

SEA WATER PROPERTIES, WATER MASSES, AND GLOBAL SCALE CURRENTS

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Physical properties of sea water (density, temperature, salinity) can be used to define water masses. The displacements of water masses (and their interactions with the surrounding water body) give rise to global scale surface currents and thermohaline circulation, providing a useful picture of the over the years-returning of the geography of the ocean circulation. The ocean however, is a superposition of processes of a great variety of time and length scales and the geography of the ocean circulation is only a convenient picture of what the whole thing can come to at a seasonal or yearly basis

1. Chemical Physics of Sea Water

A molecule of water is made of one atom of oxygen and two atoms of hydrogen forming an isosceles triangle. The centers of inertia of the positive and negative charges do not coincide so that the molecule constitutes a small electric dipole. The angle $\hat{H}\hat{O}$ ($\sim 105^\circ$) is close to the value of the angle at the center of a regular tetrahedron ($\sim 109^\circ$). Hence, in the solid state (ice) the molecules tend to follow a tetrahedral pattern in which one oxygen atom at the center is bound to four oxygen atoms at the vertexes by means of one hydrogen atom. Two of these bonds are covalent bonds; the other two are 'hydrogen bonds'. The latter (of electrostatic origin) have less energy but they are sufficient to ensure stability of the crystal and they are responsible for some of the most striking properties of sea water: high values of the specific heat ($c_p \sim 4.2 \cdot 10^3 \text{ j kg}^{-1} \text{ K}^{-1}$), the latent heat of melting ($L_f \sim 3.4 \cdot 10^5 \text{ J kg}^{-1}$) and the latent heat of evaporation ($L_v \sim 2.5 \cdot 10^6 \text{ J kg}^{-1}$) and a quite important thermal inertia. Melting of ice (breaking 'hydrogen bonds') results in a caving in of the crystalline lattice and a packing of molecules. Thus the volume decreases and the density increases until, - in normal pressure conditions - a temperature of 4° is reached, where thermal dilatation begins to compensate: ice is lighter than water and floats at the sea surface.

Because of its high dielectric constant, water is an excellent solvent for various mineral or organic substances (gases, liquids or solids).

Sea water is a complex solution and contains the majority of the known elements. Some of the more abundant components are chlorine ion ($\sim 7.7\%$), sodium ion ($\sim 30.6\%$), magnesium ion ($\sim 3.7\%$) and potassium ion ($\sim 1.1\%$). (A significant feature of sea water is that while the total concentration of dissolved salts varies from place to place, the ratios of the most abundant components remain almost constant). The total amount of dissolved material in sea water is termed the *salinity* and has been defined as ‘the total mass of solid materials contained in one kilogram of sea-water when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine and all organic matter completely oxidized’. For example, the average salinity of ocean water is about $35 \cdot 10^{-3} \text{ kg kg}^{-1}$ or 35‰ .

Many physical characteristics of sea water are functions of its salinity. In particular, the temperature of freezing decreases with increasing salinity and is about -1.91°C for $s = 35\text{‰}$.

One of the basic properties of sea water is its *density* or ‘mass per unit volume’ ρ (kg m^{-3}). The density of sea water is a function of pressure, temperature and salinity and, in the open ocean, values range from about 1021 kg m^{-3} at the surface to about 1070 kg m^{-3} at 10000 m depth. As a matter of convenience, it is usual in oceanography to quote only the last digits in the form of

$$\sigma = \rho(\theta, s, p) - 10^3$$

or, ignoring the effect of pressure

$$\sigma_t = \rho(\theta, s, p = p_a) - 10^3$$

(θ : temperature ; s : salinity ; p : pressure ; p_a : atm. pressure $\sim 10^5 \text{ pa}$).

It is often convenient to identify water masses by their temperature and salinity on a θ - s diagram.

One interesting aspect of the functional relationship between ρ , θ and s is the curvature of the isopycnals (curves of equal values of ρ). Mixing of water masses of equal density but different temperatures and salinities produces a mixture of higher density which then sinks. This phenomenon is known as ‘*cabbeling*’.

The temperature of maximum density of sea water falls below the temperature of freezing at a salinity of 24.7‰ .

The salinity of the main ocean water masses is of the order of 35‰ . Thus, cooling the surface water increases its density until the formation of ice. Ice is lighter than water and floats. In the freezing process, salts accumulate in the underlying waters which, - as a result of their low temperature and high salinity i.e. high density -, sink and are continuously replaced by warmer, fresher waters. These in turn may freeze ... repeating the process. (See also *Chemistry of the Oceans*).

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Biographical Sketch

Born in Ans, Belgium, on June 6, 1937, **Prof. Jacques C.J. Nihoul** and his wife are currently residing in St. Severin, Belgium. After receiving his Engineering Degree from Liège University in 1960, Prof. Nihoul was awarded his M.Sc. Degree in Mathematics from MIT (USA) in 1961 and his Ph. D. in Applied Mathematics and Theoretical Physics from the University of Cambridge (UK) in 1965. He served as an Air Force Officer during his National Service in 1964-1965 at the Royal Military College of Belgium and was elected to full Professorships in Liège and Louvain Universities in 1966.

Prof. Nihoul has sat on numerous international committees including SCOR, IAPSO and GLOBEC. He is at present Editor of the Journal of Marine Systems, Earth Science Reviews, Oceanography Section, and one of the Editors of *Mathematical and Computer Modelling*. President of the National Committee of Oceanography of the Royal Academy of Belgium, Prof. Nihoul is a Member of the Russian Academy of Natural Sciences and of the Academia Europaea. Author of some 200 papers in international journals, he was awarded the Francqui Prize for Medical and Natural Sciences in 1978.