Pflügers Arch. 361, 201–204 (1976) – © by Springer-Verlag 1976

Effect of Percentual Water Content in Tissues and Liquids on the Diffusion Coefficients of O_2, CO_2, N_2, and H_2

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The theory of diffusion in isotropic media is based on the hypothesis that the rate of transfer of diffusing particles through unit area of a section is proportional to the concentration gradient, whereby the proportionality factor D (cm^2/sec) is termed diffusion coefficient. D is used in the analysis of nonsteady-state exchange processes as well as in steady- state transfers coupled with chemical reactions. For gaseous and non-gaseous solutes with molecular weights below 1,000 there exists an inverse proportionality between D and the square root of molecular weight (GRAHAM's law) [43]. Using some calculated diffusion coefficients for various inert gases in rat skeletal muscle, however, a better correlation could be obtained between D and the molecular diameter [25].

The main purpose of such studies is to estimate or to predict diffusion coefficients in a specified diffusion medium if molecular weight or molecular diameter of solute molecules are known. A comparison of diffusion coefficients of various solutes with different molecular weights in different tissues, however, shows that the described useful approximation cannot be maintained anymore. The diffusion coefficient of solute molecules may differ rather considerably with regard to different tissues [45].

It is a well known fact that the concentration of certain components, such as lipids, proteins, DNA, and mucopolysaccharides (hyaluronic acid or chondroitin, which are present in extracellular ground substances of connective tissue) can largely influence the magnitude of the diffusion coefficient as well as BUNSEN's solubility coefficient [54]. Furthermore extreme variations of the viscosity may influence the magnitude of D values too.

The purpose of this note is to show that the diffusivity of various gases in aqueous media can be described satisfactorily in terms of one parameter: the water content of the diffusion medium.

The diffusion coefficients of O_2, CO_2, N_2, and H_2 listed here are published values. Percentual water content of the tissues is taken from biological data books [8,41]. All D values presented here are referred to 37°C. Published values of D which are not related to this temperature have been corrected using the equation according to SWABB et al. [45]. The D values used do not include data on O_2 and CO_2 transport where facilitated transport can occur at low partial pressures of O_2 and CO_2.

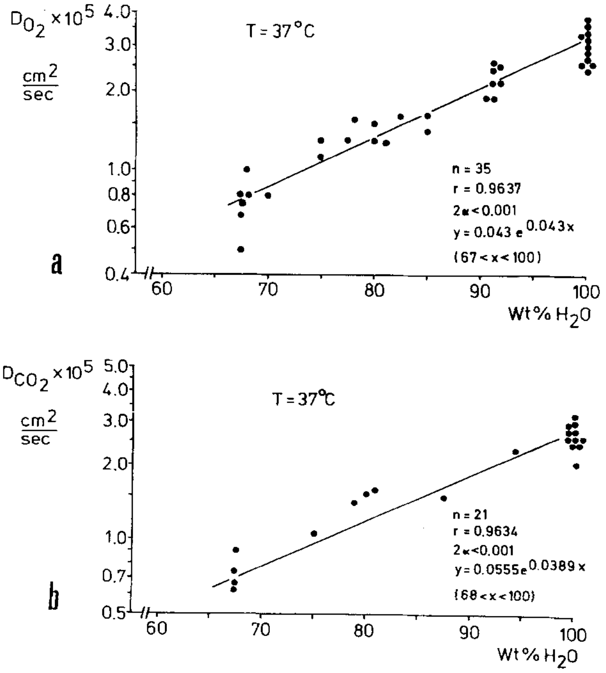

Fig. 1. Plot of available data for O_2 diffusion coefficient D_{O_2} (a) and CO_2 diffusion coefficient D_{CO_2} (b) in various diffusion media against percentual water content (wt% H_2O) of the media at 37°C

In Fig. 1a a plot of D_{O_2} values as a function of percentual water content is given for 35 diffusion coefficients in water [2,5,11,16,21,22,23,30,40,46,53], in plasma, serum, and protein solutions [6,11,13,28,29,44,53], in red blood cells [17,27,44], in blood [44], and in various tissues [14,17,20,25,26,31,35,48,49]. With diminishing water content of the diffusion media a significant exponential decrease of D_{O_2} can be observed. At water contents of about 80 wt% D_{O_2} is found to be half the D value in water. At water contents of 65 - 70 wt% D_{O_2} is reduced to 25% of the value in water, thus indicating a distinct impairment of the diffusivity. The different diffusion coefficients for O_2 plotted in Fig. 1a cannot be explained by variations of viscosities. Furthermore the agreement between the data of D_{O_2} in tissues, in KOH solutions [19,47], sucrose solutions [23], hemoglobin and protein solutions [30], i.e. media with great variations of the viscosity, is quite satisfactory in general.

In Fig. 1b D values for CO_2 are represented in a similar plot (line of the best fit). Values are D_{CO_2} in water [1,5,7,9,12,15,21,22,38,42,46], in a 2.3% NaCl solution [21], in red cells and hemoglobin solutions [15], and in several tissues [25,26,32,51,52]. In this case, too, a significant decrease of the diffusion coefficient with decreasing water content of the diffusion media can be observed.

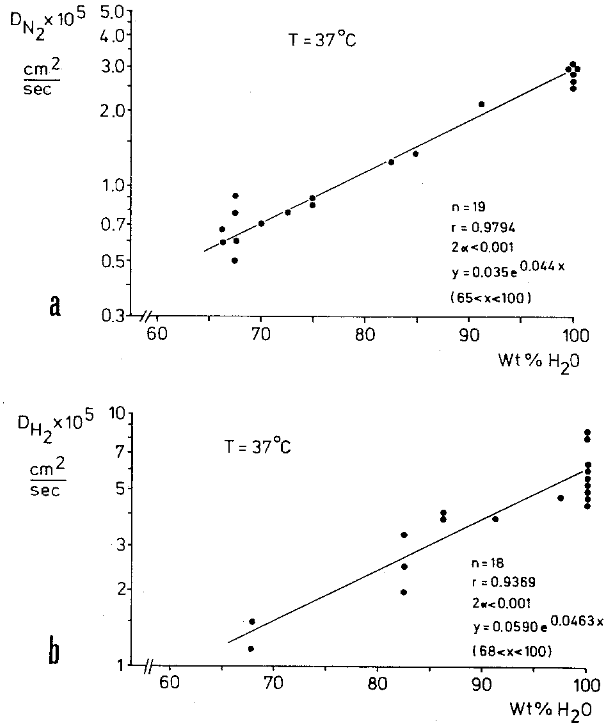

Fig.2. Plot of available data for N_2 diffusion coefficient D_{N_2} (a) and H_2 diffusion coefficient D_{H_2} (b) in various diffusion media against percentual water content (wt% H_2O) of the media at 37°C

D values for N_2 in water [1,4,11,21,22,46] in serum [11], in hemoglobin solutions [36] in a 1% agar jelly [10], and in various tissues [26,31,34,35,39] are plotted in Fig. 2a, while available data for D_{H_2} in water [1,11,21,22,24,47,50], in serum [11], in agar jellies [3], and in tissues [18,25,33,34,37,39] are presented in Fig. 2b. All figures clearly demonstrate that the water content of the diffusion media regularly influences the magnitude of the diffusion coefficients of solute molecules. D values for O_2, CO_2, N_2, and H_2 decrease exponentially with dropping water content of the tissues and diffusion media. When using the calculated regression lines for D values it is possible to predict and to estimate the diffusion coefficient for gases in various tissues if the water content is known.

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Received November 3, 1975