it has entered the blood stream and then been transported to the tissues, it is evident that the circulation rate is an important factor in respiration. The blood volume is usually slightly greater than the lung capacity. For a normal man it is approximately 6 to 7 liters.[3]

The time required for a complete circuit of the blood varies with exercise, the part of the body supplied, and many other factors, but averages somewhat less than 1 minute. The normal heart stroke is about 60 to 70 ml., with a resting pulse of 68 to 72 per minute, giving a minute volume of 4 to 5 liters. Exercise can increase the heart stroke to 100 or 200 ml. and the pulse rate to 170 or 180. Environmental temperatures above 30° C. increase the minute volume 5 to 30 per cent. Digestion of food increases the basal minute volume by 30 to 40 per cent for about 3 hours. Emotional strain causes an increase of 15 to 25 per cent. pH changes have an effect, as do naturally occurring, as well as foreign, chemicals having a vasoconstrictor or vasodilator reaction. Also, just as the amount and content of the venous supply to the lungs play a major role in regulating the breathing required to keep the arterial blood constant, so does the circulation depend on breathing, and any retardation of breathing will be quickly followed by a change in circulation. Henderson[4,5] strikingly demonstrated the control of circulation by breathing when he showed that excessive pulmonary ventilation could induce failure of the circulation. The part played by respiration in the action of atmospheric contaminants upon the body will be discussed later.

III. Absorption, Distribution, and Elimination

A. MODES OF EXPRESSING CONCENTRATIONS

The extent of atmospheric contamination in the gaseous phase is frequently expressed as parts per million (p.p.m.), denoting units of volume in 1,000,000 volumes, and is usually corrected to 25° C. and 760 mm. Hg pressure. This is a convenient mode of expression and, for routine examinations of workroom atmospheres, the actual conditions are frequently not sufficiently removed from this standard to require temperature–pressure corrections. Since comparisons in p.p.m. are on a volume—hence molecular—basis they have no direct relation to the weight–volume expression of milligrams per liter occasionally used, especially in foreign technical publications. The milligrams per liter unit has the advantage of being more readily compared with existing pharmacological and dosage data expressed as milligrams per kilogram of body weight. On the whole, however, the p.p.m. unit has proved much more convenient and expressive in industrial hygiene, where low concentrations of contaminants are the rule. Variations in the expression of parts by volume are: per cent by volume, parts per thousand, parts per ten thousand, parts per hundred thousand, parts per hundred million, and parts per billion. The excuse for employing so many units is the desire to

[4] Y. Henderson, *Am. J. Physiol.*, **25**, 310 (1910).
[5] Y. Henderson and H. W. Haggard, *J. Biol. Chem.*, **33**, 355 (1918).

use small whole numbers. However, this multiplicity of units is confusing and might better be confined to not more than three units: per cent, parts per million, and parts per billion. Per cent by volume is generally used when the concentrations are on the order of 0.1 per cent or greater. Parts per million is a logical unit for concentrations ranging from 1,000 down to 1 or even 0.1 p.p.m. For concentrations less than 1 p.p.m., parts per billion (p.p.b.) appears to be the logical unit. One million p.p.b. = 1,000 p.p.m. = 0.1 per cent = a partial pressure of 0.76 mm. Hg at sea level. One gram mole of a perfect gas or vapor has a volume of 24.45 liters at 25° C. and a pressure of 760 mm. Hg. Therefore under these conditions:

$$1 \text{ p.p.m.} = \frac{\text{molecular weight}}{1000 \times 24.45} \text{ mg. per liter;}$$

and

$$1 \text{ mg. per liter} = \frac{24.45 \times 1000}{\text{molecular weight}} \text{ p.p.m.}$$

A conversion table for gases (p.p.m. to mg. per liter and mg. per liter to p.p.m.) is given on pages xvi–xvii. Another method of expressing gas concentrations is the partial pressure method, using the unit of the pressure exerted by one millimeter of mercury. This is convertible directly to per cent by volume by multiplying by 100 and dividing by the barometric pressure; or to p.p.m. by multiplying by 1,000,000 and dividing by the barometric pressure:

$$\frac{\text{Partial pressure of one constituent}}{\text{Total barometric pressure}} \times 1{,}000{,}000 = \text{p.p.m. of constituent}$$

When the contaminant is dispersed in the atmosphere in solid or liquid form, as a mist, dust, or fume, its concentration must be expressed either on a weight per volume basis or particles per volume basis. Liquids and toxic solids are usually expressed as milligrams per cubic meter, or per 10 cu. m. to approximate the maximum amount inhaled in one 8-hour day by a workman doing moderately heavy work. This standard was originally based on 20 liters per minute × 60 minutes × 8 hours = 9600 liters = 9.6 cu. m. Henderson and Haggard[1] estimate the average breathing rate to be 8 liters per minute or about 4 cu. m. per 8-hour day. Since not only the minute volume, but also retention, the physiological dead space and other factors must be considered in computing daily systemic intake, the validity of the figure, 10 cu. m., is open to question. Those dusts that exert their effects largely within the lungs, rather than throughout the system as a whole are usually counted microscopically and expressed as million particles per cubic foot of air. Outdoor air contaminants and stack effluents are frequently expressed as grams, milligrams, or micrograms per cubic meter, ounces per thousand cubic feet, pounds per thousand pounds of air, and grains per cubic