Scientific Connections through Inquiry

Edition 1

LEVEL 5

Ratios

Compounds Have Specific Ratios of Elements

Let your student know that several additional considerations come into the picture, all derived from abundant experimentation, but experimentation that may not be practical or possible to repeat in your home. First, review the definition of a compound: atoms of two or more elements joining (bonding) together to make a basic particle (called a MOLECULE).

Experimentation showed that some elements go together to form compounds readily and spontaneously—even so rapidly as to be seen as an explosion. Others go together much more slowly, and still others will not join together at all.

Furthermore, those that do react together to form compounds do so in very specific ratios. For example, exactly two volumes (two of any specified volume) of hydrogen gas would react with exactly one volume of oxygen gas to yield exactly two volumes of water vapor. Two volumes plus one volume equals two volumes (2 + 1 = 2)! What is going on here? Yet any difference in the ratio and some of one or the other would be left over. Conversely, an electric current passed through water (H_2O) results in bubbles of hydrogen gas (H_2) coming off at one electrode and bubbles of oxygen gas (O_2) coming off at the other, exactly in the ratio of two volumes of hydrogen to one volume of oxygen. This phenomenon of specific ratios holds for all chemical reactions.

You can split water into hydrogen and oxygen at home! Take a small plastic cup and push two small silver-colored thumbtacks, or screw two small screws, in the bottom, the same distance apart as the terminals of a 9-volt battery, so the points of the tacks/screws are sticking into the cup. Fill the cup with water and a pinch of baking soda. Stir the baking soda until it is no longer visible. Place the cup on the battery so the tacks/screws are aligned with the battery terminals. What happens? The bubbles coming off of each tack are hydrogen and oxygen. The baking

SCIENCE NOTE

Your student may point out that it is not the volume of gas that matters but the number of molecules in the gas. They would be correct. However, Avogadro's Law states that, at the same temperature and pressure, equal volumes of all gases have an equal number of particles. Because of this, we can speak of equal volumes of different gases in the same situation and know that equal numbers of particles are represented.

SCIENCE NOTE

The reason that 2 + 1 = 2, rather than 2 + 1 = 1 or 3, is that hydrogen is present as H_2, a molecule with two hydrogen atoms, and oxygen is present as O_2, a molecule with two oxygen atoms. Thus 2 molecules of hydrogen gas contain 4 hydrogen atoms, and 1 molecule of oxygen gas contains 2 oxygen atoms, enough to form 2 molecules of water (H_2O).

SCIENCE NOTE

An electrode is a point at which an electric current enters or leaves a substance—in this case, the water.

ACTIVITY NOTE

With some baking soda in the water, there will also be some carbon dioxide (CO_2) gas created.

soda allows electricity to flow through the particles in the water between the two tacks. This input of energy splits water molecules into their components.

Have your student consider how this fits the general concept for elements and compounds. Using our hydrogen and oxygen examples again, we can visualize atoms of hydrogen and oxygen going together to make the compound water. In turn, we can visualize water coming apart to yield the original hydrogen and oxygen. But there is more. Pause and invite your student to formulate questions regarding the "more." Questions that will likely be forthcoming and how they may be addressed are given in the following:

- First and most curious is the fact that water is nothing like hydrogen or oxygen. Have your student cite differences. They will readily conclude that water has essentially nothing in common with hydrogen and/or oxygen. What does this say? (Think Time) The basic point to bring out is that strange as it may seem, a compound has properties and attributes that are totally different from the elements that go into it.

- Second is the curiosity of the precise ratios observed. What can we make of them? (Think Time) A compound is not just a random sticking together of the elements involved. Rather, the atoms of the two elements must join together in a very specific way; in the case discussed earlier, a way in which there are two hydrogen atoms for every oxygen atom. This and many other observations derived from experimentation led chemists to conclude that an individual particle of water consists of two hydrogen atoms attached to one oxygen atom, written in chemical notation as H_2O: H stands for hydrogen, O stands for oxygen, and the small 2 after the H means there are two hydrogens in one particle. Take this apart, and one no longer has water; one has the elements again. Relating this to the particulate nature of matter, the individual (smallest) particle of water is this unit, H_2O. Such a specific unit of two or more atoms is called a MOLECULE.

- A third curiosity involves energy. We observe energy (heat and light) coming out as hydrogen and oxygen combine to form water. Conversely, energy, namely electrical energy, is required to break water into hydrogen and oxygen.

Explore the elements in two compounds recombining to form completely different compounds with baking soda and vinegar.

Put approximately two tablespoons of baking soda into a container. Add a small amount of vinegar. Note the reaction that happens and observe until it stops. You will see bubbles of carbon dioxide gas; as the bubbles pop, the gas will go off into the air. Note how this gas is very different from either baking soda or vinegar. In addition to carbon dioxide, this reaction yields water and sodium acetate (a white powder). Carbon dioxide is simply the most immediately obvious product.

If needed, stir to make sure all of the vinegar has reacted with baking soda. You will still have baking soda left. Why is this? (Think Time) The baking soda and vinegar react in specific proportions. Having more baking soda available does not mean that each molecule of vinegar can react with more molecules of baking soda. To continue the reaction, you will need to add more vinegar. Do so, and watch how the reaction happens again until all of the baking soda has been used up. Note how once the baking soda is gone, no matter how much vinegar is added, the reaction will not start again.

A profound example of a chemical reaction is photosynthesis, i.e., plants using light energy to rearrange the atoms of carbon dioxide and water to make sugar and oxygen.

Then the reverse readily occurs, as we see both in respiration—i.e., deriving our energy from food—and in burning materials such as wood. Chemical analysis shows that in burning—i.e., releasing energy—the carbon and hydrogen atoms making up the food/wood are rearranged and combined with oxygen in the air to form carbon dioxide and water.

Note how, again, we can see energy being required to be input for the process to go one way (to turn carbon dioxide and water into sugar and oxygen) and how energy is released when the process goes the other way (when burning wood or digesting food).

Tectonic Plates

Earthquake Locations

Ask: Why is it important to monitor earthquakes? (Think Time) Your student may reflect that interest in earthquakes is not just scientific. Learning to predict them accurately has obvious safety implications, but unfortunately, we have not reached that stage yet. However, scientists have, over time, grown and connected a network of thousands of seismographs around the world. Thus, scientists, emergency response teams, and other authorities are immediately alerted regarding the location and magnitude of an earthquake occurring anywhere in the world, and action can be taken as needed.

But what else can earthquake monitoring show us? Let's look and see.

Visit sci.bz/Earthquakes5 to see a map of recent earthquakes. You can adjust the settings to include different time periods and magnitudes.

Ask your student if they can discern a pattern regarding where earthquakes occur. Without trouble, they will likely note that the large majority are located along a rough line that rings the Pacific Ocean. There are other places where an abundance of earthquakes occur, but these, too, tend to be along certain lines.

Then, your student will observe an astounding frequency of earthquakes. Most of these are so minor they pass unnoticed; they are only detected and recorded on seismographs. Still, such earthquakes and tremors are occurring more or less continuously. Allow your student to view sci.bz/Tremors5 to see real-time data of earthquake activity.

Volcano Locations

Have your student hold on to this general picture of where earthquakes occur most frequently while you turn their attention to volcanoes. Show your student a world map marking the locations of active volcanoes at sci.bz/Volcanoes5.

Comparing

Have your student contrast the locations of volcanoes with those of earthquakes. They will quickly note that the locations of volcanoes fall into the same pattern as that for earthquakes. The majority of volcanoes are in the same ring around the Pacific Ocean, commonly referred to as the "Ring of Fire." Volcanoes also occur in other regions where earthquakes are common.

Ask: How should we interpret these observations? During their Think Time, have them consider that the same cause may underlie both earthquakes and volcanic eruptions. This would explain their having a similar distribution. Saying this another way, can we find a single feature of the geological structure of the Earth that would cause both volcanic eruptions and earthquakes?

Tectonic Plates

Your student may be familiar with the concept of tectonic plates or may be totally unfamiliar. Therefore, the degree of instruction required will be highly variable. Whichever is the case, conduct Q&A discussion to bring out the following points:

- The interior of the Earth, between the crust and the core, is comprised of molten rock (magma), as witnessed by lava erupting from volcanoes. Scientists call this the Earth's mantle.
- The Earth's outermost layer, called the crust, which includes all land areas and the seafloor, rides atop the molten interior. Visualize the crust as like the peel on an orange. The thickness of the Earth's crust varies from 3-30 miles (5-50 kilometers), so there is no danger of falling through, but this is relatively thin compared to the total diameter of the Earth (approximately 7,900 miles, or 12,700 kilometers).
- The interior of the Earth gives off a lot of heat. There are several causes for this, including heat that still exists from the formation of the Earth and the radioactive decay of heavy elements in the mantle. Most of this heat comes from the lower reaches of the mantle and from the Earth's core.
- Recall that a fluid that is heated in one place and cooled in another may flow in a loop called a convection current. The heat energy coming from the interior of the Earth and the cooler crust (which is exposed to the atmosphere and, through it, to cold space) causes convection currents in the liquid magma.
- The crust, agitated by the convection currents of magma below, is broken into huge slabs called TECTONIC PLATES. These plates slowly but surely move about and grind upon one another as they float upon the currents of magma. Visualize this like a layer of crackers floating on a bowl of soup as the soup is gently stirred from below.

SCIENCE NOTE

Lava and magma are two words for the same substance—molten rock. When it is in the mantle of the Earth, contained below the crust, scientists call this substance magma; when it comes through to the Earth's surface, they call it lava.

To model the thinness of the Earth's crust, take your student outside. Using chalk, draw a straight line 33 feet long. Using a different color of chalk, add a 1-inch section of line to each end of the 33 ft line. The full line represents the diameter of the Earth. The one inch on each end represents the portion of the diameter that is made up of continental crust.

SCIENCE NOTE

This activity models the average thickness of continental crust. The oceanic crust, which underlies the Earth's ocean basins, is about 1/6th as thick on average.

Ask your student to reflect on the connection between the concept of tectonic plates and the locations of earthquakes and volcanic eruptions. (Think Time) With a little discussion, your student may conclude that earthquakes and volcanic eruptions are the consequences of these tectonic plates moving about and interacting with one another in various ways. It follows logically that the ”lines” on the world map marking where a high frequency of earthquakes and volcanoes occur are actually the borders between tectonic plates.

Visit sci.bz/Plates5 to see a map of tectonic plates. Note how the borders line up with areas of frequent earthquake and volcanic activity.

Safety Concerns

A concern for all students will be the likelihood of an earthquake or volcanic eruption occurring under their feet. In addressing such concerns, help them first consider the probability of an earthquake occurring or a volcano erupting where they live. Are they inside or outside an area where earthquakes commonly occur or near active volcanoes? Especially if they are inside such an area, this is a good time to learn safety precautions and procedures. You can also convey the importance of monitoring, especially of further developing the capability to predict where and when quakes and eruptions may/will occur.

Fungi & Bacteria III Wrap-Up

At the end of this unit, students should be able to:

- Make an argument for the existence and effectiveness of natural defense mechanisms in protecting the body against attack by fungi and bacteria.
- Point out and discuss three components of the body's defense against microorganisms. Explain how infection/disease is the result of one or another microorganism breaking through or evading the body's defenses.
- Describe infectious illnesses/diseases and the effectiveness of vaccinations in terms of microbe entry and the body's defenses.
- Distinguish between infectious and noninfectious diseases. Give examples of each. Define "contagious."
- Describe ways in which disease-causing microbes may be passed from person to person and personal actions that will minimize such transfer.
- Discuss the role of government in protecting health. Give four areas of particular concern and what government does in each.
- Locate and identify the drinking water plant, wastewater treatment facility, and refuse disposal facility that serve your community. Discuss the operation of each.
- Contrast the roles of modern medicines and public health measures in protecting the population against diseases.
- Describe how the principles of this lesson apply more broadly to animals and plants.

Topics for Further Investigation:

- Modes of pathogen transmission
- Types of pathogens
- Viruses
- The immune system
- Vaccines
- mRNA vaccines
- Early vaccine research and medical ethics
- Epidemiology
- Public health departments
- Antibiotic resistance
- The development of germ theory
- High containment laboratories (HCL) and the study of infectious agents

White Light

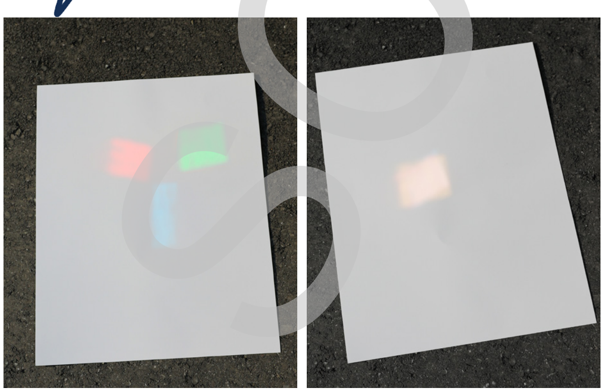
Splitting Sunlight

As direct sunlight shines through a window or outdoors, manipulate a prism or crystal in the sunlight so that it casts a rainbow. Let your student play with the prism in direct sunlight to get the effects of casting rainbows.

Invite your student to think, speculate, and offer suggestions as to how the prism casts a rainbow. Suggestions will likely fall into two categories: 1) The prism somehow colors the light coming through it. 2) Sunlight itself is comprised of rays of different colors. In passing through the prism, the rays are separated according to color and spread into the VISIBLE SPECTRUM, the technical word for the rainbow.

If both ideas are suggested, point out that scientists often think of two or more possible explanations for a given observation. Therefore, the next task is to conduct further tests that, hopefully, will yield results that support one idea and contradict the other(s). If your student already knows the answer, ask them to pretend that someone else is insisting on the other answer and challenge your student to demonstrate to the other person why their idea is wrong. Can they think of a test that will distinguish between the two ideas just suggested? (Think Time)

Here is one test that is informative. Cover 3 small mirrors with different colors of plastic wrap (red, green, and blue).



Have your student use a colored mirror to reflect a spot of sunlight onto a piece of white tagboard or poster board. As they repeat this with each mirror, they will observe that each mirror reflects a spot of light with its respective color. Next, have your student hold a mirror in each hand as you hold the other mirror. Reflect all three spots of colored light simultaneously at the same point on the white surface. They will discover that, as the spots of colored light are combined, the spot of light on the paper approach-

ACTIVITY NOTE

A crystal with multiple facets is really a multiple prism and may cast multiple rainbows. Therefore, while you may use a crystal in this exercise, the word "prism" will be used throughout.

Light from most lamps is neither strong enough, nor sufficiently white enough, nor are there rays sufficiently parallel to produce a rainbow.

SCIENCE NOTE

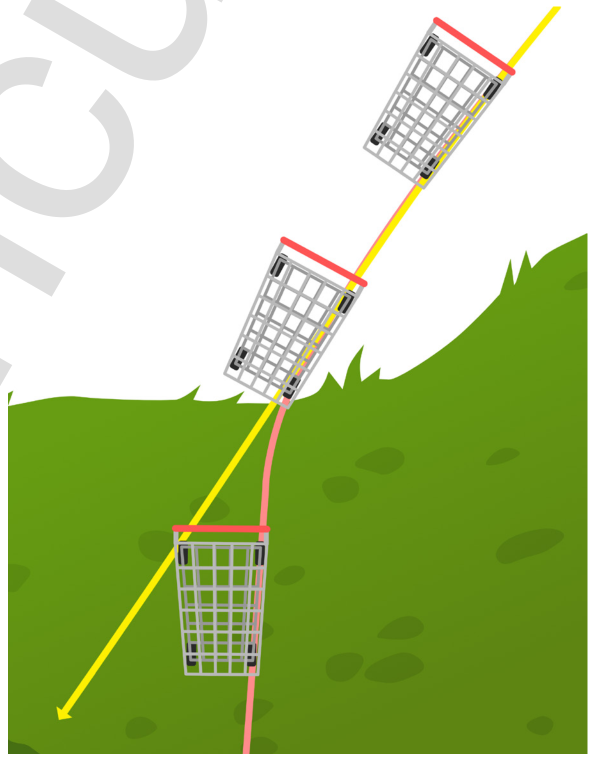
Light rays do not have different colors as such; it is a matter of different wavelengths of radiation. It is cells within our eyes that distinguish between different wavelengths and send nerve impulses accordingly. Our brains then interpret the nerve impulses coming from our eyes and give us the perception of color. For the sake of avoiding undue complexity, however, light rays are referred to in terms of their different colors.

es white. (It will not be as bright as a spot of unfiltered sunlight because the 3 beams of colored light will not equal the intensity and full spectrum of unfiltered sunlight.)

Have your student ponder this result and reflect on how it fits with one idea but not the other. (Think Time) If sunlight consists of rays of all the different colors and the prism is serving to spread them into the spectrum, we should expect that putting different colors of light back together should yield brighter, uncolored light, as we find to be the case. On the other hand, the idea that the prism produced the colors on its own does not fit. If the prism created the colors itself instead of splitting them from the sunlight, there is no reason that putting colored light together would add up to produce uncolored light.

Even more obvious is the effect of the colored filters themselves. Their effect is straightforwardly explained by sunlight being composed of all colors. The filter allows passage of one color and absorbs the others.

How does a prism split the light? To explore this, ask your student to imagine pushing a shopping cart along a smooth sidewalk. With a given energy input, the cart will move at a given speed. Next, have them imagine pushing the same shopping cart across grass or a gravel patch. This would be more difficult, so the same given energy input would cause the cart to move more slowly than it did on the sidewalk.



Next, ask your student to imagine that as they are pushing the cart down the sidewalk, the left front wheel goes off the walk onto the grass or a gravel patch. (Most kids will have had this actual experience.) What happens? The cart is pulled to the left as its left wheel travels more slowly while the right wheel continues moving more quickly. Once both wheels are on the grass, the cart wheels will again both be moving at the same speed, and the cart will again move in a straight line.

Inform your student that light acts similarly when it travels from one substance to another. If it enters the new substance at an angle, it will bend, much like the shopping cart curved, because it travels either faster or slower through the new substance. This bending is called REFRACTION.

What is more, different colors of visible light will bend different amounts. Blue bends a different amount than green, which bends a different amount than yellow, and so on. This difference in bending is why white light is separated into a spectrum when passing through a prism, with light that bends the least at one end of the spectrum and light that bends the most at the other.

Incidentally, have your student note that the rainbow (cast by a prism or naturally occurring) always consists of the same colors in the same order and that the colors are not separate and distinct. Ask: In fact, are there only six colors in the rainbow? No! Each color blends into the next; there is an entire spectrum of colors as one main color slowly changes into the next.

As we go on, we will see how more and more things may be interpreted logically by the concept that sunlight is composed of light rays of all the colors (i.e., rays of different wavelengths) of the rainbow.