Dissolved Oxygen

Background: Oxygen gas makes up about 21 percent of the earth's atmosphere. Nitrogen is the most abundant gas, at about 78 percent. Carbon dioxide, argon, and helium, hydrogen and other rare gases, account for the remaining one percent.

Oxygen is very reactive chemically, in contrast with nitrogen, which is relatively inert. Oxygen reacts with substances such as iron (Fe) and manganese (Mn), and silicon (Si) to form oxides such as iron oxide (or rust, Fe_2O_3) and manganese dioxide (a black coating on rocks called "desert varnish", MnO_2). In rocks of the earth's crust, and including the atmosphere and the oceans, oxygen is the most abundant element, making up nearly 50 percent of the earth's surface.

Its reactivity is one reason that we and other animals breathe oxygen. Oxygen combines with hemoglobin in our blood and is used in creating energy in our bodies. Without enough oxygen, we would not survive.

All living things depend on oxygen in one form or another to survive. In a water environment, the oxygen is in the form of dissolved oxygen (DO). Different species of aquatic organisms require different amounts of oxygen, but generally aquatic organisms require at least 6 mg/L for normal growth and development. Most fish cannot survive in water with below 4 mg/L DO. Water below 2 mg/L is usually considered anaerobic.

How does oxygen dissolve in water?

Oxygen, like most gases, dissolves to a small extent in water. The amount of a gas that can be dissolved depends on **the pressure of the gas** above the water, **the temperature of the water,** and **the purity of the water.**

Pressure

In the atmosphere, more than one gas is present (oxygen, nitrogen, carbon dioxide, etc.). Each gas can be considered to exert a pressure on the water proportional to its concentration in the mixture of the gases. The sum of these individual "partial pressures" equals the combined pressure of the system. This is known as Dalton's Law.

The partial pressure of each gas depends on the altitude. The higher you are in the atmosphere, the less pressure. For example, on mountain tops there is less atmospheric pressure than in their valleys. The greater the pressure, the more oxygen can dissolve in water. It is as though the molecules of oxygen were pressing against the water, and the harder they press (higher pressure)

the more will be pushed into the water. Therefore, the amount of a gas (oxygen in this case) that will dissolve in water is proportional to the partial pressure of the gas (partial pressure of oxygen) above the water. This is a paraphrase of Henry's Law.

Temperature and Purity of Water

The temperature of the water is another factor that governs the amount of oxygen that can dissolve in water. The higher the temperature, the less oxygen can dissolve in water. Table I gives the solubilities of oxygen at various elevations (pressures) and temperatures. From the table, we see that the solubility of oxygen would be about 8.4 mg/L at room temperature (20°C) at the elevation of Tucson (2300 feet). This means that a maximum of 8.4 mg/L of oxygen could dissolve into the water. A solubility of 8.4 mg/L of dissolved oxygen is the concentration of oxygen that would saturate the water with oxygen. 8.4 mg/L is the saturation point, the water's holding capacity for oxygen. The water can hold no more oxygen than its saturation or solubility value at the water's temperature.

The purity of the water can also affect how much oxygen is able to dissolve into water. The more minerals or contaminants that are in the water, the less oxygen can dissolve into the water. Table I shows solubilities for pure water. If the water had a lot of salts in it, the solubility for water at room temperature in Tucson may be less than 8.4 mg/L.

What are other sources of oxygen that can add to the dissolved oxygen in the water?

1) **Atmospheric Oxygen**
As mentioned above, atmospheric oxygen exerts pressure on water surfaces and pushes its way into the water.

More atmospheric oxygen can enter water that is turbulent than water that is sitting still. This is because when water is moving and tumbling, there is more water surface in contact with the atmosphere. These interfaces are areas where atmospheric oxygen has a chance to exert pressure on the water and enter the water. The more water surface area the atmosphere is in contact with, the more opportunity there is for gases to dissolve into the water.

2) **Photosynthesis**
Chlorophyll containing plants use energy from the sun to convert carbon dioxide and water to organic material. Oxygen is created in the process. This oxygen can dissolve to an extent in water, again depending on the temperature and purity of the water.

$$6\ CO_2 + 6\ H_2O + \text{light energy} \equiv\equiv\equiv> C_6H_{12}O_6 + 6\ O_2$$

TABLE I

For Pure water

Solubility of Oxygen (mg/L) at Various Temperatures and Elevations
(Based on Sea Level Barometric Pressure of 760 mm Hg)

Temperature	Elevation, Feet above Sea Level						
°C	0	1000	2000	3000	4000	5000	6000
0	14.6	14.1	13.6	13.2	12.7	12.3	11.8
2	13.8	13.3	12.9	12.4	12.0	11.6	11.2
4	13.1	12.7	12.2	11.9	11.4	11.0	10.6
6	12.4	12.0	11.6	11.2	10.8	10.4	10.1
8	11.8	11.4	11.0	10.6	10.3	9.9	9.6
10	11.3	10.9	10.5	10.2	9.8	9.5	9.2
12	10.8	10.4	10.1	9.7	9.4	9.1	8.8
14	10.3	9.9	9.6	9.3	9.0	8.7	8.3
16	9.9	9.7	9.2	8.9	8.6	8.3	8.0
18	9.5	9.2	8.7	8.6	8.3	8.0	7.7
20	9.1	8.8	8.5	8.2	7.9	7.7	7.4
22	8.7	8.4	8.1	7.8	7.7	7.3	7.1
24	8.4	8.1	7.8	7.6	7.3	7.1	6.8
26	8.1	7.8	7.6	7.3	7.0	6.8	6.6
28	7.8	7.5	7.3	7.0	6.8	6.6	6.3
30	7.5	7.2	7.0	6.8	6.5	6.3	6.1
32	7.3	7.1	6.8	6.6	6.4	6.1	5.9
34	7.1	6.9	6.6	6.4	6.2	6.0	5.8
36	6.8	6.6	6.3	6.1	5.9	5.7	5.5
38	6.6	6.4	6.2	5.9	5.7	5.6	5.4
40	6.4	6.2	6.0	5.8	5.6	5.4	5.2

OXYGEN DISTRIBUTION IN A STRATIFIED LAKE

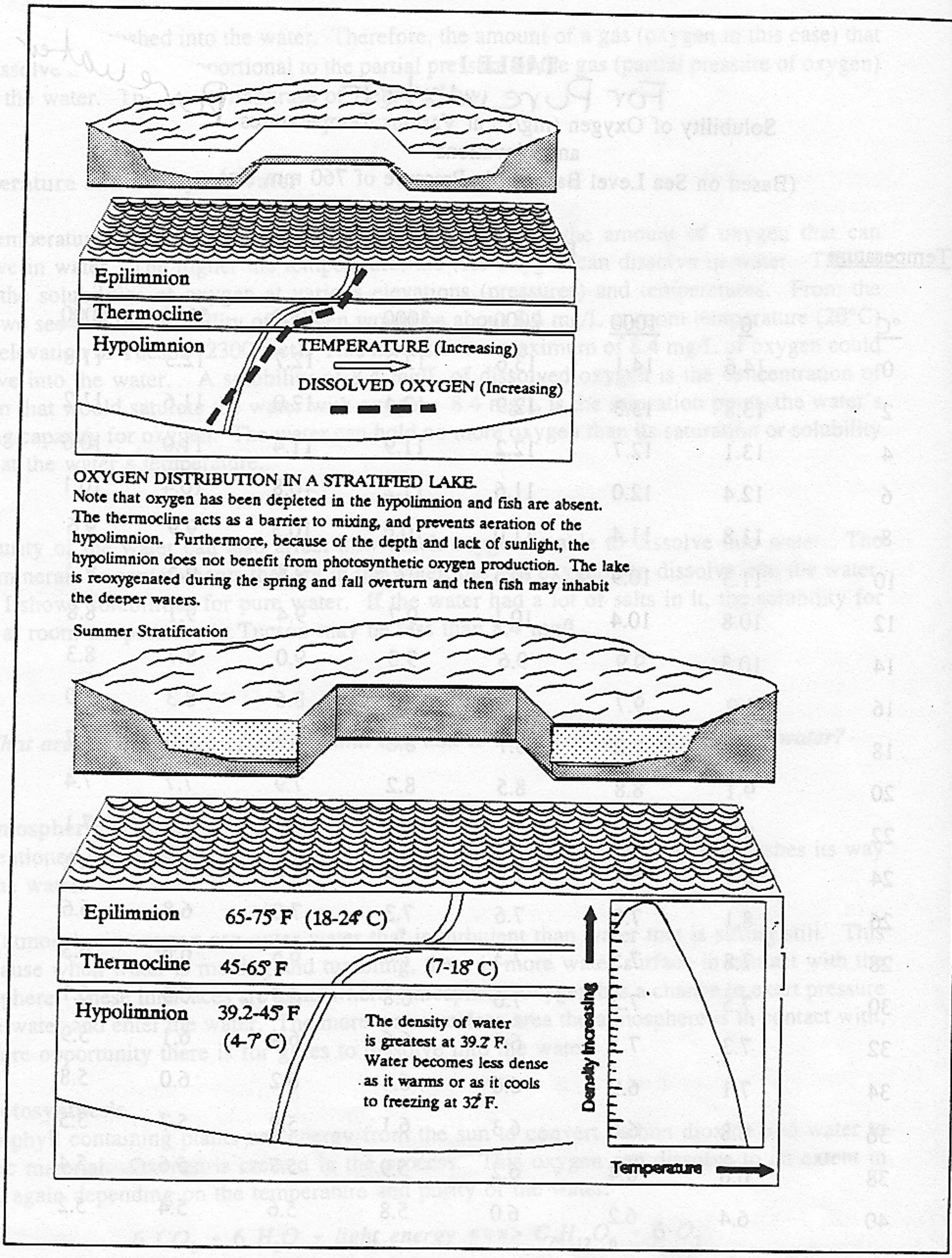

Figure 1: Relationship of Dissolved Oxygen to Temperature in a Stratified Lake.

How is dissolved oxygen lost from the water?

1) **Respiration**

Respiration is the process by which organisms derive energy by using oxygen to break down organic material to simpler materials, ultimately carbon dioxide and water. This process is usually performed by plants during times without sunlight (non-photosynthetic period) or by decomposers such as bacteria and fungi that breakdown dead organic matter at the lake or river bottom. Decomposers can also break down organic wastes input to a stream as sewage effluent or factory wastes. Oxygen is used up very rapidly as organisms respire.

$$C_6H_{12}O_6 + 6\ O_2 \equiv\equiv\!> 6\ CO_2 + 6\ H_2O + energy$$

Why is pollution a problem in water bodies?

Most pollution contains organic material that microorganisms (decomposers) feed on. When these organisms feed on these wastes, they use tremendous amounts of oxygen in the process. These organisms multiply rapidly and deplete the dissolved oxygen much faster than it can be replaced. The amount of dissolved oxygen that the microorganisms need in order to decompose the wastes is called the biochemical oxygen demand (BOD). The BOD can be measured in the laboratory with a sample of water with the wastes in it; the standard test takes 5 days to perform.

Dissolved Oxygen and Water Quality

The amount of dissolved oxygen is an important indicator of water quality. The greater the concentration of dissolved oxygen, the better the quality of the water. When DO is very low, anaerobic microorganisms can flourish and take over the water body. This is not a favorable condition because water can become septic or dark colored and odorous. If there is not sufficient oxygen, "good" organisms such as fish and invertebrates can no longer live in the water and we humans will not be able to drink the water.

Dissolved Oxygen and Lakes

Temperature and dissolved oxygen are parameters often used to study lake processes. Lakes go through cyclical changes with the seasons. During the spring and fall, lakes are generally well-mixed and have about the same temperature throughout. However, during the summer months, the lake surface is warmed by the sun and winds are light. Water in direct contact with the sun will be heated relatively quickly but that heat cannot be transmitted to the bottom layers by conduction since the specific heat of water is so high or by convection (tendency of warm air to rise) since the warmer, less dense water is already at the surface. Therefore, the lake will form two layers of considerably different temperatures. This layering effect of a lake is called **stratification.**

The top layer of warm water is called the **epilimnion** ("epi" = outer, "limnos"= lake). The

epilimnion layer itself is generally well-mixed, with the same temperature and DO concentration throughout. The bottom deeper region of colder water is called the **hypolimnion**. Between these two layers is the **metalimnion** ("meta" = middle). Since this region is characterized by a rapid change in temperature, it is often referred to as the **thermocline**.

When a lake is stratified, each layer is defined by its depth. For example, the metalimnion of a lake may be the region at a depth between 6 ft and 9 ft. Dissolved oxygen will be abundant in the epilimnion layer or photic zone, where sunlight will promote photosynthesis and the production of oxygen. In the hypolimnion, decay organisms at the lake bottom are busy decomposing the organic material that filters down to them. This process uses a lot of oxygen. Since the hypolimnion water is not exposed to atmospheric oxygen and since the metalimnion acts as a barrier, preventing oxygen from the epilimnion from going into lower layers, the hypolimnion often suffers from very low dissolved oxygen concentrations. Therefore, fish and other relatively large aquatic organisms will tend to gravitate toward the epilimnion layer in order to obtain enough oxygen to survive.

In the winter months, stratification may also occur if the epilimnion layer becomes frozen and floats on top of deeper, hypolimnion water. During the fall, as the epilimnion cools to temperatures below that of the deeper water, the cooler water from the epilimnion moves down as it is denser than the water below. This causes **overturning**, a process which mixes or de-stratifies the lake water.