College Ready
Physics Standards:
A Look to the Future

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Using the Instructional Guidance for Each Standard

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 ($E_{\text{system}}$) 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>Essential Knowledge</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</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.2.1.2</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 - gravitational potential energy
  - thermal energy - electric potential energy
  - elastic energy (e.g., spring) - magnetic potential energy

Introductions describe any approaches to the content that are not traditional but are supported by cognitive and educational research. References are usually included.

Table lists students’ common conceptual difficulties with the objective content from physics education research (see Research Base for Tables of Common Student Conceptual Difficulties in Appendix B). Also listed are the EK statements and Los that provide the opportunity for teachers to address each conceptual difficulty.

Learning Outcomes are identified by grade level (M for middle school, H for high school), and the bullet number of the learning outcome. For example, H.B.3 indicates third bullet learning outcome.

Boundaries Table lists the objects and events that limit the content of the objective. Other boundaries for specific LOs are also listed.

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GUIDE TO USING THE INSTRUCTIONAL GUIDANCE FOR EACH OBJECTIVE (continued)

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

<table>
<thead>
<tr>
<th>Technical Vocabulary</th>
<th>Technical Vocabulary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical energy transfer (work)</td>
<td>- conservation of energy principle</td>
</tr>
<tr>
<td>Thermal energy transfer (heat)</td>
<td></td>
</tr>
<tr>
<td>Electromagnetic energy transfer</td>
<td></td>
</tr>
<tr>
<td>Radiant energy transfer (EM)</td>
<td></td>
</tr>
</tbody>
</table>

**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 Δ to represent “change in.”
- Mathematical model of energy conservation (ΔE_{system} = E_{in} - E_{out})
- Mathematical model for mass-energy equivalence: E_{out} = mc^2
- Energy diagram (see description below)

**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."
INSTRUCTIONAL GUIDANCE FOR
STANDARD 3. NEWTON’S LAWS OF MOTION

Interactions of an object with other objects can be described, explained, and predicted using the concept of forces, which can cause a change in motion of one or both interacting objects. Different types of interactions are identified by their defining characteristics. At the macro (human) scale, interactions are governed by Newton’s second and third laws of motion.

OBJECTIVE 3.1
CONSTANT AND CHANGING LINEAR MOTION (Grades 5-8 and Grades 9-12)

Students understand that linear motion is characterized by speed, velocity, and acceleration, and that velocity and acceleration are vectors.

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

Students’ conceptual difficulties with motion 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>
<th>Knowledge</th>
<th>Learning Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Essential</td>
<td>Learning</td>
</tr>
<tr>
<td>1. The location of an object can be described by stating its distance from a given point, ignoring its direction.</td>
<td></td>
<td>E1</td>
<td></td>
</tr>
<tr>
<td>2. Time can be measured without establishing the beginning of the interval.</td>
<td>M.3.1.2</td>
<td>E2, M.3.1.2</td>
<td>M.B.2</td>
</tr>
<tr>
<td>3. There are only two categories for describing the motion of objects, no motion (stopped) and motion (moving)</td>
<td>M.3.1.2</td>
<td>M.3.1.2, M.3.1.3</td>
<td>M.B.1, M.B.2, M.B.3</td>
</tr>
<tr>
<td>4. When an object moves with a series of constant speeds, average speed is always the same as the average of the speeds.</td>
<td>M.3.1.1c</td>
<td>M.B.5, M.B.6</td>
<td></td>
</tr>
<tr>
<td>5. Students have difficulty interpreting the meaning of “average” for the continuously changing motion quantities of speed and velocity:</td>
<td>M.3.1.4</td>
<td>M.B.7</td>
<td></td>
</tr>
<tr>
<td>a. average speed;</td>
<td>H.3.1.3</td>
<td>M.B.2</td>
<td></td>
</tr>
<tr>
<td>b. average velocity;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. average acceleration</td>
<td>H.3.1.6</td>
<td>H.B.6</td>
<td></td>
</tr>
<tr>
<td>6. An object’s speed is the same as its velocity.</td>
<td>H.3.1.1, H.3.1.2</td>
<td>H.B.5</td>
<td></td>
</tr>
<tr>
<td>7. The distance an object travels and its displacement are always the same.</td>
<td>H.3.1.1</td>
<td>H.B.1, H.B.5</td>
<td></td>
</tr>
<tr>
<td>8. Students have difficulty distinguishing between:</td>
<td>H.3.1.2</td>
<td>H.B.6</td>
<td></td>
</tr>
<tr>
<td>a. position and speed or velocity [e.g., two objects with identical positions (at an instant) have identical speeds].</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. velocity and acceleration [e.g., two objects with identical velocities (at an instant) have identical accelerations; larger (smaller) velocity means larger (smaller) acceleration].</td>
<td>H.3.1.5</td>
<td>H.B.5, H.B.6</td>
<td></td>
</tr>
<tr>
<td>8. Constant velocity and instantaneous velocity are the same.</td>
<td>H.3.1.2, H.3.1.4</td>
<td>H.B.5, H.B.6</td>
<td></td>
</tr>
<tr>
<td>9. An object that has zero velocity at an instant cannot be accelerating.</td>
<td>H.3.1.4</td>
<td>H.B.2, H.B.8</td>
<td></td>
</tr>
</tbody>
</table>
**Grades 5-8**

**PHENOMENA, REPRESENTATIONS AND MODELS, AND TECHNICAL VOCABULARY**

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

**OBSERVATIONS/PHENOMENA (Real World)**
- **Objects**: skateboarders, cars, and skiers; low-friction cart, puck-balloon system, battery operated toy car, motion detectors.
- **Events**: Rolling or sliding in straight lines on horizontal surfaces, up an inclined surface, or down an inclined surface.
- **M.B.6.** Limit the problems for an object moving in a series of constant speeds to no more than three segments, and keep the numbers simple so students can focus on the results. An example problem is shown below.

*Exclusions*: Two- or three-dimensional motion

**REPRESENTATIONS/MODELS**
- Pictures, diagrams, or drawings of objects moving in a straight line on horizontal or inclined surfaces.
- Computer animations or simulations.
- **Motion diagrams** (see Glossary)
- Data tables and graphs of distance versus time.
- **Mathematical representations** (equations) for constant speed and average speed \( \text{speed} = \frac{\text{distance-traveled}}{\text{time-of-travel}} \)

**TECHNICAL VOCABULARY**
- **constant speed**
- **average speed**

*Exclusions*: velocity, acceleration

Underlined words and phrases are defined in the Glossary.

**M.B.2 Example Problems**

A car is slowing down. Write a verbal description of slowing down, and draw a distance versus time graph and a motion diagram for this pattern of motion.

![Distance-time graph](image)

The car is slowing down, so it travels a shorter distance in each successive time interval.

**M.B.6 Example Problem**

On a long car trip with your friend, the car traveled at 45 mi/hr for one hour though a construction zone, then traveled at 65 mi/hr for the next three hours. What was the average speed of the car? Interpret the meaning of the average speed.

*In this case, the average speed is 60 mi/hr, which is different from the average of the two speeds (55 mi/hr). The car could have traveled at a constant speed to 60 mi/hr and reached the destination in the same time.*

**M.B.5 Example Problem**

At the right is a student’s calculation of the average speed of a remote operated car. Analyze the solution and determine whether the average speed was calculated correctly. Explain your reasoning. If correct, interpret the meaning of the average speed. If incorrect, describe how to calculate the average speed correctly.
speed correctly.

The average speed from \( t = 10 \) sec to \( t = 40 \) sec is:

\[
\text{ave. speed} = \frac{\text{total distance}}{\text{total time interval}} = \frac{35 \text{ m} - 5 \text{ m}}{40 \text{ s} - 10 \text{ s}} = 1 \text{ m/s}
\]

Example Answer. The solution is wrong because the average speed is not the average of the two speeds. To calculate the average speed, you have to know the total distance traveled and the total time of travel. This is the slope of the line from the beginning time to the end time – see my diagram.

Grades 9-12

Table of Content Boundaries

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

**Observations/Phenomena** (Real World)
- The same objects and events as in middle school, but with more complex motions (e.g., an object rolls/slides up then back down an inclined surface; an object rolls/slides down an inclined surface then up a different inclined surface; object moves in a series of speeding up, constant speed, and slowing down motions, etc.

*Exclusions:* two- or three-dimensional motion

**Representations/Models**
- Computer animations and simulations
- Motion diagrams (see Glossary and example H.B.4 below)
- Vector subtraction (see Glossary)
- Data tables and graphs of position versus time and velocity versus time
- Mathematical representations (equations) for constant and average velocity \( \bar{v} = \frac{v_f - v_i}{t_f - t_i} \), constant and average acceleration \( \bar{a} = \frac{a_f - a_i}{t_f - t_i} \), and the relationship between average and instantaneous velocities for constant acceleration \( \bar{v} = \frac{v_i + v_f}{2} \).
- Analogue model of instantaneous velocity: readings on a speedometer

*Exclusions:* No other kinematics equations

**Technical Vocabulary**
- displacement
- constant and average velocity
- instantaneous velocity
- constant and average acceleration

*Exclusions:* The term “deceleration” (see H.3.1.4).

Underlined words and phrases are defined in the Glossary.

**H.B.7 Example Problem**

You and your friend are practicing for the next marathon race for your favorite charity. Your friend finishes warming up first, so she starts running the marathon route at a constant speed of 3 m/s. A few minutes later, another friend arrives with an urgent message. You start off 5 minutes after your friend, running at a constant speed of 4 m/s. How far from the starting point will you catch up to your friend?
Partial Answer

The equations for constant velocity are applied to “you” and the friend:

\[ v = \frac{x_f - x_i}{t_f - t_i} \]

\[ v_{\text{friend}} = \frac{x_f}{t_f} = 3 \text{ m/s}, \quad x_f = 3t_f \]

\[ v_{\text{you}} = \frac{x_f}{t_f - 5 \text{ min}} = 4 \text{ m/s}, \quad x_f = 4(t_f - 5) \]

**H.B.6 Examples of Verbal Descriptions of Motion**

Write a verbal description of the motion illustrated in each of the graphs below.

A. The object is speeding up slower and slower in the positive direction.
B. The object is moving with a constant velocity in the positive direction.
C. The object is slowing down at a constant rate (constant acceleration) in the negative direction.
D. The object is slowing down slower and slower in the negative direction.
E. The object is speeding up at a constant rate (constant acceleration) in the positive direction.
F. The object is not moving.
G. The object is moving with a constant velocity in the negative direction.
H. The object is slowing down faster and faster in the negative direction.
I. The object is speeding up faster and faster in the positive direction.

Of course, students should develop their own language – these are only examples.

**H.B.6 Examples Problems**

Example #1: An object is slowing down faster and faster in the negative direction. Draw a motion diagram (and/or draw an instantaneous velocity versus time graph) that represent(s) this motion.

Example #2: For the graph below (not shown here), write a verbal description (and/or draw a motion diagram) that represent(s) the motion of the object.

Example #3: For the motion diagram below (not shown here), write a verbal description (and/or draw an instantaneous velocity versus time graph) that represents the motion of the object.

**H.B.8 Example Problem**

Just for the fun of it, you and a friend decide to enter the state bicycle race. You are riding along at a comfortable speed of 20 mph when you see in your mirror that your friend is going to pass you at what you estimate to be a constant 30 mph. You will, of course, take up the challenge and accelerate just as she passes you until you pass her. If you accelerate at a constant 0.25 miles per hour each second until you pass her, how long will she be ahead of you?

*Solution requires good motion diagram and use of three equations, \( \ddot{v} = (x_f - x_i)/(t_f - t_i) \), \( \ddot{a} = (v_f - v_i)/(t_f - t_i) \), and \( v_{\text{ave}} = v_f + v_i/2 \) for constant acceleration.*
OBJECTIVE 3.2
FORCES AND CHANGES IN MOTION (Grades 5-8 and Grades 9-12)

Students understand that interactions can be described in terms of forces. The acceleration of an object is proportional to the vector sum of all the forces (net force) on the object and inversely proportional to the object’s mass (\( \vec{a} = \sum \vec{F}/m \)). When two interacting objects push or pull on each other, the force on one object is equal in magnitude but opposite in direction to the force on the other object.

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

Students’ conceptual difficulties with forces 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. Failure to distinguish between motion and change in motion:</td>
<td></td>
</tr>
<tr>
<td>a. When an object is in motion (even constant velocity), then there must be a force acting on the object.</td>
<td>M.3.2.2</td>
</tr>
<tr>
<td>b. The amount of motion (velocity) is proportional to the force, so acceleration requires an increasing force (when velocity and acceleration are undifferentiated concepts).</td>
<td>H.3.2a</td>
</tr>
<tr>
<td>c. There cannot be a force without motion, and if there is no motion, then there is no force acting.</td>
<td>H.3.2.3</td>
</tr>
<tr>
<td>2. Sum of Forces</td>
<td></td>
</tr>
<tr>
<td>a. The largest force determines motion, or some force compromises determines motion, or the last force to act determines motion (difficulty relating the “sum of forces” or “net force” and the motion of an object).</td>
<td>M.3.2.2e</td>
</tr>
<tr>
<td>b. The “net” force or “the product of mass times acceleration” (sometimes called the “ma” force) is a force acting on all moving or accelerating objects, and is unrelated to the other forces acting on the object.</td>
<td>H.3.2.2a</td>
</tr>
<tr>
<td>3. Circular Motion and Forces</td>
<td></td>
</tr>
<tr>
<td>a. An object moving in circle with constant speed has no acceleration.</td>
<td>M.3.2.2d</td>
</tr>
<tr>
<td>b. Circular motion does not require a force.</td>
<td>H.3.2.2c</td>
</tr>
<tr>
<td>c. An object moving in a circle will continue in circular motion when released, or fly out radially when released.</td>
<td></td>
</tr>
<tr>
<td>4. Newton’s Third Law</td>
<td></td>
</tr>
<tr>
<td>a. The larger, stronger, or more active object exerts a greater force on the smaller object than the smaller, weaker or passive object exerts on the larger object. Newton’s third law can be “overcome” by motion (such as by a jerking motion).</td>
<td></td>
</tr>
<tr>
<td>b. The interaction or third-law pair of forces acts on the same object.</td>
<td></td>
</tr>
<tr>
<td>c. The interaction or third-law pairs are the same as the “balanced” forces on a single object at rest (e.g., an object’s weight and the “normal” force are identified as third-law pairs).</td>
<td></td>
</tr>
<tr>
<td>d. Friction is the same as “reaction” [if students learn that “for every reaction there is an equal and opposite reaction].</td>
<td></td>
</tr>
</tbody>
</table>

++ For conceptual difficulties with specific types of forces, see Objectives 3.3, 3.4 and 3.5, and 5.1

Grades 5-8

Table of Content Boundaries

PHENOMENA, REPRESENTATIONS AND MODELS, AND TECHNICAL VOCABULARY

Middle School (Grades 5-8)

OBSERVATIONS/PHENOMENA (Real World)

- Interactions. Simple horizontal and circular contact interactions (see Objective 3.3), horizontal magnetic and electric charge interactions (see Objective 3.5); and vertical gravitational interactions (see Objective 3.4).
M.B.1: Experiment

The classic experiment for the relationship between a constant force applied to an object and its pattern of motion is from PSSC Physics (Haber-Shaim, Gardner, Dodge, Shore, & Walter, 1991). Attach a long rubber band to a low friction toy car or cart, and have students take turns running with the cart down a hallway (or in the cafeteria), keeping the force constant (the rubber band length the same length). This kinesthetic experience is helpful in addressing students’ misconception that a constant force is needed for a constant velocity.

M.B.4: Example Problem

A large magnet attracts a paper clip. At right is the force diagram for the paper clip.
(a) Predict the object’s pattern of motion and justify using Newton’s second law.
(b) The frictional force is one-half the size of the magnetic force. Use vector addition to determine the size and direction of the sum of the forces, and interpret the meaning of the sum of the forces.

M.B.6: Example Problem and Solution

A man with a parachute is falling towards the Earth at a constant speed.
(a) What types of interactions are involved in this situation. Explain your reasoning.
(b) Represent the forces acting on the man-parachute system by drawing a force diagram. Use vector addition to show the sum of forces on the man-parachute system.
(c) Explain the observed motion of the man-parachute system based on Newton’s second law.
Grades 9-12

Table of Content Boundaries

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</table>

**Observations/Phenomena** (Real World)
- Same Interactions as for middle school, but more complex motions and multiple interactions, including: motion in two parts; situations involving two objects; objects at rest -- suspended vertically or sitting on another object; and drag and static friction interactions with one object an energy source (e.g., walking, moving car, helicopter).

*Exclusions:* Collision interactions between rigid solids (see Objective 2.3); and projectile or three-dimensional motion.

**Representations/Models**
- Force diagrams (see Glossary)
- Motion diagrams (see Glossary)
- Vector addition (see Glossary)
- Animations and computer simulations
- "\( \sum \)" symbol to represent "sum of"
- "\( \text{F}_{\text{net}} \)" symbol to represent the sum of forces
- Mathematical representation of Newton's Second Law (\( \Sigma \vec{F} = m\vec{a} \)) and Newton's third law (\( \vec{F}_{12} = -\vec{F}_{21} \)).

*Exclusions:* Force diagrams that (1) do not isolate the object from the surrounding objects, and/or (2) draw all the forces from one point at the center of the object.

**Technical Vocabulary**
- Newton's second law of motion
- Newton's third law of motion
- interaction pair of forces
- net force

*Exclusions:* inertia; action/reaction pair; deceleration (see Objective 2.1)

Underlined words and phrases are defined in the Glossary.

**H.B.5: Example Problem**

Example #1. A bird is sitting on the branch of a tree. What is the third law interaction pair to the force (push) of the branch on the bird? Explain your reasoning.

Example #2. A bird is sitting on the branch of a tree. Draw force diagrams that show the third-law interaction pairs of the forces acting on the bird.

![Force Diagrams](image)

In this case, the third law interaction pairs are \( F_{BB} \) and \( F_{BB} \), and \( F_{EB} \) and \( F_{BE} \).
OBJECTIVE 3.3
CONTACT INTERACTIONS AND FORCES (Grades 5-8 and Grades 9-12)

Students understand that contact interactions occur when two objects in contact push or pull on each other, which can cause a change in motion of one or both objects. Some types of contact interactions have force laws that are empirical approximations; some have no force laws.

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

Students’ conceptual difficulties with contact forces 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>
</tbody>
</table>
| 1. The Nature of Forces | M.3.3 | M.B.1  
| a. Force is an intrinsic property of objects (e.g., “motive power” or “inertia”) that keeps them moving (e.g., force of momentum, force of inertia), rather than a property of an interaction. | M.B.3 | M.B.4 |
| b. Only “active agents” (e.g., metaphor for living things) can exert forces – active agents have the power to cause motion – to create “motive power” or “inertia” and transfer it to other objects. For example, the “force of the hit,” and “the force of the hand” are forces transferred to an object by a person, the active agent. | M.B.2 |
| 2. A push is in the same direction as a pull (difficulty distinguishing between pushes and pulls). | M.3.4  
| H.3.2 | M.B.1  
| H.3.3 | M.B.5 |
| 3. Drag Forces | M.3.3c | M.B.3  
| a. Drag interactions occur in liquids, but not in gases. | M.3.4d | M.B.6 |
| b. “Resistance to motion” means the same thing as friction, so drag is the same as friction. | H.3.3.4 | H.B.6 |
| 4. Frictional Forces | M.3.4a | H.B.5  
| a. Friction is not a force – it is an “obstacle” that must be overcome by the forces transferred to the object. | M.3.3a | H.B.6  
| b. Friction depends on movement, so if an object is not moving, there can be no frictional force. | H.B.3  
| H.B.6 |
| c. Friction always hinders motion. Thus, you always want to eliminate friction. | H.3.4b  
| H.3.4c | H.B.3 |
| d. Frictional forces are only due to irregularities in surfaces moving past one another (frictional forces increase with the “roughness” of the surfaces). | H.3.3.6 | H.B.8 |
| 5. Stationary Objects. At rest is a natural state in which no forces are acting on the object. Passive objects (e.g., floor, walls, chair, table, ropes or strings, attachment for a pendulum, and especially air) cannot exert forces. | M.B.5  
| H.B.6 |
| a. Air pressure, gravity, or an intervening object (like a table) “gets in the way” and keeps an object stationary. | H.B.5  
| H.B.6 |
| b. A “holding up” force is different from the typical pushing or pulling forces. | H.B.5  
| H.B.6 |
| c. The downward force of gravity on a book must be greater than an upward force for the book to be stationary. | H.B.5  
| H.B.6 |
| d. “Normal” means usual, so there is always an upward “usual” force on all objects in all situations that is equal to the weight of the object. | H.B.5  
| H.B.6 |

+See also Objective 3.2 for conceptual difficulties with Newton’s laws of motion.

Grades 5-8

Table of Content Boundaries

<table>
<thead>
<tr>
<th>PHENOMENA, REPRESENTATIONS AND MODELS, AND TECHNICAL VOCABULARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle School (Grades 5-8)</td>
</tr>
<tr>
<td>OBSERVATIONS/PHENOMENA (Real World)</td>
</tr>
</tbody>
</table>
PHENOMENA, REPRESENTATIONS AND MODELS, AND TECHNICAL VOCABULARY

Middle School (Grades 5-8)

- Horizontal linear motion and circular motion
- Applied interaction. Simple events like humans, ropes, car with hitched trailer, pulling or pushing on another solid system with negligible friction or drag (e.g., low-friction carts, puck-balloon system, a human-skateboard system, ice skater system, kicking a soccer ball or batting a softball, whirling object horizontally on the end of a string) etc. [Note: Whirling object can never be purely horizontal. If whirled fast enough, however, the small vertical component can be ignored.]
- Elastic Interaction. Simple events like springs and rubber bands pulling or pushing horizontally on another solid system with negligible friction or drag, etc.
- Drag Interaction. Simple events like boat moving through water; big solid objects moving through air; wind moving solid objects:
- Sliding (kinetic) Friction Interaction. Everyday simple events like books, boxes, or cars with brakes on, sliding over another surface and slowing down, etc.

M.B.3. Examples of a change in shape of an object include: a crumpled a piece of paper is flattened; a thin, flat piece of Styrofoam is dropped with flat side facing down and thin edge facing down.

M.B.5. Examples include skateboarder with shoulders facing forward turns sideways so one shoulder faces forward; the sail of boat in different positions with respect to the wind; bicyclist sits straight up then crouches down; changing the shape of the bow of a boat; and skydivers changing their shape as they fall.

Exclusions:
- Vertical, projectile, or three-dimensional motion.
- Elastic interactions between rigid bodies; at-rest situations (e.g., book sitting on the table); gravitational interactions; static friction interactions; interactions which require Newton’s third law;

REPRESENTATIONS/MODELS
- Same as for Objective 3.2.

TECHNICAL VOCABULARY
- applied interaction
- elastic interaction
- friction interaction
- drag interaction

Underlined words and phrases are defined in the Glossary.

Information About Rolling Friction

Most wheeled objects, like the skateboard shown at right, have a wheel bearing. The inner casing of the wheel bearing is attached to the axle and does not spin. The wheel is attached to the outer casing, which rolls over the ball bearings and allows the wheel to spin.

The ball bearings rub against the casings, and a force is exerted by the wheel on the axle-object system.

M.B.1 Example Problem Situations and Force Diagrams

<table>
<thead>
<tr>
<th>Problem Situation</th>
<th>Force Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The sled is speeding up.</td>
<td>![Force Diagram for sled speeding up]</td>
</tr>
<tr>
<td>2. The boat is slowing down after it runs out of gas.</td>
<td>![Force Diagram for boat slowing down]</td>
</tr>
</tbody>
</table>

© Pat Heller and Gay Stewart 2010
3. The skateboarder is slowing down as he holds onto the branch of the tree.

4. The box of cookies is slowing down as it slides along a table.

**M.B.4 Problem Situations and Force Diagrams**

<table>
<thead>
<tr>
<th>Problem Situation and Partial Answer</th>
<th>Force Diagram</th>
</tr>
</thead>
</table>
| 5. Explain why the rope is speeding up to the right.  
*The rope is speeding up to the right because the pull of the girl on the rope is larger than the pull of the boy on the rope. So the sum of the two forces is directed to the right.* | ![Force Diagram for Problem 5](image1.png)  

G = the applied pull of the girl on the rope  
B = the applied pull of the boy on the rope |

| 6. Explain why the skier is moving with a constant speed to the right.  
*The skier is moving at a constant speed because the sum of the two drag forces of the water on the skier is equal in magnitude but in the opposite direction from the pull of the rope on the skier. So the sum of the forces on the skier is zero.* | ![Force Diagram for Problem 6](image2.png)  

F = the applied pull of the rope on the skier  
D = the drag push of the water on the skier |

| 7. Explain why the sailboat is speeding up to the left.  
*The sailboat is speeding up to the left because the drag push of the wind in the sails is larger than the opposite drag push of the water in the boat. So the sum of the forces is directed to the left.* | ![Force Diagram for Problem 7](image3.png)  

D = the drag push of the wind on the sails of the boat  
W = the drag push of the water on the sailboat |

| 8. Explain why the shopping cart is moving with a constant speed.  
*The cart is moving at a constant speed because the applied push of the girl on the cart is equal in magnitude but opposite in direction from the rolling friction push of the wheels on the cart. So the sum of the forces on the cart is zero.* | ![Force Diagram for Problem 8](image4.png)  

F = the applied push of the girl on the shopping cart  
f = the rolling frictional push of the rubbing parts of the wheel on the cart |
**M.B.4 Example Problem Involving Circular Motion**

- Imagine rolling a ball along a curved track like the one shown here. What will the ball’s path be once it reaches the end of the track? Will it continue to roll in a circle? Will it roll in a straight line? Will it do something else?¹

- Analyze the problem.
  1. Identify the type of interaction of the ball with the track.
  2. Draw a force diagram of the ball for each position of the ball.
  3. Explain the circular motion of the ball while it is rolling inside the track based on Newton’s second law.

- Your teacher will demonstrate what happens to the ball when it reaches the end of the track. Explain the motion of the ball based on Newton’s second law.

**Grades 9-12**

**Table of Content Boundaries**

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

**Observations/Phenomena** (Real World)

- Horizontal or vertical motion
- Same objects as for middle school, but more complex situations.
- Compression (“normal”) Interaction. Simple at-rest situations; pressing a solid object against the wall; charged balloon stuck to a wall, among many other examples.
- Tension Interaction. Simple situations like an object suspended by a cord; cords pulling on objects horizontally.
- Static Friction Interaction. Simple situations like pushing or pulling on heavy boxes or furniture on different surfaces; situations where static friction is necessary to allow an object to move.
- Static Friction and Drag Interactions Where One Object is an Energy Source. Examples include: a drag interaction between kayaker-paddle system (energy source) and the water (interacting system); a drag interaction between the electric source-motor-rotating blades of helicopters and boats (energy sources) and the air or water (interacting systems); a static friction interaction between a person’s feet (energy source) and the ground (interacting object) when the person starts to walk; and a static friction interaction between the wheels of a car (energy source) and the ground (interacting object), among many other examples.

- **H.3.3.1.** Range of different grains of sand paper (from very rough to extra fine) to illustrate that kinetic friction is NOT related to the roughness of the surface, but to the strength of the attraction between the atoms or molecules of the two objects.

**Exclusions:**

- projectile or three dimensional motion
- collision interactions (See Objective 2.3)

**Representations/Models**

- Mathematical representation of elastic force, \( F_{\text{elastic}} = k\Delta x \).
- Mathematical representation of kinetic friction force, \( F_k = \mu_k N \).
- Mathematical representation of static friction force, \( F_s = \mu_s N \).
- Same as Objective 3.2.

**Technical Vocabulary**

- tension interaction
- compression(normal) interaction
- kinetic friction interaction
- static friction interaction
- force laws

Underlined words and phrases are defined in the Glossary.

¹ Arons, 1977
### H.B.3 and H.B.4 Kinetic and Static Friction Coefficients

<table>
<thead>
<tr>
<th>Surfaces</th>
<th>kinetic (μk)</th>
<th>static (μs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>rubber on concrete (dry)</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>rubber on concrete (wet)</td>
<td>0.25</td>
<td>0.30</td>
</tr>
<tr>
<td>Teflon on Teflon</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Teflon on steel</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>steel on steel</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>metal on metal (lubricated)</td>
<td>~0.06</td>
<td>0.15</td>
</tr>
<tr>
<td>ice on ice</td>
<td>0.03</td>
<td>0.10</td>
</tr>
<tr>
<td>waxed wood on dry snow</td>
<td>0.06</td>
<td>0.10</td>
</tr>
<tr>
<td>waxed wood on wet snow</td>
<td>0.10</td>
<td>0.14</td>
</tr>
<tr>
<td>wood on wood</td>
<td>0.02</td>
<td>0.25-0.50</td>
</tr>
</tbody>
</table>

Sometimes the goal is to reduce friction (e.g., engine oil and other lubricants), and sometimes the goal is to increase friction (e.g., brake linings, driving belts, soles of shoes, and tires).

### Objective 3.4

**Gravitational Interactions and Forces** (Grades 5-8 and Grades 9-12)

Students understand that gravity is an attractive interaction between any two objects with mass, which can cause a change in motion of the objects. Gravitational interactions are governed by a force law.

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

Students’ conceptual difficulties with gravitational forces 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. Shape of Earth and Up-Down</td>
<td>M.3.4.1</td>
</tr>
<tr>
<td>a. The Earth is round like a pancake.</td>
<td>M.B.3</td>
</tr>
<tr>
<td>b. We live on the flat middle of a sphere.</td>
<td></td>
</tr>
<tr>
<td>c. There is a definite up and down in space.</td>
<td></td>
</tr>
<tr>
<td>2. “Gravity” is not associated with an interaction between two objects. “Gravity” is not necessarily the same as “gravitational force.”</td>
<td>M.3.4.2</td>
</tr>
<tr>
<td>H.3.4.2</td>
<td>H.B.2</td>
</tr>
<tr>
<td>3. Gravity is caused by the earth’s magnetism, or the spinning earth (planets that spin faster have more gravity), or by air pressure (there is no gravity in a vacuum).</td>
<td>M.3.4.2</td>
</tr>
<tr>
<td>M.B.3</td>
<td></td>
</tr>
<tr>
<td>4. The force that acts on an apple is not the same as the force that acts on the Moon.</td>
<td>M.3.4.2b</td>
</tr>
<tr>
<td>5. There is no gravitational force in space. Objects in orbit are weightless, so gravity does not affect them.</td>
<td>H.3.4.4</td>
</tr>
<tr>
<td>6. Magnitude of the Earth’s Gravitation Force</td>
<td>H.3.4.3</td>
</tr>
<tr>
<td>a. The gravitational force is the same on all falling objects.</td>
<td></td>
</tr>
<tr>
<td>b. Gravity varies significantly over a few meters of height above the Earth’s surface.</td>
<td>M.B.3</td>
</tr>
<tr>
<td>c. The gravitational force is much stronger than the magnetic and electrical forces (because it</td>
<td></td>
</tr>
</tbody>
</table>
**Student Difficulty** Students often believe that:

- keeps the planets in their orbits.
- Near the surface of the earth, heavier objects fall faster than lighter objects.
- The gravitational forces on interacting objects are not equal and opposite – the gravitational pull of the Earth on an object is much larger than the gravitational pull of the object on the Earth.
- Mass and Weight
  - Mass and weight are the same and they are equal at all times.
  - Weight is not the same as the gravitational pull of the Earth on an object. Objects fall because of two things acting separately, gravity and the weight of an object (or the product of “in times g”).

<table>
<thead>
<tr>
<th>Where Addressed</th>
<th>Essential Knowledge</th>
<th>Learning Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H.3.4.2</td>
<td>H.B.1</td>
</tr>
<tr>
<td></td>
<td>H.3.4.4</td>
<td>H.B.5</td>
</tr>
<tr>
<td></td>
<td>M.3.4.4</td>
<td>M.B.7</td>
</tr>
</tbody>
</table>

+ See also conceptual difficulties in Objective 5.1 (Forces and Fields)

**Grades 5-8**

**Table of Content Boundaries**

**PHENOMENA, REPRESENTATIONS AND MODELS, AND TECHNICAL VOCABULARY**

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

**Observations/Phenomena** (Real World)

- Objects. Everyday examples of objects released and falling; or throwing small objects straight up or down
- Events. Circular orbits of moons around planets; orbits of planets around sun.
- **M.B.2.** Video demonstration of weight suspended by spring scale inside a vacuum chamber is one appropriate resource.
- **Exclusions:** At-rest situations; projectile motion and three-dimensional motion

**Representations/Models**

- Same as for Objective 3.2

**Technical Vocabulary**

- Label for gravitational force on force diagrams: “gravitational pull of the … [planet or moon] on the … [system of interest].”
- **Exclusions:** The phrase “force of gravity” should be avoided as much as possible. Substitute “gravitational pull of the Earth.”

Underlined words and phrases are defined in the Glossary.

**M.B.1 Example Problem situations**

**Example #1.** In this picture, four people holding balls are standing on different parts of the Earth. Suppose each person lets go of his or her ball. On the picture draw the path that shows how each person’s ball would fall. Explain why the balls follow the paths you drew.

**Example #2.** Four helicopters are hovering over the Earth as shown in the picture. Each helicopter has a crate of supplies to be delivered to Red Cross sites. On the picture draw how each helicopter’s crate would fall when the crates are released. Write your reasons for your drawing. Explain why the crates follow the paths you drew.

---

Example #3. An explorer has two half-filled water bottles at the North Pole. One bottle is capped and the other is not. Suppose the explorer travels to the South Pole and sets her bottles down. Draw on the sketch to show what will happen to the water in the bottles. Explain your sketches.

M.B.2 Example Responses

Air pressure is not the cause of the gravitational interaction. An object is placed on a scale in a bell jar. The air is then evacuated out of the bell jar. The object does not begin to float and its scale measurement did not change. Because there was no change observed, the gravitational interaction cannot be due to air pressure. (Demonstration or Video)

Earth’s rotation is not the cause of the gravitational interaction. A string is attached to the rim of a bucket, and the bucket is rotated around its vertical axis. The string straightened up (pointed outward) when the bucket rotated. The gravitational interaction is not caused by Earth’s rotation because if it were the string would not have moved outward, pointing away from the bucket, when the bucket was rotated. Rather, it should have moved inward, toward the bucket and rested itself on the bucket.

Earth’s magnetism is not the cause of gravity. The gravitational interaction is always attractive (objects are pulled toward each other); magnetic interactions are sometimes repulsive. Also, there is a magnetic attraction between a magnet and some metals, but there is a gravitational attraction between Earth and ALL objects.

M.B.9 Example Problem

a. A skydiver jumps out of a plane at 30,000 feet and spreads out her arms and legs, as shown. After a few seconds, she falls with a constant speed. Why?
   (i) Identify the object(s) interacting with the skydiver. Determine the type(s) of interaction(s) based on the characteristics of different types of interactions.
   (ii) Draw a force diagram of the skydiver.
   (iii) Explain why the skydiver falls with a constant speed (called her terminal velocity)

b. The skydiver moves so she is falling as shown. Predict what will happen to her pattern of motion as she falls. Will she continue falling at a constant speed? Will she speed up? Slow down? Explain your reasoning.

Grades 9-12

Table of Content Boundaries

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

Observations/Phenomena (Real World)
- Events. Everyday examples of small objects falling, or throwing small objects straight up. Circular orbits of satellites around Earth, moons around planets; orbits of planets around sun.
- H.B.9. See Instructional Guidance for Standard 1, Objective 1.1
- Projectile motion could be done as an extension activity (see example below)
Extension: Projectile Motion

Research indicates that the independence of the orthogonal components of a vector is a very difficult concept for students. An object moving horizontally with a constant speed and then falling, however, can be considered as two, one-dimensional problems, as illustrated in the diagram at right.

There are many investigations and problems that can be done by students assuming two one-dimensional problems.

**Objective 3.5**

**Magnetic and Electrical Interactions and Forces** (Grades 5-8 and Grades 9-12)

*Students understand that both magnetic interactions and electrical interactions occur between mutually attracting or repelling objects, which can cause a change in motion. Electrical interactions apply to point charges and are governed by a force law.*

In these standards, an object is suspended (free to swing) to determine whether it is a magnet – if it stops swinging and orients in the geographical north-south direction (operational definition). Similarly, an object is charged if it attracts small pieces of paper or thin foil (operational definition). “An operational definition uses real objects and real operations (not merely words) to produce, measure, or recognize an instance of the term [e.g., magnet].” This allows easy communication between scientists who might have different theories about magnets, but they can agree that the objects ARE magnets.

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

Students’ conceptual difficulties with magnetic and electrical forces 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>All metals are attracted to a magnet; all magnets are made of iron.</td>
<td>M.3.5.1, M.B.1</td>
</tr>
<tr>
<td>The magnetic pole of the Earth in the northern hemisphere is a north pole, and the pole in the southern hemisphere is a south pole.</td>
<td>M.3.5.1, M.B.1</td>
</tr>
<tr>
<td>A charged object can only affect other charged objects.</td>
<td>M.3.5.2b, M.B.2</td>
</tr>
</tbody>
</table>
Student Difficulty. Students often believe that:

<table>
<thead>
<tr>
<th>Where Addressed</th>
<th>Where Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essential Knowledge</td>
<td>Learning Outcome</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>H.5.5.6</td>
<td>M.B.3</td>
</tr>
<tr>
<td>H.8.6</td>
<td></td>
</tr>
<tr>
<td>H.3.5.5</td>
<td>H.B.4</td>
</tr>
<tr>
<td>M.3.5.2c</td>
<td>M.B.7</td>
</tr>
<tr>
<td>H.3.5.2</td>
<td>H.B.8</td>
</tr>
<tr>
<td>H.3.5.3</td>
<td>H.B.7</td>
</tr>
<tr>
<td>H.3.5.4</td>
<td>H.B.1</td>
</tr>
</tbody>
</table>

4. Atomic Model of Charges
   a. A charged object has only one type of charge.
   b. Positively charged objects have gained protons, rather than being deficient in electrons.
   c. Electrons that are lost by an object are really lost (no conservation of charge).

5. The electric force between two charged objects is not affected by the distance between them.

6. Coulomb’s law applies to charge systems consisting of something other than point charges.

7. Equilibrium means that all the forces on an object are equal and opposite.

8. Charges can disappear (are not conserved), especially in charging by induction.

† See also conceptual difficulties in Objective 5.1 (Forces and Fields), Objective 5.3 (Electromagnetism and Fields), and Objective 3.2 (Forces and Changing Motion)

Grades 5-8

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<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Middle School (Grades 5-8)</td>
</tr>
</tbody>
</table>

**Observations/Phenomena (Real World)**

- One dimensional motion and force
- Events and Objects. Simple, everyday events (other interactions negligible) involving the interaction of magnets of different shapes and strengths with other magnets and magnetic materials (e.g., objects made of different types of metal, household non-metallic objects, and so on).
- Events and Objects. Simple, everyday events (other interactions negligible) involving the interaction of charged objects with other charged and uncharged objects (e.g., pieces of different types of cloth; pieces of hard plastic, rubber balloons, glass, Styrofoam, scotch tape; pieces of light metals like straws covered with aluminum foil, Christmas tinsel, and so on)

**Exclusions:** two and three dimensional motion and forces; charging by induction

**Representations/Models**

- Same as Objective 3.2

**Exclusions:** Charge measurement: Coulombs (C)

**Technical Vocabulary**

- magnetic interaction
- electrical interaction
- electrical conductor and insulator

**Exclusions:** Coulomb’s Law, polarization

Underlined words and phrases are defined in the Glossary.

**M.B.1 Experiment**

Use painted bar magnets and painted long, rectangular or cylindrical bars made of steel, copper, tin, wood, plastic, and so on. Students suspend the painted objects to determine which objects align in the geographical north-south direction (the magnets).
**M.B.5 Experiment**

A long piece of coat hanger and a thin wooden dowel with Christmas tinsel attached to one end make good detectors of whether charges move from one end of the material (touched by a charged object) to the other end with the tinsel. The metal coat hanger with tinsel is similar to the construction of an electroscope. For more ideas see Robert Morse’s book, *Teaching About Electrostatics* (1992).

**Grades 9-12**

**Table of Content Boundaries**

<table>
<thead>
<tr>
<th>PHENOMENA, REPRESENTATIONS AND MODELS, AND TECHNICAL VOCABULARY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High School</strong> (Grades 9-12)</td>
</tr>
<tr>
<td><strong>OBSERVATIONS/PHENOMENA</strong> (Real World)</td>
</tr>
<tr>
<td>• Linear motion only; simple forces along direction of motion.</td>
</tr>
<tr>
<td>• Same events and objects as for grades 6-8, but can include more complicated situations and materials (e.g., light metallic spheres (or pop cans) attached to insulating bases, suspended pith balls, simple electrosopes, an electrophorus, and so on).</td>
</tr>
<tr>
<td><strong>Exclusions</strong>: magnetic interactions, two- and three-dimensional motion and forces.</td>
</tr>
<tr>
<td><strong>REPRESENTATIONS/MODELS</strong></td>
</tr>
<tr>
<td>• Same as Objective 3.2.</td>
</tr>
<tr>
<td>• Diagrams of objects that can be marked with + and – signs for charges.</td>
</tr>
<tr>
<td>• Charge measurement: Coulombs (C), multiples of the charge of an electron.</td>
</tr>
<tr>
<td><strong>TECHNICAL VOCABULARY</strong></td>
</tr>
<tr>
<td>• Coulomb’s Law</td>
</tr>
<tr>
<td>• charging by induction</td>
</tr>
</tbody>
</table>

Underlined words and phrases are defined in the Glossary.

**H.B.7 Example Explanations**

**External Charge Near a Conductor.** When a positively charged object is near a neutral metal conductor, the free electrons in the metal are attracted toward the object. According to Coulomb’s law, the force between two charged objects decreases with increasing distance between charges. The excess positive charges are farther away from the external positive charge, so the sum of the repulsive forces on the positive charges is less than the sum of the attractive forces on the excess, negatively charged electrons. This results in a net attractive force between the external charge and the neutral conductor.

**External Charge Near an Insulator.** When a charged object is near a neutral insulator, the electron cloud of each insulator atom shifts position slightly so it is no longer centered on the nucleus. According to Coulomb’s law, the force between two charged objects decreases with increasing distance between charges. The negative end of the atoms are closer to the positive external charge, so the average force on the positive end of each atom is less than the average force on the negative end, resulting in an attractive force between the external charge and each atom. The attractive force between the external charge and the whole insulator is the sum of the attractive force on all the atoms.