328-1, 328-2, 328-3) (**Cont'd**)
  - define electrical potential difference and its SI unit of measurement
  - given two of electric potential difference, the work done (or energy), and charge, calculate the third

Elaborations—Strategies for Learning and Teaching

Electrical potential difference (ΔV) is the energy required (or work done) per unit charge to move that charge from any point of low potential to any other point of higher potential. That is, $\Delta V = W/Q$ with units Joule/Coulomb called the volt. Electric Potential and Electric Potential Difference (V) have the same units:

$$W/Q = \text{joules/coulombs} = \text{volts}$$

When students encounter circuits they will realize that an electric potential difference can be a "drop" as well as a "rise". In circuitry, electric potential difference is usually shortened to potential difference or voltage. Students should understand that a battery can work as though it "spans" two equipotential lines.

Note, it is very important to emphasize electric potential difference to avoid misconceptions when studying voltage and current in electric circuit analysis.

Gravitational and Electric Fields *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- What potential difference is required to increase the energy of a electron from 0 to 3.0×10^{16} J? (328-1, 328-2, 328-3)
- A bird lands at a point on a 2.0×10^{4} V, bare transmission line. Explain why the bird does not become electrocuted? (328-1, 328-2, 328-3)
- A person stands on an insulated stand touching a high voltage Van der Graaf generator. His/her hair stands on end. Yet he/she feel no electical shock. Explain. (328-1, 328-2, 328-3)

Journal

- Research how linesman with Newfoundland Power employ safety practices to preventr electrocution in the presence of high voltage. (328-1, 328-2, 328-3)

Resources/Notes

Concepts and Connections

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pages 563 - 569

Electric Circuits

Outcomes

Students will be expected to

- apply Ohm's Law to series, parallel, and combination circuits (ACP-3)

Elaborations—Strategies for Learning and Teaching

Students could begin this topic with a discussion of familiar applications of electric circuits. They should be encouraged to ask questions such as the following: Why don't birds get electrocuted? Are there electric circuits in the human body? How does an EKG or EEG work? Why is the earphone cord to a walkman so much thinner than a booster cable for jump-starting a car? How does a circuit breaker (fuse) work? How can one light be switched on or off at two different switches? How can a house be safely connected to a very powerful line which serves many other houses? How does the electric company know how much energy we have used? These questions could be collected on a side board or poster and referred to as the study progresses.

Students should refine their operational definitions of current, potential difference, resistance, and power. Although students might have a generally acceptable understanding of current as the ratio of quantity of charge to elapsed time and know that ampere equals Coulombs/second, they might need to clarify the definition of the Coulomb. Students might have learned definitions of the volt as a unit of force or pressure; this definition should be changed to a more appropriate energy difference per charge. This is not an easy change for students to accept. First, they must "unlearn" meanings constructed several years ago. Second, they must replace that meaning with an energy definition which is much less intuitive. The teacher should consistently use the new definition, and students should be given opportunities to verbalize and write about this new concept. In the same way, electrical resistance measured in ohms should be redefined the ratio of potential difference to current. The everyday use of the term "power," when, in fact, the scientifically correct term is energy, must also be clarified, and the unit kWh revealed for what it really is.

Electric Circuits

Suggested Assessment Strategies

Resources/Notes

Electric Circuits *(continued)*

Outcomes

Students will be expected to

- apply Ohm's Law to series, parallel, and combination circuits (ACP-3) (**Cont'd**)
  - list and name the type of energy transformation from various sources of electrical energy including; voltaic cells, piezoelectric, thermoelectric, photoelectric and generators
  - define electric current and name its SI unit of measurement and the instrument used in such measurements
  - define voltage as the energy per unit charge developed within a source, and define its SI units
  - given the two of : the electric current (I), the charge (q) which passes through a cross section of a conductor, and the time(t) taken, calculate the third quantity
  - given two of: the voltage, the charge and energy developed by the source, calculate the third quantity

Elaborations—Strategies for Learning and Teaching

Teachers can reference p. 598 of the textbook.

Introduce students to the basic definitions of current, $I = \frac{q}{t}$ and voltage, $V = \frac{\varepsilon}{q}$. They may show students that if we rearrange the equations to $\varepsilon = Vq$ and q=It by substitution you get $\varepsilon = VIt$. It should also be noted that in this textbook we will use electron current flow, i.e. from negative to positive, and not conventional current (see page 591 of textbook) If students move on to AP level courses or university they will use conventional current flow. This should be pointed out to students who will move on to other physics courses.

Electric Circuits *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- What is the electric current through a conductor if a charge of 2.00 C flows through a point in the conductor in 8.0 s? (ACP-3)
- A current of 2.5 A flows for 5.0 s through a conductor. Calculate the number of electrons that pass through a point in the conductor in this time. (ACP-3)
- How long would it take 2.0 x 10^{21} electrons to pass through a point in a conductor if the current were 12A? (ACP-3)

Resources/Notes

Concepts and Connections

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Electric Circuits *(continued)*

Outcomes

Students will be expected to

- apply Ohm's Law to series, parallel, and combination circuits (ACP-3) (**Cont'd**)
  - state Ohm's Law
  - define electrical resistance and its SI unit of measurement
  - given two of: the voltage across a resistor, its resistance, and the current in it, calculate the third quantity

Elaborations—Strategies for Learning and Teaching

Students could carry out an investigation of Ohm's law with a single resistor. They could determine the relationship between voltage and current in a circuit with a single resistance (Ohm's law). Then students could predict the voltage and current readings for the following circuits and test their predictions experimentally:

- two resistors in series, three resistors in series
- two in parallel
- one in series with two in parallel
- one in parallel with two in series

The teacher must give consideration to current flow convention. Current is assumed to be electron flow.

Students should manipulate Ohm's Law equation: $R = \frac{V}{I}$, in a variety of situations. The practical study of Ohm's Law presents an excellent opportunity to develop concepts on the nature of science. The recommended invesgtigation above develops Ohm's Law from empirical data and involves the development of the relationship between V and I. If this investagation cannot be performed by individual students, teachers should demonstrate the investigation (see p. 600 for a possible investigation set up).

Electric Circuits *(continued)*

Suggested Assessment Strategies

Journal

- How has your understanding of voltage, current, and resistance changed since grade 9? (ACP-3)
- Research the operation of 3-way light bulbs. (ACP-3)

Paper and Pencil

- What potential difference is required across a conductor to produce a current of 6.0 A if there is a resistance in the conductor of 12 Ω ? (ACP-3)
- Calculate the resistance in a conductor if the potential difference is 12 V and the current is 3.0 A. (ACP-3)

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Electric Circuits *(continued)*

Outcomes

Students will be expected to

- apply Ohm's Law to series, parallel, and combination circuits (ACP-3) (**Cont'd**)
  - explain why a resistor is called a linear circuit element
  - list and describe the factors that affect resistance. Include:
    (i) length
    (ii) cross-sectional area
    (iii) type of material
    (iv) temperature
  - solve problems that model the factors of resistance using:
    (i) proportionalities
    (ii) using $R = \rho \frac{L}{A}$

Elaborations—Strategies for Learning and Teaching

A resistor is a linear circuit element because it is fairly independent of the current passing through it. In such cases a graph of V versus I gives a straight line with slope, R. Note: Linear circuit elements are also known as ohmic materials since they obey Ohm's Law. Non-ohmic elements like semi-conductors do not obey Ohm's Law.

While direct application of the formula is not especially challenging, students should be able to apply knowledge of direct proportionality and the inverse square law to answer questions like:

1. A certain piece of copper wire has a resistance of 2.0 x 10^{-3} ohms. What would be the resistance of another piece of copper wire with the same cross-sectional area but twice the length? Answer: Since $R \propto L$, the second piece will have twice the resistance, i.e, 4.0 x 10^{-3} ohms

2. A 1.0 m piece of wire with a cross-sectional radius of 3.0 mm has a resistance of 9.0 x 10^{-4} ohms. If the wire is stretched until its radius is reduced to 1.0 mm, what will be the resistance of a 1.0 m piece? Answer: Since length is the same, we deal only with the cross-sectional area. Since R is inversely proportional to the area, it is inversely proportional to the square of the radius ($A = \pi r^2$). Since the radius of the new piece of wire is three times smaller than the radius of the first piece, the new resistance will be 9 times the first resistance, giving 81 x 10^{-4} ohms or 8.1 x 10^{-3} ohms.

3. Wire "A" has a length of 2.0 m, a diameter of 2.0 mm and a resistance of 0.0040 ohms. What would be the resistance of another wire "B" of the same material has a length of 0.50 m, a diameter of 1.0 mm? Answer: 0.0040 ohms. Since $L_B = \frac{1}{4} L_A$ this has the effect of quartering the resistance to 0.0010 ohms, because R is directly proportional to L. However, the diameter, and hence the radius is reduced by a factor of 2. Therefore, the resistance increases by a factor 4, because R is inversely proportional to the square of the radius. So, this effect exactly cancels the first effect and the resistance remains at 0.0040 ohms.

4. What is the resistivity of a piece of copper wire that is 1.8 m long and 1.2 mm in diameter, if the resistance between the ends of the wire is $0.027\ \Omega$?

Answer:

$$R = \rho \frac{L}{A} \qquad \therefore\ \rho = \frac{RA}{L}$$

$$\rho = \frac{(0.027\Omega)\pi(0.00060\text{m})^2}{1.8\text{m}}$$

$$\rho = 1.7 \times 10^{-8}\Omega.\text{m}$$

Electric Circuits *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- A current flows through a copper wire 1.8 m long and 1.2 mm in diameter. Find the resistance between the end of the wire given the resistivity of copper is 1.72 x $10^{-8}\ \Omega \cdot m$ (ACP-3)
- A length of wite is cut in half and the two lengths are wrapped together side by side to make a thicker wire. How does the resistance of this new combination compare to the resistance of the original wire? (ACP-3)

Performance

- Design and perform an experiment to measure the resistivity of a large rectangular block of material. (ACP-3)

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Electric Circuits *(continued)*

Outcomes

Students will be expected to

- apply Ohm's Law to series, parallel, and combination circuits (ACP-3) (**Cont'd**)
  - draw a schematic diagram for series, parallel and simple combination circuits
  - explain the energy transfer of charge around a circuit
  - analyze the relationship between voltage rises and voltage drops across linear resistors and sources
  - state and apply Kirchoff's current rule
  - state and apply Kirchoff's voltage rule
  - use the equation for the effective value of resistance in series and parallel circuits. Include:

    (i) $R_T = R_1 + R_2 + R_3 + ..$

    (ii) $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$

Elaborations—Strategies for Learning and Teaching

Students should draw schematics of series circuits containing an electrical source, a switch, a light bulb, resistor and electrical meters.

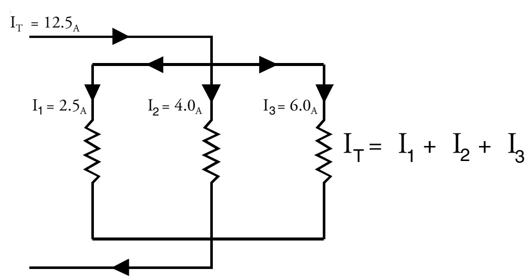
Student should know how to place ammeters and voltmeters in series and parallel circuits, and now to read their values. Students are not responsible for studying the internal construction of these meters.

Students should relate the energy rise in the source to drop around the load as per the law of conservation of energy (see table on page 598 in the textook).

Students should use a type of reasoning similar to the following:

- The law of conservation of electric charge states that charge cannot be created or destroyed.
- The amount of charge approaching a junction must equal the amount of charge leaving the junction.
- The charge cannot "pile up." Hence, the hypothesis will be that the current entering a junction will equal the current leaving the junction.

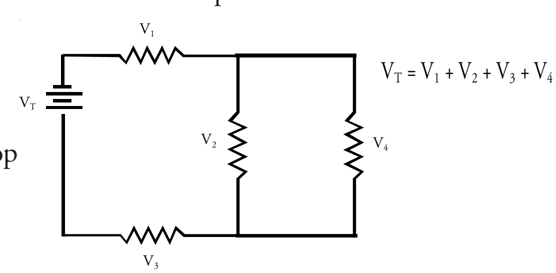
Kirchhoff's Current Rule is: "At any junction point in an electric circuit the total electric current into the junction is equal to the total electric current out."



Students should indicate a type of reasoning similar to the following: as electrons move through an electric circuit they gain energy in the sources and lose energy in the loads, but the total energy gained in one trip is equal to the total energy lost. Therefore, a reasonable hypothesis would be "the total voltage rises in a circuit will equal the total voltage drops."

Students should do diagrams and solve circuit problems.

Kirchoff's Voltage rules States: "The total of all electric potential decreases in any complete circuit loop is equal to any potential increases in that circuit loop."



Electric Circuits *(continued)*

Suggested Assessment Strategies

Journal

- Indicate what you have learned in the class discussion about electric circuits and what questions you would like to have answered on this topic. (ACP-3)

Paper and Pencil

- Two resistors are connected in series across a 30.0 V source. Draw a diagram of the circuit.
  - If the current from the source is 1.3 A, what is the current through each resistor?
  - If the voltage across one resistor is 12.4 V, what is the voltage across the other?
  - Find the resistance for each resistor. (ACP-3)
- Three resistors having values of 18 Ω, 9.0 Ω, and 6.0 Ω are connected to a 3.0 V source. Find the current through each resistor if they are connected:
  - in parallel
  - in series (ACP-3)
- What circuit elements are always connected in series? (ACP-3)

Paper and Pencil

- A 6.0 V battery is set up in a circuit. All of the current passes through a 6.0 Ω resistor, and then splits between two branches one of which has a 2.0 Ω resistor and the other a 4.0 Ω resistor. Determine the total resistance and the current and voltage in each resistor. (ACP-3)

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Concepts and Connections

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Electric Circuits *(continued)*

Outcomes

Students will be expected to

- apply Ohm's Law to series, parallel, and combination circuits (ACP-3) (**Cont'd**)
  - solve exercises with problems involving circuits with both series and parallel combinations of resistors
  - define power for electrical circuits using:
    (i) P=IV
    (ii) $P=I^2R$
    (iii) $P=V^2/R$
  - given two of: power, resistance, current and potential difference calculate the other quantities
  - calculate the cost of operating electrical equipment given the power rating or means of determining the power rating, the amount of time, and the cost per kilowatt-hour of electrical energy
- define and delimit problems to facilitate investigation (212-2)
- select and use apparatus and materials safely (213-8)
- compile and display evidence and information in a variety of formats, including diagrams, and tables (214-3)
- use instruments effectively and accurately for collecting data (213-3)

Elaborations—Strategies for Learning and Teaching

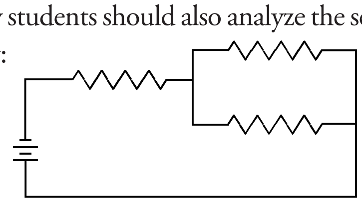
Teachers should limit circuit analysis problems to simple combinations of no more than six resistors. Internal resistance is not considered. Some excellent examples are on page 623 in the *Concepts and Connections* textbook. They should be able to calculate if a fuse will "blow" or a circuit breaker will "trip" in a circuit.

Students should be expected to calculate the power dissipated in the load of a circuit element.

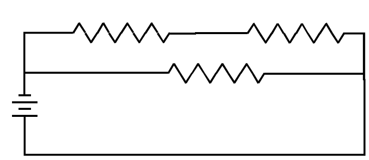
Teachers should note that they do not need to do MJ (megajoules).

The Laboratory outcomes 212-2, 213-8, 214-3, 213-3 and in part, ACP-3 are addressed by completing *Circuit Analysis,* CORE LAB #5. As part of the laboratory students should also analyze the series-parallel combination circuits below:

(a)



(b)



As an extension to the lab students could be asked to calculate the power dissipated in a resistor.

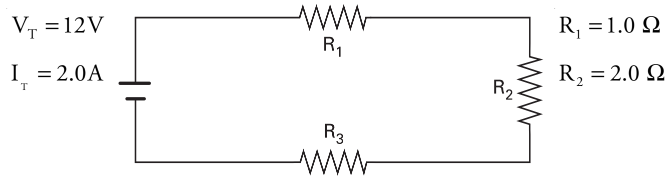
Electric Circuits *(continued)*

Suggested Assessment Strategies

Paper and Pencil

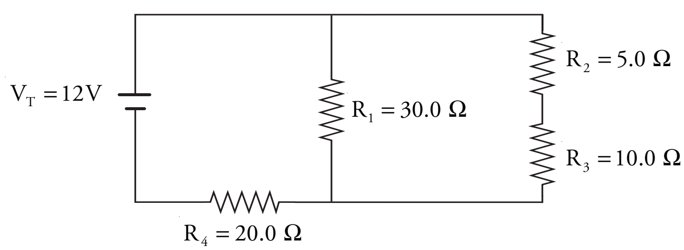
- The following circuit is connected to a source that can provide a current of 2.0 A when the potential difference (voltage) is 12 V.

What is the resistance of R_3? Show all your work. (ACP-3)



- A series-parallel electric circuit is illustrated below.

What is the potential difference across the terminals of resistor R_1?

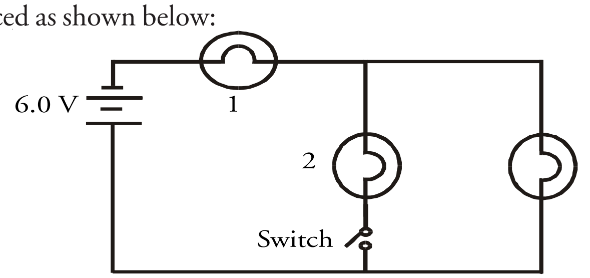


(a) 4.0 V
(b) 6.0 V
(c) 8.0 V
(d) 12 V (ACP-3)

- An electrical appliance uses 1.2×10^2 W when connected to a 1.2×10^2 V outlet. What is the resistance in the appliance? (ACP-3)

Performance

- Wire an actual DC circuit with 3 identical bulbs of known resistance placed as shown below:



Observe the relative brightness of bulbs 1 and 3, a) when the switch is opened, b) when the switch is closed. Analyze the circuit and determine the power output of bulbs 1, 2 and 3 in both situations and relate these values to your earlier observations. (ACP-3)

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Core Lab #5: *"Circuit Analysis"*, **pages 625-626**

Magnetic Fields

Outcomes

Students will be expected to

- describe magnetic fields as regions of space in terms of poles and illustrate the source and direction of the lines of force (328-1, 328-2)
  - define lodestone as a naturally occurring magnet
  - state and apply the law of magnetic forces
  - explain the domain theory
  - explain magnetic phenomenon with reference to the domain theory
  - map a magnetic field using a test compass
  - define the direction of magnetic field lines
  - draw magnetic field lines in the regions surrounding:
    - (i) single bar magnet
    - (ii) two bar magnets, opposite poles facing and like poles facing
    - (iii) horseshoe magnet
    - (iv) Earth
  - compare and contrast magnetic fields with gravitational and electrical fields

Elaborations—Strategies for Learning and Teaching

Although students will have studied magnetism in earlier grades, it is appropriate to look again at magnetic fields using iron filings and bar magnets. Students should sketch the field around a single magnet, the field between two like poles, and the field between unlike poles. The concept of north-seeking pole should be reviewed. The concept of magnetic domain should be introduced to explain the structure and behaviour of magnets.

Teachers should review the operational definitions of direction for each field:

- gravitational: the direction a 1 kg mass would take if placed in the field.
- electrical: the direction a positive charge would take if placed in the field.
- magnetic: the direction a north pole would take if placed in the field.

Magnetic Fields

Suggested Assessment Strategies

Journal

- Magnets have poles and electric fields have charges. Explain this similarity to a group of grade nine students. (328-3)
- Are there processes in the human body which depend on magnetism? Explain. (328-1, 328-2)

Paper and Pencil

- Draw diagrams to represent the field around a single bar magnet, the field and the region between like poles of two bar magnets, and the region between unlike poles of two bar magnets. (328-2, 328-3)
- Why does a compass align itself north and south? (328-1, 328-2)
- Two iron bars attract each other no matter which ends are placed close together, are they both magnets? Explain. (328-1, 328-2)
- What is your understanding of magentic, electric, and gravitational fields? How are these related? 9328-2, 328-3, ACP-4)

Presentation

- In groups, research and discuss the past changes in the orientation of the Earth's magnetic field over geological periods of time. (328-3)
- Students could begin a long-term group project in which they select a modern device that employs knowledge of one or more of the principles of magnetism, electricity, or electromagnetism studied in this unit; research the historical development of the science and technology involved; predict future developments in related areas; and prepare a multimedia presentation. (328-1, 328-2)

Performance

- give students three iron rods, two of which are magnetized but the third is not. Ask them to experimentally determine which two are the magnets (without using any additional objects). Students should present their method to the class. (328-1, 328-2)

Portfolio

- Make a collage of examples of the different types of fields studied in this unit (ie. gravitational, electric, magnetic). (328-1, 328-2, 328-3)

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Magnetic Fields *(continued)*

Outcomes

Students will be expected to

- describe the magnetic field produced by a current in both a solenoid and a long, straight conductor (328-6)
  - explain Oersted's principle for a straight conductor
  - illustrate the use of Left Hand Rule #1
  - define ferromagnetic materials in terms of magnetic dipoles
  - explain Oersted's principle as applied to a solenoid including the Left Hand Rule #2
  - explain the solenoid as an electromagnet
  - list four factors that determine the strength of an electromagnet. Include:
    (i) current
    (ii) number of loops
    (iii) type of core (magnetic permeability)
    (iv) size of loop
  - explain the role of magnetic permeability of the core and its effects on electromagnetism
  - list and briefly describe three applications of an electromagnet:
    (i) lifting electromagnet
    (ii) relay
    (iii) electric bell

Elaborations—Strategies for Learning and Teaching

Using iron filings or small compasses, the students should map out the magnetic field lines produced around a long straight conductor. The students should extend this mapping to the area around a single loop of wire and they should map the magnetic field around a solenoid. Students should describe the way that the magnetic field exists in space in these cases. Students could explore the interaction between two current-carrying wires placed close to each other.

It should be pointed out to students that the left hand rule is used because of the electron current flow. If it were conventional current, the right hand rule would be used. This is important when students do the direction of a charged particle (positive or negative) moving in a magnetic field.

Students should build on their understanding of the relationship among force $(\vec{F})$, magnetic field strength $(\vec{B})$, and the length of conductor in a magnetic field to understand the factors for the force on a charge moving in a uniform magnetic field. Emphasis should include determining the direction of the force based on whether the charge that is moving is negative or positive.

Teachers can refer to table on p. 636 of textbook.

Teachers can refer to table on p. 637 of textbook.

Magnetic Fields *(continued)*

Suggested Assessment Strategies

Performance

- Use a long piece of wire carrying a current and a piece of cardboard to act as a plane perpendicular to the wire. Then, using either iron filings or small compasses, sketch the field lines around the conducting wire. Next shape the wire into a single coil passing through the cardboard, and again sketch the field lines. Finally shape the wire into a solenoid with several coils and sketch the field lines. Prepare a set of diagrams to illustrate the distribution of the field lines in each case. (328-6)

Journal

- Make a journal entry comparing the field line distribution around a long straight conductor, a single coil, and a solenoid. (328-6)

Paper and Pencil

- The north pole of a permanent magnet is thrust into a coil of wire. Using diagrams indicate the direction of the current in the coil as the magnet is inserted and withdrawn. (328-6)

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Magnetic Fields *(continued)*

Outcomes

Students will be expected to

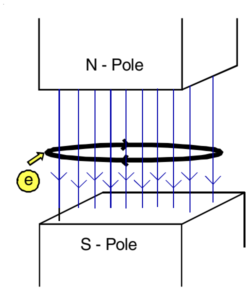
- analyze qualitatively and quantitatively the force acting on a moving charge in a uniform magnetic field (328-5)
  - define the motor principle
  - illustrate the use of the Left Hand Rule #3
  - define quantitatively the magnetic field strength and its units
  - solve problems using $F = BIL\sin\theta$
  - define the magnetic field in terms of permeability, current and distance to a conductor
  - solve problems using $B = \frac{\mu I}{2\pi r}$
  - define operationally the ampere
  - determine the direction of a moving charged particle's path in a magnetic field using the motor principle
  - analyze the motion of charged particles in a uniform magnetic field qualitatively
  - solve problems using $F = qvB\sin\theta$ for charged particles in magnetic fields
  - explain and solve problems where a charged particle is moving perpendicularly in a magnetic field generating circular motion

Elaborations—Strategies for Learning and Teaching

While students sudy the theory of the motor principle, they are not required to study the structure and funciton of AC and DC motors. Later in this unit through, they will study the generator.

Students only need to be able to apply the simplified equation of Biot's Law. Students are not responsible for Biot's Law for loops and coils shown in textbook p. 645 (Fig.15.31B and Fig. 15.31C)

While the left hand rule will work to show the deflection of a stream of electrons, the right hand rule will be useful for a stream of positive particles. If it is shot in "horizontally" (or perpendicular to the lines of force), it will follow a circular path. This is because the moving electron has a circular field concentric around its direction of motion. This circular field and the permanent field reinforce each other on the left hand side of the electron, therefore forcing it into clockwise circle (if viewed from above).



This concept is outlined in detail under "*centripetal magnetic force*", page 653 in the textbook.

Magnetic Fields *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- What is the magnetic field 2.5 cm from a long straight conductor carrying a current of 7.6 A? (328-5)
- Calculate the current in a long straight conductor if it produces a magnetic field of 2.8 x 10^{-5} T at a distance of 25.0 cm from the conductor. (328-5)
- A conductor 3.0 x 10^{-1}m is placed in a magnetic field of 2.5 x 10^{-1} T. Assuming the conductor is perpendicular to the magnetic field, and the magnetic force acting on the conductor is 3.5 x 10^{-2} N, what is the current flowing through the conductor? (328-5)

Journal

- Research the origin of the northern lights in terms of charges moving through magnetic fields. (328-5)
- Research how a TV screen or a computer monitor makes use of the motor principle to produce screen images. (328-5)

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Magnetic Fields *(continued)*

Outcomes

Students will be expected to

- analyze qualitatively and quantitatively electromagnetic induction by both changing magnetic flux and a moving conductor (328-7)
  - state Faraday's law of electromagnetic induction
  - determine the direction of current in a conductor when it is moved through a magnetic field
  - determine the direction of a current induced in a coil when a magnet is moved
  - explain Faraday's Iron Ring apparatus
  - state Lenz's Law
  - use Lenz's Law to predict the direction of induced currents
  - apply Faraday's Law and Lenz's Law in determining the direction of current in a loop of an electric generator
  - interpret the current output of both AC and DC generators

Elaborations—Strategies for Learning and Teaching

Teachers could present a series of review demonstrations in which there is relative motion between a magnet and a coil, including changing the number of coils, changing the relative speed, and using magnets of different strength.

A good introduction to electromagnetic induction is Faraday's famous iron ring apparatus. Teachers could present the setup (as a demonstration or drawing) and engage the students with some leading questions:

- How many circuits do you see?
- Does the secondary circuit have the necessary components to be labelled a circuit?
- Does the current from the primary go "into" the ring and then to the secondary coil?
- If the secondary circuit has no energy supply, why did the galvanometer detect a current when the primary switch was opened and closed?
- Why was there no current in the primary when the primary switch stayed closed?

The answers to these questions should help develop the concept of electromagnetic induction. Teachers could, as an optional extension, relate Faraday's Iron ring experiment to applications using AC like the transformer.

Students should develop an understanding of Lenz's law and predict the direction of the current in a coil produced by a changing magnetic flux.

Some possible demonstrations for Lenz's Law include:

i) Ask a student to spin a hand cranked generator without a load attached. Short circuit the output wires (by touching them together) to produce maximum current. Then ask the students to observe the magnetic force opposing their motion as explained by Lenz's Law.

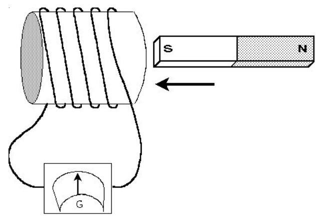
ii) Drop a niobium rare earth magnet through a copper pipe and a plastic pipe. Ask students to time the length of the fall. This can be repeated with a cracked copper pipe, so that there is no induced current.

Magnetic Fields *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- In what direction is the induced current (electron flow) through G? (328-7)



- Compare and contrast Faraday's Law and Lenz's Law. (328-7)

Performance

- Illustrate Lenz's Law with the use of a ring tosser apparatus. Plans for the ring tosser are shown below. (328-7, 213-8)

Plans for Electromagnetic Ring Toss
- 1.5 to 2.5 inch PVC pipe approximately 30 inches long
- 14 gauge to 20 gauge wire
- 3 or 4 threaded rod approx 20 inches long
- 6 bolts per rods and washers
- Switch
- 2 6-inch square pieces of plywood, with hole cut in center to allow PVC and wrapping to fit through
- One larger piece of wood for base
- Piece of heavy gauge aluminum (ring)
- Soft iron for core - (welding rods are good)
- Heavy duty wire with plug (three prong)

Construction
- Mark off approximately 1 inch from bottom to 10 inches
- Leave about a foot or 2 as a leader and start winding carefully up the PVC to about the 10 inch mark. Be careful not to cross and keep neat. (Similar to a fishing reel)
- Overlap at least one more layer from top down
- Tape at bottom and top as needed
- Leave about one foot or two at end of wire
- Fill center of PVC with soft iron, connect to electricity with ring to check it out. Do not leave plugged in for long time
- Rest of construction is to support it. Run the threaded rod through a base and ply with bolts and washers to support it
- Connect to a throw switch

Besides throwing the ring some other ideas:
- Ring with slit on one side so you don't have a complete circuit
- Several coils connected to a lamp socket and low watt bulb

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Electromagnetism

Outcomes

Students will be expected to

- select and use apparatus and materials safely (213-8)
- state a prediction based on background information (212-4)
- carry out procedures controlling the major variables and extending procedures where required (213-2)
- interpret patterns and trends in data and infer relationships among variables (214-5)
- identify questions, analyze, compile and display evidence and information to investigate the development over time of a practical problem, issue or technology. (212-3, 214-3, 115-5)
- analyze and evaluate, from a variety of perspectives, using a variety of criteria, the risks and benefits to society and the environment of a particular application of scientific knowledge and technology. (118-2, 118-4)
- identify, analyze and describe examples where technologies were developed based on scientific understanding, their design and function as part of a community's life and science and technology related careers. (116-4, 116-6, 117-5, 117-7)

Elaborations—Strategies for Learning and Teaching

The Laboratory outcomes 213-8, 212-4, 213-2, 214-5 and in part, 328-7 are addressed by completing *Electromagnetic Induction,* CORE LAB #6.

The CORE STSE component of this unit incorporates a broad range of Physics 3204 outcomes. More specifically it targets (in whole or in part) 212-3, 214-3, 115-5, 328-6, 328-7, 118-2, 118-4, 116-4, 116-6, 117-5, and 117-7. The STSE component, *The Physics of Cellular Telephones,* can be found in Appendix B.

Electromagnetism

Suggested Assessment Strategies

Resources/Notes

Core STSE #6: *"Electromagnetic Induction"*, **pages 691-692**

Core STSE #2: *"The Physics of Cellular Telephones"*, Appendix B