An expanding ocean

The planetary ocean is a mass of water that covers most of our planet and interconnects all parts of the globe. It plays an important role in the Earth's climate and, although a complex system, still obeys the simple laws of physics and chemistry taught in schools. When teaching these laws, teachers can use this example to raise awareness of the dynamics of the ocean and its impact on our lives.

Thermal expansion and volumetric coefficient of thermal expansion

When talking about a rise in sea level due to global heating, many people think only of melting ice sheets and glaciers and do not realise that thermal expansion is actually a significant factor. Most materials expand when heated. We say ‘most materials’ because water in the liquid state does not follow this trend between 0 and 4°C. Despite this behaviour, above 4°C, water will expand when heated. This is one of the problems with an increase in the sea-surface temperature – the water dilates and contributes to rising sea levels. Thermal expansion is responsible for about 43% of rising sea levels, which pose a serious threat to populations living along coastlines.

Activity 1: Observing the thermal expansion of water

Students can see first-hand how water behaves with temperature. This simple experiment is suitable for students aged 11–14 and demonstrates how the volume of water changes with temperature. The activity lasts about 15 minutes.

Not just melting ice: a simple experiment demonstrates how thermal expansion contributes to rising sea levels as one of the consequences of climate change.

An ocean in the school lab: rising sea levels

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Activity 2: Measuring the thermal expansion coefficient of water

Older students can expand on Activity 1 to roughly calculate the thermal expansion coefficient of water. This physical quantity, in K⁻¹, can be calculated using the following equation:

\[ \alpha = \frac{\Delta V}{V \Delta T} \]  

(1)

where \( \Delta V \) is the variation (increase) in volume, \( V \) is the initial volume, and \( \Delta T \) is the variation in temperature.

This is a rough calculation because, as proposed, the experiment contains several errors that are difficult to overcome, as we will explain below. However, if this is acknowledged and the main objective is not to determine an exact value for the coefficient of thermal expansion, but rather a value of the same order of magnitude as the actual one, students can still perform measurements and draw some conclusions.

One of the problems with this experiment is that the thermal expansion coefficient of water varies with temperature: for example, at 10°C it is 8.8×10⁻⁵ K⁻¹, at 20°C it is 2.07×10⁻⁴ K⁻¹, and at 30°C it is 3.03×10⁻⁴ K⁻¹.[2] The value is also small; therefore, to allow a measurable variation in water volume, it is best to use a significant initial volume of water and a significant variation in temperature.

The activity is suitable for students aged 14–16 and lasts about 45 minutes.

Materials
- 250 cm³ Erlenmeyer flask
- Approx. 300 cm³ water containing food colouring
- Graduated pipette
- Laboratory rubber stopper
- 500 cm³ beaker
- 200 cm³ hot water, approx. 50°C
- Thermometer

Procedure
1. The process is the same as that in Activity 1, but some measurements have to be made.
2. The water’s temperature is measured at the beginning of the experiment \( (T_i) \), when it is at room temperature, and at the end \( (T_f) \), so we can determine the temperature change \( (\Delta T) \).
3. The water level inside the graduated pipette is measured at the beginning and end of the experiment to calculate the volume change ($\Delta V_{\text{pipette}}$). The total volume of water, $V$, is measured using a graduated cylinder at the end of the experiment, after the water has cooled to room temperature again. This way displacement resulting from insertion of the stopper will not be measured.

Results
In this experiment, we obtained the following values:

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<tbody>
<tr>
<td>21.2</td>
<td>294.3</td>
<td>30.4</td>
<td>303.5</td>
<td>9.2</td>
<td>0.52</td>
<td>298</td>
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Experimental data to determine the thermal expansion coefficient of water.

Using equation (1), water’s coefficient of thermal expansion can be calculated:

$$\alpha_V = \frac{\Delta V}{V \times \Delta T} = \frac{0.52}{298 \times 9.2} = 1.9 \times 10^{-4} \text{ K}^{-1} \quad (2)$$

As mentioned, this is a simplification. Thermal expansion is not linear with temperature, and the ocean also expands inland, with the rise in water level depending on the gradient of the coast. Nevertheless, the result highlights the point that this expansion is not negligible.

Conclusion
So, even a small increase in temperature of 0.1°C can translate into a significant rise in sea level. And this is only thermal expansion at play; the rise in temperature of the planet also causes melting of the ice sheets and glaciers, which contributes to the rise in sea levels. On average, and over the last 25 years, the sea level has been rising by about 3 mm a year, as determined from satellite data, and this rise is accelerating.[4]

Questions to ask the students:
1. Why does global heating lead to a rise in sea levels?
2. How will populations living near the coasts be affected by a rise in sea level?
3. With a constant rise of 3.3 mm a year, how much higher will the sea level be in the year 2100?
References


Resources


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