Marine Science Lesson Enhancements
based on **Grade 11 & 12 curriculum** in
Physics, Chemistry & Biology

Water

Ocean Explorer

Module 2

Bayworld Centre for Research & Education

Overview

1 - The chemistry of water

2 - Intermolecular Forces

3 - Geometrical Optics

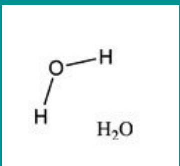
4 - Reflection and refraction in water

5 - Diffraction

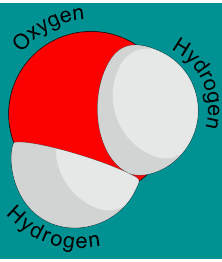
6 - Activity : Conductivity of water

1 - The chemistry of water

Water is one of the most unique molecules known to man and also one of the most important to biological systems. Not only does water exist in nature in all three states of matter (solid, liquid, gas), it also covers 75 percent of the earth and composes roughly 78 percent of the human body.



Water is a chemical compound. Each molecule of water, H_2O (dihydrogen monoxyde), consists of two atoms of hydrogen (H) bonded to one atom of oxygen (O).



Water boils at 100°C and turns into ice at 0°C.

Ice is less dense than liquid water. For most materials, the solid phase is denser than the liquid phase. An important consequence is that lakes and rivers freeze from the top down, with ice floating on water.

The high heat of vaporization means a lot of energy is needed to break hydrogen bonds between water molecules. Because of this, water resists extreme temperature changes. This is important for weather and also species survival. The high heat of vaporization means evaporating water has a significant cooling effect.

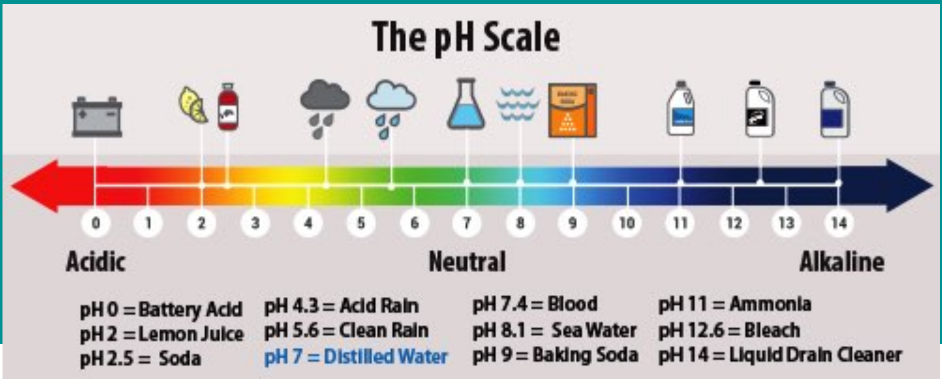
Info +

Many animals use perspiration to keep cool, using the vaporization effect.

pH

pH is a measure of how acidic/basic water is. The range goes from 0 (acid) to 14 (basic / alkaline), with 7 being neutral. pH is a measure of the relative amount of free hydrogen and hydroxyl ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic. Since pH can be affected by chemicals in the water, pH is an important indicator of water that is changing chemically. Each number represents a 10-fold change in the acidity/alkalinity of the water. Water with a pH of 5 is ten times more acidic than water having a pH of 6. Pollution can change a water's pH, which in turn can harm animals and plants living in the water as well as people drinking or using it.

- **Acid** = substance containing hydrogen which gives free hydrogen ions (H^+) in excess when dissolved in water
- **Base** = substance containing the OH group that yields free hydroxyl ions (OH^-) in excess when dissolved in water
- A reaction between an acid and a base is called **neutralization**.



Specific Conductance (SC)

Specific conductance is a measure of the ability of water to conduct an electrical current. It is highly dependent on the amount of dissolved solids (such as salt) in the water. Pure water, such as distilled water, will have a very low specific conductance, and sea water will have a high specific conductance. Rainwater dissolves airborne gasses and dust while it is in the air, and thus often has a higher specific conductance than distilled water. Specific conductance is an important water-quality measurement because it gives a good idea of the amount of dissolved solids in the water.

Polarity

Polarity simply means that the molecule has both a positively and negatively charged end. More important, the polarity of water is responsible for effectively dissolving other polar molecules, for example sugars and ionic compounds such as salt. Ionic compounds dissolve in water to form ions. This is important to remember because for most biological reactions to occur, the reactants must be dissolved in water. Because water is able to dissolve so many common substances, it is known as the **universal solvent**.

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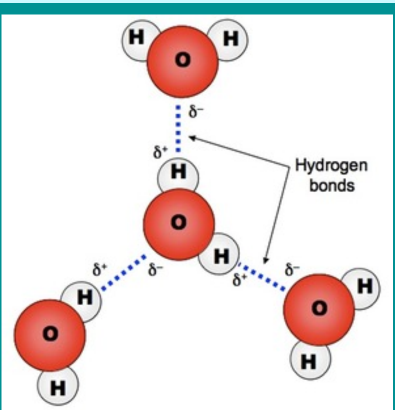
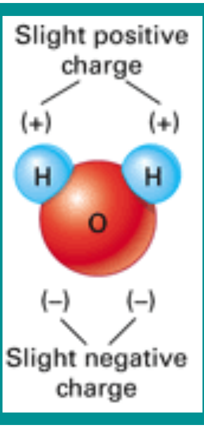
Substances that cannot be dissolved by water (such as oils) are called fat soluble and are nonpolar, nonionic compounds that are strongly covalently bonded. Insoluble substances make excellent containers of water, such as cell membranes and cell walls.

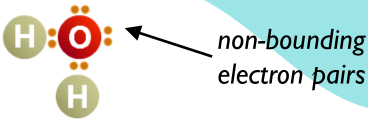


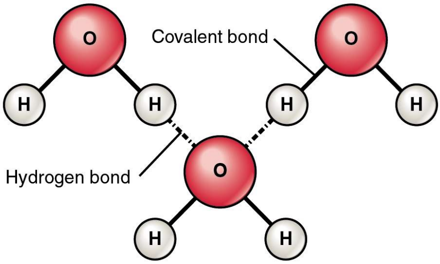
The water molecule is a **polar molecule**. It has a slight positive charge on one side (H+) and a slight negative charge on the other (O-). The negative side of the molecule, made of 2 loose electrons, gives it the ability to build **hydrogen bounds** with other water molecules.



Hydrogen bounding

When water molecules align with each other, a weak bond is established between the negatively charged oxygen atom of one water molecule and the positively charged hydrogen atoms of a neighbouring water molecule. The weak bond that often forms between hydrogen atoms and neighbouring atoms is the hydrogen bond. Water is adhesive to molecules capable of forming hydrogen bonds with it. Adhesion and cohesion lead to capillary action, which is seen when the water rises up a narrow glass tube or within the stems of plants.





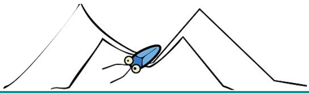
Cohesion

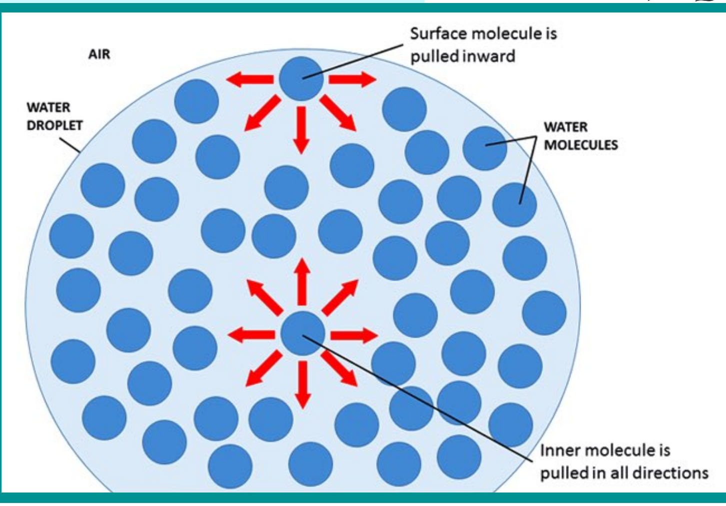
It is a key property of water. Because of the polarity of the molecules, water molecules are attracted to each other. Hydrogen bonds form between neighbouring molecules. Because of its cohesiveness, water remains a liquid at normal temperatures rather than vaporizing into a gas.

Info +

To avoid the pain of a belly-flop, divers enter the water with their hands or feet first to break the surface tension of water !

Cohesiveness also leads to high surface tension. An example of the surface tension is seen by beading of water on surfaces and by the ability of insects to walk on liquid water without sinking.





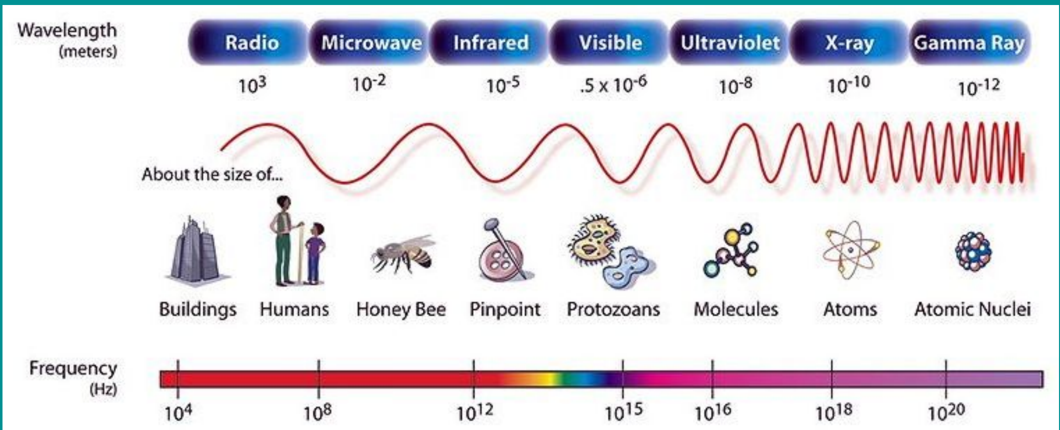
Water molecules on the liquid surface have fewer neighbouring molecules so exhibit stronger attractive forces to their nearest neighbours. This is why the tension on the surface of the water is superior to the tension inside the water body.

Geometric optics is the technology that underlies most of the optical devices important to various aspects of our lives. These range from simple things like eyeglasses to complex instruments, such as the Hubble Space Telescope. Geometrical Optics describe the passing of light waves inside different transparent materials such as air and water, but also its reflection against non transparent materials.

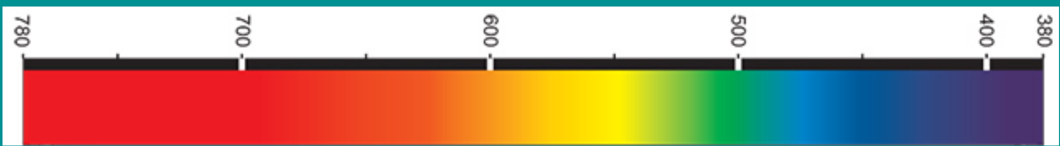
What is "light" ?

It is at the same time a **particle** and a **wave**. This is why it is so difficult to understand how it works ! A. Einstein himself wrote : "*separately neither of them fully explains the phenomena of light, but together they do.*"

The electromagnetic spectrum



The visible spectrum



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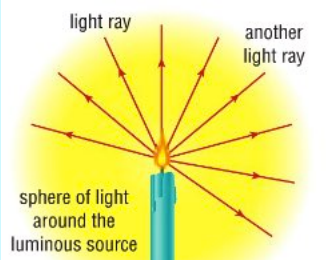
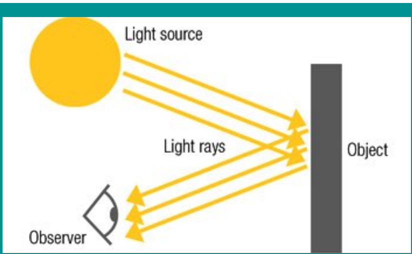
In diagrams, light is represented by light rays. Light always travels in straight lines from the emitting source.



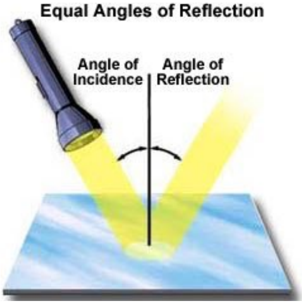
The law of reflection

Most visible objects are seen by reflected light. There are few natural sources of light, such as the stars (our sun is one of them), and a flame; other sources are man–made, such as electric lights. For an object to be visible, light from a source is reflected off the object into our eyes.

Here, the light is coming from the sun, light rays are parallel due to the distance of the source. The light reflects off the object and travels in straight lines to the eye of the viewer. The brain can now process the information carried by the light rays and gives us an image as a result.

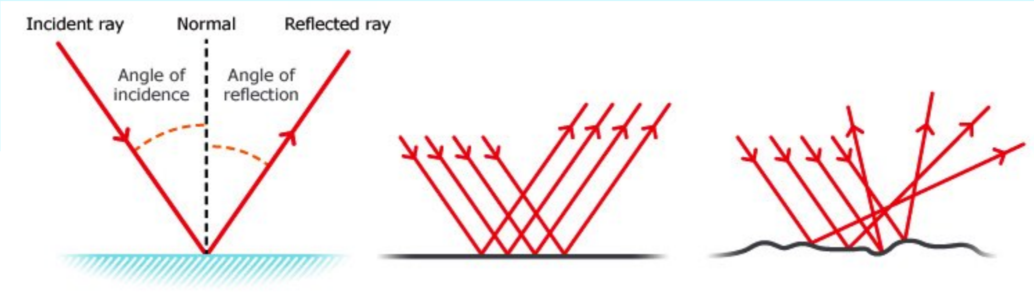


When light strikes a surface, it is reflected. The original ray is called the **incident ray**, and after reflection, it is called the **reflected ray**. The angles of the incident and reflected rays are always measured from the normal. The normal is a line perpendicular to the surface at the point where the incident ray reflects. The incident ray, reflected ray, and normal all lie in the same plane perpendicular to the reflecting surface, known as the plane of incidence. The angle measured from the incoming ray to the normal is termed the incident angle. The angle measured from the outgoing ray to the normal is called the reflected angle. The law of reflection states that the angle of incidence equals the angle of reflection. This law applies to all reflecting surfaces.



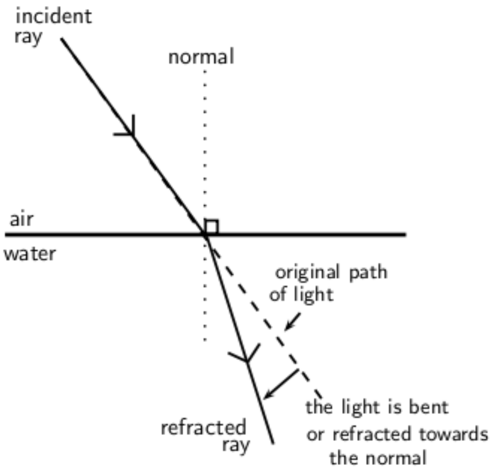
Light undergoes either diffuse or specular reflection. When the surface is rough, the reflection will be called ***diffuse*** *because all reflected rays will not go in the same direction.*

Mirroir **Specular** **Diffuse**



The law of refraction

Refraction is the bending of light when the beam passes from one transparent medium into another, and changes its speed. A transparent object allows the transmission of light, in contrast to an opaque object, which does not. Some of the light will also be reflected.



4 - Reflection and refraction in water

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If a straw is dipped inside a glass of water, even though the straw is perfectly straight, it will look bent once inside the water. This is the result of the different refraction between air and water.

Light travels at different speeds in different mediums, because their composition is different. As a result, the angle of refraction within different mediums will also be different.

Snell's law

To calculate the angle of refraction, we use Snell's law. The constant (**n**) is called the **index of refraction** and depends only upon the optical properties of the material. θ_1 and θ_2 are the angles of incidence and refraction.

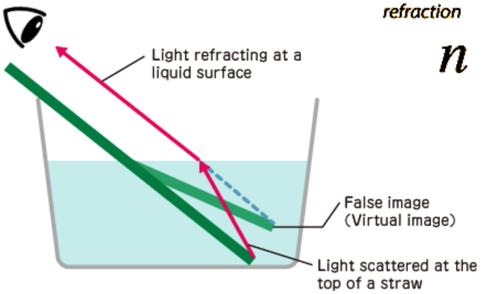
Snell's Law

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$

The index of refraction (**n**) is also equal to the ratio of the speed of light in a vacuum (**c**) and the speed of light in that medium (**v**).

$$n = \frac{c}{v}$$

index of refraction (n); *velocity of light in vacuum* (c); *velocity of light in the medium* (v)



Medium	Index of Refraction
vacuum	1.0000
air	1.0003
ice	1.31
water	1.33
ethanol	1.37
glycerin	1.47
quartz glass	1.47
crown glass	1.52
light flint glass	1.58
Lucite (Plexiglas)	1.52
ruby	1.54
zircon	1.92
diamond	2.42

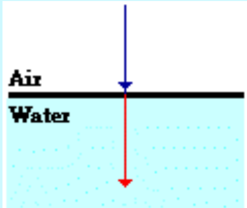
The index of refraction gives a measure of the amount of bending occurring when light travels from air into the material. It is a dimensionless number and can be located in tables of properties of materials such as this one. For example, the index of refraction of water is 1.33, and the index of refraction of air is 1.

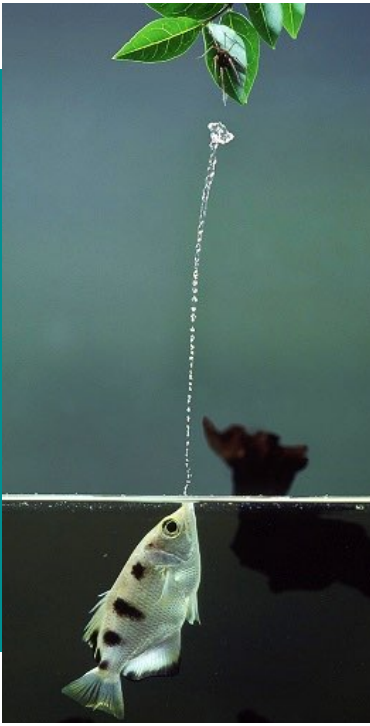
Passing Across a Boundary Without Bending

There is only one condition in which light can pass from one medium to another, change its speed, and still not refract. If the light is traveling in a direction that is perpendicular to the boundary, no refraction occurs. As the light wave crosses over the boundary, its speed and wavelength still change. Yet, since the light wave is approaching the boundary in a perpendicular direction, each point on the wavefront will reach the boundary at the same time. For this reason, there is no refraction of the light. Such a ray of light is said to be approaching the boundary while traveling along the normal, perpendicular to the medium surface.

Info +

No reflection occurs if the light rays are approaching in a direction which is perpendicular to the surface.



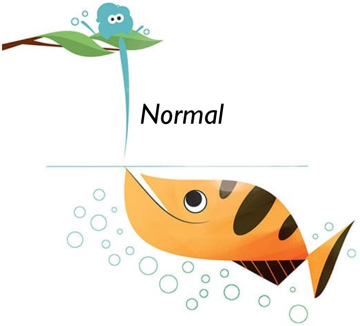


The Archer Fish

There is an unusual fish known as the Archer fish. The Archer fish is unlike any other fish in that it finds its prey living outside the water. An insect, butterfly, spider or similar creature is the target of the Archer fish's powerful spray of water.

The Archer fish will search for prey that are resting upon a branch or twig above the water. With pinpoint accuracy, the fish knocks the prey off the branch using a powerful jet of water. The prey falls to the water as the Archer fish simultaneously swims directly to the location on the surface where the prey strikes the water, wasting no time to retrieve its meal.

How can I do the same as the Archer Fish ?

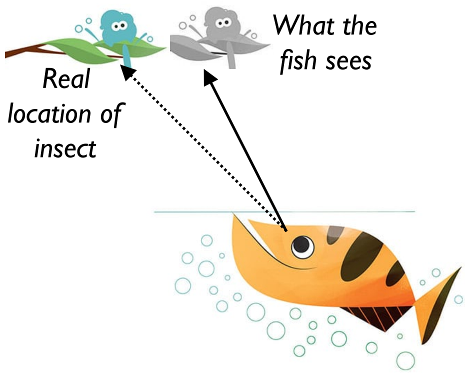


If we were to reproduce the technique of the Archer fish, we would be sitting right underneath the prey. From this vantage point, light from the prey travels directly to our eye without undergoing a change in direction. Since the light is traveling along the normal to the surface, it does not refract. Normally, when light from an object changes medium on the way to the eye, there is a visual distortion of the image. But if we sight along the normal, there is no refraction and no visual distortion of the image. From this ideal line of sight, we would be able to hit the prey time after time (assuming we could master the task of spraying a jet of water in the desired direction).

So what is his secret ?

From this discussion, one might conclude that the secret of the Archer fish is to aim at its prey from directly below. Refraction is less when sighting along the normal. However, the Archer fish's accomplishments are more remarkable than that !

It has been found that Archer fish are able to strike their prey when sighting upwards at angles of 40 degrees with the normal. In fact, it has been found that hit probabilities do not show significant variance with the angle of sighting, meaning that an Archer fish is just as likely to strike its prey whether the amount of refraction is great or minimal. Now that's remarkable !



5 - Diffraction

Diffraction involves a change in direction of waves as they pass through an opening or around a barrier in their path. Diffraction can be demonstrated by placing small barriers and obstacles in a ripple tank and observing the path of the water waves as they encounter the obstacles. The waves are seen to pass around the barrier into the regions behind it; subsequently the water behind the barrier is disturbed. The amount of diffraction (the sharpness of the bending) increases with increasing wavelength and decreases with decreasing wavelength. In fact, when the wavelength of the waves is smaller than the obstacle, no noticeable diffraction occurs.

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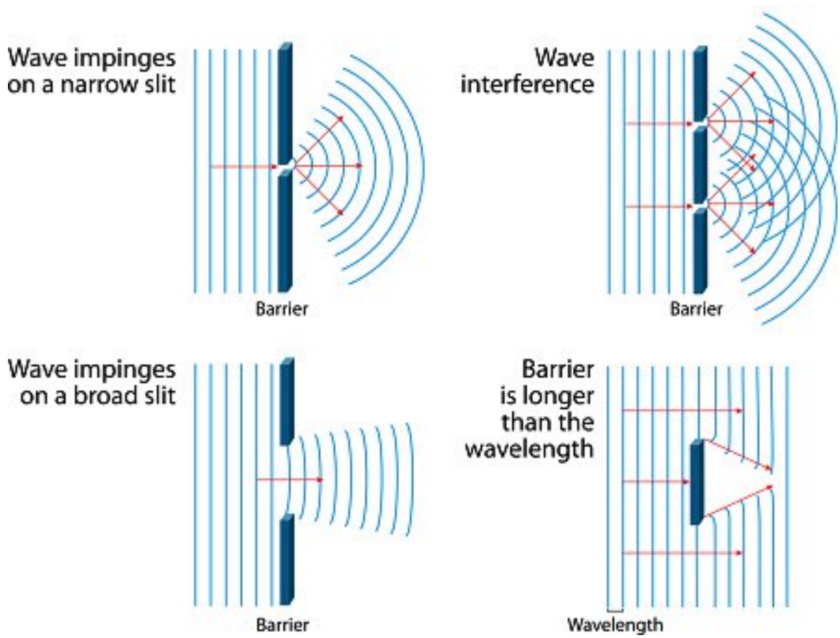
Just like water waves, light waves have the ability to travel around corners, around obstacles and through openings.



6 - Activity : Conductivity of water

Material needed

1 battery

1 light bulb

Connectors (wires)

Beaker of salt water

Beaker of distilled water

Method

Hook up the battery to the light bulb and run two wires from the battery into a beaker of water. When the wires are put into a beaker of distilled water, the light will not light. But, the bulb does light up when the beaker contains salt water (saline).

Questions

1 - Explain why the saline solution helps to light the bulb.

2 - Which salt concentration is needed to light the bulb ? Try the experiment a few times with different salt concentrations and keep note of your results.

Explanation

In the saline water, the salt has dissolved, releasing free electrons, and the water will conduct an electrical current thanks to these free electrons.

Info +

Seawater has a salinity of 3,5%. It is denser than pure water because the dissolved salts increase the mass by a larger proportion than the volume. Seawater freezes at about -2°C. It means that the freezing point of seawater decreases as salt concentration increases. Seawater pH is usually between 7,5 and 8,4, it is alcaline.