Then during expiration, alveolar air containing 5 to 6 per cent carbon dioxide and 12 to 14 per cent oxygen, is forced from the alveoli through the dead space, leaving this dead space filled with alveolar air. The first part of the exhalation is essentially atmospheric air and the last part alveolar air, with the mixture growing richer in alveolar air throughout expiration. Undiluted alveolar air can be obtained successfully only from air forcibly exhaled at the end of an ordinary respiration. Failure to consider this well-established fact can lead to serious errors in sampling expired air, as for instance in the determination of the radon content of the alveolar air. The maximum rate of physical activity that can be maintained by an individual is probably more dependent upon his maximum breathing capacity, minute ventilation, than upon lung volume. This minute ventilation is partially conditioned by frictional resistance along the air passages due to impediments, such as constrictions and abrupt changes in direction, or air passages merging at too great an angle.

C. REGULATION AND CONTROL OF RESPIRATION

The respiratory movements are regulated and controlled chemically as well as by the voluntary and involuntary nervous systems. Carbon dioxide acts as a stimulus to the respiratory center, and the CO_2 tension in the blood is by far the most significant factor of control. It is thought to act by raising the hydrogen-ion concentration of the respiratory center. Lactic acid resulting from strenuous exercise is thought to have a similar effect. Oxygen—or, rather, lack of it—is likewise a stimulus, but under normal conditions does not come into play because the partial pressure of oxygen in the alveolar air must fall markedly before the oxygen tension of the arterial blood is significantly affected. This is easily understood upon examination of the oxygen dissociation curve for blood, as is illustrated in Figure 1. Men with long experience in testing atmospheres in the holds

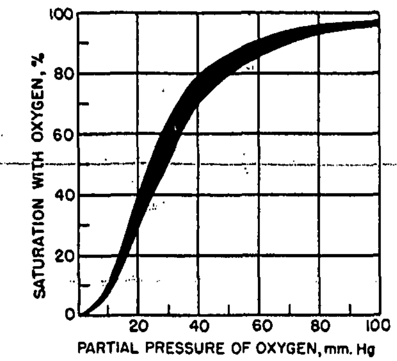

Figure 1. Dissociation curve of oxyhemoglobin for human blood expressed as the normal range of percentage of saturation with oxygen. (After Barcroft.)

of ships say that they can recognize atmospheres deficient in oxygen by this stimulating effect, but this is not recommended practice even for the well initiated because the margin between irrespirable atmospheres and those causing respiratory distress in the form of hyperpnea and dyspnea is too narrow. The suddenness of the onset of weakness and unconsciousness is so very marked that should a man enter an oxygen-deficient atmosphere by means of a ladder, the probability of his being able to remount the ladder unassisted, after becoming aware of distress, is not favorable.

The tension or partial pressure of oxygen in normal air is 20.95 per cent of an atmosphere, which equals 159.2 mm. Hg at sea level. Significant symptoms of distress do not occur until the percentage falls below 16 per cent, while unconsciousness may occur at concentrations below 11 per cent, and breathing soon stops if the oxygen falls below 6 per cent.

D. FUNCTION OF HEMOGLOBIN

The transportation of oxygen from the lungs to the cellular tissues is accomplished largely by means of the hemoglobin in the red cells of the blood. Likewise the carbon dioxide removed from the tissues is transported chiefly by the same agent. Each 100 ml. of arterial blood contains about 15 g. of hemoglobin, which combines with 19 or 20 ml. of oxygen. In blood that is in equilibrium with air at normal atmospheric pressure, about 1 per cent of the total oxygen is in solution in the plasma. Normal venous blood contains 12 to 14 ml. of oxygen per 100 ml. of blood, and about 1 per cent of this is dissolved in the plasma. For the return trip to the lungs the venous blood carries 55 to 60 volume per cent carbon dioxide and deposits about 10 per cent of this as it takes up its oxygen supply. The amount of carbon dioxide in simple solution is about 3 volume per cent in the venous blood and 2.5 volume per cent in the arterial blood. Since the blood in making its circuit flows through the capillaries of the lungs in approximately 1 second,[3] and through active tissue in a similar time, it is evident that mere solution of oxygen and carbon dioxide cannot account for the exchange of these gases, even though the equilibration in the lungs is highly efficient. The speed of exchange is due to the light combination of these gases with hemoglobin to form oxyhemoglobin and carbhemoglobin, respectively, as well as to the presence of catalysts in the red cells that play an important part in the oxygen and carbon dioxide exchange. Carbonic anhydrase is said by Best[3] enormously to increase in either direction the reversible chemical reaction $H_2CO_3 \rightleftharpoons CO_2 + H_2O$, while oxidation and reduction in the tissues are greatly accelerated by oxygen-activating catalysts or by dehydrogenases.

E. CIRCULATION AS A FACTOR, AND ITS REGULATION

Since the oxygen in the lungs cannot take part in the metabolic process until

[3] C. H. Best and N. B. Taylor, *The Physiological Basis of Medical Practice.* 6th ed., Williams & Wilkins, Baltimore, 1955.