College Ready
Physics Standards:
A Look to the Future

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Using the Instructional Guidance

Each standard is divided into sections, one for each objective (see sidebar). These sections provide minimal guidance for interpreting the learning outcomes (LOs) and essential knowledge (EK) statements in each objective, especially the difference in the level of intellectual abstractness and sophistication of reasoning expected at the middle school and high school levels. The purpose of the Instructional Guidance is to provide middle school, high school, and college instructors with sufficient guidance to understand the types of events and tasks in which students engage to meet the goals of each objective.

Three items in each objective guide the interpretation of the LOs and EK statements. The first is a Table of Common Student Conceptual Difficulties for the content of the objective. The table also includes the specific LOs and EK statements that most directly provide an opportunity for teachers to address the conceptual difficulty. The research literature in students’ conceptual difficulties guided the writing of the learning outcomes and essential knowledge statements. Consequently, the table may also facilitate understanding some ideas in the EK statements that are not found in most state standards. For example, many students believe that a force (e.g., throwing a ball) is imparted to the object that is pushed or pulled. Consequently, an EK statement is:

Grades 5-8. During contact interactions, forces are not transferred to objects (unlike energy) — the interaction stops as soon as the objects stop touching. [M.3.3.3]

The second item of instructional guidance is a Table of Content Boundaries for each grade-level band. These tables describe the bounds and depth of knowledge for each grade-level band. They identify objects and phenomena appropriate for the learning outcomes. Any special limitations for specific learning outcomes are also described. In addition, the tables summarize the models and representations expected and excluded, and the technical terms introduced in the objective.

Finally, most objectives include some example questions or problem situations for a few of the learning outcomes. These example problems are intended to facilitate the understanding of how the essential knowledge is to be developed and used through reasoning and in problem solving. For the most part, the examples reflect tasks that are typically not found in textbooks. It should be noted that the examples are only a few of the many questions and problem situations that could be used to meet the goals of each objective.
GUIDE TO USING THE INSTRUCTIONAL GUIDANCE FOR EACH OBJECTIVE

OBJECTIVE 2.1
CONSERVATION OF MASS, ENERGY, AND CHARGE (Grades 5-8 and Grades 9-12) continued

Grades 9-12
The approach taken to the conservation of energy equation is similar to that of John Jewett (2008d) in his article Energy and the Confused Student: A Global Approach to Energy:

“It is my position in this article that there is only one fundamental energy equation and that all other energy equations are special cases. The fundamental equation is called the conservation of energy equation or the continuity equation for energy, both of which can be abbreviated as CEE:

\[ \Delta E_{\text{system}} = \Sigma T, \]

where T represents the amount of energy transferred (T for transfer) across the boundary of the identified system by a given mechanism. The general conceptual basis of the equation is this: the only way the total energy (E of a system) can change is if energy crosses the system boundary by one or more mechanisms described by T. The mathematical basis is this: the total change in energy of the system during some time interval is exactly equal to the net amount of energy crossing the system boundary. The summation sign indicates that energy may cross the boundary by several methods...” [page 210]

Table of Common Student Conceptual Difficulties

<table>
<thead>
<tr>
<th>Student Difficulty. Students often believe that</th>
<th>Where Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. All energies are the same.</td>
<td>Learning Outcome</td>
</tr>
<tr>
<td>a. Energies are always the same (electrical, kinetic, thermal, etc) for all defined systems and time intervals. [Because one form of energy can always be transformed into another form of energy.]</td>
<td>H.2.1.1, H.2.1.2, H.2.1.4</td>
</tr>
<tr>
<td>b. There are no energy terms for transfer (energy in transit from one location to another) that are different from the energies that objects have.</td>
<td>H.B.3, H.B.4, H.B.5</td>
</tr>
<tr>
<td>2. Energy is only conserved in a closed system. When the system is open, energy can sometimes disappear. [Things, like light bulbs, “use up” energy.]</td>
<td>H.2.1.1</td>
</tr>
<tr>
<td>3. There is nothing special about the conservation of energy – all quantities are conserved in a closed system.</td>
<td>M.2.1.4</td>
</tr>
<tr>
<td>4. The conservation of energy is useless; it does not help think about or solve problems (qualitatively or quantitatively).</td>
<td>H.2.1.1</td>
</tr>
<tr>
<td>5. The conservation of mass, charge, and energy are not fundamental principles of science.</td>
<td>H.2.1.6</td>
</tr>
</tbody>
</table>

Table of Content Boundaries

PHENOMENA, REPRESENTATIONS AND MODELS, AND TECHNICAL VOCABULARY
High School (Grades 9-12)

OBSERVATIONS/PHENOMENA (Real World)
- Objects and events similar to Objectives 4.1 through 4.5, and Objective 5.2. However, situations involve multiple interactions (contact, gravitational, electrical, electric circuit, radiant, and thermal interactions).
- H.B.2 Methods of energy storage (within a system include) (See Objectives 4.1 through 4.5):
  - kinetic energy
  - thermal energy
  - elastic energy (e.g., spring)
GUIDE TO USING THE INSTRUCTIONAL GUIDANCE FOR EACH OBJECTIVE (continued)

**Representations/Models** describes the analogue and mental models in the objective. It also describes visual and mathematical representations of ideas, and special mathematical symbols introduced.

**Technical Vocabulary** specifies the technical vocabulary for the objective, as well as any exclusions.

**Final sections** provide some examples to facilitate understanding of level of intellectual abstraction and sophistication required for the grade-level band. The examples tend to differ from those found in traditional textbooks. Of course, specific wording in the examples is not required. Learning outcomes (LOs) are identified by grade band and bullet number (e.g., M.B.2).

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**Phenomena, Representations and Models, and Technical Vocabulary**

**High School (Grades 9-12)**

- Methods of energy transfer include (See Objectives 4/1 through 4/5):
  - mechanical energy transfer (work)
  - mechanical wave energy transfer
  - thermal energy transfer (heat)
  - electrical energy transfer in circuits, and
  - radiant energy transfer (EM)

**Exclusions.** two- and three-dimensional forces

**Representations/Models**

- More complex analogue models can be considered for the conservation of energy: for example, a banking account that includes savings, investments with dividends, interest charges, etc. See comments below for H.2.1.1.
- Symbol $\Delta$ to represent “change in.”
- Mathematical model of energy conservation ($\Delta E_{\text{system}} = E_{\text{in}} - E_{\text{out}}$)
- Mathematical model for mass-energy equivalence: $E_{\text{out}} = mc^2$
- Energy diagram (see description below)

**Technical Vocabulary**

- conservation of energy principle

**H.B.2 Example Problem**

**Event:** A battery is connected to a switch and bulb.

(a) System of interest is the complete circuit; time interval is the tiny (unnoticeable) time after the switch is closed and while the bulb’s brightness is increasing. The energy change within the system is a decrease in the chemical energy of the battery and an increase in the thermal energy of the bulb filament (because the temperature of the bulb filament is increasing). There is a transfer of radiant energy (mostly visible light and infrared) out of the system. (Note: A heat conduction energy transfer is much slower than a radiant energy transfer, so for this tiny time interval, it can be ignored.)

(b) System of interest is the bulb filament; time interval is the tiny (unnoticeable) time after the switch is closed and while the bulb’s brightness is increasing. The energy change within the system is an increase in the thermal energy of the bulb filament (because the temperature of the bulb filament is increasing). There is a transfer of electrical energy into the bulb filament (from the battery) and a radiant energy transfer out of the system.

(c) System of interest is the bulb filament; time interval is a few minutes while the bulb brightness is not changing. There is a transfer of electrical energy into the system and a transfer of radiant energy out of the system. There is no change in energy of the filament. (Changes in the internal energy of the bulb filament are ignored at the high school level.)

**Energy Diagrams**

There are, of course, many different ways of drawing energy diagrams. The most extensive discussion is by Greg Swackhamer in his paper Cognitive Resources for Understanding Energy.

Some diagrams show the transfers of energy

Some diagrams show changes of stored energy
INSTRUCTIONAL GUIDANCE FOR
STANDARD 5. FORCES, ENERGY AND FIELDS

Attractive and repulsive interactions at a distance (e.g., gravitational, magnetic, electrical and electromagnetic) can be described and explained using a field model.

OBJECTIVE 5.1
FORCES AND FIELDS (Grades 5-8 and Grades 9-12)

Students understand that the field model explains how objects exert attractive and repulsive forces on each other at a distance: their fields are the agents of the interaction.

Table of Common Student Conceptual Difficulties Grades 5-8 and Grades 9-12

Students’ conceptual difficulties with fields persist through several years. This table shows the overlap between the middle school years and high school.

<table>
<thead>
<tr>
<th>Student Difficulty. + Students often believe that:</th>
<th>Where Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Field lines are real. Field lines can begin/end anywhere. There are a finite number of field lines. If a charge or compass is not on a field line, it feels no force.</td>
<td>Field lines are not introduced; field diagrams are used instead.</td>
</tr>
<tr>
<td>2. All forces have to be contact forces.</td>
<td>M.S.1.1 M.B.1</td>
</tr>
<tr>
<td>3. Fields don’t exist unless there is something to detect them.</td>
<td>M.S.1.1 M.B.6</td>
</tr>
<tr>
<td>H.S.1.1 H.B.6</td>
<td></td>
</tr>
<tr>
<td>4. Forces at a point exist without a compass, mass, or charge there.</td>
<td>M.S.1.3 M.B.2 M.B.4</td>
</tr>
<tr>
<td>5. A field and a force are the same thing and in the same direction.</td>
<td>M.S.3.1a M.B.3</td>
</tr>
<tr>
<td>M.S.1.3b M.B.5</td>
<td></td>
</tr>
<tr>
<td>6. a. Magnetic fields are the same as electric fields. b. The electric force is the same as the gravitational force.</td>
<td>H.S.1.2 M.B.3</td>
</tr>
<tr>
<td>H.S.1.3 M.B.4</td>
<td></td>
</tr>
<tr>
<td>7. Fields are not 3-dimensional.</td>
<td>M.S.1 H.B.5</td>
</tr>
</tbody>
</table>

+ See also conceptual difficulties for Objective 3.4 (Gravitational Interaction and Forces) and Objective 3.5 (Magnetic and Electric Interactions and Forces).

Grades 5-8

Table of Content Boundaries

PHENOMENA, REPRESENTATIONS AND MODELS, AND TECHNICAL VOCABULARY

Middle School (Grades 5-8)

OBSERVATIONS/PHENOMENA (Real World)
- Objects. Long springs, cords, strips of rubber sheeting (see first comment below); large, strong bar and horseshoe magnets; several small compasses and a few good compasses; spring scale with unit mass and a plumb line.
- Events/Phenomena. Magnetic and gravitational interaction, interaction between two wooden balls with attached spring.

Exclusions: Interaction between two magnets or planets.

REPRESENTATIONS/MODELS
- Analogue model of springs stretched or compressed and then released to energy stored in and extracted from magnetic and
M. B. 1 Investigating and Inventing the Field Model

J. Myron Atkin and Robert Karplus (1962) described how to introduce 2nd-grade students to the ideas of direct interactions and interactions-at-a-distance, and the field model of magnetic interactions. A brief summary, with language appropriate to middle-school, is given below.

Experiment #1: Two students pull in a rope in opposite directions. While the two students are interacting, it is not a direct interaction but an “interaction-at-a-distance.” The rope made the interaction possible.

Experiment #2. Show two wooden balls held together by a strip of rubber tacked to the balls. Students identify system is the two balls, the rubber strip, and two thumbtacks. The direct interactions are ball-thumbtack and rubber sheet-thumbtack. The interaction-at-a-distance is ball-ball. The force of one ball on the other ball is weak when the balls are close together, and stronger when the balls are farther apart. The rubber sheet made the interaction-at-a-distance possible.

Experiment #3. Repeat Experiment 2 with a long spring. The interaction-at-a-distance is the ball-ball. The spring makes the interaction-at-a-distance possible.

Experiment #4. Attach horseshoe magnets to two low-friction carts, mounted to attract each other. The interaction-at-a-distance is the magnet-magnet interaction. The magnetic force decreases with increasing distance between the magnets. Is there something now between the two magnets that make the interaction-at-a-distance possible? Students explore interaction of two magnets (at a fixed distance apart) with other objects, including magnetic materials (e.g., steel nail suspended on a string). Even though invisible, there is evidence of something between the two magnets that make the interaction-at-a-distance possible. This “something” is called the magnetic field.

Examples of Magnetic Field Diagrams

It is impossible to avoid iron-filings photos of magnetic fields. Students should know that the iron filings only show the direction of the magnetic field, not the magnitude of the magnetic forces.

Examples of Gravitational Field Diagrams
Grades 9-12

Table of Content Boundaries

<table>
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<th>PHENOMENA, REPRESENTATIONS AND MODELS, AND TECHNICAL VOCABULARY</th>
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</thead>
<tbody>
<tr>
<td><strong>High School</strong> (Grades 9-12)</td>
</tr>
</tbody>
</table>

**Observations/Phenomena** (Real World)
- Different planets and moons (gravitational field strength), different magnitudes of point charges, dipoles, two large capacitor plates with uniform charge distributions, large sheet with uniform charge distribution.

*Exclusions:* More complex charge distributions.

**Representations/Models**
- Analogies to other quantities that have a values at each point in space (e.g., temperature, pressure)
- Gravitational and electrical field diagrams

*Exclusions:* Field line diagrams are excluded. Magnetic and electromagnetic interactions excluded.

**Technical Vocabulary**
- electric field strength, \( E = F/e \).
- gravitational field strength (intensity); \( g = F/m \).

H.B.5 Examples of Electric Field Diagrams

- Electrical field of large uniformly charged sheet.
- Electrical field of a charged capacitor.
Mercury & Venus & Earth & Moon & Mars & Jupiter & Saturn & Uranus & Neptune & Pluto
\hline
\( g \) (N/kg) & 3.76 & 8.89 & 9.81 & 1.63 & 3.70 & 2.31 & 8.98 & 8.72 & 10.98 & 0.58
\hline

Example Problem(s).
(a) Calculate your weight on Earth in Newtons.
(b) On which planet would you weigh the least? The most? Explain your reasoning.
(c) Calculate your weight on these two planets.
(d) Would your weight be larger on the moon or on Pluto? Explain your reasoning.
(e) Calculate your weight on the Moon.

**Objective 5.2**

**Energy and Fields** (Grades 5-8 and Grades 9-12)

Students understand that the field model explains where the energy is stored in a system of two mutually attracting or repelling objects – in the field of the system. Only systems (not single objects) can have field (potential) energies. Energy can be transferred to and from the field of the system.

**Table of Common Student Conceptual Difficulties Grades 5-8 and Grades 9-12**

Students’ conceptual difficulties with potential energy persist through several years. This table shows the overlap between the middle school years and high school.

<table>
<thead>
<tr>
<th><strong>Student Difficulty.</strong>† Students often believe that:</th>
<th><strong>Where Addressed</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Essential Knowledge</strong></td>
</tr>
<tr>
<td>1. The only type of potential energy is gravitational.</td>
<td>M.5.2.2</td>
</tr>
<tr>
<td></td>
<td>H.5.2.4</td>
</tr>
<tr>
<td>2. Potential energy is not energy. It becomes energy when it is transferred.</td>
<td>M.5.2.2</td>
</tr>
<tr>
<td></td>
<td>H.5.2.4</td>
</tr>
<tr>
<td>3. Gravitational Potential Energy</td>
<td></td>
</tr>
<tr>
<td>a. Gravitational potential energy depends only on the height of an object.</td>
<td>H.5.2.3</td>
</tr>
<tr>
<td>b. When an object is released to fall, the gravitational potential energy immediately becomes all kinetic energy.</td>
<td></td>
</tr>
</tbody>
</table>
**Student Difficulty:** Students often believe that:

4. Single Object s Have Potential Energy  
   • An object has to stop in order to have potential energy.  
   • The potential energy that an object has before it starts moving is more than its kinetic energy it has at the final stage of motion.  
   • Objects always have potential energy. Potential energy is a thing that objects hold (like cereal stored in a closet).

5. “Voltage”  
   • There is no connection between “voltage” and electric field.  
   • Voltage is energy

† See also conceptual difficulties for Objective 3.4 (Gravitational Interaction and Forces) and Objective 3.5 (Magnetic and Electrical Interactions and Forces)

**Grades 5-8**

**Table of Content Boundaries**

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</thead>
<tbody>
<tr>
<td><strong>Middle School</strong> (Grades 5-8)</td>
</tr>
</tbody>
</table>
| **Observations/Phenomena** (Real World)  
  • Events and Objects. Dropping and lifting small objects, stretching and compressing springs or stretching rubber bands.  
  **Exclusions**: Electric charge fields. |
| **Representations/Models**  
  • Analogue model of stretching and compressing a spring to increasing or decreasing magnetic field energy.  
  • Analogue model of stretching a spring to increasing gravitational field energy. |
| **Technical Vocabulary**  
  • magnetic field energy  
  • gravitational field energy  
  **Exclusions**: The phrase potential energy is not introduced until grades 9-12. |

Underlined words and phrases are defined in the Glossary.

**M.B.2. and M.B.3 Suggested Experiment**

Use books or blocks to support a smooth wood or Plexiglas board. Sprinkle iron finings thinly over the board. Hold two strong repelling magnets, far apart, under the board. Observe the pattern of iron filings. Slowly move the repelling magnets closer together and observe what happens to the iron filings. Repeat the procedure for separating repelling magnets, separating attracting magnets, and moving attracting magnets closer together.

**M.B.3 Suggested Animations**

PhET Interactive Simulations, University of Colorado, Boulder ([http://phet.colorado.edu/index.php](http://phet.colorado.edu/index.php)) has produced three animations that help students visualize magnetic fields and how electromagnets and generators work: *Magnet and Compass*, *Magnets and Electromagnets*, and *Generators*.

**M.B.4 Example Response**

*Question*. Predict how the gravitational field energy changes (a) when an object is moved at a constant speed from the ground to a height h above the ground, and (b) when the object is released and falls to the ground.
**Example Response.** When an object is lifted, to a height \( h \), the gravitational field increases, similar to storing energy by stretching a spring. When the object is released and falls toward the ground, the gravitational field energy decreases, similar to releasing a stretched spring. The energy appears as an increase in the motion (kinetic) energy of the object.

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**Grades 9-12**

**Table of Content Boundaries**

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>High School (Grades 9-12)</td>
</tr>
</tbody>
</table>

**Observations/Phenomena** (Real World)
- Events and Objects. Similar to middle school, but with the addition of different methods of separating charges.
  - Exclusions: Electromagnetic interactions are excluded.

**Representations/Models**
- Energy diagrams
  - Mathematical representation of the conservation of energy for systems that include magnetic, gravitational or electric field potential energies. For situations in which the only transfers of energy are mechanical energy transfers (work), and with the system defined as the two magnets, the Earth and the object, or the two charged objects, then \( \Delta E_{\text{kinetic}} + \Delta E_{\text{elastic}} + \Delta E_{\text{thermal}} + \Delta E_{\text{chemical}} + \Delta E_{\text{field}} = W_{\text{in}} - W_{\text{out}} \)
  - Visual representations, animations, and computer simulations of different methods of separating charges (e.g., battery, van de Graaff machine, changing two materials by friction then separating two materials, capacitor)

**Technical Vocabulary**
- potential energy
- gravitational (field) potential energy
- electric (field) potential energy

Underlined words and phrases are defined in the Glossary.

**H.B.3 Example Problem**

You hold together two repelling magnets, the defined system, close together on a table. You release the magnets and they each slide a distance \( \Delta x \) across the table before coming to a stop. The time interval is from the instant you release the magnets to the instant the magnets come to a stop.

The conservation of energy equation is:

\[
\begin{align*}
\Delta E_{\text{system}} &= E_{\text{in}} - E_{\text{out}} \\
\Delta E_{\text{magnets}} &= W_{\text{in}} - W_{\text{out}} \\
\Delta E_{\text{magnets}} &= -2f_{\text{friction}} \Delta x
\end{align*}
\]

The decrease in magnetic field energy of the magnets is equal to the transfer of mechanical energy (work) out the system to the table and air (friction and drag). The changes in thermal energy of the system (due to friction) and the transfer of mechanical energy to the air are assumed to be negligible.

**H.B.4 Example Problem**

A ball is dropped from a height \( h \) above the floor. The time interval is just after the ball is released to just before it hits the floor.
The conservation of energy equation for the Earth-ball system is:
\[
\Delta E_{\text{system}} = E_{\text{in}} - E_{\text{out}}
\]
\[
\Delta E_{\text{kinetic}} + \Delta E_{\text{grav field}} = W_{\text{in}} - W_{\text{out}}
\]
\[
1/2mv^2 - mgh = - W_{\text{out}}
\]
\[
1/2mv^2 = mgh - W_{\text{out}}
\]

For objects that do not fall too far or too fast through the atmosphere, the mechanical energy transfer out of the system to the air (work done on the air) is very small and can be neglected.

**H.B.5 Example Problem**

You rub together a piece of fur and a rubber rod, the defined system, then slowly move the fur and rod apart at a constant speed with an average force of \( F \). The time interval is from just as you start rubbing the fur and rubber rod together to just as you have separated the fur and rubber rod a distance \( \Delta x \).

The conservation of energy equation is:
\[
\Delta E_{\text{system}} = E_{\text{in}} - E_{\text{out}}
\]
\[
\Delta E_{\text{electric field}} + \Delta E_{\text{thermal}} = W_{\text{in}}
\]
\[
\Delta E_{\text{electric field}} + \Delta E_{\text{thermal}} = F_{\text{ext}}\Delta x
\]

**H.B.5 Other Methods of Separating Charges**

In a van de Graaff machine, a nonconducting conveyor belt carries charges to a hollow conducting dome that rests on a nonconducting support.

In a battery, two conducting terminals are submerged in a solution containing mobile ions. A chemical reaction with the ions at one terminal deposits electrons, while the chemical reaction at the other terminal detaches an electron from the terminal.
A capacitor consists of two conducting plates, separated by a nonconductor. When connected to a battery, the capacitor acquires opposite charges on each plate, which can be stored for a long time.

**H.B.9 Suggested Animations**

PhET Interactive Simulations, University of Colorado, Boulder (http://phet.colorado.edu/index.php), has several useful simulations, including: *Electric Field of Dreams* and *Electric Field Hockey*.

Ruth Chabay has also produced many animations of what happens to the electric field of a system of charged particles in different circumstances (http://www4.ncsu.edu/~rwchabay/emimovies/, Chabay, R. and Sherwood, B., *Electric and Magnetic Interactions*, (Wiley, New York, 1995). For example, the four pictures below show what happens to the electric field when two attracting charged particles are released and move closer together.

These interactive computer simulations and animations can help students visualize that the energy stored in the field around the two charged objects decreases as they move closer together.

![Images](a.png) ![Images](b.png)

![Images](c.png) ![Images](d.png)

**Objective 5.3**

**Electromagnetism and Fields** (Grades 5-8 and Grades 9-12)

Students understand that an electromagnetic interaction occurs when a flow of charged particles creates a magnetic field around the moving particles, or when a changing magnetic field creates an electric field.

**Table of Common Student Conceptual Difficulties Grades 5-8 and Grades 9-12**
Students’ conceptual difficulties with electromagnetism persist through several years. This table shows the overlap between the middle school years and high school.

<table>
<thead>
<tr>
<th>Student Difficulty:*+</th>
<th>Where Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Essential Knowledge</td>
</tr>
<tr>
<td>1. Connection Between Current Electricity and Magnetism</td>
<td></td>
</tr>
<tr>
<td>a. Charges, when released, will move toward the poles of a magnet.</td>
<td>-----</td>
</tr>
<tr>
<td>b. North and south magnetic poles are the same as positive and negative charges.</td>
<td>M.S.3.2</td>
</tr>
<tr>
<td>c. Magnetic poles can be isolated.</td>
<td>H.S.3.2</td>
</tr>
<tr>
<td>d. A suspended battery (2-ended) will align in the north-south direction like a magnet.</td>
<td>M.S.3.4</td>
</tr>
<tr>
<td>2. Only magnets produce magnetic fields (forces).</td>
<td>M.S.3.2</td>
</tr>
<tr>
<td>3. Only charges can produce electric fields (forces).</td>
<td>M.S.3.1</td>
</tr>
<tr>
<td>4. Generating Electricity</td>
<td></td>
</tr>
<tr>
<td>a. When generating electricity only the magnet can move.</td>
<td>M.S.3.2</td>
</tr>
<tr>
<td>b. Generating electricity requires no work.</td>
<td>H.S.3.3</td>
</tr>
<tr>
<td>c. A magnetic field, rather than a changing magnetic field, causes an electric current.</td>
<td>H.B.3</td>
</tr>
<tr>
<td>5. Charges at rest can experience magnetic forces.</td>
<td></td>
</tr>
</tbody>
</table>

*+ See also conceptual difficulties in Objectives 3.5 (Magnetic and Electrical Interactions and Forces)

Grades 5-8

Table of Content Boundaries

### PHENOMENA, REPRESENTATIONS AND MODELS, AND TECHNICAL VOCABULARY

**Middle School (Grades 5-8)**

**Observations/Phenomena (Real World)**
- Objects: Magnets and simple battery and bulb circuits; simple motors and hand-held generators
- Events: moving magnets and coils of wires; moving magnet near current-carrying wires, building a simple motor; investigating a hand-held generator.

*Exclusions:* Investigating changing electric and magnetic fields is done in grades 9-12.

**Representations/Models**
- Visual representations, animations, and computer simulations of motors and generators.

*Exclusions:* Field representations of electromagnetism.

**Technical Vocabulary**
- generator
- electromagnetic interaction

**M.B.1 Connection Between Electric Circuits and Magnetism**

Most students think there is a direct connection between electric charges and the magnetic poles – positive charges are attracted to north poles and negative charges to south poles. A suspended battery is like a magnet and will orient in the geographic north-south direction. A magnet can be cut in half to isolate a north pole and a south pole (like charges).

A simple exploration to begin to explore the connection is to place a current-carrying wire above and below a compass.

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M.B.2 and M.B.3 Experimenting with Motors and Analyzing Generators

There are many ways to investigate the variables that influence the size of the magnetic force on a rotating coil of wire, from very simple qualitative explorations (see diagram of motor at right) to more complex experimental apparatus. Similarly, there are simple ways to investigate how a generator works, from using a hand-held generator to light a bulb to more complex experimental apparatus.

M.B.5 Example Problem. In which cases below (a through g) will a current flow in a loop? Explain your reasoning.

M.B.4 Experiment

Some different orientations of magnet and current carrying wire are shown above.

Grades 9-12

Table of Content Boundaries
PHENOMENA, REPRESENTATIONS AND MODELS, AND TECHNICAL VOCABULARY

High School (Grades 9-12)

OBSERVATIONS/PHENOMENA (Real World)
- Objects: Magnets, wire loops with bulb, simple circuits with current-carrying wires, coils and loops of wire; old, broken generators, motors, microphones and speakers.
- Magnetic fields around wires with electric current, induced current in wire loops, effect of radio waves on a wire antenna.

REPRESENTATIONS/MODELS
- Visual representations, animations, and computer simulations of Faraday’s law, the magnetic field around wires, the effects of changing magnetic and electric fields, generators, motors, microphones, and speakers.
  Exclusions: Electromagnetic equations

TECHNICAL VOCABULARY
- Faraday’s Law
  Exclusions: Oersted’s Law, Ampere’s Law, and so on.

Underlined words and phrases are defined in the Glossary.

Two good sources of interactive computer simulations and animations in electromagnetism:
