

A Generalized Correlation of Diffusion Coefficients

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Graphical correlations of binary gas diffusion coefficients are developed based on the Hirschfelder-Bird-Spotz diffusion equation and the theorem of corresponding states. A critical diffusion coefficient is defined and is used in turn for a definition of a "reduced" coefficient. The reduced diffusion coefficient is correlated graphically in generalized form in terms of the reduced properties of the diffusing gas. Using air as a reference "barrier" gas, the authors compared critical diffusion coefficients for various gases diffusing through a single barrier gas with the critical coefficients for these gases through air. This ratio, termed the *barrier gas ratio*, was found to be independent of the properties of the diffusing gas. A graphical correlation of the barrier gas ratio enables rapid estimation of a binary diffusion coefficient with a minimum of information.

While the importance of gaseous diffusion coefficients in chemical engineering calculations is well recognized, the availability of experimental data is limited and desired values must usually be estimated. This paper discusses the problems attendant on gaseous-diffusion-coefficient estimation and presents a generalized estimating technique which is both reliable and simple, particularly when applied to repetitive calculations.

Early theoretical work by Sutherland (13) and Gilliland (5) led to diffusion coefficient equations which had several recognized shortcomings. The equations were not applicable over wide temperature and pressure ranges, and the required calculations were sometimes tedious and cumbersome, particularly in their application to multicomponent systems. In general, the equations were based on a somewhat primitive kinetic theory of molecular collision, with empirical or semiempirical correction factors obtained from a meager supply of reliable experimental information.

Chapman and Cowling (2) made use of a realistic and correct approach to molecular interaction by taking into

account the potential field surrounding a molecule. Hirschfelder and coworkers (4, 6, 7, 8) then utilized the Chapman and Cowling model, applied the Lennard-Jones 6-12 equation for the energy profile on close approach of two molecules, and arrived at basic equations for each of the transport properties of a gas. Mathematical analysis of the intermolecular forces resulting from close molecular approach involved an evaluation of a complex function called the collision integral ϕ . This function serves as a correction factor for the familiar expressions derived from the simple kinetic theory. Thus the modified diffusion equation derived by Hirschfelder, Bird, and Spotz (7) (hereafter called the H-B-S equation) for binary pairs of spherical, nonpolar molecules is as follows:

$$D_{AB} = \frac{(1.492 \times 10^{-3})T^{3/2}}{Pr_{AB}^2 \phi_{AB}} \cdot \left(\frac{1}{M_A} + \frac{1}{M_B} \right)^{1/2} \quad (1)$$

where A and B are the diffusing and barrier gases, respectively.

The collision integral ϕ as evaluated by Hirschfelder, Bird, and Spotz may be plotted as a function of the group kT/ϵ as shown in Figure 1. A simple analytical expression is not easily fitted to a rela-

tionship of this kind, as Scheibel (12) indicated in his discussion of the collision integral function involved in the viscosity expression for gases. It is of interest to note, however, that the slope varies from about -0.1 to about -0.5 over the normal range of engineering calculations. Thus the net dependence of D_{AB} on T in Equation (1) is of the order of the 1.6 to 2.0 power, which agrees with most experimental findings.

The proper use of Equation (1) involves determination of the mean molecular diameter, evaluation of the collision integral, and assumption of linear dependency of the diffusion coefficient on total pressure. Because of ternary and higher order collisions, this last named assumption breaks down at elevated pressures approaching the critical, but linear extrapolation with pressure is permissible in pressure ranges for which binary collisions predominate. Within these limitations it was suggested by Hirschfelder (7) that in the absence of reliable experimental data on molecular diameters and interaction energy, the diameter be estimated by the equation

$$r_A = 3.30(V_{cA})^{1/3} \quad (2)$$

The arithmetic average of the diameters of the diffusing and barrier molecules, obtained by use of Equation (2), is taken

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as the collision diameter. The characteristic ratio ϵ_{AB}/k may be taken as the geometric mean of ϵ_A/k and ϵ_B/k . These values may be obtained from viscosity measurements or second virial coefficients or may be estimated from the equation

$$\epsilon_A/k = 0.75T_{cA} \quad (3)$$

The H-B-S equation is generally recognized as the best means presently available for estimating binary diffusion coefficients in the gas phase. It is not difficult to use for occasional calculations, although a table of collision integrals is required. When many coefficients must be evaluated, however, the procedure becomes time consuming, and a simplified yet accurate technique becomes desirable. Accordingly, graphical correlations are developed in this paper which have as their basis Equations (1), (2), and (3) above.

CRITICAL DIFFUSION COEFFICIENT

In a recent monograph Hougen (9) pointed out that generalized graphical correlations based on the theorem of corresponding states had been developed for both viscosity and thermal conductivity in terms of reduced properties but that no comparable correlation had as yet been devised for diffusion coefficients. As all gas transport properties may be related to essentially identical molecular interaction mechanisms, it is logical to assume that a graphical correlation with reduced properties can be developed for the diffusion coefficient.

Inasmuch as the H-B-S transport equations were used successfully by Bromley and Wilke (1) in the generalization of gas viscosity in terms of reduced properties, it appeared to the authors that a parallel development for diffusion coefficients on the same basis would be in order. Diffusion coefficients however present a unique situation with regard to correlation, because it is necessary to deal initially with a binary system rather than a pure substance, as is the case with other transport properties. As a starting point for the prediction of diffusion coefficients by means of reduced properties of a binary system, it was therefore necessary to define a critical diffusion coefficient as a reference point for a particular gas diffusing through another gas. This was done by means of Equation (1), the critical diffusion coefficient for A diffusing through B being arbitrarily defined as

$$D_{cAB} = \frac{(1.492 \times 10^{-3})T_{cA}^{3/2}}{P_{cA}T_{cAB}^2\phi_{cAB}} \cdot \left(\frac{1}{M_A} + \frac{1}{M_B} \right)^{1/2} \quad (4)$$

where ϕ_{cAB} is evaluated with the aid of Equation (3) at the critical temperature of A.

The foregoing equation, of course, introduces the difficulty that the critical

diffusion coefficient so defined loses some physical significance, since it is possible for the binary collision basis of Equation (1) to be violated at conditions approaching the critical. If the critical properties of the diffusing gas are employed, the critical diffusion coefficient of A through B is not equal to that of B through A, as is the case for "ordinary" diffusion coefficients. Rather, the critical coefficients are related by the equation

$$\frac{D_{cAB}}{D_{cBA}} = \left(\frac{T_{cA}}{T_{cB}} \right)^{3/2} \left(\frac{P_{cB}}{P_{cA}} \right) \left(\frac{\phi_{cBA}}{\phi_{cAB}} \right) \quad (5)$$

The inequality of the two critical diffusion coefficients is due to the arbitrary use of the critical properties of the diffusing gas as system conditions in Equation (4); the only properties of the barrier gas affecting the equation directly are its molecular weight, molecular diameter, and its contribution to the collision integral. A further qualification must be introduced in that the critical diffusion coefficient has no meaning when the barrier material is not in the gaseous state at the critical temperature and pressure of the diffusing gas. In spite of this limitation, the concept of the critical diffusion coefficient has been found to be quite convenient as a datum, and its further application presents no serious practical problems as long as the inherent limitations are borne in mind.

REDUCED DIFFUSION COEFFICIENT

In view of the definition of the critical diffusion coefficient given above, a reduced diffusion coefficient may now be defined as follows:

$$\begin{aligned} D_{rAB} &= \frac{D_{AB}}{D_{cAB}} \\ &= \left(\frac{T_A^{1.5}}{P_A\phi_{AB}} \right) \bigg/ \left(\frac{T_{cA}^{1.5}}{P_{cA}\phi_{cAB}} \right) \\ &= \frac{T_{rA}^{1.5}}{P_{rA}\phi_{rAB}} \end{aligned} \quad (6)$$

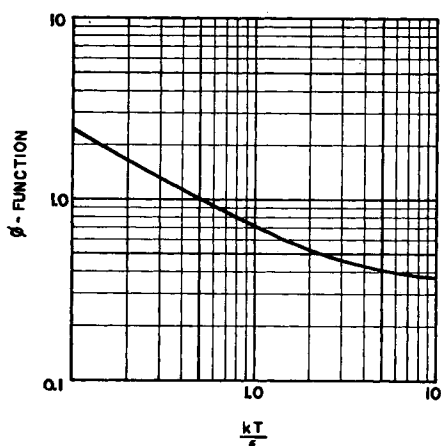


Fig. 1. Collision integral as function of group (kT/ϵ) .

where

$$\phi_{rAB} = \frac{\phi_{AB}}{\phi_{cAB}} = \frac{f\left(\frac{kT_A}{\epsilon_{AB}}\right)}{f\left(\frac{kT_{cA}}{\epsilon_{AB}}\right)}$$

TABLE 1—CRITICAL DATA AND BARRIER GAS RATIOS

Gas A	D_{cA-air} sq. ft./hr.	$\frac{D_{c(z-A)}}{D_{c(z-air)}}$
Acetic acid	0.0253	0.48
Acetone	0.0218	0.47
Acetylene	0.0110	0.82
Air	0.00462	1.00
Aniline	0.0280	0.36
Ammonia	0.0126	1.04
Argon	0.00435	0.90
Benzene	0.0223	0.40
Bromine	0.0130	0.42
Bromobenzene	0.0266	0.30
Butadiene 1,3	0.0179	0.49
Isobutane	0.0183	0.46
n-Butane	0.0190	0.46
Butene-1	0.0182	0.48
Carbon dioxide	0.00846	0.73
Carbon disulfide	0.0156	0.46
Carbon monoxide	0.00496	0.98
Carbon tetrachloride	0.0214	0.35
Chlorine	0.0116	0.55
Chloroform	0.0182	0.38
Cyclohexane	0.0241	0.37
Cyclopentane	0.0210	0.42
Dimethyl ether	0.0142	0.55
Ethane	0.0120	0.71
Ethyl acetate	0.0240	0.38
Ethyl alcohol	0.0192	0.54
Ethyl chloride	0.0171	0.48
Ethyl ether	0.0217	0.41
Ethylene	0.0110	0.79
Ethylene oxide	0.0157	0.60
Fluorobenzene	0.0231	0.38
Freon-11	0.0177	0.38
Freon-12	0.0148	0.42
Freon-113	0.0211	0.32
n-Heptane	0.0296	0.32
n-Hexane	0.0261	0.35
Hydrogen	0.00365	4.08
Hydrogen chloride	0.0111	0.91
Hydrogen cyanide	0.0224	0.69
Iodobenzene	0.0293	0.29
Methane	0.00789	1.11
Methyl acetate	0.0208	0.43
Methyl alcohol	0.0187	0.60
Methyl chloride	0.0134	0.58
Nitric oxide (NO)	0.00510	0.10
Nitrogen	0.00470	0.99
Nitrogen dioxide (NO ₂)	0.0116	0.70
Nitrous oxide (N ₂ O)	0.00885	0.72
n-Octane	0.0329	0.28
Oxygen	0.00459	0.97
Ozone	0.00755	0.74
n-Pentane	0.0227	0.39
Phosgene	0.0150	0.44
Propane	0.0157	0.55
Propionic acid	0.0247	0.41
n-Propyl acetate	0.0270	0.34
n-Propyl alcohol	0.0221	0.45
Propylene	0.0146	0.58
Sulfur dioxide	0.0122	0.56
Sulfur trioxide	0.0135	0.51
Toluene	0.0256	0.35
Trimethylamine	0.0184	0.45
Trimethyl benzene-1,2,3	0.0358	0.29
Water	0.0158	1.03

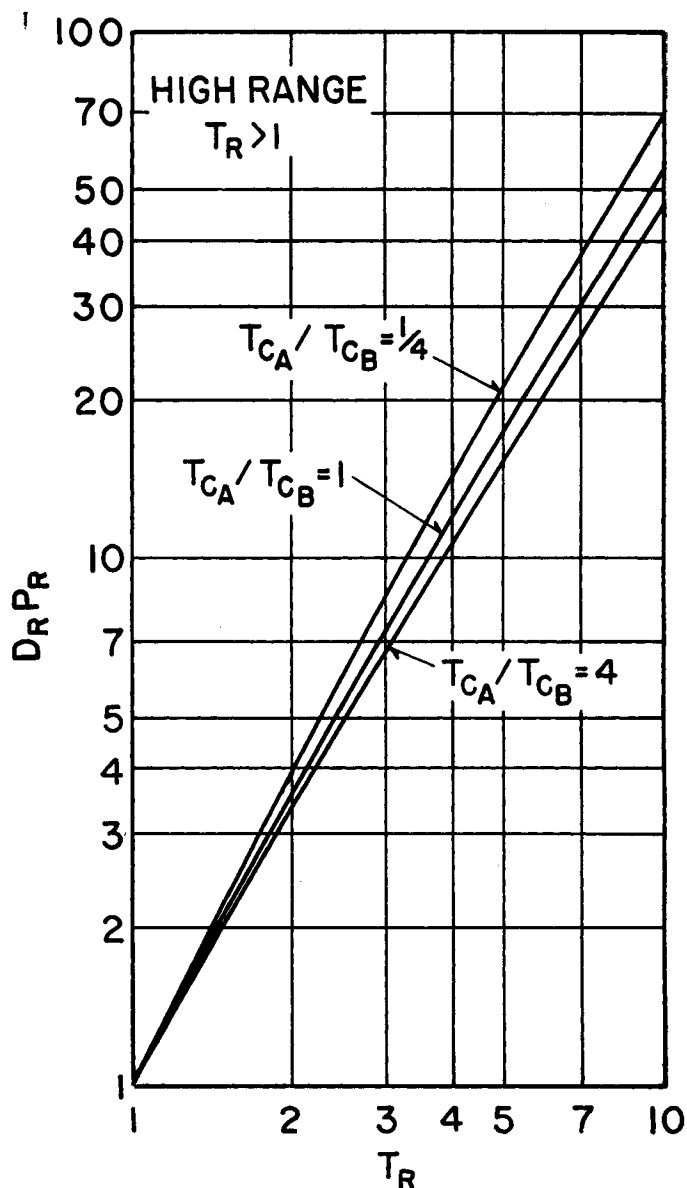
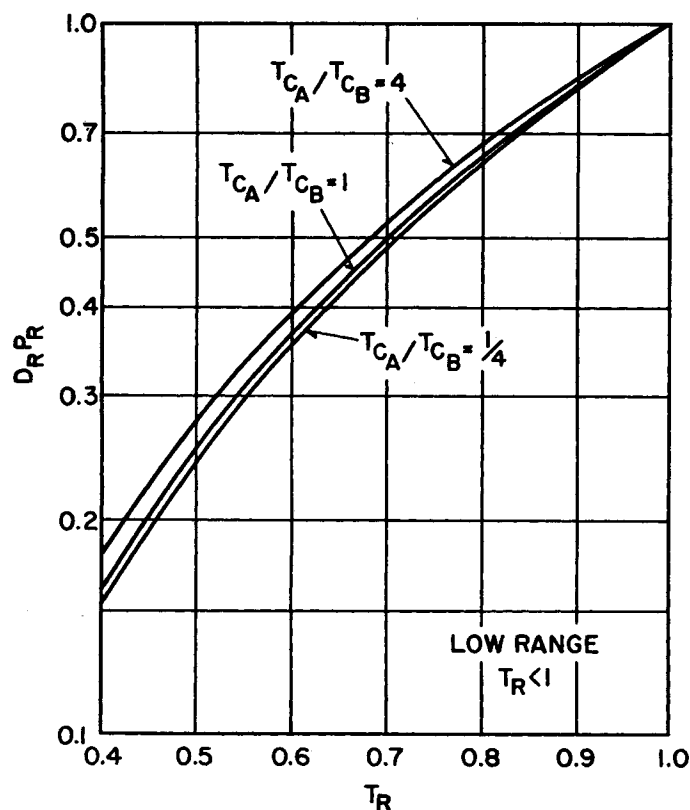


Fig. 2. Reduced diffusion coefficient correlation: A↑, low range; B, high range.

and $f(kT/\epsilon)$ is shown graphically in Figure 1. From Equation (3) and the geometric mean definition of ϵ_{AB}/k ,

$$\phi_{RAB} = \frac{f\left[\frac{kT_A}{0.75(T_{cA}T_{cB})^{0.5}}\right]}{f\left[\frac{kT_{cA}}{0.75(T_{cA}T_{cB})^{0.5}}\right]} \quad (7)$$

or

$$\phi_{RAB} = \frac{f\left[\frac{kT_{RA}}{0.75}\left(\frac{T_{cA}}{T_{cB}}\right)^{0.5}\right]}{f\left[\frac{k}{0.75}\left(\frac{T_{cA}}{T_{cB}}\right)^{0.5}\right]} \quad (8)$$

Thus ϕ_{RAB} should be a function of T_{RA} and the ratio of the critical temperatures of the gases under consideration. Inspection of Equations (6) and (8) indicated that it would be possible to plot $D_R P_R$ against T_R on logarithmic coordinates, by use of (T_{cA}/T_{cB}) as a parameter. This was done by calculating $D_R P_R$ for many combinations of gases (by use of tabulated ϕ values from reference 6), and the results are shown in Figure 2A and B. It should be noted that Figure 2 is a graphical presentation of the H-B-S diffusion equation with parameters derived from an approximation of the collision integral and does not represent experimental data

directly. However, the H-B-S equation has been used to detect errors in experimental results, and so Figure 2 may be taken as a tentative standard chart in lieu of extensive and precise experimental data on diffusion coefficients.

EXAMPLE

The use of Figure 2 may be illustrated by means of the following problem.

Estimate the diffusion coefficient for carbon dioxide through air at 1.0 atm. total pressure and a temperature of 900°R.

From Table 1

for carbon dioxide

$$D_c \text{ (through air)} = 0.00846 \text{ sq. ft./hr.}$$

$$T_c = 548^\circ\text{R.}$$

$$P_c = 72.9 \text{ atm.}$$

and for air,

$$T_c = 238^\circ\text{R.}$$

from which

$$T_R \text{ (carbon dioxide)} = 1.64$$

$$P_R \text{ (carbon dioxide)} = 0.0137$$

$$T_{cA}/T_{cB} = 2.3$$

Then, from Figure 2B, for $T_R = 1.64$ and the parameter value of 2.3,

$$D_R P_R = 2.43$$

whence

$$\begin{aligned} D &= D_R D_c = \frac{(2.43)(D_c)}{P_R} \\ &= \frac{(2.43)(0.00846)}{0.0137} \\ &= 1.50 \text{ sq. ft./hr.} \end{aligned}$$

which agrees with the value of 1.50 sq. ft./hr. calculated by means of the H-B-S equation.

BARRIER GAS RATIO

In the foregoing example it is apparent that the utility of Figure 2 for rapid estimation of diffusion coefficients is limited by the necessity for first calculating the critical diffusion coefficient for A through B. Indeed, the whole purpose of the graph is defeated if it requires direct use of Equation (1) for this calculation. A graphical estimation technique therefore

hinges on a means for arriving at the critical diffusion coefficient quickly, a requirement best satisfied by a graphical method.

Tabulation of initial calculations on the value of the critical diffusion coefficient as related to binary-system properties showed that any graphical estimation method would require specification of a reference barrier gas. In order to systematize comparison, air was chosen as the reference gas. Although it is a slightly variable mixture in itself, air has the advantages of suitable critical properties and also of frequent occurrence in actual problems as the diffusion barrier. By means of Equation (4), critical diffusion coefficients for a number of gases through air were calculated. These values are listed in Table 1. Values of other critical properties were taken from the compilation by Kobe and Lynn (10).

Critical diffusion coefficients for various gases diffusing through a single barrier gas were compared with the coefficients for these gases through air. Comparison was made on the basis of the barrier gas ratio, defined as

$$\frac{D_{cAB}}{D_{cA-air}} = \left(\frac{r_{A-air}}{r_{AB}} \right)^2 \left(\frac{\phi_{cA-air}}{\phi_{cAB}} \right) \cdot \left(\frac{M_A + M_B}{M_A + M_{air}} \right)^{0.5} \left(\frac{M_{air}}{M_B} \right)^{0.5} \quad (9)$$

A large number of calculations revealed that the barrier gas ratio was *independent of the properties of the diffusing gas*. This may be illustrated by a single series of calculations involving the coefficients of randomly chosen gases diffusing through carbon dioxide and the coefficients of the same gases diffusing through air. The results of these calculations are presented in Table 2, where it may be observed that the barrier gas ratio is essentially independent of the properties of the diffusing gas, with a maximum difference of the order of $\pm 4\%$.

It is thus possible to characterize the barrier diffusion behavior of all gases relative to air by the assignment to each gas of a dimensionless barrier ratio number. The characteristic barrier numbers were calculated by taking the same series of twenty-five diffusing gases listed in Table 2 through each barrier gas. The resulting average values of the ratios are tabulated in Table 1. It was obvious that if the barrier ratio could be generally related to the molecular properties of the barrier gas, then the use of the reduced diffusion chart would require information only on D_{cA-air} .

The correlating terms for the barrier ratio were obtained from an analysis of Equation (9). Of the several correlations derived, only Figure 3 represents the most successful generalization of the barrier ratio as a function of molecular properties. The data points of Figure 3 include all the gases listed in Table 1 with the exception of hydrogen.

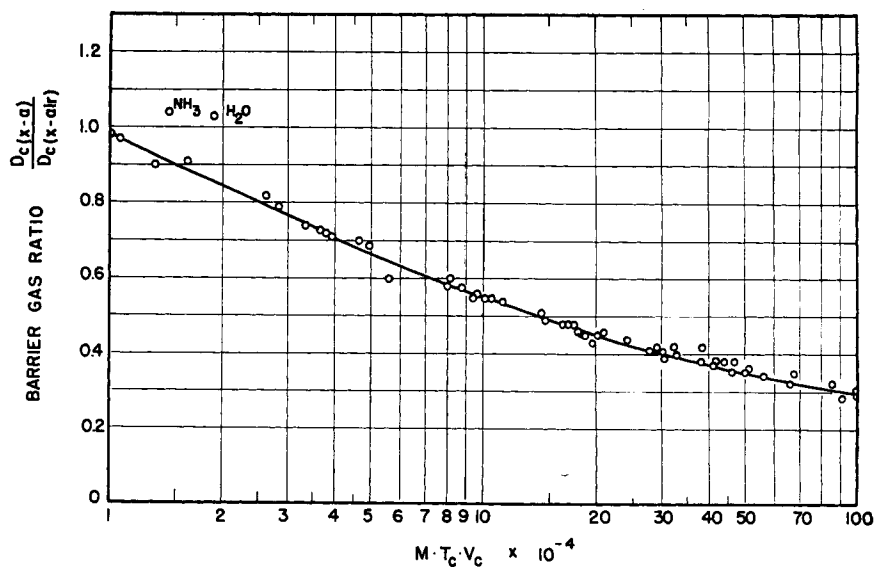


Fig. 3. Barrier gas ratio as function of MT_cV_c .

As pointed out by Cook and Rowlinson (3), certain gases possess electronic arrangements which will cause them to deviate from any generalization based on the theorem of corresponding states. Since structural anomalies would be reflected in measured values of the critical properties, deviations from the correlation of Figure 3 are to be expected, particularly for molecules which have a strong tendency for hydrogen bonding. Thus, H_2O , NH_3 , and CH_3OH are all off the curve of Figure 3. Caution should therefore be exercised in applying the correlation to other molecules which are highly

associated in the liquid state. With this reservation, the correlation of Figure 3 may be used to estimate the barrier gas ratio when direct data are unavailable. Because D_{cAB} for any barrier gas B can thus be obtained by simply multiplying the barrier gas ratio by D_{cA-air} , the value of D_{cA-air} may be viewed as a fundamental property of a gas of equal rank with its other critical transport or molecular properties.

CALCULATION PROCEDURE

It should be reiterated that the correlations presented in this paper are based on the Hirschfelder-Bird-Spotz equation, which in turn is valid only for nonpolar-nonpolar and polar-nonpolar pairs of gases. On this basis the calculation procedure may be summarized briefly as follows:

1. Considering the diffusion of A through B , the value of D_c for A through air is obtained from Table 1. The barrier gas ratio for B is also obtained from Table 1. These values are multiplied together to obtain D_{cAB} .

2. From the values of T_{RA} and P_{RA} and the critical temperature ratio T_{cA}/T_{cB} , $D_{RA}P_{RA}$ is read from Figure 2.

3. D_{AB} is obtained by multiplying D_{RA} by D_{cAB} .

If the necessary barrier ratio is not listed in Table 1, then the correlation of Figure 3 may be used. If neither of the gases is included in Table 1, it will be necessary to calculate one of the critical diffusion coefficients (through air) by means of Equation (4).

Binary Examples

Example 1

Calculate the diffusion coefficient for ethylene through methane at 100 lb./sq. in. gauge (7.80 atm. abs. pressure) and 120° F. (580° R.).

From Table 1

TABLE 2—DIFFUSION OF GASES THROUGH CARBON DIOXIDE

Gas A	D_{cA-CO_2} sq. ft./ hr.	D_{cA-air} sq. ft./ hr.	D_{cA-CO_2} D_{cA-air}
Acetic acid	0.0187	0.0253	0.74
Acetone	0.0159	0.0218	0.73
Acetylene	0.00822	0.0110	0.75
Aniline	0.0205	0.0280	0.73
Ammonia	0.0096	0.0126	0.76
Benzene	0.0162	0.0223	0.73
Bromine	0.00920	0.0130	0.71
Bromobenzene	0.0191	0.0266	0.72
n-Butane	0.0139	0.0190	0.73
Carbon disulfide	0.0115	0.0156	0.74
Carbon tetrachloride	0.0152	0.0214	0.71
Chlorine	0.00832	0.0116	0.72
Chloroform	0.0130	0.0182	0.71
Cyclopentane	0.0152	0.0210	0.72
Dimethyl ether	0.0105	0.0142	0.74
Ethyl acetate	0.0174	0.0240	0.73
Ethyl alcohol	0.0142	0.0192	0.74
Ethyl chloride	0.0124	0.0171	0.73
Ethylene oxide	0.0115	0.0157	0.73
Freon-11	0.0127	0.0177	0.72
n-Heptane	0.0214	0.0296	0.72
Hydrogen chloride	0.00805	0.0111	0.73
Hydrogen cyanide	0.0170	0.0224	0.76
Iodobenzene	0.0208	0.0293	0.71
Methane	0.00590	0.00789	0.75
Average			0.73

for ethylene,

$$D_c (\text{through air}) = 0.0110 \text{ sq. ft./hr.}$$

$$T_c = 508^\circ\text{R.}$$

$$P_c = 50 \text{ atm.}$$

and for methane,

$$T_c = 344^\circ\text{R.}$$

$$\text{Barrier ratio} = 1.11$$

Then

$$D_c (\text{ethylene-methane}) = 1.11(0.0110) = 0.0122 \text{ sq. ft./hr.}$$

$$T_{cA}/T_{cB} = 1.48$$

From Figure 2B, for $T_R = 1.14$, $P_R = 0.156$

$$D_R P_R = 1.26$$

whence

$$D = \frac{1.26(0.0122)}{0.156} = 0.0988 \text{ sq. ft./hr.}$$

which may be compared with a value of 0.0950 calculated by means of the H-B-S equation.

When $D_{cA-\text{air}}$ for the diffusing gas is not listed in Table 1 and its value for the barrier gas is known, advantage may be taken of the fact that $D_{AB} = D_{BA}$, as shown in the following example:

Example 2

Estimate the diffusion coefficient for 1,2-dichloroethane through hydrogen chloride at 2.0 atm. total pressure and 200°F. (660°R.).

1,2-dichloroethane is not listed in Table 1. Consider it as the barrier gas. From Table 1 and from reference 11

	HCl	C ₂ H ₄ Cl ₂
D_c (through air), sq. ft./hr.,	0.0111	
T_c , $^\circ\text{R.}$,	584	1,011
P_c , atm.,	81.6	53
V_c , cu. ft./lb.-mole,	—	3.78

For 1,2-dichloroethane, $MT_c V_c = 99(1,011)(3.78) = 37.8 \times 10^4$ for which, from Figure 3, the barrier ratio is 0.37.

Then

$$D_c (\text{HCl} - \text{C}_2\text{H}_4\text{Cl}_2) = 0.37(0.0111) = 0.00411 \text{ sq. ft./hr.}$$

from Figure 2B, for $T_R = 1.13$, $T_{cA}/T_{cB} = 0.58$, $P_R = 0.0245$

$$D_R P_R = 1.28$$

whence

$$D = \frac{0.00411(1.28)}{0.0245} = 0.214 \text{ sq. ft./hr.}$$

which may be compared with a value of 0.216 sq. ft./hr. calculated by means of the H-B-S equation.

MULTICOMPONENT SYSTEMS

It has been shown by Wilke (14) that the effective diffusion coefficient for gas A through a mixture of gases B, C, D, . . . , n may be obtained from the expression

$$D_A' = \frac{1 - y_A}{\sum_{i=B}^n \frac{y_i}{D_{A-i}}} \quad (10)$$

where

D_A' = effective diffusion coefficient for A in a multicomponent system

y = mole fraction in the gas

Thus the number of separate binary coefficients to be determined equals the number of binary gases. The direct use of the H-B-S equation for this situation, particularly when a range of temperatures is involved, becomes somewhat tedious. The graphical correlations presented here offer a rapid and simple means for multicomponent diffusion calculations and lend themselves readily to elementary desk-calculator computation. The time-saving advantages inherent in the present correlation may be illustrated by the following example.

Multicomponent Example

Estimate the effective diffusion coefficient for methane at a temperature of 200°F. and a total pressure of 3.0 atm. in a mixture of the following composition:

	Mole %
Methane	16.0
Ethane	20.0
Propane	12.0
n-Butane	40.0
n-Pentane	12.0
	100.0

The details of the estimation procedure are tabulated below.

For methane:

$$T_{cA} = 344^\circ\text{R.} \quad P_{cA} = 45.8 \text{ atm.}$$

$$T_{RA} = 1.92 \quad P_{RA} = 0.0655$$

From Table 1

$$D_c (\text{CH}_4\text{-air}) = 0.00789 \text{ sq. ft./hr.}$$

	C ₂ H ₆	C ₃ H ₈	C ₄ H ₁₀	C ₅ H ₁₂
T_{cB} , $^\circ\text{R.}$	550	666	765	846
T_{cA}/T_{cB}	0.63	0.52	0.45	0.41
$D_R P_R$ (Fig. 2B)	3.55	3.58	3.62	3.65
D_R	54.2	54.7	55.3	55.7
Barrier ratio (Table 1)	0.710	0.550	0.460	0.390
D_{cAB}	0.00560	0.00434	0.00363	0.00310
$D_i = (D_R)(D_{cAB})$	0.304	0.237	0.201	0.171

$$D_A' = \frac{0.840}{\frac{0.200}{0.304} + \frac{0.120}{0.237} + \frac{0.400}{0.201} + \frac{0.120}{0.171}} = 0.218 \text{ sq. ft./hr.}$$

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NOTATION

D = gaseous diffusion coefficient, sq. ft./hr. D_{AB} = diffusion coefficient for A diffusing through B. D_A' = effective diffusion coefficient for A diffusing through a mixture.
 D_c = critical diffusion coefficient, sq. ft./hr.

D_R = reduced diffusion coefficient, D/D_c
 k = Boltzmann constant, ergs/ $^\circ\text{R.}$ -molecule
 M = molecular weight
 P = pressure, atm. abs.
 P_c = critical pressure, atm. abs.
 P_R = reduced pressure, P/P_c
 r = molecular diameter, Angstroms
 r_{AB} = collision diameter for molecules A and B, Angstroms
 T = temperature, $^\circ\text{R.}$
 T_c = critical temperature, $^\circ\text{R.}$
 T_R = reduced temperature, T/T_c
 V_c = critical volume, cu. ft./lb.-mole
 x = any gas diffusing through A (Table 1)
 y = mole fraction

Greek Letters

ϵ = minimum interaction energy, ergs
 ϕ = collision function
 ϕ_c = collision function evaluated at critical temperature

Subscripts

A, B = gases in the binary system under consideration
 c = a critical property
 R = a reduced property

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