EXPERIENCING THE NATURAL WORLD

Laboratory for Secondary Level Students

Student Manual

WOMEN SUPPORTING WOMEN IN THE SCIENCES

Meet a Science Educator

Mwanahawa Mohamed Kwengu

Teacher at Olomitu Secondary School, Tanzania

About me:

After completing my secondary education, I got the opportunity to study advanced level education in the PCM combination (Physics, Chemistry, and Mathematics). Upon finishing, I joined Korogwe Teachers' College for a Diploma, specializing in two subjects—Physics and Chemistry. I didn't stop there; I further enrolled at the Open University of Tanzania to pursue a Bachelor's degree (BSc with Education) in Physics and Information and Communications Technology.

What excites me about science?

To be honest, science is amazing because it helps us to understand various aspects of the modern world. I would like to encourage young women, in particular, to study science so that we can understand the many things around us. My plan is to continue my studies in science at the Master's and PhD levels.

Mission Statement

The mission of this lab is to teach secondary school students about floatation, heat transfer and emission, and the mechanics of a volcano and volcanic eruption.

Contents

1. Introduction to WS2 Laboratory Kits

1.1. Information about WS2

Women Supporting Women in the Sciences (WS2), an international organization unifying and supporting graduate and professional-level women and allies in science, technology, engineering, and mathematics (STEM), was awarded an American Physical Society (APS) Innovation Fund in 2020 to form international teams to design and distribute low-cost physics and materials science lab kits to primary and secondary school students, predominantly in eastern Africa. The lab kits utilized local resources and included topics that are especially relevant to young girls in order to spur their interest in STEM subjects. From 2020-2023, over 5100 students from eastern Africa at over 40 school sites engaged with our lab kits, with 62% being girls. Following this initiative, WS2 leadership was selected for a Mandela Washington Fellowship Reciprocal Exchange Program which expanded the reach of our kits through a teacher training workshop. With support from the APS Forum on Education, a subset of teachers from this workshop created this new kit, "Experiencing the Natural World", which has been enjoyed by over 300 students to date. For more information about WS2, please visit our website at ws2global.org.

WS2 is sponsored by the APS Forum on Education, APS Innovation Fund, Mandela Washington Fellowship Reciprocal Exchange Program, Northwestern University Materials Research Science and Engineering Center, and Northwestern University Multicultural Student Affairs. WS2 gratefully acknowledges the team of teachers that worked on the creation of this lab kit.

1.2. Key Vocabulary

- Up-thrust
  - ✓ Upward acting force on floating bodies in liquids or gases
- Sinking
  - ✓ Drop below the surface of a liquid; drop to a lower level of liquids or gases
- Floating
  - ✓ Remain on the top surface of a liquid
- Fresh water
  - ✓ Water with small concentration of salt
- Salt water
  - ✓ Water with high concentration of salt
- Heat
  - ✓ Form of energy that can be transferred from one point to another due to temperature difference
- Heat transfer
  - ✓ Movement of heat from one point (object) to another, usually from hot region to cold region
- Radiation
  - ✓ Heat transfer in vacuum by electromagnetic wave
- Conduction
  - ✓ Heat transfer through direct contact
- Convection
  - ✓ Heat transfer through fluid like gas or liquid in which warmer portions rise and colder portions sink
- Volcano
  - ✓ Opening in Earth's surface where lava, ash, and gas can escape
- Eruption
  - ✓ Process by which liquid or gas is pushed out at high speed through small opening
- Chemical reaction
  - ✓ Process in which one or more chemical substances are converted to one or more different substances

1.3. Key Questions

- State conditions for an object to float.

- Why is white paint preferred over black paint for buildings in tropical climates?

- What is a volcanic eruption?

1.4. Purpose

The purpose of this lab kit is to showcase the physics and science that underpin various aspects of the natural world with which students may interact. The experiments will demonstrate the principles and conditions governing bodies sailing in water, the influence of heat transfer, absorption, and emission on the choice of color of objects, and the process and impacts of volcanic eruption.

2. Background on Main Topics

2.1. Let's Take a Trip Outside

There are so many things in the natural world that impact us and the ways we live. Consider all that is around you right now and how it affects your life: your climate, weather, geography, and nearby natural features all can play a significant role in your day-to-day life. Furthermore, underpinning all of these natural processes are some very interesting physics that we do not often think about.

Today, we will consider the underlying science in the natural world on a visit to northern Tanzania, near the active Ol Doinyo Lengai volcano. Here, there is also Lake Natron, a saltwater lake, though nearby larger bodies of water are Lake Victoria, the world's largest tropical lake, and the Indian Ocean. This region is also located quite near to the equator, and its climate is tropical and quite sunny. How might living in a tropical climate near an active volcano with nearby freshwater and saltwater bodies impact your life? What is the science that helps to explain the experiences we have with these parts of the natural world? Let's find out!

2.2. Archimedes' Principle & the Law of Floatation

Archimedes of Syracuse was an ancient Greek mathematician, physicist and engineer who lived in the 3rd century BC. He developed a scientific principle that has come to be named after him. Archimedes' principle states that "when a body is partially or totally immersed in fluid it experiences an up-thrust equal to the weight of fluid displaced". An up-thrust is the upward force acting on bodies in gas or liquid.

The story behind the discovery of Archimedes' principle is well known and often remembered by the phrase "Eureka". According to the legend, king Hiero II of Syracuse commissioned a goldsmith to make a golden crown. However, he suspected that the goldsmith might have mixed some silver into the crown making it impure. The king asked Archimedes to determine whether the crown was made of pure gold without damaging it.

Archimedes pondered the problem and eventually found a solution while taking a bath. As entered the bathtub, he noticed that the water level rose, and he realized that his body was displacing a volume of water equal to his own volume (similar to the example with a rock shown in Figure 1). This observation led him to the principle of buoyancy, which is the power of a fluid to exert an upward force on a body placed in it. He also understood that he could submerge the crown and an equal mass of pure gold in water and determine the difference in the two objects' density by the difference in their volumes. The difference in the densities of the two objects proved the crown was not made of pure gold. Density is related to mass and volume by the equation:

$$density = \frac{mass}{volume}$$

Excited by his discovery, Archimedes reportedly shouted "Eureka" (which means, "I have found it" in Greek) and ran naked through the street of Syracuse to share the news. He conducted further experiments and mathematical calculations to verify and explain the principle, and it became one of his most significant contributions to science.

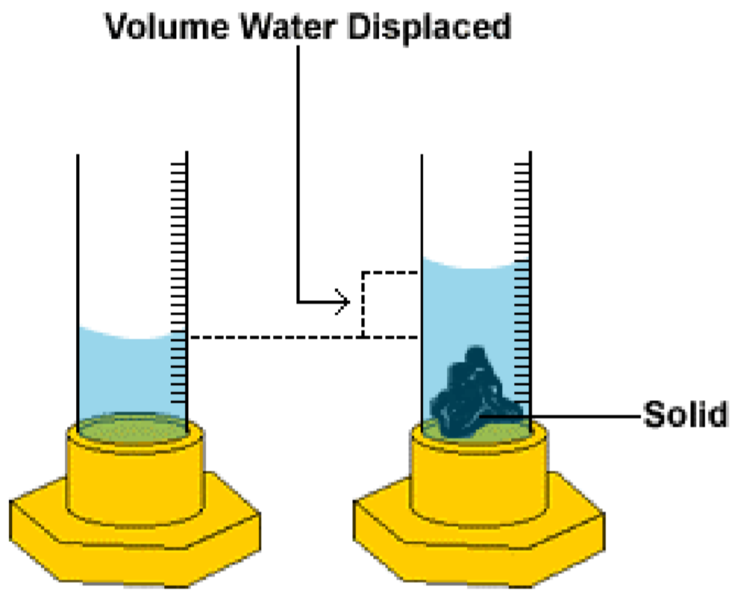

Figure 1. When an object is submerged, it displaces a volume of water equal to its own volume. This Photo by Unknown Author is licensed under CC BY-SA-NC

Archimedes' principle has various practical applications. It provides the basis for understanding the behavior of floating objects such as ships and boats and helps in designing and constructing them. Floating is when an object is suspended in liquid or gas: in the case of a liquid, the floating object will remain on the surface of the liquid. On the other hand, sinking objects drop below the surface of the liquid. The density of the object and the liquid matters: an object will float more easily in salt water, or water with a high concentration of salt, than in fresh water, or water with a low concentration of salt, because of the difference in density. Salt water has a larger density than fresh water, so objects sink more in fresh water than in salt water.

In summary, for an object to float, there are conditions that will be met, including that the weight of floating object is equal to or less than the up-thrust due to the fluid, the volume of the fluid displaced by the object is equal to the volume of the object that is submerged, and the density of the fluid must be equal to or greater than the density of floating object. Archimedes' principle has had a significant impact on the development of physics and engineering and helped to lay the foundation for later advancements in fluid mechanics. It remains important even in today's science.

2.3. Heat Transfer

Heat transfer is a fundamental concept in physics and engineering that deals with the exchange of thermal energy between different systems or regions. Specifically, heat is a form of energy that can be transferred from one place to another due to temperature difference, and heat transfer is the movement of heat from one place to another. Heat flows from hot to cold regions. Heat transfer occurs through three different processes: conduction, or direct transfer by contact; convection, or transfer through fluid like gas or liquid in which warmer portions rise and colder portions sink; and radiation, or transfer by electromagnetic waves or photons (light). Examples of these types of heat transfer are shown in Figure 2.

In heat transfer, materials can be placed into two broad groups: good and poor conductors. Good conductors are those materials which allow heat to flow through them easily (for example, metals like iron, silver). Good conductors are used in making motor car engines, pistons, and cylinders due to high thermal conductivity. Poor conductors or insulators are those materials which do not allow heat to pass through them easily (for example, wood, plastic, wool, glass, even air). Insulators like these are used to make handles of saucepans, teapots, and kettles.

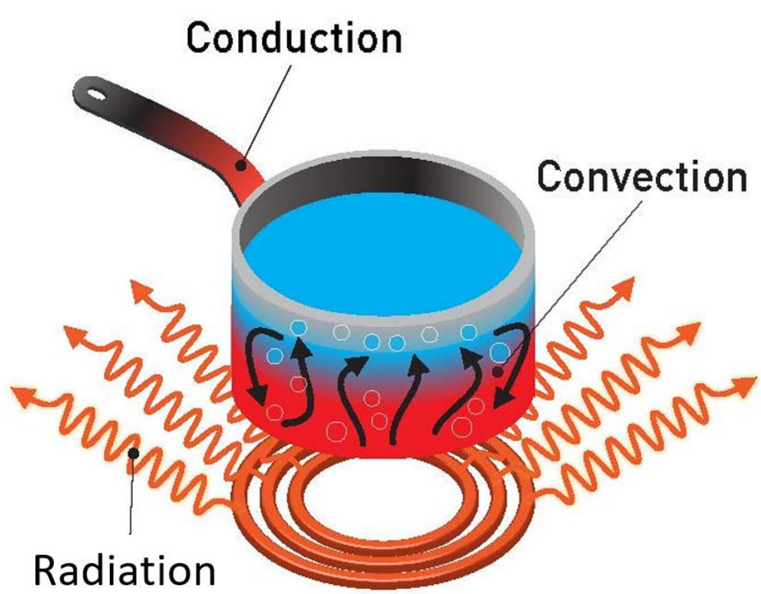

Figure 2. Conduction, convection, and radiation are three types of heat transfer. When you boil water in a pot, all three types are working to heat up the water and the pot! This Photo by Unknown Author is licensed under CC BY.

An important example of radiative heat transfer is through sunlight. Light from the Sun is incident on the Earth every day, and whether materials absorb or reflect light has important consequences for how much they heat up. Absorbers are materials that gain radiative energy incident on them. For example, clothes that are black are good absorbers and absorb incident light. When placed outside in the sunlight, black clothes dry faster than white clothes, which mostly reflect sunlight. White clothes or bright surfaces are poor absorbers of heat through sunlight as compared to other colors. Radiative heat transfer is thus important in many situations: houses in tropical countries are often painted white or light colors to reflect sunlight and keep the house cooler inside.

Color also matters when it comes to emission of heat that is absorbed, regardless of how the heat is absorbed (whether through conductive, convective, or radiative means). Black objects are better emitters of heat than lighter-colored objects. You may have noticed this if you have walked on a black-colored roadway in the bright sunlight: you will feel the roadway emitting a lot of heat. As with heat absorption previously discussed, the impact of color on heat emission also has important implications in selection of paint on buildings, as darker-painted buildings will emit more heat than lighter-painted buildings.

Ancient civilizations such as the Egyptians, Greeks and Romans had practical knowledge of heat transfer through their architectural designs. They used natural convection to improve ventilation and employed insulating materials such as clay and straw to regulate temperature. Today, heat transfer remains a critical area of research and has practical application in numerous industries, including energy, manufacturing, aerospace and environmental engineering. Ongoing advancements continue to deepen our understanding of heat transfer phenomena and enable the development of more efficient and sustainable heat transfer technologies.

2.4. Volcanic eruption

Volcanoes are features in the Earth's crust that allow lava, ash, and gas to escape from a large pool of molten rock beneath the Earth's surface. The molten rock is called magma, and the pool of magma is called the magma chamber. Magma originates from the mantle where high temperature and pressure cause the rock to melt. Magma in the magma chamber is denser than the surrounding rock, thus the rock provides force that tends to drive the magma upward. If the magma finds a path to the Earth's surface, this results in a volcanic eruption, which is the process by which magma and gas are pushed at high speeds through a small opening. The magma that has been erupted to the Earth's surface is called lava. Some volcanoes erupt with an explosive spray of lava and ash, whereas in others the lava flows out of an opening. It all depends on the shape and the opening; the more confined space, the more explosive the eruption. A cross-section of a volcano is shown in Figure 3.

The sandbox model volcano is an example of an eruption where the chemical reaction between vinegar and baking soda produces a gas which pushes the liquid up and out of the container. A chemical reaction is the process by which one or more chemicals are converted into one or more different chemicals. This eruption in the sandbox volcano is similar to an actual volcano where gas builds up underneath the Earth's surface and forces liquid (in the case of a real volcano, magma) up through the hole in the volcano, causing an eruption. When baking soda (a base) comes into contact with vinegar (an acid), they chemically react to form water and carbon dioxide gas. The gas tries to escape from the mixture, creating bubbles that rise to the surface. These bubbles make a fizzing sound and give the impression of a mini volcano eruption. It is important to note that while the mechanics of gas build up and eruption of material in the model volcano is *similar* to an actual volcano, a chemical reaction is not what is responsible for a real volcanic eruption. In a real volcanic eruption, the magma rises because it is less dense than the solid rock surrounding it beneath the Earth's surface.

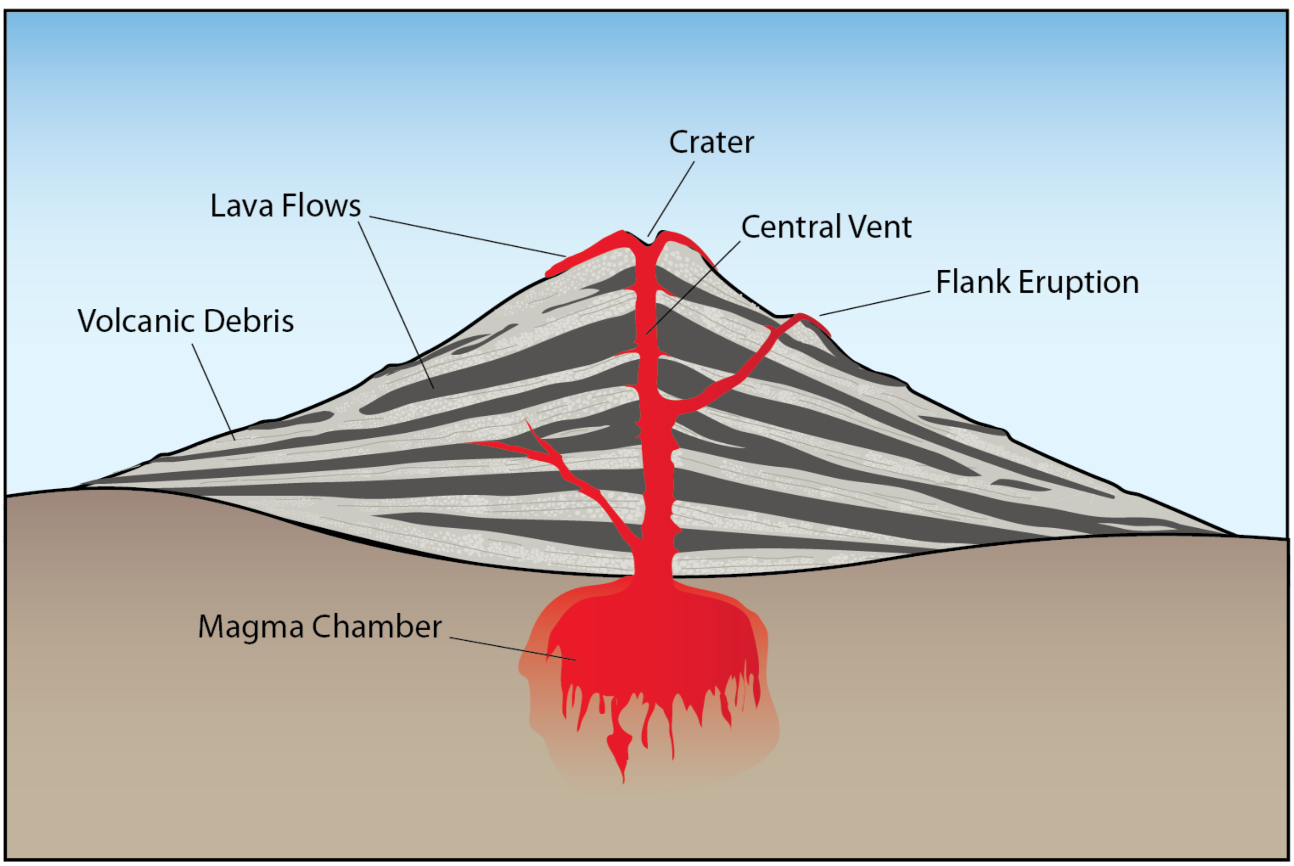

Figure 3. Cross-section of volcano. The magma resides in the magma chamber below the Earth's surface. Magma that finds a way to the Earth's surface is called lava. This Photo by Unknown Author is licensed under CC BY-SA-NC

Are there any benefits to a real volcanic eruption? During real volcanic eruptions, sometimes valuable metallic minerals like zinc, gold, and copper are exposed to the Earth's surface. Magma that sits close to the Earth's surface can also be used to generate geothermal energy. Volcanic eruptions also come with some very negative impacts, as well, such as loss of biodiversity, loss of property and life, environmental pollution, and deformation of landscapes.

2.5. Supplies List

- Water
- Eggs
- Salt
- Spoons (teaspoon sized)
- Wooden sticks
- Clear plastic or glass jars or cups
- Tin or metal cans (half outside painted black and half painted white or left shiny)
- Candles
- Wax (or other very low melting point material like butter or coconut oil)
- Matches or lighter
- Wood blocks (or metal pieces) to act as stand for metal can
- Empty bottles
- Vinegar
- Baking soda
- Food coloring (natural or synthetic)
- Clay soil
- Wood blocks to act as stand for model volcano

2.6. Safety Information

Before the students begin the laboratory, please take into consideration the following safety concerns:

- While the lab utilizes some food items, students should not taste or smell any of the chemicals during the experiments.
- Students should handle fire and candles with care, as well as the metal can once it is heated by the candle, to ensure they do not burn themselves.

3. Experiments

3.1. Part I. Effect of Density on Floating Object

3.1.1. *Summary*

In this experiment, we are going to test how added salt to water impacts an object's ability to float or sink.

3.1.2. *Pre-Experiment Questions*

1. How does density relate to mass and volume?

2. Why is salt water more dense than fresh water? Your answer should include the words "mass" and "volume".

3. What would you try to make an object like an egg sink or float quickly in salt water?

3.1.3. *Supplies*

- Tap water (about 700 mL)
- 2 fresh eggs
- Table salt (about 5 teaspoons or 25 g)
- Spoon
- Stirrer
- 2 clear plastic or glass jars

3.1.4. *Procedure (work in groups of 2-4)*

1. Label two jars as A and B.
2. Measure 350 mL of tap water then pour the measured amount into A.
3. Repeat step 2 for B.
4. Gently lower the fresh eggs into each jar containing tap water (fresh water).
5. Measure five (5) teaspoons of table salt and pour into A
6. Stir and observe what happens to the egg.

3.1.5. *Results*

Jar	Volume of water	Amount of salt	Observation
A			
B			

3.1.6. *Post-Experiment Questions*

1. What happened to the egg when placed in B?

2. What happened to the egg placed in A after adding salt? Why?

3. How could we make the egg in A float again?

4. If you knew the density of fresh water to be 1 g/mL, and the submerged egg displaced 3.5 mL of water, what is the mass of the egg?

5. Is it possible for a boat designed for the Indian Ocean to sail in Lake Victoria?

6. What factors should be considered when designing and constructing swimming equipment or boats?

3.2. Part II. Heat Transfer & Emission

3.2.1. *Summary*

Students will be able to demonstrate the effect of color on heat emission.

3.2.2. *Pre-Experiment Questions*

1. What are the different types of heat transfer?

2. How do you expect color will impact heat absorption and emission?

3.2.3. *Supplies*

- 1 tin or metal can (half painted black and half painted white or left shiny)
- 2 wooden sticks
- Candle
- Wax (or other very low melting point solid like butter or coconut oil)
- Lighter or matches
- Wood blocks to use as stand

3.2.4. *Procedure (work in groups of 2-4)*

1. Position the wood blocks so that they act like a stand.
2. Place the candle between the wood blocks on the table.
3. Place the metal can on the top of wood blocks with the bottom of the can facing up. The can should be directly over the candle (see Figure 4 for reference).
4. Coat the top of wooden sticks with wax (or other very low melting point material like coconut oil or butter).

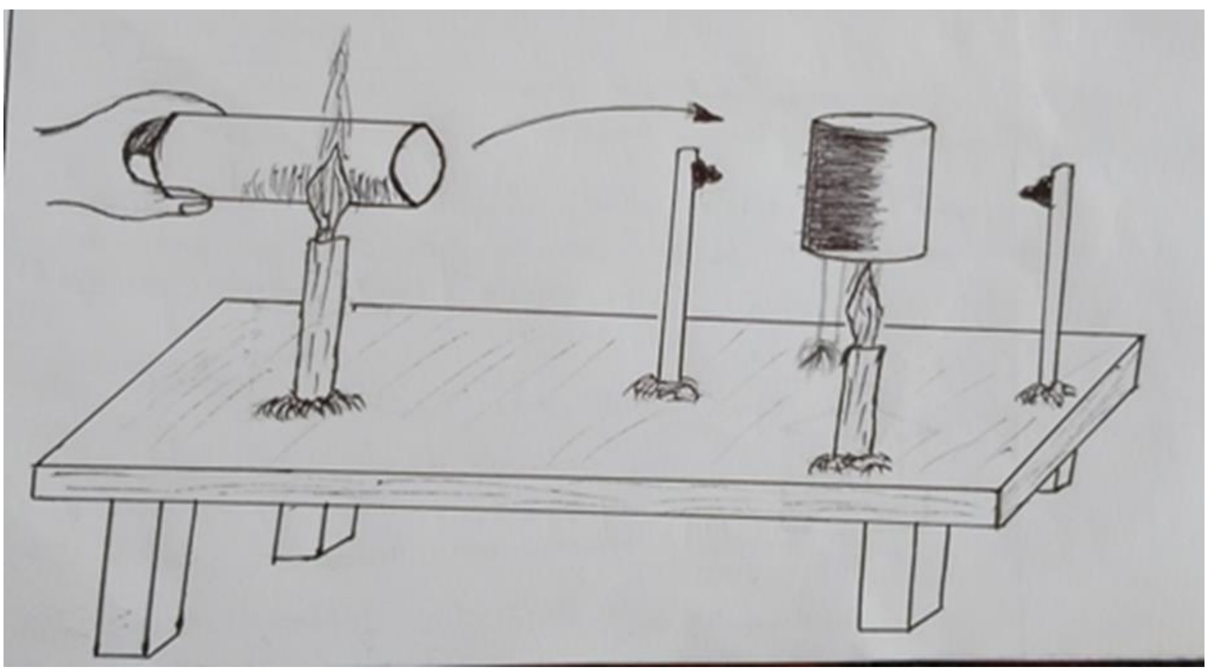

Figure 4. Schematic of the set up with the can (placed upside down) over the candle and two sticks (tops coated with wax) placed equal distance from the sides of the can (right). Instead of painting the side of the can black, you can also use the candle to create soot on one side of the can (left).

5. Place one waxed wooden stick next to the black-painted side of the can and the other next to the white-painted side of the can – both equal distance from the can.
6. Light the candle.
7. Observe what happens to the wax on the wooden sticks.

3.2.5. *Results*

STICK LOCATION	OBSERVATION	IMPLICATION
Black-painted side		
White-painted side (or shiny side)		

3.2.6. *Post-Experiment Questions*

1. What happened to the wax (or other material) on the two sticks? Why did this happen? Use the word "emission" or "emitter" in your answer.

2. How was heat transferred between the candle, can, and wax (or other material)?

3. How is heat absorption (through radiation) different than heat emission? How does color matter and what implications does this have in real life?

4. What are other areas of life in which heat transfer is important?

3.3. Part III. Volcanic Eruption

3.3.1. *Summary*

Students will learn about volcanic eruption and be able to model how this happens using a chemical reaction.

3.3.2. *Supplies*

- Empty plastic or glass bottle (500 ml)
- Vinegar (1 liter)
- Baking soda (2 tablespoons)
- Red food coloring (2 teaspoons)
- Clay soil
- Spoon (for measuring)
- Wood base (40 cm to 50 cm long)

3.3.3. *Procedure (work in groups of 2-4)*

1. Place wood base on table or working bench.
2. Place the 500 mL empty bottle in the middle of the wood (the mouth of the bottle should be pointing upward).
3. Spray or sprinkle some amount of water onto clay soil to make it slightly sticky.
4. Cover the empty bottle with the wet clay soil to model the shape of a mountain (don't cover the mouth of the bottle) (see Figure 5).
5. Measure 400 mL of vinegar and pour into the bottle through the uncovered mouth.
6. Measure 2 teaspoons of food coloring and pour into the bottle containing vinegar
7. Measure 2 tablespoons of baking soda and pour gently into the bottle containing vinegar and food color, then observe what happens.
8. Optional: repeat steps 1-6 for 3, 4, and 5 tablespoons of baking soda (step 7) and record the observation.

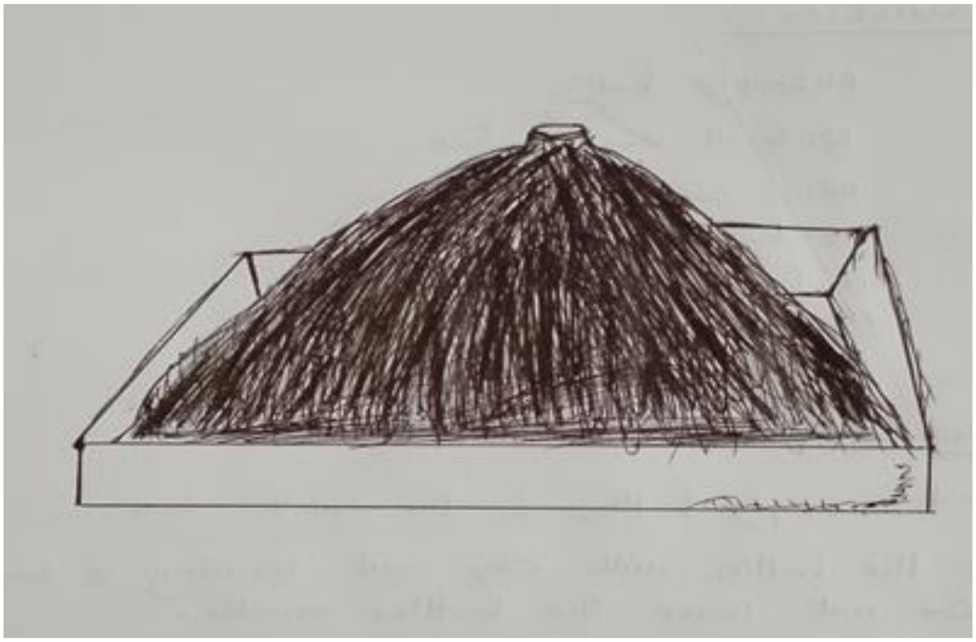

Figure 5. Schematic of volcano model with clay soil surrounding bottle with mouth exposed at top of the structure.

3.3.4. *Results*

EXPERIMENT STEP	OBSERVATION
1. After adding vinegar into empty bottle	
2. After adding food coloring into bottle containing vinegar	
3. After adding baking soda into battle containing vinegar and food coloring	

3.3.5. *Post-Demonstration Questions*

1. What happened when baking soda was added into a bottle containing vinegar and food coloring?

2. From the demonstration, what materials represent the Earth's crust, lava, and magma?

3. How was the model different than and similar to a real volcanic eruption?

4. In a real volcanic eruption, what are the positive and negative effects?

5. What are safety precautions to be taken during real-life volcanic eruptions?

4. Design Challenge

You have learned about Archimedes' principle and various factors that affect the sinking or floating of objects in water. Now it is time to design and construct a boat that can move through water without sinking easily.

5.1 Design Questions

1. What materials would you use to create your boat? Why would you choose these materials? Consider common materials like wood, metal, and plastic, and think about how density matters to keep your boat afloat.

2. How could you make your constructed boat float better?

5.2 Design Sketch

Sketch out your design for your boat in the space below. Be creative!

5. Sources

- TIE (2022), Physics for secondary schools, student's Book form four, TIE, DSM.
- http://www.civildefence.govt.nz/resources/what-to-do-during-a-volcanic-eruption
- J.B.A Mihigo et all (1991) Enjoy physics, Mzumbe Book project, Morogoro,Tz.
- https://littlebinsforlitlehands.com/best-sandbox-volcano-eruption/