ARM

CLIMATE RESEARCH FACILITY

Education and Outreach Lesson Plan

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Grade levels 9-12

Thermal Expansion of Water

Thermal Expansion of Water

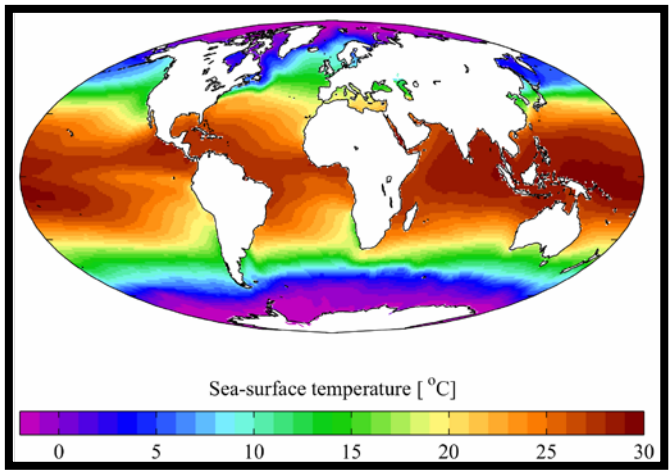
Approximate Time

1 hour

Objective

The student will prove that heated water has more volume than cooler water due to a process called thermal expansion, as evidenced by the completion of an experiment and written conclusions.

Background Information



Key Points to Understand

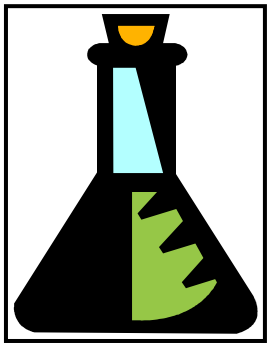
- Global temperature is gradually rising according to long-term temperature records.
- Solid, liquid, or gas in any shape may expand because of heat.
- If heat from the rise of global temperature is passed on to the water, water expands and increases its volume.
- Causes of sea level change:
  - Volume of water in the oceans
  - Inputs from rainfall, snowfall, rivers, groundwater, melting ice, and volcanism
  - Outputs through evaporation and freezing
  - Properties: temperature of water, amount of dissolved and suspended matter in it
  - Shape of the basin
  - Global thickness and area of continental crust
  - Relative thermal states of the continental and oceanic crusts (i.e., density and volume of active spreading ridges
  - Mass of water and sediments in the ocean and the resultant load on the ocean crust.

Key Vocabulary

- **Bunsen burner**: A type of gas burner, commonly used in chemical laboratories, with which a very hot, practically non-luminous flame is obtained by allowing air to enter at the base and mix with the gas.

- **Erlenmeyer flask**: The Erlenmeyer flask is usually marked on the side (graduated) to indicate the approximate volume of contents, and has a spot of ground glass or enamel where it can be labeled with a pencil. It differs from the beaker in its tapered body and narrow neck. The neck allows for a clamp or stopper.
- **Thermal expansion**: Thermal expansion is the tendency of matter to change in volume in response to a change in temperature. When a substance is heated, its particles begin moving and become active, thus maintaining a greater average separation.
- **Thermal transfer**: The moving, conveying, or handing over of heat.
- **Volume**: Volume is measured in "cubic" units. The volume of a figure is the number of cubes required to fill it completely, like blocks in a box.

Materials



- 500-milliliter conical flask (Erlenmeyer flask)
- 2-hole stopper
- Hollow glass tube
- Thermometer
- Metric ruler
- Stand with gauze mat
- Bunsen burner
- Student Record Sheet (for plotting temperature versus water-level expansion data)

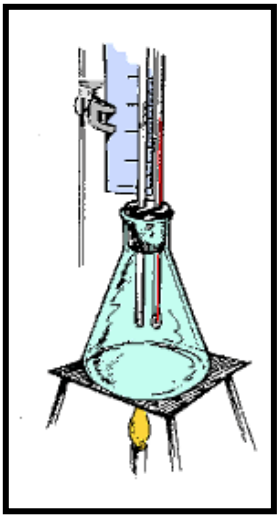
Preparation

Before the demonstration explain the concept of volume and volume expansion due to heat by giving some practical examples:

- If a lid of a glass jar is tight, holding it under hot water for a short time will make it easier to open. This is because the lid will be struck by the hot water more directly than the glass, and so it will expand sooner. Furthermore, metals generally expand more than glass for the same temperature change.
- If a steel bridge expands or contracts, it can cause structural damage. However, steel bridges are often mounted on rollers to prevent this problem.
- Expansion gaps also exist in train tracks.
- Water and steam pipes often have a U-bend in them to allow for thermal expansion.

Then, explain that when global warming heats up the upper layer of the ocean, the volume of sea water expands. It is this thermal expansion of the ocean water that makes the sea level rise.

Procedure



1. Assign student reading prior to beginning experiment.
2. Fill the flask to the top with water. Place the hollow glass tube and thermometer in the stopper and gently press the stopper into the flask.
3. Mount the ruler so that the water level in the glass tube can be measured.
4. Heat the water slowly and record the water level at 2-degree Celsius intervals. Record the temperature and water level at least 10 times.
5. Plot your results on student worksheet: temperature versus water level (volume expansion).

Closure and Evaluation

Ask students:

1. What happened to the water level in the flask as the temperature rose?
2. Explain why the water level in the flask changed over time. What caused this?
3. Would salt water react the same way as fresh water? How might other liquids react?

Suggested Follow-Up Activities

- Reproduce the experiment using salt water instead of fresh water. Be sure to use the same volume of salt water as was used in the fresh water experiment. How does the data compare?
- Research sea water levels as affected by global warming (use http://education.arm.gov/studyhall.stm as a resource)
- Collect current newspaper articles related to global warming and thermal expansion.
- Suppose the trend of global warming continues, leading to a massive expansion of sea water in the future. Which coastal cities or regions on each continent would most likely be affected first?

Thermal Expansion of Water: Student Reading

All radiation (ultraviolet, visible, infrared, microwave, etc.) comes in the form of waves, which carry energy through matter. When waves travel through a gaseous, liquid, or solid medium, more or less of their energy (depending on the medium's properties) is absorbed by the medium. This absorbed energy usually turns to heat. When this heat is absorbed by masses of water, such as oceans, an expansion of that water mass occurs due to thermal expansion, and sea levels rise.

The sun emits shortwave radiation that is absorbed, in part, by the surface of the Earth. Longwave radiation is then emitted by the surface and heats the atmosphere (atmospheric radiation). Clouds, water vapor, and other gases in the atmosphere help to "trap" that heat. This process is also known as the "greenhouse effect."

Sea Level and Global Warming

Global temperature is believed to be gradually rising. Because of this, the Earth's surface is maintained at a higher temperature than that appropriate to balance the incident solar radiation. Observed increases in the concentrations of atmospheric carbon dioxide due to burning of fossil fuels, and of other components from industry and other human activity, could lead to a steady increase of global temperature.

The resulting thermal expansion of the oceans and the melting of land ice would increase sea levels. Concern about the possibility of coastal flooding due to this increase has stimulated recent research into climate dynamics.

The most important factors controlling the volume of water in the oceans are believed to be the balance between the freezing and melting of land ice, such as in mountain glaciers, but also in the thermal expansion of the ocean surface layers.

Ignoring ice sheets and glaciers, global temperature changes will cause a sea-level change of the order of 10 centimeters. This does not seem like much in relation to the depth of the oceans, but when we are considering changes of the order of millimeters for the low-lying atolls, especially in the Pacific region such as Tuvalu, Marshall Islands, Kiribati, and Tokelau, then sea-level response to temperature changes could become an important factor.

Effect of Local Thermal Expansion

Thermal expansion of the upper layer of the ocean at a particular region is generally seasonal, and it may not affect the long-term sea-level change. However, if the global warming is taken into account for a particular locality, that sea-level change will be a considerable addition to the regional sea level. Accordingly, we may infer that a 1-degree Celsius temperature increase over the upper layer of approximately 50 meters will raise the sea level by approximately 1.5 centimeters (some simply say – 1 centimeter).

Monitoring Sea Levels

Forecasting sea-level rise is still an extremely inexact science. In the Pacific region, sea-level monitoring stations have been installed throughout the islands under the program of the South Pacific Sea Level and Climate Monitoring Project to measure relative sea-level changes due mainly to climate change. In view of the uncertainties of the climate change models, this is regarded as the most responsible approach at this time.

A growing number of people in the Pacific region are concerned about the climate change and sea-level rise. Consequently, they are interested to see the present relative sea-level trends of the Pacific region in general and the trends of their own islands in particular.

Sea Level and Climate Change

Atmospheric and oceanic processes have a powerful effect on changes in sea level. These changes are associated with variations in space and time of temperature, salinity, ocean currents, and the combined results of the atmosphere and the ocean interaction, which causes irregular patterns, such as the El Niño effect. The following are changes of sea level occurring in a wide range of time scales:

- **Wind Waves** are periods of a few seconds.
- **Tides** are regular periodic cycles with periods of a few hours to many years.
- **Storm Surges**, sometimes locally named as King Tides, are temporary disturbances due to the effects of atmospheric pressure and to wind stress setting water in motion.
- **Seasonal Oscillations** in response to seasonal cycles of atmospheric conditions reaching prominence in the case of monsoon conditions.
- **Longer Period Changes** in response to climate change through thermal expansion of Mean Sea Level of the upper layers of the ocean and/or the addition of mass to the oceans by changes in precipitation [or evaporation] and/or melting of land ice.

Statistics on Sea Level Rise

According to many studies, the global Mean Sea Level may have risen by one or two centimeters since 1990 at the rate of one to 2 millimeters per year. Climate change is expected to cause a further sea-level rise as the years progress.

There remains much uncertainty as to the size of the sea-level response despite the attention of world experts. For example, the Intergovernmental Panel on Climate Change (IPCC) met in Rome in December 1995 to prepare the Second Assessment Report, which was reviewed by 2000 scientists from 130 countries over a 2-1/2 year period. The complete assessment contained 1500 pages and 10,000 references. Based upon a “best estimate” of the elements of climate change, the report suggests that the sea level may rise by 50 centimeters from the present to the year 2100. The uncertainty is such, however, that the report acknowledges that this estimate lies within a range of probabilities from a low-sensitivity estimate of 15 centimeters to a high-sensitivity estimate of 95 centimeters.

It is theorized that this rate would continue beyond the year 2100 even if concentrations of greenhouse gases were to be stabilized in the interval. The following interesting findings have been extracted from published works:

The IPCC points out that regional sea-level changes may differ from global mean values owing to land movement and changes in ocean currents. Also it is important to note that changes in the mass of the ocean would cause some warping of the Earth's crust due to the geographic shape of the ocean basins. Sea-level rise is unlikely to be the same everywhere.

- The Tropical Pacific experienced temporary sea-level anomalies of the order -30 to +30 centimeters during the El Niño South Oscillation period, according to a study by French scientists undertaken between 1979–1990.
- Tide gauge measurements at Pago Pago in American Samoa and at Honolulu in Hawaii showed a steady sea-level rise of around 1.5 millimeters per year in the last 100 years.

The combination of ocean expansion with a reduction in sea ice, possibly some melting of ice shelves, and a small positive mass balance of the Antarctica ice sheet, could cause a rise in sea level of up to 40 centimeters by 2030.

Though it is true that a rise in temperature would lead to melting, there is evidence that ice from Antarctica would not melt to cause a catastrophic sea-level rise! Instead, melted ice would most likely return as precipitate ice. The interior of Antarctica is a desert where very little snow falls because the air is too cold to hold much water vapor. An increase in air temperature would enable more water vapor to be carried inland and to fall as snow, thus increasing the ice in Antarctica.

Causes of Sea-Level Change

- Volume of water in the oceans.
- Inputs from: rainfall, snowfall, rivers, groundwater, melting ice, volcanism.
- Outputs through evaporation and freezing.
- Properties: Temperature of water, amount of dissolved and suspended matter in it.
- Shape of the basin.
- Global thickness and area of continental crust.
- Relative thermal states of the continental and oceanic crusts (i.e., density and volume of active spreading ridges).
- Mass of water and sediments in the ocean and the resultant load on the ocean crust.

More information on this topic can be found at http://education.arm.gov/.

Name:_____

Date:_____

Title:_____

Thermal Expansion of Water

Research Question: Does heated water have more volume than cooler water?

Hypothesis

_____
_____
_____
_____

List Materials Used

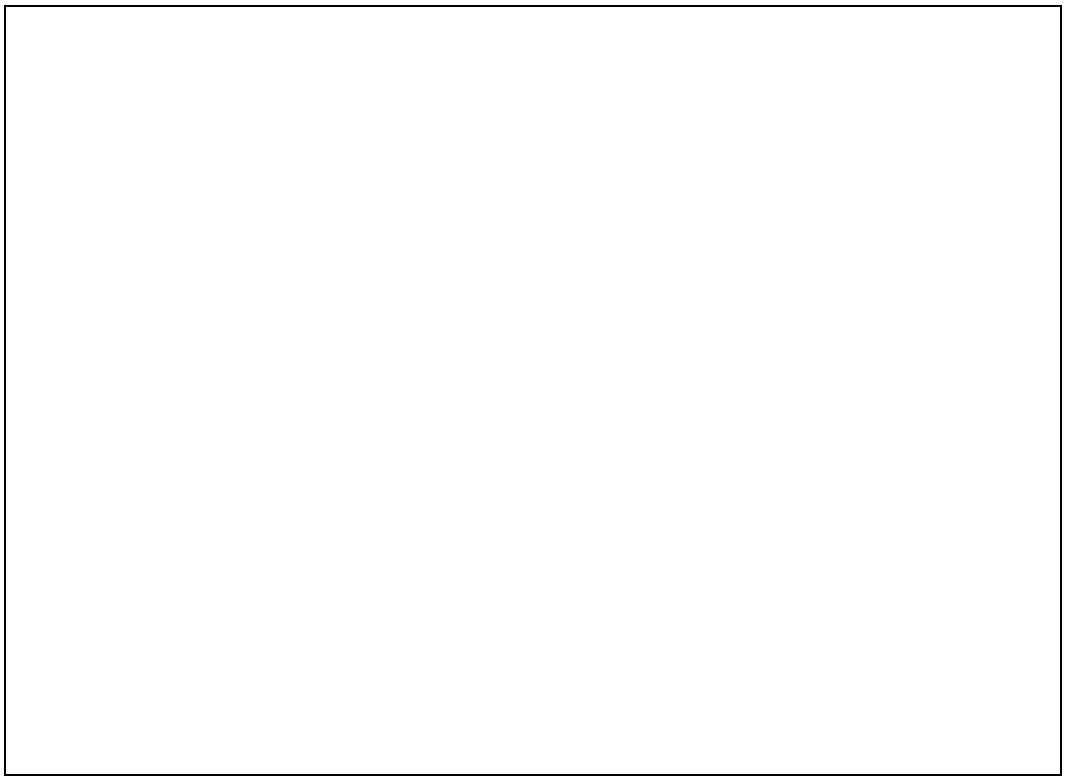
1.
2.
3.
4.
5.
6.
7.
8.

Data

Water Level as Affected by Temperature

	1	2	3	4	5	6	7	8	9	10
Temperature (degrees Celsius)										
Water Level (millimeters)										

Graph the data from the Water Level Table. Include: Title, labels for each axis, scale, and key.



Conclusion

Based on your hypothesis, recorded data, and findings from the experiment, write a conclusion.