JOURNAL OF MATERIALS SCIENCE 3 (1968) 206-222

Self-Diffusion in Simple Oxides (A Bibliography)

P. J. HARROP
Allen Clark Research Centre, The Plessey Company Limited, Caswell, Towcester, Northants, UK

The paper is directed towards the materials scientist who wishes to employ published values of diffusion coefficients in his investigations. A brief review of self-diffusion behaviour and the likely inaccuracies of the various techniques used in the measurement of diffusion is followed by a selected bibliography and tabulation of coefficients for oxides.

1. Introduction

The materials scientist frequently requires knowledge of the ease with which the ions that compose a substance move within that substance, i.e. rates of self-diffusion. For instance, creep, sintering, and the annealing of radiation damage can all depend on the ease of ionic motion. Corrosion rates of metals are often related to the diffusion of ions through the protective film that forms [1, 2]. Heat treatment of capacitors probably improves their resistivity by diffusional healing of flaws in the dielectric.

The study of diffusion has reached a high degree of sophistication and much is now known about the various processes, particularly in the simplest systems such as the single-crystal alkali-halides [3]. However, it is generally difficult for the materials scientist (i) to obtain estimates of diffusion rates in the materials that are of concern to him, and (ii) to appreciate in a general fashion the probable shortcomings in the data available. This review attempts to provide such a service for a practical class of materials—the simple oxides. A brief assessment of the behaviour expected, and of the techniques used to determine diffusion, is followed by a selected bibliography.

2. General Behaviour

The diffusion of an ion in a solid is characterised by a diffusion coefficient D cm^2/sec. Since the diffusion is an activated process (the ion has to hop over an energy barrier in order to move), D is expressed by an equation of the form

$$D = D_0 \exp^{-Q/RT} \qquad (1)$$

where D_0 cm^2/sec is a constant, Q kcal/mole is the activation energy for the process, R is the gas constant, and T is the absolute temperature. Values of D_0 may vary widely—in the following bibliography values between 10^{31} and 10^{-14} cm^2/sec are reported, although values much above unity are suspect from a theoretical viewpoint. Q is occasionally quoted in electron volts, in which case R in equation 1 is replaced by k, Boltzmann's constant. As the temperature is increased, D usually follows a series of equations of the form of equation 1, where Q takes increasing discrete values as illustrated in fig. 1. In view of this it is desirable that D be determined over a wide range of temperatures before straight line relations are drawn. Clearly it is dangerous to attempt to extrapolate from known data.

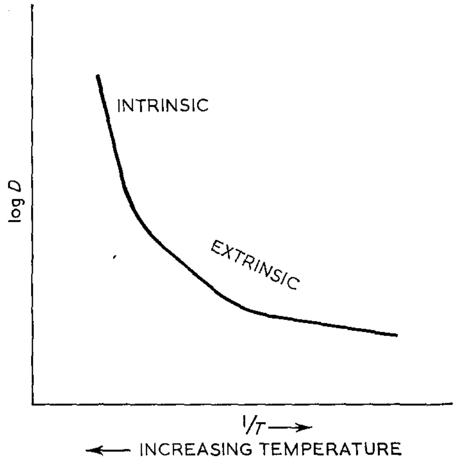

Figure 1 Relationship between the diffusion coefficient D of a given ion in a given solid, and the absolute temperature T, showing regions of different slope, i.e. activation energy.

2.1. Intrinsic Diffusion

In the high temperature region (say very roughly above three-quarters of the melting point) diffusion is generally intrinsic, i.e. the diffusing species are both formed and moved by the thermal energy available. *Q* is high (see fig. 1) being typically 150 ± 50 kcal/mole for oxides above 1000° C. Intrinsic *D*'s converge with increasing temperature, usually being within a few magnitudes of 10^{-10} cm^2/sec at the melting point of the solid in question. They may vary by a magnitude or more with the orientation of the crystal considered. Intrinsic *D*'s for polycrystals lie between the extremes. In this context it must be noted that many chemical compounds have a variety of crystalline phases even at a given temperature, and that *D* will vary somewhat between phases as well. Further, intrinsic diffusion usually varies quite sharply with the ambient partial pressure of the species. For oxides, oxygen pressure is therefore important.

A rough rule is that the more insulating the oxide (this usually means the lighter the metal ion) the higher the value of *Q* for intrinsic diffusion of the metal. This has been particularly related to the ease with which the metal ion can be ionised to a higher valence state [4].

2.2. Extrinsic Diffusion

At lower temperatures, extrinsic factors such as impurities and inhomogeneities can retard or assist self-diffusion in a solid, altering D_0 and *Q* as in fig. 1.

At these temperatures *D* may vary widely between samples owing to these factors, and also to the earlier mentioned complications of phase and orientation, although here the situation is usually simplified with respect to pressure in that impurity controlled diffusion is usually independent of pressure [5]. One final consideration, that also applies to the intrinsic range, is that equation 1 may only apply for given stoichiometry and if, at a given pressure, the stoichiometry varies with temperature, equation 1 will not be obeyed. For oxides, values of *Q* for this extrinsic range (e.g. 300 to 1000° C) are typically 60 ± 40 kcal/mole.

At the lowest temperatures, near ambient and below, the easiest (i.e. lowest *Q*) processes dominate. These can include diffusion down dislocations [5] and across surfaces [6], and the situation can be further complicated by the substance being in a quenched state, since equilibration may take several days at these temperatures [7]. The few relevant values of *Q* quoted below for oxides are in the range 20 ± 10 kcal/mole.

One can now see that diffusion coefficients measured at the highest temperatures can be fairly confidently used by other workers, provided that crystal orientations and oxygen pressures are compared. By contrast, data for the lower temperatures may vary by many magnitudes, regardless of the care taken in measurement simply because these values depend on extrinsic factors. Accordingly, if diffusion coefficients for below, say, three-quarters of the melting point in degrees Kelvin are to be taken from published work, every effort must be made to compare crystallinity and impurity content. Near ambient temperature and below thermodynamic equilibrium, surface paths, dislocation densities, etc, must be considered in addition.

2.3. General Trends

In simple inorganic compounds one generally finds that the anion (oxygen in oxides) diffuses more slowly than the cation. Exceptions for the oxides can apparently include UO_2 [8], TiO_2 [9], ThO_2 [9], Nb_2O_5 [9], ZrO_2 [9], HfO_2 [10], Fe_2O_3 [11], and WO_3 [25]. These compounds probably represent a group of materials that easily become oxygen-deficient, and the observation may only apply to lower temperatures. For instance, for Fe_2O_3, crossover of *D*'s near 1000° C is suspected [12]. For UO_2 oxygen-diffusion may still be dominant at 1600° C [8], but this may owe something to the U^{4+} ion being exceptionally large.

Some oxides have metal and oxide diffusion coefficients that are within a few magnitudes of each other in the lower temperature region. These include Al_2O_3 [16] and, from more indirect evidence [17], Nb_2O_5, Ta_2O_5, and WO_3.

Particularly at the lower temperatures, *D* can be increased by the presence of grain boundaries [13]. This is frequently true for anions [14-16], probably because they are usually the largest and therefore the most slowly diffusing ions in the solid, and it seems to occur by D_0 increasing with little change in *Q*.

2.4. Detailed Interpretation

A given ion may move in a solid by either thermally-created defects or impurity-created defects. It may diffuse by a variety of mechanisms, the simplest being as an interstitial (i.e. by passing from one interstitial lattice site to another) or by jumping into vacant sites in the lattice. In principle, where the defect concentration and the energy of motion are understood on a microscopic scale for a given system, the macroscopic quantities D_0 and Q may be split into their constituent parts [24] and the correlation factor f of equation 2 below may be calculated [18, 20]. At present, such information is seldom available for the oxides and will not be further discussed in the present context.

3. Measurement Techniques

One can now turn to the techniques commonly used for the measurement of diffusion coefficients. Probably the most reliable are the various techniques based on the use of radioactive tracers, since these techniques are very sensitive, and usually enable the ion in question to be identified unambiguously. Recently, proton activation has been used to give radio-tracers for the study of oxygen-diffusion [26]. Previously, mass spectrometers monitoring the gaseous exchange of O^{18} gave the best values of O diffusion. This method identified the ion unambiguously but had other shortcomings [26].

With diffusion coefficients measured by other techniques the identity of the ion in question may only be implied. Into this category come measurement of kinetics of necking of spheres, shrinkage in sintering, creep, the growth of an oxide film on the metal, and measurement of ionic electrical conductivity. These latter methods are also subject to various quantitative interpretations, and therefore the magnitude of the coefficients implied can also be in great doubt. Considerations for necking, sintering and creep have been discussed elsewhere [5]. The theory of metallic oxidation usually calls for a uniform film [2], and this can be falsely taken to be the case in a given experiment [19]. With electrical conductivity, there is often only meagre evidence that ions are involved at all. However, since ionic conduction is rarely quoted in terms of values of D, and recourse to such data may be necessary, we now briefly consider the theory.

For ionic conduction entirely due to one type of ion the conductivity σ is related to D by the Nernst-Einstein equation [18]

$$\sigma f = D\left[\frac{Nz^2e^2}{\mathrm{k}T}\right] \qquad (2)$$

where z is the charge on the ion that is moving, e is the electronic charge, N is the number of ions per cm^3, and k is Boltzmann's constant. f is the "correlation factor", a crystallographic quantity that takes account of the fact that conductivity follows the motion of the defect (e.g. vacancy, interstitial) whereas tracer-diffusion follows the ion in question directly. f varies with the mechanism of diffusion and has been discussed elsewhere [20]. For magnitude estimates of D, f may be taken as 1, since its value usually lies between 0.5 and 1.5. Other pitfalls in the use of equation 2 are the fact that neutral species may contribute to D but not σ, particularly at low temperatures [21], and irrelevant relaxation processes may increase σ in some cases [22], leading to a spuriously high D as implied from equation 2. Further, equation 2 applies where only one ion and one diffusional mechanism contributes, and this is not always the case.

Two other types of measurement that have been interpreted in terms of diffusion rates in oxide specimens deserve mention. The first is the study of oxidation of reduced oxide (or reduction of stoichiometric oxide) using weight change or change in optical absorption. The second is the measurement of gaseous permeation when there is a difference of gas pressure across a material. Clearly these methods can be very insensitive and may be difficult to interpret.

4. Use of the Bibliography

The following bibliography is intended as a guide to the best available values of diffusion coefficients in simple solid oxides. It incorporates data from a few earlier and more restricted bibliographies that are available [9, 11, 23], and represents an attempt to cover the literature up to October 1967. A Table of Values summarises the data available, and detailed references are given in an Appendix that follows.

The bibliography should be seen in conjunction with the cautionary remarks above. The comments column is intended as some guide towards the reliability of the data by mention of the methods used. There is no indication of whether the diffusion is intrinsic or extrinsic, since even the workers themselves are seldom willing to speculate. For comparative purposes it is indicated whether single crystals or polycrystals were measured, the temperature ranges are quoted, as are the type of ion moving, and where possible the composition and stoichiometry of the material in which they move is indicated. Most of the work quoted refers to ambient oxygen pressures. The crystalline phase examined is not always indicated in the literature, but where several phases are possible at the temperatures used (e.g. for ZrO_2 and iron oxides) the widest possible variety of data is presented. Where one phase only is usual, the least reliable data are omitted. Where data for a pure oxide is sparse, values for related mixed oxides are quoted. In the final section listing the references, the language is indicated where it is known not to be English. The references should, of course, be studied where further information is required and omission of figures for D_0, Q, and D from the table must not be taken to imply that these quantities cannot be derived from a more thorough examination of the reference in question. Where values of D are required to high accuracy, a check should be made whether the values quoted refer to the true ("tracer") coefficient or the diffusion coefficient of the species which enables the ion to move (vacancy etc). These quantities are related by the correlation factor f as used in equation 2.

Acknowledgements

The author is most grateful to Dr L. W. Barr, Mr D. S. Campbell, and various colleagues for comments on the manuscript. He also thanks the Plessey Co Ltd for permission to publish.

General References

1. G. C. WOOD, *Corrosion Science* **2** (1962) 173.
2. J. K. DAWSON, UKAEA (Harwell) Report AERE R 4820 (1965).
3. See, for instance, R. W. DREYFUS and A. S. NOWICK, *J. Appl. Phys.* **33** (1962) 473; J. H. SHULMAN and W. D. COMPTON, "Color Centers in Solids" (Pergamon, New York, 1963); and [18].
4. J. BIRCHENALL, "Physics and Chemistry of Ceramics", edited by C. Klingsberg (Gordon and Breach, New York, 1963) p. 147.
5. "Kinetics of High Temperature Processes", edited by W. D. Kingery (Wiley, New York, 1959).
6. R. W. REDINGTON, *Phys. Rev.* **87** (1952) 1066.
7. C. BUCCI *et al, Nuovo Cimento Supplement* **4** (1966) 607.
8. J. F. MARIN and H. MICHAUD, *Compt. rend.* **261** (1965) 693.
9. R. DARRAS, *Industries Atomiques* **3/4** (1965) 69.
10. A. W. SMITH, F. W. MESZAROS, and C. D. AMATA, *J. Amer. Ceram. Soc.* **49** (1966) 240.
11. F. VODOPIVEC, *Metaux-Corrosion-Industries* **38** (1963) 159.
12. W. C. HAGEL, *Trans. Met. Soc. AIME* **236** (1966) 179.
13. A. D. LE CLAIRE, *Brit. J. Appl. Phys.* **14** (1963) 351.
14. J. F. LAURENT and J. BENARD, *J. Phys. Chem. Solids* **7** (1958) 218.
15. J. CABANE, thesis, Faculty of Sciences, University of Paris, 1962.
16. Y. OISHI and W. D. KINGERY, *J. Chem. Phys.* **33** (1960) 480.
17. J. A. DAVIES *et al, J. Electrochem. Soc.* **112** (1965) 675.
18. A. B. LIDIARD, "Encyclopedia of Physics", Vol. 22 (Springer, Berlin, 1957).
19. J. N. WANKLYN, ASTM Special Technical Publication 368 (1964) p. 58.
20. See, for instance, L. W. BARR and A. D. LE CLAIRE, *Proc. Brit. Ceram. Soc.* **1** (1964) 109; J. R. MANNING, *Phys. Rev.* **139** (1965) 126.
21. L. W. BARR, J. A. MORRISON, and P. A. SCHROEDER, *J. Appl. Phys.* **36** (1965) 624.
22. P. H. SUTTER and A. S. NOWICK, *ibid* **34** (1963) 734.
23. P. A. CUMMING and P. J. HARROP, UKAEA (Harwell) Report AERE Bib 143 (1965).
24. R. W. DREYFUS and A. S. NOWICK, *Phys. Rev.* **126** (1962) 1367.
25. F. SCHIEN, B. LE BOUCHER, and P. LACOMBE, *Compt. rend.* **252** (1961) 4157.
26. J. B. HOLT, L. W. BARR, and R. A. PITT-PLADDY, *Brit. J. Appl. Phys.* **17** (1966) 657.

Substance	Ref	Diffusing element	D_0 (cm^2/sec)	Q (kcal/mole)	Temperature range (° C)	Comments (S) Single crystal (P) Polycrystalline	Year
Aluminium oxide (Al_2O_3)	1	Al	—	165	1100-1800	(S) from sintering shrinkage	1958
	2	Al	2.5×10^4	135	1700-1800	in wet H_2, He or O_2. (S) from sintering of spheres	1958
			5.0×10^{18}	230	1700-1800	in dry H_2	
	3	O	6.3×10^{-8}	57.6	1200-1620	(S) (P) O^{18} mass spec.	1960
			1.9×10^3	152 ± 25	1500-1700		
	4	Al	—	130 ± 20	1600-1800	(S) from creep	1961
	5	Al	28	114 ± 15	1670-1905	(P) Al^{26} radiotracer	1962
	6	O	—	—	$D = 4.0 \pm 3.0 \times 10^{-11}$ at 170	(P) —	1963
Barium oxide (BaO)	1	Ba	—	—	—	(S) Ba^{140} radiotracer	1951
	2	Ba	$10^{29 \pm 7}$	253	1077-1247	(S) bulk Ba^{140} radiotracer	1952
			$10^{31 \pm 8}$	306	1077-1247	(S) surface	
			$10^{-9 \pm 1}$	14.5	277-1077	(S) structure sensitive bulk	
Beryllium oxide (BeO)	1	Be	5.56×10^3	111.6	1570-1730	(P) Be^7 radiotracer	1958
			6.14×10^{-2}	66.1	1730-1934		
	2	Be	—	114	—	(P) from creep 54 to 216 lb/in.^{2}*	1958
	3	Be	1.37	91.9	1550-1725	(P) Be^7 radiotracer	1961
			1.10×10^{-6}	36.15	1725-2000	(P)	
	4	O	5.2×10^{-7}	42.9	1600-1900	(P) O^{18} mass spec.; at least two processes operative	1961
			5.2×10^{-6}	42.9			
	5	O	—	—	1600-1900	(P) O^{18} mass spec.; "rapid" low-magnitude process only	1962
	6	O	2.95×10^{-5}	68.5	1560-1727	(S) O^{18} mass spec.	1962
	7	Be	2.49×10^{-3}	62.5	1150-1800	(P) Be^7 radiotracer	1964
	8	Be	1.27×10^{-3}	64	1760-2000	(S) Be^7 radiotracer	
			1.23×10^{-6}	36	1490-1720		
			1.35	92	1550-1725	(P) hot pressed	
			1.07×10^{-6}	36	1760-1825		
			5.56×10^3	111.6	1300-1730	(P) slip cast sintered	
			6.14×10^{-2}	66.1	1730-1910		
	9	Be	3.2×10^{-3}	63.0	1100-1800	(P) Be^7 radiotracer and ionic conductivity	1966
	10	Be	—	52	1500-2000	(S) (P) Be^7 radiotracer	1966
	11	Be	—	—	500-1500	(P) Be^7 radiotracer, various points plotted	1967
	12	Be	—	92	1330-1500	(P) Be^7 radiotracer	1967
		Be	—	62	1500-2135	(P) Be^7 radiotracer—related to impurity	
Bismuth oxide (Bi_2O_3)	1	Bi	4.29×10^{-6}	20.7	710	(P) Bi^{210} radiotracer	1963
			4.5×10^{-1}	66.0	710		
Cadmium oxide (CdO)	1	O	8.0×10^6	93 ± 5	640-820	(S) O^{18} mass spec.	1960
			1.3×10^6	93 ± 5		(P)	

*1.0 lb/in.^{2} = 7×10^{-2} kg/cm^2

Substance	Ref	Diffusing element	D_0 (cm^2/sec)	Q (kcal/mole)	Temperature range (° C)	Comments (S) Single crystal (P) Polycrystalline	Year
Cadmium oxide (CdO)	2	O	3.8×10^6	92 ± 4	630-855	(S) O^{18} mass spec.	1962
			3.9×10^5	92 ± 4		(P)	
Calcium oxide (CaO)	1	Ca	0.4	81	900-1400	(P) Ca^{45} radiotracer	1952
	2	O	—	80	27-1127	(S) possible ionic conductivity giving D via the Nernst-Einstein equation	1966
	3	Ca	0.444	100.2 ± 2.8	1700-2150	(P) Ca^{45} radiotracer in CaO with 84% ZrO_2	1966
	4	Ca	8.75 ± 1.32	34.6 ± 0.95	1000-1400	(S) Ca^{45} radiotracer near surface	1967
		Ca	1.95 ± 0.06	34.02 ± 1.80	1000-1400	(S) Ca^{45} radiotracer near bulk	
Cerium oxide (CeO_2)	1	O	—	—	250-350	(P) CeO_2 reduction	1951
Chromium oxide (Cr_2O_3)	1	Cr	4.0×10^3	100	1000-1350	(P) Cr^{51} radiotracer	1956
	2	Cr	4.29×10^{-8}	22	900-1100	(P) Cr^{51} radiotracer	1958
	3	Cr	0.137	61.1	1045-1550	(P) Cr^{51} radiotracer; independent of impurity	1961
	4	Cr	—	88.7	$D = 1.54$ at 1100	(P) film evaporation	1960
					$D = 15.2$ at 1200		
					$D = 36.3$ at 1250		
	5	Cr	—	—	$D = 5.0 \times 10^{-10}$ at 1300	(S) Cr^{51} radiotracer	1963
	6	O	15.9	101	1100-1450	(P) O^{18} mass spec.	1965
	7	Cr	—	—	$D = 1.54 \times 10^{-11}$ at 1100		1960
					$D = 4.55 \times 10^{-11}$ at 1150		
					$D = 1.52 \times 10^{-10}$ at 1200		
					$D = 3.63 \times 10^{-10}$ at 1250		
	8	Cr	—	—	$D = 5.0 \times 10^{-5}$ at 1300	(S) Cr^{51} radiotracer	1965
	9	O	440	109.9 ± 7.3	1100-1450	(P) sintering shrinkage-two interpretations	1966
			3370	123.0 ± 8.0			
Cobalt oxide (CoO)	1	Co	2.15×10^{-3}	34.5 ± 0.4	800-1350	(P) Co^{60} radiotracer	1954
	2	O	some points plotted on graph		900-1400	(S) (P) O^{18} reaction (p, n) F^{18}	1967
	3	O	some points plotted in [2]		1000	(S) (P) O^{18} mass spec.	1962
	4	Co	—	—	$D = 1.39 \times 10^{-8}$ at 1100	(S) deduced from changes in electronic conductivity at 1 atm/O_2	1966
					4.07×10^{-9} at 1100		
					9.06×10^{-10} at 900		
					3.91×10^{-10} at 800		
Copper oxide (Cu_2O)	1	Cu	3.58×10^{-2}	37	800-1000	(P) radiotracer during oxidation	1949
	2	Cu	4.36×10^{-2}	36.1 ± 2	800-1050	(P) radiotracer	1951
	3	O	6.5×10^{-3}	39.3 ± 4.4	1030-1120	(P) O^{18} mass spec.	1958
	4	O	6.3×10^{-3}	39.3 ± 4.4	—	(P) O^{18} mass spec.	1959
		Cu	1.22×10^{-1}	36.1 ± 2.5	—	(P)	
	5	O	—	43.1 ± 4.4	1030-1100	(P) O^{18} mass spec.	1962
	6	O	1.5×10^{-2}	39.3	1024-1120	(S) O^{18} mass spec.	1963

Substance	Ref	Diffusing element	D_0 (cm²/sec)	Q (kcal/mole)	Temperature range (° C)	Comments (S) Single crystal (P) Polycrystalline	Year
Erbium oxide (Er_2O_3)	1	O	1.22	47.8	850-1250	(P) weight gain of reduced oxide on oxidation	1967
Germanium oxide (GeO_2)	1	O	—	—	(at 1200)	(vitreous) D's given for 3-film thicknesses	1959
	2	O	10^{-3}	27.6 ± 2.3	480-630	(vitreous) opt. absorption disappearance with temp.	1960
	3	Ge	—	—	—	vaporisation relations found	1964
Hafnium oxide (HfO_2)	1	O	—	—	—	(P) Ionic conductivity is postulated. Hence D can be calculated using the Nernst-Einstein relation. But see criticism in P. J. Harrop and J. N. Wanklyn. *J. Electrochem. Soc.* **110** (1963) 1285	1963
	2	O	22.0	55.7	1100-2050	(P) pressure drop across tube of $Hf_{0.86}Ca_{0.14}O_{1.86}$	1966
Hydrogen oxide (ice)	1	O	—	12.4-15.0	—	(S) O^{18} mass spec.	1967
	2	H_2O	—	—	$D = 1 \pm 0.2 \times 10^{-10}$ at -2	(P) D tracer and O^{18} mass spec.	1958
	3	H		13.5	$\begin{cases} -35 - 0 \\ D = 2.0 \times 10^{-11} \text{ at } -7 \end{cases}$	(S) protons (tritons)	1963
	4	H_2O	—	15.7	-29.5 to -5	(S) O^{18} (p, n) F^{18} reaction	1966
	5	H_2O	—	15.7	-30 to -10	(S) H^3 radiotracer	1964
	6	H_2O	—	14.4 ± 0.7	-26.8 to -3.5	(S) H^3 radiotracer	1966
	7	H_2O	—	14.5 ± 1.0	-32 to -5	(S) H^3 radiotracer	1966
Iron oxides	1	Fe	4.0×10^4	112	750-1300	(P) Fe^{59} radiotracer in Fe_2O_3	1952
	2	Fe	0.118	29.7	700-1000	(P) Fe^{55} radiotracer in FeO	1953
		Fe	—	30.2	$D = 1.4 \times 10^{-2}$ at 1420	(P) oxidation FeO	
			5.2	55	750-1000	(P) oxidation $Fe_{2.993}O_4$	1954
		Fe	4.0×10^5	112	1000-1217	(S) oxidation Fe_2O_3	
	3	Fe	0.014	30.2 ± 0.5	700-1000	(P) Fe^{55} tracer in $Fe_{0.92}O$ in oxidation	1954
	4	Fe	0.25	53.9	770-1200	(P) Fe^{59} in Fe_3O_4	1958
	5	O	10^{11}	146	1150-1250	(P) Fe^{59} in Fe_2O_3	1960
	6	Fe	6.0×10^5 104.0	84.0 ± 5.9 74.7 ± 4.5	850-1075	(S) Fe^{55} tracer in Fe_3O_4 (P)	1960
	7	Fe	—	25 to 33	860-1260	(P) Fe^{59} tracer in FeO with $75.5 < Fe < 76.5\%$	1965
	8	O	2.04	77.9	900-1250	(P) O^{18} mass spec. in αFe_2O_3	1966
	9	Fe	1.3×10^6	100.2	950-1050	(P) Fe^{59} tracer in Fe_2O_3	1962
	10	Fe	—	24.8-37.4	900-1100	(P) by weight change FeO	1965
Lead oxide (PbO)	1	Pb	—	—	$10^{-12} < D < 10^{-14}$ at 485-570	(P) contact method-decrease in surface activity	1949
	2	Pb	10^5	66	400-590	(P) Pb^{212} radiotracer	1952
	3	O	5.39×10^{-5}	22.4	500-650	(P) O^{18} mass spec.	1963
	4	Pb	—	64	circa 640	(P) Pb^{210} radiotracer	1965
Magnesium oxide (MgO)	1	Mg	2.3×10^{-1}	78.7	1400-1600	(S) radiotracer	1957
	2	O	2.5×10^{-6}	62.4	1300-1750	(S) O^{18} mass spec.	1960

Substance	Ref	Diffusing element	D_0 (cm^2/sec)	Q (kcal/mole)	Temperature range (° C)	Comments (S) Single crystal (P) Polycrystalline	Year
Magnesium oxide (MgO)	3	Mg	—	50	1000-1500	(S) ionic conductivity is found, permitting D to be calculated using the Nernst-Einstein equation	1962
	4	Mg	—	—	1061-1510	(S) ionic conductivity is found, permitting D to be calculated using the Nernst-Einstein equation	1962
	5	O	4.3×10^{-5} 4.8×10^{-14}	82.1 ± 3.0 30.2×3.0	$\left.\begin{matrix}1000\\1000\end{matrix}\right\}$	(P) O^{18} mass spec.	1966
Manganese oxide (MnO)	1	Mn	—	40.5-45.6	800-1200	(P) oxidation kinetics	1965
Neodymium (Nd_2O_3)	1	O	—	—	—	(P) oxidation study D increased by excess O	1965
Nickel oxide (NiO)	1	Ni	4.1×10^{-2}	55	900-1000	(P) Ni^{63} radiotracer	1951
	2	Ni	2.8×10^{6}	119.5	1140-1400	(P) Ni^{63} radiotracer	1956
	3	Ni	5.0×10^{-4} 3.9×10^{-4}	44.2 ± 3 44.2 ± 3	1000-1400 1000-1400	$\left.\begin{matrix}\text{(P)}\\\text{(S)}\end{matrix}\right\}$ Ni^{63} radiotracer	1957
	4	Ni	1.7×10^{-2}	56 ± 1.3	700-1400	(S) (P) Ni^{63} radiotracer	1957
	5	O	—	—	$D = 3.9 \times 10^{-13}$ at 1300	(S) O^{18} mass spec.	1960
		Ni	8.0×10^{-4}	53.5 ± 3	1300-1700	(S) Ni radiotracer	
	6	O	1.0×10^{-5}	54	1100-1500	(S) O^{18} mass spec.	1962
	7	Ni	1.83×10^{-3}	45.6	1000-1400	(S) Ni^{63} radiotracer	1962
	8	Ni	4.8×10^{-4}	48.4 ± 2	1190-1400	(S) Ni^{63} radiotracer during oxidation	1962
	9	Ni	—	—	$D = 3.59 \times 10^{-11}$ at 1100 1.12×10^{-11} at 1000 4.29×10^{-12} at 900 7.70×10^{-13} at 800	(S) deduced from change in electronic conductivity at 0.209 atm O_2	1966
	10	Ni	1.26×10^{-5}	46.6	276-723	(P) electrical study of sintering shrinkage	1966
Niobium oxides	1	Nb	—	—	800-1200	(P) Nb^{95} radiotracer in $NbO_{(2.4-2.5)}$	1961
	2	O	3.6×10^{-2}	28.2 ± 1.8	500-900	(P) $Nb_2O_{4.978}$	1962
	3	Nb	—	29.6	900-1100	(P) Nb^{95} in NbO	1963
		Nb	—	52-53	900-1100	(P) Nb^{95} in Nb_2O_5 and Nb_2O_4	
	4	O	4.7×10^{-3}	27.6	600-1350	(S) ionic conductivity	1966
	5	—	—	—	700-950	(P) 2% ionic conductivity permitting D to be calculated from the Nernst-Einstein equation	1967
	6	O	—	—	$D = 7.9 \times 10^{-10}$ at 600 $D = 6.5 \times 10^{-9}$ at 815	(P) —	1965
	7	O	1.72×10^{-2}	49.4 ± 3.3	850-1200	(S) O^{18} mass spec. Nb_2O_5	1967
Praseodymium oxide (PrO_2)	1	O	—	42	700-990	(P) weight loss of PrO_2 under vacuum	1958
Silicon oxide (SiO_2)	1	O	—	27	$D = 1.2 \times 10^{-8}$ at 1078 $D = 4.2 \times 10^{-9}$ at 950	(vitreous) gaseous permeation	1961

Substance	Ref	Diffusing element	D_0 (cm^2/sec)	Q (kcal/mole)	Temperature range (° C)	Comments (S) Single crystal (P) Polycrystalline	Year
Silicon oxide	2	O	3.7×10^{-9}	55	1010-1220	(P) isotopic exchange	1962
(SiO_2)			4.3×10^{-9}	56	900-1200	(vitreous) isotopic exchange	
	3	O	—	—	—	(vitreous) mass spec. for stripped film giving permeation constant	1962
	4	O	1.51×10^{-2}	71.2	925-1225	O^{18} mass spec.	1963
	5	O	2.0×10^{-9}	29	850-1250	isotopic exchange	1965
	6	O	—	—	$D = 8.0 \times 10^{14}$ perpendicular to c axis and 4×10^{-12} parallel at 667	O^{18} (p, α) N^{15} reaction in quartz	1965
	7	O				O^{18} (p, α) N^{15} reaction in quartz	1965
	8	Na	1.88×10^{-2}	30	470-900	(P) Na^{22} radiotracer in $Na_2O.2CaO.3SiO_2$	1966
		Na	3.67×10^{-2}	27.4	200-600	(Glass) ditto	
Strontium oxide (SrO)	1	O	—	46	327-777	(S) possible ionic conductivity giving D via the Nernst-Einstein equation	1966
Tantalum oxide (Ta_2O_5)	1	Ta	—	14.7	−195-100	(S) ionic conductivity	1964
Terbium oxide (TbO_2)	1	O	—	41.5	700-990	(P) weight loss of TbO_2 under vacuum	1958
Tin oxide	1	Sn	10^6	118.7 ± 3.7	1000-1260	(P) radiotracer	1955
(SnO_2)	2	Sn	10^7	126	—	—	1955
Titanium oxide	1	O	1.1	73	860-1030	(S) O^{18} mass spec.	1960
(TiO_2)	2	O	2.3	75	710-950	(S) O^{18} mass spec.	1962
			1.4×10^{-4}	53	950-1300	(S) O^{18} mass spec.	
	3	O	2.0×10^{-3}	60 ± 1.5	710-1300	(S) O^{18} mass spec.	1965
	4	Ti	—	24	—	(S) implied from changes in optical absorption	1965
Tungsten oxide (WO_3)	1	O	—	39	400-700	(P) from oxidation kinetics	1966
Uranium oxide	1	O	5.5×10^{-3}	26.3 ± 1.5	160-350	(P) oxidation study in $UO_{(2.0-2.34)}$	1957
(UO_2)	2	U	—	90-125	1410-1750	(P) radiotracer in $UO_{(2.00-2.01)}$	1957
		O	2.6×10^{-5}	29.7 ± 2.3	450-600	(P) O^{18} isotopic exchange in $UO_{(2.00-2.01)}$	
	3	O	1.2×10^{3}	65.3 ± 5	550-800	(P) in $UO_{2.002}$	1958
		O	2.1×10^{-3}	29.7 ± 2.5	320-500	(P) in $UO_{2.063}$	
	4	O	2.6×10^{-5}	29.7 ± 2.3	450-600	(P) in $UO_{2.004}$ } O^{18} mass spec.	1958
			4.0×10^{-4}	29.7	317-465	(P) in $UO_{2.064}$	
		U	—	90-125	1410-1750	(P) in $UO_{(2.0-2.91)}$	
	5	U	—	—	$D = 5.0$ to 45.0×10^{-18} at 1000	(P) sectioning and accounting in UO_2 (U^{235} radiotracer)	1960
	6	O	1.2×10^{3}	65.3	550-780	(P) surface activity increase in $UO_{2.002}$ (U^{235} radiotracer)	1960
		U	4.3×10^{-4}	88 ± 11	1450-1785	(P) surface activity method in UO_2 (U^{235} radiotracer)	

Substance	Ref	Diffusing element	D_0 (cm^2/sec)	Q (kcal/mole)	Temperature range (° C)	Comments (S) Single crystal (P) Polycrystalline	Year
Uranium oxide (UO_2)	7	U	2.3×10^{-1}	104.6	1300-1600	(P) U^{233} radiotracer in UO_2	1961
			—	52	900-1200		
	8	U	—	—	$D = 3.3 \times 10^{-16}$ at 1300 $D = 2.2 \times 10^{-15}$ at 1450	(S) U^{235} radiotracer	1964
	9	U	1.2 4.0×10^{-7}	108 70	1450-1700 1450-1700	(S) and (P) (S) and (P) surface activity method in UO_2	1965
	10	O	—	—	900-1000 D greater than for uranium	(P) ionic conductivity in UO_2	1967
	11	U	—	—	$D = 5 \times 10^{-16}$ at 1700	(P) U^{235} radiotracer in $UO_{2.00}$	1965
	12	U	—	—	$D = 2.43 \times 10^{-14}$ at 1615	(S) U^{235} radiotracer in $UO_{2.00}$	1963
	13	O	—	—	500-1000 O diffusion for $UO_{2.000}$ is much lower than any of above values	theoretical	1966
	14	U	5.82×10^{-5}	72.7	1900-2150	(P) U^{237} radiotracer bulk	1966
		U	5.19×10^{-9}	47.2	1900-2150	U^{237} radiotracer grain boundary	
Yttrium oxide (Y_2O_3)	1	Y	2.41×10^{-4}	43.9	1400-1800	(P) Y^{91} radiotracer in Y_2O_3	1962
	2	O	7.24	58.6	1000-1500	(P) weight gain on oxidation of reduced oxide	1967
Zinc oxide (ZnO)	1	Zn	—	—	—	(P) ionic conductivity	1941
	2	Zn	—	—	—	(P) Zn^{65} radiotracer	1952
	3	Zn	1.3	73.7	800-1370	(P) Zn^{65} surface activity	1952
	4	Zn	3.0×10^{-9}	20	850-940	(S) Zn^{65} activity decrease	1960
			5.0	75	940-1025		
	5	Zn	—	39	827-1097	(S) ionic conductivity	1955
	6	Zn	4.8	73 ± 3	900-1025	(S) Zn^{65} radiotracer	1955
	7	Zn	—	—	907-1167	(S) and (P) Zn^{65} radiotracer	1956
	8	Zn	30	74	907-1167	(S) and (P) Zn^{65} radiotracer	1956
	9	Zn	—	—	$D = 6.0 \times 10^{-11}$ at 1290 $D = 2.2 \times 10^{-10}$ at 1290	(P) Zn^{65} radiotracer (annealed in O_2) (P) Zn^{65} radiotracer (annealed in Ar)	1956
	10	Zn	10^{-1}	89	800-1300	(P) Zn^{65} radiotracer	1957
	11	Zn	2.7×10^{-4}	12.7	180-350	(S) ionic conductivity	1957
	12	Zn	170	—	800-1190	(S) Zn^{65} radiotracer	1958
	13	Zn	—	—	—	(S) (P) discussion on other work on ZnO	1958
	14	Zn	1.25×10^{-5}	43.5 ± 10	1000-1265	(S) Zn^{65} radiotracer	1959
		O	6.52×10^{11}	165 ± 6	1100-1300	(S) O^{18} mass spec.	
	15	Zn	1.6×10^{-2}	39	700-1330	(S) ionic conductivity	1959
	16	Zn	—	—	800-1400	(P) Zn^{65} radiotracer	1960

Substance	Ref	Diffusing element	D_0 (cm^2/sec)	Q (kcal/mole)	Temperature range (° C)	Comments (S) Single crystal (P) Polycrystalline	Year
Zinc oxide (ZnO)	17	Zn	10^2 10	73 73	720-780 800-840	(P) Zn^{65} radiotracer	1960
	18	Zn	3.0×10^{-7}	25	720-780	(S) Zn^{65} radiotracer	1961
	19	Zn	—	—	$D = 10^{-16}$ at 400	—	1955
Zirconium oxide (ZrO_2)	1	O	1.0×10^4	28.1	700-1100	(P) O^{18} mass spec. in $Zr_{0.85}Ca_{0.15}O_{1.85}$	1959
	2	O	1.05×10^{-3}	29.3	400-850	(P) from oxidation kinetics	1962
	3	O	5.5×10^{-2}	33.4 ± 3.1	700-1000	(P) visual observation of oxidation of $ZrO_{1.975}$	1962
	4	O	—	—	700-1400	(P) estimated intrinsic diffusion in $ZrO_{2.00}$	1962
	5	O	—	—	—	(P) ionic conductivity is postulated permitting D to be found from the Nernst-Einstein equation—see criticism in P. J. Harrop and J. N. Wanklyn, *J. Electrochem. Soc.* **110** (1963) 1285.	1965
	6	O	9.0×10^{-4}	28.7 ± 0.6	380-386	(P) from oxidation kinetics	1965
	7	O	—	—	500	(P) D estimated from diffusion in films from reaction O^{17}(He, α)O^{16}	1965
	8	O	0.018	31.2 ± 4.3	800-1097	(S) (P) O^{18} mass spec. in $Zr_{0.858}Ca_{0.142}O_{1.858}$	1966
	9	O	185	57.6	1100-2050	(P) Pressure drop across tube of $Zr_{0.92}Ca_{0.08}O_{1.92}$	1966
	10	Zr	0.035	92.5 ± 2.4	1700-2150	(P) Zr^{95} radiotracer in ZrO_2 with 12 or 16 mole % CaO	1966
	11	O	—	—	$D > 0.22$, $D < 1.1 \times 10^{-8}$ at 1400	(P) ionic conductivity in tetragonal ZrO_2	1966

Appendix

Detailed references are discussed in the Table of Values

Aluminium Oxide

1. R. L. COBLE, "Initial Sintering of Alumina and Haematite". *J. Amer. Ceram. Soc.* **41** (1958) 55.
2. G. C. KUCZYSKI, L. ABERNETHY, and J. ALLAN, "Sintering Mechanisms of Aluminium Oxide", edited by W. D. Kingery. Kinetics of High Temperature Processes, Conference (Dedham, Mass., 1958) Proceedings (Wiley, New York, 1959) p. 163.
3. Y. OISHI and W. D. KINGERY, "Self-Diffusion of Oxygen in Single Crystalline and Polycrystalline Aluminium Oxide". *J. Chem. Phys.* **33** (1960) 480.
4. S. I. WARSHAW, "Deformation Behaviour of Polycrystalline Aluminium Oxide". Thesis, Massachusetts Inst. Tech., June 1961; or see discussion of same values in A. E. PALADINO and R. L. COBLE, "Effect of Grain Boundaries Controlled Process in Aluminium Oxide". *J. Amer. Ceram. Soc.* **46** (1963) 133.
5. A. E. PALADINO and W. D. KINGERY, "Aluminium Ion Diffusion in Aluminium Oxide". *J. Chem. Phys.* **37** (1962) 957.
6. D. HAYES, D. W. BUDWORTH, and J. P. ROBERTS, "Permeability of Sintered Aluminium Materials to Gases at High Temperatures". *Trans. Brit. Ceram. Soc.* **62** (1963) 507.

Barium Oxide

1. R. W. REDINGTON, "Diffusion of Barium in Barium Oxide". *Phys. Rev.* **82** (1951) 574. (Abstract only of American Physical Society, Division of Electron Physics, meeting paper No. EP. 8.)
2. *Idem*, "Diffusion of Barium in Barium Oxide". *Phys. Rev.* **87** (1952) 1066.

Beryllium Oxide

1. S. B. AUSTERMAN, "Diffusion of Beryllium in Beryllium Oxide". US Atomic Energy Commission Report, NAA-SR-3170 (December, 1958).
2. R. CHANG, "Creep in Polycrystalline Beryllium Oxide at High Temperatures and Low Stresses". US Atomic Energy Commission Report, NAA-SR-2458; or see "High Temperature Creep and Anelastic Phenomena in Polycrystalline Refractory Oxides". *J. Nucl. Matls.*, **1** (1959) 174; *Chem. Abs.* **53** 7544*i*.
3. S. B. AUSTERMAN and D. G. SWARTHOUT, "Diffusion of Beryllium in Beryllium Oxide", Part II. US Atomic Energy Commission Report, NAA-SR-5893 (May, 1961).
4. S. B. AUSTERMAN, R. A. MEYER, and D. G. SWARTHOUT, "Oxygen Diffusion in Beryllium Oxide". US Atomic Energy Commission Report, NAA-SR-6427 (September, 1961).
5. S. B. AUSTERMAN and R. A. MEYER, "Rapid Oxygen Diffusion in BeO". US Atomic Energy Commission Report, NAA-SR-7637 (1962).
6. J. B. HOLT, "Self-Diffusion of Oxygen in Single Crystal Beryllium Oxide". *J. Nucl. Matls.*, **11** (1964) 107; see also US Atomic Energy Commission Report, UCRL-6940 (1962).
7. H. J. DE BRUIN and G. M. WATSON, "Self-Diffusion of Beryllium in Unirradiated Beryllium Oxide". AAEC, Beryllium Oxide, First International Conference (Sydney, October, 1963); see also US Atomic Energy Commission Reports CONF-281-48 and ORNL-3526 (September, 1963); or *J. Nucl. Matls.* **14** (1964) 239.
8. S. B. AUSTERMAN, "Self-diffusion in Beryllium Oxide". AAEC, Beryllium Oxide, First International Conference (Sydney, October, 1963), *J. Nucl. Matls.* **14** (1964) 248.
9. H. J. DE BRUIN, G. M. WATSON, and C. M. BLOOD, "Cation Self-Diffusion and Electrical Conductivity in Polycrystalline Beryllium Oxide". *J. Appl. Phys.* **37** (1966) 4543.
10. S. B. AUSTERMAN and J. W. WAGNER, "Cation Self-Diffusion in Single Crystal and Polycrystalline BeO". *J. Amer. Ceram. Soc.* **49** (1966) 94.
11. H. J. DE BRUIN, G. M. WATSON, C. M. BLOOD, and D. ROMAN, "Cation Diffusion in Neutron-Irradiated BeO". *Phil. Mag.* **16** (1967) 427.
12. R. H. CONDIT and Y. HASHIMOTO, "Self-Diffusion of Be in Polycrystalline BeO". *J. Amer. Ceram. Soc.* **50** (1967) 425.

Bismuth Oxide

1. G. D. PALKAR, D. N. SITHARAMARAO, and A. K. DAS GUPTA, "Self-Diffusion of Bismuth in Bismuth Oxide". *Trans. Faraday Soc.* **59** (1963) 2634.

Cadmium Oxide

1. R. L. HAUL, D. JUST, and G. DUMBGEN, "Oxygen Diffusion in Oxides" (in German); J. A. DE BOER (editor), Reactivity of Solids, International Conference (Amsterdam, May, 1960) Proceedings (Elsevier, Amsterdam, 1961) p. 65. Preliminary work in R. HAUL, and D. JUST "Measurement of Diffusion in Oxide Crystals by Isotopic Exchange with Gaseous Oxygen" (in German). *Naturwiss.* **45** (1958) 435; *Z. Elektrochem.* **62** (1958) 1124.
2. R. HAUL and D. JUST, "Disorder and Oxygen Transport in Cadmium Oxide". *J. Appl. Phys.* **33** (1962) 487.

Calcium Oxide

1. R. LINDNER, ST. AUSTRÜMDAL, and A. AKERSTRÖM, "Kinetics in Calcium Oxide" (in German). *Acta. Chem. Scand.* **6** (1952) 468.
2. N. A. SURPLICE, "The Electrical Conductivity of Strontium Oxide and Calcium Oxide". *Brit. J. Appl. Phys.* **17** (1966) 175.
3. W. H. RHODES, and R. E. CARTER, "Catonic Self-Diffusion in Calcia Stablised Zirconia". *J. Amer. Ceram. Soc.* **49** (1966) 244.

4. Y. P. GUPTA, and L. J. WEIRICK, "Self-Diffusion of Ca in Single-Crystal CaO". *J. Phys. Chem. Solids* **28** (1967) 811.

Cerium Oxide

1. G. RIENACKER and M. BIRKENSTAEDT, "Notes on the Reduction of Cerium Oxide Considered Between 250 and 350° C" (in German). *Z. anorg. Chem.* **265** (1951) 99.

Chromium Oxide

1. R. LINDNER and A. AKERSTRÖM, "Self-Diffusion and Reaction in Oxide and Spinel Systems" (in German). *K. Physik. Chem.* **6** (1965) 162; *Chem. Abs.* **50** 6237*h*.
2. D. V. IGNATOV, I. N. BELOKUROVA, and I. N. BELGANIN, "An Investigation of the Diffusion Processes of Iron and Chromium in the Oxides of α-Al_2O_3, α-Cr_2O_3, $NiCr_2O_4$, and $NiAl_2O_4$" (in Russian). The Use of Radioactive and Stable Isotopes and Radiation in the National Economy and in Science, Conference Proceedings (USSR, 1958) p. 326 (in Russian); see also US Atomic Energy Commission Report, NP-tr-448 (1958) p. 256; *Nuclear Sci. Abs.* **14** 1935*i*.
3. W. C. HAGEL and A. U. SEYBOLT, "Cation Diffusion in Cr_2O_3". *J. Electrochem. Soc.* **108** (1961) 1146.
4. I. M. FEDORCHENKO and Y. B. ERMOLOVICH, "Diffusion of Chromium Through its Oxide" (in Russian). *Ukrain. Chim. Zhur.* **26** (1960) 429; *Chem. Abs.* **55** 7219*b*.
5. L. C. WALTERS and R. E. GRACE, "Self-Diffusion of Chromium in Single Crystals of Cr_2O_3". *J. Appl. Phys.* **36** (1965) 2331; *J. Electrochem. Soc.* **110** (1963) 192*c abs*. 194.
6. W. C. HAGEL, "Anion Diffusion in α-Cr_2O_3". *J. Amer. Ceram. Soc.* **48** (1965) 70. Preliminary work in "Factors Controlling the High Temperature Oxidation of Chromium". *Trans. Amer. Soc. Metals* **56** (1963) 583.
7. I. M. FEDORCHENKO and Y. B. ERMOLOVICH, *Ukrain Khim. Zhur.* **26** (1960) 429 (in Russian).
8. L. C. WALTERS and R. E. GRACE, "Self-Diffusion of Cr^{51} in Single Crystals of Cr_2O_3". *J. Appl. Phys.* **36** (1965) 2331.
9. W. C. HAGEL, P. J. JORGENSEN and D. S. TOMALIN, "Initial Sintering in Alpha Cr_2O_3". *J. Amer. Ceram. Soc.* **49** (1966) 23.

Cobalt Oxide

1. R. E. CARTER and F. D. RICHARDSON, "An Examination of the Decrease-of-Surface-Activity Method of Measuring Self-Diffusion Coefficients in Wüstite and Cobaltous Oxide". *N.Y. J. Metals* (*Trans. AIME* **200**) **6** (1954) 1244.
2. J. B. HOLT, "Oxygen Diffusion in CoO as Measured by Proton Activation of Oxygen-18". *Proc. Brit. Ceram. Soc.* **9** (1967) in press.
3. B. A. THOMPSON, PhD thesis, Rensselaer Polytechnique Institute (1962).
4. J. B. PRICE and J. B. WAGNER JR, "Determination of the Chemical Diffusion Coefficients in Single Crystals of CoO and NiO". *Z. phys. Chem.* **49** (1966) 257.

Cuprous Oxide

1. G. W. CASTELLAN and J. W. MOORE, "Diffusion of Radioactive Copper During Oxidation of Copper Foil". *J. Chem. Phys.* **17** (1949) 41.
2. W. J. MOORE and B. SELIKSON, "The Diffusion of Copper in Cuprous Oxide". *Ibid* **19** (1951) 1539; see also an error corrected in *ibid* **20** (1952) 927.
3. W. J. MOORE, Y. EBISUZAKI, and J. A. SLUSS, "Exchange and Diffusion of Oxygen in Crystalline Cuprous Oxide". *J. Phys. Chem.* **62** (1958) 1438; or see W. J. MOORE, J. J. LANDER, S. R. LOGAN, M. O'KEEFE, J. S. CHOI, Y. EBISUZAKI, S. BROWN, and D. MITCHELL, "Physical Chemistry of the Solid State". US Atomic Energy Commission Progress Report, TID-11020 (October, 1960).
4. W. J. MOORE, "Parabolic Rate Constants and Diffusion Mechanisms in Oxides and Sulphides". *Z. Elektrochem.* **63** (1959) 794.
5. J. A. SLUSS, "Aspects of Oxygen Movement in Cuprous Oxide". Thesis (June, 1962); *Diss. Abs.* **23** (1962) 1947.
6. Y. EBISUZAKI, "Solid State Studies on Cuprous Oxide Preparation in Single Crystals Oxygen Diffusion, Optical Properties". *Diss. Abs.* **23** (1963) 2712.

Erbium Oxide

1. M. F. BERARD and D. R. WILDER, "Self-Diffusion of Oxygen in Y_2O_3 and Er_2O_3". *J. Amer. Ceram. Soc.* **50** (1967) 113.

Germanium Oxide

1. V. GARINO-CANINA, "Diffusion of Oxygen in Vitreous Germanium Oxide" (in French). *Compt. rend.* **248** (1959) 1319.
2. *Idem*, "Optical Studies of the Oxygen Diffusion in Non-Stoichiometric Vitreous Germanium Dioxide" (in French). *Ibid* **250** (1960) 1815.
3. T. TOKUDA and W. D. KINGERY, "Rule of Vaporization from the Surface of Molten Germanium Dioxide". *Bull. Chem. Soc. Japan* **37** (1964) 589.

Hafnium Oxide

1. P. KOFSTAD and D. J. RUZICKA, "On the Defect Structure of ZrO_2 and HfO_2". *J. Electrochem. Soc.* **110** (1963) 181.
2. A. W. SMITH, F. W. MESZAROS, and C. D. AMATA, "Permeability of Zirconia, Hafnia, and Thoria to Oxygen". *J. Amer. Ceram. Soc.* **49** (1966) 240.

Hydrogen Oxide (Ice)

1. K. ITAGAKI, "Self-Diffusion in Single Crystal Ice". *J. Phys. Soc. Japan.* **22** (1967) 427.

2. W. KUHN and M. THURKAUF, "Isotopeutrennung bein Gefrieren von Wasser und Diffusionskonstanten von D und O^{18} im Eis" (in German). *Helv. Chim. Acta* **15** (1958) 938.
3. O. DENGEL and N. RIEHL, "Diffusion von Protonen (Tritonen) in Eiskristallen" (in German). *Phys. Kondens. Materie.* **1** (1963) 191.
4. P. DELIBALTAS, O. DENGEL, D. HELMREICH, N. RIEHL, and H. SIMON, "Diffusion of O^{18} in Single Ice Crystals (in German). *ibid* **5** (1966) 166.
5. K. ITAGAKI, "Self-diffusion in Single-Crystal Ice". *J. Phys. Soc. Japan* **19** (1964) 1081.
6. H. BLICKS, O. DENGEL, and N. RIEHL, "Diffusion von Protonen (Tritonen) in reiner und dotieren Eis Einkristallen". *Phys. Kondens Materie.* **4** (1966) 375.
7. O. DENGEL, E. JAKOBS, and N. RIEHL, "Diffusion von Tritonen in NH_4F dotieren Eis Einkristallen" (in German). *Ibid* **5** (1966) 58.

Iron Oxides

1. R. LINDNER, "Diffusion of Radioactive Iron in Iron (III) Oxide and Zinc-Iron Spinel" (in German). *Arkiv Kemi* **4** (1952) 381.
2. L. HIMMEL, N. F. MEHL, and C. E. BIRCHENALL, "Self-Diffusion of Iron in Iron Oxides and the Wagner Theory of Oxidation". *N.Y.J. Metals* (*Trans. AIME* **197**) **5** (1953) 827.
3. R. E. CARTER and F. D. RICHARDSON, "An Examination of the Decrease-of-Surface-Activity Method of Measuring Self-Diffusion Coefficients in Wüstite and Cobaltous Oxide". *Ibid* (*Trans. AIME* **200**) **6** (1954) 1244.
4. V. I. IZVEKOV, "Diffusion of Fe in Magnetite" (in Russian). *Inzh.-fiz. Zh.* (Eng.-Phys. J.) *Akad. Nauk. Belorus SSR* **1** (1958) 64; or see V. I. IZVEKOV, and K. M. GORBUNOVA, "Study of Iron Diffusion in Corundum, Magnetite, and Rutile with the Help of Fe^{59} Indicator" (in Russian). The Use of Radioactive and Stable Isotopes and Radiation in the National Economy and in Science, National Conference (USSR), Proceedings (Acad. Sci., Moscow, 1958) p. 511.
5. W. D. KINGERY, D. C. HILL, and R. P. NELSON, "Oxygen Mobility in Polycrystalline $NiCr_2O_4$ and α-Fe_2O_3". *J Amer. Ceram. Soc.* **43** (1960) 473.
6. S. M. KLOTSMANN, A. N. TIMOFEYEV, and I. SH. TRAKTENBERG, "The Problem of the Measurement of Diffusion Coefficients in Oxide Phases". *Fiz. Metall. i metallov* **10** (1960) 733 (in Russian); *Phys. Metals Metallogr.*, **10** (1960) 93.
7. PH. DESMARESCAUX, J. P. BOCQUET, and P. LACOMBE, "Autodiffusion and Electrotransport in Iron Monoxide" (in French). *Bull. Soc. chim. France* **15** (1965) 1106.
8. W. C. HAGEL, "Oxygen Diffusion in Hematite". *Trans. Met. Soc. AIME.* **236** (1966) 179.
9. V. I. IZVEKOV, N. S. GORBUNOV, and A. A. BABUB-ZAKHRAPIN, "Diffusion of Iron in Haematite". *Phys. Metals Metallogr.* **14** (1962) 33.
10. R. L. LEVIN and J. B. WAGNER, "Reduction of Undoped and Chromium-Doped Wüstite in Carbon Dioxide/Carbon Monoxide Mixtures". *Trans. AIME* **233** (1965) 159.

Lead Oxide

1. R. LINDNER, "Self-Diffusion in Some Solids". *J. Chem. Soc.* part V (1949) 5395.
2. *Idem*, "Self-Diffusion in Lead Oxide" (in German). *Arkiv Kemi* **4** (1952) 385; *Chem. Abs.* **47** 3072*b*; or see R. LINDNER and H. N. TEREM, "Diffusion of Radioactive Lead in Lead Oxide Layers" (in German). *Arkiv Kemi* **7** (1954) 273; *Chem. Abs.* **49** 2807*c*.
3. B. A. THOMPSON and R. L. STRONG, "Self-Diffusion of Oxygen in Lead Oxide". *J. Phys. Chem.* **67** (1963) 594.
4. A. K. DAS GUPTA, D. N. SITHARAMARAO, and G. D. PALKAR, "Self-Diffusion of Lead in Lead Oxide (PbO)". *Nature* **207** (1965) 628.

Magnesium Oxide

1. R. LINDNER and G. D. PARFITT, "Diffusion of Radioactive Magnesium in Magnesium Oxide Crystals". *J. Chem. Phys.* **26** (1957) 182.
2. Y. OISHI and W. D. KINGERY, "Oxygen Diffusion in Periclase Crystals". *Ibid* **33** (1960) 905.
3. S. P. MITOFF, "Electronic and Ionic Conductivity in MgO". *Ibid* **36** (1962) 1383.
4. *Idem*, "Bulk Versus Surface Conductivity of MgO Crystals". *Ibid* **41** (1964) 2561.
5. L. H. ROVNER, "Diffusion of Oxygen in Magnesium Oxide". Cornell Univ., Ithaca, N.Y., Dept. of Engineering Physics, Technical Report TR-10 (March, 1966).

Manganese Oxide

1. K. FUEKI and J. B. WAGNER, "Oxidation of Manganese in CO_2/CO Mixtures". *J. Electrochem. Soc.* **112** (1955) 970.

Neodymium Oxide

1. M. F. BARRETT and T. I. BARRY, "Non-Stoichiometry in Neodymium and Europium Oxides in Relation to their Interaction with Oxygen and Hydrogen". *J. Inorg. Nucl. Chem.* **27** (1965) 1483.

Nickel Oxide

1. W. J. MOORE (submitted by F. O. Rice), "Rate Processes in Inorganic Solids at High Temperatures". US Atomic Energy Commission Report, ORO-78 (1951).
2. R. LINDNER and A. AKERSTRÖM, "Self-Diffusion and Reaction in Oxide and Spinel Systems" (in German). *Z. Phys. Chem.* **6** (1956) 162.
3. M. T. SHIM and W. J. MOORE, "Diffusion of Nickel in Nickel Oxide". *J. Chem. Phys.* **26** (1957) 802.
4. R. LINDNER and A. AMERSTRÖM, "Diffusion of Ni-63 in Nickel Oxide (NiO)". *Discuss. Faraday.Soc.* **23** (1957) 133.

5. W. J. MOORE, J. J. LANDER, S. R. LOGAN, M. O'KEEFFE, J. S. CHOI, Y. EBISUZAKI, S. BROWN, and D. MITCHELL, "Physical Chemistry of the Solid State". US Atomic Energy Commission Report, TID-11020 (1960).
6. M. O'KEEFFE and W. J. MOORE, "Diffusion of Oxygen in Single Crystals of Nickel Oxide". *J. Phys. Chem.* **65** (1961) 1438.
7. J. S. CHOI and W. J. MOORE, "Diffusion of Nickel in Single Crystals of Nickel Oxide". *Ibid* **66** (1962) 1308.
8. S. M. KLOTSMANN, A. N. TIMOFEYEV, and I. SH. TRAKTENBERG, "Self-Diffusion of Nickel in Nickel Oxide". *Phys. Metals Metallogr.* **14** (1962) 91.
9. J. B. PRICE and J. B. WAGNER JR, "Determination of the Chemical Diffusion Coefficients in Single-Crystal CoO and NiO". *Z. phys. Chem.* **49** (1966) 257.
10. F. Y. WANG, "Sintering Studies of NiO Compacts by the Electrical Resistance Method". *J. Appl. Phys.* **37** (1966) 929.

Niobium Oxide

1. P. KOFSTAD, K. ØYSTEIN, P. B. ANDERSON, and G. LUNDE, "Studies of Diffusion of Nb^{95} in Sintered Nb$_2$O$_5$." Central Inst. for Industrial Research, Blindern, Norway, Report No. 51, Publ. no. 346 (October, 1961).
2. D. L. DOUGLASS, "Diffusion of Oxygen in Columbium Pentoxide and Zirconium Dioxide". IAEA Corrosion of Reactor Materials, Conference (Salzburg, June, 1962). Proceedings, Vol. 2 (IAEA, Vienna, 1962) p. 223.
3. P. V. GEL'D and V. D. LYUBIMOV, "Activation Energy in Niobium Diffusion in its Oxides" (in Russian). *Izvest. Sibirsk. Otd., Akad. Nauk SSSR, Ser. Khim. Nauk* **7** (1963) 79.
4. W. K. CHEN and R. A. SWALIN, "Studies of the Defect Structure of Alpha Nb$_2$O$_5$". *J. Phys. Chem. Solids* **27** (1966) 57.
5. R. ELO, R. A. SWALIN, and W. K. CHEN, "Electronic and Ionic Conductivity in Alpha Nb$_2$O$_5$". *Ibid* **28** (1967) 1625.
6. A. P. LITMAN, "Diffusion of Oxygen in Columbium". *Phys. Stat. Solidi* **11** (1965) K47.
7. W. K. CHEN and R. A. JACKSON, *J. Chem. Phys.* **47** (1967) 1144.

Praseodymium Oxide

1. U. E. KUNTZ, and L. EYRING, "Diffusion of Oxygen in Rare-Earth Oxides". Kinetics of High Temperature Processes, Conference (Dedham, Mass. 1958) Proceedings (edited by W. D. Kingery) p. 50 (Wiley, New York, 1959).

Silicon Oxide

1. F. J. NORTON, "Permeation of Gaseous Oxygen through Vitreous Silica". *Nature* **181** (1961) 701.
2. R. HAUL and G. DÜMBGEN, "Investigation of Oxygen Diffusion in Titanium Dioxide, Quartz, and Vitreous Quartz using Heterogeneous Isotopic Exchange" (in German). *Z. Elektrochem* **60** (1962) 636. Preliminary results in R. HAUL, D. JUST, and G. DÜMBGEN, "Oxygen Diffusion in Oxides" (in German). Reactivity of Solids, International Conference (Amsterdam, May, 1960). Proceedings (edited by J. H. de Boer) (Elsevier, Amsterdam, 1961) p. 65
3. S. W. ING, R. E. MORRISON, and J. E. SANDOR, "Gas Permeation of Thin SiO$_2$ Films". *J. Electrochem. Soc.*, **109** (1962) 221.
4. E. W. SUCOV, "Diffusion of Oxygen in Vitreous Silica". *J. Amer. Ceram. Soc.*, **46** (1963) 14.
5. E. L. WILLIAMS, "Diffusion of Oxygen in Fused Silica". *Ibid*, p. 190.
6. A. CHOUDHURY, D. W. PALMER, G. AMSEL, H. CURIEN, and P. BARUCH, "A Study of Oxygen Diffusion in Quartz by using the Nuclear Reaction O^{18} (p, α) N^{15}". *Solid State Communs.* **3** (1965) 119.
7. D. W. PALMER, "Oxygen Diffusion in Quartz Studied by Proton Bombardment". *Nucl. Instr. Methods (Netherlands)* **38** (1965) 187.
8. G. H. FRISCHAT and H. J. OEL, "Eine Restaktivitatsmethode zur Bestiunnung von Selbstdiffusions Koefficienten in Festkorpern" (in German). *Z. angew. Phys.* **20** (1966) 195.

Strontium Oxide

1. N. A. SURPLICE, "The Electrical Conductivity of SrO and CaO". *Brit. J. Appl. Phys.* **17** (1966) 175.

Tantalum Oxide

1. A. S. PAVLOVIC, "Some Dielectric Properties of Tantalum Pentoxide". *J. Chem. Phys.* **40** (1964) 951.

Terbium Oxide

1. U. E. KUNTZ and L. EYRING, "Diffusion of Oxygen in Rare-Earth Oxides". Kinetics of High Temperature Processes, Conference (Dedham, Mass., 1958) Proceedings (edited by W. D. Kingery) (Wiley, New York, 1959) p. 50.

Tin Oxide

1. R. LINDNER and O. ENGVIST, "Self-Diffusion in Zinc Stannate and Stannic Oxide". *Arkiv Kemi* **9** (1956) 471.
2. R. LINDNER, "Selbstdiffusion in Oxydsystemen" (in German). *Z. Naturforsch.* **10A** (1955) 1027.

Titanium Oxide

1. R. HAUL, D. JUST, and G. DÜMBGEN, "Oxygen Diffusion in Oxides" (in German). Reactivity of Solids, International Conference (Amsterdam, May, 1960). Proceedings (edited by J. H. de Boer) (Elsevier, Amsterdam, 1961) p. 65.
2. R. HAUL and G. DÜMBGEN, "Investigation of Oxygen Diffusion in Titanium Dioxide, Quartz, and Vitreous Quartz using Heterogeneous Isotropic Exchange" (in German). *Z. Elektrochem.* **66** (1962) 636.

3. *Idem*, "Oxygen Self-Diffusion in Rutile Crystals". *Phys. Chem. Solids* **26** (1965) 1.
4. R. D. CARNAHAN and J. D. BRITTAIN, "Optical Absorption Study of Reduction Kinetics of Rutile Crystals". *J. Amer. Ceram. Soc.* **48** (1965) 365.

Tungsten Oxide

1. L. D. DUFOUR and P. DUFOUR, "Sigmoidal Oxidation of Powdered Tungsten at an Intermediate Temperature and Low Oxygen Pressure" (in French). *Compt. rend.* **262** (1966) 409.

Uranium Oxide

1. S. ARONSON, R. B. ROOF, and J. BELLE, "Kinetic Study of the Oxidation of Uranium Dioxide". *J. Chem. Phys.* **27** (1957) 137.
2. J. BELLE and B. LUSTMAN, "Properties of UO_2". US Atomic Energy Commission Report, WAPD-184 (September, 1957); or see CEA and USAEC Fuel Elements Conference (Paris, November, 1957). US Atomic Energy Commission Report, TID-7546 (1958) p. 442. both include the data in J. BELLE and A. B. AUSKERN, "Oxygen Ion Self-Diffusion in Uranium Dioxide". Kinetics of High Temperature Processes, Conference (Dedham, Mass., 1958) Proceedings (edited by W. D. Kingery) (Wiley, New York, 1959) p. 44.
3. *Idem*, "Self-Diffusion of Oxygen in Uranium Dioxide". *J. Chem. Phys.* **28** (1958) 171.
4. J. BELLE, "Properties of Uranium Dioxide". United Nations, Peaceful Uses of Atomic Energy, 2nd International Conference (Geneva, 1958) Proceedings, Vol. 6 (IAEA, Vienna, 1958) p. 569, Paper A/CONF. 15/P/2404 USA.
5. D. S. KNEPPEL, "Isotopic Interchange of Dispersion Fuels". US Atomic Energy Commission Report, NMI-1232 (October, 1960) p. 1.
6. J. BELLE, A. B. AUSKERN, W. A. BOSTROM, and F. S. SUSKO, "Diffusion Kinetics in Uranium Dioxide". Reactivity of Solids, International Conference (Amsterdam, May, 1960) Proceedings (edited by J. H. de Boer) (Elsevier, Amsterdam, 1961) p. 452. This contains work in A. B. AUSKERN and J. BELLE, "Oxygen Ion Self-Diffusion in Uranium Dioxide". *J. Nucl. Matls.*, **3** (1961) 267 and *Idem*, "Uranium Ion Self-Diffusion in UO_2". *Ibid* p. 311.
7. R. LINDNER and F. SCHMITZ, "The Diffusion of Uranium^{233} in Uranium Dioxide" (in German). *Z. Naturforsch.* **16A** (1961) 1373.
8. W. VAN LIERDE, "Physical Properties of UO_2 Single Crystals". Quarterly Report No. 11 (July-October, 1964). USA-Euratom Report EURAEC-1320 (1964).
9. G. B. ALCOCK, R. J. HAWKINS, A. W. D. HILL, and P. MCNAMARA, "A Study of Cation Diffusion in Stoichiometric UO_2 using X-ray Spectrometry". IAEA, Thermodynamics with Emphasis on Nuclear Materials and Atomic Transport in Solids, Symposium (Vienna, July, 1965) Proceedings (IAEA, Vienna, 1966) Paper SM-66/36.
10. W. DARNELAS and P. LACOMBE, "Diffusion sans Champ Électrique de l'Oxygène aux Températures de 900° à 1000° C dans l'Oxide d'Uranium UO_2" (in French). *J. Nucl. Matls.* **21** (1967) 100.
11. J. F. MARIN and H. MICHAUD, "Application de la Spectrometrie α à la Mesure de Faibles Coefficients de Diffusion; Cas du Bioxyde d'Uranium" (in French). *Compt. rend.* **621** (1965) 693.
12. W. J. DEISS and H. MICHAUD, "Dispositif Experimental pour la Mesure de Faibles Coefficients de Diffusion pour la Methods de Sectionnement" (in French). Centre d'Études Nucleares de Grenoble, Rapport CEA 2267 (1963).
13. R. J. THORN and G. H. WINSLOW, "Oxygen Self-Diffusion in Uranium Dioxide". *J. Chem. Phys.* **44** (1966) 2822.
14. S. YAJIMA, H. FURUYA, and T. HIRAI, "Lattice and Grain Boundary Diffusion of Uranium in UO_2". *J. Nucl. Matls.* (*Netherlands*) **20** (1966) 162.

Yttrium Oxide

1. M. F. BERARD and D. R. WILDER, "Self-Diffusion in Polycrystalline Yttrium Oxide". *J. Appl. Phys.* **34** (1963) 2318; or see US Atomic Energy Commission Report, IS-518 (July, 1962).
2. M. F. BERARD and D. R. WILDER, "Self-Diffusion of Oxygen in Y_2O_3 and Er_2O_3". *J. Amer. Ceram. Soc.* **50** (1967) 113.

Zinc Oxide

1. P. H. MILLER, "The Electrical Conductivity of Zinc Oxide". *Phys. Rev.* **60** (1941) 890.
2. H. FRITZCHE, "Effect of Dissolved Oxygen on the Electrical Conductivity of Zinc Oxide". *Z. Physik.* **133** (1952) 422; *Chem. Abs.* **47** 7851*f*.
3. R. LINDNER, D. CAMPBELL, and A. ASKERSTRÖM, "The Diffusion of Radioactive Zinc in $ZnO.Fe_2O_3$ (spinel) and Zinc Oxide". *Acta Chem. Scand.* **6** (1952) 457.
4. F. MUNNICH, "Diffusion of Zinc in Zinc Oxide" (in German). *Naturwiss.* **42** (1955) 340; *Ceramic Abs.* **219B** (1960).
5. R. ARNETH, "Diffusion of Zinc in Zinc Oxide Crystals and their Infra Red Absorption" (in German). Diploma project, Univ. of Erlangen, Germany (1955).
6. W. A. SECCO and W. J. MOORE, "Diffusion of Zinc in Crystalline Zinc Oxide". *J. Chem. Phys.* **23** (1955) 1170; or see "Diffusion and Exchange of Zinc in Crystalline Zinc Oxide". *Ibid* **26** (1957) 942.
7. E. SPICAR, "Diffusion of Zinc in Zinc Oxide". Reactivity of solids, 1st International Conference (Madrid, 1956) Proceedings (Elsevier, Amsterdam, 1957) p. 637.
8. *Idem*, "Establishment of Point Equilibrium in Crystal Compounds" (in German). Thesis, Stuttgart (1956).

9. J. P. ROBERTS, J. HUTCHINGS, and C. WHEELER, "Sintering and Diffusion Studies of Zinc Oxide". *Trans. Brit. Ceram. Soc.* **55** (1956) 75.
10. J. P. ROBERTS and C. WHEELER, "Diffusion of Zinc in Zinc Oxide". *Phil. Mag.* **2** (1957) 708.
11. D. G. THOMAS, "Interstitial Zinc in Zinc Oxide". *Phys. Chem. Solids* **3** (1957) 229.
12. H. LAMATSCH, (in German) diploma project, Univ. of Erlangen, Germany (1958).
13. W. J. MOORE, "Parabolic Rate Constants and Diffusion Mechanisms in Oxides and Sulphides". *Z. Elektrochem.* **63** (1958) 794.
14. E. L. WILLIAMS, "Diffusion of Zinc and Oxygen in Single Crystals of Zinc Oxide". Thesis, Indiana University, *Diss. Abs.* **20** (1959) 1200; or see W. J. MOORE and E. L. WILLIAMS, "Diffusion of Zinc and Oxygen in Zinc Oxide". *Discuss. Faraday Soc.* **28** (1959) 86.
15. R. POHL, "The Diffusion of Surplus Zinc into Single Crystals of Zinc Oxide". *Z. Physik.* **155** (1959) 120.
16. J. P. ROBERTS and C. WHEELER, "Diffusion of Zinc in Polycrystalline Zinc Oxide". *Trans. Faraday Soc.* **56** (1960) 570.
17. E. A. SECCO, "Gas-solid Exchange Reactions, Zinc Vapour and Polycrystalline Zinc Oxide". Reactivity of Solids, International Conference (Amsterdam, May, 1960) Proceedings (edited by J. H. de Boer) (Elsevier, Amsterdam, 1961) p. 188. Preliminary work in *Discuss. Faraday Soc.* **28** (1959) 94.
18. *Idem*, "Diffusion of Zn in ZnO". *Can. J. Chem.* **39** (1961) 1544.
19. R. LINDNER, "Selbstdiffusion in Oxdsystemen" (in German). *Zeit. Naturforsch.* **10A** (1955) 1027.

Zirconium Oxide

1. W. D. KINGERY, J. PAPPIS, M. E. DOTY, and D. C. HILL, "Oxygen Ion Mobility in Cubic $Zr_{0.85}Ca_{0.15}O_{1.85}$". *J. Amer. Ceram. Soc.* **42** (1959) 393.
2. J. DEBUIGNE and P. LEHR, "The Determination of Oxygen Diffusion Coefficient in the Zirconium-Oxygen System" (in French). *Compt. rend.* **256** (1963) 1136; or see "Dry Corrosion of Non-Alloyed Zirconium" (in French). IAEA, Corrosion of Reactor Materials Conference (Salzburg, June, 1962) Proceedings (IAEA, Vienna, 1962) Vol. 2, p. 105.
3. D. L. DOUGLASS, "Diffusion of Oxygen in Columbium Pentoxide and Zirconium Dioxide". IAEA, Corrosion of Reactor Materials Conference (Salzburg, June, 1962) Proceedings (IAEA, Vienna, 1962) Vol. 2, p. 223.
4. L. A. MCCLAINE, "Thermodynamic and Kinetic Studies for a Refractory Materials Program". USA Report ASD/TDR/62/204, Part II (April, 1962) p. 54.
5. P. KOFSTAD and D. J. RUZICKA, "On the Defect Structure of ZrO_2 and HfO_2". *J. Electrochem. Soc.* **110** (1963) 181.
6. T. SMITH, "Diffusion Coefficients and Anion Vacancy Concentrations for the Zirconia-Zirconium Dioxide System". *Ibid.* **112** (1965) 560.
7. B. COX and C. ROY, "Transport of Oxygen in Oxide Films on Zirconium Determined by the Nuclear Reaction O^{17} (He^3, α) O^{17}". Canadian Report, AECL-2350 (October, 1965) and *Electrochem. Tech.* **4** (1966) 121.
8. L. A. SIMPSON and R. E. CARTER, "Oxygen Exchange and Diffusion in Calcia-Stabilised Zirconia". *J. Amer. Ceram. Soc.* **49** (1966) 139.
9. A. W. SMITH, F. W. MESZAROS, and C. D. AMATA, "Permeability of Zirconia, Hafnia and Thoria to Oxygen". *Ibid* p. 240.
10. W. H. RHODES and R. E. CARTER, "Catonic Self-Diffusion in Calcia Stabilised Zirconia". *Ibid* p. 244.
11. L. A. MCCLAINE and C. P. COPPEL, "Electrical Conductivity of Tetragonal Zirconia". *J. Electrochem. Soc.* **113** (1966) 80.

Letters

The Influence of Microporosity on the Ductility of Al/Al_2O_3 Alloys

Generally, the ductility of Al/Al_2O_3 (SAP) alloys decreases with increasing temperature and with decreasing deformation speed. Examples are given in figs. 1a and b. Electron micrographs [1] and density measurements [2] have indicated that this may be connected with the formation of microcracks.

This note presents first results of a systematic study on the influence of temperature on crack-formation in SAP alloys during tensile tests and creep.

Samples of 1.5 g were taken from the rupture zones of SAP specimens, of 10 mm diameter, broken in tensile and accelerated creep tests at temperatures between 20 and 620° C. The density of the samples was determined by the immersion technique; the precision was better than ± 0.002 g/cm^3. SAP alloys with various fabrication histories and different oxide contents were investigated.

Typical results of density measurements of samples taken from tensile specimens of SAP with different Al_2O_3 contents (4, 7, 14 wt % Al_2O_3) are shown in fig. 1b. All alloys show the same behaviour. The density decreases slowly