SPACE awareness

THE THERMAL LAYERS OF OCEANS

Learn, where in the oceans heat is stored

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SPACE awareness

Curriculum topic
Oceans, interior

Big idea of science
Earth is a system of systems which influences and is influenced by life on the planet

Keywords
Thermic radiation, oceans, lakes, temperature layers, thermocline, heat

Age range
12 - 16

Education level
Middle School, Secondary School

Time
30min

Group size
Group

Supervised for safety
Unsupervised

Cost
Average (5 - 25 EUR)

Location
Indoors (small, e.g. classroom)

Core skills
Developing and using models, Planning and carrying out investigations, Analysing and interpreting data, Constructing explanations, Engaging in argument from evidence, Communicating information

Type of learning activity
Partial enquiry

BRIEF DESCRIPTION

This activity illustrates the generation of temperature layers observed in oceans and lakes. The Sun and it irradiation is replaced by a strong lamp. The ocean or lake is modelled by a transparent cup that contains water. The temperatures at different depths are measured within given time intervals. The data are used to construct a diagram that depicts the development of temperature layers in time.

GOALS

- Learn that water in the oceans only warms up in the upper layers near the surface.
- Exercise data recording from experiments.
- Analyse data by means of diagrams.

LEARNING OBJECTIVES

The pupils are supposed to

- realise that the heating of the oceans by the sun only occurs in the upper water layers.
- learn about the density anomaly of water and its effects on the formation of the layers in the ocean.

EVALUATION

The pupils should be able to give an explanation of the phenomenon observed in their own wording. They should also be able to collect and analyse data on their own and draw the conclusions for their environment. With the necessary support they should be able to explain the data correctly.

In case the necessary physical basic concepts have not been reviewed yet the pupils should be able to explain their observations in their own wording.

Answers to questions

Question 1: Since the sunlight is attenuated on its way to the bottom of the oceans and lakes, the upper layers get heated more than the others.

Question 2: The various temperature layers get mixed. The results in a rather uniform temperature down to a certain depth.

Question 3: The water on the water surface will warm up quicker than the water at the bottom of the cup.

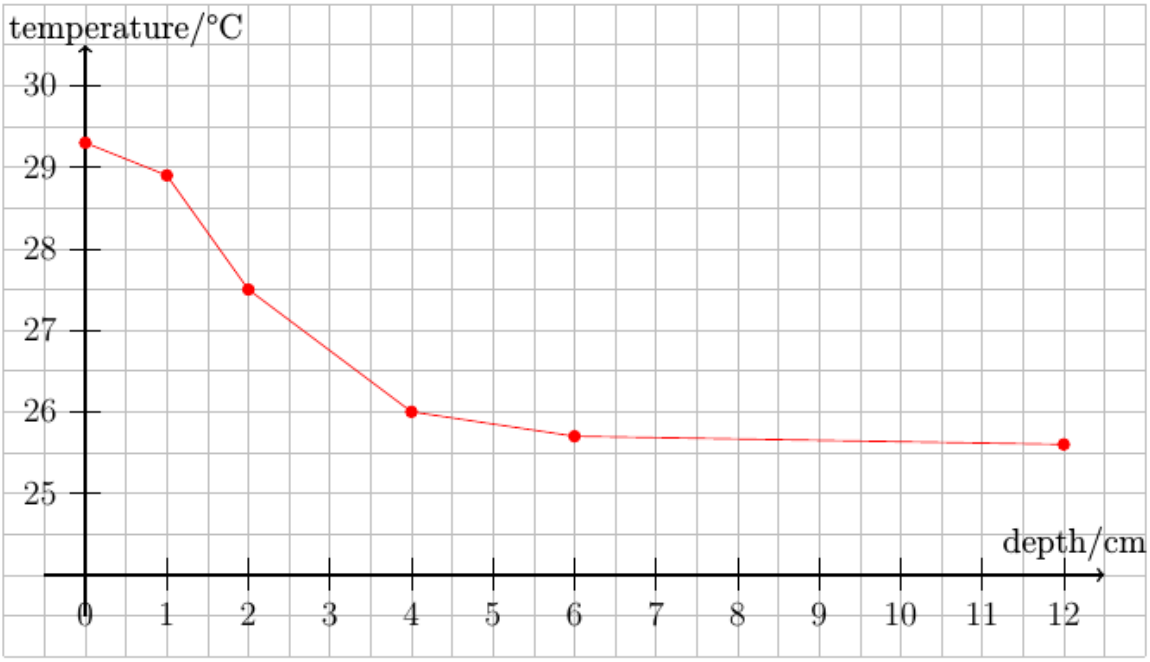

Figure 1: Diagram with data points added from the experiment.

Task:
Water does not warm up evenly, i.e. the temperature decreases from top to bottom. Each layer absorbs a portion of the incident radiation which is used for heating. The remaining transmitted radiation has less power to heat the next layer, and so on.

Question 4: The total of the intruding radiation is being absorbed by the upper water layers of the Oceans, so that the deep sea cannot be heated directly by the Sun. However this model is extremely simplified not taking convective flows into consideration. This issue must be approached shortly during the discussion of the experiment.

Remark: A possible approach to illustrate the exponential decline is to discretise the absorption by means of an example by assuming that e.g. a water layer of 1 cm thickness absorbs 20% of the remaining thermic radiation. This leaves less radiative power for the next layers that also absorb 20%, which means that in absolute numbers the absorbed power is smaller. This leads to a less effective heating with increasing depth.

MATERIALS

The list of items corresponds to one experimental set-up.

- plastic cup (10 - 15 cm high or more)
- marker
- ruler
- strong lamp
- cold water
- thermometer
- stop watch

BACKGROUND INFORMATION

Thermal layers of oceans and lakes

It is known that a large percentage of the heat supplied by solar irradiation is stored within oceans (see activity Water is a Heat Sink). However, only a thin layer of a few centimetres at the surface of the oceans is directly heated by insolation. Waves and currents stir up the upper ocean layers and thus distribute the heat to greater depths by mixing. This leads to a layer of rather uniform temperature with a thickness of typically 200 metres. The deep sea beyond 1 km depth basically never changes its temperature. The range in between is the so called thermocline (see Figure 2) which exhibits a temperature gradient and can be several hundred metres thick. It is subject to seasonal variation and depends on the latitude. This is the transition zone between the heated surface and the always cold deep sea.

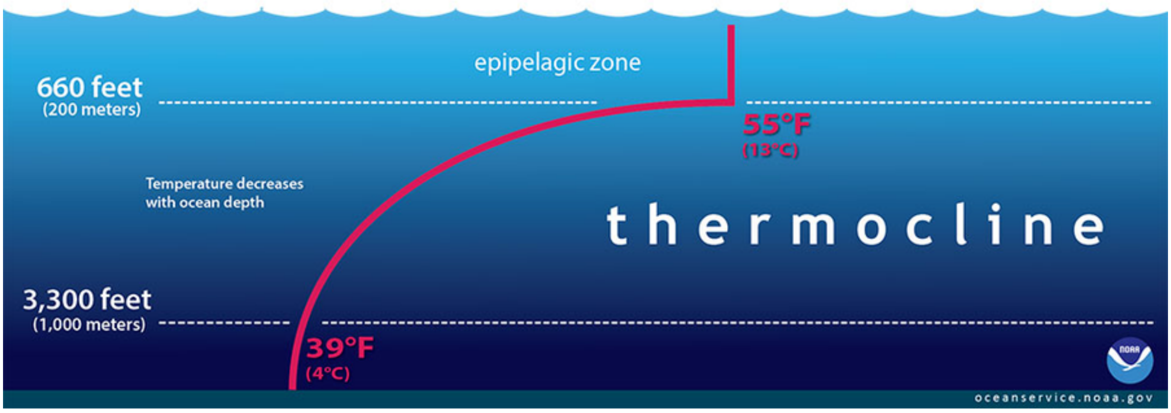

Figure 2: The red line in this illustration shows a typical seawater temperature profile. In the

thermocline, temperature decreases rapidly from the mixed upper layer of the ocean (called the epipelagic zone) to much colder deep water in the thermocline (mesopelagic zone). Below 3,300 feet to a depth of about 13,100 feet, water temperature remains constant. At depths below 13,100 feet, the temperature ranges from near freezing to just above the freezing point of water as depth increases (Credit: National Oceanic and Atmospheric Administration/NOAA, United States Department of Commerce, http://oceanservice.noaa.gov/facts/thermocline.html).

An example of a measured distribution of ocean water temperatures is given in Figure 3. This map also demonstrates that only the upper layers are relatively warm. Therefore, remote sensing data obtained from Earth observation satellites alone only provide a limited view of the overall energy budget of the oceans. The full picture can only be completed with in situ sample measurements. Therefore, the EU programme Copernicus, a comprehensive European Earth observing programme, in which marine monitoring is a crucial aspect, not only employs satellite observations from space, but also traditional measurement campaigns on ground.

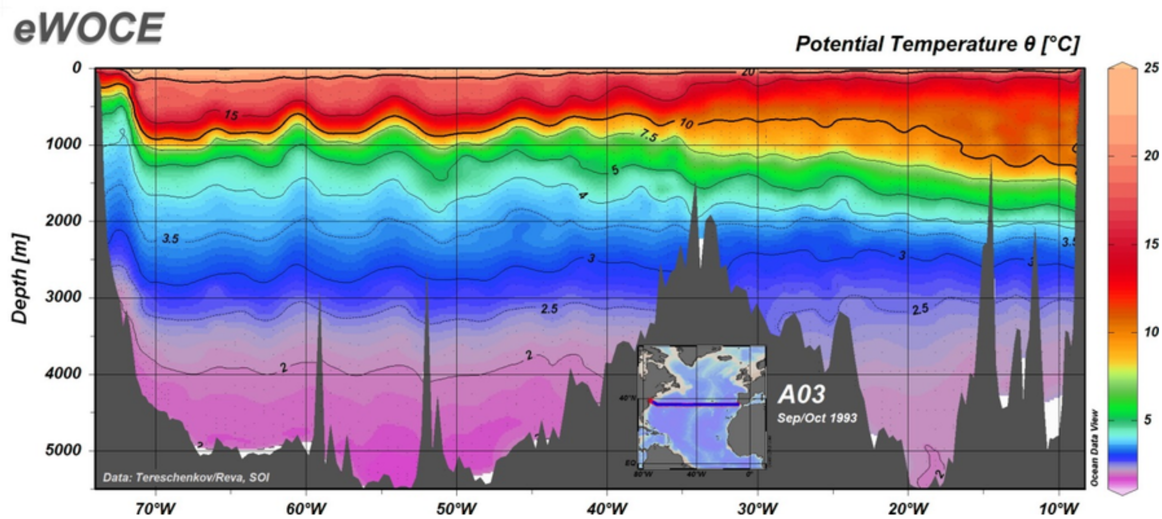

Figure 3: Temperature stratification of the Atlantic between New England and Spain. Salt water reaches its highest density at lower temperatures than sweet water. Depending on the salinity, the deepest layers of the oceans provide a rather constant temperature around 1 to 2°C (Credit: eWOCE, electronic atlas of the World Ocean Circulation Experiment, Schlitzer, R., Electronic Atlas of WOCE Hydrographic and Tracer Data Now Available, Eos Trans. AGU, 81(5), 45, 2000, http://www.ewoce.org).

Even lakes possess different layers of water temperatures, although they are usually too shallow to produce a thermocline. Nevertheless, the stratification is strongly influenced by seasonal changes of insolation. Since sweet water attains its highest density at a temperature of 4°C, the bottom layer hardly changes its thermal state and permits constant conditions throughout the year (Figure 4).

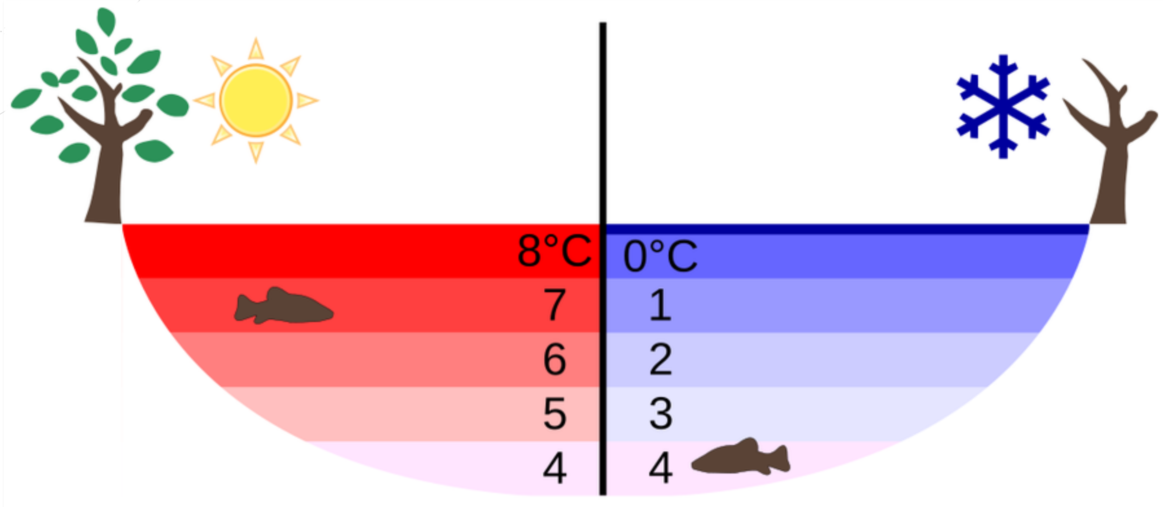

Figure 4: Temperature stratification of a lake and its seasonal change. While the upper layer are subject to external heating and cooling, their temperatures changes depending on the season of the year. The deepest layers usually provide rather constant conditions (Credit: Klaus-Dieter Keller, https://commons.wikimedia.org/wiki/File:Anomalous_expansion_of_water_Summer_Winter.svg, https://creativecommons.org/licenses/by-sa/3.0/legalcode).

Physical background

The Lambert Beer law relates the attenuation of light to the properties of the material through which the light is traveling. According to this relation, the initial power of an incoming beam of light is attenuated to a value that depends on the path length of the beam transmitted through the absorbing medium.

$$P(d) = P_0 \cdot e^{-\mu \cdot d}$$

The parameters are:
P_0: incoming power

μ : attenuation coefficient in m^{-1}
d : light path length in m

However one has to realise that the attenuation coefficient μ is a function that depends on the wavelengths of the incident light and on the material. Nevertheless, one can see that with increasing depths less energy is being absorbed, which leads to a reduced heating of the water. One would expect a temperature gradient with an exponential decline of temperature with increasing depth.

The stratification materialises in combination with the density of water, which changes with temperature (see above). This rather simple process can be perturbed when the density is modified by other processes and conditions like e.g. the salinity.

FULL ACTIVITY DESCRIPTION

A large part of the solar radiation is being absorbed by the Earth, the oceans in particular.

Question 1: How evenly do you think water in oceans or lakes warm up due to insolation?

In fact, only the upper few centimetres of the oceans are directly heated by the solar radiation. However, strong winds and waves perturb the upper layers of the oceans

Question 2: How does this modify the temperature distribution? You can find an answer, if you think of an explanation, why you stir the meal when cooking it.

Experimental set-up

1. The cup is filled with cold water.
2. Mark the cup on the outside at various equidistant depths (six including the water surface and the bottom of the cup in this example).
3. The lamp is positioned so that it illuminates the cup from above.

Figure 5: Experimental set-up (own work).

Question 3: What do you think happens inside the water when switching on the lamp?

Experimental procedure

1. The lamp is switched on and the water is illuminated for approximately 2-3 minutes
2. Measure the temperature at different depths.
3. Note down the values together with the depth according to the markers on the cup.
4. Insert the data points into the following diagram.

Figure 6: Diagram for adding the data points.

Task:
Write down your observations and try to find a possible explanation for the data recorded.

Question 4: The deep sea is an area completely void of light and has a constant low temperature around freezing point. How can you explain this phenomenon with the given results?

CURRICULUM

Space Awareness curricula topics (EU and South Africa)

Our fragile planet, Oceans, interior

CONCLUSION

With this activity, the pupils learn how the oceans absorb thermic radiation from the Sun. The hands-on experiment with a lamp and a cup of water suits as a model, from which the stratification of temperatures with increasing depth can be investigated. The students measure the temperature at different depth, translate this into a diagram and discuss the result.

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