

## EXERCISE 9

# THE SALINITY OF SEAWATER

**T**he density, or mass per unit volume, of seawater depends upon two properties: temperature and salt content, or **salinity**. As water cools, its density increases. As its salt content increases, its density also increases. Because water of high density tends to sink, and that of low density tends to rise above or settle below water that is at the average density of the oceans, the change in density is one process whereby water motion is generated. Therefore we are interested in the distribution of both salinity and temperature of water, since these are the two factors that determine the circulation that is caused by density changes. In Exercise 8 we discussed seawater temperatures; in this one we will be concerned with salinity.

### THE DISTRIBUTION OF SALINITY

The oceans get their salt from the weathering and dissolution of minerals on land and from volcanic emanations. The mobile constituents of minerals are carried in solution by streams to the sea where they accumulate and are recycled by various processes. Salinity is a "conservative" property; that is, one that

remains constant for the ocean as a whole for long periods of time, even though the local salinity varies within limits over the surface of the oceans. The average salinity for the oceans as a whole is 34.73 parts salt per 1000 parts water (34.73‰), but concentrations between 33.0‰ and 37.0‰ have been measured in the open ocean. High salinity, or dilution, is found only in coastal waters or in partially enclosed seas. Such extremes are due largely to excessive runoff from the land, or to high evaporation rates and little mixing with other waters, as in the Red Sea and the Mediterranean Sea.

General variations in salinity are zoned from the equator to the poles. Values are low at the equator, highest in subtropical regions and at mid-latitudes, and lowest in the polar regions. The major processes responsible for this distribution are evaporation, precipitation, and mixing. Where evaporation exceeds precipitation, salinity values are high, and in areas of high rainfall, as at the equator, they are lower (Figure 9-1). The distribution of surface salinity in the major oceans for the months of August is shown in Figure 9-2. Points of equal salinity are connected by **isohalines**.

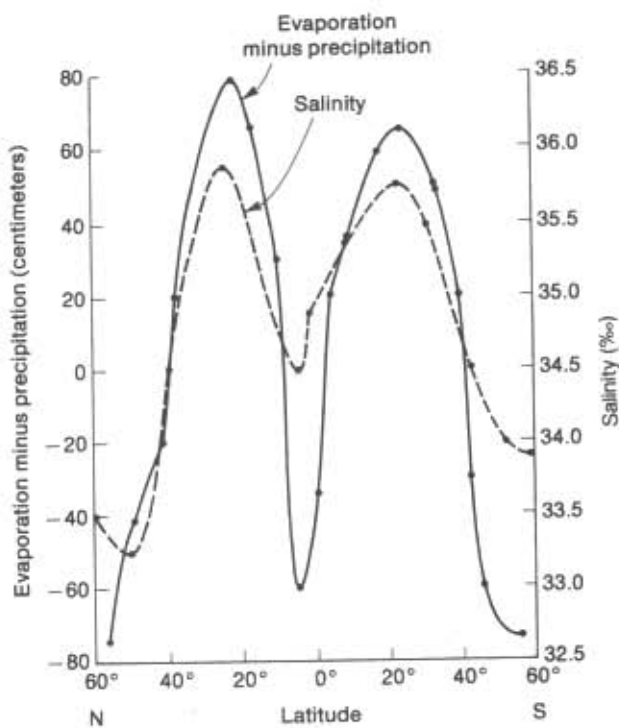


FIGURE 9-1 Distribution of surface salinity plotted against the evaporation minus precipitation. [After S. Defant, *Physical Oceanography*, Vol. 1. Pergamon Press. Copyright © 1961.]

## DETERMINATION OF SALINITY

The salinity of seawater is not a difficult property to determine. One reason is that regardless of the absolute concentration of salts in solution, the major dissolved constituents exist in virtually a constant ratio to one another. This fact was first recognized by Johann Forchhammer and later confirmed in 1884 by Wilhelm Dittmar, who carefully analyzed 77 samples collected on the *Challenger* expedition (1872–1876). Modern analytical techniques have enabled refinement of Dittmar's ratios; however, the importance of his work is not the accuracy of its numerical values, but rather its demonstration of the constancy of the ratios of about a dozen dissolved constituents (Table 9-1). In theory, if you determine the concentration of a major dissolved ion in a sample, you should be able to calculate the concentration of the other major constituents. In practice this is not quite so simple because of the analytical problems in distinguishing between several of the elements. Because chloride is the most common dissolved ion and one of the easiest to determine precisely, its concentration is determined, usually by a procedure known as the **Knudsen titration**, and from that measurement the salinity is calculated:

$$\text{Salinity } (\text{‰}) = 1.80655 \times \text{chlorinity } (\text{‰})$$

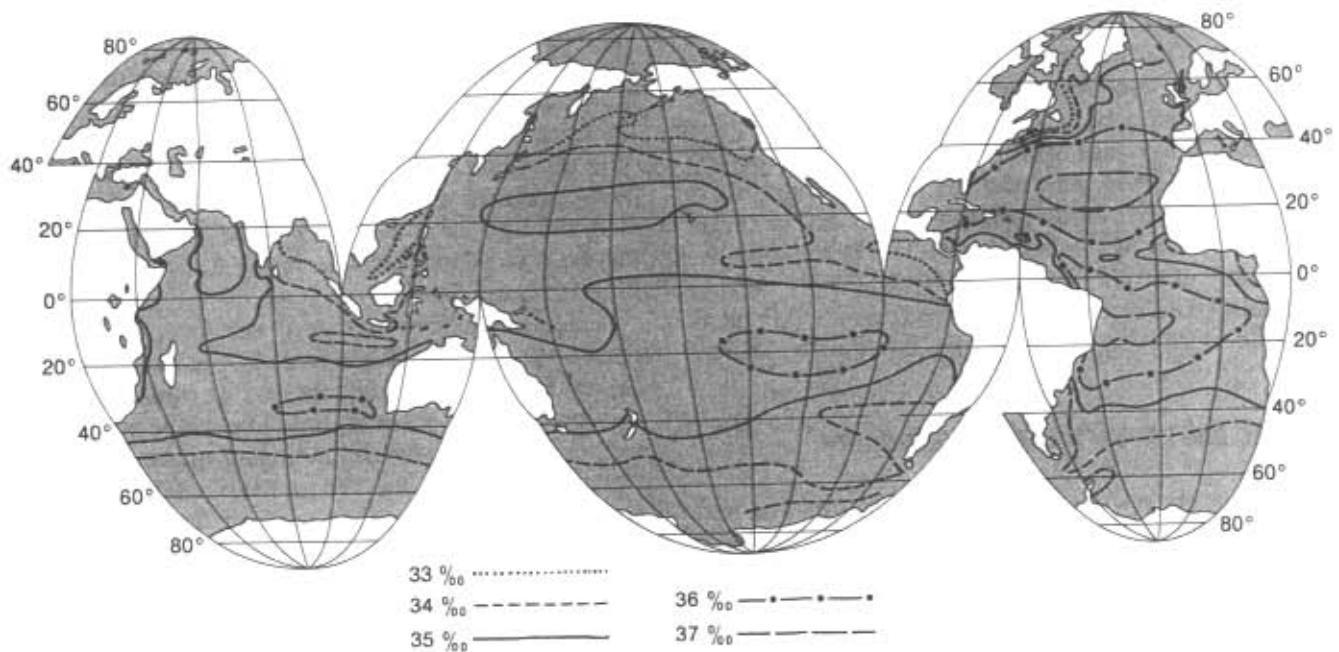


FIGURE 9-2 Salinity distribution in the surface waters of the oceans in August. [Goode Base Map Series. Copyright by the University of Chicago Department of Geography.]

**TABLE 9-1**  
Major dissolved constituents in seawater with a chlorinity of 19‰ and a salinity of 34.32‰.

Dissolved substance	Concentration (grams per kilogram)	Ratio of dissolved salt to chlorinity (‰)	Percentage by weight
Chloride	18.980	0.99895	55.04
Sodium	10.556	0.55557	30.61
Sulfate	2.649	0.13942	7.68
Magnesium	1.272	0.06695	3.69
Calcium	0.400	0.02105	1.16
Potassium	0.380	0.02000	1.10
Bicarbonate	0.140	0.00737	0.41
Bromide	0.065	0.00342	0.19
Boric acid	0.026	0.00137	0.07
Strontium	0.013	0.00008	0.04
Fluoride	0.001	0.00005	0.00
Totals	34.482		99.99

Note in Table 9-1 that the salinity (34.32‰) calculated from the chlorinity of 19.00‰ is less than the salinity determined from the ratios of the elements to chloride ion (34.482). The reason is that bromine and iodine behave as if they were atoms of chlorine in the chemical analysis. However, the definition of salinity specifies that bromine and iodine should be converted to chlorine equivalent (weight) and carbonate converted to the oxide. When these mathematical manipulations have been completed, the chloride concentration increase, carbonate and bromide contents are reduced, and the salinity calculated from a chlorinity of 19.00‰ and that determined from the ratios in Table 9-1 agree very well.

Another analytical method of determining salinity of a salt solution is to measure its ability to conduct an electrical current. **Conductivity** increases with increasing salt content and this property of seawater may be measured with an electrical salinometer. At present, salinity determinations by high-precision conductivity measurements are more standard than chemical methods.

## RESIDENCE TIME

An important concept in oceanography and marine geochemistry is that of **residence time**. It is defined as being equal to the quantity of a substance, whatever that might be, divided by the influx (or deposition) per unit time. It is the mean length of time an atom, molecule, or particle of a given substance spends in its reservoir, be it the atmosphere, oceans, or a lake, and

it is a measure of the reactivity of that substance. Highly reactive substances have short residence times, and vice versa. There are several primary assumptions in the concept: (1) that the substance is thoroughly mixed in the reservoir, and (2) that the rates of supply and removal are constant over at least several residence times. For example, water vapor in the lower atmosphere has a residence time of about 10 days. This means that if no vapor were added to the atmosphere, it would be totally depleted of water in 10 days. Conversely, if the lower atmosphere contained no water vapor, about 10 days of evaporation from oceans and lakes would be required for the water vapor content to reach equilibrium; that is, the amount added by evaporation is equal to the amount lost by precipitation. Water vapor has a much shorter residence time than most substances in the oceans. In this exercise we will be concerned with the residence times for total salt, water, and sodium in the oceans, given the rate of addition from rivers (in tons per year). Residence time,  $R$ , is equal to the total quantity of the substance,  $C$ , divided by the rate of addition,  $A$ , of that substance:  $R = C/A$ .

## DEFINITIONS

**Conductivity.** The ability of a fluid to conduct electrical currents. The conductivity increases with increased salt content. Salinity may be determined by measuring the conductance of seawater with an electronic device called a *salinometer*.

**Density.** The mass per unit volume of a substance. The density of seawater is expressed in grams per cubic centimeter.

**Isohalines.** Lines connecting points of equal salinity in the oceans.

**Knudsen titration.** The classical method for determining the chlorinity. The halides (chlorine, bromine, and iodine) are precipitated from a standard volume of seawater by a silver nitrate solution. The analysis is calibrated against a standard, or normal, seawater sometimes also called *Copenhagen water*.

**Residence time.** The mean length of time a quantity of a given substance—for example, salt, sodium, or water—spends in the ocean before removal.

**Salinity.** The total amount of solid material in grams contained in kilograms of seawater when all the bromine and iodine have been replaced by an equivalent amount of chlorine, all the carbonate has been converted to oxide, and all organic matter has been oxidized. It is usually expressed in parts per thousand.



4. Recall that residence time,  $R$ , is the mean length of time a given element remains in the ocean. It is equal to the total amount of substance,  $C$ , divided by the rate of influx or addition,  $A$  (that is,  $R = C/A$ ). The following table gives the total amounts of water, salt, and sodium in the oceans, and the totals contributed each year by the river.

	Water	Dissolved salt	Sodium
Oceans	$1.4 \times 10^{18}$ tons (C)	$5 \times 10^{16}$ tons (C)	$14 \times 10^{15}$ tons (C)
Rivers	$26.4 \times 10^{12}$ tons per year (A)	$2.7 \times 10^9$ tons per year (A)	$15 \times 10^7$ tons per year (A)

Using these figures, give the residence time for each of the following.

- (a) Water

\_\_\_\_\_ years.

- (b) Dissolved salt

\_\_\_\_\_ years.

- (c) Sodium

\_\_\_\_\_ years.

5. (a) A series of stations off the California coast have been set up to measure the residence time of water in the ocean. The following table gives the total amounts of water, salt, and sodium in the oceans, and the totals contributed each year by the river.