PROPERTIES OF NATURAL WATERS

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Contents

Summary

The chemical composition of sea and some brackish waters are listed, and the solubility of scale forming salt species is discussed. The thermodynamic and transport properties of seawater are presented by equations.

1. Some Basic Chemical Principles

In the study of chemistry we are concerned with the structure, properties, and transformation of matter. Matter possesses a certain mass and occupies space. It can exist in any one of the commonly found states, namely gas, liquid, and solid. Gases are characterized by their property of occupying the whole space that is freely available to them, since there are no intermolecular attractive forces. Liquids have considerable intermolecular forces and, hence, they possess constant volume. On the other hand, very strong intermolecular forces exist in solids, because of which the latter have a constant volume as well as a definite shape. Ice, water, and air are common examples of a solid, liquid, and gas, respectively.

Matter can be either homogeneous or heterogeneous with respect to its properties. Homogeneous matter has the same properties throughout its mass; gold, common salt, and air are examples of homogeneous matter. On the other hand, heterogeneous matter consists of parts of substances with different properties, e.g. quartz and gunpowder. Homogeneous substances are of two kinds, namely elements and compounds. An element is a homogeneous matter that cannot be further split into simpler substances, e.g. copper, bromine, and oxygen. Approximately 104 different elements are known to us. The smallest particle of an element is called an atom, which has a unique atomic number. When two or more elements combine chemically in a definite proportion, the substance obtained is called a compound. For instance, water is a compound of two elements, namely hydrogen and oxygen combined in definite proportions. One molecule of water consists of two atoms of hydrogen and one atom of oxygen.

When two or more substances are simply mixed in variable proportions, mixtures are obtained. Gunpowder is a mixture of sulfur, saltpeter, and charcoal; it is a heterogeneous substance. On the other hand, sugar or salt mixed in water in a variable proportion till the saturation limit gives a homogeneous mixture called a solution. The properties of a compound are entirely different from those of its constituents, whereas this is not the case for the mixtures. For instance, water being a compound of oxygen and hydrogen, it has its own properties totally different from those of its constituent elements. The properties of a mixture, however, can be related to the properties of the substances mixed. For ideal mixtures, in the absence of phase change, properties are proportional to those of the constituents. For example, air being mainly an ideal mixture of oxygen and nitrogen has the properties proportional to the properties of both elements, e.g.:

$$H_{air} = x_{O_2} \times H_{O_2} + (1 - x_{O_2}) \times H_{N_2}.$$

2. Chemical Composition of Natural Waters

2.1. Seawater

The chemical composition of seawater is listed in Tables 1 to 5. Table 1 lists the average temperature and salinity of the major oceans. Table 2 gives the salinity, chlorinity, and salt mass fractions of normal seawater. Table 3 gives the ionic composition. Table 4 lists the major chemical elements in seawater in ppm. Table 5 lists the leading components in mole fraction and mass fraction.

Oceans	**Temperature (°C)**	**Salinity g kg^{-1}**
Pacific	3.36	34.62
Atlantic	3.73	34.90
Indian	3.72	34.76
All oceans	3.52	34.72

Table 1. Average temperatures and salinities of major oceans (Wright and Colling 1995)

Salt	**m(g kg^{-1})**	**m S^{-1}**	**Cl (g kg^{-1})**
NaCl	26.9	0.782	16.33
$MgCl_2$	3.2	0.093	2.38
$MgSO_4$	2.2	0.064	-
$CaSO_4$	1.4	0.041	-
KCl	0.6	0.017	0.29

Rest	0.1	0.003	-
Total salts	34.4	1.000	18.99

Table 2. Composition of salt of seawater (Dorsey 1940). Salinity S; Chlorinity Cl.

Ion type	**(g kg^{-1})**
Chloride, Cl^-	18.980
Sulphate, SO_4^{--}	2.649
Bicarbonate, HCO_3^-	-
(including CO_3^{--})	0.140
Bromide, Br^-	0.065
Borate, $H_2BO_3^-$	0.026
Fluoride, F^-	0.001
Total anions	21.861 g kg^{-1}
Sodium, Na^+	10.556
Magnesium, Mg^{++}	1.272
Calcium, Ca^{++}	0.400
Potassium, K^+	0.380
Strontium, Sr^{++}	0.013
Total cations	12.621 g kg^{-1}
Total salinity	34.482 g kg^{-1}

Table 3. Major constituents of seawater (Dorsey 1940).

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Element	**Symbol**	**Concentration (ppm or mg l^{-1})**	**Probable chemical species**	**Total amount in oceans (tones)**
Chlorine	Cl	19500.0	Cl^-	2.570×10^{16}
Sodium	Na	10770.0	Na^+	1.420×10^{16}
Magnesium	Mg	1290.0	Mg^{++}, $MgSO_4$, $MgCO_3$	0.171×10^{15}
Sulphur	S	905.0	SO_4^{--}, $NaSO_4^-$	0.120×10^{15}
Calcium	Ca	412.0	Ca^{++}	5.450×10^{14}
Potassium	K	380.0	K^+	5.020×10^{14}
Bromine	Br	67.0	Br^-	0.886×10^{14}
Carbon	C	28.0		
Nitrogen	N	11.5		
Strontium	Sr	8.0		
Oxygen	O	6.0		
Boron	B	4.4		

Silicon	Si	2.0		
Fluorine	F	1.3		
Argon	Ar	0.43		
Lithium	Li	0.18		
Rubidium	Rb	0.12		
Phosphorous	P	0.06		
Iodine	I	0.06		
Barium	Ba	0.02		
Molybdenum	Mo	0.01		
Uranium	U	0.0032	$UO_2(CO_3)_2^{4-}$	
Vanadium	V	0.002	$H_2VO_4^-, H_2VO_4$	
Arsenic	As	0.002	$HAsO_4^{--}, H_2AsO_4^-$	
Titanium	Ti	0.001	$Ti(OH)_4$	
Zinc	Zn	0.005	$ZnOH^+$, Zn^{++}, $ZnCO_3$	

Table 4. Averages abundances of chemical elements in seawater (Wright and Colling 1995).

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Ion	**Charge**	**Mole fraction**	**Weight fraction**
Cl	-1	0.4878	0.5508
SO_4	-2	0.0251	0.0769
HCO_3	-1	0.0021	0.0041
Br	-1	0.0007	0.0017
Na	+1	0.4186	0.3068
Mg	+2	0.0476	0.0369
Ca	+2	0.0091	0.0116
K	+1	0.0089	0.0110
Sr	+2	0.0001	0.0003

Table 5. Sea salt composition (Ray 1973).

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Salinity is defined as the total amount of dissolved solids in grams contained in one kg of seawater when all carbonate is converted to oxide, all bromine and iodine are replaced by chlorine and all organic material is completely oxidized. Salinity is usually expressed by symbol *S*.

Chlorinity is expressed by the symbol Cl in g kg^{-1} and is equal to salinity *S* divided by 1.812.

Standard seawater is defined by the Standard Seawater Service of the International Association for Physical Oceanography with Cl = 19.375 and S = 35.0019.

Normal seawater is a term used loosely to mean any seawater with approximately S = 34.5.

2.2. Brackish Waters

There are many saline ground waters in arid areas. Some large lakes in arid regions may have a salt content much higher than seawater. Utah great salt lake has a salt content of 200 g l^{-1}. Mono lake, the largest lake in California has a salt content that reached 97 g l^{-1} in 1987. In general the salinity of ground water increases with depth, although there are exceptions. In drilling for petroleum, porous rocks containing salt water, of higher salt content than seawater, are usually penetrated. This brackish water is too deep for utilization.

The composition and total salt content of ground brackish waters vary greatly with the location. Although the major components are the same as in seawater, their relative abundance is often quite different. Surface water generally has relatively lower salinity, composed mostly of salts of calcium and magnesium. These salts cause the hardness of surface waters, which can be treated by softening because of their low concentration in surface waters. Table 6 (private communication with Dr. Yehia M. El-Sayed) lists, in ppm, the composition of some selected brackish waters, river waters and irrigation drain water.

Species	**Na^+**	**Mg^{2+}**	**Ca^{2+}**	**Cl^-**	SO_4^{2-}	HCO_3^-	**Total**
Lake Erie at Buffalo, NY	7	7	31	9	13	114	181
Shenandoah River at Mileville, WV	7	8	32	3	6	132	188
Brackish Well[b] at Buckeye, AZ	446	24	95	700	219	103	1587
Irrigation drain at Wellton-Mohawk	790	80	330	1360	760	360	3680

[a] Minor constituents such as nitrate, iron and silica are not listed.
[b] Average composition drawn from different wells, serving as feed to an electrodialysis desalting plant.

Table 6. Composition of some non-seawater supplies in ppm[a].

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