Georgia Milestones Assessment System

# Study/Resource Guide for Students and Parents

# Physical Science

Study/Resource Guide

The Study/Resource Guides are intended to serve as a resource for parents and students. They contain practice questions for the course. The standards identified in the Study/Resource Guides address a sampling of the state-mandated content standards.

For the purposes of day-to-day classroom instruction, teachers should consult the wide array of resources that can be found at www.georgiastandards.org.

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# THE GEORGIA MILESTONES ASSESSMENT SYSTEM

## Dear Student,

The **Georgia Milestones Physical Science EOC Study/Resource Guide for Students and Parents** is intended as a resource for parents and students.

This guide contains information about the core content ideas and skills that are covered in the course. There are practice sample questions for every section. The questions are fully explained and describe why each answer is either correct or incorrect. The explanations also help illustrate how each question connects to the Georgia state standards.

The standards and additional instructional resources can be found on the Georgia Department of Education website, www.georgiastandards.org.

***Get ready—open this guide—and get started!***



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# GEORGIA MILESTONES END-OF-COURSE (EOC) ASSESSMENTS

The EOC assessments serve as the final exam in certain courses. The courses are:

**English Language Arts**

- Ninth Grade Literature and Composition
- American Literature and Composition

**Mathematics**

- Algebra I
- Analytic Geometry
- Coordinate Algebra
- Geometry

**Science**

- Physical Science
- Biology

**Social Studies**

- United States History
- Economics/Business/Free Enterprise

**All End-of-Course assessments accomplish the following:**

- Ensure that students are learning
- Count as part of the course grade
- Provide data to teachers, schools, and school districts
- Identify instructional needs and help plan how to meet those needs
- Provide data for use in Georgia's accountability measures and reports



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# HOW TO USE THIS GUIDE

## Let's get started!

First, preview the entire guide. Learn what is discussed and where to find helpful information. Even though the focus of this guide is Physical Science, you need to keep in mind your overall good reading habits.

- Start reading with a pencil or a highlighter in your hand and sticky notes nearby.
- Mark the important ideas, the things you might want to come back to, or the explanations you have questions about. On that last point, your teacher is your best resource.
- You will find some key ideas and important tips to help you prepare for the test.
- You can learn about the different types of items on the test.
- When you come to the sample items, don't just read them, *do* them. Think about strategies you can use for finding the right answer. Then read the analysis of the item to check your work. The reasoning behind the correct answer is explained for you. It will help you see any faulty reasoning in those you may have missed.
- With the Depth of Knowledge (DOK) information, you can gauge just how complex the item is. You will see that some items ask you to recall information and others ask you to infer or go beyond simple recall. The assessment will require all levels of thinking.
- Plan your studying and schedule your time.
- Proper preparation will help you do your best!

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# OVERVIEW OF THE PHYSICAL SCIENCE EOC ASSESSMENT

## ITEM TYPES

The Physical Science EOC assessment consists of **selected-response** and **technology-enhanced** items.

A **selected-response** item, sometimes called a multiple-choice item, is a question, problem, or statement that is followed by four answer choices. These questions are worth one point.

A **technology-enhanced (TE)** item has a question, problem, or statement. These types of questions are worth two points. Partial credit may be awarded if you select some but not all of the correct answers or if you get one part of the question correct but not the other part.

- In multi-select questions, you will be asked to select more than one right answer.
- In multi-part questions, the questions will have more than one part. You will need to provide an answer in each part.
- In drag-and-drop questions, you will be asked to use a mouse, touchpad, or touchscreen to move responses to designated areas on the screen.
- Since some technology-enhanced items in this guide were designed to be used in an online, interactive-delivery format, some of the item-level directions will not appear to be applicable when working within the format presented in this document (for example, “Move the characteristics into the boxes” or “Click To Respond”).
- This icon ➲ identifies special directions that will help you answer technology-enhanced items as shown in the format presented within this guide. These directions do not appear in the online version of the test but explain information about how the item works that would be easily identifiable if you were completing the item in an online environment.

To practice using technology-enhanced items in an online environment very similar to how they will appear on the online test, visit “Experience Online Testing Georgia.”

1. Go to the website “Welcome to Experience Online Testing Georgia” (http://gaexperienceonline.com/).
2. Select “Test Practice.”
3. Under “End-of-Course (EOC) All Assessments,” select “Online Tools Training.”
4. Select “EOC Test Practice.”
5. Select “Technology Enhanced Items.”
6. You will be taken to a login screen. Use the username and password provided on the screen to log in and practice navigating technology-enhanced items online.

Please note that Google Chrome is the only supported browser for this public version of the online testing environment.



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## DEPTH OF KNOWLEDGE DESCRIPTORS

Items found on the Georgia Milestones assessments, including the Physical Science EOC assessment, are developed with a particular emphasis on the kinds of thinking required to answer questions. In current educational terms, this is referred to as Depth of Knowledge (DOK). DOK is measured on a scale of 1 to 4 and refers to the level of cognitive demand (different kinds of thinking) required to complete a task, or in this case, an assessment item. The following table shows the expectations of the four DOK levels in detail.

The DOK table lists the skills addressed in each level, as well as common question cues. These question cues not only demonstrate how well you understand each skill, but they relate to the expectations that are part of the Characteristics of Science and Nature of Science standards.



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| Level 1—Recall of Information | |
|---|---|
| Level 1 generally requires that you identify, list, or define. This level usually asks you to recall facts, terms, concepts, and trends and may ask you to identify specific information contained in documents, maps, charts, tables, graphs, or illustrations. Items that require you to "describe" and/or "explain" could be classified as Level 1 or Level 2. A Level 1 item requires merely that you recall, recite, or reproduce information. | |
| **Skills Demonstrated** | **Question Cues** |
| • Make observations<br>• Recall information<br>• Recognize formulas, properties, patterns, processes<br>• Know vocabulary, definitions<br>• Know basic concepts<br>• Perform one-step processes<br>• Translate from one representation to another<br>• Identify relationships | • Tell what, when, or where<br>• Find<br>• List<br>• Define<br>• Identify; label; name<br>• Choose; select<br>• Compute; estimate<br>• Express<br>• Read from data displays<br>• Order |

| Level 2—Basic Reasoning | |
|---|---|
| Level 2 includes the engagement (use) of some mental processing beyond recalling or reproducing a response. A Level 2 "describe" and/or "explain" item would require that you go beyond a description or explanation of recalled information to describe and/or explain a result or "how" or "why." | |
| **Skills Demonstrated** | **Question Cues** |
| • Apply learned information to abstract and real-life situations<br>• Use methods, concepts, theories in abstract and real-life situations<br>• Perform multi-step processes<br>• Solve problems using required skills or knowledge (requires more than habitual response)<br>• Make a decision about how to proceed<br>• Identify and organize components of a whole<br>• Extend patterns<br>• Identify/describe cause and effect<br>• Recognize unstated assumptions; make inferences<br>• Interpret facts<br>• Compare or contrast simple concepts/ideas | • Apply<br>• Calculate; solve<br>• Complete<br>• Describe<br>• Explain how; demonstrate<br>• Construct data displays<br>• Construct; draw<br>• Analyze<br>• Extend<br>• Connect<br>• Classify<br>• Arrange<br>• Compare; contrast |



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| **Level 3—Complex Reasoning**<br>Level 3 requires reasoning, using evidence, and thinking on a higher and more abstract level than Level 1 and Level 2. You will go beyond explaining or describing "how and why" to justifying the "how and why" through application and evidence. Level 3 questions often involve making connections across time and place to explain a concept or "big idea." | |
|---|---|
| **Skills Demonstrated** | **Question Cues** |
| • Solve an open-ended problem with more than one correct answer<br>• Create a pattern<br>• Generalize from given facts<br>• Relate knowledge from several sources<br>• Draw conclusions<br>• Make predictions<br>• Translate knowledge into new contexts<br>• Compare and discriminate between ideas<br>• Assess value of methods, concepts, theories, processes, formulas<br>• Make choices based on a reasoned argument<br>• Verify the value of evidence, information, numbers, and data | • Plan; prepare<br>• Predict<br>• Create; design<br>• Ask "what if?" questions<br>• Generalize<br>• Justify; explain why; support; convince<br>• Assess<br>• Rank; grade<br>• Test; judge<br>• Recommend<br>• Select<br>• Conclude |

| **Level 4—Extended Reasoning**<br>Level 4 requires the complex reasoning of Level 3 with the addition of planning, investigating, applying significant conceptual understanding, and/or developing that will most likely require an extended period of time. You may be required to connect and relate ideas and concepts *within* the content area or *among* content areas in order to be at this highest level. The Level 4 items would be a show of evidence, through a task, a product, or an extended response, that the cognitive demands have been met. | |
|---|---|
| **Skills Demonstrated** | **Question Cues** |
| • Analyze and synthesize information from multiple sources<br>• Examine and explain alternative perspectives across a variety of sources<br>• Apply mathematical models to illuminate a problem or situation<br>• Design a mathematical model to inform and solve a practical or abstract situation<br>• Combine and synthesize ideas into new concepts | • Design<br>• Connect<br>• Synthesize<br>• Apply concepts<br>• Critique<br>• Analyze<br>• Create<br>• Prove |



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## DEPTH OF KNOWLEDGE EXAMPLE ITEMS

Example items that represent the applicable DOK levels across various Physical Science content domains are provided on the following pages.

**All example and sample items contained in this guide are the property of the Georgia Department of Education.**



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## Example Item 1

**Selected-Response**

**DOK Level 1:** This is a DOK level 1 item because it requires the student to recall information concerning a known relationship between voltage, current, and resistance.

**Physical Science Domain:** Physics: Waves, Electricity, and Magnetism

**Standard:** SPS10. Obtain, evaluate, and communicate information to explain the properties of and relationships between electricity and magnetism.

a. Use mathematical and computational thinking to support a claim regarding relationships among voltage, current, and resistance.

**Which claim about current is shown to be mathematically supported from the relationship between the voltage, the current, and the resistance?**

**A.** claim 1: $I = V + R$
**B.** claim 2: $I = V - R$
**C.** claim 3: $I = V \times R$
**D.** claim 4: $I = V / R$

**Correct Answer:** D

**Explanation of Correct Answer:** The correct answer is choice (D) claim 4: $I = V / R$. The formula sheet shows that voltage ($V$) equals current ($I$) multiplied by resistance ($R$). So solving for current, $I = V / R$. Choice (A) is incorrect because adding the voltage to the resistance will not give the current. Choice (B) is incorrect because subtracting the resistance from the voltage will not give the current. Choice (C) is incorrect because multiplying the voltage and the resistance will not give the current.



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## Example Item 2

**Selected-Response**

**DOK Level 2:** This is a DOK level 2 item because it requires the student to apply learned information, the concept of convection, to abstract and real-life situations.

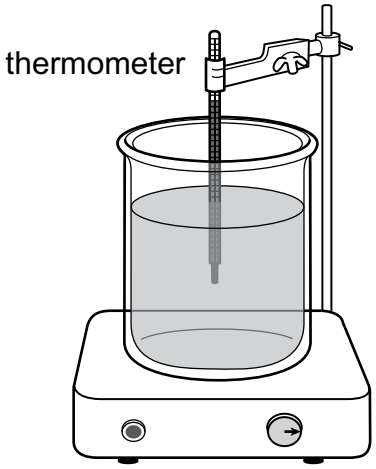
**Physical Science Domain:** Physics: Energy, Force, and Motion

**Standard:** SPS7. Obtain, evaluate, and communicate information to explain transformations and flow of energy within a system.

b. Plan and carry out investigations to describe how molecular motion relates to thermal energy changes in terms of conduction, convection, and radiation.

**A student wants to set up two demonstrations to show different ways that heat can be transferred from a hot plate to a thermometer. Demonstration 1 is set up with the thermometer suspended in water as shown.**

**Heat Transfer Investigation**




***Go on to the next page to finish example item 2.***



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**Example Item 2. *Continued*.**

**How should the student change the setup in demonstration 2 to observe a single type of thermal energy transfer, and which explanation correctly describes the type of heat transfer shown in each demonstration?**

**A.** **demonstration 2:** Replace the water with an equal amount of sand and keep the thermometer suspended in the sand.
**explanation:** In demonstration 1, the hot plate transfers heat to the thermometer by conduction and convection. In demonstration 2, the hot plate transfers heat to the thermometer by conduction only.

**B.** **demonstration 2:** Replace the water with an equal amount of sand and suspend the thermometer 3 centimeters above the sand.
**explanation:** In demonstration 1, the hot plate transfers heat to the thermometer by convection and radiation. In demonstration 2, the hot plate transfers heat to the thermometer by radiation only.

**C.** **demonstration 2:** Remove half of the water from the container. Place a copper plate barrier on top of the water, and replace the water above the barrier so that the water above and below the barrier does not mix. Place the thermometer so it is touching the copper plate barrier.
**explanation:** In demonstration 1, the hot plate transfers heat to the thermometer by conduction and convection. In demonstration 2, the hot plate transfers heat to the thermometer by conduction only.

**D.** **demonstration 2:** Remove half of the water from the container. Place a copper plate barrier on top of the water, and replace the water above the barrier so that the water above and below the barrier does not mix. Keep the thermometer suspended in the water above the copper plate barrier.
**explanation:** In demonstration 1, the hot plate transfers heat to the thermometer by convection and radiation. In demonstration 2, the hot plate transfers heat to the thermometer by radiation only.

**Correct Answer:** A

**Explanation of Correct Answer:** The correct answer choice is (A) **demonstration 2:** Replace the water with an equal amount of sand and keep the thermometer suspended in the sand.
**explanation:** In demonstration 1, the hot plate transfers heat to the thermometer by conduction and convection. In demonstration 2, the hot plate transfers heat to the thermometer by conduction only. Choice (A) is correct because there is no convection in a solid or a mass of solid particles like sand. Convection only occurs in fluids, such as water or air. Choice (B) is incorrect because demonstration 1 shows conduction and convection, and this demonstration 2 would show conduction, convection, and radiation. In addition to radiation from the hot sand to the thermometer, air warmed by conduction from the sand would then rise (convection) and then transfer heat energy to the thermometer by conduction. Choice (C) is incorrect because this demonstration 2 would still show convection (below the barrier). Choice (D) is incorrect because demonstration 1 shows conduction and convection and this demonstration 2 would not show radiation.



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## Example Item 3

**Selected-Response**

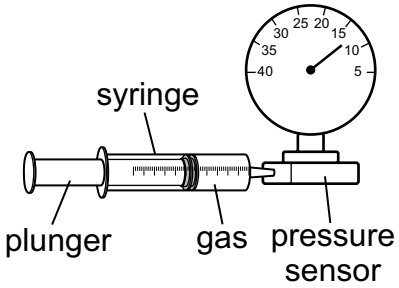
**DOK Level 3:** This is a DOK level 3 item because it requires the student to construct arguments supported by evidence, to analyze and interpret data, to construct explanations and design solutions, and to plan and carry out investigations.

**Physical Science Domain:** Chemistry: Chemical Reactions and Properties of Matter

**Standard:** SPS5. Obtain, evaluate, and communicate information to compare and contrast the phases of matter as they relate to atomic and molecular motion.

b. Plan and carry out investigations to identify the relationships among temperature, pressure, volume, and density of gases in closed systems.

**A student wants to investigate the relationship between pressure and volume in nitrogen gas ($N_2$) by using a pressure sensor on an airtight 25-milliliter (mL) syringe as shown in the diagram.**




**In step 1 of the investigation, the student will add $N_2$ to the syringe at 20°C.**

***Go on to the next page to finish example item 3.***



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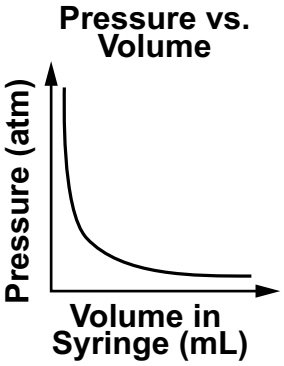
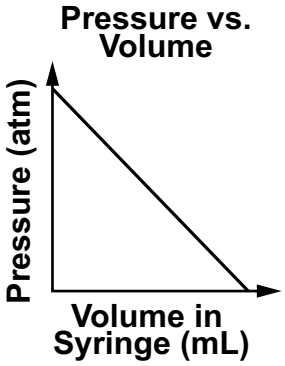
**Example Item 3. *Continued*.**

**How should the student proceed with the investigation, and which graph shows what the student will MOST LIKELY observe?**

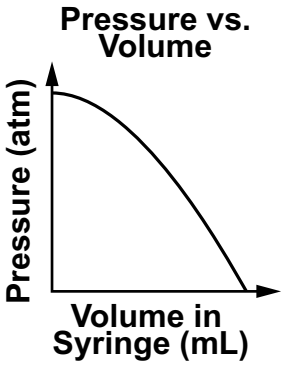
**A.** **step 2.** Keep the temperature of the gas constant.
**step 3.** Increase the volume of the gas in the syringe and record the resulting pressure of the gas.



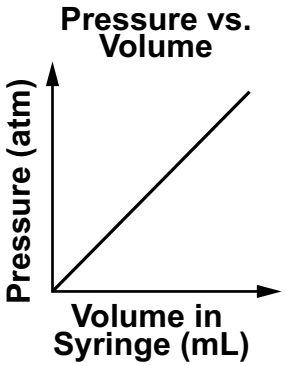

**B.** **step 2.** Increase the temperature of the gas.
**step 3.** Push the plunger on the syringe to apply different amounts of pressure on the gas and record the resulting volume of the gas.




**C.** **step 2.** Keep the temperature of the gas constant.
**step 3.** Push the plunger on the syringe to apply different amounts of pressure on the gas and record the resulting volume of the gas.




**D.** **step 2.** Increase the temperature of the gas.
**step 3.** Increase the volume of the gas in the syringe and record the resulting pressure of the gas.



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**Example Item 3. *Continued*.**

**Correct Answer:** A

**Explanation of Correct Answer:** The correct answer is choice (A). Choice (A) is correct because the temperature of the gas should remain constant in this investigation since temperature will also affect the pressure; step 3 is correct because this change of volume will change the pressure; and this is the correct graph for an inverse relationship of pressure and volume. Choice (B) is incorrect because the temperature of the gas should remain constant in this investigation and the graph shows a direct negative relationship, not an inverse proportional relationship. Choice (C) is incorrect because the graph shows that as the gas is compressed the pressure reaches a maximum value. Choice (D) is incorrect because the temperature of the gas should remain constant in this investigation, and this graph shows increasing pressure with increasing volume, which is the reverse of the correct relationship.



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# DESCRIPTION OF TEST FORMAT AND ORGANIZATION

The Georgia Milestones Physical Science EOC assessment consists of a total of 42 items. You will be asked to respond to selected-response (multiple-choice) and technology-enhanced items.

The test will be given in two sections.

- You may have up to 40 minutes per section to complete Sections 1 and 2.
- The total estimated testing time for the Physical Science EOC assessment ranges approximately from 40 to 80 minutes. Total testing time describes the amount of time you have to complete the assessment. It does not take into account the time required for the test examiner to complete pre-administration and post-administration activities (such as reading the standardized directions to students).
- Sections 1 and 2 may be administered on the same day or across two consecutive days, based on the district's testing protocols for the EOC measures (in keeping with state guidance).
- During the Physical Science EOC assessment, a Physical Science Reference Sheet of formulas and the Periodic Table of the Elements will be available for you to use. See page 22 for an example.

### Effect on Course Grade

It is important that you take this course and the EOC assessment very seriously.

- For students in Grade 10 or above beginning with the 2011–2012 school year, the final grade in each course is calculated by weighting the course grade 85% and the EOC score 15%.
- For students in Grade 9 beginning with the 2011–2012 school year, the final grade in each course is calculated by weighting the course grade 80% and the EOC score 20%.
- A student must have a final grade of at least 70% to pass the course and earn credit toward graduation.



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# PREPARING FOR THE PHYSICAL SCIENCE EOC ASSESSMENT

## STUDY SKILLS

As you prepare for this test, ask yourself the following questions:

- How would you describe yourself as a student?
- What are your study-skills strengths and/or weaknesses?
- How do you typically prepare for a classroom test?
- What study methods do you find particularly helpful?
- What is an ideal study situation or environment for you?
- How would you describe your actual study environment?
- How can you change the way you study to make your study time more productive?

## ORGANIZATION—OR TAKING CONTROL OF YOUR WORLD

- Establish a study area that has minimal distractions.
- Gather your materials in advance.
- Develop and implement your study plan.

## ACTIVE PARTICIPATION

The most important element in your preparation is *you*. You and your actions are the key ingredient. Your active studying helps you stay alert and be more productive. In short, you need to interact with the course content. Here's how you do it.

- Carefully read the information and then DO something with it. Mark the important material with a highlighter, circle it with a pen, write notes on it, or summarize the information in your own words.
- Ask questions. As you study, questions often come into your mind. Write them down and actively seek the answers.
- Create sample test questions and answer them.
- Find a friend who is also planning to take the test and quiz each other.

## TEST-TAKING STRATEGIES

Part of preparing for a test is having a set of strategies you can draw from. Include these strategies in your plan:

- Read and understand the directions completely. If you are not sure, ask a teacher.
- Read each question and all the answer choices carefully.
- If you use scratch paper, make sure you copy your work to your test accurately.
- Make a sketch for items that describe a situation. This will help you visualize what is being described and help you understand the problem.
- Underline the important parts of each task. Make sure that your answer goes on the answer sheet.



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- Be aware of time. If a question is taking too much time, come back to it later.
- Answer all questions. Check your answers for accuracy.
- Stay calm and do the best you can.

## PREPARING FOR THE PHYSICAL SCIENCE EOC ASSESSMENT

Read this guide to help prepare for the Physical Science EOC assessment.

The section of the guide titled “Content of the Physical Science EOC Assessment” provides a snapshot of the Physical Science course. In addition to reading this guide, do the following to prepare to take the assessment:

- Read your textbooks and other materials.
- Think about what you learned, ask yourself questions, and answer them.
- Read and become familiar with the way questions are asked on the assessment.
- Answer the practice Physical Science questions.
- Practice your skills using additional items that are available online. Ask your teacher about online practice sites that are available for your use.



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# CONTENT OF THE PHYSICAL SCIENCE EOC ASSESSMENT

Up to this point in the guide, you have been learning how to prepare for taking the EOC assessment. Now you will learn about the topics and standards that are assessed in the Physical Science EOC assessment and see some sample items.

- The first part of this section focuses on what will be tested. It also includes sample items that will let you apply what you have learned in your classes and from this guide.
- The next part contains a table that shows the standard assessed for each item, the DOK level, the correct answer (key), and a rationale/explanation of the right and wrong answers.
- You can use the sample items to familiarize yourself with the item format found on the assessment.

**All example and sample items contained in this guide are the property of the Georgia Department of Education.**

The Physical Science EOC assessment will assess the physical science standards documented at www.georgiastandards.org. The Science Georgia Standards of Excellence are designed to provide foundational knowledge and skills for all students to develop proficiency in science. These standards focus on a limited number of core disciplinary ideas and crosscutting concepts that build from kindergarten to high school. The standards are written with the core knowledge to be mastered integrated with the science and engineering practices needed to engage in scientific inquiry and engineering design. Crosscutting concepts are used to make connections across different science disciplines.

The content of the assessment is organized into four groupings, or domains, of standards for the purposes of providing feedback on student performance.

- A content domain is a reporting category that *broadly* describes and defines the content of the course, as measured by the EOC assessment.
- On the actual test, the standards for Physical Science are grouped into four domains and divided between chemistry and physics as follows:

**Chemistry**

- Atomic and Nuclear Theory and the Periodic Table
- Chemical Reactions and Properties of Matter

**Physics**

- Energy, Force, and Motion
- Waves, Electricity, and Magnetism

- Each domain was created by organizing standards that address related science core ideas.



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## SNAPSHOT OF THE COURSE

This section of the guide is organized into sections that cover each of the four domains of the Physical Science course. In each section, you will find sample items similar to what you will see on the EOC assessment. The final section of the guide contains a table that shows for each item the standard assessed, the DOK level, the correct answer (key), and a rationale/explanation about the key and distractors.

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### Reference Materials

The next two pages show the reference sheet and the Periodic Table of the Elements that can be used during the state assessment.



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# Physical Science Reference Sheet

## Formulas

### Energy, Force, and Motion

Velocity = $\frac{\text{displacement}}{\text{time}}$ $\left(v = \frac{d}{t}\right)$

Acceleration = $\frac{\text{final velocity} - \text{initial velocity}}{\text{time}}$ $\left(a = \frac{v_f - v_i}{t}\right)$

Weight = mass × acceleration of gravity $(w = mg)$

Force = mass × acceleration $(F = ma)$

Work = force × distance $(W = Fd)$

Mechanical advantage =

$\frac{\text{effort distance}}{\text{resistance distance}} = \frac{\text{resistance force}}{\text{effort force}}$ $\left(\text{MA} = \frac{d_e}{d_r} = \frac{f_r}{f_e}\right)$

### Chemical Reactions and Properties of Matter

Volume of a rectangular solid = length × width × height $(V = lwh)$

Heat lost or gained =
mass × specific heat capacity × change in temperature $(Q = mc\Delta T)$

### Waves, Electricity, and Magnetism

Voltage = current × resistance $(V = IR)$

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## Constants and Relationships

Kelvin = °Celsius + 273 (K = °C + 273)

newton: 1 N = 1 kg • $\frac{\text{m}}{\text{s}^2}$

Acceleration due to gravity: $g \approx 10 \frac{\text{m}}{\text{s}^2}$

joule: 1 J = 1 N • m

Turn over for the Periodic Table.



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# PERIODIC TABLE OF THE ELEMENTS

KEY

79 — Atomic Number
Au — Element Symbol
Gold — Element Name
196.97 — Average Atomic Mass

| | 1 IA | 2 IIA | 3 IIIB | 4 IVB | 5 VB | 6 VIB | 7 VIIB | 8 VIIIB | 9 VIIIB | 10 VIIIB | 11 IB | 12 IIB | 13 IIIA | 14 IVA | 15 VA | 16 VIA | 17 VIIA | 18 VIIIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 H Hydrogen 1.01 | | | | | | | | | | | | | | | | | 2 He Helium 4.00 |
| 2 | 3 Li Lithium 6.94 | 4 Be Beryllium 9.01 | | | | | | | | | | | 5 B Boron 10.81 | 6 C Carbon 12.01 | 7 N Nitrogen 14.01 | 8 O Oxygen 16.00 | 9 F Fluorine 19.00 | 10 Ne Neon 20.18 |
| 3 | 11 Na Sodium 22.99 | 12 Mg Magnesium 24.31 | | | | | | | | | | | 13 Al Aluminum 26.98 | 14 Si Silicon 28.09 | 15 P Phosphorus 30.97 | 16 S Sulfur 32.07 | 17 Cl Chlorine 35.45 | 18 Ar Argon 39.95 |
| 4 | 19 K Potassium 39.10 | 20 Ca Calcium 40.08 | 21 Sc Scandium 44.96 | 22 Ti Titanium 47.87 | 23 V Vanadium 50.94 | 24 Cr Chromium 52.00 | 25 Mn Manganese 54.94 | 26 Fe Iron 55.85 | 27 Co Cobalt 58.93 | 28 Ni Nickel 58.69 | 29 Cu Copper 63.55 | 30 Zn Zinc 65.41 | 31 Ga Gallium 69.72 | 32 Ge Germanium 72.64 | 33 As Arsenic 74.92 | 34 Se Selenium 78.96 | 35 Br Bromine 79.90 | 36 Kr Krypton 83.80 |
| 5 | 37 Rb Rubidium 85.47 | 38 Sr Strontium 87.62 | 39 Y Yttrium 88.91 | 40 Zr Zirconium 91.22 | 41 Nb Niobium 92.91 | 42 Mo Molybdenum 95.94 | 43 Tc Technetium (98) | 44 Ru Ruthenium 101.07 | 45 Rh Rhodium 102.91 | 46 Pd Palladium 106.42 | 47 Ag Silver 107.87 | 48 Cd Cadmium 112.41 | 49 In Indium 114.82 | 50 Sn Tin 118.71 | 51 Sb Antimony 121.76 | 52 Te Tellurium 127.60 | 53 I Iodine 126.90 | 54 Xe Xenon 131.29 |
| 6 | 55 Cs Cesium 132.91 | 56 Ba Barium 137.33 | 57 La Lanthanum 138.91 | 72 Hf Hafnium 178.49 | 73 Ta Tantalum 180.95 | 74 W Tungsten 183.84 | 75 Re Rhenium 186.21 | 76 Os Osmium 190.23 | 77 Ir Iridium 192.22 | 78 Pt Platinum 195.08 | 79 Au Gold 196.97 | 80 Hg Mercury 200.59 | 81 Tl Thallium 204.38 | 82 Pb Lead 207.2 | 83 Bi Bismuth 208.98 | 84 Po Polonium (209) | 85 At Astatine (210) | 86 Rn Radon (222) |
| 7 | 87 Fr Francium (223) | 88 Ra Radium (226) | 89 Ac Actinium (227) | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 58 Ce Cerium 140.12 | 59 Pr Praseodymium 140.91 | 60 Nd Neodymium 144.24 | 61 Pm Promethium (145) | 62 Sm Samarium 150.36 | 63 Eu Europium 151.96 | 64 Gd Gadolinium 157.25 | 65 Tb Terbium 158.93 | 66 Dy Dysprosium 162.50 | 67 Ho Holmium 164.93 | 68 Er Erbium 167.26 | 69 Tm Thulium 168.93 | 70 Yb Ytterbium 173.04 | 71 Lu Lutetium 174.97 |
| 90 Th Thorium 232.04 | 91 Pa Protactinium 231.04 | 92 U Uranium 238.03 | 93 Np Neptunium (237) | 94 Pu Plutonium (244) | 95 Am Americium (243) | 96 Cm Curium (247) | 97 Bk Berkelium (247) | 98 Cf Californium (251) | 99 Es Einsteinium (252) | 100 Fm Fermium (257) | 101 Md Mendelevium (258) | 102 No Nobelium (259) | 103 Lr Lawrencium (262) |



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# ATOMIC AND NUCLEAR THEORY AND THE PERIODIC TABLE

Atoms and other subatomic particles make up all matter in the universe. Atoms have a nucleus containing protons and neutrons surrounded by a larger region containing electrons. The number of protons in the nucleus of the atom defines the characteristics of each atom and is known as the "atomic number." Protons and neutrons have relatively the same mass, while electrons have approximately 1,837 times less mass than protons and neutrons. The "atomic mass" of an atom is equivalent to the number of protons and neutrons in the nucleus of the atom. Not all atoms of a particular element contain the same number of neutrons in the nucleus. Atoms with different numbers of neutrons but with the same number of protons in their nuclei are called isotopes. Despite the great number of substances in the universe, there are only about 100 different stable elements.

Through the years, scientists have developed models to organize the elements according to their properties. The result of this work is the periodic table. The periodic table is a model in which elements are organized horizontally by increasing atomic number and vertically by families of elements with related chemical properties. Today, scientists recognize that patterns in chemical properties, such as in chemical reactivity and bond formation, are related to the patterns in atoms' outermost electrons.

The nucleus of an atom is an active space. Understanding of the processes that take place in the nucleus is important to explain the formation and abundance of the elements, radioactivity, the generation of nuclear energy, and the release of energy from stars. Two important forces, the strong and weak nuclear forces, play a fundamental role in the type of processes that take place in the nucleus. Without the strong nuclear force, the electromagnetic forces between protons would make all nuclei other than hydrogen unstable. Nuclear fission is a process in which a heavy nucleus splits into two or more smaller nuclei. These processes release radiation in the form of alpha particles and beta particles and/or the emission of gamma rays. Nuclear fusion is a process in which a collision of two small nuclei results in the formation of a single heavy nucleus and the release of energy.

## CORE IDEAS

- The characteristics of an atom are determined by its structure. (SPS1a)
- A change in the nuclear structure or electron configuration, or both, results in the emission of radiation. (SPS4a)
- Valence electrons determine the chemical properties of atoms. (SPS1b)
- The rate of radioactive decay for an isotope is constant and is measured by its half-life. (SPS4b)
- The number of protons determines the type of element. (SPS1a)
- The elements, arranged by increasing atomic number, exhibit periodic trends in properties. (SPS1c)
- Non-stable nuclei are radioactive and emit ionizing radiation in the form of alpha particles, beta particles, or gamma radiation. (SPS4a)
- Properties such as valence electrons, ion formation, metallic or nonmetallic properties, and phase at room temperature can be predicted for representative elements by using the periodic table. (SPS1b)
- Chemical reactions are the result of changes in electron configuration. (SPS1a, b)
- Nuclear reactions convert matter into energy through the processes of radioactive decay, fission, and fusion. (SPS4a, b)
- Bonds between atoms are formed when electrons are transferred or shared. (SPS2a)
- The International Union for Pure and Applied Chemistry (IUPAC) conventions provide a standard system for naming compounds and writing formulas. (SPS2c)



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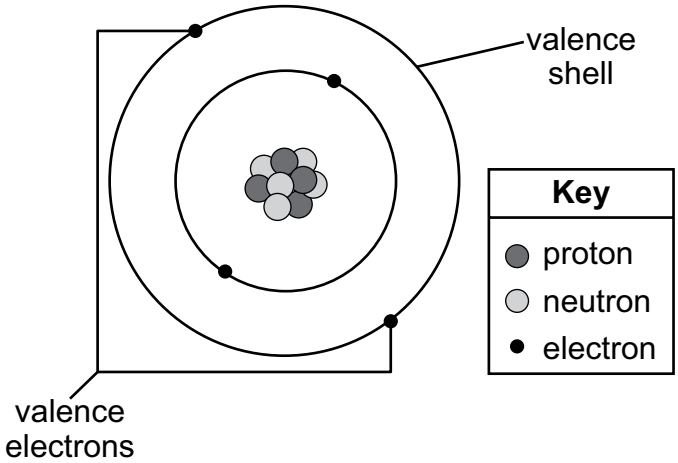
## KEY CONCEPTS

All the things that we observe in the universe are made up of atoms. Atoms contain subatomic particles called protons, neutrons, and electrons. These particles are composed of smaller particles named quarks.

**Protons** and **neutrons** are located in the **nucleus**, or center, of the atom. The proton has a single positive (+) charge, while the neutron has a zero (0), or neutral, charge. The proton and neutron have approximately the same mass. The electron has a single negative (–) charge, and its mass is about 1,837 times less than the proton or neutron. Electrons, unlike protons and neutrons, are found outside the nucleus in a region called the **electron cloud**. The electron cloud is divided into **energy levels**, which are sometimes referred to as **electron shells**. Electrons in the outermost energy level, or **valence shell**, are called **valence electrons**. The outermost electrons determine how the element will react chemically with other elements.




There are many ways to describe an atom. One way is to use the **atomic number**. It tells how many protons reside in the nucleus and identifies the element. For example, an element with an atomic number of 6 (an atom with six protons) is a carbon (C) atom. All atoms with the same number of protons are of the same element, no matter how many electrons or neutrons they might have.

### Look It Up

Use the periodic table to locate the following information about the first 20 elements:

- Element name
- Symbol
- Atomic number
- Atomic mass



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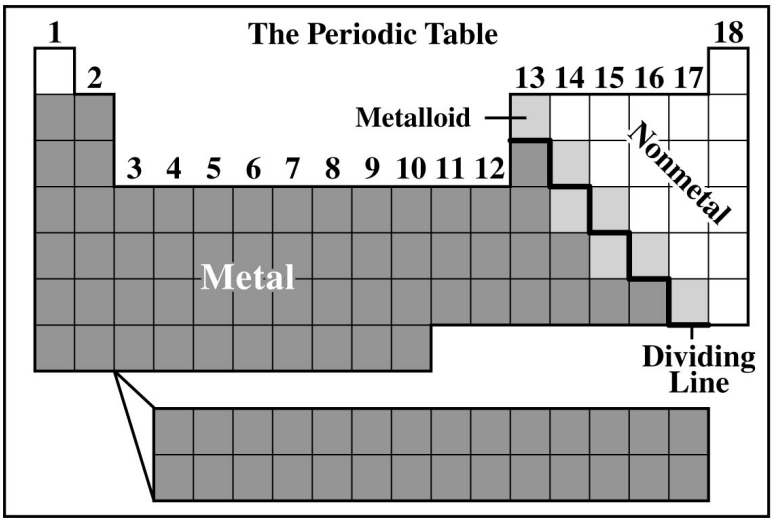
**Isotopes** are atoms that have the same number of protons but different numbers of neutrons. For example, there are several isotopes of carbon. Most carbon on Earth is in the form of carbon-12, which has 6 protons and 6 neutrons. However, carbon also exists naturally with 7 neutrons, called carbon-13, and 8 neutrons, called carbon-14. Similarly, hydrogen normally has a single proton and no neutrons but also can exist with 1 neutron, as hydrogen-2, which is sometimes called deuterium, and as hydrogen-3 with 2 neutrons, sometimes called tritium. As a result, a sample of a single element may contain atoms that have different masses. The **atomic mass** is the average mass of all the different isotopes that make up the element in the proportions found in nature.

In the nineteenth century, chemists discovered that certain elements had similar properties. They found that when elements were arranged according to reactivity, a periodic pattern in the properties of the elements could be observed. The **periodic table** was then developed to organize and classify these elements and even predict the existence of elements that had not yet been discovered.

There are three major classifications for the elements. These can be seen in the periodic table below.




- The **metal** elements are located to the left of the dividing line. These elements are all solids at room temperature with the exception of mercury (Hg). Metals are notable for their shiny luster and ability to conduct electricity.
- The **nonmetal** elements are located to the right of the dividing line. Nitrogen (N), oxygen (O), fluorine (F), chlorine (Cl), and the noble gases (in the last column) are gases at room temperature. Bromine (Br) is a liquid, while all other nonmetals are solid. Nonmetals do not conduct electricity.
- **Metalloids** have both metallic and nonmetallic properties. These are solid at room temperature. They are located between the metals and nonmetals and straddle the diagonal dividing line. Metalloids are useful as part of electronic circuits.

Elements that have similar chemical properties are arranged in vertical columns called **families**. Each column is identified by a number seen at the top of each column as in the periodic table above. The **representative elements** are those elements located in columns 1 and 2 and 13–18. Elements in columns 1 and 2 have the same number of valence electrons as their column number. The number of valence electrons for elements in columns 13–18 can be found by subtracting 10 from the column number. Valence electrons for non-representative elements (columns 3–12) will not be covered on the test. It is important to note that elements within the same column have the same number of valence electrons. Elements with the same number of valence electrons react with other elements in a very similar way. Elements in column 1, the **alkali metals**, column 2, the **alkaline earth metals**, and column 17, the



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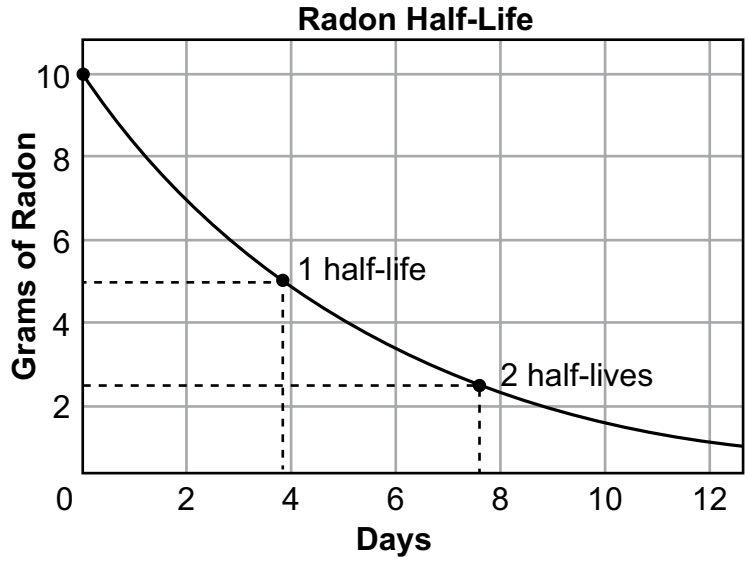
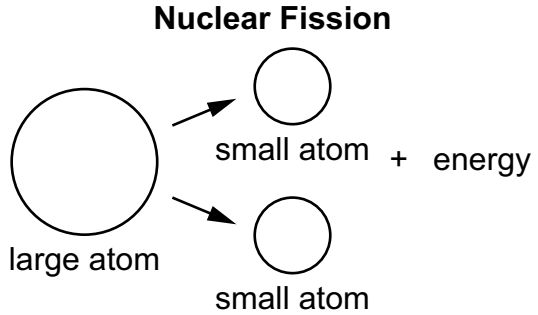
**halogens**, are the most reactive representative elements, while the **noble gases** (column 18) are the most nonreactive elements.

When a metal and a nonmetal react with each other, the metal forms a positive ion (cation) and the nonmetal forms a negative ion (anion). Metals in column 1 lose one electron to form an ion with a charge or valence number of $1^+$. Column 2 metals lose two electrons to form ions with a $2^+$ charge. Nonmetallic elements in columns 15, 16, and 17 gain electrons, forming ions with a negative charge. Column 15 elements gain three electrons to form ions with a $3^-$ charge. Column 16 elements gain two electrons and form ions with a $2^-$ charge. Column 17 elements gain one electron and form ions with a $1^-$ charge.

Every radioactive element has a distinctive rate of decay. This rate is measured by the **half-life** ($t_{1/2}$). The half-life is the time required for one-half of the atoms to undergo decay to isotopes of other atoms. Radon, a radioactive gas, has a half-life of 3.8 days. That means after 3.8 days, only one-half of the original radon atoms are left. After 7.6 days, only one-fourth are left, and so on.




**Fission** occurs when some atomic nuclei decay spontaneously or when they are bombarded by neutrons. This results in the production of elements with less mass and radiation. One benefit of fission is that it provides a significant amount of electrical energy for the United States and other developed nations. Compared to coal or oil, fission provides about a million times more energy per pound of fuel. It also eliminates air pollutants. However, nuclear waste from fission creates disposal problems. Improper disposal of radioactive wastes underground can lead to radioactive contamination of water supplies.



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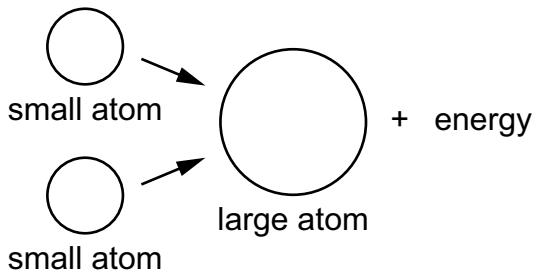
**Fusion** as a future energy source might provide all the benefits of fission with few of its problems. Fusion occurs when low mass nuclei, such as hydrogen, collide and combine to form nuclei with greater mass. Fusion occurs in the sun and is one of the most energetic processes in the universe.

**Nuclear Fusion**




### Memory Aid—Fission/Fusion Confusion

Here is a way to help remember the difference between fission and fusion. *Fission* is similar to *fissure*, the process of splitting. So fission happens when the nucleus splits in two. *Fusion* is like *fuse*, to unite two things. So fusion occurs when two nuclei join.

**Radiation** is the emission of energy as electromagnetic waves or as moving particles. Sometimes, very massive elements have unstable nuclei, causing them to decay into less massive elements. This process, called radioactive decay, could result in three main types of radiation:

- **Alpha** ($\alpha$) radiation or particles: These particles consist of helium (He) nuclei, which are very large. Usually, a sheet of paper can stop them.
- **Beta** ($\beta$) radiation or particles: These particles consist of electrons ($e^-$), which are much smaller and have less mass than alpha particles. They have much more penetrating power, and a thick wooden board is required to stop them.
- **Gamma** ($\gamma$) rays: These rays are an extremely energetic form of light. Usually, several inches of lead or a few feet of concrete are required to shield people from the damaging effects of gamma radiation.



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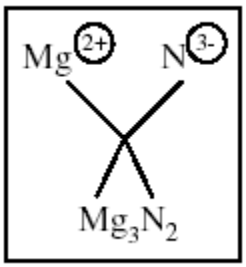
**Covalent bonds** form when atoms share valence electrons. The names of **binary covalent compounds** must include prefixes to show the number of atoms of each element in the compound. The first atom is named after the element it represents. If there are two or more atoms of that element, the prefixes *di-*, *tri-*, or *tetra-* or a higher numeral prefix are used. The prefix *mono-* (one) is never used for the first element. All numerical prefixes, however, are used to indicate the number of atoms of the second element. This prefix is placed before the first syllable of the element name. The suffix *-ide* is then added to the end. For example, the covalent compound $CO_2$ is named carbon dioxide. Notice the *di-* prefix for the second element and the lack of a prefix for the first element. Another example is $P_2S_5$. It is named diphosphorus pentasulfide. Notice that the *di-* prefix is used for the two phosphorus atoms and that the *penta-* prefix is used for the five sulfur atoms in the compound.

**Numerical Prefixes**

| | |
|---|---|
| *mono-* | 1 |
| *di-* | 2 |
| *tri-* | 3 |
| *tetra-* | 4 |
| *penta-* | 5 |
| *hexa-* | 6 |
| *hepta-* | 7 |
| *octa-* | 8 |
| *nona-* | 9 |
| *deca-* | 10 |

**Binary ionic compounds** contain only two different elements. Ionic bonds form between metals and nonmetals because of a complete transfer of electrons from the metal to the nonmetal. The resulting oppositely charged ions attract. Sodium chloride, NaCl, is an example of a binary ionic compound. In binary ionic compounds with more than one atom of each element, the correct formula can be found by making a cross, as in the example below.




Notice that the charge on the nitrogen ion ($N^{3-}$) becomes the number of magnesium ions in the formula. Likewise, the charge on the magnesium ion ($Mg^{2+}$) becomes the number of nitrogen ions in the formula. In this way, the net charges are balanced ($6^+$ and $6^-$), making magnesium nitride neutral. This method usually works, except when the charges on the ions are exact opposites, such as $2^+$ and $2^-$. In that case, the ions should be combined in a 1:1 ratio to balance the charges.



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A **cation** is an ion that results from atoms or molecules that have lost one or more valence electrons, giving them a positive charge. An **anion** is an ion that results from atoms or molecules that have gained one or more valence electrons, giving them a negative charge. In the cross above, $Mg^{2+}$ is the cation and $N^{3-}$ is the anion.

Any combination of cations and anions can form a binary ionic compound. To name this type of compound, simply write the name of the element that forms the cation first. Then follow with the name of the anion. The name of the anion will usually contain the first syllable of the element name and end with the suffix *-ide*. For example, the formula unit $AlCl_3$ would be named aluminum chloride. Notice that the cation has the element name and that the first syllable of chlorine, *chlor-*, has taken the *-ide* ending.



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## SAMPLE ITEMS

### Item 1

**Selected-Response**

**The half-life of cadmium-109 is 464 days. A scientist measures out a 256.0 gram (g) sample.**

**Approximately how many grams of cadmium-109 would remain after 1,392 days?**

**A.** 32.0 g
**B.** 64.0 g
**C.** 2,048.0 g
**D.** 1,024.0 g

### Item 2

**Selected-Response**

**The elements neon and argon are not reactive. Which hypothesis BEST explains this?**

**A.** They are not stable atoms.
**B.** They are not readily available on Earth.
**C.** They tend to give up all of their valence electrons easily.
**D.** They have the maximum possible number of electrons in their outermost shell.



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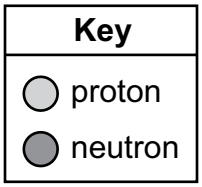
## Item 3

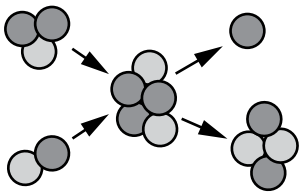
**Selected-Response**

**A group of students proposed four different models to show the fusion of hydrogen to form helium. The key to the models is shown.**

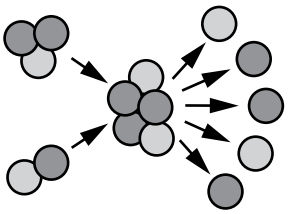



**Which model shows the process of nuclear fusion?**

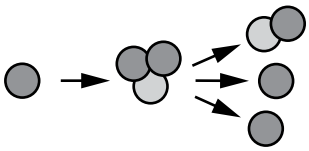
**A.**



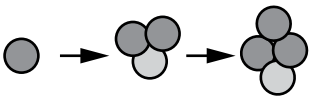
**B.**



**C.**



**D.**





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## Item 4

**Drag-and-Drop Multi-Part Technology-Enhanced**

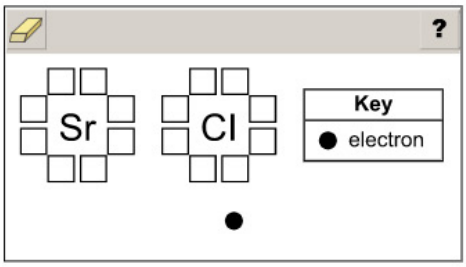
**Part A**

**Use the periodic table to answer the question.**

A student is asked to create a model using the elements strontium (Sr) and chlorine (Cl).

**Part A**

Move the correct number of valence electrons from below the model into the boxes around the elements Sr and Cl. It does not matter which box you place each electron in; only the number of electrons around each element is important. The dot representing an electron can be used as many times as necessary.




Use a mouse, touchpad, or touchscreen to move the dot representing an electron into the boxes around each element to indicate the correct number of valence electrons. The dot will be used more than once.

***Go on to the next page to finish item 4.***



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**Item 4. *Continued*.**

**Part B**

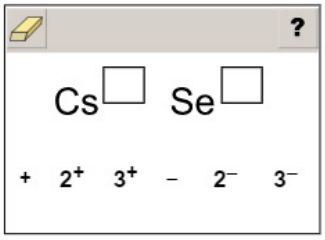
**Use the periodic table to answer the question.**

A student is asked to create a model using the elements strontium (Sr) and chlorine (Cl).

**Part B**

Then the student is asked to identify the charges for the elements cesium (Cs) and selenium (Se).

For each element, move the correct charge from below the elements into the box next to the element.




Use a mouse, touchpad, or touchscreen to move the charges below the elements into the boxes. Each charge can be used more than once. Some charges will not be needed.



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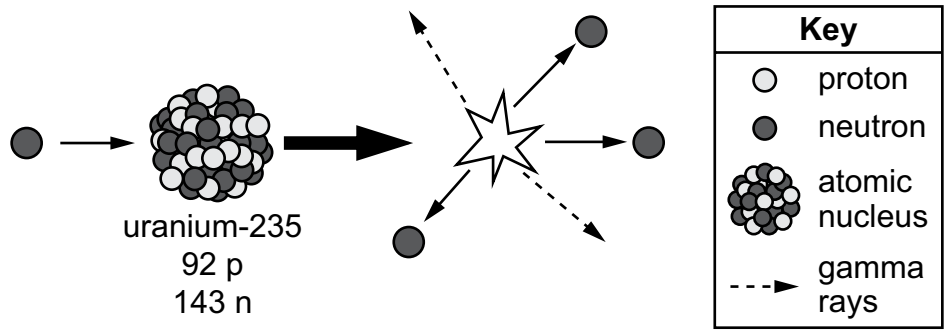
## Item 5

**Multi-Select Technology-Enhanced**

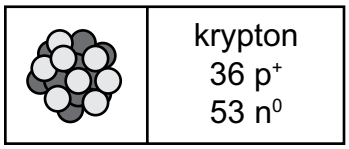
**A student is modeling the fission of uranium nuclei. The student started the model as shown in the diagram.**

**Nuclear Fission Model**

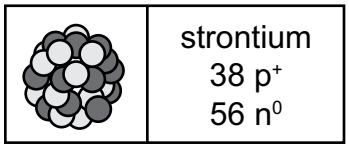



**Which TWO particles should the student add to the right-hand side of the model to complete the fission reaction?**

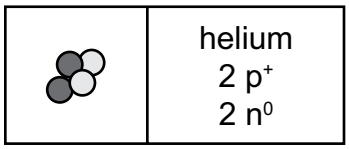
**A.**



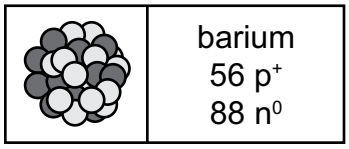

**B.**



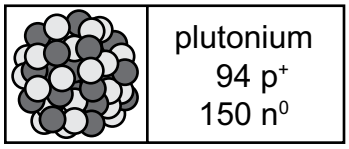

**C.**



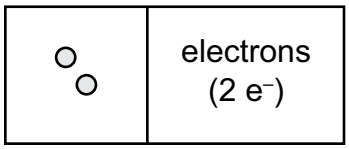

**D.**




**E.**




**F.**



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## Item 6

### Drag-and-Drop Technology-Enhanced

An incomplete data table comparing five unknown elements is shown below. Move a label into each empty box to complete the data table.

| Unknown Element | State of Matter at Room Temperature | Number of Valence Electrons | Type of Ion Formed | Element Type |
|---|---|---|---|---|
| V | gas | 7 | negative | nonmetal |
| W | | 8 | none | |
| X | solid | 1 | | |
| Y | | 2 | positive | |
| Z | | 3 | | metal |

| State of Matter at Room Temperature | Type of Ion Formed | Element Type |
|---|---|---|
| **solid** | **positive** | **metal** |
| **liquid** | **negative** | **nonmetal** |
| **gas** | **none** | |

Use a mouse, touchpad, or touchscreen to move the words below each header into the correct box in the appropriate column in the table. Each word may be used more than once. Some words may not be needed.



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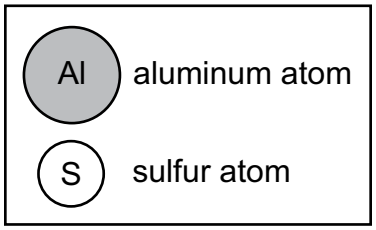
## Item 7

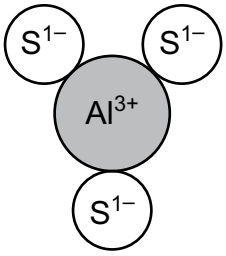
**Selected-Response**

**A student is modeling the units in the formula for aluminum sulfide using the spheres shown below to represent aluminum (Al) and sulfur (S) atoms.**

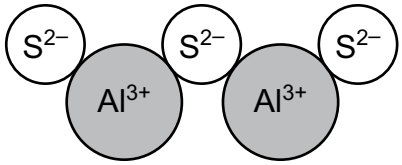



**Which model correctly shows a stable ionic compound for aluminum sulfide?**

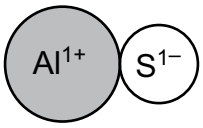
**A.**



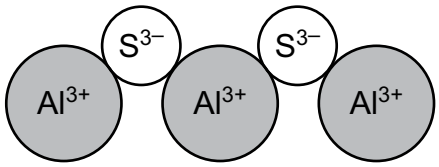

**B.**




**C.**




**D.**



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# CHEMICAL REACTIONS AND PROPERTIES OF MATTER

In simple terms, chemistry is the study of particle collisions in which electrons are agitated by energy differences and subjected to dislocation. In chemical reactions, the mass of the matter before and after the reaction remains the same, as does the number of atoms of each type that are involved in the reaction. Students will explore to what extent solute particles interact with a solvent and any new properties that may occur, such as changes in the concentration of hydrogen ions ($H^+$) or hydroxide ions ($OH^-$).

## CORE IDEAS

- For gaseous substances, pressure, volume, and temperature are interdependent. (SPS5b)
- Temperature is a measure of the internal energy of a system. (SPS5b)
- The greater the molecular or particle motion, the higher the internal energy of a system. (SPS5a)
- The phases of matter are states of a system that have relatively the same physical properties. (SPS5a)
- Matter cannot be destroyed nor created in a chemical reaction. (SPS3a, b)
- Solutions are mixtures in which the relative proportion of solute and solvent varies. (SPS6b)
- The degree to which a solute dissolves is affected by physical conditions of the system. (SPS6b)
- The properties of a solution, such as conductivity and acidity, are related to whether the solute is ionic or covalent. (SPS6d, e)
- Acidic solutions have excess hydrogen ions, and basic solutions contain excess hydroxide ions. (SPS6d)

## KEY CONCEPTS

### Conservation of Matter in Chemical Reactions

Matter, like energy, is neither created nor destroyed. In a chemical reaction, the same number and types of atoms occur in the products as in the original reactants. As a result, the mass of the **products** always equals the mass of the **reactants**. This statement summarizes the **law of conservation of mass**. One example of this law in action involves the burning of firewood. At first glance, it appears that the law of conservation of mass is violated because the mass of the ashes left over is much less than the mass of the original wood. In fact, if one could measure the mass of the smoke, water vapor, and carbon dioxide given off in addition to the ash, the mass would exactly equal that of the unburned firewood.

The law of conservation of matter/mass can be used to balance **chemical equations**, which are used to show what happens in a chemical reaction. In chemical equations, the coefficients in front of the chemical formulas represent the number of molecules of reactants or products. For example, the reaction of hydrogen and oxygen to form water is shown below.

$$\mathbf{2H_2 + O_2 \rightarrow 2H_2O}$$

Two molecules of hydrogen plus one molecule of oxygen combines to form, or yields, two molecules of water. Notice that the number of hydrogen atoms ($2 \times 2 = 4$) and oxygen atoms ($1 \times 2 = 2$) on the reactants side (left side of the arrow) of the equation equals the number of hydrogen and oxygen atoms on the products side (right side of the arrow) of the equation. The equation is balanced because the numbers of atoms of each element (H, O) are the same on both sides of the arrow.



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In a **synthesis** reaction, two or more substances combine to form a compound. A synthesis reaction is represented by the general equation ***A + B → AB***. When balancing an equation for a synthesis reaction, the coefficients should be used to make the number of atoms of each element the same on each side of the equation. The following "bookkeeping" method was used to obtain the above balanced equation. The equation was first written without coefficients. Understand that even though no coefficients are written in the original equation, coefficients of one are understood. The steps are shown below.

In Step 1, two hydrogen atoms appeared on both sides of the equation. No change was needed.

$$\mathbf{H_2 + O_2 \rightarrow H_2O}$$

**Step 1**

| Element | No. of Atoms in Reactants | No. of Atoms in Product(s) |
|---|---|---|
| H | 2 | 2 |
| O | 2 | 1 |

The reactants side contained two oxygen atoms, while the product(s) side contained only one oxygen atom. In Step 2, the number of water molecules was multiplied by two to balance the oxygen atoms. A two coefficient was placed before the $H_2O$.

$$\mathbf{H_2 + O_2 \rightarrow 2\ H_2O}$$

**Step 2**

| Element | No. of Atoms in Reactants | No. of Atoms in Product(s) |
|---|---|---|
| H | 2 | 4 |
| O | 2 | 1 x 2 |

Finally, in Step 3, the reactants side still contained two hydrogen atoms, while the product(s) side contained four hydrogen atoms. The hydrogen molecule ($H_2$) was multiplied by two to balance the hydrogen atoms. The equation is balanced when a two coefficient is placed before the $H_2$.

$$\mathbf{2H_2 + O_2 \rightarrow 2\ H_2O}$$

**Step 3**

| Element | No. of Atoms in Reactants | No. of Atoms in Product(s) |
|---|---|---|
| H | 2 x 2 | 4 |
| O | 2 | 1 x 2 |

Similar bookkeeping can be used to balance other types of simple equations.

A **decomposition** reaction is the opposite of a synthesis reaction. In a decomposition reaction, a compound breaks down into more simple substances. It is represented by the general equation ***AB → A + B***. An example of this reaction is the decomposition of sodium chloride (NaCl).

$$\mathbf{2NaCl \rightarrow 2Na + Cl_2}$$



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Notice that the equation is balanced as written. Count the number of atoms of each element on each side of the equation (right and left of the arrow). On the reactants side of the equation are two atoms of sodium and two atoms of chlorine. On the products side of the equation are two atoms of sodium and two atoms of chlorine. The coefficient for chlorine is understood, though not written.

A **single replacement** reaction involves a single element replacing another element in a compound, forming a different compound. A single replacement reaction may be represented by the general equation $A + BC \rightarrow AC + B$. An example of this reaction is the replacement of iodine (I) by chlorine (Cl) in a potassium iodide (KI) solution.

$$2KI + Cl_2 \rightarrow 2KCl + I_2$$

In a **double replacement** reaction, two elements in two different compounds replace each other, forming two different compounds. A double replacement reaction has the general equation $AB + CD \rightarrow AD + CB$. The reaction of sodium sulfide ($Na_2S$) by hydrogen chloride (HCl) is a good example of this type of reaction.

$$Na_2S + 2HCl \rightarrow 2NaCl + H_2S$$

If you count the number of atoms of each element on the reactants side of the equation and the number of atoms of the same elements on the products side of the equation, you will find that they are equal. There are two sodium (Na) atoms on the left side (reactants) and right side (products) of the arrow; one sulfur (S) atom on each side, two chlorine (Cl) atoms on each side, and two hydrogen (H) atoms on each side. The equation is balanced.

**Pressure (*P*)**, **volume (*V*)**, and **absolute temperature (*T*)** are usually used to describe the condition of a gas. Pressure is the force exerted on a surface per unit area. To understand how the above variables are related, consider air in a fixed volume container. When the temperature of a gas is increased, the atoms or molecules move faster since they have more energy. Since the volume remains the same, the force pushing on the walls of the container increases, resulting in a rise in pressure. Conversely, if a gas is cooled at a constant volume, the pressure decreases. Compressing a gas at a constant temperature into a smaller volume results in an increase in the amount of collisions between the gas molecules and the walls of the container due to the reduction of volume. This change results in an increase in pressure. When the converse is true, the pressure decreases. Chemists have summarized these relationships mathematically with the following laws, assuming the amount of gas is constant:

| |
|---|
| ***PV* =** a constant when the temperature is constant. |
| ***V*** is directly proportional to ***T*** when the pressure is constant. |
| ***P*** is directly proportional to ***T*** when volume is constant. |

These laws can prove very useful when trying to describe the properties of a gas under changing conditions.



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Atoms and molecules are in constant motion. The type and degree of motion determine the phase or state of matter.

- In the **solid phase**, atoms or molecules are held in a rigid structure. They are free to vibrate but cannot move around. As a result, solids have a definite volume and shape.
- In the **liquid phase**, intermolecular forces hold these atoms or molecules loosely together but do not force them into a rigid structure. The molecules of a liquid are free to move around to a certain degree and have a definite volume. As a result, liquids conform to the shape of their container.
- In the **gas phase**, atoms and molecules experience their greatest freedom. The forces attracting gas molecules are almost nonexistent. As a result, gas molecules are much farther apart and can move around freely. Since gas does not possess a definite volume, and since the molecules move freely, a gas expands to fill the container it is in.
- **Plasmas** are gases that have been so energized that their atoms have been stripped of some or all electrons. Solar flares are great examples of plasmas. Solar flares eject extremely hot hydrogen ions ($H^+$) away from the sun toward Earth.

**Matter**, the substance that is seen all around us, consists of anything that has mass and volume. The **density**, *d*, of an object is defined as the ratio of the object's **mass**, *m*, to its **volume**, *V.*

$$d = \frac{m}{V}$$

Density is a unique property of matter. Gases tend to have very low densities compared to liquids and solids. The large distances between atoms or molecules of a gas are responsible for the very low density.

**Physical properties** are any properties that are measurable and can be observed or measured without changing the identity of the substance. Color, hardness, area, length, strength, density, temperature, melting point, boiling point, solubility, electrical conductivity, and state of matter are examples of physical properties.

**Chemical properties** are any properties that can be measured only by chemically changing an object. Flammability, oxidation, toxicity, and heat of combustion are examples of chemical properties.

A **mixture** is a material that is made up of two or more different substances that has a uniform composition. A **solution** is a special type of mixture. It has a uniform composition throughout and is made up of two parts—a solute and a solvent. The **solute** is the substance that is being dissolved or broken down into smaller particles. The **solvent** is the substance doing the dissolving. Usually the solute is the substance that is in smaller quantity. For example, in a sodium chloride (NaCl) solution in water, the NaCl is the solute, while water is the solvent. What is chemically happening with the atoms of sodium chloride and water is shown in the diagram on the next page. **Solubility** is the ability of a substance to dissolve in a solvent, such as water. When the maximum amount of solute that can be dissolved is added to the solvent, the solution becomes **saturated**. Below this maximum amount, the solution is **unsaturated**.



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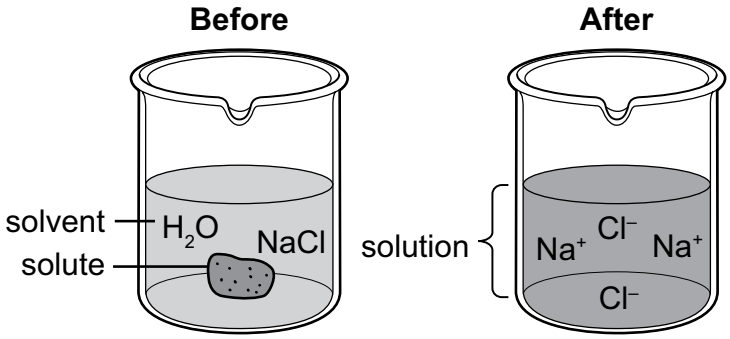


The **concentration** describes how much solute has been dissolved in solution. Almost all concentration units express some kind of ratio. For example, the mass percent of a solution is equal to the mass of the solute (in grams) divided by the mass of the solution (in grams) times 100%.

There are a number of factors that can affect the rate at which a solid solute dissolves in a liquid solvent:

- Stirring increases the amount of fresh solvent that comes in contact with a solute. When there is no stirring, the solvent around the solute becomes nearly saturated. Stirring keeps the solvent near the solute unsaturated, increasing the dissolving rate.
- When a solute is ground into smaller particles, the amount of surface area exposed to the solvent increases. This additional surface area allows the dissolving process to occur faster. The smaller the solute particles, the faster the rate of dissolving.
- Solvent molecules move faster when the temperature increases. These faster liquid solvent molecules come in contact with solid solute particles more often, increasing the dissolving rate. Also, at higher temperatures, the solubility usually increases. Higher temperatures, therefore, favor faster dissolving rates.
- In contrast, when a gas solute is dissolved in a liquid, the molecules of the gas are already energetic and have weak intermolecular attractive forces. As a result, gas solutes tend to escape from a solution by evaporation when the temperature increases, so solubility for gases in liquids tends to decrease at increasing temperatures.



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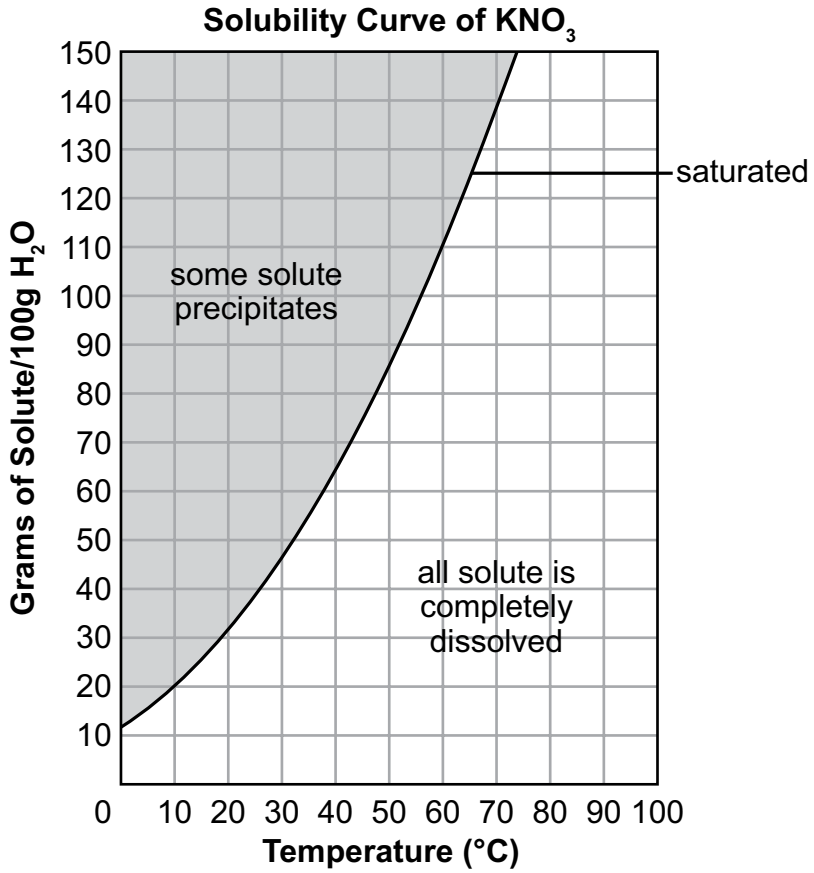
A **solubility curve** shows how the amount of dissolved solute changes with temperature. The solubility curve shown below graphs the solubility of potassium nitrate ($KNO_3$) as a function of temperature. Under certain circumstances a solution can hold more of the solute than the usual limit. This is called **supersaturation** and is usually a temporary condition since the solution is unstable. Notice that the dimensions of solubility are grams of solute per 100 grams of solvent (water). The solubility of most salts, such as $KNO_3$, increases with higher temperatures, as can be seen in the graph below.




A solubility curve also shows the temperature at which a solute will begin to precipitate out of the solution. For example, if approximately 110 grams of $KNO_3$ are dissolved in 100 grams of water at 70°C, the salt completely dissolves. When the solution cools, though, the $KNO_3$ begins to precipitate out at 60°C because the solution has become saturated. As you can see above, as the solution cools further, more of the $KNO_3$ will precipitate out until, at 0°C, only 12 grams of $KNO_3$ will remain in solution. Can you determine from the graph how many grams of $KNO_3$ will be dissolved in solution at 50°C? If your answer is about 85 grams, you are correct.



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**Conductivity** is the measure of a solution's ability to conduct electricity. Conductivity gives important clues as to the type of solute dissolved. In **aqueous** (water-based) solutions, dissolved ionic compounds yield solutions with high conductivity. Solutions with higher concentrations of ionic compounds tend to conduct electricity better than dilute solutions. Cations and anions easily carry electrical charges through the solution. Strong acids and bases also have a high conductivity for the same reason. All of these solutions are considered **strong electrolytes**.

Weak acids or bases ionize only partially, so they form solutions with low conductivity. These compounds are called **weak electrolytes**. Solutions made from covalent compounds have zero conductivity since they dissolve as molecules, not ions. They cannot carry electrical charges. These substances are known as **nonelectrolytes**. Some selected compounds and their electrical conductivity are shown in the chart below.

| Conductivity of Some Aqueous Solutions | | |
|---|---|---|
| **High Conductivity/ Strong Electrolyte** | **Low Conductivity/ Weak Electrolyte** | **Zero Conductivity/ Nonelectrolyte** |
| $AlCl_3$ | $CH_3COOH$ (acetic acid) | $CH_3OH$ (methanol) |
| $CaCl_2$ | | |
| $H_2SO_4$ | $NH_3$ (ammonia) | $C_{12}H_{22}O_{11}$ (table sugar) |
| HCl | | |
| KCl | HF (hydrofluoric acid) | $C_6H_{12}O_6$ (glucose) |
| KOH | | |
| $MgSO_4$ | | |
| NaCl | | |
| NaOH | | |

As early as the 1600s, chemists recognized that some substances could be classified as either **acids** or **bases**. It took many more years to define and describe the behavior of these important compounds. Chemists today know that acids and bases have the properties shown in the following chart:

| | **Acid** | **Base** |
|---|---|---|
| **Taste** | • Sour or tart | • Bitter |
| **Touch** | • Feels like water/may sting | • Feels smooth and slippery |
| **Reactions with Metals** | • Vigorously reacts with most metals to produce hydrogen gas, $H_2$ | • Does not react with most metals |
| **Electrical Conductivity** | • Readily conducts electricity (less so for weak acids) | • Readily conducts electricity (less so for weak bases) |
| **Litmus Paper* Test** | • Turns blue litmus paper red | • Turns red litmus paper blue |

*A type of paper containing a dye that changes color when exposed to acids or bases



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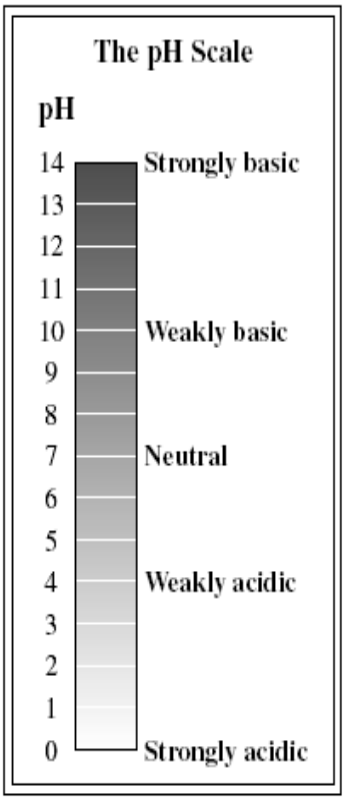
The **pH scale** gives a measure of the acidity or basicity of a solution. The lower the pH of a solution, the more acidic it is. The higher the pH, the more basic it is. Any solution with a pH less than 7 is acidic. A solution with a pH greater than 7 is considered basic. Any solution with a pH of exactly 7 is neutral. See the pH scale on the right. Lemon juice has a pH between 2 and 3. It is acidic. Common household bleach is basic, with a pH between 12 and 13. Pure water has a pH of 7 and is neutral. All compounds that give off **hydrogen ions** ($H^+$) in solution are acids. Bases are any compounds that accept the hydrogen ions to form a salt. For example, hydrochloric acid (HCl) and sodium hydroxide (NaOH) react together in a **neutralization reaction**.




$$\underset{\text{acid}}{HCl} + \underset{\text{base}}{NaOH} \rightarrow \underset{\text{salt}}{NaCl} + \underset{\text{water}}{H_2O}$$

The hydroxide ion ($OH^-$) from the NaOH accepted the hydrogen ion ($H^+$) from the HCl to form water. The salt (NaCl) was formed from the sodium ion ($Na^+$) and the chloride ion ($Cl^-$) left over.



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## SAMPLE ITEMS

### Item 8

**Selected-Response**

**Use this chemical equation to answer the question.**

$$__Fe + __O_2 \rightarrow __Fe_2O_3$$

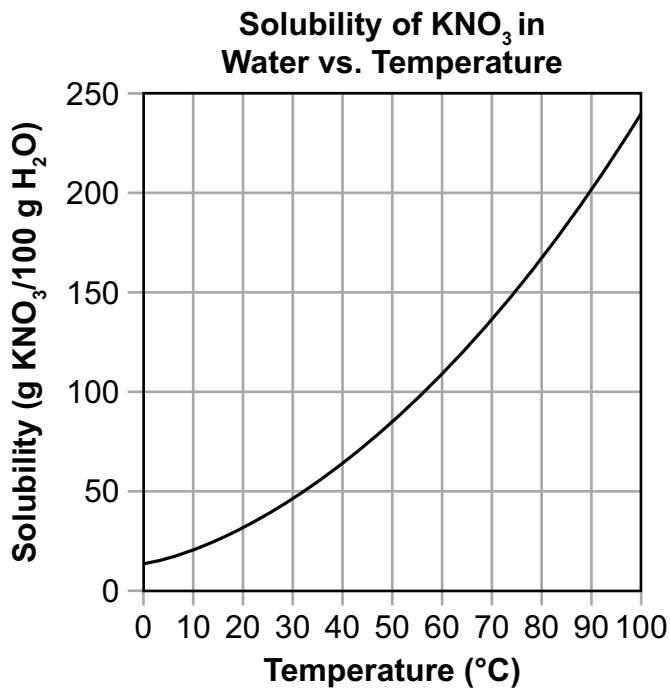
**What coefficients of Fe, $O_2$ and $Fe_2O_3$ will show that matter is conserved in this chemical reaction?**

**A.** 2, 1, 2
**B.** 2, 3, 2
**C.** 4, 1, 2
**D.** 4, 3, 2

### Item 9

**Selected-Response**

**A solubility curve for potassium nitrate ($KNO_3$) is shown.**




**According to the graph, what is the maximum approximate mass of $KNO_3$ that would dissolve at 60°C and what is the relationship between temperature and solubility?**

**A.** The mass is approximately 140 g; increased temperatures lead to a decrease in solubility.
**B.** The mass is approximately 110 g; increased temperatures lead to an increase in solubility.
**C.** The mass is approximately 140 g; increased temperatures lead to an increase in solubility.
**D.** The mass is approximately 110 g; increased temperatures lead to a decrease in solubility.



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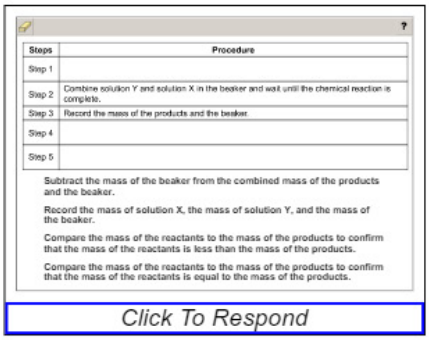
## Item 10

### Drag-and-Drop Technology-Enhanced

A student wants to perform an experiment to prove that mass is conserved in a chemical reaction. The student will combine two solutions (X and Y) to cause a chemical reaction that forms a solid.

Move a statement into each blank space in the table to show the correct order of steps for the experiment. Not all statements will be used.



| Steps | Procedure |
|---|---|
| Step 1 | |
| Step 2 | Combine solution Y and solution X in the beaker and wait until the chemical reaction is complete. |
| Step 3 | Record the mass of the products and the beaker. |
| Step 4 | |
| Step 5 | |

Subtract the mass of the beaker from the combined mass of the products and the beaker.

Record the mass of solution X, the mass of solution Y, and the mass of the beaker.

Compare the mass of the reactants to the mass of the products to confirm that the mass of the reactants is less than the mass of the products.

Compare the mass of the reactants to the mass of the products to confirm that the mass of the reactants is equal to the mass of the products.

Click To Respond

Due to the size of the response area, this item has a “Click To Respond” button on the screen. Clicking this button will bring up the response area at full size.

***Go on to the next page to finish item 10.***



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**Item 10.** ***Continued.***

| Steps | Procedure |
|---|---|
| Step 1 | |
| Step 2 | Combine solution Y and solution X in the beaker and wait until the chemical reaction is complete. |
| Step 3 | Record the mass of the products and the beaker. |
| Step 4 | |
| Step 5 | |

**Subtract the mass of the beaker from the combined mass of the products and the beaker.**

**Record the mass of solution X, the mass of solution Y, and the mass of the beaker.**

**Compare the mass of the reactants to the mass of the products to confirm that the mass of the reactants is less than the mass of the products.**

**Compare the mass of the reactants to the mass of the products to confirm that the mass of the reactants is equal to the mass of the products.**

Use a mouse, touchpad, or touchscreen to move the sentences below the table into the boxes. Each sentence can be used once. Some sentences will not be needed.



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## Item 11

**Multi-Part Technology-Enhanced**

**A student plans to investigate how different factors affect the dissolving rate of a certain mass of potassium chloride (KCl) in water. The student will test a different variable in each investigation: the diameter of the crystals in millimeters (mm), the temperature of the solution in degrees Celsius (°C), and agitation (stirring) of the solution. The first table shows details and predictions for investigation 1.**

**Investigation 1**

| Trial Number | Diameter of Crystals (mm) | Temperature (°C) | Stirring | Predicted Dissolving Time (minutes) |
|---|---|---|---|---|
| 1 | 1.0 | 20 | no | 20 |
| 2 | 2.0 | 20 | no | ? |

**The second table shows details and predictions for investigation 2.**

**Investigation 2**

| Trial Number | Diameter of Crystals (mm) | Temperature (°C) | Stirring | Predicted Dissolving Time (minutes) |
|---|---|---|---|---|
| 3 | 1.0 | 20 | no | 20 |
| 4 | 1.0 | 40 | no | 10 |

**Part A**

**Based on the predicted dissolving times for trials 1, 3, and 4, which statement contains the BEST prediction for the dissolving time in trial 2?**

**A.** 5 minutes, because the larger diameter of crystals increases the total surface area of the solute exposed to the solvent, decreasing the length of exposure to the solvent

**B.** 15 minutes, because the larger diameter of crystals increases the total surface area of the solute exposed to the solvent, increasing the length of exposure to the solvent

**C.** 20 minutes, because the larger diameter of crystals decreases the total surface area of the solute exposed to the solvent, but the length of exposure to the solvent stays the same

**D.** 30 minutes, because the larger diameter of crystals decreases the total surface area of the solute exposed to the solvent, increasing the length of exposure to the solvent

***Go on to the next page to finish item 11.***



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**Item 11. *Continued*.**

**Part B**

**How should the student design investigation 3 to finish testing the factors that affect the dissolving rate of KCl?**

**A.** Increase the diameter of crystals to 2.0 mm.
Keep the temperature at 40°C.
Do not stir the solution.

**B.** Keep the diameter of crystals at 1.0 mm.
Keep the temperature at 20°C.
Stir the solution.

**C.** Increase the diameter of crystals to 4.0 mm.
Decrease the temperature to 0°C.
Do not stir the solution.

**D.** Keep the diameter of crystals at 1.0 mm.
Increase the temperature to 60°C.
Stir the solution.



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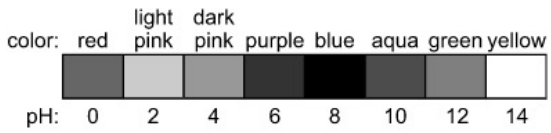
## Item 12

**Drag-and-Drop Multi-Part Technology-Enhanced**

**Part A**

A student is investigating the pH of some common household substances. The student plans to use red cabbage to help indicate the pH. A color chart for red cabbage as an indicator and the pH for the different colors are shown below.

**Color Range for Red Cabbage Indicator**




**Part A**

The student collected the data shown below using red cabbage as the indicator.

| Substance | Color of Red Cabbage Indicator |
|---|---|
| x | purplish pink |
| y | aqua |
| z | purplish blue |

Move each label into the table to correctly identify each substance as acidic, neutral, or basic.

| Classification | Substance |
|---|---|
| acidic | |
| neutral | |
| basic | |

x y z

Use a mouse, touchpad, or touchscreen to move the letters below the table into the boxes. Each letter can be used once.

***Go on to the next page to finish item 12.***



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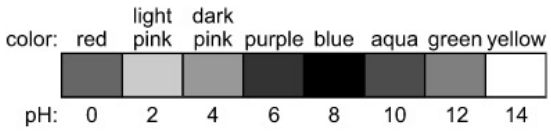
**Item 12. *Continued*.**

**Part B**

A student is investigating the pH of some common household substances. The student plans to use red cabbage to help indicate the pH. A color chart for red cabbage as an indicator and the pH for the different colors are shown below.

**Color Range for Red Cabbage Indicator**




**Part B**

The table below describes how red litmus paper and blue litmus paper indicators react to different substances.

| Classification | Red Litmus Paper | Blue Litmus Paper |
|---|---|---|
| acidic | does not change | turns red |
| neutral | does not change | does not change |
| basic | turns blue | does not change |

Move a description into each box in the table to show the results of adding a drop of a substance with a pH of 7 to each type of litmus paper.

?

| Red Litmus Paper | Blue Litmus Paper |
|---|---|
| | |

**does not change**

**turns red**

**turns blue**

Use a mouse, touchpad, or touchscreen to move the choices below the table into the boxes. Each choice may be used more than once.



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# ENERGY, FORCE, AND MOTION

This section is based on the understanding that energy is conserved. In a system, energy can be transferred and transformed. In doing so, energy affects, and is affected by, matter. This section ties together energy at the nuclear level, the atomic/molecular level, and the macroscopic level of everyday experience. Content topics include energy transformations in systems, and the relationships among force, mass, and motion. The principles of force and motion influence our daily lives whether we walk, throw a ball, rake leaves, or launch missiles. At the atomic level, the relative motion of tiny particles such as atoms and molecules is used to explain the phases of matter. The relative proximity of one particle to another in a system describes the denseness of that matter. In this section, students will have opportunities to observe, measure, and discuss how matter and the forces that act upon it combine to create regularities and patterns that explain scientific phenomena.

## CORE IDEAS

- Transformations of energy usually release some energy, typically in the form of heat. (SPS7a)
- Heat, or thermal energy, only moves from warmer places to cooler places, and does so by conduction, convection, or radiation. (SPS7b)
- Different substances absorb different amounts of heat before their temperature changes. (SPS7c)
- Temperature can change as heat is being transferred. (SPS7a, b, c)
- If a substance's temperature or pressure is altered, a phase change may result. (SPS7d)
- While the total amount of work remains constant, when using a simple machine, a mechanical advantage can be calculated. (SPS8d)
- Work is defined as applied force acting through a distance. (SPS8d)
- A simple machine changes the applied force and distance while maintaining the total amount of work. (SPS8d)
- Mechanical advantage is a comparison of the applied force required in using a simple machine versus using no machine. (SPS8d)
- Objects change their motion only when a net force (that is not zero) is applied. (SPS8b)
- Force, mass, and acceleration are interdependent. A change in any one of these affects the others. (SPS8a)
- Knowledge of the conditions of an object's motion allows us to predict how its motion will change. (SPS8b)
- Friction is an ever-present force that opposes motion. (SPS8b)
- Whenever one object exerts a force on another, an equal amount of force is exerted in return. (SPS8b)
- A change in the energy of a system affects the attraction between the particles or molecules, and a phase change may occur. (SPS7d)



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## KEY CONCEPTS

Just as matter is conserved, so is energy. The **law of conservation of energy** states that energy, like matter, cannot be created or destroyed; it can only be changed from one form of energy to another. Energy takes many forms in the world around us. Each form of energy can be converted to and from other forms of energy. The box to the right shows some energy types. **Electrical energy** is used in our homes to produce stereo sound through speakers, light from a fluorescent lamp, and **thermal energy** for cooking and heating. **Nuclear energy**, which is stored in the nucleus of atoms, is harnessed to produce electrical energy in modern power plants. **Chemical energy** is stored in the bonds that hold atoms together in molecules. When fuels or foods are broken down, chemical energy is converted to heat energy or to kinetic energy. **Kinetic energy** is the energy contained by moving objects due to their motion. Even objects at rest have energy, based on their position. **Potential energy**, also known as stored energy, is the energy of position. When a boulder sits on top of a cliff, it has gravitational potential energy as a result of its height above the ground. When the boulder tumbles off the cliff, its gravitational potential energy is converted to kinetic energy. When a ball is thrown up into the air, the kinetic energy of the ball is converted into gravitational potential energy as the ball approaches its highest point. As the ball falls back to the ground, the potential energy it gained during its upward flight turns back into kinetic energy. Kinetic and potential energy are types of mechanical energy.

**Energy Types**

- Chemical
- Electrical
- Electromagnetic
- Mechanical
- Nuclear
- Radiant or Light
- Sound
- Thermal

We obtain energy from a variety of sources. The most common source of energy for electrical generation worldwide is coal. The chemical energy contained in coal is converted to electrical energy through the following series of energy transformations:

**Chemical** $\xrightarrow{\textit{burning}}$ **Heat** $\xrightarrow{\textit{turbine}}$ **Mechanical** $\xrightarrow{\textit{generator}}$ **Electrical**

Petroleum and natural gas represent other fuels that, along with coal, are known collectively as **fossil fuels**. The box to the right shows some energy sources.

**Energy Sources**

- Fossil Fuels
- Geothermal
- Hydroelectric
- Nuclear
- Solar
- Wind

The movement of thermal energy from hot to cold materials is called **heat transfer**. There are three basic types of heat transfer: conduction, convection, and radiation.

- **Conduction** is the transfer of heat energy between materials that are in direct contact with each other. Heat transfer by conduction occurs as hot molecules and free electrons become agitated and collide with less energetic neighbors. These neighbors then become agitated and pass along thermal energy in a process similar to a “fire-bucket brigade.” The process of conduction can be felt in the handle of a metal spoon that has been placed in a bowl of hot soup. The hot soup transfers heat to the end of the spoon; the heat is then transferred through the spoon to the handle. The rate of heat transfer depends on the type of material. Good conductors, such as metals, conduct heat rapidly. **Insulators**, such as wood or plastic, conduct heat very slowly.
- **Convection** is the transfer of heat energy by the mass movement of fluids containing heated particles. Fluids are materials that can flow. Liquids and gases are examples of fluids. When particles of a fluid are heated, the particles move farther apart, causing the fluid to expand and rise. This movement of heated particles creates convection currents. Home heating systems force heated air into rooms by way of convection currents. These currents heat the colder air in the room.



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- **Radiation** is the transfer of heat energy through electromagnetic waves. These waves originate from accelerated charged particles. Electromagnetic waves travel through matter or through empty space. Heat transfer through empty space is unique to radiation. Both conduction and convection require a medium or matter to transfer heat energy. Since the space between the sun and Earth is essentially a vacuum, the heat energy from the sun is transferred to Earth only by radiation.

Different substances have varying capacities for storing energy within their molecules. Heat energy can cause molecules to move about faster, increasing their random kinetic energy. An increase in this energy raises the temperature of the substance. Heat energy can also increase the vibrational or rotational energy of molecules, but this does not result in a temperature increase. Each substance has a unique **specific heat capacity**, meaning different substances have the ability to absorb only a certain amount of heat in given conditions. Specific heat values for some common substances are shown in the table below. The specific heat capacity is generally defined as the amount of heat energy required to raise the temperature of 1 kilogram of a substance by 1°C. It is a measure of how much heat energy a particular substance can hold. The units most commonly used are joules per kilogram per degree Celsius. The amount of heat energy that a substance gains or loses ($Q$) depends on the mass ($m$), the specific heat ($c$), and the change in the temperature ($\Delta T$) of the substance. The formula for calculating the heat energy is simply the product of the three factors, $Q = mc\Delta T$.

**Specific Heat for Some Common Substances**

| Substance | Specific Heat, $c$ $\left(\frac{J}{kg \cdot °C}\right)$ |
|---|---|
| air (dry) | 1,010 |
| aluminum | 900 |
| copper | 390 |
| ethanol | 2,450 |
| glass | 840 |
| ice (at −15°C) | 2,000 |
| mercury | 140 |
| steel | 450 |
| water (at 15°C) | 4,190 |



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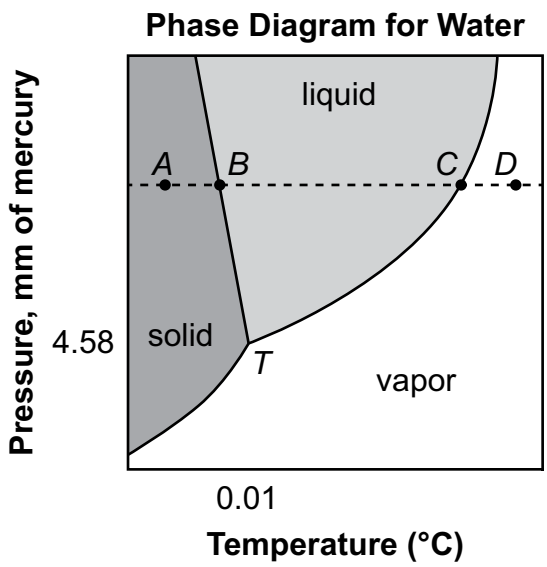
A **phase diagram** shows how a pure substance changes from one phase to another based on the temperature and the pressure. The phase diagram for water, below, shows how pressure and temperature changes are related to cause water to change phases. At point *T* on the diagram all three phases of water exist in equilibrium. On this point, the temperature is equal to 0.01°C and the pressure is equal to 4.58 mm of mercury, which is 0.6% of one atmosphere of pressure. One atmosphere (atm) is a unit of measurement equal to the average air pressure at sea level at a temperature of 15°C. One atmosphere is equal to 760 mm of mercury, or 1,013 millibars. Above point *T*, pathway *AD* has been marked on the diagram. If we trace along this dashed pathway on the phase diagram, we find at point *A*, water exists as a solid. As the temperature increases at a constant pressure, we reach point *B* on the diagram. At that point, solid ice melts and the temperature remains constant until all ice has melted.

From point *B* to point *C*, water exists as a liquid and the temperature increases. At point *C*, water boils, turning into a vapor (or gas). The temperature remains constant again during this phase change. After vaporization is complete, the temperature of the resulting vapor increases until we reach point *D*. There are no other phase changes after this point. Notice that if another pathway is marked out at a constant pressure of less than 4.58 mm of mercury (below point *T*), water will experience only one phase change, solid to vapor.



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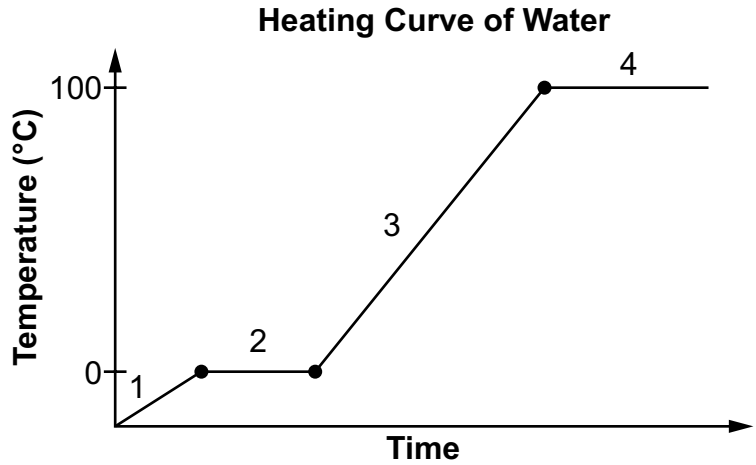
A diagram called a **heating curve** shows how temperature changes as a substance is heated at a constant rate. The heating curve below shows how the state of matter changes as water is heated at a constant rate. In section 1, the water is solid ice, because not enough energy has been added to weaken the intermolecular forces enough. In section 2, enough energy has been added to make the ice start to melt, so now there is a mixture of solid ice and liquid water. In section 3, the water is all liquid, and the molecules of water are moving faster and faster as more energy is added. In section 4, the water has finally started to boil, so there is a mixture of liquid and gas until all of the liquid has changed into gas.




Simply stated, a **force** is an action that can change the motion of an object. A push or pull is an example of a force. The unit for force is the newton (N). All the forces acting on an object can be combined to determine the net force acting on the object. If all the forces acting on the object are balanced, the net force is zero and the motion of the object does not change. If an object is already at rest, it will remain at rest. If an object is moving, it will keep moving. **Balanced forces** do not change the motion of an object. If the combination of forces acting on an object is not balanced, then the net force is greater than zero and the motion of the object changes. **Unbalanced forces** change the motion of an object.

**Displacement** is the length and direction of a straight line between two locations, or positions. Since displacement considers only the length and direction of a straight line, it doesn't depend on the actual path of a moving object. If Town A is 10 miles east of Town B, the displacement of Town A is 10 miles east relative to Town B. For a moving object, displacement can be defined as the change between the initial and final position of the object.

**Distance** is a measure of the length of a path that a moving object travels. If the only road between the two towns has to wind through hills, the distance traveled between the two towns is longer than 10 miles, even though the displacement between the two towns is 10 miles east.

The distance an object moves per unit of time is known as the **speed (*s*) (often shown, as here, in *italics* to help distinguish it from the abbreviation s for seconds)**. The average speed ($s_{ave}$) can be found by dividing the change in the distance ($d$) of an object by the amount of time ($t$) over which the change occurs.

$$\textit{Average speed} = \frac{\text{distance}}{\text{time}} \quad \left(s_{ave} = \frac{d}{t}\right)$$

Where time, $t$, can be found by subtracting the initial time from the final time of the period in which the object is moving:

$$t = t_{final} - t_{initial}$$



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**Velocity (*v*)** is a quantity that indicates the rate at which on object changes its position. The velocity of an object includes a measurement of its speed and information about the direction in which the object is moving. Velocity can be calculated in the same way as speed but in this case the *d* in the equation stands for displacement instead of distance.

$$Velocity = \frac{\text{displacement}}{\text{time}} \quad (v = \frac{d}{t})$$

**Acceleration (*a*)**, like velocity, has magnitude and direction. The average acceleration (*a*) of an object is found by dividing the change in the velocity (*v*) of the object by the amount of time (*t*) over which the change occurs, with the same definition of time *t*.

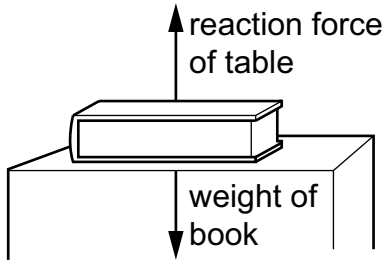
$$Acceleration = \frac{\text{final velocity} - \text{initial velocity}}{\text{time}} \quad (a = \frac{v_f - v_i}{t})$$

Sir Isaac Newton was the first scientist to clearly describe the relationships among force, mass, and motion. The three laws of motion are named after him.

- **Newton's first law** of motion states that an object *at rest* will stay at rest unless it is acted upon by an unbalanced force. An object *in motion* will continue to move in the same direction and with the same speed unless acted upon by an unbalanced force. An object's tendency to resist a change in motion is called **inertia**. Inertia is directly related to an object's mass. An object with a large mass has a large amount of inertia, while an object with a small mass has a small amount of inertia. Large forces are required to change the motion of objects with large masses, while small forces can change the motion of objects with small masses.
- **Newton's second law** of motion states that the acceleration, *a*, of an object is directly related to the net force, *F*, which is the result of unbalanced forces acting on an object, applied to the object and inversely related to the mass, *m*, of the object. The following equation represents Newton's second law of motion.

  $$a = \frac{F}{m} \quad \text{or} \quad F = ma$$

  According to the equation, the greater the net force acting on an object, the greater the acceleration of the object, for an object of a given mass. Also, the greater the mass of the object, the lower the acceleration of the object for a given force acting on the object. For example, a large truck has a much lower acceleration than a compact car when the same force is applied by each vehicle's engine. The larger mass (or inertia) of the truck resists acceleration.
- **Newton's third law** of motion states that forces occur as equal and opposite pairs. For every action force, there is an equal and opposite reaction force. For example, when a book is sitting on a table, the weight of the book produces a downward action force on the table. The tabletop in turn pushes on the book with an upward reaction force. These forces are equal in magnitude but opposite in direction.



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**Frictional forces** tend to stop the motion of an object by dispersing its energy as heat. Friction must be overcome for an object to move.

There are four types of fundamental forces in nature, as shown in the box. However, in this course we will focus only on the gravitational and electromagnetic fundamental forces.

**Some Types of Forces**

- Gravitational
- Electromagnetic
- Strong nuclear
- Weak nuclear

**Gravitational force** is a force between any two objects. The strength of the force is related to the masses of the objects and the distance between them. The more mass an object has, the greater the gravitational force it exerts. As the distance between two objects increases, the force of gravity decreases by a factor equal to the square of the distance. For example, if the distance between two objects is doubled, the force of gravity will decrease by a factor of four. The moon has less mass than Earth. The resulting lower gravitational force made astronauts appear nearly "weightless" as they moved across the lunar surface.

One should note that mass and **weight** are not the same quantity. An object has mass regardless of whether gravity or any other force is acting upon it. Weight, on the other hand, changes depending on the influence of gravity. The relationship between weight, $W$, and mass, $m$, can be written as the following equation:

$$W = mg$$

In this equation, $g$ represents the acceleration due to gravity. At the surface of Earth, the acceleration of gravity is approximately 10 $m/s^2$. The value of $g$ decreases the farther away from the center of Earth an object gets. This means the weight of an object would decrease if it were placed on top of a mountain or put into space.

Other forces include **electromagnetic forces**. These forces include both electric forces and magnetic forces. The forces exerted within the nucleus of an atom are called **nuclear forces**. These forces hold the protons and neutrons together.

The idea of **work** is familiar to most people. For example, it takes more work to move heavier objects, such as a car at rest, than much-lighter objects, such as a bicycle. Work is the transfer of energy when an applied force moves an object over a distance. For work to be done, the force applied must be in the same direction as the movement of the object and the object must move a certain distance. If a person moves a box a distance of 10 meters, the applied force times the distance moved equals the work done, summarized with the following equation:

$$W = Fd$$

In the equation, $W$ is equal to work, $F$ is equal to the force applied, and $d$ is equal to the distance that an object has moved. Remember, force is measured in newtons (N) and distance is measured in meters (m). A unit of work is the newton-meter (N-m) or the joule (J). So, if 10 newtons is applied to move the box a distance of 10 meters, 100 joules of work is done on the box. A person may push on a wall and get tired muscles as a result, but, unless the wall moves, the person has done zero work on the wall.



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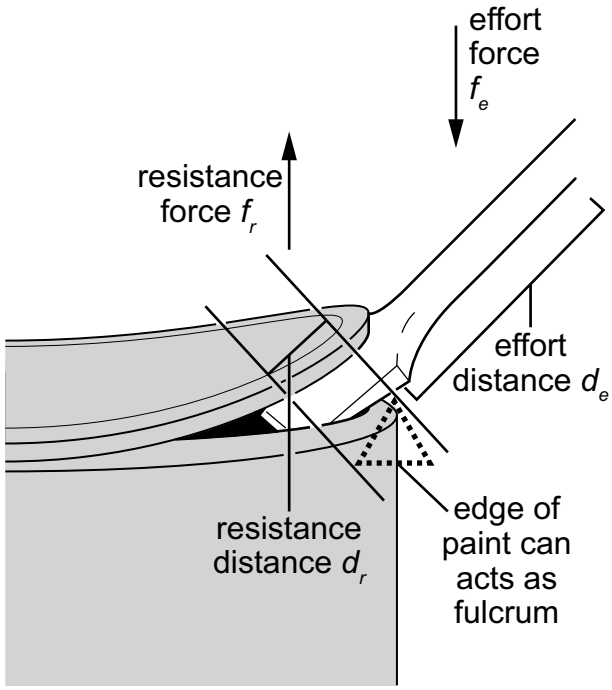
Work can be made easier or be done faster by using machines. Machines that work with one movement are called **simple machines**. There are six types of simple machines. These are listed in the box below.

**Simple Machines**

- Inclined Plane
- Lever
- Pulley
- Screw
- Wedge
- Wheel and Axle

Simple machines cannot decrease the amount of work done, but they can change the size and direction of the force used to do the work. The force applied to a simple machine is called the **effort force**, $f_e$. For a machine to do work, an effort force must be applied over a distance. The force exerted by the machine is called the **resistance force**, $f_r$. A lever rotates about a point called a fulcrum. The fulcrum is the reference point to find the resistance distance on one side of the fulcrum and the effort distance on the opposite side. For example, consider how a painter uses a screwdriver as a lever to pry open the lid on a can of paint. An illustration showing the bottom end of the screwdriver and the top of a paint can is shown below. When the painter pushes down on the screwdriver, an effort force is applied over a distance known as the **effort distance**, $d_e$. As a result, the tip of the screwdriver exerts a resistance force against the lid of the paint can. The screwdriver acts as a lever, with the fulcrum being the edge of the paint can where the screwdriver pivots. This force moves the lid of the can over the **resistance distance**, $d_r$.



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**Mechanical advantage** is the ratio of the resistance force to the effort force or equivalently the ratio of the effort distance to the resistance distance. The mechanical advantage is determined using the following equations:

$$\text{Mechanical advantage} = \frac{\text{effort distance}}{\text{resistance distance}} = \frac{\text{resistance force}}{\text{effort force}} \left(MA = \frac{d_e}{d_r} = \frac{f_r}{f_e}\right)$$

Since these two ratios are equal, the mechanical advantage can also be computed by using each ratio separately:

$$MA = \frac{f_r}{f_e} \quad \text{or} \quad MA = \frac{d_e}{d_r}$$

For the lever described on the previous page, pushing down on the effort side raises the load on the resistance side, and the mechanical advantage is the distance from the effort force to the fulcrum divided by the distance from the resistance force to the fulcrum. Applying the equations shows the ratio of the resistance force to the effort force.

For example, if 15 N of force is applied to the handle of the screwdriver against a resistance force of 150 N, the mechanical advantage of the screwdriver is 10. The tip of the screwdriver has multiplied the effort force 10 times. For an inclined plane, the mechanical advantage is the length of the sloped surface divided by the height of the ramp. For a simple pulley with one wheel, the mechanical advantage is 1, but the direction of the force to lift a weight has been changed from upward to downward. A compound pulley with multiple wheels has increasing mechanical advantage with additional wheels. Classroom resources can provide examples of the mechanical advantage of other simple machines.



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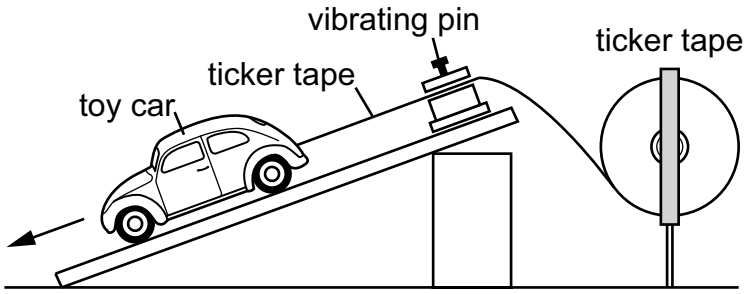
## SAMPLE ITEMS

### Item 13

**Selected-Response**

**A student sets up an investigation to analyze the motion of a battery-powered toy car. The student uses a machine with a vibrating pin that makes a mark every 0.1 second on a long narrow piece of paper called ticker tape.**

**Investigation Setup**

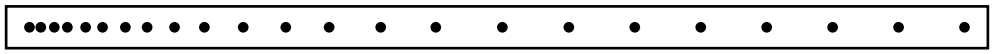



**Steps 1 and 2 are shown.**

> **step 1.** Attach one end of the ticker tape to the toy car; the rest of the ticker tape is in the spool.
>
> **step 2.** Release the toy car so that it moves away from the machine.

**The student conducts the first two steps. The ticker tape from the investigation is shown.**

start end



**Which action should the student take in step 3 to determine the speed of the car, and which analysis of the speed of the car is correct?**

**A.** **step 3.** Count the total number of dots on the ticker tape.
**analysis:** The speed remained constant during the entire period.

**B.** **step 3.** Measure the distance between each successive dot on the ticker tape.
**analysis:** The speed decreased at first and then became constant.

**C.** **step 3.** Count the total number of dots on the ticker tape.
**analysis:** The speed continued to increase during the entire period.

**D.** **step 3.** Measure the distance between each successive dot on the ticker tape.
**analysis:** The speed increased at first and then became constant.



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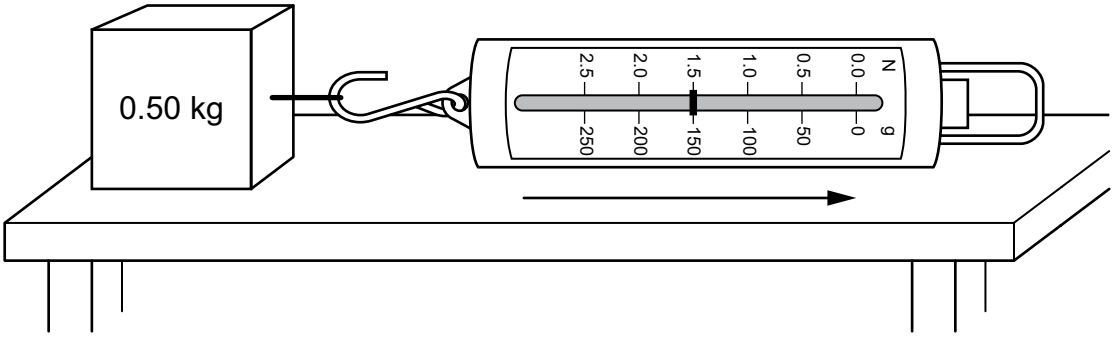
## Item 14

**Selected-Response**

**To investigate Newton's second law of motion, a student used a motion sensor and a spring scale to measure the force acting on a lead block as it was pulled in the direction of the arrow, across the top of a table. A diagram of the setup is shown.**

**Newton's Second Law Investigation**




**The student measured a force of 1.5 newtons (N) acting on the lead block. The student expected the block to accelerate in the same direction as the arrow; however, as the block moved across the table, the motion sensor detected a constant velocity. The student interpreted the results and claimed that Newton's second law does not always apply.**

**Which explanation BEST describes why the student's claim is invalid?**

**A.** The 1.5 N reading on the spring scale is due to the force of friction acting in the opposite direction of the motion, since the net force is zero at constant velocity. Without friction, the lead block would have accelerated at 0.33 $m/s^2$.

**B.** The 1.5 N reading on the spring scale is due to the net force of 1.50 N to the right acting on the block, as indicated by the constant velocity to the right. Without this force, the lead block would have accelerated at 0.33 $m/s^2$.

**C.** The 1.5 N reading on the spring scale is due to the force of friction acting in the opposite direction of the motion, since the net force is zero at constant velocity. Without friction, the lead block would have accelerated at 3.0 $m/s^2$.

**D.** The 1.5 N reading on the spring scale is due to the net force of 1.50 N to the right acting on the block, as indicated by the constant velocity to the right. Without this force, the lead block would have accelerated at 3.0 $m/s^2$.



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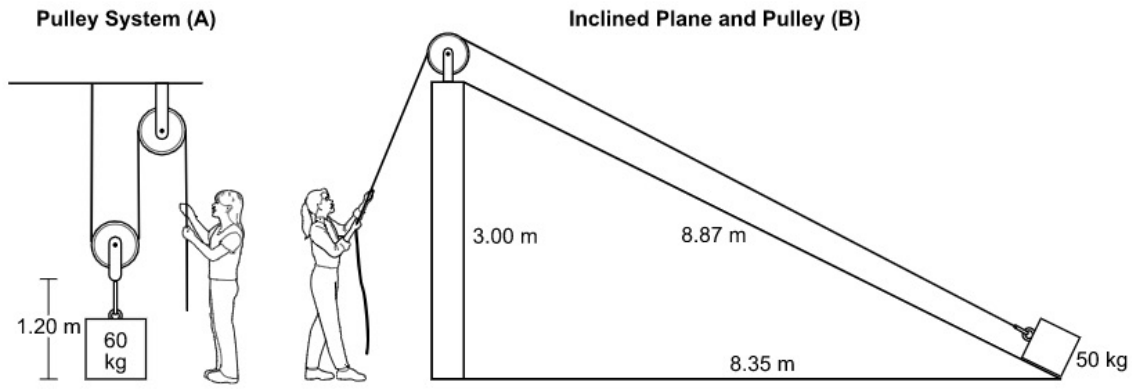
## Item 15

**Drag-and-Drop Technology-Enhanced**

A supervisor observed two workers lifting a crate using different simple machines as shown in the diagram.




Ignoring friction, move a number into each box in the table to correctly identify the mechanical advantage of the pulley system A and the inclined plane B.

| Simple Machine | Mechanical Advantage |
|---|---|
| pulley system A | |
| inclined plane B | |

1.00 1.20 2.96 8.35
1.06 2.00 3.00 8.87

Use a mouse, touchpad, or touchscreen to move the numbers to the right of the table into the boxes. Each number can be used once.



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## Item 16

**Selected-Response**

**A teacher dropped three different objects down a 5.0 m vacuum chamber. The teacher then determined the force on each object given its mass and created the table shown.**

| Object | Mass (kg) | Force (N) |
|---|---|---|
| rock | 0.10 | 1.0 |
| tennis ball | 0.060 | 0.60 |
| pebble | 0.010 | 0.10 |

**What relationship can be determined based on an analysis of the data?**

**A.** Each object has a final velocity that is proportional to its mass.
**B.** Each object has an acceleration that is proportional to its mass.
**C.** All three objects have the same downward acceleration regardless of mass.
**D.** All three objects have the same amount of inertia regardless of mass.



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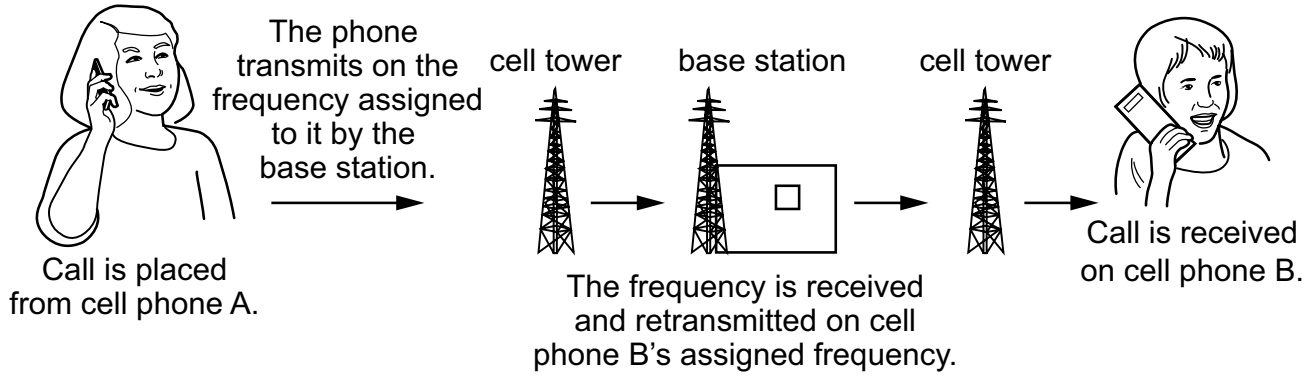
## Item 17

**Selected-Response**

**A student investigated the energy transformations that occur when a call is placed from cell phone A and received by cell phone B. The student drew a diagram to show the process.**

**How a Call Is Made on Cell Phones**




**Based on the diagram, what evidence is there for the transformation of chemical energy into electrical energy, and which other energy transformations must occur for the call to be received by cell phone B?**

**A.** **evidence:** Cell phones are powered by a battery that produces the electricity used to send or receive a call.
**transformation 1:** Sound energy is transformed into electrical energy by cell phone A.
**transformation 2:** Electrical energy is transformed into mechanical energy in the cell towers and base station.

**B.** **evidence:** Cell phones are powered by a battery that produces the electricity used to send or receive a call.
**transformation 1:** Sound energy is transformed into electromagnetic waves by cell phone A.
**transformation 2:** Electromagnetic waves are transformed back into sound energy by cell phone B.

**C.** **evidence:** Base stations are powered by a battery that produces the electricity used to receive and forward a call.
**transformation 1:** Sound energy is transformed into electrical energy by cell phone A.
**transformation 2:** Electrical energy is transformed into mechanical energy in the cell towers and base station.

**D.** **evidence:** Base stations are powered by a battery that produces the electricity used to receive and forward a call.
**transformation 1:** Sound energy is transformed into electromagnetic waves by cell phone A.
**transformation 2:** Electromagnetic waves are transformed back into sound energy by cell phone B.



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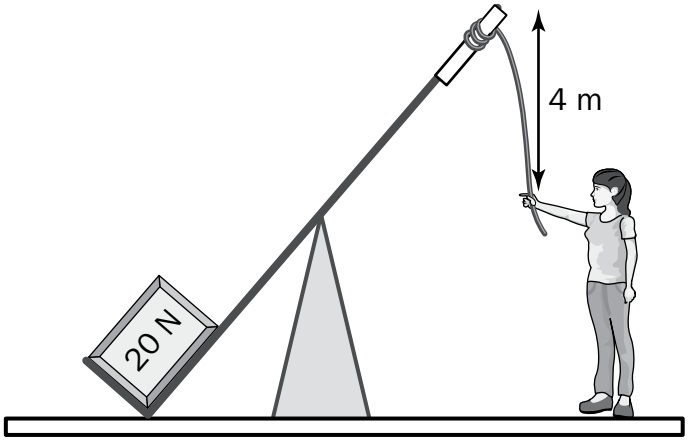
## Item 18

**Selected-Response**

**A student pulls a lever down 4 m. The lever lifts a box that weighs 20 N up a distance of 2 m.**




**How much work was done on the box?**

**A.** 10 J
**B.** 40 J
**C.** 80 J
**D.** 160 J



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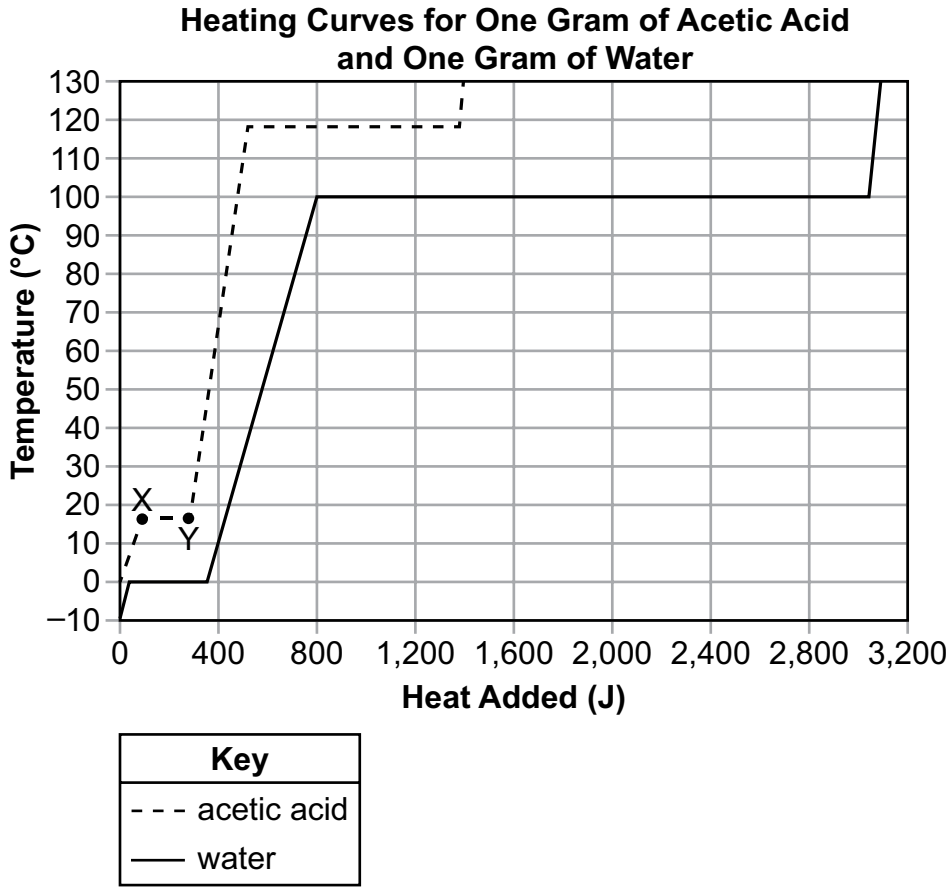
## Item 19

**Multi-Part Technology-Enhanced**

**A student collected thermal data for acetic acid ($CH_3COOH$) and water ($H_2O$) and graphed the heating curves for the two substances.**




**Part A**

**What is happening to the acetic acid between points X and Y on the graph?**

**A.** Liquid acetic acid is becoming warmer as it absorbs heat energy from the surroundings.

**B.** Liquid acetic acid is being converted from a liquid to a gas by absorbing heat energy from the surroundings.

**C.** Solid acetic acid is becoming warmer as it absorbs heat energy from the surroundings.

**D.** Solid acetic acid is being converted from a solid to a liquid by absorbing heat energy from the surroundings.

***Go on to the next page to finish item 19.***



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**Item 19. *Continued*.**

**Part B**

**Which comparison can be made about a phase change common to acetic acid and water based on the graph?**

**A.** More heat energy is required to melt a gram of acetic acid than to melt a gram of water.
**B.** More heat energy is required to vaporize a gram of water than to vaporize a gram of acetic acid.
**C.** Given the same rate of added heat, the temperature of a gram of water will increase at a faster rate than a gram of acetic acid.
**D.** Given the same rate of heat loss, the temperature of a gram of acetic acid vapor will decrease at a slower rate than a gram of water.



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# WAVES, ELECTRICITY, AND MAGNETISM

For electricity and magnetism, this section focuses on the concepts that the motion of electric charges is caused by the presence of an electric force, that there is a fundamental connection between a moving charged particle and the presence of electric and magnetic fields, and that in a closed circuit the movement of electrically charged particles (current) is modified by the amount of resistance in the circuit and the amount of energy (electrical potential energy) that is available for the charged particles to move. In addition, the section builds an understanding of the implications of different simple circuit configurations (series and parallel circuits), the movement of electrically charged particles through them, and the circuits' uses in real life situations.

By studying this section you will develop the understanding that electric and magnetic forces are different aspects of a single electromagnetic interaction. These forces are both repulsive and attractive, depending on the sign of the electric charges involved or the orientation of the magnets. Charged particles are sources of electric fields and can be affected by the electric fields generated by other charged particles. Magnets and charged particles in motion are sources of magnetic fields and can also be affected by magnetic fields generated by other sources. The magnitude of electric forces depends on the size of the charges and the distance between them. The magnitude of magnetic forces depends on the magnitude of the electric current or magnetic strength and the distance between the objects.

In an electric circuit, electric charges continually flow through a complete loop, returning to their origin and cycling through the loop again. In order for an electrically charged particle to move, energy must be provided to increase the electric potential energy of the charged particle.

This section also covers the behavior of waves. Energy can travel over great distances in the form of waves. The two significant types of waves for this course are mechanical waves and electromagnetic waves. The most familiar type of electromagnetic wave is visible light. However, electromagnetic waves also include radio, microwaves, infrared, ultraviolet, X rays, and gamma radiation that can travel through air; liquids, such as water; or solid objects.

## CORE IDEAS

- An electric current requires a complete circuit and a voltage source. (SPS10a, b)
- The amount of current that flows in a circuit depends on both the resistance of the circuit and the voltage of the source. (SPS10a)
- In a series circuit, the same amount of current flows through all the components. (SPS10b)
- In a parallel circuit, the voltage drop across each branch of the circuit is equal and is also equal to the voltage of the power source. (SPS10b)
- In a direct-current circuit, the electrons flow in only one direction. (SPS10b)
- In an alternating current, the motion of the electrons alternates back and forth, due to the changing polarity of the voltage source. (SPS10b)
- Charges in motion generate magnetic fields. (SPS10c)
- Variable magnetic fields induce currents in a circuit. (SPS10c)
- A moving electrical charge, or current, in a magnetic field experiences a force. (SPS10c)
- Waves carry energy that can be transferred or transformed in interactions with matter or other waves. (SPS9a)
- The pitch of a sound is a measure of its frequency. (SPS9d)
- Although electromagnetic and mechanical waves share some characteristics, they are different in the way they are generated and transfer energy. (SPS9b)
- The speed at which sound travels is dependent upon the material in which it travels. (SPS9d)



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- As a wave encounters another medium, it may be reflected and/or refracted. (SPS9c, d)
- As a wave encounters an obstacle or an opening, it may be reflected, refracted, and/or diffracted. (SPS9c)
- Two waves that meet will create a pattern of interference. (SPS9c)
- The energy of a wave can be determined from the wave's physical characteristics. (SPS9a)

## KEY CONCEPTS

The word **electricity** sounds very much like *electron*. The similarity between the words is no accident. Recall that electrons are negatively charged particles, while protons are positively charged particles. When like charges come near each other, the charges repel each other. When opposite charges come near each other, the charges attract each other.

- In **conduction**, electrons flow through one object into another by direct contact. Silver, copper, aluminum, and magnesium are examples of good conductors. These materials allow electrons to flow freely.
- **Induction** involves electrons being rearranged. No contact needs to occur between two objects for induction to take place. A neutral object only needs to approach a charged object. For example, a negatively charged rubber rod picks up tiny slips of paper by induction. The electrons on the parts of the paper nearest to the rod are pushed away, leaving positive charges. Because the positive charges are closer to the negatively charged rod, the slips of paper are attracted to the rod.

Electric charges leave a charged object during an **electric discharge**. Lightning is probably the most dramatic example of an electric discharge. The repulsion and attraction of particles can be described in terms of **electric fields**. The electric field is an alteration of space caused by the presence of an electric charge. The manifestation of the presence of an electric field results in other charges experiencing an electric force.

The strength of the electric field depends on the magnitude of the electric charge generating the field and decreases inversely proportionally to the square of the distance from the charge.

**Electric current** results from the movement of electric charges. A **circuit** is a complete, closed path for electron flow. A simple circuit consists of a source of electrons (such as a battery), a resistance or load, conducting wires, and a switch. In a battery, electrical energy is produced by a chemical reaction. When charged particles flow through the wire in a circuit, an electric current, represented by the letter I, results. The current is measured in amperes whose symbol is A. The electron is the charged particle that most likely moves through the circuit. To get electrons flowing through a circuit, a voltage, represented by the letter V, is applied. **Voltage**, which is measured in volts (symbol V), is the potential difference in electrical potential energy between two places in a circuit. In other words, voltage is the energy per unit of charge that causes charges to move. The opposition to current is called **resistance**, represented by the letter R, which is measured in ohms, represented by the Greek letter capital Omega ($\Omega$). Light bulbs and resistors are examples of objects with resistance. Materials like copper that are good conductors of electricity have low resistance. The resistance of a wire depends on the thickness, length, and temperature of the wire. As a wire is made longer, its resistance increases, while thicker wires have lower resistance. Increasing a wire's temperature will also increase its resistance. Insulators keep electrons from flowing easily. Although electrons move one way through a wire, the current, by convention, is the relative movement of a positive charge. Electrons flow opposite the direction of the current.

Charges can move through a circuit continuously in the same direction, producing a **direct current**, or **DC**. Electrons can also change direction, moving back and forth in cycles. This kind of current is known as **alternating current**, or **AC**. Batteries, such as those found in cars, produce DC, while a gasoline-driven generator usually produces AC.



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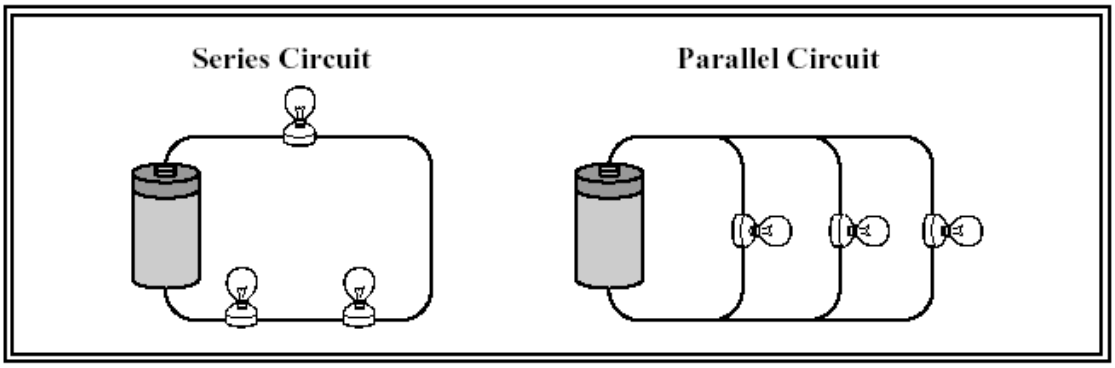
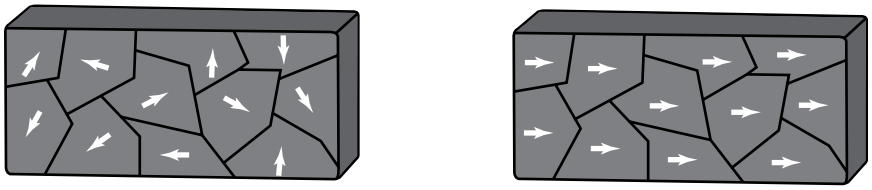
When the electric charges in a circuit have only one path in which to flow, the circuit is called a **series circuit**. If the circuit has different branches in which the electric charges can flow, the circuit is called a **parallel circuit**. Parallel circuits are used in houses. The following box shows examples of these circuits:




An electric current will also produce a magnetic field. A **magnetic field** is a region around a magnet or current-carrying wire where magnetic forces can be measured. **Magnetism** is the force of attraction or repulsion that is caused by the motion of electric charges. Magnets have two poles: a north pole and a south pole. *Unlike* magnetic poles attract each other, while *like* magnetic poles repel each other. Groups of atoms with magnetic poles aligned are called **magnetic domains**. Materials with most of these domains lined up are considered magnetized. When a metal bar or another object is composed of stable magnetic domains, a **permanent magnet** results.



**Not Magnetized** **Magnetized**

When an electric current is used to produce a magnetic field in a coil of wire, the coil becomes an electromagnet. An electromagnet using just a simple wire coil is comparatively weak. Electromagnets can be made stronger by wrapping the coils around a core made of a material that responds to a magnetic field, particularly iron; by using more coils; and by using a stronger electrical current.

When a magnet is moved near a wire, an electric current is generated. This process, called **electromagnetic induction**, is used to operate a **generator**. A generator is a device that converts mechanical energy to electrical energy. In a commercial generator, an electric current is produced when a large coil of wire is rotated in a strong magnetic field.



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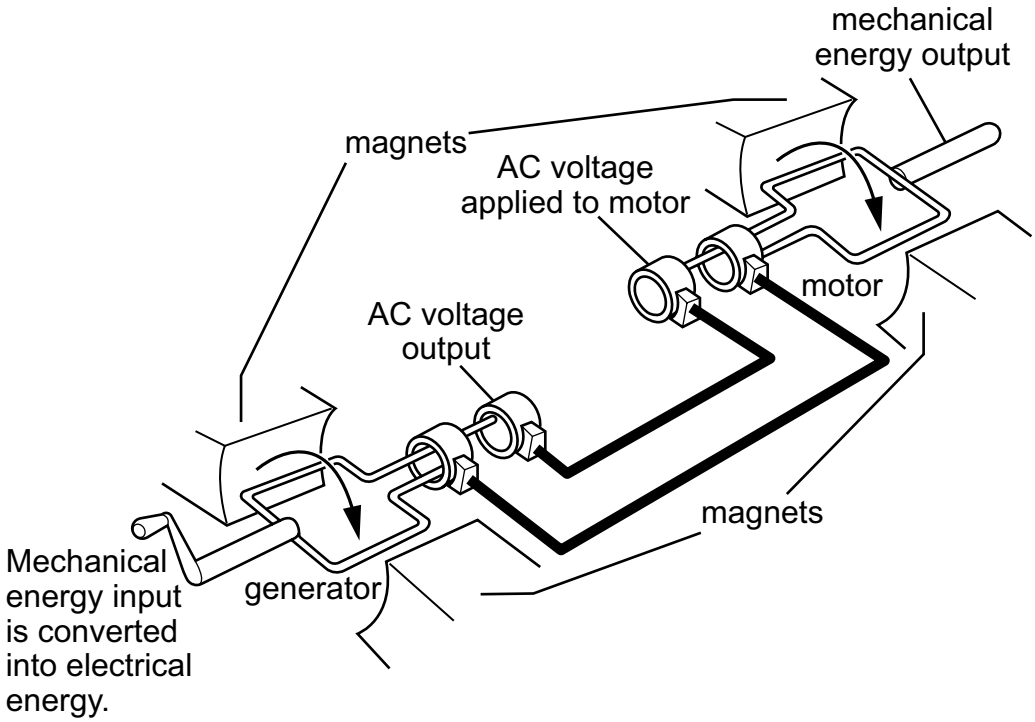


**Waves** are phenomena that occur, seen and unseen, all around us. Suppose that a student drops a stone into a pond; the surface of the water becomes disturbed. Some of the kinetic energy of the stone as it falls into the water is transferred to surrounding water molecules. This causes the surface of the water to be disturbed as water molecules move up and down while transferring energy through the water. This energy transfer can be seen moving in all directions through waves moving outward in concentric circles. Particles of matter do not move along with the waves. Only the energy that creates the waves moves with them. Waves by definition are disturbances that repeat the same cycle of motion and transfer energy through matter or empty space.

Mechanical waves (such as sound waves) are similar to electromagnetic waves (such as light waves) in that both types of waves transmit energy over a distance. However, there are some major differences:

- Sound waves require a medium for traveling. Light waves may travel either through a transparent medium or through empty space.
- Sound waves travel through all substances, but light waves are absorbed and reflected by opaque materials so that no light travels through them.
- A sound wave travels slowly through air at a speed of about 340 meters per second at 15°C. Electromagnetic waves, on the other hand, travel through air or the vacuum of space at extremely high speeds of about 300,000,000 meters per second.



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Sound waves travel by compressing and stretching the separation of the particles of the medium in which they travel. Because of this, the nature of a medium has a significant effect on the speed of sound. Sound travels faster through solids and liquids than it does through gases because particles are closer together in solids or liquids than in gases. Sound also travels fastest through elastic materials. Elasticity refers to the characteristic of the material allowing it to maintain its shape and not deform when a force is applied to it. For example, sound travels at about 1,500 meters per second in water, but in aluminum, which is more elastic, the speed of sound is about 5,000 meters per second. In materials of the same phase, or state of matter, the speed of sound tends to decrease as the density increases. The molecules of a denser substance have greater inertia and do not move as quickly as molecules of a less dense substance. The table below shows the speed of sound in various substances.

| Speed of Sound (at 25°C) | | |
|---|---|---|
| **Substance** | **State** | **Speed (m/s)** |
| Air | Gas | 346 |
| Helium | Gas | 1,016 |
| Ethanol | Liquid | 1,144 |
| Water | Liquid | 1,494 |
| Steel | Solid | 5,000 |
| Lead | Solid | 1,320 |

Because waves involve the transfer of energy, the properties of a wave will change when a wave encounters another wave or an object. Waves undergo four basic interactions. **Reflection** occurs when a wave hits an object that it cannot pass through or when it reaches the boundary of the medium of transmission. Both situations involve the return of the wave as it bounces off the object or medium boundary. **Refraction** takes place when a wave passes from one medium into another at an angle and bends (changes direction) due to a change in speed. **Diffraction** results when a wave passes through a hole or moves past a barrier and spreads out in the region beyond the hole or barrier. Finally, **interference** occurs when two or more waves arrive at the same point at the same time. As a result, they combine to produce a single wave. This new wave will have different properties from the two waves that composed it. For example, when similar parts such as the peaks of the waves line up, the combined wave's amplitude will be larger. When the low part of one wave lines up with the peak of another, the combined amplitude will be smaller.



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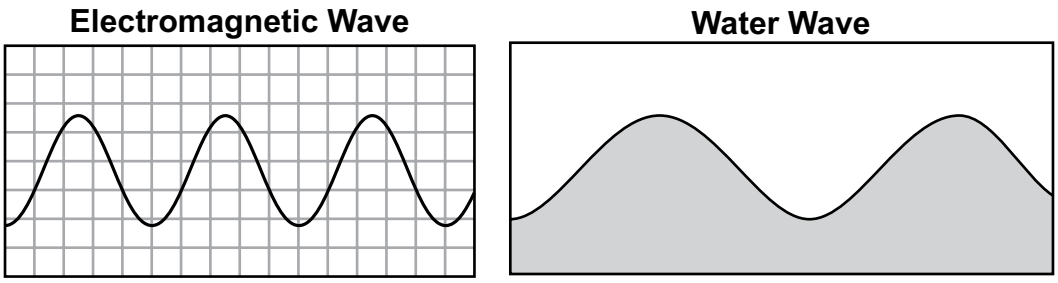
## SAMPLE ITEMS

### Item 20

**Selected-Response**

**A student drew models of an electromagnetic wave and a water wave.**




**Which scientific question did the student MOST LIKELY ask to know how to draw these models?**

**A.** Are water waves and electromagnetic waves examples of transverse waves?
**B.** Do water waves travel at a slower speed than electromagnetic waves?
**C.** Can water waves and electromagnetic waves travel through different media?
**D.** How do water waves and electromagnetic waves increase their amplitude?

### Item 21

**Selected-Response**

**The table compares data for two different light-emitting diodes (LEDs).**

| LED Type | Emission Wavelength (nanometers) | Current through LED (milliamps) |
|---|---|---|
| green diffused | 565 | 40 |
| gallium arsenide | 930 | 120 |

**Based on the data, what can be identified about the energy of the waves emitted by the LEDs?**

**A.** The wave energy of the green diffused LED is 1.65 times that of the gallium arsenide LED.
**B.** The wave energy of the green diffused LED is 0.333 times that of the gallium arsenide LED.
**C.** The wave energy of the green diffused LED is 0.608 times that of the gallium arsenide LED.
**D.** The wave energy of the green diffused LED is 3.00 times that of the gallium arsenide LED.



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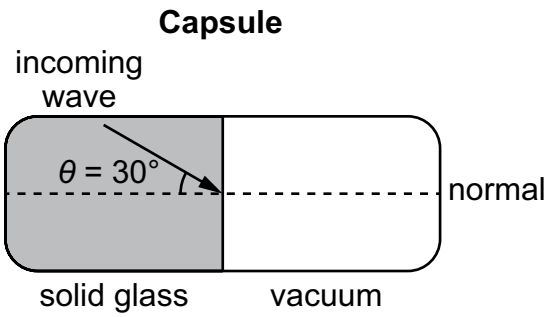
## Item 22

**Multi-Select Technology-Enhanced**

**A student is investigating the differences between light waves and sound waves. The student does this by using a capsule filled with solid glass at one end and a vacuum at the other end. The student will transmit waves into the capsule at a 30° angle to the (normal) centerline.**




**Which TWO questions should the student ask, and which predictions are MOST LIKELY correct based on this investigation?**

**A.** **question:** How are electromagnetic waves and mechanical waves affected when traveling from a solid glass medium to a vacuum?
**prediction:** The electromagnetic waves and mechanical waves will continue through the vacuum at a lower speed.

**B.** **question:** How is the speed of electromagnetic waves affected when traveling from a solid glass medium to a vacuum at a 30° angle?
**prediction:** The electromagnetic waves will travel in a straight line, showing that they have maintained a constant speed.

**C.** **question:** How are electromagnetic waves and mechanical waves affected when traveling from a solid glass medium to a vacuum?
**prediction:** The electromagnetic waves will continue through the vacuum, while the mechanical waves will go no farther.

**D.** **question:** Can electromagnetic waves and mechanical waves travel from a solid glass medium into a liquid medium?
**prediction:** Both electromagnetic waves and mechanical waves will bend, showing that they have passed through each medium.

**E.** **question:** How is the speed of electromagnetic waves affected when traveling from a solid glass medium to a vacuum at a 30° angle?
**prediction:** The electromagnetic waves will bend downward, showing that they have sped up slightly.

**F.** **question:** Can electromagnetic waves and mechanical waves travel from a solid glass medium into a liquid medium?
**prediction:** The electromagnetic waves will continue through the liquid medium, while the mechanical waves will go no farther.



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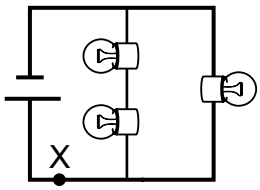
## Item 23

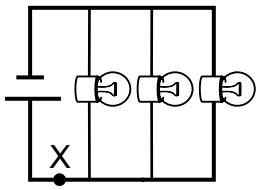
**Selected-Response**

**A student is modeling an electric circuit containing three light bulbs and a battery. Which model shows a circuit where the current flowing through each bulb will be the same as the current at point X?**

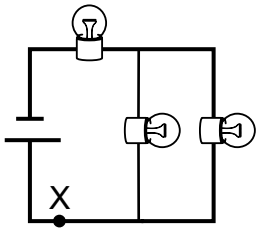
**A.**



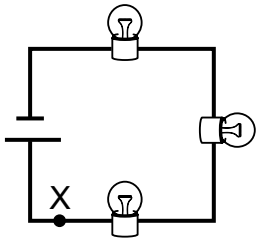

**B.**




**C.**




**D.**



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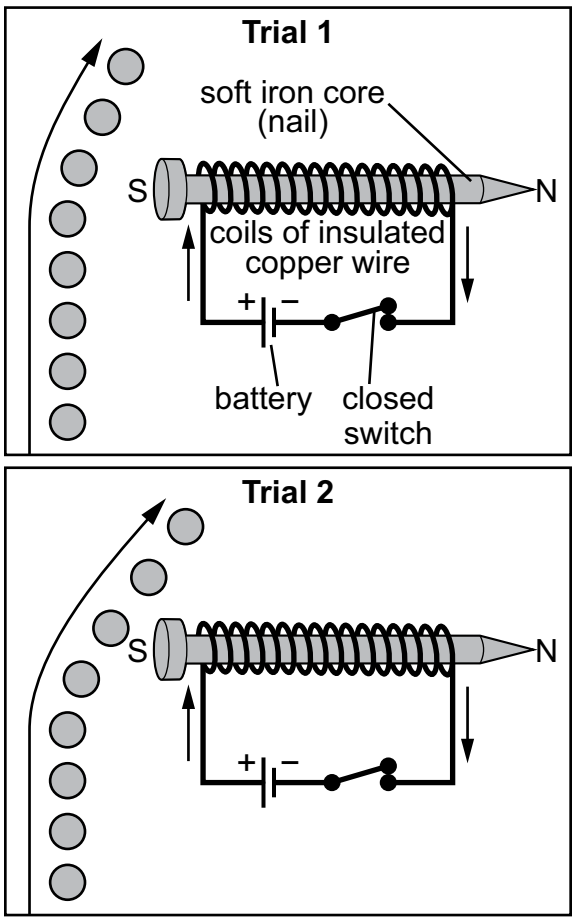
## Item 24

**Selected-Response**

**A student did an investigation to determine the effect of a magnetic field on a moving steel sphere. The student recorded the motion of the steel sphere in trial 1 and then drew the desired motion of the steel sphere for trial 2 as shown in the diagram.**

**Electromagnetic Investigation**




**If the steel sphere has the same initial velocity in both trials, which action would BEST help to achieve the motion of the steel sphere shown in trial 2?**

**A.** putting a resistor between the battery and switch
**B.** replacing the nail with one made out of aluminum
**C.** reversing the direction of the poles of the iron core
**D.** increasing the number of coils of insulated copper wire



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## Item 25

**Selected-Response**

**A parallel circuit contains a battery with a voltage of 9 volts. The total resistance in the circuit is 18 ohms. Which claim about the current in the circuit can be supported mathematically from the relationships between voltage, current, and resistance?**

**A.** **claim 1:** the current flowing through the circuit is 0.5 amps because current is related to voltage and resistance by the formula $I = V/R$

**B.** **claim 2:** the current flowing through the circuit is 2 amps because current is related to voltage and resistance by the formula $I = R/V$

**C.** **claim 3:** the current flowing through the circuit is 27 amps because current is related to voltage and resistance by the formula $I = R + V$

**D.** **claim 4:** the current flowing through the circuit is 162 amps because current is related to voltage and resistance by the formula $I = VR$



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# ADDITIONAL SAMPLE ITEM KEYS

| Item | Standard/ Element | DOK Level | Correct Answer | Explanation |
|---|---|---|---|---|
| 1 | SPS4b | 2 | A | The correct answer is choice (A) 32.0 g. Choices (B), (C), and (D) are incorrect because they did not follow these steps: Taking the days and dividing by the half-life gives a value of 3. Since three half-lives have passed, one-eighth ($\frac{1}{8}$) of the sample remains. 256.0 g divided by 8 yields 32.0 g. |
| 2 | SPS1b | 2 | D | The correct answer is choice (D) They have the maximum possible number of electrons in their outermost shell. The noble gases, including neon, argon, and krypton, are group 18 elements, which means that they have the maximum number of valence electrons. Therefore, these elements tend to be chemically inert. Choice (A) is incorrect because the noble gases are stable elements. Choice (B) is incorrect because the noble gases are reasonably plentiful elements. Choice (C) is incorrect because the noble gases do not readily give up their valence electrons. |
| 3 | SPS4a | 2 | A | The correct answer is choice (A). Choice (A) is correct because it shows two nuclei, one of the hydrogen isotope deuterium and the other of the hydrogen isotope tritium, combining in such a way that the final product is a helium nucleus plus a spare neutron. Choice (B) is incorrect because this process simply results in the atomic nuclei being split into all the constituent subatomic particles. Choice (C) is incorrect because this process merely converts tritium (H-3) to deuterium (H-2), different isotopes of hydrogen, with neutron emission. Choice (D) is incorrect because a neutron combining with an atomic nucleus does not represent fusion; this process results only in the formation of a new highly unstable isotope of hydrogen. |
| 4 | SPS2b | 2 | N/A | See scoring rubric and exemplar response beginning on page 92. |



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| Item | Standard/ Element | DOK Level | Correct Answer | Explanation |
|---|---|---|---|---|
| 5 | SPS4a | 3 | A, D | The correct answers are choices (A) and (D). The krypton isotope and the barium isotope represent the two nuclei that account for all the nuclear particles in the nuclear fission reaction. Choice (B) is incorrect because this isotope cannot be added to any of the other isotopes to account for all the nuclear particles in the nuclear fission reaction. Choice (C) is incorrect because a reaction involving alpha decay is not generally considered a nuclear fission reaction. Choice (E) is incorrect because a larger atomic nucleus occurs in a fusion reaction not a fission reaction. Choice (F) is incorrect because a reaction involving beta decay is not generally considered a nuclear fission reaction. |
| 6 | SPS1b | 2 | N/A | See scoring rubric and exemplar response on page 94. |
| 7 | SPS2b | 2 | B | The correct answer is choice (B). Choice B is correct because based on the families that the elements sulfur and aluminum are found in on the periodic table, sulfur ions should have a $^{-}2$ charge and aluminum ions a $^{+}3$ charge and combine in a 3:2 ratio as shown in this model. Choice (A) is incorrect because sulfur's valence is $^{-}2$ not $^{-}1$ and the number of aluminum atoms in aluminum sulfide is two not one. Choice (C) is incorrect because sulfur's valence is $^{-}2$ not $^{-}1$, aluminum's valence is $^{+}3$ not $^{+}1$, and there are two aluminum atoms and three sulfur atoms in aluminum sulfide. Choice (D) is incorrect because sulfur's valence is $^{-}2$ not $^{-}3$ and there are two aluminum atoms and three sulfur atoms in aluminum sulfide. |
| 8 | SPS3b | 2 | D | The correct answer is choice (D) 4, 3, 2. Four Fe combine with three $O_2$ to yield two $Fe_2O_3$. Choice (A) is incorrect because the coefficients 2, 1, 2 result in an unbalanced number of both Fe and O. Choice (B) is incorrect because the coefficients 2, 3, 2 result in an unbalanced number of Fe atoms. Choice (C) is incorrect because the coefficients 4, 1, 2 result in an unbalanced number of O atoms. |
| 9 | SPS6c | 2 | B | The correct answer is choice (B) The mass is approximately 110 g; increased temperatures lead to an increase in solubility. This is correct because the reading of the graph is this value, and this describes the solubility trend that can be seen from the curve on the graph. Choice (A) is incorrect because 140 g is too much to dissolve completely at 60°C. Increasing the temperature increases the solubility. Choice (C) is incorrect because 140 g is too much to dissolve completely at 60°C. Choice (D) is incorrect because increasing the temperature increases the solubility. |
| 10 | SPS3a | 2 | N/A | See scoring rubric and exemplar response on page 95. |



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| Item | Standard/ Element | DOK Level | Correct Answer | Explanation |
|---|---|---|---|---|
| 11 | SPS6b | 3 | D, B | The correct answer for Part A is choice (D) 30 minutes, because the larger diameter of crystals decreases the total surface area of the solute exposed to the solvent, increasing the length of exposure to the solvent. Choices (A), (B), and (C) are incorrect because a larger crystal size means it would take longer than 20 minutes to dissolve.<br><br>The correct answer for Part B is choice (B) Keep the diameter of crystals at 1.0 mm. Keep the temperature at 20°C. Stir the solution. Choice (A) is incorrect because the larger crystal size requires more time. Choice (C) is incorrect because the larger crystal size requires more time and the lower temperature provides less exposure to the solvent. Choice (D) is incorrect because you are changing 2 variables, temperature and stirring. |
| 12 | SPS6e | 3 | N/A | See scoring rubric and exemplar response beginning on page 96. |
| 13 | SPS8a | 2 | D | The correct answer is choice (D) **step 3.** Measure the distance between each successive dot on the ticker tape. **analysis:** The speed increased at first and then became constant. The farther apart the marks on the ticker tape are, the faster the toy car is going. When the marks are equally spaced, the toy car is moving at a constant speed. Choice (A) is incorrect because counting reveals only the length of the investigation and because the speed increased at first and then became constant. Choice (B) is incorrect because the speed increased at first according to the increasing distance between the dots. Choice (C) is incorrect because counting reveals only the length of the investigation and the speed eventually became constant. |



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| Item | Standard/ Element | DOK Level | Correct Answer | Explanation |
|---|---|---|---|---|
| 14 | SPS8b | 3 | C | The correct answer is choice (C) The 1.5 N reading on the spring scale is due to the force of friction acting in the opposite direction of the motion, since the net force is zero at constant velocity. Without friction, the lead block would have accelerated at 3.0 m/s$^2$. Choice (A) is incorrect because $a = \frac{F}{m} = \frac{1.5\text{ N}}{0.50\text{ kg}} = 3.0\text{ m/s}^2$. Choice (B) is incorrect because if the net force were 1.5 N to the right, then the lead block would have accelerated to the right, not moved at constant velocity, and the acceleration would be 3.0 m/s$^2$. Choice (D) is incorrect because the explanation is incorrect and does not account for the zero net force and force of friction in the opposite direction of the motion. |
| 15 | SPS8d | 2 | N/A | See scoring rubric and exemplar response on page 98. |
| 16 | SPS8c | 2 | C | The correct answer is choice (C) All three objects have the same downward acceleration regardless of mass. The claim that all three objects have the same downward acceleration, regardless of mass, is supported by Newton's second law that relates force, mass, and acceleration, $a = \frac{F}{m}$. Choice (A) is incorrect because the final velocity of all three objects will be the same since they all start from rest and have the same acceleration. Choice (B) is incorrect because although this statement is partially true for situations involving air resistance, the acceleration is independent of the mass in a vacuum. Choice (D) is incorrect because the acceleration, not the amount of inertia, is independent of the mass of each object. |



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| Item | Standard/ Element | DOK Level | Correct Answer | Explanation |
|---|---|---|---|---|
| 17 | SPS7a | 2 | B | The correct answer is choice (B)<br>**evidence:** Cell phones are powered by a battery that produces the electricity used to send or receive a call.<br>**transformation 1:** Sound energy is transformed into electromagnetic waves by cell phone A.<br>**transformation 2:** Electromagnetic waves are transformed back into sound energy by cell phone B.<br>Choice (A) is incorrect because sound energy is transformed into electromagnetic waves and cell towers receive and transmit electromagnetic waves using electrical energy, not mechanical energy. Choice (C) is incorrect because a base station is powered by electricity from a larger source than a chemical battery, sound energy is transformed into electromagnetic waves, and cell towers receive and transmit electromagnetic waves using electrical energy, not mechanical energy. Choice (D) is incorrect because a base station is powered by electricity from a larger source than a chemical battery. |
| 18 | SPS8d | 2 | B | The correct answer is choice (B) 40 J. To find the work done on the box, calculate the force applied to the box times the distance it was applied. The force applied is the force in opposition to gravity, which is 20 N. It was applied over a distance of 2 m. 2 m times 20 N is 40 J. Choices (A), (C), and (D) are incorrect because they do not equal 40 J. |



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| Item | Standard/ Element | DOK Level | Correct Answer | Explanation |
|---|---|---|---|---|
| 19 | SPS7d | 3 | D, B | The correct answer for Part A is choice (D) Solid acetic acid is being converted from a solid to a liquid by absorbing heat energy from the surroundings. There is no temperature increase, which indicates a phase change between points X and Y. This is the lower of the two phase changes, which means acetic acid is changing from a solid to a liquid.<br><br>Choices (A) and (C) are incorrect because no temperature increase occurs between these two points, so the liquid acetic acid molecules are not becoming warmer. Choice (B) is incorrect because the second horizontal segment represents boiling.<br><br>The correct answer for Part B is choice (B) More heat energy is required to vaporize a gram of water than to vaporize a gram of acetic acid. The graph shows that acetic acid boils at a higher temperature than water does. However, moving along the upper horizontal line indicating boiling (vaporization), acetic acid starts boiling at about 500 joules added and has converted completely to vapor at about 1,400 joules added, so about 900 joules were required to vaporize the acetic acid. Water started vaporizing at about 800 joules added but didn't completely vaporize until about 3,000 joules added, or 2,200 joules required to vaporize, so more energy was required to vaporize water than to vaporize acetic acid.<br><br>Choice (A) is incorrect because according to the graph, more heat energy is required to melt a gram of water than a gram of acetic acid. Choice (C) is incorrect because the slope of the line segment representing the heating of liquid water is shallower than that of the liquid acetic acid, so the temperature of a gram of liquid acetic acid will increase at a faster rate. Choice (D) is incorrect because the rate at which acetic acid vapor cools is actually faster than that of water based on the slope of the line segments corresponding to cooling vapor. |
| 20 | SPS9b | 2 | A | The correct answer is choice (A) Are water waves and electromagnetic waves examples of transverse waves? The models show both electromagnetic waves and water waves as transverse waves. Choice (B) is incorrect because the models show the characteristics of the two waves but do not give indications of the speed of each wave. Choice (C) is incorrect because the models do not show each wave traveling through different media, so the question did not give rise to the models. Choice (D) is incorrect because the models show qualitatively the amplitude of the water wave and electromagnetic wave, but the models do not show how the waves increase their amplitude. |



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| Item | Standard/ Element | DOK Level | Correct Answer | Explanation |
|---|---|---|---|---|
| 21 | SPS9a | 2 | A | The correct answer is choice (A) The wave energy of the green diffused LED is 1.65 times that of the gallium arsenide LED. This can be understood because the energy of an electromagnetic wave is proportional to the wavelength, so the ratio of energies of two waves is proportional to the ratio of the wavelengths, so $\frac{930\text{ nm}}{565\text{ nm}} = 1.65$. Note that one does not have to actually calculate the energy; just understanding the relationship of proportionality allows one to find the ratio of energies based on the ratio of wavelengths. Choice (B) is incorrect because the ratio of the current through the LED does not identify the relative energy of the two LEDs. Choice (C) is incorrect because the energy is calculated as inversely proportional to the wavelength, not directly proportional, so the ratio of the energy is not $\frac{565\text{ nm}}{930\text{ nm}} = 0.608$. Choice (D) is incorrect because the inverse ratio of the current through the LED does not identify the relative energy of the two LEDs. |



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| Item | Standard/ Element | DOK Level | Correct Answer | Explanation |
|---|---|---|---|---|
| 22 | SPS9b | 3 | C, E | The correct answers are choice (C)<br>**question:** How are electromagnetic waves and mechanical waves affected when traveling from a solid glass medium to a vacuum?<br>**prediction:** The electromagnetic waves will continue through the vacuum, while the mechanical waves will go no farther.,<br>and choice (E)<br>**question:** How is the speed of electromagnetic waves affected when traveling from a solid glass medium to a vacuum at a 30° angle?<br>**prediction:** The electromagnetic waves will bend downward, showing that they have sped up slightly.<br>These are correct because both questions can be answered with this experiment, and both predictions correctly describe the behavior of the waves. Mechanical waves cannot travel through a vacuum, and electromagnetic waves will bend away from the normal, or downward, when moving from a denser medium to a less dense medium because they will speed up. Choice (A) is incorrect because the prediction is wrong, since electromagnetic waves should speed up when entering a vacuum and mechanical waves should go no farther. Choice (B) is incorrect because the prediction is wrong, since different media affect the speed of electromagnetic waves, causing them to bend through refraction. Choice (D) is incorrect because this question cannot be answered here, since a liquid medium is not used. Choice (F) is incorrect because this question cannot be answered here, since a liquid medium is not used; the prediction is also incorrect, since mechanical waves can travel through a liquid. |
| 23 | SPS10b | 2 | D | The correct answer is choice (D) All points on a series circuit experience the same current, so point X and each bulb will experience the same current. Choice (A) is incorrect because the current will be different through the two branches of the parallel circuit since a different number of light bulbs are on those branches. Choice (B) is incorrect because each of the three bulbs will experience one-third of the current that flows through point X since the current must divide to flow through each branch. Choice (C) is incorrect because each bulb on the branch will have half the current that flows through point X or the other bulb. |



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| Item | Standard/ Element | DOK Level | Correct Answer | Explanation |
|---|---|---|---|---|
| 24 | SPS10c | 2 | D | The correct answer is choice (D) increasing the number of coils of insulated copper wire. This is correct because increasing the number of coils within the same length around the core allows each individual coil's magnetic field to add up, thereby increasing the strength of the electromagnet. Choice (A) is incorrect because this would decrease the current in the wire and decrease the magnetic field strength, so the electromagnet would have less of an effect on the motion of the steel sphere. Choice (B) is incorrect because the lack of ferromagnetism in aluminum would cause the magnetic field strength to decrease and result in less of an effect on the motion of the steel sphere. Choice (C) is incorrect because this change would have little effect on the path of the steel sphere since the change does not affect the magnetic field strength. |
| 25 | SPS10a | 2 | A | The correct answer is choice (A) **claim 1:** the current flowing through the circuit is 0.5 amps because current is related to voltage and resistance by the formula $I = \frac{V}{R}$. The formula sheet shows that voltage ($V$) equals current ($I$) multiplied by resistance ($R$). So solving for current, $I = \frac{V}{R} = \frac{9}{18} = 0.5$ amps. Choice (B) is incorrect because the response divided $R$ by $V$. Choice (C) is incorrect because the response added $V$ and $R$. Choice (D) is incorrect because the response multiplied $V$ and $R$. |



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# SCORING RUBRICS AND EXEMPLAR RESPONSES

## Item 4

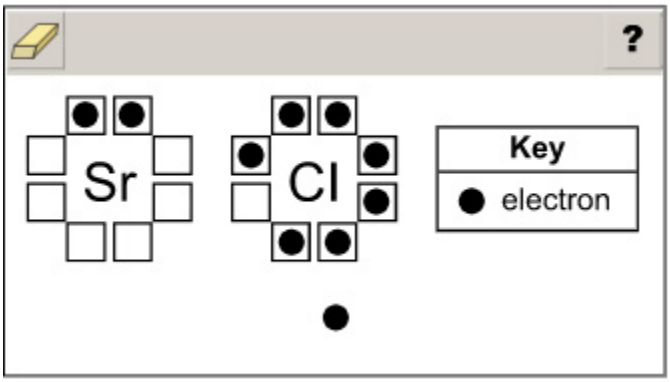
### Scoring Rubric

| Points | Description |
|---|---|
| 2 | The student correctly answers both Part A and Part B. |
| 1 | The student correctly answers either Part A OR Part B. |
| 0 | The student does not correctly answer either part. |

### Exemplar Response

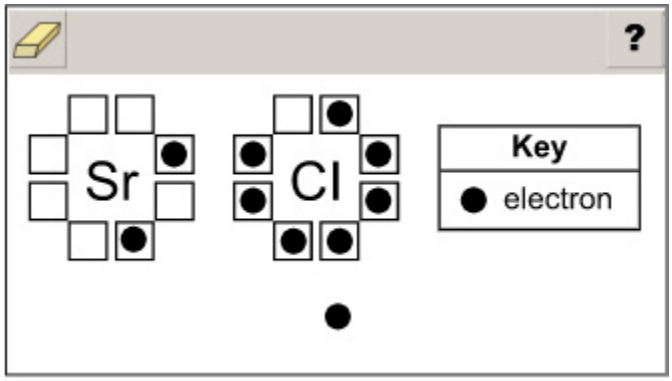
**Part A**

The correct response is shown below.




Since strontium (Sr) is found in group 2 of the periodic table, it will have 2 valence electrons. Since chlorine (Cl) is found in group 17 of the periodic table, it will have 7 valence electrons.

**OR**




For full credit in Part A, the dots representing the electrons may be entered into any two boxes around Sr and any seven boxes around Cl.

***Go on to the next page to finish item 4.***



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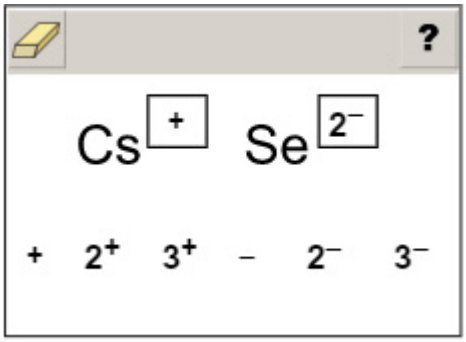
## Item 4

**Part B**

The correct response is shown below.




Since cesium (Cs) is found in group 1 of the periodic table, it will have a single positive charge. Since selenium (Se) is found in group 16 of the periodic table, it will have a negative 2 charge.



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## Item 6

### Scoring Rubric

| Points | Description |
|---|---|
| 2 | The student correctly fills in all three columns. |
| 1 | The student correctly fills in two columns OR correctly fills in two rows. |
| 0 | The student does not correctly fill in at least two columns OR two rows. |

### Exemplar Response

The correct response is shown below.

| Unknown Element | State of Matter at Room Temperature | Number of Valence Electrons | Type of Ion Formed | Element Type |
|---|---|---|---|---|
| V | gas | 7 | negative | nonmetal |
| W | **gas** | 8 | none | **nonmetal** |
| X | solid | 1 | **positive** | **metal** |
| Y | **solid** | 2 | positive | **metal** |
| Z | **solid** | 3 | **positive** | metal |

| State of Matter at Room Temperature | Type of Ion Formed | Element Type |
|---|---|---|
| **solid** | **positive** | **metal** |
| **liquid** | **negative** | **nonmetal** |
| **gas** | **none** | |

Unknown element W has 8 valence electrons and does not form ions, so it is found in group 18 of the periodic table. Elements found in this group are nonmetals and are gaseous at room temperature.

Unknown element X is a solid at room temperature with 1 valence electron, so it is found in group 1 of the periodic table. Elements found in this group are metals and form positive ions.

Unknown element Y has 2 valence electrons and forms positive ions, so it is found in group 2 of the periodic table. Elements found in this group are metals and are solid at room temperature.

Unknown element Z is a metal with 3 valence electrons, so it is found in group 13 of the periodic table. Elements found in this group are solid at room temperature and form positive ions.



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## Item 10

### Scoring Rubric

| Points | Description |
|---|---|
| 2 | The student correctly fills in all three steps. |
| 1 | The student correctly fills in two steps. |
| 0 | The student does not correctly fill in at least two steps. |

### Exemplar Response

The correct response is shown below.

?

| Steps | Procedure |
|---|---|
| Step 1 | **Record the mass of solution X, the mass of solution Y, and the mass of the beaker.** |
| Step 2 | Combine solution Y and solution X in the beaker and wait until the chemical reaction is complete. |
| Step 3 | Record the mass of the products and the beaker. |
| Step 4 | **Subtract the mass of the beaker from the combined mass of the products and the beaker.** |
| Step 5 | **Compare the mass of the reactants to the mass of the products to confirm that the mass of the reactants is equal to the mass of the products.** |

**Compare the mass of the reactants to the mass of the products to confirm that the mass of the reactants is less than the mass of the products.**

First the student must record the masses of both solutions and the beaker. After the reaction is complete, subtract the mass of the beaker from the mass in Step 3 to find the mass of the products. Finally, to prove that mass was conserved, the mass of the reactants and the mass of the products must be the same.



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## Item 12

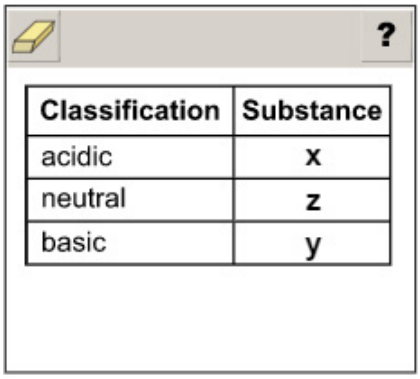
### Scoring Rubric

| Points | Description |
|---|---|
| 2 | The student correctly answers both Part A and Part B. |
| 1 | The student correctly answers either Part A OR Part B. |
| 0 | The student does not correctly answer either part. |

### Exemplar Response

**Part A**

The correct response is shown below.



| Classification | Substance |
|---|---|
| acidic | x |
| neutral | z |
| basic | y |

Substance x shows a purplish pink color when using the red cabbage indicator, which means the pH is 5. A pH of 5 indicates that the substance is an acid.

Substance y shows an aqua color when using the red cabbage indicator, which means the pH is 10. A pH of 10 indicates that the substance is a base.

Substance z shows a purplish blue color when using the red cabbage indicator, which means the pH is 7. A pH of 7 indicates that the substance is neutral.

The acidic substance cannot be y or z, as the pH of the substance needs to be below 7. The neutral substance cannot be x or y, as the pH of the substance needs to be 7. The basic substance cannot be x or z, as the pH of the substance needs to be above 7.

***Go on to the next page to finish item 12.***



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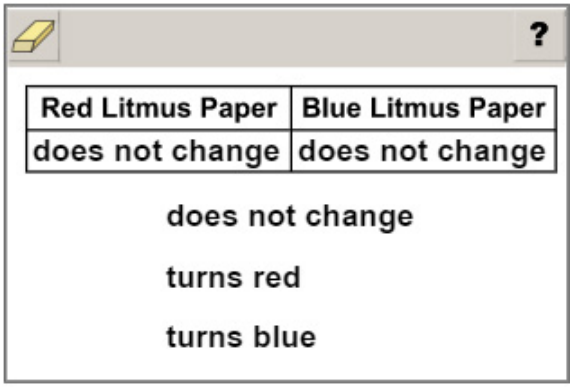
## Item 12

**Part B**

The correct response is shown below.




A substance with a pH of 7 is neutral. A neutral substance will not change the color of red litmus paper or blue litmus paper. A neutral substance will not turn red litmus paper blue or blue litmus paper red.



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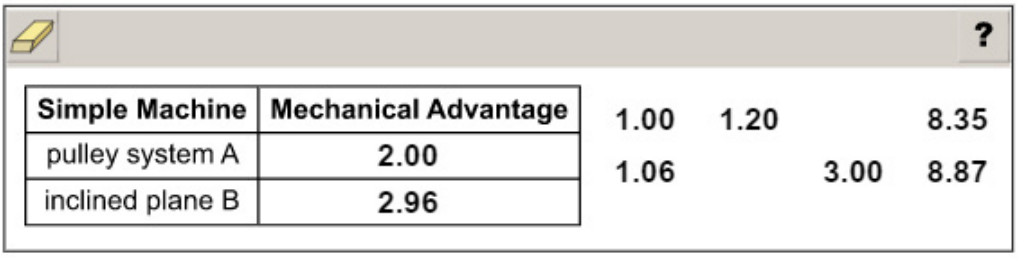
## Item 15

### Scoring Rubric

| Points | Description |
|---|---|
| 2 | The student correctly identifies both mechanical advantages. |
| 1 | The student correctly identifies one of the mechanical advantages. |
| 0 | The student does not correctly identify either mechanical advantage. |

### Exemplar Response

The correct response is shown below.



| Simple Machine | Mechanical Advantage |
|---|---|
| pulley system A | 2.00 |
| inclined plane B | 2.96 |

1.00 1.20 8.35
1.06 3.00 8.87

The mechanical advantage of the pulley system is equal to the number of lines of the rope that are supporting the load (the weight). Since two lines of the rope are supporting the load, the mechanical advantage of this pulley is 2.00. The mechanical advantage of an inclined plane is the length of the ramp divided by the height of the end of the ramp above the ground. For this inclined plane, the length is 8.87 meters and the height is 3.00 meters, so the mechanical advantage is 8.87 divided by 3.00, which equals 2.96.



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END OF PHYSICAL SCIENCE

*EOC STUDY/RESOURCE GUIDE*
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