Movers and shakers: physics in the oceans

Contrary to the popular saying, deep waters are often far from still – which is just as well for marine life. Activities using simple water tanks are a good way to find out about the physics at work beneath the waves.

By Susan Watt

hen we think about climate change, one of the biggest concerns is that major ocean currents such as the Gulf Stream are being sent off course, jeopardising the weather systems that depend on them. But what causes such currents to be established in the first place? Part of the answer is gravity. Gravity acts on water masses of different density and this, together with wind and Earth's rotation, produces forces and currents within the oceans. Such processes not only have a potential impact on our climate, but are also a huge influence on the environment inhabited by marine organisms.

As a result, any student of oceanography will need a good understanding of these processes. But a group of

PhysicsBiology

Ages 12+

Physics is often seen as unrelated to everyday life, which makes many students uninterested in the subject. This article uses oceanography to provide a context for physical concepts, thus helping to raise students' interest. It could be used in biology or physics lessons, particularly when studying marine topics.

The two activities described can either be used by teachers as demonstrations or carried out by students. They can be used before explaining the physics concepts that appear in them (to make students think about them) or after their explanation. Additional exercises about physical oceanography that would be useful for teaching physics to students aged 12-18 are listed at the end of the article.

Finally, the text could help students understand that seemingly diverse scientific subjects can be interlinked. For example, to understand how the environment affects marine life, we need concepts from physics (and also chemistry and geology).

Mireia Güell Serra, Spain

university oceanographers in Maine, USA, noticed a few years ago that their marine science students seemed unaware of the physics involved in their subject, focusing instead mainly on the biology. As a result, they decided to put together a teaching resource to convince students that oceans are an unusually exciting place to study physics. This article is based on that resource (Karp-Boss et al., 2009), which focuses on key concepts in physics that are also fundamental in oceanography, and provides a compelling environmental context for ideas within physics.

Of course, students learn best when they are actively engaged, so central to the resource is a series of activities designed to engage students and challenge their assumptions. Two activities that the oceanographers have



REVIEW

Image courtesy of Nicola Grat

Teaching activities

The Gulf Stream is one of the strongest ocean currents in the world. It originates at the tip of Florida in the US, then follows the eastern coastlines of the USA and Newfoundland, Canada, before crossing the Atlantic Ocean towards the British Isles.

The Gulf Stream is driven by winds and differences in water density. Surface water in the north Atlantic is cooled by winds from the Arctic, whereupon it becomes denser and sinks to the ocean floor. This cold water then moves towards the Equator where it is slowly warmed. To replace the cold water moving towards the Equator, warm water moves from the Gulf of Mexico north into the Atlantic.

Figure 1: In open ocean regions, there are at least three distinct water layers: an upper mixed layer of warm water; the thermocline, in which the temperature decreases rapidly with increasing depth; and a deep zone of cold, dense water in which density increases slowly with depth. The three layers are illustrated in this cross-sectional diagram of the Atlantic Ocean. Note that the thickness of the layers varies with latitude. At high latitudes, only the deep-water layer exists.

Europe

Africa



Image from the DataStreme Ocean project. ©American Meteorological Society. Used with permission.

used successfully in their classes are described here: one focusing on density, the other on waves. Both could be used with secondary-school students of all ages (11-19).

The first activity shows how stratification occurs as a result of density differences due to temperature or salinity. The second activity looks at internal waves; resonance and natural frequency are also demonstrated. For both activities, the apparatus is set up prior to class, and the students carry out the activities for up to 30 minutes per activity (using worksheets). The last part of the lesson is used for summarising findings and discussion.

Density and stratification

Density is a fundamental property of matter. It is the mass per unit volume of a material – that is, how much mass is packed into a given volume.



Density layers. The top image shows the tap water and salt solution before the divider is removed. Afterwards (lower image), the salt solution forms a stable layer at the bottom of the tank with the tap water above it.

In oceanography, density is used to characterise water masses and to study ocean circulation. Many ocean processes are caused by differences in densities: large-scale ocean circulation and carbon transport by particles sinking from surface to deep waters are just two examples.

Whereas the density of water ranges from 998 kg/m³ for fresh water at room temperature to nearly 1250 kg/m³ in salt lakes, ocean waters have a much smaller density range (about 1020–1030 kg/m³). Most of the variability in seawater density is due to salinity and temperature. As salt concentration increases, due to evaporation or ice formation, density increases. Higher temperatures reduce density, whereas cooling increases it.

Ocean seawater density increases with depth, but not in a uniform way: instead, water of different densities forms a series of layers (figure 1).

This stratification acts as a barrier for the exchange of nutrients and dissolved gases between the top, sunlit layer where phytoplankton thrive, and the deep, nutrient-rich waters.



- **3** The process repeats, cooling whole lake to the temperature of maximum density (4°C).
- **4** The surface layer cools further and ice starts to form on the surface. This is stable, as it is less dense than water below.
- 5 With more cooling, the whole lake freezes.

5





Image courtesy of Nicola Graf

Mixing stratified layers requires work: think how hard you need to shake a bottle of salad dressing to mix the oil and vinegar. So, without enough energetic mixing due to wind or breaking waves, phytoplankton at the ocean's surface will lack nutrients.

Types of waves

Although density is not the first thing that comes to mind when we think of the sea, waves are a different matter. Waves are ubiquitous in the ocean, in lakes, and of course on beaches – and they are feared in their destructive form as tsunamis.

Most of these waves are what physicists call surface waves. But there are also internal waves, which occur at the interface between density layers of water. In the ocean, breaking internal waves mix up the water layers and lift the nutrients they contain.

The geometry of a water basin (such as a lake or a bay) determines which waves are excited when force is applied and then released (e.g. due to a passing storm). These waves are **Density is fundamental to how lakes freeze.** As winter approaches in high latitudes, lake waters are cooled from the top. When the upper waters become cooler and denser than the waters below, they sink. The warmer, less dense water underneath then rises to replace the sinking water. If low air temperatures persist, these processes will eventually cool the entire lake to 4 °C – the temperature of maximum density for fresh water. With yet further surface cooling, the density of the upper waters will decrease, and the lake becomes stably stratified with colder but less dense water at the top. As surface waters cool to 0 °C, they begin to freeze. If cooling continues, the frozen layer deepens.

Image courtesy of Moroder: image source: Wikimedia Commons



Acqua alta ('high water' in Italian) is the name given to the high water levels that occur periodically in the Venetian lagoon. The phenomenon occurs in part due to the Adriatic seiche. Shown here is Venice's famous Piazza San Marco, partially submerged during an acqua alta in 2004. the 'natural modes' of the basin – in a similar way to sound waves in a musical instrument, where a particular frequency is produced by a given length of string or air column. This phenomenon is called resonance.

In oceanography, there is an additional phenomenon known as seiche (pronounced 'saysh', from an old French word meaning 'to sway'). This is when a standing wave is established in a semi-enclosed body of water, which moves from side to side as a mass – rather like tides. For example, the Adriatic seiche, which has a period of 21.5 hours, is associated with serious floods in Venice, Italy. Other naturally occurring examples of seiches have been observed in Lake Geneva and in the Baltic Sea.

Teaching activities

Activity 1: Investigating water density and stratification

Materials

- Rectangular tank with a divider
- Bottle containing salt solution (approximately 75 g salt dissolved in 1 l water)
- Two beakers containing tap water, at room temperature
- Food colouring (two different colours)
- Ice

Procedure

1. Calculate the densities of the tap water and the salt solution. To do this, students measure the weight of a known volume of water, making sure to subtract the mass of the container from the total mass of the container plus liquid. The density can then be calculated, since density (ρ) is mass (m) divided by volume (v) (or $\rho = m/v$).

- 2. Place the tap water in one compartment of the tank and salt solution in the other.
- 3. Add a few drops of food colouring to the water in each compartment, so that each has a different colour.
- 4. What do you predict will happen when you remove the divider between the compartments? Explain your reasoning.
- 5. Remove the tank divider. What happens? Are your observations consistent with the densities you measured?
- 6. Empty the tank and the beakers. Now fill one beaker with hot tap water and one beaker with ice-cold water.
- 7. Add a few drops of food colouring to each of the beakers (a different colour in each beaker).

- 8. Place the hot water in one tank compartment and the ice-cold water in the other. What do you predict will happen when you remove the divider? Explain your reasoning.
- 9. Remove the tank divider. What happens? Is it as you predicted?
- 10. After observing the new equilibrium in the tank, place your fingertips on top of the fluid surface and slowly move your hand towards the bottom of the tank. Can you feel a temperature change?
- 11. How might the effects of climate change, such as warming and melting of sea ice, affect the vertical structure of ocean water? Discuss possible scenarios.



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Activity 2: Investigating internal waves

Materials

- Rectangular tank with a divider
- Stopwatch
- Food colouring or other appropriate dye
- Two containers: one with fresh water and the other with dyed salt water (approximately 75g salt dissolved in 1 l tap water)
- Wave paddle (a wide piece of plastic about 2 cm high, with a width similar to that of the tank)
- Optional: a piece of plastic the same width as the tank but about one-third of its length

Procedure

- 1. Place the tap water in one compartment of the tank and the coloured salt solution in the other.
- 2. Remove the divider between the compartments, and watch what happens. Make a note of any waves you see, and describe their movements.
- 3. Identify the internal wave this travels back and forth along

the interface between the two differently coloured fluids. Measure the speed of this wave by timing how long it takes for the wave to travel the length of the tank. (Make sure you use an average value by timing several traverses.) Find the speed of the wave using the formula:

Length of tank (m) / time taken(s) = wave speed (m/s)

- 4. Try producing surface and internal waves using the wave paddle. For surface waves, lower the paddle into the water and raise it again, repeating the cycle at a fast frequency (at least once a second). For internal waves, do this more slowly (about once every 10 seconds).
- 5. Discuss your results.
- 6. Optional: if you have time, you can repeat the experiments using the piece of plastic inserted at an angle to the bottom of the tank, to give the effect of a shallow sea bed. Place the plastic in position as shown below.

Discussion

The energy of internal waves is generally lower than that of surface waves. This is because the gravitational restoring force is smaller for internal waves, due to the relatively slight difference in density between water layers (compared to that between water and air for surface waves). This lower energy means that, for a tank (or water basin) of a given size, the natural frequency of the internal waves will also be lower than for surface waves.

In additional to surface waves, stratified fluids support internal waves; in two-layer fluids, these waves ride on top of the interface between the two fluids. Their periods are significantly longer than those of surface waves and their amplitudes can be significantly higher. When we perturb the two-layer system, many waves are initially excited, but only those that fit (resonate) with the geometry of the basin remain. Inserting the piece of plastic at one end of the tank, simulating an increasingly shallow seabed, can cause internal waves to break, similar to surface waves breaking on a beach, but occurring below the surface.

Image courtesy of Lee Karp-Boss

An internal wave at the interface between the denser (blue) salt water and less dense (clear) water. A wave paddle is shown on the right of the tank, and a piece of plastic to simulate shallow topography on the left.

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Teaching activities

Image courtesy of Lycaon; image source: Wikimedia Commons



Planktonic organisms are incapable of swimming against a current.

Acknowledgement

This article is based on the resource developed through the organisation COSEE (Center for Ocean Sciences Education Excellence) by oceanographers Lee Karp-Boss, Emmanuel Boss, Herman Weller, James Loftin and Jennifer Albright (Karp-Boss et al., 2009).

Reference

Karp-Boss L, et al. (2009) Teaching physical concepts in oceanography: an inquiry based approach. Oceanography 22(3): supplement. doi: 10.5670/oceanog.2009. supplement.01

Resources

The tanks can be obtained from sciencekit.com, where a set of six tanks costs 130 USD. You could also try building your own, using a small fish tank and constructing a divider with a good seal.

- For more information and activities on ocean layering and mixing, see the article Mix it up, mix it down: Intriguing implications of ocean layering, available online at: www.tos.org/ oceanography/archive/22-1_franks. pdf
- The website of COSEE Ocean Systems offers images of density profiles and thermohaline circulation, videos on ocean convection, a collection of hands-on activities, and links to related concepts. See: http://cosee. umaine.edu/climb

In particular, there are videos demonstrating activity 1: water density and stratification (http://cosee. umaine.edu/files/coseeos/ video_tsoi04.htm or use the shorter link: http://tinyurl.com/crjzwoq) and activity 2: internal waves (http://cosee.umaine.edu/files/ coseeos/video_tsoi11.htm or use the shorter link: http://tinyurl.com/ cf4so47#).

- NASA offers a website with information and resources on ocean currents. See: http://oceanmotion.org/ index.htm
- Additional educational resources in oceanography are available on website of COSEE (Centers for Ocean Sciences Education Excellence). See: www.cosee.net/resources/ educators
- These two books are accessible introductions to oceanography:

Denny MW (1993) Air and Water: The Biology and Physics of Life's Media. Princeton, NJ, USA: Princeton University Press

Denny M (2007) How the Ocean Works: An Introduction to Oceanography. Princeton, NJ, USA: Princeton University Press

If you found this article useful, why not browse the other teaching activities in Science in School? www.scienceinschool.org/teaching

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To learn how to use this code, see page 65.

HOW CAN TEACHERS RECOGNISE CONTENT THAT HAS THE POTENTIAL TO TRAVEL ACROSS NATIONAL, CULTURAL AND LINGUISTIC BOUNDARIES?

European Schoolnet, a network of 30 European Ministries of Education based in Brussels, has been active in the field of Open Educational Resources (OER) for over a decade. It has particularly focused on promoting the exchange of guality OERs at the pan-European level via the Learning Resource Exchange for schools (LRE): http://lreforschools.eun.org

- The LRE, as a pan-European exchange, enables educators and learners to find over 240,000 resources from more than 50 content providers.
- The LRE relies on a rigorously tested set of criteria developed by the eONet project to help assess which resources have the potential to 'travel well' across national, cultural and linguistic boundaries.
- Teachers and content producers can now use the criteria in their own work to create and discover OERs with real potential for re-use across Europe.



TRAVEL WELL CRITERIA WITH EXAMPLES

Travel Well

1. TRANS-NATIONAL TOPICS (must be present)

The resource addresses curriculum topics that could be considered trans-national. It can also be a resource well suited for use in multi-disciplinary or cross-curricular contexts. Example: Encyclopedia of Life Source: Encyclopedia of Life



eQ Ne

2. KNOWLEDGE OF A SPECIFIC LANGUAGE IS NOT NEEDED (must be present)

The resource can be used without having to translate accompanying texts and/or the resource may be available in at least 3 European languages. Example: Caves at Lascaux

Source: French Ministry of Culture and Communication

3. STORED AS A FILE TYPE THAT IS USABLE WITH GENERALLY AVAILABLE SOFTWARE

The resource can be used in any environment (online and offline) and runs on multiple platforms (also hand-held, IWB). Example: Diffusion and Osmosis

Source: Bio-DiTRL





4. METHODOLOGICAL SUPPORT FOR TEACHERS IS NOT NEEDED

Subject teachers can easily recognize how this resource meets their curriculum requirements or how this resource could be used in a teaching scenario without further instructions. Example: Human Anatomy Source: ThatQuiz.org

5. INTUITIVE AND EASY TO USE

The resource is intuitive to use in the sense that it has a userfriendly interface and is easy to navigate for both teachers and students without having to read or translate complex operating instructions.

Example: Map Maker Source: TeacherLED

6. INTERACTIVITY WITH OR WITHOUT FEEDBACK IN A DIGITAL ENVIRONMENT

This kind of resource invites or requires a significant degree of user input or engagement, other than just reading something on a page in an online or offline environment.

Example: Balancing Act Source: PhET

7. CLEAR LICENSE STATUS (must be present)

The user can easily find information about the license/rights (sometimes called Terms of Use, Copyright or Permissions) for this resource, clearly outlining what educators can do with this animation and what they may not do because it will infringe copyright.

Example: CellsAlive! Permission Page Source: CellsAlive!



Blaings







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For more information: European Schoolnet: www.europeanschoolnet.org

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Lifelong Learning

The Quality Network for a European Learning Resource Exchange (eQNet) and the work presented in this print ad is supported by the European Commission's Ufelong Learning Programme.

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