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DIFFUSION IN MOLTEN METALS

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[Tables referred to herein are appended.]

The speed of most metallurgical processes is determined by the rate with which the reacting materials are fed to the reaction zone. Consequently, the kinetics of many processes, which take place in open-hearth and electric steel melting furnaces have a diffusion character.

Experimental data on diffusion in the molten state is very limited. The extent to which we will apply the general rules of the diffusion process to this system deserves an explanation. The basic equation for diffusion, found by Einstein, has the following form:

$$D = \frac{RT}{N} \frac{1}{\pi \eta r} \qquad (1)$$

where R is the gas constant, T is the absolute temperature, N is Avogadro's number, η is the viscosity of the medium, and r is the radius of the diffusing particle.

Strictly speaking, this equation is applicable only on condition that the diffusing particle is considerably greater than the particles making up the fluid, i.e., if Stoke's hydrodynamic formula holds good. Equation (1), which is called the Stokes-Einstein equation, has been often confirmed by experiments which showed its applicability to suspensions and emulsions. Tests were also made of the applicability of this equation to molecular diffusion.

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In this paper, we wish to point out that the Stokes-Einstein equation gives approximately the correct results for the diffusion of metals in molten metals at low as well as high temperatures.

Using the data on the viscosity of molten metals, included in the Landol't-Bernshteyn physicochemical tables, and the radii of atoms according to Goldshmidt, we calculated the coefficients of diffusion of various metals with the use of equation (1). In Table 1, the calculated coefficients of diffusion of various metals in mercury at temperatures 8-15° are compared with the experimentally found dimensions included in the Landol't-Bernshteyn tables.

As is clear from Table 1 for alkali and alkali-earth metals, the calculated and experimental dimensions D are distinguished from one another, on the average, by only 10 percent. There is a much greater deviation for lead, zinc, and cadmium. But even for these metals, the Stokes-Einstein equation gives the correct order of magnitude for the diffusion coefficients.

It is also interesting to notice that, for alkali and alkali-earth metals, and for thallium and gold, the equation resulting from equation (1) holds good.

For diffusion in the same solvent and at the same temperature, the product of the diffusion coefficient and the radius of the diffusing particle is a constant dimension,

$$Dr = \text{constant} \qquad (2)$$

From an examination of Table 2, a satisfactory constant of this product for the metals indicated above can be deduced

As for cadmium, zinc, and lead, the dimension $D r$ is noticeably different from the corresponding value for alkali metals. It remains, however, approximately constant for these three metals.

Data on diffusion at higher temperature is given below.

The diffusion of gold in bismuth at 555°: D calculated = 3.2 sq cm/day; D experimental = 4.5 sq cm/day

Comparing the experimental data with the results of the calculations, it must be noticed that the correspondence of the calculated and experimental figures appears better than could have been expected, especially if the sizable error in experimental determination of the viscosity and diffusion coefficients is considered

Thus it can be assumed that the Stokes-Einstein equation gives approximately correct dimensions for the diffusion coefficients of metals in a molten metal at low as well as high temperatures.

/Appended tables follow./

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Table 1. Diffusion in Mercury

Diffusing Metal	Calculated D sq cm/day	Experimentally Determined D sq cm/day
Lithium	0.72	0.66
Sodium	0.59	0.64
Potassium	0.48	0.53
Rubidium	0.44	0.46
Cesium	0.41	0.45
Calcium	0.52	0.47
Strontium	0.58	0.54
Barium	0.55	0.52
Gold	1.02	0.69
Gallium	0.73	1.45
Zinc	0.83	1.53
Lead	0.65	1.50

Table 2

Diffusing Metal	D V $\cdot 10^8$ Experimental Atom
Lithium	1.04
Sodium	1.22
Potassium	1.24
Rubidium	1.17
Cesium	1.20
Calcium	0.93
Strontium	1.17
Barium	1.17
Gold	0.99
Thallium	1.50
Cadmium	2.20
Zinc	2.05
Lead	2.55

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Table 3. Diffusion in Tin at 555°

Diffusing Metal	Calculated D sq cm/day	Experimentally Determined D sq cm/day
Gold	3 33	4.67
Silver	3.33	4.15
Lead	2.75	4.06

Table 4.

Diffusing Metal	$D \quad V \cdot 10^8$ Experimental Atom
Gold	6.63
Silver	5.90
Lead	7.00

Table 5 Diffusion in Lead

Diffusing Metal	Calculated D sq cm/day	Experimentally Determined D sq cm/day	
Platinum	2.10	1.70	T° 492° C
Gold	2.16	3.20	T° 550° C
Radium	2.89	3.02	T° 550° C

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