

Tracer Diffusion Data for Metals, Alloys, and Simple Oxides

John Askill



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Millikin University, Decatur, Illinois

IFI/Plenum • New York—Washington—London • 1970

Library of Congress Catalog Card Number 73-95202

ISBN-13: 978-1-4684-6077-3

e-ISBN-13: 978-1-4684-6075-9

DOI:10.1007/978-1-4684-6075-9

© 1970 IFI/Plenum Data Corporation

Softcover reprint of the hardcover 1st edition 1970

A Subsidiary of Plenum Publishing Corporation
227 West 17th Street, New York, N.Y. 10011

United Kingdom edition published by Plenum Press, London
A Division of Plenum Publishing Company, Ltd.
Donington House, 30 Norfolk Street, London W.C.2, England

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Preface

Atomic diffusion in metals was first discovered some sixty-five years ago, and since then a considerable wealth of data has accumulated on diffusion in various systems. However, work prior to about the year 1940 is now mainly of historical interest, since experiments were often carried out under experimental conditions and with methods of analysis leading to uncertainties in interpreting the measured diffusion coefficients. Data on diffusion rates are of importance in processes which are controlled by rates of atomic migration such as growth of phases and homogenization of alloys. In addition diffusion plays an important part in theories of such phenomena as oxidation, plastic deformation, sintering, and creep.

A tremendous advance in diffusion studies was made possible by the availability of radioactive isotopes of sufficiently high specific activity after the second world war. Measurements of self-diffusion rates then became possible using radioactive isotopes having the same chemical properties as the solvent material, and it also became possible to study tracer impurity diffusion when the concentration of the impurity is so small as not to alter the chemical homogeneity of the system. In the last ten to fifteen years the purity of materials used in diffusion studies has increased considerably and the methods of analysis have become more standardized.

The main purpose of this book is to bring together in one compilation all the radioactive tracer diffusion data of metals in pure metals, alloys, and simple oxides that have been reported in the literature between 1938 and December 1968.

The data have been divided into four parts:

- I. Self-diffusion in pure metals.
- II. Impurity diffusion in pure metals.
- III. Self- and impurity diffusion in alloys.
- IV. Self- and impurity diffusion in simple metal oxides.

Over 1200 diffusion entries are included with elements and solutes arranged alphabetically. A complete list of references and an index of authors are also given.

The various aspects of the diffusion data listed in the tables, such as temperature range, method of analysis of the diffusion samples, and the diffusion parameters D_0 and Q in the Arrhenius equation $D = D_0 \exp(-Q/RT)$ are discussed in an introductory chapter. The various mechanisms which have been proposed for atomic diffusion in solids are also described..

Often one needs values of the diffusion coefficient for a particular system which has not yet been studied experimentally. In this case one or more of the many empirical relations between diffusion and other physical properties of solids may be useful. For this reason, the various empirical relations for diffusion, particularly self-diffusion, are discussed in a second introductory chapter. In this way the applied scientist can make a reasonable estimate of the diffusion coefficient at some temperature in most systems for which direct experimental data are not available.

Most of the work involved in compiling these tables was carried out while the author was at the University of Reading, Reading, England, and at the Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Contents

Chapter 1

Diffusion, the Diffusion Coefficient, and Mechanisms of Diffusion	1
1. Diffusion	1
2. The Diffusion Coefficient	1
3. Solutions to the Diffusion Equation	2
4. Methods of Analysis of the Diffusion Samples	4
4.1. Serial Sectioning	4
4.2. Residual Activity Method	5
4.3. Surface Decrease Method	6
4.4. Autoradiography	7
5. The Temperature Dependence of the Diffusion Coefficient	9
6. Mechanisms of Diffusion	11
6.1. Vacancy Mechanism	11
6.2. Interchange of Exchange Mechanism	12
6.3. Ring Mechanism	12
6.4. Interstitial Mechanism	12
6.5. Interstitialcy Mechanism	14
6.6. Crowdion Mechanism	14
6.7. Dislocations	14
6.8. Grain Boundary	14
7. Summary of Terms	15
8. Suggested Further Reading	16

Chapter 2

Empirical and Semi-Empirical Diffusion Relations	19
1. The Dushman and Langmuir Relation	19
2. Simple Empirical Correlations Between the Self-Diffusion Activation Energy and Various Properties of Metals	20
2.1. Melting Point.	20
2.2. Latent Heat of Fusion and Sublimation	22
2.3. Compressibility	22
2.4. Coefficient of Linear Expansion	22
3. Relations Involving Elastic Moduli	23
4. An Extended Melting Point Correlation	23
5. Empirical Relations for Impurity Diffusion and Self-Diffusion in Alloys	24
6. Summary of Empirical Relations	25

Chapter 3

Radioactive Tracer Diffusion Data in Metals, Alloys, and Oxides	27
1. Introduction	27
2. Some Predicted Diffusion Parameters.	28

Tables

Part I. Self-Diffusion in Pure Metals	31
Part II. Impurity Diffusion in Pure Metals.	43
Part III. Self- and Impurity Diffusion in Alloys.	57
Part IV. Self- and Impurity Diffusion in Simple Metal Oxides	79
References	83
Author Index	101
General Index	107

Chapter I

Diffusion, the Diffusion Coefficient, and Mechanisms of Diffusion

1. DIFFUSION

Diffusion is the way in which matter is transported through matter. It occurs by approximately random motions of the atoms in a crystal lattice. The net result of many such random movements of a large number of atoms is actual displacement of matter, the movement being activated by the thermal energy of the crystal. In a pure material any particular atom is continually moving from one position to another in the material. This is called self-diffusion and can be studied experimentally by the use of radioactive tracers.

2. THE DIFFUSION COEFFICIENT

The transfer of heat also occurs by random motions of atoms or molecules. This led Fick¹ to produce what is now generally known as Fick's first law of diffusion,

$$J = -D \frac{dc}{dx} \quad (1.1)$$

where J is the diffusion flux or the rate of transfer of atoms of a particular constituent of a system through unit area in unit time, dc/dx is the concentration gradient in the direction of diffusion, and D is the diffusion coefficient. The units of J are atoms/cm²·sec, and those of c atoms/cm³, so that D is measured in cm²/sec.

¹A. Fick, Ann. Phys. Leipzig, 94:59 (1855).

Equation (1.1) is similar to that for heat flow where heat flux is directly proportional to the temperature gradient, and also to the electrical conductivity analogue. If the fluxes of atoms through two planes a distance dx apart are J and $J + dJ/dc$, then the difference in flux is

$$\frac{dJ}{dc} = \left(-D \frac{dc}{dx} \right) - \left(-D \frac{dc}{dx} + \frac{d}{dx} D \frac{dc}{dx} \right) = -\frac{d}{dx} \left(D \frac{dc}{dx} \right)$$

Since no atoms are produced or lost (a continuity condition), this difference in flux must be equal to $-dc/dt$. This gives us Fick's second law of diffusion:

$$\frac{dc}{dt} = \frac{d}{dx} \left(D \frac{dc}{dx} \right) \quad (1.2)$$

For self-diffusion and impurity diffusion at tracer concentrations, the diffusion coefficient D is independent of concentration c so that equation (1.2) becomes

$$\frac{dc}{dt} = D \frac{d^2c}{dx^2} \quad (1.3)$$

Diffusion experiments are analyzed in terms of a suitable solution of equation (1.2) or (1.3) for the particular geometrical conditions used.

3. SOLUTIONS TO THE DIFFUSION EQUATION

Both the initial conditions and the boundary conditions of the system have to be determined. The initial conditions fix the state before diffusion takes place ($t = 0$). The boundary conditions contain geometric factors defining the experimental conditions such as specimen dimensions and continuity conditions.

The majority of diffusion experiments are carried out with a semi-infinite specimen with an infinitesimally thin layer of radioactive isotope deposited on one face (Fig. 1A). In this case the solution of the general diffusion equation (1.3) is

$$c(x, t) = \frac{S}{\sqrt{\pi D_T t}} \exp\left(-\frac{x^2}{4D_T t}\right) \quad (1.4)$$

where $c(x, t)$ is the concentration of radioactive atoms at a distance x from the initial face, S is the initial total amount of activity, t is the time of the diffusion anneal, and D_T is the diffusion coefficient

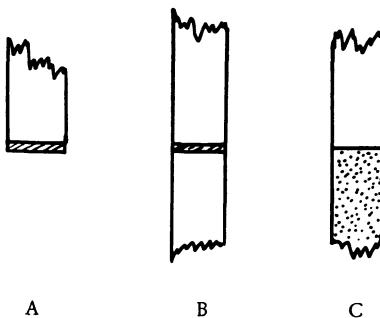


Fig. 1. Experimental arrangement of samples. (A) Semi-infinite specimen — infinitesimally thin layer of isotope; (B) double semi-infinite specimen — infinitesimally thin layer of isotope; (C) semi-infinite specimen — semi-infinite uniformly active specimen.

at a temperature of $T^{\circ}\text{K}$. Equation (1.4) can be simplified to

$$c(x) = c(0) \exp\left(-\frac{x^2}{4D_T t}\right) \quad (1.5)$$

since S and t are constants for a particular diffusion sample obtained from a particular diffusion anneal.

Sometimes two semi-infinite specimens with an infinitesimally thin layer of radioactive material between them are used (Fig. 1B). In this case the solution of the diffusion equation is

$$c(x, t) = \frac{S}{2\sqrt{\pi D_T t}} \exp\left(-\frac{x^2}{4D_T t}\right) \quad (1.6)$$

This is of the same form as for a single sample, i.e.,

$$c(x) = c(0) \exp\left(-\frac{x^2}{4Dt}\right)$$

One other arrangement that is sometimes used is a semi-infinite specimen with a semi-infinite uniformly active second specimen (Fig. 1C). In this case the concentration distribution equation can be shown to be

$$c(x) = \frac{c(0)}{2} \left[1 - \operatorname{erf}\left(\frac{x}{2\sqrt{Dt}}\right) \right] \quad (1.7)$$

The aim of any method of analysis is to measure the concentration $c(x)$ as a function of distance x through the diffused specimen. If the concentration distribution obeys equation (1.5), for example, then a plot of $\log_e c(x)$ versus x^2 will be linear with slope $-1/4D_T t$, giving a value of the diffusion coefficient D_T at the particular temperature $T^\circ K$ of the anneal. The four most widely used methods of analysis are the serial sectioning method, the residual activity method, the surface decrease method, and autoradiography. Nearly all of the entries in the bibliography of diffusion data given in Chapter 3 used one or more of these four methods of analysis. Each will be discussed here in some detail.

4. METHODS OF ANALYSIS OF THE DIFFUSION SAMPLES

4.1. Serial Sectioning

The serial sectioning method is the method of analysis most frequently used in the study of diffusion using radioactive tracers. The diffusion specimen is subjected to a series of sectioning operations, the specimen being weighed before and after each cut in order to determine the thickness of material removed. The cuttings are collected and their activity measured with a Geiger tube or a scintillation counter. From the weights the coordinates of the mid-points of each slice (x) are calculated, and a plot of \log_e (count rate) versus x^2 then has a slope of $-1/4D_T t$ for volume diffusion. Hence, if the time of the anneal t is known, the diffusion coefficient D_T may be calculated. If the \log (count rate) versus x^2 relationship is not linear over the full length of the penetration plot, this means that bulk diffusion is not the only mechanism present. Grain boundary diffusion is usually observed at low temperatures in polycrystalline specimens where a linear \log (count rate) versus x plot is expected. Upward curvature at the high x^2 end of the \log (count rate) versus x^2 plot is then normally associated with grain boundary or dislocation diffusion.

The main advantage of the serial sectioning method is that it is simple, direct, and does not depend on the properties of the radiations from the radioactive material used. In addition, it does not presuppose the nature of the diffusion phenomenon. If the values of $\sqrt{2Dt}$ are between 10^{-5} and 10^{-2} cm, the sectioning is conveniently performed on a precision lathe. The smallest value of the diffu-

sion coefficient that can conveniently be measured by lathe sectioning is about $10^{-11} \text{ cm}^2/\text{sec}$. To make it possible to measure smaller diffusion coefficients, the method can be modified by removing the slices by grinding. If a microbalance is available to measure the material removed to about $1 \mu\text{g}$, diffusion coefficients down to 10^{-13} to $10^{-14} \text{ cm}^2/\text{sec}$ can be measured in this way. Recently a process of anodizing and stripping has been developed² by which diffusion coefficients as low as 10^{-6} to $10^{-17} \text{ cm}^2/\text{sec}$ can be measured. With this process, which at present is only applicable to niobium and tungsten, very small layers of the order of 100 \AA can be removed. Serial sectioning is regarded as the most reliable and most accurate method of diffusion analysis.

4.2. Residual Activity Method

The residual activity (or Gruzin) method is similar to the serial sectioning analysis in that layers of thickness x are removed by lathe sectioning, grinding, etching, or anodizing, but the total remaining activity of the sample I is measured in this case. If one considers an elementary thickness dx between x and $x + dx$, we have

$$dI = k \frac{S}{\sqrt{\pi D_T t}} \exp \left(-\frac{x^2}{4D_T t} \right) \exp \left[-\mu (x - x_n) \right]$$

where μ is the absorption coefficient for the radiation by the solvent material, x_n is the thickness of the n -th layer, I_n is the activity of the sample after n layers are removed, and k is a constant depending on the geometric counting conditions. Integrating this equation gives

$$I_n = k \frac{S}{\sqrt{\pi D_T t}} \int_{x_n}^{\infty} \exp \left(-\frac{x^2}{4D_T t} \right) \exp[-\mu(x - x_n)] dx \quad (1.8)$$

Equation (1.8) can be solved to give

$$\mu I_n - \frac{dI_n}{dx_n} = k \frac{S}{\sqrt{\pi D_T t}} \exp \left(-\frac{x_n^2}{4D_T t} \right)$$

or

$$\mu I_n - \frac{dI_n}{dx_n} = kc(x_n) \quad (1.9)$$

²R. E. Pawel and T. S. Lundy, J. Appl. Phys., 34:1001 (1964); R. E. Pawel, Rev. Sci. Instr., 35:1066 (1964).

This method is of particular importance in two limiting cases.

(a) Weakly absorbed radiation - strong γ -rays. In this case $\mu I_n \ll dI_n/dx_n$ so that

$$-\frac{dI_n}{dx_n} = k \frac{S}{\sqrt{\pi D_T t}} \exp\left(-\frac{x_n^2}{4D_T t}\right)$$

and

$$\log_e\left(-\frac{dI_n}{dx_n}\right) = \text{constant} - \frac{x_n^2}{4D_T t} \quad (1.10)$$

Thus a plot of $\log_e (-dI_n/dx_n)$ versus x_n^2 should be a straight line of slope $-1/4D_T t$, which, the anneal time t being known, gives a value of the diffusion coefficient D_T at $T^\circ K$.

(b) Strongly absorbed radiation - weak β -rays. Here $\mu I_n \ll dI_n/dx_n$ so that

$$\mu I_n = k \frac{S}{\sqrt{\pi D_T t}} \exp\left(-\frac{x_n^2}{4D_T t}\right)$$

and

$$\log_e I_n = \text{constant} - \frac{x_n^2}{4D_T t} \quad (1.11)$$

A plot of $\log_e I_n$ versus x_n^2 should also be a straight line of slope $-1/4D_T t$, from which D_T is calculated as before.

In the intermediate case of an isotope emitting both γ -rays and β -rays the difference in the count rate of the specimen with and without an absorber (i.e., the count rate of the γ -rays alone) is used as I_n in (b) above.

The residual activity method of analysis is regarded as less reliable than the standard serial sectioning method, but it does allow us to measure diffusion coefficients several orders of magnitude smaller (10^{-13} to $10^{-14} \text{ cm}^2/\text{sec}$).

4.3. Surface Decrease Method

In this method the total activity of the specimen is measured as a function of time. No sectioning of the sample is necessary. As before, consider an element of thickness dx lying between x and $x + dx$. If the absorption is exponential, this element will contribute dI to the total activity I , so that

$$dI = \frac{kS}{\sqrt{\pi Dt}} \exp \left(-\frac{x^2}{4Dt} \right) \exp(-\mu x) dx$$

Integrating gives

$$I = \frac{kS}{\sqrt{\pi Dt}} \int_0^\infty \exp \left[-\left(\frac{x^2}{4Dt} + \mu x \right) \right] dx \quad (1.12)$$

which can be integrated to give

$$I = kS \exp(\mu^2 Dt) [1 - \operatorname{erf} \mu \sqrt{Dt}]$$

or

$$\frac{I}{I_0} = \exp(\mu^2 Dt) [1 - \operatorname{erf} \mu \sqrt{Dt}] \quad (1.13)$$

The total activity I is measured as a function of time t . A master curve may be drawn giving I/I_0 as a function of $\mu^2 Dt$. The experimental curve is compared with a master to obtain a value of $\mu^2 Dt$, which, the value of the absorption coefficient μ and the anneal time t being known, yields the diffusion coefficient D .

This method can be useful for measuring small diffusion coefficients (10^{-13} to 10^{-15} cm 2 /sec), particularly in the case of strongly absorbed radiation. However, one limitation is that an accurate value of μ is required and this is often difficult to ascertain in practice. The surface decrease method is not useful in the case of weakly absorbed (small μ) radiation. The method is considerably less reliable than the serial sectioning method of analysis.

4.4. Autoradiography

All of the previously described methods of analysis have required detection of the radiation by its ionizing action in some form of detector. There is one other method of detection, that of the action on photographic emulsions. The principle of the method is to determine the photographic density of the blackening of an exposed emulsion as a function of the distance from the interface of the specimen with the initial radioactive deposit.

The specimen is cut at a measured angle α (usually 90°) to the initial face, and the cut face is placed in contact with a piece of appropriate X-ray film. The type of film to be used and the length of exposure time are best found by experimentation. As a guide for normal diffusion samples with a few microcuries of initial activity, an exposure time of 24 hours is typical for the standard

types of X-ray film such as Kodak C or M. The blackening of the emulsion (which is usually found to be directly proportional to the concentration of activity) is measured with a microdensitometer. To eliminate the uncertainty of determining the position of the original interface, two specimens can be used with their active faces welded together. The blackening of the emulsion is then symmetrical about the interface position.

A graph of photographic density versus distance is truly Gaussian only in the case of a pure β -emitting isotope. In the case of radioisotopes which are γ emitters as well as β emitters, a background blackening due to incompletely absorbed γ -rays from atoms within the sample will be present. Various functions, such as log (photographic density) versus distance, or log (photographic density) versus distance squared, or photographic density versus distance squared, give linear background plots. This " γ -tail" can then be extrapolated back into the region of the diffusion zone permitting a true log (photographic density) versus distance squared graph to be drawn from the slope of which the diffusion coefficient is easily calculated. The appropriate concentration distribution equation is

$$c(x) = c(0) \exp\left(-\frac{x^2}{4Dt}\right)$$

and as the photographic density P is usually found to be directly proportional to the concentration of active material c , we have

$$P(x) = P(0) \exp\left(-\frac{x^2}{4Dt}\right) \quad (1.14)$$

Hence a plot of $\log_e P(x)$ versus x^2 has a slope of $-1/4Dt$, from which D may be calculated if the anneal time t is known.

The autoradiographic method is most suitable for pure β -emitting isotopes of low or medium energies (less than 1 MeV). The background correction is somewhat arbitrary, so that in general the accuracy of this method of analysis is not as high as that of the standard serial sectioning method. However, it is very useful for low-energy β -emitting isotopes and for materials which for various reasons may be difficult to section. The range of values of the diffusion coefficients that can be measured by the autoradiographic method depends on the time of the anneal, the resolution

of the microdensitometer, and the type of film used. A typical lower limit is 10^{-11} to $10^{-12} \text{ cm}^2/\text{sec}$.

The choice of the method of analysis depends on the material used, the nature of the emitted particles from the radioactive isotope, and the range of the diffusion coefficients being studied.

- (a) The serial sectioning method is undoubtedly the best although it is not practicable for weak β emitters. It is the most accurate method for γ emitting isotopes.
- (b) The residual activity method can be used for both β - and γ -emitting isotopes and can measure smaller values of the diffusion coefficient. However, a value of the absorption coefficient is required except in the case of pure β emitters.
- (c) The surface decrease method suffers from the same disadvantage as the residual activity method in that it requires an accurate value of the absorption coefficient, as well as other problems from evaporation of the isotope, etc.
- (d) Autoradiography is most suitable for pure β emitters and can be used with isotopes emitting γ -rays as well as β -rays but cannot be used with strong γ emitters.

The choice of the form of analysis is summarized in Table I.

5. THE TEMPERATURE DEPENDENCE OF THE DIFFUSION COEFFICIENT

Experimentally, the temperature dependence of the diffusion coefficient can usually be expressed by an Arrhenius equation of the form

$$D_T = D_0 \exp\left(-\frac{Q}{RT}\right)$$

where D_T is the diffusion coefficient in cm^2/sec at a temperature $T^\circ\text{K}$, R is the universal gas constant (1.98 cal/mole · deg), Q is the activation energy in cal/mole, and the constant D_0 is normally referred to as the frequency factor (cm^2/sec).

For self-diffusion in metals the values of D_0 usually lie between 0.1 and 10 cm^2/sec , often close to unity. If diffusion takes

Table I

Strong β and/or strong γ	Weak β	Weak γ	Diffusion coefficient (cm ² /sec)		Typical isotopes
			10^{-5} 10^{-11}	10^{-10} 10^{-14}	
✓	-	-	1	1a 2	P ³² , Lu ¹⁷⁰ Hf ¹⁷¹ , Ta ¹⁷⁷
✓	✓	-	1	1a	Co ⁶⁰ , Mo ⁹⁹ , W ¹⁸⁵ , V ⁴⁸ , Cu ⁶⁴ , Ag ¹¹⁰
✓	✓	✓	1	1a	Mo ⁹⁹ , Au ¹⁹⁸
-	✓	-	2 4 3	2 3	Ni ⁶³ , Fe ⁵⁵ , In ¹¹⁴ , Pd ¹⁰⁷
-	-	✓	1	1a	Sn ¹¹³ , U ²³⁸
-	✓	✓	1 2 4 3	1a 2 3	Nb ⁹⁵ , Cr ⁵¹ , Mn ⁵⁴ , Zr ⁹⁵
✓	-	✓	1	1a	Rb ⁸³ , Zr ⁹⁷

1—Serial sectioning (lathe).

1a—Serial sectioning (grinding or stripping).

2—Residual activity.

3—Surface decrease.

4—Autoradiography.

place by more than one mechanism, or is affected by chemical gradients, then the measured D_0 values could be very different. Values of D_0 in pure grain boundary or dislocation diffusion also appear to be of the order of magnitude of unity, but the activation energies are usually less than for pure volume diffusion, often one-half the value.

6. MECHANISMS OF DIFFUSION

The energy barrier which opposes motion of an atom in a solid lattice is greater than that in a liquid or gas. Thus the activation energy Q for volume diffusion (diffusion through the lattice) is greater than that for liquids and gases. In addition to normal lattice diffusion, diffusion can also take place along grain boundaries, dislocations, or cracks in the material. The activation energies for grain boundary diffusion, dislocation diffusion, and surface diffusion along a crack are all less than that for volume diffusion through the lattice. This is so because grain boundaries, dislocations, and cracks are regions of higher energy than the lattice. The activation energies of diffusion in these three cases are related by

$$Q_{\text{volume}} > Q_{\text{grain boundary}} > Q_{\text{surface}}$$

The volume, grain boundary, and surface activation energies have been determined in a few cases and their relative values are of the order

$$Q_{\text{volume}} : Q_{\text{grain boundary}} : Q_{\text{surface}} = 4 : 2 : 1$$

Similarly, typical values of the frequency factor D_0 are related by

$$D_0_{\text{volume}} > D_0_{\text{grain boundary}} > D_0_{\text{surface}}$$

and the actual diffusion coefficients are related by

$$D_{\text{surface}} > D_{\text{grain boundary}} > D_{\text{volume}}$$

These three types of diffusion are illustrated in Fig. 2.

Several atomic mechanisms have been proposed for diffusion in solids. Each is illustrated in Fig. 3 and is briefly described below.

6.1. Vacancy Mechanism

The vacancy mechanism is simply the movement of an atom originally in a normal lattice site into a neighboring vacant site. In all materials, vacant sites or vacancies are present at all temperatures above absolute zero in equilibrium concentrations. Complex aggregates of vacancies such as divacancies and tri-vacancies are thought to exist. Normally diffusion by single

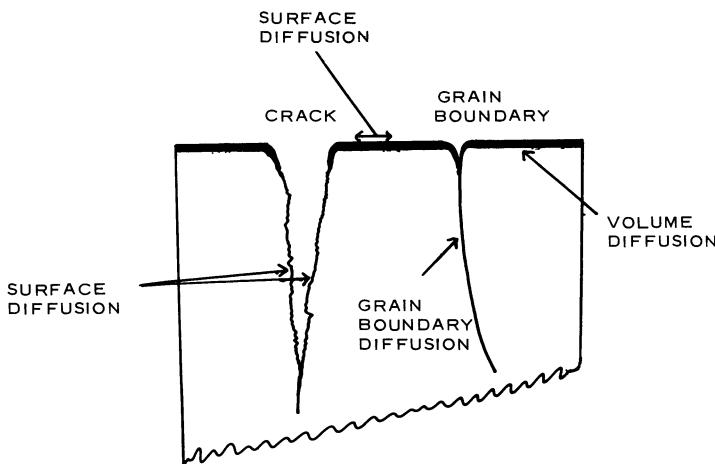


Fig. 2. Volume, grain boundary, and surface diffusion in a solid.

vacancies predominates over diffusion by divacancies, but divacancy diffusion may be appreciable at high temperatures. Enhanced diffusion in some systems at high temperatures has been explained on the basis of a divacancy contribution.

6.2. Interchange or Exchange Mechanism

This is the simplest mechanism by which an atom can move. It is simply the direct exchange of two nearest neighbor atoms. This mechanism is unlikely in tightly bound crystals.

6.3. Ring Mechanism

The ring mechanism is merely a more general form of exchange mechanism consisting of a number (three or more) of atoms forming a closed ring. Atomic diffusion then takes place by rotation of the ring.

6.4. Interstitial Mechanism

The two preceding mechanisms can operate in a perfect crystal. Small atoms such as carbon will dissolve in metallic lattices as impurities so as to occupy interstitial positions between the solvent atoms. This has been shown to be the case for carbon in α -iron, for example. (Larger impurity atoms must occupy the

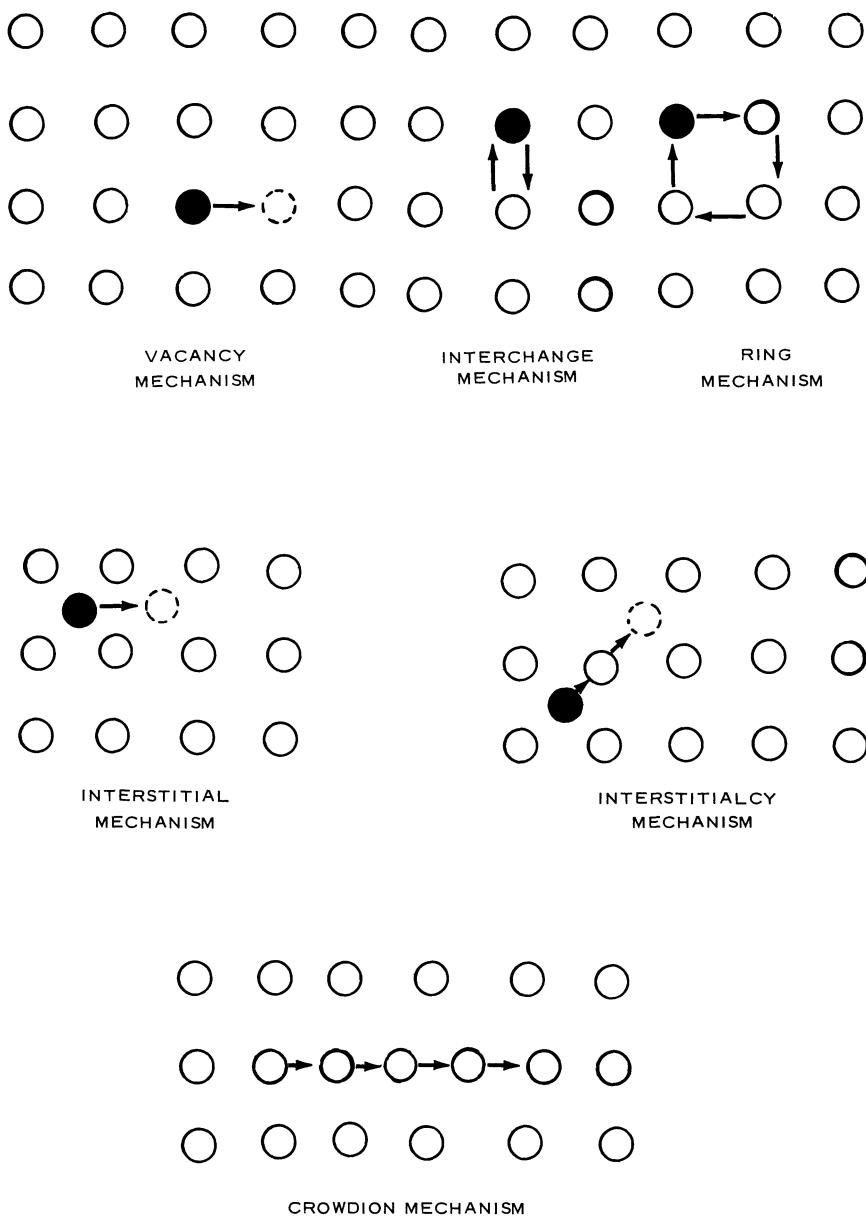


Fig. 3. Mechanisms of diffusion.

same atomic position as the solvent atoms when in solid solution; such positions are referred to as substitutional positions.) In the interstitial mechanism, diffusion takes place by atomic transport from one interstitial position to another.

6.5. Interstitialcy Mechanism

In the interstitialcy mechanism, an interstitial atom moves from an interstitial position into an adjacent normal lattice site. In doing so it displaces the atom that had occupied that site to a new interstitial position.

6.6. Crowdion Mechanism

A crowdion mechanism is a line imperfection consisting of n nearest neighbor atoms compressed into a space normally occupied by $(n - 1)$ atoms. Diffusion then takes place by movement along the line of atoms.

6.7. Dislocations

In practice, all materials are known to have intragranular defects called dislocations. Dislocations can provide easier paths for diffusion than a perfect lattice so that diffusion along dislocations is faster than true volume diffusion. Diffusion down dislocations has been proposed to explain enhanced diffusion rates at low temperatures, particularly, for example, in single crystals of the noble metals.

6.8. Grain Boundary

The areas of intergranular misfit in a crystal also provide easy paths for a diffusing atom. In general diffusion along grain boundaries takes place faster than through the bulk of the material and in most cases the activation energy for diffusion along grain boundaries has been found to be smaller than that for lattice diffusion. Dislocation pipe diffusion, grain boundary diffusion, and surface diffusion all involve intricate paths within the crystal. Detailed kinetic analysis is therefore very difficult, especially as the numbers of dislocations, grain boundaries, and surfaces all depend to some extent on the temperature. These three types of diffusion, grain boundary, dislocation pipe, and surface diffusion, are

relatively important only at low temperatures (less than about two-thirds of the melting point of the material).

7. SUMMARY OF TERMS

Activation energy	The term Q in the Arrhenius equation $D = D_0 \exp(-Q/RT)$
Autoradiography	Method of analysis utilizing the blackening of photographic film by radioactivity
Crowdion	Line imperfection consisting of n atoms occupying the space of $(n - 1)$ atoms in the regular lattice
Diffusion	Movement of matter through matter
Diffusion coefficient D	Proportionality constant in Fick's laws
Dislocation	Intragranular defect in the form of a line discontinuity
Fick's first law	Flux of diffusing species is proportional to concentration gradient: $J = -Ddc/dx$
Fick's second law	Rate of change of concentration is proportional to second derivative of concentration with distance: $dc/dt = Dd^2c/dx^2$
Frequency factor D_0	The constant term D_0 in the Arrhenius equation $D = D_0 \times \exp(-Q/RT)$
Grain boundary diffusion	Diffusion in the intergranular region
Interchange	Direct exchange of two nearest neighbor atoms
Interstitial mechanism	Movement from one interstitial position to another

Interstitialcy mechanism	Movement from an interstitial position to a normal lattice position
Residual activity	Sectioning method of analysis in which the activity remaining in the sample is measured
Self-diffusion	Diffusion of one substance into the same substance in the absence of a chemical gradient
Serial sectioning	Sectioning method of analysis in which the activity of each section is measured
Surface decrease	Method of analysis in which the total activity of the surface of the sample is measured as a function of time
Surface diffusion	Diffusion along the surface of a material or down a crack in it
Vacancy	Unoccupied lattice site in a crystal
Volume diffusion	Diffusion within the grains of a crystal

8. SUGGESTED FURTHER READING

1. Jost, W., Diffusion in Solids, Liquids, and Gases, Academic Press, New York (1952).
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Chapter 2

Empirical and Semi-Empirical Diffusion Relations

Many empirical relations between the diffusion parameters Q and D_0 and other physical properties of materials have been proposed during the past 30 to 40 years. In general the relations are of two types:

- (a) those derived without any consideration of diffusion mechanism, and
- (b) those derived on the basis of some assumed mechanism.

The purpose here is to present the more important relations and to discuss their usefulness in estimating the diffusion parameters D_0 and Q for systems for which experimental data are not yet available.

1. THE DUSHMAN AND LANGMUIR RELATION

In 1922 Dushman and Langmuir¹ proposed a relation for diffusion in metallic systems. They derived the relation

$$D = \frac{Qa^2}{Nh} \exp(-Q/RT)$$

where a is the lattice constant, N is Avogadro's number, and h is

¹S. Dushman and I. Langmuir, Phys. Rev., 20:113 (1922).

Planck's constant. Thus,

$$D_0 = \frac{Qa^2}{Nh} = 1.04 \times 10^{-3} Qa^2 \quad (2.1)$$

where a is measured in Å (1×10^{-8} cm) and Q is measured in kcal/mole. The values of D_0 vary over the fairly narrow limits of 0.2 to 0.9 cm²/sec for the various elements. However, the equation is useful since it permits values of D_0 and Q to be calculated from one experimental measurement of the diffusion coefficient at one temperature. If we assume a typical value of D_0 of 0.5 cm²/sec, this is essentially the same as calculating Q from

$$Q = -RT \ln 2D \quad (2.2)$$

where Q is the activation energy in cal/mole, R is the gas constant (1.98 cal/mole · deg), T is the temperature in degrees Kelvin, and D is the diffusion coefficient in cm²/sec.

Equations (2.1) and (2.2) are in good agreement with self-diffusion data in pure metals (except for the "anomalous" b.c.c. metals) and for much of the impurity and alloy data.

2. SIMPLE EMPIRICAL CORRELATIONS BETWEEN THE SELF-DIFFUSION ACTIVATION ENERGY AND VARIOUS PHYSICAL PROPERTIES OF METALS

A number of empirical correlations have been suggested between the self-diffusion activation energy Q and various physical properties of materials such as melting point, heats of fusion and vaporization, and elastic moduli since all of these and atomic diffusion in solids depend on the binding forces between atoms. In such correlations the self-diffusion activation energy Q is related to the physical property P by a relation of the form

$$Q = AP \quad \text{or} \quad Q = B/P \quad (2.3)$$

where A and B are proportionality constants. Some of these correlations are very useful in predicting values of the self-diffusion activation energy with a fair degree of accuracy. However, care must be taken in attempting to give the correlation any type of fundamental interpretation.

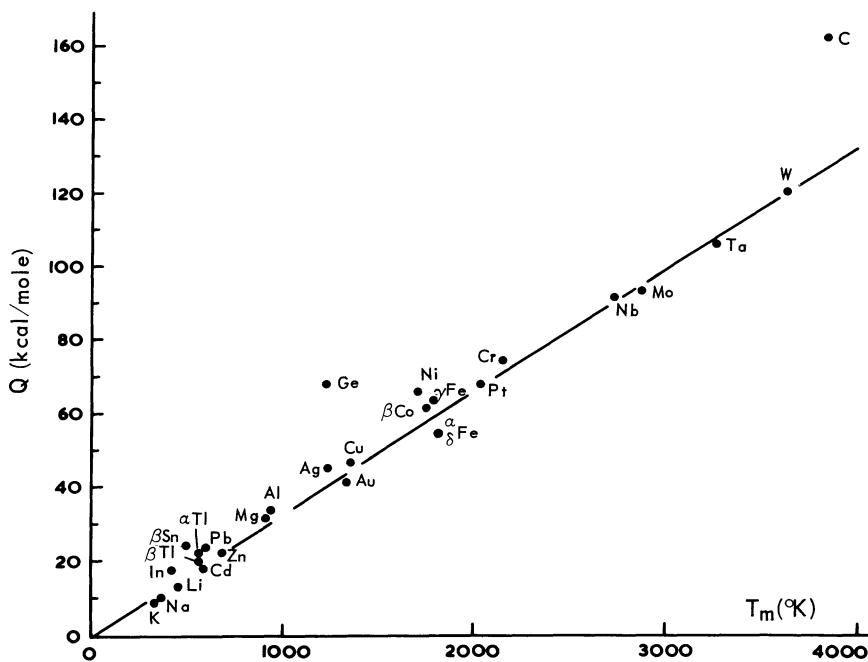


Fig. 4. Self-diffusion activation energy as a function of melting point.

2.1. Melting Point

The melting point, T_m , is one physical property of materials that is closely related to atomic transport. This has led to one of the most useful correlations

$$Q = AT_m$$

where A is a constant. Values of the self-diffusion activation energy are plotted as a function of the melting point in Fig. 4. An average value of the constant A for all structures is 33.7 cal/mole·deg, giving

$$Q = 33.7T_m \quad (2.4)$$

However, a value of $A = 38.0$ cal/mole · deg gives a better fit for f.c.c. structures and a value of $A = 32.5$ cal/mole · deg a better fit for b.c.c. structures. The elements Sn, Ge, C, γ -U, β -Ti, and β -Zr (all elements in Group IV of the periodic table) do not fit this simple correlation at all well.

Oshyarin² derived a relation between the atomic radius r , the force constant K , and the atomic packing fraction f (0.78 for f.c.c., 0.68 for b.c.c., and 0.34 for diamond structures) of the form $Q = Kr^3/f^{2/3}$. From this, using other relationships, Oshyarin deduced the simple relation

$$Q = \frac{\text{constant } T_m}{f^{2/3}} [\text{cal/mole}]$$

This gives values of A in the relation $Q = AT_m$ which are smallest for b.c.c. structures and highest for diamond structures, in qualitative agreement with experiment.

A useful approximate relation for the temperature dependence of the self-diffusion coefficient can be obtained by combining equations (2.1) and (2.4), i.e.,

$$D = 3.4 \times 10^{-5} T_m a^2 \exp(-17.0T_m/T) [\text{cm}^2/\text{sec}]$$

where T and T_m are measured in °K and a is measured in Å.

2.2. Latent Heat of Fusion and Sublimation

Correlations have been proposed between the activation energy for self-diffusion Q and the latent heats of fusion L_f and sublimation L_s . Approximate relationships are $Q = 16.5L_f$ and $Q = 0.65L_s$, where the latent heats are given in kcal/mole. Such correlations are much less consistent than the melting point correlation, and are not generally used.

2.3. Compressibility

Compressibility is another physical property of materials that depends on the binding energy between atoms. Such a correlation of the form $Q = B/\chi$, where χ is the compressibility, has been given by Gibbs.³

2.4. Coefficient of Linear Expansion

Another physical property directly related to compressibility is the coefficient of linear expansion. An analysis by the author⁴ shows that an approximate correlation exists between the self-diffusion activation energy Q and the room temperature coefficient of linear expansion, α :

$$Q = \frac{700}{\alpha} [\text{kcal/mole}]$$

²B. N. Oshyarin, Phys. Status Solidi, 3:K61 (1963).

³G. B. Gibbs, C.E.G.B. Report RD/B/N.355, Nov. 1964.

⁴G. Askill, Phys. Status Solidi, 11:K49 (1965).

where α is measured in ppm/ $^{\circ}\text{C}$, gives a good fit to the majority of the experimental data with an accuracy of about 10%.

3. RELATIONS INVOLVING ELASTIC MODULI

A relation of the form $Q = A$ (elastic modulus) has been given by Buffington⁵ using the vacancy model of diffusion. The relation is $Q = KE_0\alpha^3$, where E_0 is an appropriate elastic constant, α is the lattice parameter, and K is a proportionality constant depending only on the crystal structure.

A relation between the frequency factor D_0 and the activation energy Q was proposed by Zener⁶ using elasticity theory. Using random walk theory he deduced the relation

$$D_0 = \alpha^2 \nu \exp(\lambda\beta Q / RT_m)$$

or

$$\ln\left(\frac{D_0}{\alpha\nu}\right) = \frac{Q}{T_m} \frac{\lambda\beta}{R}$$

where λ is the fraction of energy which goes into straining the lattice and β is the dimensionless constant $-d(\mu/\mu_0)/d(T/T_m)$ and μ is an appropriate elastic constant. Values of β lie in the range 0.25 to 0.45 for most metals, and since $\lambda = 0.6$ for f.c.c. and 0.8 for b.c.c. metals, the values of $\lambda\beta$ are between 0.15 and 0.35.

A relation of the form $D_0 = \alpha^2 \nu K \exp(Q/RT_m)$ was found empirically by Diennes with $K = 10^{-6}$. The value of K together with $Q/T_m = 34$ gives a value of $\lambda\beta = 0.2$. A more extensive analysis has been made by LeClaire⁷ considering mechanisms other than the vacancy mechanism.

4. AN EXTENDED MELTING POINT CORRELATION

The self-diffusion activation energy has been shown to be dependent on the melting point of a metal. However, one would also expect the self-diffusion activation energy to be dependent on the valence and crystal structure of the material. Sherby and

⁵F. S. Buffington and M. Cohen, *Acta Met.*, 2:660 (1954).

⁶C. Zener, *Acta Cryst.*, 3:346 (1950).

⁷A. D. LeClaire, *Acta Met.*, 1:438 (1953).

Simnad⁸ have given an empirical analysis of the variation of the self-diffusion activation energy Q with the melting point T_m , valence V , and crystal structure factor K_0 . From a plot of $\log D$ versus T/T_m it is evident that the majority of the diffusion data falls into three distinct groups: (a) b.c.c., (b) f.c.c. and c.p.h., and (c) metals of diamond structure, giving the relation $D = D_0 \exp(-KT_m/T)$, where the constant K varies with the valence V according to $K = K_0 + V$ and K_0 is 14 for b.c.c. metals, 17 for f.c.c. and c.p.h. metals, and 21 for metals of the diamond structure.

Thus $Q = (K_0 + V)RT_m$ gives a much greater fit to all the experimental data than the simpler relation $Q = \text{constant } T_m$. The effective valence of the transition metals can be deduced from their experimental values of the self-diffusion activation energies. They seem to be fairly constant for the elements in each group of the periodic table. Values of V are 1.5 for Group IVB (Ti, Zr, Hf), 3.0 for Group VB (V, Nb, Ta), 2.8 for Group VIB (Cr, Mo, W), 2.6 for Group VIIIB (Mn, Re), and 2.5 for other transition elements. The relation $Q = (K_0 + V)RT_m$ appears to be the best fit to all the self-diffusion data, and therefore is the best relation for predicting unknown self-diffusion activation energies.

A similar relation has been deduced by LeClaire.⁹ He found that the relation $Q = RT_m(K + 1.5V)$ was a slightly better fit with $K = 13$ for b.c.c. metals, 15.5 for f.c.c. and c.p.h. metals, and 20 for metals of the diamond structure.

5. EMPIRICAL RELATIONS FOR IMPURITY DIFFUSION AND SELF-DIFFUSION IN ALLOYS

Impurity diffusion has been studied in detail in several solvent elements. However, no single correlation between the diffusion parameters D_0 and Q and properties of the impurity elements such as valence and size factor has been found to fit more than one or two elements. Extensive analyses of impurity diffusion in the noble metals have been made by Lazarus¹⁰ and LeClaire,¹¹ who

⁸O. Sherby and M. T. Simnad, Trans. ASM, 54:227 (1961).

⁹A. D. LeClaire, Diffusion in Body-Centered Cubic Metals, American Society for Metals, Metals Park, Ohio (1965), page 10.

¹⁰D. Lazarus, Phys. Rev., 93:973 (1954).

¹¹A. D. LeClaire, Phil. Mag., 7(73):141 (1962).

showed that the activation energies for impurity solutes decrease with increasing valence. Experimental results are in excellent agreement.

Impurity diffusion in the transition elements follows a different pattern. In molybdenum, for example, the D_0 and Q values for impurity diffusion of Co^{60} , Nb^{95} , and W^{185} are all greater than self-diffusion although no simple correlation with size factor is apparent. In contrast to this, the activation energies for impurity diffusion in niobium are all less than that for self-diffusion. Titanium is the transition element for which the largest number of impurity solutes have been studied. They are Sc, V, Cr, Mn, Fe, Co, Ni, Nb, Mo, Sn, Ag, and P. An analysis of the low- and high-temperature impurity diffusion parameters D_0 and Q gave the relations

$$D_{0(\text{low})} = 2 \times 10^{-4} \exp(0.29S_f) \quad \text{and} \quad D_{0(\text{high})} = 1 \exp(0.20S_f)$$

where S_f is the size factor. These relations hold only for solutes of negative size factor. No correlation was found for the impurity activation energies. It seems, therefore, that no general empirical relations have been found for the impurity diffusion parameters D_0 and Q . General trends seem to be obeyed only for specific elements. From these one can estimate how the parameters D_0 and Q may be expected to vary for impurities similar to those studied.

Several alloy systems of transition and nontransition elements have been studied in detail. As for impurity diffusion, most relations that have been found hold true only for that particular system. However, one simple relation that has been found to hold true for many dilute alloy systems is $Q = Q_p[1 + \alpha c]$, where Q_p is the impurity activation energy in a pure metal A, and Q is the impurity activation energy for an alloy of concentration c of B in A. A similar relation often holds true for the frequency factor D_0 of the form

$$\ln D_0 = \ln D_{0p} [1 + \alpha c]$$

where α is a constant depending on the system.

6. SUMMARY OF EMPIRICAL RELATIONS

The various empirical and semi-empirical relations that have been discussed in this chapter are summarized here. They are given in the order of their importance and usefulness.

Self-diffusion activation energy

$$Q = (K_0 + V)RT_m$$

$$Q = 33.7T_m$$

$$Q = -RT \ln 2D$$

$$Q = 700/\alpha$$

$$Q = 16.5L_f$$

$$Q = 0.65L_s$$

Self-diffusion coefficient

$$D = 3.4 \times 10^{-5} T_m \alpha^2 \exp(-17T_m/T)$$

Self-diffusion frequency factor

$$D_0 = \alpha^2 \nu \exp(\lambda \beta Q / RT_m)$$

$$D_0 = 1.04 \times 10^{-3} Q \alpha^2$$

Alloy diffusion

$$Q = Q_0[1 + \text{constant} \times \text{conc.}]$$

$$\ln D_0 = \ln D_{0_p}[1 + \text{constant} \times \text{conc.}]$$

where

D = diffusion coefficient in cm^2/sec

D_0 = frequency factor in cm^2/sec

α = interatomic distance or lattice constant in \AA ($1 \times 10^{-8} \text{ cm}$)

T_m = melting point in $^\circ\text{K}$

T = temperature in $^\circ\text{K}$

ν = vibrational frequency in sec^{-1}

R = gas constant (1.98 cal/mole \cdot deg)

L_f = latent heat of fusion in kcal/mole

L_s = latent heat of sublimation in kcal/mole

λ = constant (0.6 for b.c.c., 0.8 for f.c.c. metals)

β = constant ($\approx 1/2$)

α = coefficient of linear expansion in $\text{ppm}/^\circ\text{C}$

K_0 = constant (14 for b.c.c., 17 for f.c.c. and c.p.h., and 21 for diamond structure)

V = valence

Chapter 3

Radioactive Tracer Diffusion Data in Metals, Alloys, and Oxides

1. INTRODUCTION

The data given in these tables cover radioactive tracer diffusion data of metals in metals, alloys, and simple oxides published in the literature from 1938 to December 1968. It is divided into four parts.

- I. Self-diffusion in pure metals.
- II. Impurity diffusion in pure metals.
- III. Self- and impurity diffusion in metal alloys.
- IV. Self- and impurity diffusion in simple metal oxides.

The data are presented as the constants of the Arrhenius equation $D = D_0 \exp(-Q/RT)$, when D is the diffusion coefficient in cm^2/sec at absolute temperature T, Q is the activation energy in kcal/mole, and R is the gas constant (1.98 cal/mole · deg).

The following abbreviations are used throughout:

S.S.	= serial sectioning	P	= polycrystal
R.A.	= residual activity	S	= single crystal
S.D.	= surface decrease	$\perp c$	= perpendicular to c direction
A.R.G.	= autoradiography	$\parallel c$	= parallel to c direction
at	= atomic	99.95	= 99.95% purity
wt	= weight		

In general, the most reliable measurements are the more recent ones using high-purity materials, serial sectioning analysis,

and giving D_0 values in the range 0.1 to 10 cm^2/sec . Some sections, for example, self-diffusion in silver, have several entries. It is often difficult to determine which set or sets of data are most representative of the system. One has to consider the purity of the samples, method of analysis, number of data points, and the general experimental arrangement. Those sets of data which, in the opinion of the author based on the above criteria, are most representative of the particular system are indicated by asterisks: *** *.

The four main methods of analysis of the diffusion samples are serial sectioning, residual activity, surface decrease, and autoradiography. These are discussed in some detail in Chapter 1.

2. SOME PREDICTED DIFFUSION

PARAMETERS

In the event that a certain set of experimental data is not available, the various empirical relations that are summarized at the end of Chapter 2 can be used to estimate the diffusion parameters. The following are estimates of the self-diffusion activation energies Q for some elements for which few or no experimental data are available.

Element	T_m ($^{\circ}\text{K}$)	Q (kcal/mole)
δ -Mn	1533	51
γ -Mn	1533	59
Ru	2750	107
Rh	2240	87
Re	3440	135
Os	2975	116
Ir	2720	107

Diffusion experiments in the high-temperature b.c.c. phases of the Group IVB metals (Ti, Zr, and U) have shown that the Arrhenius plots for each of these elements and for each of the many impurity elements that have been studied are nonlinear. The activation energies are about 1/2 that expected from the various empirical relations, and the frequency factors are all typically $10^{-3} \text{ cm}^2/\text{sec}$. Diffusion in these metals has been called anomalous, and it is predicted that diffusion in the other Group IV

elements, Hf, Th, and also Pa, Np, and Pu, will also be anomalous. On this basis the following are estimates of the self-diffusion activation energy Q in these materials. The frequency factors are all expected to be about 10^{-3} cm²/sec.

Element	T _m (°K)	Q (kcal/mole)
β -Hf	2520	34
β -Th	2120	32
b.c.c. Pa	1200	19
f.c.c. Pa	1200	22
b.c.c. Np	810	13
f.c.c. Np	810	15
b.c.c. Pu	810	13
f.c.c. Pu	810	15

Part I

Self-Diffusion in Pure Metals

Material	Temperature range (°C)	Form of analysis	Activation energy Q (kcal/g-atom)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
ALUMINUM Tracer ²⁶ Al						
P 99.99	450-650	S.S.	34.0	1.71	1	(1962)
S	400-610	R.A.	34.5	—	2	(1968)
ANTIMONY Tracer ¹²⁴ Sb						
S ₁ c 99.998	500-620	S.S.	44.4	16.6	3	(1964)
S ₁₁ c 99.998	500-620	S.S.	47.1	22.1	3	(1964)
P 99.99	473-583	R.A.	39.5	1.05	4	(1965)
S ₁₁ c 99.999	500-630	—	48.0	56.0	5	(1965)
S ₁ c 99.9999	500-630	—	35.8	0.1	5	(1965)
BERYLLIUM Tracer ⁷ Be						
S ₁ c 99.75	565-1065	R.A.	37.6	0.52	6	(1965)
S ₁₁ c 99.75	565-1065	R.A.	39.4	0.62	6	(1965)
P 99.9	650-1200	R.A.	38.4	0.36	7	(1968)
CADMIUM Tracer ¹¹⁵ Cd						
S ₁ c 99.5	130-280	S.S.	19.1	0.10	8	(1955)
S ₁₁ c 99.5	130-280	S.S.	18.2	0.05	8	(1955)
S, P	200-285	S.D.	19.7	0.14	9	(1958)
S	180-300	—	20.6	0.68	10	(1967)

Material	Temperature range (°C)	Form of analysis	Activation energy Q (kcal/g-atom)	Frequency factor, D ₀ (cm ² /sec)	Reference	
					No.	Year
CARBON (Graphite) Tracer ¹⁴C						
Natural crystals	2000-2200	-	163	0.4-14.4	11	(1957)
CHROMIUM Tracer ⁵¹Cr						
P 99.94	1000-1350	A.R.G.	76.0		12	(1957)
P	1000-1350	-	85.0	45.0	13	(1959)
P 99.8	950-1260	S.D., R.A.	52.7	1.5×10^{-4}	14	(1959)
P 99.95	700-1350	A.R.G.	76.0	0.4	15	(1959)
P 99.87	1080-1340	A.R.G.	62.4	1.65×10^{-3}	16	(1960)
P 99.96	1060-1400	R.A.	59.2	6.47×10^{-2}	17	(1962)
P 99.99	1200-1600	R.A. ***	73.2***	0.28	18	(1962)
P 99.98	1030-1545	S.S. ***	73.7***	0.2	19	(1965)
β -COBALT Tracer ⁶⁰Co						
P 98.7	1050-1250	S.D.	67.0	0.367	20	(1951)
P 99.9	1000-1250	S.D.	61.9	0.032	21	(1951)
P 98.4	1000-1300	R.A.	62.0	0.2	22	(1952)
P 99.9	1100-1405	S.S. ***	67.7***	0.83	23	(1955)
P	772-1048		65.4	0.50	24	(1962)
P	1192-1297		62.2	0.17	24	(1962)
P 99.5	1047-1311	R.A.	68.7	1.66	25	(1965)
COPPER Tracer ⁶⁴Cu						
P	830-1030	S.S.	61.4	47.0	26	(1939)
P	750-850		57.2	11.0	27	(1939)
P	860-970	S.S.	45.1	0.10	28	(1942)
S	860-970	S.S.	49.0	0.6	28	(1942)
P	650-850	S.D.	46.8	0.3	29	(1942)
P	685-1060	S.S. ***	47.12***	0.2	30	(1954)
P	850-1050	S.S. ***	49.56***	0.621	31	(1955)
P 99.99	863-1057	S.S.	48.2	0.33	32	(1964)

Material	Temperature range (°C)	Form of analysis	Activation energy Q (kcal/g-atom)	Frequency factor, D _n (cm ² /sec)	Reference	
					No.	Year
Copper Tracer ⁶⁴ Cu (continued)						
P	780-890	—	49.2	2.32	33	(1967)
S	700-990	—	46.9	—	2	(1968)
GERMANIUM Tracer ⁷⁴ Ge						
S	780-930	S.S.	73.5	87.0	34	(1954)
S	766-928	S.S.***	68.5***	7.8	35	(1956)
S	730-916	R.A.	69.4	10.8	36	(1961)
S	730-916	R.A.	77.5	44.0	36	(1961)
GOLD Tracer ¹⁹⁸ Au						
P	720-970	R.A.	51.0	2	37	(1938)
P	800-1000	A.R.G.	45.0	—	38	(1952)
P	775-1060	A.R.G.	45.3	0.265	39	(1954)
P 99.96	730-1030	A.R.G.	45.3	0.26	40	(1955)
S 99.999	600-954	S.S.	39.36	0.031	41	(1956)
P 99.99	720-1000	S.S.	42.9	0.14	42	(1957)
P 99.95	700-1050	S.S.***	41.7***	0.091	43	(1957)
P 99.93	700-900	R.A.***	42.1***	0.117	44	(1963)
S 99.97	850-1050	S.S.***	42.26***	0.107	45	(1965)
P 99.999	706-1010	S.S.	45.7	0.15	46	(1965)
S	600-900	S.S.	40.0	—	2	(1968)
β -HAFNIUM Tracer ¹⁸¹ Hf						
P 97.9	1795-1995	S.S.	38.7	1.2×10^{-3}	47	(1965)
INDIUM						
P, S 99.998	50-160	S.S.	17.9	1.02	48	(1952)
S ⊥ c 99.99	44-144	S.S.	18.7	3.7	49	(1959)
S c 99.99	44-144	S.S.	18.7	2.7	49	(1959)
P 99.9999	130-149	R.A.	21.2	8.0	50	(1965)

Material	Temperature range (°C)	Form of analysis	Activation energy Q (kcal/g-atom)	Frequency factor, D ₀ (cm ² /sec)	Reference	
					No.	Year
α -IRON Tracer ⁵⁵ Fe, ⁵⁹ Fe						
P	715-890	R.A.	77.2	34,000	51	(1948)
P	700-900	R.A.	73.2	2300	52	(1950)
P 99.97	800-900	S.D.	59.7	5.8	53	(1951)
P	800-900	R.A.	48.0	0.1	54	(1952)
P	700-900		47.4	0.019	55	(1955)
P 99.96	650-850	S.D.	67.1	530	56	(1955)
P,S	775-900		64.1	18	57	(1958)
P	800-900	R.A.	67.24	118	58	(1958)
P,S 99.97	700-790	S.S., R.A. ***	60.0 ***	2.0	59	(1961)
P,S 99.97	790-900	S.S., R.A. ***	57.2 ***	1.9	59	(1961)
P 99.998	860-900	A.R.G. ***	57.3 ***	2.0	60	(1963)
P 99.98	750-850		72.17	900	61	(1964)
P 99.95	638-768	R.A. ***	60.7 ***	27.5	62	(1966)
P 99.95	808-884	R.A. ***	57.5 ***	2.01	62	(1966)
γ -IRON Tracer ⁵⁵ Fe, ⁵⁹ Fe						
P	935-1110	R.A.	48.0	1.0 × 10 ⁻³	51	(1948)
P	950-1400	S.D.	67.9	0.58	53	(1951)
P	1000-1360	R.A.	74.2	5.8	52	(1950)
P	1000-1300	R.A.	68.0	0.76	54	(1952)
P 99.1	950-1250	R.A.	68.0	0.7	63	(1953)
P	900-1200		67.9	1.3	55	(1955)
P	1000-1300	S.S.	67.0	0.44	64	(1956)
P	900-1200		64.0	0.16	65	(1957)
P	1000-1250	R.A.	63.5	0.11	66	(1958)
P 99.6	1000-1200	A.R.G.	64.0	0.16	15	(1959)
P,S 99.97	1064-1395	S.D., R.A. ***	64.5 ***	0.18	59	(1961)
P	950-1200	S.S.	67.7	2.5	67	(1962)
P 99.998	1156-1350	A.R.G. ***	64.0 ***	0.22	60	(1963)
P 99.94	1075-1340	R.A.	67.8	1.05	68	(1965)
δ -IRON Tracer ⁵⁵ Fe, ⁵⁹ Fe						
P	1405-1520	R.A.	42.4	0.019	69	(1961)
P 99.96	1415-1510	S.S., R.A. ***	57.0 ***	1.9	70	(1963)
P 99.998	1405-1515	A.R.G.	61.7	6.8	60	(1963)
P 99.95	1428-1492	S.S. ***	57.5 ***	2.01	62	(1962)

Material	Temperature range (°C)	Form of analysis	Activation energy Q (kcal/g-atom)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
LEAD						
Tracer ²¹⁰ Pb						
P	260-320	S.D.	27.9	6.56	71	(1932)
S,P	190-270	S.S.	25.7	1.17	72	(1954)
S 99.999	175-322	S.S.***	24.21***	0.281	73	(1955)
S 99.99	207-323	S.S.***	26.06***	1.372	74	(1961)
MAGNESIUM						
Tracer ²⁸ Mg						
P 99.92	470-630	S.S.	32.0	1.0	75	(1954)
S _± c	467-635	S.S.	32.5	1.5	76	(1956)
S c	467-635	S.S.	32.2	1.0	77	(1956)
MOLYBDENUM						
Tracer ⁹⁹ Mo						
P	1800-2200	R.A.	115	4	77	(1959)
P	1800-2200	R.A.	114	4	13	(1959)
P	1700-1900		111	2.77	78	(1960)
P	1600-2200		100.8	0.38	79	(1961)
S 99.99	1850-2350	S.S.***	92.2***	0.1	80	(1963)
P 99.98	1850-2350	S.S.***	96.9***	0.5	80	(1963)
P 99.97	2155-2540	R.A.***	110.0***	1.8	81	(1964)
NICKEL						
Tracer ⁶³ Ni						
P 99.93	870-1250	S.D.,R.A.	66.8	1.27	82	(1956)
P	1100-1175	S.S.	63.8	0.4	83	(1957)
S 99.95	700-1100	A.R.G.	65.9	0.48	84	(1958)
P	1150-1400	S.S.	69.8	3.36	85	(1959)
P 99.92	1150-1400	R.A.	71.0	5.12	86	(1959)
S	680-830	R.A.	69.7	5.8	87	(1961)
S 99.999	950-1020	S.D.	66.8	1.9	88	(1961)
	700-1100		68.1	1.70	24	(1962)
P 99.98	1085-1300	S.S.***	69.5***	2.59	89	(1963)
P	950-1250	R.A.	67.0	2.4	90	(1963)
P 99.95	1042-1404	S.S.***	68.0***	1.9	32	(1964)
P 99.97	1155-1373	R.A.	64.9	1.11	25	(1965)
S,P 99.99	475-650	S.D.	66.8	1.9	91	(1965)
S,P 99.99	675-750	S.D.	66.8	1.9	92	(1965)
S 99.9	900-1200	R.A.***	70.1***	2.59	93	(1966)

Material	Temperature range (°C)	Form of analysis	Activation energy Q (kcal/g-atom)	Frequency factor, D ₀ (cm ² /sec)	Reference	
					No.	Year
NICKEL Tracer ⁶³ Ni (continued)						
P 99.9	900-1200	R.A.***	69.2***	2.22	93	(1966)
S 99.999	980-1400	R.A.	Nonlinear		94	(1968)
P	1000-1400	R.A.	60.5	9.96	95	(1968)
NIOBIUM Tracer ⁹⁵ Nb						
P 99.4	1535-2120	S.S.	105.0	12.4	96	(1960)
P 99.8	1700-2100	A.R.G.	95.0	1.3	97	(1962)
P,S 99.99	878-2395	S.S.***	96.0***	1.1	98	(1965)
S 99.95	1700-2100	R.A.	115.0	49.0	99	(1964)
P 99.95	1700-2100	R.A.	110.0	17.0	99	(1964)
PALLADIUM Tracer ¹⁰³ Pd						
S 99.999	1060-1500	S.S.	63.6	0.205	100	(1964)
PHOSPHORUS Tracer ³² P						
P	0-44	S.S.	9.4	1.07×10^{-3}	101	(1955)
PLATINUM Tracer ¹⁹⁵ Pt, ¹⁹⁹ Pt						
P 99.99	1325-1600	S.S.	68.2	0.33	102	(1958)
P	1250-1725	S.D.	66.5	0.22	103	(1962)
POTASSIUM Tracer ⁴² K						
P 99.95	0-60	S.S.	9.75	0.31	104	(1967)
γ-PLUTONIUM Tracer ²³⁸ Pu						
P	190-310	S.S.	16.7	2.1×10^{-5}	105	(1966)
δ-PLUTONIUM Tracer ²³⁸ Pu						
P	350-440	S.S.	23.8	4.5×10^{-3}	106	(1964)

Material	Temperature range (°C)	Form of analysis	Activation energy Q (kcal/g-atom)	Frequency factor, D _n (cm ² /sec)	Reference No.	Year
<i>ε</i> -PLUTONIUM Tracer ²⁴⁰ Pu						
P	500-612	R.A.	18.5	2 × 10 ⁻²	107	(1968)
SELENIUM Tracer ⁷⁵ Se						
P	35-140		11.7	1.4 × 10 ⁻⁴	108	(1957)
SILICON Tracer ²⁸ Si						
S 99.99999	1225-1400	S.S.	110.0	1800.0	109	(1966)
S 99.999999	1100-1300	S.S.	118.5	9000.0	110	(1966)
SILVER Tracer ¹¹⁰ Ag						
P	500-900	S.S.	45.95	0.895	111	(1941)
S,P	500-950		46.0	0.9	112	(1949)
P,S 99.99	500-875	S.S., S.D.***	45.95***	0.895	113	(1951)
P 99.99	670-940	S.S.***	45.50***	0.724	114	(1952)
P,S	640-905	S.S.	40.8	0.11	115	(1952)
P	725-925		47.4	1.8	116	(1953)
P	700-860	A.R.G.	45.0	0.905	117	(1954)
P	750-925		45.0	0.53	118	(1955)
P	700-900	R.A.	45.4	0.65	119	(1955)
S	550-900	S.S.	44.05	0.40	120	(1955)
P	707-880	A.R.G.	44.9	0.834	121	(1955)
S 99.99	630-940	S.S.***	44.09***	0.395	122	(1956)
P	660-740		41.8	2.78	123	(1956)
S	715-940	S.S.***	43.7 ***	0.27	124	(1957)
P	500-900		44.6	0.86	125	(1957)
P	690-900	R.A.	45.2	0.62	126	(1957)
P	750-950	S.S.	41.53	0.094	127	(1958)
P	650-900		44.8	1.08	128	(1958)
P 99.99	456-792	R.A.	45.8	0.69	129	(1960)
P 99.99	250-380		43.5	0.34	130	(1963)
P	718-914		48.8	1.27	131	(1964)
S	750-900	S.S.***	44.4 ***	1.06	132	(1966)
S 99.999	668-958	R.A.	Nonlinear		133	(1968)
P	720-950	R.A.	43.39	0.278	134	(1968)

Material	Temperature range (°C)	Form of analysis	Activation energy Q (kcal/g-atom)	Frequency factor, D ₀ (cm ² /sec)	Reference	
					No.	Year
SODIUM		Tracer ²² Na				
P	10-95	S.S.	10.45	0.242	135	(1952)
P 99.99	0-98	S.S.	10.09	0.145	136	(1966)
SULFUR		Tracer ³⁵ S				
S _⊥ c	40-100		3.08	8.3 × 10 ⁻¹²	137	(1951)
S c	40-110		78.0	1.7 × 10 ³⁶	137	(1951)
TELLURIUM		Tracer ¹²⁷ Te				
S 99.9999 _± c	300-400	S.S.	46.7	3.91 × 10 ⁴	138	(1967)
S 99.9999 c	300-400	S.S.	35.5	1.30 × 10 ²	138	(1967)
TANTALUM		Tracer ¹⁸² Ta				
P	1830-2530		110(89.5)	2(0.03)	139	(1953)
P	1200-1350	R.A.	110	1300	140	(1955)
P,S 99.996	1250-2200	S.S.	98.7	1.24	141	(1965)
α-THALLIUM		Tracer ²⁰⁴ Tl				
S _⊥ c 99.9	135-230	S.S.	22.6	0.4	142	(1955)
S c 99.9	135-230	S.S.	22.9	0.4	142	(1955)
β -THALLIUM		Tracer ²⁰⁴ Tl				
S 99.9	230-280	S.S.	20.7	0.7	142	(1955)
α-THORIUM		Tracer ²²⁸ Th				
P			71.6	395	143	(1967)

Material	Temperature range (°C)	Form of analysis	Activation energy Q (kcal/g-atom)	Frequency factor, D ₀ (cm ² /sec)	Reference	
					No.	Year
β-TIN Tracer ¹¹³ Sn, ¹²³ Sn						
S ⊥ c	180-225	S.S.	10.5	8.4×10^{-4}	144	(1949)
S c	180-225	S.S.	5.9	3.7×10^{-8}	144	(1949)
S ⊥ c	180-223	S.S.	6.7	9.2×10^{-8}	145	(1950)
S c	180-223	S.S.	9.4	3.6×10^{-6}	145	(1950)
P 99.9	-2-100	A.R.G.	9.4	—	15	(1959)
S ⊥ c	178-222	S.S.***	23.3***	1.4	146	(1960)
S c	178-222	S.S.***	25.6***	8.2	146	(1960)
S,P	140-217	R.A.	10.8	9.9×10^{-4}	147	(1960)
P 99.99	130-255		22.4	0.78	148	(1961)
S ⊥ c 99.999	160-226	S.S.***	25.1***	10.7	149	(1964)
S c 99.999	160-226	S.S.***	25.6***	7.7	149	(1964)
P	416-490		7.7	1.73×10^{-6}	150	(1967)
α-TITANIUM Tracer ⁴⁴ Ti						
P	690-850	R.A.	29.3	6.4×10^{-8}	151	(1963)
β-TITANIUM Tracer ⁴⁴ Ti						
P 99.95	900-1540	S.S.***	31.2, 60.0***	3.58×10^{-4} , 1.09	152	(1964)
P 99.9	900-1580	R.A.	36.5	1.9×10^{-3}	153	(1968)
TUNGSTEN Tracer ¹⁸⁵ W						
P	1290-1450	S.D.	135.8	6.3×10^7	154	(1950)
P	2000-2700		120.5	0.54	155	(1961)
S 99.2	2670-3225	S.S.	153.1	42.8	156	(1965)
P 99.9	1740-2100	S.S.	93.1	1.8×10^{-3}	157	(1966)
α-URANIUM Tracer ²³⁴ U						
P	580-650		40.0	2×10^{-3}	158	(1961)
β-URANIUM Tracer ²³⁴ U						
P	700-760	R.A.	42.0	0.0135	159	(1959)

Material	Temperature range (°C)	Form of analysis	Activation energy Q (kcal/g-atom)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
γ -URANIUM	Tracer ²³³ U, ²³⁴ U, ²³⁵ U					
P	800-1050	A.R.G.	21.0	1.4×10^{-4}	160	(1958)
P	800-1050	S.S.	26.6	1.17×10^{-3}	160	(1958)
P	800-1040	S.S.	27.5	1.8×10^{-3}	161	(1958)
P 99.99	800-1070	S.S.	28.5	2.33×10^{-3}	162	(1960)
VANADIUM	Tracer ⁴⁸ V					
S 99.7	1000-1400	S.S.	61.0	1.1×10^{-2}	163	(1965)
S 99.7	1600-1890	S.S.	91.5	58.0	163	(1965)
S,P 99.99	880-1360	S.S.***	73.65***	0.36	164	(1965)
S,P 99.99	1360-1830	S.S.***	94.14***	214.0	164	(1965)
S 99.92	700-1050	R.A.	64.6	0.107	165	(1968)
S 99.92	1050-1400	R.A.	76.8	10.45	165	(1968)
ZINC	Tracer ⁶⁵ Zn					
S _± c	340-410	S.S.	19.6	0.02	166	(1941)
S _± c	340-410	S.S.	31.0	93.0	167	(1942)
S c	340-410	S.S.	20.4	0.05	167	(1942)
S _± c 99.999	300-400	S.S.	25.4	1.3	168	(1952)
S c 99.999	300-400	S.S.	21.7	0.1	168	(1952)
S _± c 99.999	240-400	S.S.	24.3	0.58	169	(1953)
S c 99.999	240-400	S.S.	21.8	0.13	169	(1953)
S _± c	260-400	S.S.	25.9	1.6	170	(1954)
S c	260-400	S.S.	19.6	0.02	170	(1954)
P	260-400	S.S.	23.8	0.41	170	(1954)
S _± c	200-415	S.S.,S.D.***	24.9***	0.39	171	(1956)
S c	200-415	S.S.,S.D.***	22.0***	0.08	171	(1956)
P	200-415	S.S.,S.D.	22.7	0.19	171	(1956)
S _± c	270-370		26.0	2.78	172	(1957)
S c	270-370		19.0	0.013	172	(1957)
P	325-405	S.S.	20.5	0.031	173	(1959)
S _± c 99.999	240-418	S.S.***	23.0***	0.18	174	(1967)
S c 99.999	240-418	S.S.***	21.9***	0.13	174	(1967)

Material	Temperature range (°C)	Form of analysis	Activation energy Q (kcal/g-atom)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
α -ZIRCONIUM Tracer ⁹⁵ Zr						
P 99.96	700-800	R.A.	22.0	5×10^{-8}	175	(1958)
P 99.96	650-825	R.A.	52.0	5.9×10^{-2}	176	(1959)
P 99.95	750-850	S.S.	45.5	5.6×10^{-4}	177	(1963)
β -ZIRCONIUM Tracer ⁹⁵ Zr						
P 99.9	1000-1250	R.A.	26.0	4.0×10^{-5}	178	(1959)
P 99.6	1115-1500	R.A.	38.0	2.4×10^{-3}	176	(1959)
P 99.6	900-1200	R.A.	27.0	1×10^{-4}	179	(1960)
P	900-1240	S.S.	24.0	4.2×10^{-5}	180	(1960)
P 99.89	1100-1500	S.S.	30.1	2.4×10^{-4}	181	(1961)
P 99.94	900-1750	S.S.***	19.6 +***	$3 \times 10^{-6} \times$	182	(1963)
			30.9(T - 1136)	(T/1136) ^{15.6}		

Part II

Impurity Diffusion in Pure Metals

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
ALUMINUM							
¹¹⁰ Ag	P	400-630	R.A.	29.0	0.21	183	(1967)
¹¹⁰ Ag	P	450-632	R.A.	27.9	0.08	184	(1968)
¹¹⁵ Cd	P 99.995	400-630	R.A.	21.7	7.94×10^{-8}	183	(1967)
⁶⁴ Cu	P	350-630	R.A.	30.20	0.15	185	(1965)
⁵¹ Cr	P 99.99	360-630	R.A.	19.9	1.1×10^{-6}	186	(1962)
⁵¹ Cr	P 99.95	250-605	R.A.	15.4	3.01×10^{-7}	187	(1964)
⁵⁹ Fe	P 99.99	360-630	R.A.	13.9	4.1×10^{-9}	186	(1962)
¹¹⁴ In	P 99.995	400-630	R.A.	22.2	1.42×10^{-8}	183	(1967)
⁵⁴ Mn	P 99.99	450-650	S.S.	28.8	0.22	1	(1962)
⁹⁹ Mo	P 99.995	400-630	R.A.	13.1	1.04×10^{-9}	188	(1967)
⁶³ Ni	P 99.99	360-630	R.A.	15.7	2.9×10^{-8}	186	(1962)
¹⁰³ Pd	P 99.995	400-630	R.A.	20.2	1.92×10^{-7}	183	(1967)
¹²⁴ Sb	P	448-620	R.A.	29.1	0.09	184	(1968)
¹¹³ Sn	P 99.995	400-630	R.A.	20.2	3.05×10^{-7}	183	(1967)
⁴⁸ V	P 99.995	400-630	R.A.	19.6	6.05×10^{-8}	189	(1968)
⁶⁵ Zn	P 99.99	405-654	S.S.	30.9	1.1	173	(1959)
⁶⁵ Zn	S 99.995	327-375	R.A.	30.8	1.4	190	(1960)
BERYLLIUM							
¹¹⁰ Ag	c 99.75	656-897	R.A. ***	39.1 ***	0.41	191	(1964)
¹¹⁰ Ag	± c 99.75	656-897	R.A. ***	45.7 ***	1.98	191	(1964)
¹¹⁰ Ag	P 99.75	656-897	R.A.	46.1	6.2	191	(1964)

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
BERYLLIUM (continued)							
¹¹⁰ Ag	S ⊥ c 99.75	650-900	R.A. ***	43.2 ***	1.76	192	(1965)
¹¹⁰ Ag	S c 99.75	650-900	R.A. ***	39.3 ***	0.43	192	(1965)
⁵⁹ Fe	S 99.75	700-1076	R.A.	51.6	0.67	192	(1965)
⁵⁵ Fe	c 99.75	656-897	R.A.	51.8	0.53	191	(1964)
CADMIUM							
¹¹⁰ Ag	S 99.99	180-300	-	25.4	2.21	10	(1967)
⁶⁵ Zn	S 99.99	180-300	-	19.0	0.0016	10	(1967)
CARBON							
¹¹⁰ Ag	⊥ c	750-1050	R.A.	64.3	9.28 × 10 ³	193	(1965)
⁶³ Ni	⊥ c	540-920	R.A.	47.2	102	193	(1965)
⁶³ Ni	c	750-1060	R.A.	53.3	2.2	193	(1965)
²²⁸ Th	⊥ c	1400-2200	R.A.	145.4	1.33 × 10 ⁵	193	(1965)
²²⁸ Th	c	1800-2200	R.A.	114.7	2.48	193	(1965)
²²⁸ Th		1600-2000	S.S.	114	15.5	194	(1967)
²³² U	⊥ c	1400-2200	R.A.	115	6.76 × 10 ³	193	(1965)
²³² U	c	1400-1820	R.A.	129.5	385	193	(1965)
CHROMIUM							
⁵⁵ Fe	P 99.8	980-1420	R.A.	79.3, 40.4	0.47, 1.1 × 10 ⁻⁶	195	(1964)
COBALT							
¹⁴ C	P 99.82	600-1400	-	34.0	0.21	196	(1963)
⁵⁵ Fe	P 99.9	1104-1303	S.S.	62.7	0.21	23	(1955)
⁵⁵ Fe	P 99.97	930-1240	S.D.	55.5	0.2	197	(1965)
⁶³ Ni	P 99.5	1152-1400	S.D.	72.1	1.25	85	(1959)
⁶³ Ni	P	772-1048	R.A. ***	64.3 ***	0.34	24	(1962)
⁶³ Ni	P	1192-1297	R.A. ***	60.2 ***	0.10	24	(1962)
⁶³ Ni	P 99.5	1227-1416	R.A.	71.0	3.35	25	(1965)
³⁵ S	P 99.99	1150-1250	R.A.	5.4	1.3	198	(1964)

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D_0 (cm ² /sec)	Reference No.	Year
COPPER							
¹¹⁰ Ag		—	—	46.5	0.63	199	(1960)
⁷⁶ As		—	—	42.0	0.12	199	(1960)
¹⁹⁸ Au	P 99.95	750-1000	S.S.	44.9	0.1	200	(1954)
¹⁹⁸ Au		—	—	49.7	0.69	199	(1960)
¹⁹⁸ Au	P 99.999	706-1010	S.S. ***	45.7 ***	0.15	46	(1965)
¹¹⁵ Cd	S 99.98	725-950	S.S.	45.7	0.935	201	(1958)
⁶⁰ Co	S 99.99	700-950	S.S.	55.2	5.7	202	(1958)
⁶⁰ Co	S 99.998	701-1077	S.S.	54.1	1.93	203	(1958)
⁵⁵ Fe	S 99.99	1130-1320	S.S.	93.02	1.6×10^6	204	(1958)
⁵⁹ Fe	S 99.998	720-1075	S.S.	51.8	1.4	203	(1958)
⁵⁹ Fe	S 99.99	720-1060	S.S.	50.95	1.01	205	(1961)
⁷² Ga		—	—	45.90	0.55	199	(1960)
²⁰³ Hg		—	—	44.0	0.35	199	(1960)
⁵⁴ Mn	S 99.99	754-950	S.S.	91.4	10^7	206	(1959)
⁶³ Ni	P	650-915	A.R.G.	64.8		207	(1955)
⁶³ Ni	S 99.998	743-1076	S.S. ***	56.5 ***	2.7	203	(1958)
⁶³ Ni	S 99.99	695-1061	S.S. ***	56.8 ***	3.8	208	(1959)
⁶³ Ni	P 99.9999	250-520	S.D.	46.8	4.2×10^{-2}	209	(1966)
⁶³ Ni	S	899-1067	S.S. ***	55.3 ***	1.7	210	(1968)
⁶³ Ni	P	300-450	S.D.	45.3	6.4×10^{-2}	211	(1968)
⁶⁶ Ni	S 99.999	855-1055	S.S. ***	55.6 ***	1.93	212	(1968)
¹⁰² Pd	S 99.999	807-1056	S.S.	54.37	1.71	213	(1963)
¹⁹⁵ Pt	P	843-997	S.S.	37.5	4.8×10^{-4}	214	(1963)
¹²⁴ Sb	S 99.999	600-1000	S.S.	42.0	0.34	215	(1960)
¹¹³ Sn		680-910		45.0	0.11	216	(1962)
²⁰⁴ Tl	S 99.999	785-996	S.S.	43.3	0.71	217	(1963)
⁶⁵ Zn	S	600-1050	S.S.	45.6	0.34	218	(1957)
⁶⁵ Zn		800-850		45	—	219	(1966)

GERMANIUM

¹¹⁵ Cd	S	750-950	R.A.	102.0	1.75×10^9	220	(1959)
⁵⁹ Fe	S	775-930	R.A.	24.8	0.13	221	(1957)
¹¹⁴ In	S	600-920	—	39.9	2.9×10^{-4}	222	(1961)
¹²⁴ Sb	S	800-900	—	52	1.3	223	(1957)
¹²⁴ Sb	S	720-900	—	50.2	0.22	224	(1964)
¹²⁵ Te	S	770-900	S.S.	65, 56	2, 6	225	(1962)
²⁰⁴ Tl	S	800-930	S.S.	78.4	1700	226	(1962)

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
GOLD							
¹¹⁰ Ag	S 99.99	699-1007	S.S.	40.2	0.072	227	(1963)
¹¹⁰ Ag	P 99.99	773-1039	-	40.4	0.08	228	(1965)
⁶⁰ Co	P 99.93	702-948	R.A.	41.6	0.068	44	(1963)
⁵⁹ Fe	P 99.93	701-948	R.A.	41.6	0.082	44	(1963)
²⁰³ Hg	S 99.994	600-1027	-	37.38	0.116	229	(1965)
⁶³ Ni	P 99.96	880-940	S.S.	46.0	0.30	83	(1957)
⁶³ Ni	P 99.93	702-988	R.A.	42.0	0.034	44	(1963)
¹⁹⁵ Pt	P,S 99.98	800-1060	S.S.	60.9	7.6	230	(1960)
INDIUM							
¹¹⁰ Ag	S ₁ c 99.99	25-140	S.S.	12.8	0.52	231	(1966)
¹¹⁰ Ag	S _{II} c 99.99	25-140	S.S.	11.5	0.11	231	(1966)
¹⁹⁶ Au	S 99.99	25-140	S.S.	6.7	9×10^{-3}	231	(1966)
²⁰⁴ Tl	S 99.99	49-157	S.S.	15.5	0.049	48	(1952)
α-IRON							
¹⁹⁵ Au	P 99.999	800-900	R.A.	62.4	31	232	(1963)
¹⁴ C	P	350-850	R.A.	19.2	6.2×10^{-3}	233	(1955)
¹⁴ C	P	500-800	R.A.	24.6	0.2	234	(1954)
¹⁴ C	P 99.98	616-844	R.A.	29.3	2.2	235	(1964)
⁶⁰ Co	P	700-790	S.D.	54.0	0.2	236	(1954)
⁶⁰ Co	P 99.5	700-850	S.D.	54.0	0.4	237	(1954)
⁶⁰ Co	P	800-905	S.D.	64.6	64.4	238	(1961)
⁶⁰ Co	P 99.999	690-905	R.A.	68.3	118	234	(1963)
⁶⁰ Co	P 99.98	825-890	S.S. ***	62.3 ***	9.5	239	(1964)
⁶⁰ Co	P 99.995	638-768	R.A. ***	62.2 ***	7.19	62	(1966)
⁶⁰ Co	P 99.995	808-884	R.A. ***	61.4 ***	6.38	62	(1966)
⁵¹ Cr	P 99.5	750-850	S.D.	82.0	3×10^4	237	(1954)
⁵¹ Cr	99.95	775-875	R.A. ***	57.5 ***	2.53	240	(1967)
⁶⁴ Cu	P 99.0	800-1050	R.A.	57.0	0.57	241	(1966)
⁶⁴ Cu	P 99.0	650-750	R.A.	58.38	0.47	241	(1966)
⁴² K	P 99.92	500-800	R.A.	42.3	0.036	242	(1967)
⁴² K	P 99.92	500-800	R.A.	30.6	4.6×10^{-4}	242	(1967)
⁴² K	P 99.92	600-800	R.A.	24.2	1.17×10^{-7}	242	(1967)
⁹⁹ Mo	P	750-875	R.A.	73.0	7800	243	(1966)
⁶³ Ni	P 99.97	600-680	R.A.,S.D.	58.7	1.4	244	(1961)

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D_0 (cm ² /sec)	Reference No.	Reference Year
α-IRON (continued)							
⁶³ Ni	P 99.97	680-800	R.A., S.D.	56.0	1.3	244	(1961)
⁶³ Ni	P 99.999	700-900	R.A.	61.9	9.9	232	(1963)
³² P	P 99.99	700-850	—	40.0	7.1×10^{-3}	245	(1963)
³² P	P	860-900	R.A.	55.0	2.9	246	(1963)
¹²⁴ Sb	P	800-900	R.A.	66.6	1100	247	(1968)
¹⁸⁵ W	P 99.5	700-785	S.D.	70.0	380	237	(1954)
¹⁸⁵ W	P 99.99	700-900	R.A.	63.5	69	248	(1967)
γ-IRON							
⁷ Be	P 99.9	1100-1350	R.A.	57.6	0.1	249	(1968)
¹⁴ C	P	900-1050	R.A.	32.4	0.1	234	(1955)
¹⁴ C	P 99.34	800-1400	—	34.0	0.15	196	(1963)
⁶⁰ Co	P 99.5	1050-1250	R.A.	104.0	1.2×10^5	237	(1954)
⁶⁰ Co	P	1100-1200	—	87.0	300	250	(1955)
⁶⁰ Co	P 99.98	1138-1340	S.S. ***	72.9 ***	1.25	251	(1961)
⁵ Cr	P 99.5	1050-1250	R.A.	97.0	1.8×10^4	237	(1954)
⁶⁴ Cu	P 99.2	800-1200	R.A.	61.0	3	252	(1955)
¹⁸¹ Hf	P 99.94	1075-1340	R.A.	113.0	9×10^4	68	(1965)
⁹⁵ Nb	P 99.94	1075-1340	R.A.	82.3	530	68	(1965)
⁶³ Ni	P 99.91	1152-1400	S.D.	77.6	6.92	85	(1959)
⁶³ Ni	P 99.97	930-1050	S.D., R.A.	67.0	0.77	244	(1961)
³² P	P	1280-1350	R.A.	69.8	28.3	246	(1963)
³² P	P 99.99	950-1200	R.A.	43.7	1.0×10^{-2}	245	(1963)
³⁵ S	P 99.97	1200-1350	S.D.	48.4	1.35	254	(1962)
¹⁸⁵ W	P 99.5	1050-1250	R.A.	90.0	1000	239	(1954)
δ-IRON							
⁶⁰ Co	P 99.98	1396-1502	S.S., R.A.	61.2	5.5	70	(1963)
⁶⁰ Co	P 99.995	1428-1521	R.A.	61.4	6.38	62	(1966)
³² P	P 99.99	1370-1460	R.A.	55.0	2.9	246	(1963)
LEAD							
¹¹⁰ Ag	S,P	220-320	S.S.	8.02	7.9×10^{-3}	254	(1966)
¹⁹⁵ Au	S,P 99.999	94-325	S.S.	9.35	4.1×10^{-3}	255	(1960)
¹⁹⁸ Au	S 99.999	190-320	S.S.	10.0	8.7×10^{-3}	256	(1966)

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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LEAD (continued)

¹¹⁵ Cd		150-330		21.2	0.405	257	(1967)
⁶⁴ Cu	S,P	150-320	S.S.	14.44	4.6 × 10 ⁻²	254	(1966)
²⁰⁵ Tl	P 99.999	207-322	S.S.	24.33	0.511	258	(1961)

LITHIUM

²² Na	P	52-176	S.S.	12.61	0.41	259	(1967)
¹¹⁰ Ag	P	67-160	S.S.	12.83	0.37	260	(1968)

MOLYBDENUM

¹⁴ C	P 99.98	1200-1600	R.A.	41.0	2.04 × 10 ⁻²	261	(1966)
⁶⁰ Co	P 99.98	1900-2300	A.R.G.	100	3	262	(1962)
⁶⁰ Co	P 99.98	1850-2350	S.S. ***	106.7	18	263	(1965)
⁴² K	S	800-1100	S.S.	26.5	9.34 × 10 ⁻⁹	264	(1966)
⁴² K	P	800-1100	S.S.	14.6	2.86 × 10 ⁻¹⁰	264	(1966)
⁹⁵ Nb	P 99.98	1850-2350	S.S.	108.1	14	263	(1965)
¹⁸⁶ Re	P	1700-2100	A.R.G.	94.7	9.7 × 10 ⁻²	265	(1965)
³⁵ S	S 99.97	2220-2470	S.S.	101.0	320	266	(1968)
²³⁵ U	P 99.98	1500-2000	R.A.	76.4	7.6 × 10 ⁻³	267	(1965)
¹⁸⁵ W	P	1750-2150	R.A.	78	4 × 10 ⁻⁴	77	(1959)
¹⁸⁶ W	P	1700-2100	A.R.G. ***	112.9***	3.18	265	(1965)
¹⁸⁵ W	P 99.98	1700-2260	S.S.***	110***	1.7	268	(1967)
¹⁸⁵ W	S	2000-2430	S.S.	151	25.1	269	(1966)

NICKEL

¹⁹⁸ Au	P	900-1060	A.R.G.	65.0	2.0	40	(1955)
¹⁹⁸ Au	S,P 99.999	700-1075	S.S.	55.0	0.02	270	(1968)
⁷ Be	P 99.9	1020-1400	R.A.	46.2	0.019	249	(1968)
¹⁴ C	P	500-800	R.A.	33	0.08	271	(1957)
¹⁴ C	P 99.86	600-1400	—	34.0	0.12	196	(1953)
⁶⁰ Co	P 99.9	900-1250	S.D.	68.3	1.46	272	(1951)
⁶⁰ Co	P 99.8	748-1192	R.A.	64.7	0.75	24	(1962)
⁶⁰ Co	P 99.97	1149-1390	R.A. ***	65.9***	1.39	25	(1965)
⁵¹ Cr	P 99.997	350-600	R.A.	13.7	5.45 × 10 ⁻⁹	273	(1964)
⁵¹ Cr	P 99.997	600-900	R.A.	40.8	0.03	273	(1964)
⁵¹ Cr	P 99.95	1100-1270	S.S.	65.1	1.1	32	(1964)
⁶⁴ Cu	P 99.95	850-1050	R.A.	61.0	0.724	185	(1965)

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Reference Year
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NICKEL (continued)

⁶⁴ Cu	P 99.95	1050-1360	S.S.	61.7	0.57	32	(1964)
⁵⁹ Fe	P	950-1150	R.A.	51.0	8.4×10^{-3}	274	(1953)
⁵⁹ Fe	P	400-800	-	31.8	7.3×10^{-4}	275	(1955)
⁵⁹ Fe	P 99.99	940-1100	R.A.	61.0	0.8	276	(1960)
⁶³ Ni	P 99.99	900-1200	R.A.	69.2	2.22	277	(1966)
⁶³ Ni	S 99.99	900-1200	R.A.	70.1	2.59	277	(1966)
¹²⁴ Sb	P 99.97	1020-1220	-	27.0	1.8×10^{-5}	278	(1962)
¹¹³ Sn	P	700-1000	A.R.G.	21.0	2.1×10^{-7}	279	(1956)
¹¹³ Sn	P 99.8	700-1350	A.R.G.	58.0	0.83	15	(1959)
¹¹³ Sn	P	1270-1480	R.A.	65.5	30.0	280	(1967)
⁴⁸ V	P 99.99	800-1300	R.A.	66.50	0.87	189	(1968)
¹⁸⁵ W	P,S 99.9	1100-1275	S.S.	71.0	1.13	281	(1958)
¹⁸⁵ W	P 99.95	1100-1300	S.S.	71.5	2.0	185	(1964)

NIOBIUM

¹⁴ C		900-1100		32.0	1.09×10^{-5}	282	(1961)
¹⁴ C	P 99.14	1100-1400	R.A.	35.0	9.32×10^{-2}	261	(1966)
¹⁴ C	P 99.5	930-1800	R.A. ***	37.9 ***	0.033	283	(1967)
⁶⁰ Co	P 99.85	1500-2100	A.R.G.	70.5	0.74	262	(1962)
⁵¹ Cr	S	953-1435	S.S.	83.5	0.30	284	(1968)
⁵¹ Cr		947-1493	S.S.	80.59	0.13	284	(1968)
⁵⁵ Fe	P 99.85	1400-2100	A.R.G.	77.7	1.5	262	(1962)
⁹⁵ Nb		1600-2000		113	28.18	285	(1967)
³⁵ S	S 99.9	1100-1500	R.A.	73.1	2600	286	(1968)
¹¹³ Sn	P 99.85	1850-2400	S.S.	78.9	0.14	287	(1965)
¹⁸² Ta	P,S 99.997	878-2395	S.S.	99.3	1.0	98	(1965)
²³⁵ U	P 99.55	1500-2000	R.A.	76.8	8.9×10^{-3}	267	(1965)
⁴⁸ V	S 99.99	1000-1400	R.A.	85.0	2.21	165	(1968)

PALLADIUM

⁵⁹ Fe	P	1240-1450	R.A.	-	-	280	(1967)
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PLATINUM

⁶⁴ Cu	P	-	S.S.	59.5	0.074	214	(1963)
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POTASSIUM

²² Na		0-62	S.S.	7.45	0.058	288	(1967)
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Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Reference Year
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SELENIUM

⁵⁹ Fe	P —	40-100	R.A.	8.88	—	289	(1958)
²⁰³ Hg	P 99.996	25-100	R.A.	1.2	—	289	(1958)
⁹⁵ Zr	P 99.996	40-100	R.A.	6.3	—	289	(1958)

SILICON

¹⁹⁸ Au	S —	700-1300	R.A.	25.8	1.1×10^{-3}	290	(1956)
¹⁹⁸ Au	S —	700-1300	S.S.***	8.9***	2.4×10^{-4}	291	(1964)
¹⁹⁸ Au	S —	700-1300	S.S.***	47.0***	2.75×10^{-3}	291	(1964)
¹⁴ C	P —	1070-1400	R.A.	67.2	0.33	292	(1961)
⁶⁴ Cu	P —	800-1100	R.A.	23.0	4×10^{-2}	293	(1958)
⁵⁹ Fe	S —	1000-1200	R.A.	20.0	6.2×10^{-3}	290	(1956)
⁶³ Ni		450-800		97.5	1000	294	(1967)
³³ P	S —	1100-1250	—	41.5	—	295	(1962)
¹²⁴ Sb	S —	1190-1398	R.A.	91.7	12.9	296	(1959)

SILVER

¹⁹⁸ Au	S 99.99	650-950	S.S.	45.5	0.26	297	(1956)
¹⁹⁸ Au	P 99.99	656-905	S.S.	46.4	0.41	42	(1957)
¹⁹⁸ Au	S 99.99	718-942	S.S.***	48.28 ***	0.85	227	(1963)
¹¹⁵ Cd	S 99.99	592-937	S.S.	41.687	0.441	298	(1954)
⁶⁰ Co	S 99.99	745-943	S.S.	59.9	104	299	(1961)
⁶⁰ Co	P 99.999	600-850	R.A.	29.9	3.0×10^{-7}	300	(1963)
⁶⁴ Cu	P 99.99	717-945	S.S.	46.1	1.23	301	(1957)
⁵⁹ Fe	P	300-725	—	21.5	2.0×10^{-5}	252	(1955)
⁵⁹ Fe	S 99.99	720-930	S.S.***	49.04***	2.42	205	(1962)
⁵⁹ Fe	P 99.999	600-850	R.A.	29.6	9.4×10^{-7}	300	(1963)
⁷⁷ Ge	P —	640-870	S.S.	36.5	0.084	302	(1958)
²⁰³ Hg	P 99.99	653-948	S.S.	38.1	0.079	301	(1957)
¹¹⁴ In	S 99.99	592-937	S.S.	40.801	0.412	298	(1954)
¹¹⁴ In	P	770-940		41.79	0.55	303	(1967)
⁶³ Ni	S 99.99	749-950	S.S.***	54.8 ***	21.9	304	(1961)
⁶³ Ni	P 99.999	600-850	R.A.	28.7	8.5×10^{-7}	299	(1963)
²¹⁰ Pb	P —	700-800	S.S.	39.2	0.39	305	(1953)
²¹⁰ Pb	P —	700-865	S.S.	38.1	0.22	306	(1955)
¹⁰² Pd	S 99.999	736-939	S.S.	56.75	9.56	213	(1963)
¹⁰³ Ru	S 99.99	793-945	S.S.	65.8	180	307	(1959)
³⁵ S	S 99.999	600-900	R.A.	40.0	1.65	308	(1967)

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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SILVER

¹²⁴ Sb	S —	650-950	S.S.	39.4	0.29	309	(1952)
¹²⁴ Sb	S,P 99.99	468-942	S.S.	38.32	0.169	310	(1954)
¹²⁴ Sb	P 99.999	780-950 ***	S.S.,R.A.***	39.07	0.234	311	(1967)
¹¹³ Sn	S 99.99	592-937	S.S.	39.30	0.255	298	(1954)
²⁰⁴ Tl	P —	640-870	S.S.	37.9	0.15	302	(1958)
⁶⁵ Zn	S 99.99	640-925	S.S.	41.7	0.54	312	(1955)
⁶⁵ Zn	S	785-895		41.7	0.532	313	(1967)

SODIUM

⁴² K		0-91	S.S.	8.43	0.08	289	(1967)
⁸⁶ Rb		0-85	S.S.	8.49	0.15	289	(1967)

TANTALUM

¹⁴ C	P —	600-2200	—	23.8	2.78×10^{-3}	314	(1964)
¹⁴ C	P 99.01	1200-1600	R.A.	43.0	2.57×10^{-2}	261	(1966)
¹⁴ C				40.3	0.012	315	(1966)
⁵⁹ Fe	P —	930-1240	—	71.4	0.505	275	(1955)
⁹⁵ Nb	P,S 99.996	921-2484	S.S.	98.7	0.23	141	(1965)

TELLURIUM

²⁰³ Hg	P	270-440	—	18.7	3.4×10^{-5}	316	(1962)
⁷⁵ Se	P	320-440	—	28.6	2.6×10^{-2}	316	(1962)
²⁰⁴ Tl	P	360-430	—	41.0	320	317	(1962)
²⁰⁴ Tl	S \perp c	380-430	—	84.4	1.8×10^{16}	317	(1962)
²⁰⁴ Tl	S c	380-430	—	73.1	8.5×10^{11}	317	(1962)

 α -THALLIUM

¹¹⁰ Ag	P \perp c 99.999	80-250	S.S.	11.8	3.8×10^{-2}	318	(1968)
¹¹⁰ Ag	P c 99.999	80-250	S.S.	11.2	2.7×10^{-2}	318	(1968)
¹⁹⁸ Au	P \perp c 99.999	110-260	S.S.	2.8	2.0×10^{-5}	318	(1968)
¹⁹⁸ Au	P c 99.999	110-260	S.S.	5.2	5.3×10^{-4}	318	(1968)

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
β -THALLIUM							
¹¹⁰ Ag	P ⊥ c	99.999	230-310	S.S.	11.9	4.2×10^{-2}	318 (1968)
¹⁹⁸ Au	P c	99.999	230-310	S.S.	6.0	5.2×10^{-4}	318 (1968)
α -THORIUM							
²³¹ Pa	P		690-910		71.6	395	143 (1967)
²³³ U	P		690-910		79.3	2210	143 (1967)
TIN							
¹¹⁰ Ag	c		135-225	S.S.	12.3	7.1×10^{-3}	319 (1966)
¹¹⁰ Ag	⊥ c		135-225	S.S.	18.4	0.18	319 (1966)
¹¹⁰ Ag	P		478-500	S.D.	24.0	12.0	320 (1967)
¹⁹⁸ Au	c		135-225	S.S.	11.0	5.8×10^{-3}	319 (1966)
¹⁹⁸ Au	⊥ c		135-225	S.S.	17.7	0.16	319 (1966)
⁶⁰ Co	S,P		140-217	R.A.	22.0	5.5	321 (1960)
¹¹⁴ In	S ⊥ c	99.998	181-221	S.S.	25.8	34.1	322 (1958)
¹¹⁴ In	S c	99.998	181-221	S.S.	25.6	12.2	322 (1958)
⁶⁵ Zn	S,P		140-217	R.A.	7.8	9.8×10^{-4}	321 (1960)
β -TITANIUM							
¹⁴ C	P —	1150-1650	—	19.8	3.18×10^{-3}	323 (1963)	
¹⁴ C	P 99.62	1100-1400	R.A.	20.0	3.02×10^{-3}	261 (1960)	
⁵¹ Cr	P —	500-1300	A.R.G.	67	200	175 (1958)	
⁵¹ Cr	P 99.74	1000-1200	A.R.G.	37.7	1×10^{-2}	324 (1959)	
⁵¹ Cr	P 99.24	1000-1200	A.R.G.	35.3	5×10^{-3}	324 (1959)	
⁵¹ Cr	P 99.7	950-1600	A.R.G.***	35.1,***	5×10^{-3}	325 (1963)	
				61	4.9		
⁶⁰ Co	P 99.7	900-1250	S.S.	30.6	1.2×10^{-2}	326 (1962)	
⁶⁰ Co	P 99.7	900-1600	S.S. ***	30.6,***	1.2×10^{-2} ,	325 (1963)	
				52.5	2.0		
⁵⁵ Fe	P —	500-1300	A.R.G.	50	20	175 (1958)	
⁵⁵ Fe	P 99.7	900-1250	A.R.G.	31.6	7.8×10^{-3}	326 (1962)	
⁵⁹ Fe	P 99.7	900-1250	A.R.G.	32.9	1.23×10^{-2}	326 (1962)	
⁵⁵ Fe	—	—	A.R.G.	32.0	8.5×10^{-3}	326 (1962)	
⁵⁵ Fe	P 99.7	900-1600	A.R.G. ***	31.6,***	7.8×10^{-3} ,	325 (1963)	
				55	2.7		
⁹ Mo	P 99.7	1000-1600	S.S. ***	43.0, ***	8×10^{-3} ,	325 (1963)	
				73	20		

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D_0 (cm ² /sec)	Reference No.	Year
β-TITANIUM (continued)							
⁹⁹ Mo	P 98.94	900-1100		33.2	2.82×10^{-4}	327	(1967)
⁹⁹ Mo	P 98.94	1100-1560		51.3	0.24	327	(1967)
⁵⁴ Mn	P 99.7	900-1250	S.S.	33.7	6.1×10^{-3}	326	(1962)
⁵⁴ Mn	P 99.7	900-1600	S.S.***	33.7,***	$6.1 \cdot 10^{-3}$,	325	(1963)
				58	20		
⁹⁵ Nb	P 99.7	1000-1250	A.R.G.	39.3	5.0×10^{-3}	326	(1962)
⁹⁵ Nb	P 99.7	1000-1600	A.R.G.***	39.3,***	5.0×10^{-3} ,	325	(1963)
				73	20		
⁶³ Ni	P 99.7	900-1250	A.R.G.	29.6	9.2×10^{-3}	326	(1962)
⁶³ Ni	P 99.7	295-1600	A.R.G.***	29.6,***	9.2×10^{-3} ,	325	(1963)
				52.5	2.0		
³² P	P 99.7	950-1600	S.S.	24.1,	3.62×10^{-3} ,	328	(1965)
				56.5	5		
⁴⁶ Sc	P 99.7	919-1290	S.S.	32.7	2.1×10^{-3}	328	(1965)
¹¹³ Sn	P 99.78	900-1100	S.D.	78.0	1630	329	(1960)
¹¹³ Sn	P 99.3	900-1100	S.D.	86.5	10	329	(1960)
¹¹³ Sn	P 99.7	950-1600	S.S.***	31.6,***	3.8×10^{-4} ,	328	(1965)
				69.2	10		
²³⁵ U	P 99.62	915-1200	R.A.	29.3	4.9×10^{-3}	267	(1966)
⁴⁸ V	P 99.95	900-1545	S.S.	32.2,	3.1×10^{-4} ,	330	(1964)
				57.2	1.4		
⁴⁸ V	P 99.99	1100-1800	S.S.		Nonlinear	331	(1968)
¹⁸⁵ W	P —	500-1300	A.R.G.	49	0.3	175	(1958)
¹⁸⁵ W	P 98.94	900-1250	***	43.9 ***	3.6×10^{-3}	327	(1967)
⁹⁵ Zr	P 98.94	920-1500		35.4	4.7×10^{-3}	327	(1967)

TUNGSTEN

¹⁴ C	P 99.51	1200-1600	R.A.	53.5	8.9×10^{-3}	261	(1966)
⁵⁹ Fe	P —	940-1240	—	66.0	1.4×10^{-2}	275	(1955)
⁹⁹ Mo	S	2000-2400	S.S.	121	5×10^{-2}	332	(1967)
⁹⁹ Mo	P	2100-2400	S.S.	110	3.7×10^{-3}	332	(1967)
¹⁸⁶ Re	S 99.92	2660-3230	S.S.	162.8	275	156	(1965)
¹⁸⁶ Re	P	2100-2400	S.S. ***	141 ***	19.5	332	(1967)

 γ -URANIUM

¹⁹⁵ Au	P 99.99	785-1007	S.S.	30.4	4.86×10^{-3}	333	(1961)
⁶⁰ Co	P 99.99	783-989	S.S.	12.57	3.51×10^{-4}	334	(1964)
⁵¹ Cr	P —	844-948	S.S.	21.8	1.98×10^{-3}	335	(1961)

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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 γ -URANIUM

⁵¹ Cr	P 99.99	797-1037	S.S.***	24.46***	5.47×10^{-3}	334	(1964)
⁶⁴ Cu	P 99.99	787-1039	S.S.	24.06	1.96×10^{-3}	334	(1964)
⁵⁵ Fe	P 99.99	787-990	S.S.	12.01	2.69×10^{-4}	334	(1964)
⁵⁴ Mn	P 99.99	787-939	S.S.	13.88	1.81×10^{-4}	334	(1964)
⁶³ Ni	P 99.99	787-1039	S.S.	15.66	5.36×10^{-4}	334	(1964)
⁹⁵ Nb	P 99.99	791-1102	S.S.	39.65	4.87×10^{-2}	334	(1964)

VANADIUM

⁵¹ Cr	P 99.8	960-1200	R.A.	64.6	9.54×10^{-3}	195	(1962)
⁵⁵ Fe	S,P 99.97	842-1171	S.S.	70.5	0.60	164	(1965)
⁴⁴ Ti	P 99.98	1100-1800	S.S.		Nonlinear	331	(1968)

ZINC

¹¹⁰ Ag	S ₁ c 99.999	271-413	S.S.	27.6	0.45	336	(1961)
¹¹⁰ Ag	S ₁₁₂ c 99.999	271-413	S.S.	26.0	0.32	336	(1961)
¹⁹⁸ Au	S ₁ c 99.999	315-415	S.S.	29.72	0.29	337	(1963)
¹⁹⁸ Au	S ₁₁₂ c 99.999	315-415	S.S.	29.73	0.97	337	(1963)
¹¹⁵ Cd	S ₁ c 99.999	225-416	S.S.	20.12	0.117	337	(1963)
¹¹⁵ Cd	S ₁₁₂ c 99.999	225-416	S.S.	20.54	0.114	337	(1963)
⁶⁴ Cu	S ₁ c 99.999	338-415	S.S.	29.53	2.22	338	(1966)
⁶⁴ Cu	S ₁ c 99.999	338-415	S.S.	29.92	2.0	338	(1966)
⁷² Ga	S ₁₁₂ c 99.999	240-403	S.S.	18.4	0.016	338	(1966)
⁷² Ga	S ₁ c 99.999	240-403	S.S.	18.15	0.018	338	(1966)
²⁰³ Hg	P 99.96	20-200	—	3.2	5.8×10^{-10}	339	(1963)
²⁰³ Hg	S ₁ c 99.999	260-413	S.S.	20.18	0.073	340	(1967)
²⁰³ Hg	S ₁₁₂ c 99.999	260-413	S.S.	19.70	0.056	340	(1967)
¹¹⁴ In	S ₁ c 99.999	271-413	S.S.	19.6	0.14	336	(1961)
¹¹⁴ In	S ₁₁₂ c 99.999	271-413	S.S.	19.1	0.062	336	(1961)

 α -ZIRCONIUM

⁵¹ Cr	P 99.9	700-850	R.A.	18.0	1.19×10^{-8}	341	(1965)
⁵⁵ Fe	P —	750-840	—	48.0	2.5×10^{-2}	342	(1964)
⁹⁹ Mo			R.A.	24.7	6.2×10^{-8}	343	(1967)
¹¹³ Sn	P —	300-700	A.R.G.	22.0	1×10^{-8}	175	(1958)

Solute	Material	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
α-ZIRCONIUM							
¹⁸² Ta	P 99.6	700-800	R.A.	70.0	100	344	(1960)
⁴⁸ V	P 99.99	600-850	R.A.	22.9	1.12×10^{-8}	165	(1968)
β-ZIRCONIUM							
¹⁴ C	P 99.9	900-1260		26.7	4.8×10^{-3}	346	(1965)
¹⁴ C	P 99.6	1100-1600	S.S.	34.2	3.57×10^{-2}	346	(1966)
⁵¹ Cr	P 99.9	880-1100	R.A.	41.0	3.85×10^{-2}	341	(1964)
⁵¹ Cr	P 99.7	900-1200	R.A.***	32.0^{***}	4.17×10^{-3}	347	(1967)
⁵⁵ Fe	P —	890-1100	—	30.0	4×10^{-2}	342	(1964)
⁵⁹ Fe	P 99.7	900-1400	R.A.***	27.0^{***}	9.1×10^{-3}	347	(1967)
⁹⁹ Mo	P 99.7	900-1200	R.A.***	44.4^{***}	3.63×10^{-2}	347	(1967)
⁹⁹ Mo	P 99.7	1355-1560	R.A.***	58.2^{***}	. 1.29	347	(1967)
⁹⁹ Mo	P		R.A.	68.55,	2.63,	343	(1967)
				35.2	1.99×10^{-4}		
⁹⁵ Nb	P 99.9	882-1758	S.S.	25.1 +	$9 \times 10^{-6} \times$	348	(1963)
				35.5 ×	(T/1136) ^{18.1}		
				(T-1136)			
¹¹³ Sn	P —	1000-1250	R.A.	39.0	5×10^{-3}	178	(1959)
¹⁸² Ta	P 99.6	900-1200	R.A.	27.0	5.5×10^{-5}	244	(1960)
⁴⁸ V	P 99.99	870-1200	R.A.	45.8	7.59×10^{-3}	347	(1967)
⁴⁸ V	P 99.99	1200-1400	R.A.	57.2	0.32	347	(1967)
¹⁸⁵ W	P 99.7	900-1250	R.A.	55.8	0.41	347	(1967)

Part III

Self- and Impurity Diffusion in Alloys

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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ALUMINUM

¹¹⁰ Ag	30 wt% Ag	400-595		28.9	0.39	349	(1968)
⁶⁰ Co	44.5 at% Ni	1050-1350	R.A.	47.1	7.2×10^{-3}	350	(1954)
⁶⁰ Co	46.9 at% Ni	1050-1350	R.A.	67.6	2.6	350	(1954)
⁶⁰ Co	49.3 at% Ni	1050-1350	R.A.	80.6	57.7	350	(1954)
⁶⁵ Zn	4.33 at% Zn	360-610	S.S.	28.3	0.35	173	(1959)
⁶⁵ Zn	9.23 at% Zn	360-575	S.S.	27.0	0.2	173	(1959)
⁶⁵ Zn	16.7 at% Zn	360-525	S.S.	25.0	0.1	173	(1959)
⁶⁵ Zn	36.9 at% Zn	360-450	S.S.	24.1	0.16	173	(1959)
⁶⁵ Zn	49.4 at% Zn	325-440	S.S.	21.9	0.048	173	(1959)

CHROMIUM

⁵¹ Cr	16 at% Fe	1040-1250		64.2	0.376	351	(1958)
⁵¹ Cr	31 at% Fe	1000-1275	R.A., S.D.	75.5	24.6	352	(1960)
⁵¹ Cr	49 at% Fe	1000-1275	R.A.	70.0	40	352	(1960)
⁵⁹ Fe	9.4 at% Fe	1000-1250	R.A.	52.3	5×10^{-4}	353	(1965)
⁵⁹ Fe	16 at% Fe	1040-1250		81.9	146	351	(1958)
⁵⁹ Fe	19 at% Fe	957-1250	S.S.	103.2	3.4×10^5	354	(1958)
⁵⁹ Fe	19.0 at% Fe	1000-1150	R.A.	68.0	1.0	353	(1965)
⁵⁹ Fe	28.5 at% Fe	950-1250	R.A.	74.5	32.0	353	(1965)
⁵⁹ Fe	38.5 at% Fe	957-1250	S.S.	88.2	10^4	354	(1958)
⁵⁹ Fe	38.5 at% Fe	1050-1150	R.A.	80.0	200	353	(1965)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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CHROMIUM (continued)

⁵⁹ Fe	43.5 at% Fe	957-1250	S.S.	81.4	1500	354	(1958)
⁵⁹ Fe	47.2 at% Fe	957-1250	S.S.	84.7	7700	354	(1958)
⁵⁹ Fe	48.3 at% Fe	1000-1200	R.A.	68.8	27.0	353	(1965)
⁵⁹ Fe	49.0 at% Fe	1040-1250		74.6	250	351	(1958)

COBALT

⁶⁰ Co	10% Al	1040-1250	R.A.	67.5	2.65	355	(1956)
⁶⁰ Co	42% Al	1000-1250	R.A.	85	184	356	(1956)
⁶⁰ Co	49% Al	900-1200	R.A.	102	3.3×10^4	356	(1956)
⁶⁰ Co	50% Al	900-1100	R.A.	105		356	(1956)
⁶⁰ Co	4 at% Cr	1100-1350		65.8	0.67	357	(1955)
⁶⁰ Co	6.75% Cr	1020-1240	R.A.	73.3		355	(1956)
⁶⁰ Co	7 at% Cr	1100-1350		79.3	56.3	357	(1955)
⁶⁰ Co	11.5% Cr	1020-1240	R.A.	86.3		355	(1956)
⁶⁰ Co	16.5% Cr	1020-1240	R.A.	102		355	(1956)
⁶⁰ Co	27.5% Cr	1020-1240	R.A.	110		355	(1956)
⁶⁰ Co	15 at% Fe			51.2	8×10^{-3}	357	(1956)
	4 at% Ti						
⁶⁰ Co	21 at% Fe			65.0	0.54	357	(1955)
⁶⁰ Co	50 at% Fe	840-925	S.S.	27.4	2.6×10^{-6}	358	(1958)
⁶⁰ Co	50% Fe	1050-1200	R.A.	37.0	5×10^{-6}	355	(1956)
⁶⁰ Co	50 at% Fe	1000-1250	S.S.	41.8	1.1×10^{-4}	358	(1958)
⁶⁰ Co	4 at% Ni			87.4	838	357	(1955)
⁶⁰ Co	6.2 at% Ni	1213-1368	R.A.	72.9	7.4	25	(1965)
⁶⁰ Co	8 at% Ni			81.2	124	325	(1955)
⁶⁰ Co	10.9 at% Ni	864-1048		67.1	0.61	24	(1962)
⁶⁰ Co	10.9 at% Ni	1144-1297	R.A.	63.6	0.21	24	(1962)
⁶⁰ Co	11.0 at% Ni	1163-1393	R.A.	69.3	2.52	25	(1965)
⁶⁰ Co	19.4 at% Ni	1163-1393	R.A.	65.9	0.99	25	(1965)
⁶⁰ Co	19.5% Ni	1000-1200	R.A.	54.5	0.05	355	(1956)
	20.6% Mn						
⁶⁰ Co	20.1 at% Ni	845-988	R.A.	73.5	5.96	24	(1962)
⁶⁰ Co	20.1 at% Ni	1090-1246	R.A.	71.0	2.42	24	(1962)
⁶⁰ Co	26.0 at% Ni	1100-1350		72.1	6.3	357	(1955)
	9 at% Cr						
⁶⁰ Co	26.0 at% Ni	1100-1350		64.2	0.4	357	(1955)
	18 at% Cr						

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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COBALT (continued)

⁶⁰ Co	27.4 at% Ni	1163-1393	R.A.	64.6	0.70	25	(1965)
⁶⁰ Co	30 at% Ni			60.3	0.155	357	(1955)
⁶⁰ Co	30.1 at% Ni	772-899	R.A.	68.6	1.16	24	(1962)
	0.26 at% Si						
⁶⁰ Co	30.1 at% Ni	1048-1246	R.A.	67.0	0.78	24	(1962)
	0.26 at% Si						
⁶⁰ Co	0.26 at% Si	778-1048	R.A.	65.4	0.5	24	(1962)
⁶⁰ Co	0.26 at% Si	1192-1297	R.A.	62.2	0.17	24	(1962)
⁶³ Ni	6.2 at% Ni	1213-1368	R.A.	72.2	5.4	25	(1965)
⁶³ Ni	10.9 at% Ni	864-1048	R.A.	65.6	0.46	24	(1962)
⁶³ Ni	10.9 at% Ni	1144-1297	R.A.	62.7	0.17	24	(1962)
⁶³ Ni	11.0 at% Ni	1241-1410	R.A.	72.6	6.42	25	(1965)
⁶³ Ni	19.4 at% Ni	1163-1410	R.A.	68.2	1.89	25	(1965)
⁶³ Ni	20.1 at% Ni	864-988	R.A.	69.7	1.66	24	(1962)
⁶³ Ni	20.1 at% Ni	1060-1246	R.A.	65.7	0.41	24	(1962)
⁶³ Ni	27.4 at% Ni	1163-1410	R.A.	67.2	1.60	25	(1965)
⁶³ Ni	30.1 at% Ni	772-899	R.A.	68.5	2.01	24	(1962)
⁶³ Ni	30.1 at% Ni	1048-1246	R.A.	64.8	0.67	24	(1962)
⁶³ Ni	0.26 at% Si	772-1048	R.A.	64.3	0.34	24	(1962)
⁶³ Ni	0.26 at% Si	1192-1297	R.A.	60.2	0.10	24	(1962)
¹⁸⁵ W	0.82 wt% W	1150-1350		68.0	2.88	359	(1961)
	0.14 wt% Fe						

COPPER

⁶⁴ Cu	1 wt% Ni	780-890		48.9	1.86	33	(1967)
⁶⁴ Cu	21.5 at% Ni	863-1112	S.S.	55.3	1.9	32	(1964)
⁶⁴ Cu	9.8 at% Pt	899-1046	S.S.	52.8	1.1	214	(1963)
⁶⁴ Cu	24.6 at% Pt	947-1096	S.S.	54.7	0.53	214	(1963)
⁶⁴ Cu	49.4 at% Pt	1000-1293	S.S.	51.0	0.027	214	(1963)
⁶⁴ Cu	18.0 at% Sn	600-725	S.S.	29.2	0.32	360	(1968)
⁶⁴ Cu	19.8 at% Sn	600-725	S.S.	27.1	9.2×10^{-2}	360	(1968)
⁶⁴ Cu	20.5 at% Sn	440-575	S.S.	30.9	4.7	360	(1968)
⁶⁴ Cu	27 wt% Zn	800-900	S.S.	44.5	0.85	361	(1954)
⁶⁴ Cu	31 wt% Zn	600-900	S.S.	41.9	0.34	218	(1957)
⁶⁴ Cu	45 wt% Zn	640-870	S.S.	25.0	0.038	361	(1954)
⁶⁴ Cu	48.0 at% Zn	497-817	S.S.	22.0	0.011	362	(1956)
⁶³ Ni	21.5 at% Ni	930-1113	S.S.	49.7	0.063	32	(1964)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D_0 (cm ² /sec)	Reference No.	Year
COPPER (continued)							
¹⁹⁵ Pt	9.8 at% Pt	906-1058	S.S.	52.6	0.093	214	(1963)
¹⁹⁵ Pt	24.6 at% Pt	946-1094	S.S.	51.4	0.019	214	(1963)
¹⁹⁵ Pt	49.4 at% Pt	1034-1287	S.S.	59.5	0.066	214	(1963)
¹²⁴ Sb	48.0 at% Zn	351-594	S.S.	23.5	0.08	315	(1956)
¹¹³ Sn	18.0 at% Sn	600-725	S.S.	17.8	1.4×10^{-2}	360	(1968)
¹¹³ Sn	19.8 at% Sn	600-725	S.S.	10.2	3.6×10^{-3}	360	(1968)
¹¹³ Sn	20.5 at% Sn	440-575	S.S.	49.7	2400	360	(1968)
⁶⁵ Zn	10.0 at% Ni	800-900	—	44	—	219	(1966)
⁶⁵ Zn	10.0 at% Ni	800-900	—	47	—	219	(1966)
	+10.0 at% Zn						
⁶⁵ Zn	10.0 at% Ni	800-900		41	—	219	(1966)
	+20.0 at% Zn						
⁶⁵ Zn	10.0 at% Ni	800-900		34	—	219	(1966)
	+30.0 at% Zn						
⁶⁵ Zn	20.0 at% Ni	800-900		54	—	219	(1966)
⁶⁵ Zn	20.0 at% Ni	800-900		45	—	219	(1966)
	+10.0 at% Zn						
⁶⁵ Zn	20.0 at% Ni	800-900		53	—	219	(1966)
	+20.0 at% Zn						
⁶⁵ Zn	20.0 at% Ni	800-900		42	—	219	(1966)
	+30.0 at% Zn						
⁶⁵ Zn	10 at% Zn	800-900		47	—	219	(1966)
⁶⁵ Zn	20 at% Zn	800-900		38	—	219	(1966)
⁶⁵ Zn	27.0 wt% Zn	800-900	S.S.	41.16	0.85	361	(1954)
⁶⁵ Zn	30.0 at% Zn	800-900		45	—	219	(1966)
⁶⁵ Zn	31.0 wt% Zn	600-900	S.S.	40.07	0.73	218	(1957)
⁶⁵ Zn	45.0 wt% Zn	640-870	S.S.	23.3	0.031	361	(1954)
⁶⁵ Zn	48.0 at% Zn	499-718	S.S.	18.78	3.5×10^{-3}	362	(1956)

GOLD

¹¹⁰ Ag	6 at% Ag	660-961	S.S.	40.26	0.72	363	(1963)
¹¹⁰ Ag	17 at% Ag	650-1010	S.S.	41.02	0.09	363	(1963)
¹¹⁰ Ag	34 at% Ag	654-971	S.S.	41.73	0.11	363	(1963)
¹⁹⁸ Au	6 at% Ag	718-1010	S.S.	42.08	0.09	363	(1963)
¹⁹⁸ Au	17 at% Ag	712-1001	S.S.	43.05	0.12	363	(1963)
¹⁹⁸ Au	17.1 wt% Ag	717-992	S.S.	40.7	0.041	42	(1957)
¹⁹⁸ Au	34 at% Ag	715-1001	S.S.	44.51	0.17	363	(1963)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Reference Year
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GOLD (continued)

¹⁹⁸ Au	50 at% Cd	303-604	S.S.	27.9	0.17	364	(1961)
¹⁹⁸ Au	47.5% Cd	354-600	S.S.	28.1	0.23	365	(1967)
¹⁹⁸ Au	49.0% Cd	440-550	S.S.	30.0	0.61	365	(1967)
¹⁹⁸ Au	50.0% Cd	440-550	S.S.	27.9	0.17	365	(1967)
¹⁹⁸ Au	50.5% Cd	440-550	S.S.	26.2	0.12	365	(1967)
¹¹⁵ Cd	50 at% Cd	330-620	S.S.	28.0	0.23	364	(1961)
¹¹⁵ Cd	47.5% Cd	354-600	S.S.	31.0	1.36	365	(1967)
¹¹⁵ Cd	49.0% Cd	440-550	S.S.	31.2	1.50	365	(1967)
¹¹⁵ Cd	50.0% Cd	440-550	S.S.	28.0	0.23	365	(1967)
¹¹⁵ Cd	50.5% Cd	440-550	S.S.	27.1	0.22	365	(1967)
⁶³ Ni	10 at% Ni	880-940	S.S.	47.6	0.8	83	(1957)
⁶³ Ni	20 at% Ni	880-940	S.S.	47.8	0.82	83	(1957)
⁶³ Ni	36 at% Ni	873-920	S.S.	49.1	1.10	83	(1957)

HAFNIUM

¹⁴ C	1.5 wt% Zr 0.15 wt% Fe	1120-1760		74.6	74	366	(1968)
¹⁴ C	1.5 wt% Zr 0.15 wt% Fe	1820-2130		40.0	4.2×10^{-2}	366	(1968)
¹⁸¹ Hf	2.7 wt% Zr	1785-2158		43.8	4.8×10^{-3}	366	(1968)

IRON

¹⁴ C	0.92 wt% Cr	500-800	R.A.	33.6	16.4	234	(1960)
¹⁴ C	0.56 wt% Mo	500-800	R.A.	28.9	2.0	234	(1960)
¹⁴ C	2.58 wt% Mo	500-800	R.A.	33.5	20.0	234	(1960)
¹⁴ C	0.46 wt% Ni	500-800	R.A.	24.8	0.2	234	(1960)
¹⁴ C	2.0 wt% Ni	500-800	R.A.	26.6	0.3	234	(1960)
¹⁴ C	0.79 wt% Si	500-800	R.A.	26.0	0.4	234	(1960)
¹⁴ C	2.38 wt% Si	500-800	R.A.	27.2	0.8	234	(1960)
¹⁴ C	2.5 wt% Si	500-800	R.A.	34.5	0.12	234	(1960)
	0.8 wt% C						
¹⁴ C	3.6 wt% Si	500-800	R.A.	29.3	2.2	234	(1960)
⁶⁰ Co	50 at% Co	1000-1250	R.A.	41.8	1.1×10^{-4}	358	(1958)
⁶⁰ Co	50 at% Co	840-925	R.A.	27.4	2.6×10^{-6}	358	(1958)
⁶⁰ Co	0.8 wt% C	1050-1250	R.A.	80.0	90	237	(1954)
	0.4 wt% Mn						

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
IRON (continued)							
⁶⁰ Co	18 wt% Cr 17 wt% Ni 5 wt% Al	900-1200	S.D.	68.0	0.37	367	(1960)
⁶⁰ Co	15 wt% Cr 18 wt% Ni 5 wt% Al, 1 wt% Mo	900-1200	S.D.	78.0	58	367	(1960)
⁶⁰ Co	15 wt% Cr 18 wt% Ni 5 wt% Al, 1 wt% Nb	900-1200	S.D.	71.1	111	367	(1960)
⁶⁰ Co	15 wt% Cr 18 wt% Ni 5 wt% Al, 1 wt% Zr	900-1200	S.D.	74.5	16.4	367	(1960)
⁶⁰ Co	15 wt% Cr 18 wt% Ni 5 wt% Al, 1/2 wt% Nb, 1/2 wt% Zr	900-1200	S.D.	76.5	206	367	(1960)
⁶⁰ Co	18 wt% Cr 18 wt% Ni 8 wt% Al, 2 wt% Mo	800-1000	S.D.	66.4	1.26	367	(1960)
⁶⁰ Co	18 wt% Cr 17 wt% Ni 8 wt% Al, 1 wt% Mo, 1/2 wt% Nb	800-1000	S.D.	59.8	103	367	(1960)
⁶⁰ Co	15 wt% Cr 18 wt% Ni 8 wt% Al, 1 wt% Mo, 1/2 wt% Zr	800-1000	S.D.	65.5	53	367	(1960)
⁶⁰ Co	15 wt% Cr 18 wt% Ni 8 wt% Al, 1 wt% Nb	800-1000	S.D.	61.5	20.4	367	(1960)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
IRON (continued)							
⁶⁰ Co	15 wt% Cr 18 wt% Ni 8 wt% Al, 1 wt% Zr	800-1000	S.D.	57.1	1.97	367	(1960)
⁶⁰ Co	15 wt% Cr 18 wt% Ni 8 wt% Al, 1/2 wt% Nb, 1/2 wt% Zr	800-1000	S.D.	65.5	92.5	367	(1960)
⁵¹ Cr	0.8 wt% C 0.4 wt% Mn	1050-1250	R.A.	75.0	10	367	(1954)
⁵¹ Cr	12.3 wt% Cr	900-1400	R.A.	55.1	1.29	369	(1964)
⁵¹ Cr	17.4 wt% Cr	900-1400	R.A.	52.5	0.46	369	(1964)
⁵¹ Cr	26.0 at% Cr	950-1275	R.A.	48.5	0.156	352	(1960)
⁵¹ Cr	15 wt% Cr		R.A.	57.0	2.0	368	(1968)
⁵¹ Cr	1.7 wt% V		R.A.	57.0	2.0	368	(1968)
⁶⁴ Cu	0.6% Mn 0.1% Cu	800-1200	S.D.	61.0	3.0	370	(1955)
⁵⁹ Fe	0.27 wt% Al	700-900		52.0	0.17	371	(1958)
⁵⁹ Fe	0.27 wt% Al	1000-1250		75.0	4.27	371	(1958)
⁵⁹ Fe	0.39 wt% Al	700-900		53.0	0.29	371	(1958)
⁵⁹ Fe	0.39 wt% Al	1000-1250		75.0	5.13	371	(1958)
⁵⁵ Fe	0.0001 at% Bi	750-890		70.34	414.0	372	(1965)
⁵⁵ Fe	0.0006 at% Bi	750-890		66.23	80.8	372	(1965)
⁵⁵ Fe	0.0010 at% Bi	750-890		62.27	13.97	372	(1965)
⁵⁵ Fe	0.0013 at% Bi	750-890		59.27	3.65	372	(1965)
⁵⁹ Fe	0.1 wt% C	720-800		59.0	2.24	129	(1960)
⁵⁹ Fe	0.14 wt% C	950-1300	R.A.	58.0	0.07	373	(1951)
⁵⁹ Fe	0.18 wt% C	1000-1250	R.A.	58.0	0.7	373	(1951)
⁵⁹ Fe	0.25 wt% C	1100-1300	S.S.	59.0	5.2 × 10 ⁻²	374	(1956)
⁵⁹ Fe	0.54 wt% C	1090-1300	S.S.	54.0	1.5 × 10 ⁻²	374	(1956)
⁵⁹ Fe	0.75 wt% C	1090-1300	S.S.	54.0	2.1 × 10 ⁻²	374	(1956)
⁵⁹ Fe	1.11 wt% C	1000-1300	S.S.	53.8	2.9 × 10 ⁻²	374	(1956)
⁵⁹ Fe	1.4 wt% C	1000-1260	S.S.	53.8	5 × 10 ⁻²	374	(1956)
⁵⁹ Fe	2.09 wt% C	1000-1250	R.A.	50.0	8 × 10 ⁻³	373	(1951)
⁵⁹ Fe	3.40 wt% C	950-1150	R.A.	45.0	1 × 10 ⁻³	373	(1951)
⁵⁹ Fe	3.70 wt% C	950-1150	R.A.	33.0	1 × 10 ⁻⁵	373	(1951)
⁵⁹ Fe	9.1 wt% Cr	575-725		55.1	9.27	340	(1967)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D_0 (cm ² /sec)	Reference No.	Year
IRON (continued)							
⁵⁹ Fe	9.1 wt% Cr	777-825		52.4	0.42	340	(1967)
⁵⁹ Fe	15.2 wt% Cr	595-677		54.1	1.25	340	(1967)
⁵⁹ Fe	15.2 wt% Cr	725-777		51.5	0.27	340	(1967)
⁵⁹ Fe	17 wt% Cr	900-1400	R.A.	55.8	1.34	369	(1964)
⁵⁹ Fe	19.75 wt% Cr	575-645		51.9	0.65	340	(1967)
⁵⁹ Fe	19.75 wt% Cr	700-825		51.5	0.22	340	(1967)
⁵⁹ Fe	21 at% Cr	1060-1250	S.S.	54	0.32	354	(1958)
⁵⁹ Fe	21.0 at% Cr	1000-1200	R.A.	52.2	0.115	353	(1965)
⁵⁹ Fe	27 at% Cr	1040-1400		50.4	0.195	351	(1958)
⁵⁹ Fe	41.5 at% Cr	950-1250		65.2	0.11	354	(1958)
⁵⁹ Fe	41.5 at% Cr	1000-1200	R.A.	63.3	5.0	353	(1965)
⁵⁹ Fe	46.7 at% Cr	1000-1200	R.A.	65.9	15.8	353	(1965)
⁵⁹ Fe	50.0 at% Cr	1000-1200	R.A.	68.7	26.6	353	(1965)
⁵⁹ Fe	17.5 wt% Cr	800-1200	S.D.	67.1	0.58	375	(1955)
	11.3 wt% Ni						
	1.8 wt% Mo						
⁵⁹ Fe	19.9 wt% Cr	900-1290	S.S.	67.9	1.74	376	(1968)
	24.7 wt% Ni						
⁵⁹ Fe	0.4 wt% Mn	1150-1350		83.0	2×10^{-4}	377	(1955)
⁵⁹ Fe	1.15 wt% Mn	1150-1350		91.0	2.5×10^{-3}	377	(1955)
⁵⁹ Fe	2.25 wt% Mn	1150-1350		94.0	8×10^{-3}	377	(1955)
⁵⁹ Fe	3.18 wt% Mn	1150-1350		96.0	1.05×10^{-2}	377	(1955)
⁵⁹ Fe	4.33 wt% Mn	1150-1350		98.0	2.4×10^{-2}	377	(1955)
⁵⁹ Fe	5.19 wt% Mn	1150-1350		95.0	1.2×10^{-2}	377	(1955)
⁵⁹ Fe	6.06 wt% Mn	1150-1350		92.5	4×10^{-3}	377	(1955)
⁵⁹ Fe	8.23 wt% Mn	1150-1350		89.0	1×10^{-3}	377	(1955)
⁵⁹ Fe	10 at% Ni	950-1200	R.A.	67.0	0.5	378	(1955)
⁵⁹ Fe	11.8 at% Ni	1000-1200	R.A.	66.6	1.21	379	(1955)
⁵⁹ Fe	16 at% Ni	950-1200	R.A.	63.0	0.2	378	(1955)
⁵⁹ Fe	20 wt% Ni	1050-1350		75.0	20.0	380	(1955)
	0.02 wt% C						
⁵⁹ Fe	20 wt% Ni	1050-1350		69.0	2.0	380	(1955)
	0.18 wt% C						
⁵⁹ Fe	20 wt% Ni	1050-1350		64.0	0.4	380	(1955)
	0.4 wt% C						
⁵⁹ Fe	20 wt% Ni	1050-1350		47.0	2×10^{-3}	380	(1955)
	0.95 wt% C						
⁵⁹ Fe	23 at% Ni	950-1200	R.A.	65.0	0.6	378	(1955)
⁵⁹ Fe	24.3 at% Ni	1000-1200	R.A.	62.0	0.35	379	(1955)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
IRON (continued)							
⁵⁹ Fe	24.1 at% Ni 0.2 at% Nb	1000-1200	R.A..	85.2	1260	379	(1955)
⁵⁹ Fe	24.1 at% Ni 0.8 at% Nb	1000-1200	R.A..	89.0	4910	379	(1955)
⁵⁹ Fe	24.1 at% Ni 2.25 at% Nb	1000-1200	R.A..	95.5	3.48×10^4	379	(1955)
⁵⁹ Fe	24.4 at% Ni 0.1 at% Ti	1000-1200	R.A..	67.6	2.38	379	(1955)
⁵⁹ Fe	24.4 at% Ni 2.0 at% Ti	1000-1200	R.A..	92.6	15,000	379	(1955)
⁵⁹ Fe	24.7 at% Ni 2.3 at% V	1000-1200	R.A..	55.2	0.035	379	(1955)
⁵⁹ Fe	24.7 at% Ni 4.7 at% V	1000-1200	R.A..	48.0	2.2×10^{-3}	379	(1955)
⁵⁹ Fe	25.0 at% Ni 0.3 at% Mo	1000-1200	R.A..	68	3.09	379	(1955)
⁵⁹ Fe	25.0 at% Ni 1.5 at% Mo	1000-1200	R.A..	77.5	43.3	379	(1955)
⁵⁹ Fe	25.0 at% Ni 2.25 at% Mo	1000-1200	R.A..	96.0	2.2×10^{-3}	379	(1955)
⁵⁹ Fe	25 wt% Ni 0.02 wt% C	1050-1350		79	70	380	(1955)
⁵⁹ Fe	25 wt% Ni 0.53 wt% C	1050-1350		67	1.0	380	(1955)
⁵⁹ Fe	25 wt% Ni 0.69 wt% C	1050-1350		65	1.0	380	(1955)
⁵⁹ Fe	25 wt% Ni 0.9 wt% C	1050-1350		58	0.1	380	(1955)
⁵⁹ Fe	49 at% Ni	950-1200	R.A..	63.0	0.2	378	(1955)
⁵⁵ Fe	0.0002 at% Pb	750-890		70.43	435.6	372	(1965)
⁵⁵ Fe	0.0007 at% Pb	750-890		67.56	145.0	372	(1965)
⁵⁵ Fe	0.0012 at% Pb	750-890		64.28	34.2	372	(1965)
⁵⁵ Fe	0.0020 at% Pb	750-890		58.35	2.45	372	(1965)
⁵⁵ Fe	0.0002% Pb			71.35	1.507	382	(1966)
⁵⁵ Fe	0.0007% Pb			69.0	0.652	382	(1966)
⁵⁵ Fe	0.0012% Pb			66.5	0.34	382	(1966)
⁵⁵ Fe	0.002% Pb			64.3	0.171	382	(1966)
⁵⁵ Fe	0.0006% Sb			71.5	1.553	382	(1966)
⁵⁵ Fe	0.0012% Sb			69.4	1.170	382	(1966)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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IRON (continued)

⁵⁵ Fe	0.004% Sb			67.1	0.495	382	(1966)
⁵⁵ Fe	0.014% Sb			64.5	0.185	382	(1966)
⁵⁹ Fe	3 wt% Si	967-1416	R.A.	52.2	0.44	381	(1965)
⁵⁵ Fe	0.001% Sn	1050-1350		71.15	1.742	382	(1966)
⁵⁵ Fe	0.004% Sn	1050-1350		68.4	0.645	382	(1966)
⁵⁵ Fe	0.012% Sn	1050-1350		66.5	0.297	382	(1966)
⁵⁵ Fe	0.032% Sn	1050-1350		64.3	0.156	382	(1966)
⁵⁹ Fe	1.8 at% V	700-1500	R.A.	56.5	1.39	383	(1965)
⁹⁹ Mo	0.7% Mo	750-875	R.A.	75.0	1.3×10^4	240	(1966)
⁶³ Ni	5.8 at% Ni	1152-1400	S.D.	73.5	2.11	86	(1959)
⁶³ Ni	14.88 at% Ni	1152-1400	S.D.	75.6	5.0	86	(1959)
¹⁸⁵ W	0.006 wt% C	1050-1250	R.A.	85.7	1900	248	(1967)
¹⁸⁵ W	0.23 wt% C	1050-1250	R.A.	80.3	164	248	(1967)
¹⁸⁵ W	0.56 wt% C	1050-1250	R.A.	77.5	38	248	(1967)
¹⁸⁵ W	0.71 wt% C	1050-1250	R.A.	75.4	13	248	(1967)
¹⁸⁵ W	1.12 wt% C	1050-1250	R.A.	68.4	0.41	248	(1967)
¹⁸⁵ W	8.5 wt% W	1015-1190	S.S.	74.1	40	384	(1968)
	4.0 wt% Cr						
¹⁸⁵ W	9.5 wt% W	1015-1190	S.S.	63.9	0.6	384	(1968)
	4.1 wt% Cr						
	9.7 wt% Co						

LEAD

²¹⁰ Pb	5 at% Tl	207-323	S.S.	25.75	1.108	74	(1961)
²¹⁰ Pb	10 at% Tl	207-323	S.S.	25.45	0.88	74	(1961)
²¹⁰ Pb	20 at% Tl	207-323	S.S.	25.05	0.647	74	(1961)
²¹⁰ Pb	34 at% Tl	207-323	S.S.	24.53	0.367	74	(1961)
²¹⁰ Pb	50 at% Tl	207-323	S.S.	24.44	0.231	74	(1961)
²¹⁰ Pb	60 at% Tl	207-231	S.S.	25.29	0.287	74	(1961)
²¹⁰ Pb	62 at% Tl	207-231	S.S.	25.64	0.393	74	(1961)
²¹⁰ Pb	74 at% Tl	207-231	S.S.	26.82	0.691	74	(1961)
²¹⁰ Pb	76 at% Tl	207-231	S.S.	27.13	0.862	74	(1961)
²¹⁰ Pb	82 at% Tl	207-231	S.S.	28.24	2.575	74	(1961)
²¹⁰ Pb	87 at% Tl	207-231	S.S.	29.71	17	74	(1961)
²⁰⁴ Tl	5 at% Tl	207-325	S.S.	23.89	0.364	74	(1961)
²⁰⁴ Tl	10 at% Tl	207-325	S.S.	23.83	0.361	74	(1961)
²⁰⁴ Tl	20 at% Tl	207-325	S.S.	23.78	0.353	74	(1961)
²⁰⁴ Tl	34 at% Tl	207-325	S.S.	23.12	0.193	74	(1961)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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LEAD (continued)

²⁰⁴ Tl	50 at% Tl	207-325	S.S.	22.52	0.091	74	(1961)
²⁰⁴ Tl	60 at% Tl	207-325	S.S.	23.20	0.126	74	(1961)
²⁰⁴ Tl	62 at% Tl	206-321	S.S.	22.93	0.101	74	(1961)
²⁰⁴ Tl	74 at% Tl	206-321	S.S.	23.86	0.194	74	(1961)
²⁰⁴ Tl	76 at% Tl	206-321	S.S.	24.48	0.33	74	(1961)
²⁰⁴ Tl	82 at% Tl	206-321	S.S.	25.37	0.957	74	(1961)
²⁰⁴ Tl	87 at% Tl	206-321	S.S.	25.53	1.2	74	(1961)

MAGNESIUM

¹¹⁰ Ag	42.8 at% Ag	500-600	S.S.	28.7	0.051	385	(1964)
¹¹⁰ Ag	47.2 at% Ag	500-700	S.S.	36.7	0.33	385	(1964)

MOLYBDENUM

⁵¹ Cr	9.9 wt% Cr	1200-1350		72.7	4.3	386	(1961)
⁹⁹ Mo	15 at% W	1700-2300	R.A.	106	265	387	(1963)
⁹⁹ Mo	25 at% W	1700-2300	R.A.	95	62	388	(1963)
⁹⁹ Mo	35 at% W	1500-2400	R.A.	85	6.9	389	(1965)
¹⁸⁵ W	15 at% W	1500-2200	R.A.	73.0	1.4	387	(1963)
¹⁸⁵ W	25 at% W	1500-2200	R.A.	77.0	2.4	388	(1963)
¹⁸⁵ W	35 at% W	1500-2400	R.A.	92	28	389	(1965)

NICKEL

¹⁴ C	0.74 wt% Cr	500-800	R.A.	34	0.15	271	(1957)
¹⁴ C	4.65 wt% Cr	500-800	R.A.	37	0.5	271	(1957)
¹⁴ C	5.25 wt% Co	500-800	R.A.	37	0.4	271	(1957)
¹⁴ C	2.94 wt% Mo	500-800	R.A.	38	1.0	271	(1957)
⁶⁰ Co	47.3 at% Al	1050-1350	R.A.	56.6	4.7×10^{-2}	350	(1954)
⁶⁰ Co	48.5 at% Al	1050-1350	R.A.	59.9	9.3×10^{-2}	350	(1954)
⁶⁰ Co	49.4 at% Al	1050-1350	R.A.	52.5	4.4×10^{-3}	350	(1954)
⁶⁰ Co	4.3 at% Co	1213-1368	R.A.	62.4	0.49	25	(1965)
⁶⁰ Co	10.8 at% Co	1163-1393	R.A.	63.0	0.66	25	(1965)
⁶⁰ Co	21.1 at% Co	1163-1393	R.A.	61.1	0.33	25	(1965)
⁶⁰ Co	43.3 at% Co	1163-1393	R.A.	62.6	0.52	25	(1965)
⁶⁰ Co	48.6 at% Co	701-819	R.A.	61.5	0.096	24	(1962)
⁶⁰ Co	48.6 at% Co	899-1192	R.A.	60.2	0.12	24	(1962)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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NICKEL (continued)

⁶⁰ Co	49.4 at% Co	1110-1319	R.A.	59.8	0.18	25	(1965)
⁶⁰ Co	3.14 at% Mo	1050-1250	S.D.	66.0	0.078	390	(1960)
⁶⁰ Co	7.91 at% Mo	1050-1250	S.D.	69.0	0.21	390	(1960)
⁶⁰ Co	10.29 at% Mo	1050-1250	S.D.	79.6	6.35	390	(1960)
⁶⁰ Co	12.99 at% Mo	1050-1250	S.D.	66.5	0.086	390	(1960)
⁶⁰ Co	16.79 at% Mo	1050-1250	S.D.	65	0.046	390	(1960)
⁶⁰ Co	20.56 at% Mo	1050-1250	S.D.	58.5	4.4 × 10 ⁻³	390	(1960)
⁶⁰ Co	19.5 wt% Co	1000-1250	R.A.	60.5	0.86	356	(1956)
	20.3 wt% Mn						
⁶⁰ Co	0.13 wt% Si	700-1000	R.A.	48	4 × 10 ⁻³	391	(1955)
	0.03 wt% S						
⁵¹ Cr	6.35 at% Cr	950-1200	R.A.	50.5	0.01	90	(1963)
⁵¹ Cr	11.69 at% Cr	950-1200	R.A.	54.7	0.037	90	(1963)
⁵¹ Cr	19.8 wt% Cr						
	0.66 wt% Al	700-1000	R.A.	58	0.1	90	(1955)
	46 wt% Fe						
⁵¹ Cr	20 at% Cr			58.0		392	(1955)
⁵¹ Cr	20.3 wt% Cr	900-1000	R.A.	66	2	391	(1955)
	2.6 wt% Ti						
	1.0 wt% Si,						
	0.82 wt% Al						
⁵¹ Cr	19.7 wt% Cr	700-1000	R.A.	81	400	391	(1955)
	1.85 wt% Ti						
	1.3 wt% Fe,						
	0.79 wt% Si						
⁵¹ Cr	19.8 wt% Cr	900-1300		59.5	0.21	386	(1961)
	2.6 wt% Ti						
⁵¹ Cr	20.4 wt% Cr	900-1200		64	0.5	393	(1957)
	2.5 wt% Ti						
	1.0 wt% Al						
⁵¹ Cr	10 at% Cr	1100-1260	S.S.	66.5	1.4	32	(1964)
	0.19 at% Mn						
⁵¹ Cr	19.9 at% Cr	1100-1270	S.S.	67.7	1.9	32	(1964)
	0.16 at% Mn						
⁵⁹ Fe	20 wt% Cr	950-1250	S.S.	80.0	160	392	(1960)
	6 wt% W						
⁶⁴ Cu	13 at% Cu	1054-1360	S.S.	63.0	1.5	32	(1964)
⁶⁴ Cu	45.4 at% Cu	985-1210	S.S.	60.3	2.3	32	(1964)
⁵⁹ Fe	6 wt% Ti	950-1250	S.S.	68.6	0.039	392	(1960)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D_0 (cm²/sec)	Reference No.	Year
NICKEL (continued)							
⁵⁹ Fe	8 wt% Ti	950-1250	S.S.	73.1	16	392	(1960)
⁵⁹ Fe	10.6 wt% Ti	950-1250	S.S.	71.2	6.8	392	(1960)
⁵⁹ Fe	14 wt% Ti	950-1250	S.S.	73	15	392	(1960)
⁵⁹ Fe	20 wt% Cr 6 wt% W 4.5 wt% Al	950-1250	S.S.	71.8	3.1	392	(1960)
⁵⁹ Fe	20 wt% Cr 6 wt% W 4.5 wt% Al, 0.5 wt% Ti	950-1250	S.S.	69.7		392	(1960)
⁵⁹ Fe	20 wt% Cr 6 wt% W 4.5 wt% Al, 1.0 wt% Ti	950-1250	S.S.	70.4	8.8	392	(1960)
⁵⁹ Fe	20 wt% Cr 6 wt% W 4.5 wt% Al, 2.0 wt% Ti	950-1250	S.S.	76.1		392	(1960)
⁵⁹ Fe	20 wt% Cr 6 wt% W 4.5 wt% Al, 3.0 wt% Ti	950-1250	S.S.	87.6	1700	392	(1960)
⁵⁹ Fe	20 wt% Cr 6 wt% W 4.5 wt% Al, 5.0 wt% Ti	950-1250	S.S.	85.5	1000	392	(1960)
⁵⁹ Fe	20 wt% Cr 6 wt% W 4.5 wt% Al, 7.0 wt% Ti	950-1250	S.S.	80.0	160	392	(1960)
⁵⁹ Fe	20 wt% Cr 6 wt% W 4.5 wt% Al, 9.0 wt% Ti	950-1250	R.A.	76.3	57	392	(1960)
⁵⁹ Fe	19 at% Fe	950-1250	R.A.	53.0	4×10^{-3}	378	(1955)
⁵⁹ Fe	26 at% Fe	950-1250	R.A.	56.0	0.04	378	(1955)
⁵⁹ Fe	33 at% Fe	950-1200	R.A.	57.0	0.03	378	(1955)
⁵⁹ Fe	4 wt% Ti	950-1250	S.S.	62.8	0.0155	392	(1960)
⁵⁴ Mn	13.81 wt% Mn, 2.01 wt% Sn			54.4	0.55	394	(1954)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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NICKEL (continued)

⁵⁴ Mn	13.86 wt% Mn 3.67 wt% Sn			70.85	130	394	(1954)
⁵⁴ Mn	15.88 wt% Mn 1.83 wt% Cu			62.7	0.21	394	(1954)
⁵⁴ Mn	16.06 wt% Mn 0.8 wt% Ti			64.9	1.09	394	(1954)
⁵⁴ Mn	16.57 wt% Mn 2.13 wt% Al			66.9	1.39	394	(1954)
⁵⁴ Mn	16.82 wt% Mn 5.15 wt% Sn			65.8	37.4	394	(1954)
⁵⁴ Mn	16.93 wt% Mn 1.7 wt% Mo			72.7	9.23	394	(1954)
⁶³ Ni	10 at% Au	999-1057	S.S.	51.0	0.04	364	(1957)
⁶³ Ni	20 at% Au	940-999	S.S.	49.2	0.05	364	(1957)
⁶³ Ni	35 at% Au	882-940	S.S.	39.6	0.005	364	(1957)
⁶³ Ni	50 at% Au	876-925	S.S.	44.5	0.09	364	(1957)
⁶³ Ni	4.3 at% Co	1213-1368	R.A.	68.0	2.86	25	(1965)
⁶³ Ni	10.8 at% Co	1166-1410	R.A.	60.0	1.47	25	(1965)
⁶³ Ni	21.1 at% Co	1166-1410	R.A.	62.6	0.45	25	(1965)
⁶³ Ni	43.3 at% Co	1163-1410	R.A.	63.8	0.69	25	(1965)
⁶³ Ni	48.6 at% Co	701-819	R.A.	63.6	0.36	24	(1962)
⁶³ Ni	48.6 at% Co	899-1192	R.A.	60.6	0.21	24	(1962)
⁶³ Ni	49.4 at% Co	1104-1347	R.A.	61.1	0.25	25	(1965)
⁶³ Ni	10 at% Cr	1040-1275	S.S.	70.2	3.3	32	(1964)
⁶³ Ni	19.9 at% Cr	1040-1275	S.S.	68.2	1.6	32	(1964)
⁶³ Ni	29.7 at% Cr	1040-1275	S.S.	70.5	2.9	32	(1964)
⁶³ Ni	13 at% Cu	1054-1360	S.S.	74.9	35	32	(1964)
⁶³ Ni	45.4 at% Cu	985-1210	S.S.	66.8	17	32	(1964)
⁶³ Ni	20% Fe	814-1200		52.3	7.19×10^{-3}	395	(1967)
⁶³ Ni	26% Fe	814-1200		49.7	1.76×10^{-3}	395	(1967)
⁶³ Ni	27% Fe	814-1200		48.7	1.95×10^{-3}	395	(1967)
⁶³ Ni	30% Fe	814-1200		51.9	6.8×10^{-3}	395	(1967)
⁶³ Ni	35% Fe	814-1200		54.8	1.67×10^{-2}	395	(1967)
⁶³ Ni	1.2 wt% Nb	1030-1230	S.S.	60.8	0.12	396	(1968)
⁶³ Ni	8.0 wt% Nb	1030-1230	S.S.	62.2	0.20	396	(1968)
⁶³ Ni	10.0 wt% Nb	1030-1230	S.S.	67.1	1.0	396	(1968)
⁶³ Ni	1.7 at% W	1100-1300	S.S.	76.5	30	32	(1964)
⁶³ Ni	5.3 at% W	1100-1300	S.S.	80.6	58	32	(1964)
⁶³ Ni	9.2 at% W	1100-1300	S.S.	70.3	1.1	32	(1964)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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NICKEL (continued)

¹⁸⁵ W	1.7 at% W	1100-1300	S.S.	73.1	2.2	32	(1964)
¹⁸⁵ W	5.3 at% W	1100-1300	S.S.	80.5	17	32	(1964)
¹⁸⁵ W	9.2 at% W	1100-1300	S.S.	74.5	1.4	32	(1964)

NIOBIUM

⁹⁵ Nb	10.0% Mo	1600-2100	R.A.	126.0	26.9	397	(1966)
⁹⁵ Nb	20.0% Mo	1700-2100	R.A.	112.0	60.3	397	(1966)
⁹⁵ Nb	30.0% Mo	1700-2100	R.A.	105.0	5.26	397	(1966)
⁹⁵ Nb	45.0% Mo	1700-2100	R.A.	94.0	0.27	397	(1966)
⁹⁵ Nb	11 at% Ti	1720-2160	A.R.G.	91.0	1.0	398	(1962)
⁹⁵ Nb	34 at% Ti	1490-1960	A.R.G.	73.0	0.15	398	(1962)
⁹⁵ Nb	47 at% Ti	1240-1790	A.R.G.	64.8	0.08	398	(1962)
⁹⁵ Nb	5% W	1600-2000		130	2334	285	(1967)
⁹⁵ Nb	10% W	1600-2000		117	164	285	(1967)
⁹⁵ Nb	30% W	1600-2000		85	2.57×10^{-2}	285	(1967)

PLATINUM

⁶⁴ Cu	25.5 at% Cu	1098-1385	S.S.	64.4	0.67	214	(1963)
⁶⁴ Pt	25.5 at% Cu	1140-1382	S.S.	60.3	0.022	214	(1963)

SILVER

¹¹⁰ Ag	2.05 at% Al	700-850	S.S.	42.5	0.25	306	(1955)
¹¹⁰ Ag	9.47 at% Al	700-850	S.S.	42.9	0.83	306	(1955)
¹¹⁰ Ag	14.1 at% Al	700-850	S.S.	41.2	0.73	306	(1955)
¹¹⁰ Ag	8 at% Au	654-945	S.S.	44.79	0.52	363	(1963)
¹¹⁰ Ag	17 at% Au	634-952	S.S.	44.05	0.32	363	(1963)
¹¹⁰ Ag	35 at% Au	635-956	S.S.	43.54	0.23	363	(1963)
¹¹⁰ Ag	38.1 wt% Au	656-910	S.S.	42.8	0.064	42	(1957)
¹¹⁰ Ag	50 at% Au	634-972	S.S.	43.11	0.19	363	(1963)
¹¹⁰ Ag	0.9 wt% Cd	500-800	R.A.	41.5	0.18	399	(1957)
¹¹⁰ Ag	1.09 wt% Cd	500-800	R.A.	39.9	0.13	399	(1957)
¹¹⁰ Ag	2.8 wt% Cd	500-800	R.A.	38.3	0.06	399	(1957)
¹¹⁰ Ag	5.13 wt% Cd	500-800	R.A.	37.0	0.03	399	(1957)
¹¹⁰ Ag	6.5 at% Cd	571-908	S.S.	42.61	0.306	400	(1958)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D_0 (cm ² /sec)	Reference No.	Year
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SILVER (continued)

¹¹⁰ Ag	13.6 at% Cd	558-850	S.S.	40.96	0.234	400	(1958)
¹¹⁰ Ag	22 wt% Cd			35.0	0.03	399	(1957)
¹¹⁰ Ag	28 at% Cd	505-740	S.S.	37.25	0.156	400	(1958)
¹¹⁰ Ag	0.17 wt% Cu	780-906	R.A.	45.2	0.65	126	(1957)
¹¹⁰ Ag	0.17 wt% Cu	690-780	R.A.	41.0	1.06	126	(1957)
¹¹⁰ Ag	0.84 wt% Cu	780-906	R.A.	45.2	0.68	126	(1957)
¹¹⁰ Ag	0.84 wt% Cu	690-780	R.A.	39.0	0.08	126	(1957)
¹¹⁰ Ag	1.68 wt% Cu	690-780	R.A.	40.6	0.07	126	(1957)
¹¹⁰ Ag	1.75 at% Cu	750-850	S.S.	44.8	0.66	306	(1955)
¹¹⁰ Ag	4.16 at% Cu	750-890	S.S.	46.6	1.84	306	(1955)
¹¹⁰ Ag	5.0 wt% Cu	700-840	R.A.	39.9	0.06	126	(1957)
¹¹⁰ Ag	6.56 at% Cu	700-840	S.S.	43.5	0.51	306	(1955)
¹¹⁰ Ag	8.15 wt% Cu	725-830	R.A.	38.3	0.04	126	(1957)
¹¹⁰ Ag	1.50 at% Ge	700-850	S.S.	44.0	0.55	306	(1955)
¹¹⁰ Ag	3.0 at% Ge	700-850	S.S.	45.3	1.59	306	(1955)
¹¹⁰ Ag	4.3 at% Ge	700-800	S.S.	44.5	1.89	306	(1955)
¹¹⁰ Ag	5.43 at% Ge	700-770	S.S.	44.2	2.18	306	(1955)
¹¹⁰ Ag	4.4 at% In	646-888	S.S.	42.67	0.358	400	(1958)
¹¹⁰ Ag	12.6 at% In	573-795	S.S.	37.40	0.116	400	(1958)
¹¹⁰ Ag	16.7 at% In	576-728	S.S.	36.27	0.183	400	(1958)
¹¹⁰ Ag	41.1 at% Mg	500-700	S.S.	33.2	0.095	385	(1964)
¹¹⁰ Ag	43.6 at% Mg	500-700	S.S.	35.3	0.15	385	(1964)
¹¹⁰ Ag	48.5 at% Mg	500-700	S.S.	39.5	0.37	385	(1964)
¹¹⁰ Ag	48.7 at% Mg	500-700	S.S.	39.7	0.39	385	(1964)
¹¹⁰ Ag	0.21 at% Pb	600-800	S.S.	42.5	0.22	306	(1955)
¹¹⁰ Ag	0.71 at% Pb	650-850	S.S.	44.7	0.89	306	(1955)
¹¹⁰ Ag	1.30 at% Pb	650-850	S.S.	43.5	0.70	306	(1955)
¹¹⁰ Ag	1.49 at% Pd	715-942	S.S.	43.7	0.239	401	(1957)
¹¹⁰ Ag	3.69 at% Pd	715-942	S.S.	43.7	0.194	401	(1957)
¹¹⁰ Ag	9.87 at% Pd	715-942	S.S.	43.7	0.122	401	(1957)
¹¹⁰ Ag	21.8 at% Pd	715-942	S.S.	43.7	0.043	401	(1957)
¹¹⁰ Ag	0.5 wt% Sb			39.6	0.304	402	(1956)
¹¹⁰ Ag	0.53 at% Sb	700-900	S.S.	43.5	0.382	403	(1955)
¹¹⁰ Ag	0.6 wt% Sb			39.6	0.1	399	(1957)
¹¹⁰ Ag	0.89 at% Sb	570-890	S.S.	42.6	0.302	403	(1955)
¹¹⁰ Ag	1.42 at% Sb	568-891	S.S.	42.0	0.275	403	(1955)
¹¹⁰ Ag	3.65 wt% Sb			27.8	1.2×10^{-3}	399	(1957)
¹¹⁰ Ag	5.2 wt% Sb			29.8	5.6×10^{-3}	399	(1957)
¹¹⁰ Ag	5.2 wt% Sb			28.8	7.4×10^{-3}	399	(1957)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
SILVER (continued)							
¹¹⁰ Ag	0.18 wt% Sn	830-900	R.A.	45.2	0.622	126	(1957)
¹¹⁰ Ag	0.18 wt% Sn	700-830	R.A.	41.7	0.132	126	(1957)
¹¹⁰ Ag	0.48 wt% Sn	700-850	R.A.	40.9	0.128	126	(1957)
¹¹⁰ Ag	0.91 wt% Sn	700-850	R.A.	40.5	0.17	126	(1957)
¹¹⁰ Ag	0.97 wt% Sn			39.4	0.28	399	(1957)
¹¹⁰ Ag	1.0 wt% Sn			39.8	0.47	402	(1956)
¹¹⁰ Ag	2.8 wt% Sn	700-850	R.A.	40.3	0.20	399	(1957)
¹¹⁰ Ag	4.6 wt% Sn	700-830	R.A.	39.7	0.225	399	(1957)
¹¹⁰ Ag	5.1 wt% Sn			38.6	0.2	399	(1957)
¹¹⁰ Ag	7.4 wt% Sn			37.0	0.16	399	(1957)
¹¹⁰ Ag	7.5 wt% Sn			37.3	0.56	402	(1956)
¹¹⁰ Ag	1.1 at% Tl	640-870	S.S.	43.5	0.42	302	(1958)
¹¹⁰ Ag	2.6 at% Tl	640-870	S.S.	44.9	0.35	302	(1958)
¹¹⁰ Ag	5.5 at% Tl	640-870	S.S.	37.6	0.10	302	(1958)
¹¹⁰ Ag	5 wt% Zn	640-925	S.S.	41.7	0.54	404	(1950)
¹¹⁰ Ag	30 at% Zn	773-971	S.S.	35.99	0.29	405	(1956)
¹¹⁵ Cd	6.5 at% Cd	571-922	S.S.	40.48	0.328	400	(1958)
¹¹⁵ Cd	13.6 at% Cd	522-867	S.S.	38.61	0.218	400	(1958)
¹¹⁵ Cd	27.5 at% Cd	526-795	S.S.	35.95	0.253	400	(1958)
¹¹⁴ In	4.7 at% In	573-795	S.S.	40.30	0.453	400	(1958)
¹¹⁴ In	12.4 at% In	573-888	S.S.	38.39	0.566	400	(1958)
¹¹⁴ In	16.6 at% In	474-729	S.S.	36.61	0.537	400	(1958)
²¹⁰ Pb	0.21 at% Pb	700-810	S.S.	42.5	0.22	406	(1952)
²¹⁰ Pb	0.25 at% Pb	700-850	S.S.	37.8	0.22	306	(1955)
²¹⁰ Pb	0.52 at% Pb	700-850	S.S.	38.7	0.38	306	(1955)
²¹⁰ Pb	0.71 at% Pb	700-810	S.S.	44.7	0.89	406	(1952)
²¹⁰ Pb	1.30 at% Pb	700-810	S.S.	43.5	0.70	406	(1952)
²¹⁰ Pb	1.32 at% Pb	700-850	S.S.	38.5	0.46	306	(1955)
¹²⁴ Sb	0.89 at% Sb	570-710	S.S.	38.3	0.17	403	(1955)
²⁰⁴ Tl	1.1 at% Tl	640-870	S.S.	40.4	0.72	302	(1958)
²⁰⁴ Tl	2.6 at% Tl	640-870	S.S.	39.4	0.57	302	(1958)
⁶⁵ Zn	30 at% Zn	768-969	S.S.	35.21	0.46	405	(1958)

TITANIUM

⁵ Cr	10 at% Cr	900-1200	A.R.G.	40.2	0.02	324	(1959)
⁵ Cr	18 at% Cr	900-1200	A.R.G.	44.5	0.09	324	(1959)
⁵ Fe	5 at% Fe	850-1250	A.R.G.	39.6	0.092	326	(1962)
⁵ Fe	10 at% Fe	850-1250	A.R.G.	48.6	2.14	326	(1962)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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TITANIUM (continued)

⁵⁵ Fe	15 at% Fe	850-1100	A.R.G.	58.1	52.5	326	(1962)
⁵⁵ Fe	5 at% Nb	850-1250	A.R.G.	33.1	7.9×10^{-3}	326	(1962)
⁵⁵ Fe	10 at% Nb	850-1300	A.R.G.	34.9	1.15×10^{-3}	326	(1962)
⁵⁵ Fe	15 at% Nb	850-1250	A.R.G.	35.0	7.9×10^{-3}	326	(1962)
⁹⁵ Nb	5 at% Fe	1000-1250	A.R.G.	34.9	1.82×10^{-4}	326	(1962)
⁹⁵ Nb	10 at% Fe	900-1250	A.R.G.	41.3	2.9×10^{-2}	326	(1962)
⁹⁵ Nb	15 at% Fe	900-1100	A.R.G.	56.0	9.9	326	(1962)
⁹⁵ Nb	5 at% Nb	950-1250	A.R.G.	29.9	1.2×10^{-4}	326	(1962)
⁹⁵ Nb	10 at% Nb	800-1250	A.R.G.	36.1	6.8×10^{-4}	326	(1962)
⁹⁵ Nb	15 at% Nb	880-1260	A.R.G.	39.3	1.5×10^{-3}	326	(1962)
⁴⁴ Ti	10 wt% V	900-1600	S.S.		Nonlinear	331	(1968)
⁴⁴ Ti	20 wt% V	900-1550	S.S.		Nonlinear	331	(1968)
⁴⁴ Ti	30 wt% V	950-1575	S.S.		Nonlinear	331	(1968)
⁴⁴ Ti	40 wt% V	1000-1575	S.S.		Nonlinear	331	(1968)
⁴⁸ V	10 wt% V	900-1575	S.S.		Nonlinear	331	(1968)
⁴⁸ V	20 wt% V	900-1575	S.S.		Nonlinear	331	(1968)
⁴⁸ V	30 wt% V	950-1575	S.S.		Nonlinear	331	(1968)
⁴⁸ V	40 wt% V	950-1575	S.S.		Nonlinear	331	(1968)
⁴⁸ V	50 wt% V	1050-1575	S.S.		Nonlinear	331	(1968)
⁹⁵ Nb	34 at% Nb	1060-1750	A.R.G.	50.5	9.6×10^{-3}	398	(1962)
⁴⁶ Sc	10 wt% Nb	1000-1200		15.77	—	407	(1957)
⁴⁶ Sc	20 wt% Nb	1000-1200		30.15	—	407	(1957)
⁴⁶ Sc	30 wt% Nb	1000-1200		31.50	—	407	(1957)
⁴⁶ Sc	40 wt% Nb	1000-1200		13.50	—	407	(1957)
⁴⁶ Sc	50 wt% Nb	1000-1200		4.77	—	407	(1957)

TUNGSTEN

⁹⁹ Mo	25 at% Mo	1900-2500	R.A.	83	0.18	388	(1963)
¹⁸⁶ Re	27% Re	2000-2400		94.0	9.2×10^{-3}	332	(1967)
¹⁸⁵ W	2 wt% Be	900-1200		33.8	1.18×10^{-3}	408	(1962)
¹⁸⁵ W	12 wt% Be	900-1200		66.95	2.36	408	(1962)
¹⁸⁵ W	24 wt% Be	900-1200		33.12	1.1×10^{-4}	408	(1962)
¹⁸⁵ W	25 at% Mo	2100-2600	R.A.	116	26	389	(1963)

URANIUM

²³⁵ U	4 wt% Mo	800-1040	R.A.	33.0	2.5×10^{-3}	409	(1961)
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Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D_0 (cm ² /sec)	Reference No.	Year
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URANIUM (continued)

²³⁵ U	4 wt% Nb	800-1040	R.A.	28.2	1.66×10^{-4}	409	(1961)
²³⁵ U	4 wt% Zr	800-1040	R.A.	22.0	1.26×10^{-4}	409	(1961)

VANADIUM

⁴⁴ Ti	10 wt%	1150-1750	S.S.		Nonlinear	331	(1968)
⁴⁴ Ti	20 wt%	1100-1670	S.S.		Nonlinear	331	(1968)
⁴⁴ Ti	30 wt%	1100-1650	S.S.		Nonlinear	331	(1968)
⁴⁴ Ti	40 wt%	1000-1600	S.S.		Nonlinear	331	(1968)
⁴⁸ V	10 wt%	1150-1750	S.S.		Nonlinear	331	(1968)
⁴⁸ V	20 wt%	1150-1650	S.S.		Nonlinear	331	(1968)
⁴⁸ V	30 wt%	1100-1600	S.S.		Nonlinear	331	(1968)
⁴⁸ V	40 wt%	1050-1570	S.S.		Nonlinear	331	(1968)

ZINC

⁶⁵ Zn	0.57 wt% Ag, c,S	345-420		21.95	0.14	410	(1967)
⁶⁵ Zn	0.57 wt% Ag, ⊥c,S	345-420		23.12	0.22	410	(1967)
⁶⁵ Zn	1.4 wt% Ag, c,S	345-420		22.07	0.17	410	(1967)
⁶⁵ Zn	1.4 wt% Ag, ⊥c,S	345-420		23.13	0.26	410	(1967)
⁶⁵ Zn	0.5 wt% Al, c		R.A.	19.0	1.0×10^{-2}	411	(1957)
⁶⁵ Zn	0.5 wt% Al, ⊥c		R.A.	26.0	1.56	411	(1957)
⁶⁵ Zn	37.1 at% Al	325-405	S.S.	20.0	0.012	173	(1959)
⁶⁵ Zn	0.5 wt% Cu, c		R.A.	19.5	3.1×10^{-2}	411	(1957)
⁶⁵ Zn	0.5 wt% Cu, ⊥c		R.A.	26.0	3.47	411	(1957)
⁶⁵ Zn	1 wt% Cu, c		R.A.	19.5	4.0×10^{-2}	411	(1957)
⁶⁵ Zn	1 at% Cu, ⊥c		R.A.	25.5	4.4	411	(1957)

ZIRCONIUM

¹¹³ Sn	0.7 wt% Sn	1000-1250	R.A.	43	2×10^{-2}	178	(1959)
¹¹³ Sn	3.3 wt% Sn	1000-1250	R.A.	50	0.2	178	(1959)
¹¹³ Sn	5.6 wt% Sn	1000-1250	R.A.	52	0.4	178	(1959)
⁹⁵ Zr	1.33 wt% Nb	900-1200	R.A.	33	3×10^{-4}	346	(1960)
	0.7 wt% Ta						
⁹⁵ Zr	2 wt% Nb	900-1200	R.A.	31	1.5×10^{-4}	346	(1960)
⁹⁵ Zr	5 wt% Nb	900-1200	R.A.	33	3×10^{-4}	346	(1960)
⁹⁵ Zr	10 wt% Nb	900-1200	R.A.	35	4×10^{-4}	346	(1960)

Solute	Composition	Temper- ature range (°C)	Form of analy- sis	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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ZIRCONIUM (continued)

⁹⁵ Zr	0.7 wt% Sn	1000-1250	R.A.	36	2×10^{-3}	412	(1959)
⁹⁵ Zr	1.3 wt% Sn	740-827	R.A.	62	5.0	412	(1959)
⁹⁵ Zr	2.39 wt% Sn	740-827	R.A.	75	2100	412	(1959)
⁹⁵ Zr	3.3 wt% Sn	1000-1250	R.A.	39	3×10^{-3}	178	(1959)
⁹⁵ Zr	3.54 wt% Sn	740-827	R.A.	64.0	10	412	(1959)
⁹⁵ Zr	5.6 wt% Sn	1000-1250	R.A.	50	0.2	178	(1959)
⁹⁵ Zr	2 wt% Ta	900-1200	R.A.	26.5	3×10^{-5}	344	(1960)
⁹⁵ Zr	5 wt% Ta	900-1200	R.A.	28.0	6×10^{-5}	344	(1960)
⁹⁵ Zr	10 wt% Ta	900-1200	R.A.	30.5	1.5×10^{-4}	344	(1960)

Part IV

Self- and Impurity Diffusion in Simple Metal Oxides

Tracer	Material	Temper- ature range (°C)	Activation energy, Q (kcal/mole)	Frequency factor, D_0 (cm ² /sec)	Reference No.	Year
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ALUMINUM OXIDE, Al₂O₃

²⁶ Al	P 99.9	1670-1905	114.0	28	413	(1962)
²⁴¹ Am	P 99.9	1200-1430	135.0	4.94×10^6	414	(1968)
⁵⁹ Fe	P	900-1200 ***	82.0 ***	1.13	415	(1958)
⁵⁹ Fe	P 99.5	900-1100	27.0	9.18×10^{-8}	416	(1958)
¹⁴⁷ Pt	P	1350-1540	157	1.18×10^8	417	(1965)
²³⁹ Pu	P 99.9	1200-1450	142.2	1.54×10^8	414	(1968)

BARIUM OXIDE, BaO

¹⁴⁰ Ba	S	1080-1250	253	10^{29}	418	(1952)
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BERYLLIUM OXIDE, BeO

⁷ Be	P 99.97	1725-2000	36.15	1.1×10^{-6}	419	(1961)
⁷ Be	P 99.97	1550-1725	91.9	1.37	419	(1961)
⁷ Be	P 99.6	1730-1930	66.1	6.14×10^{-2}	420	(1964)
⁷ Be	P 99.6	1570-1730	111.6	5560	420	(1964)
⁷ Be	S 99.99	1760-2000	64	1.27×10^{-3}	420	(1964)
⁷ Be	S 99.99	1490-1720	36	1.23×10^{-6}	420	(1964)
⁷ Be	P 99.97	1500-1725	92.0	1.35	420	(1964)
⁷ Be	P 99.97	1760-2000	36.0	1.07×10^{-6}	420	(1964)
⁷ Be	P 99.9	1150-1800	62.5	2.49×10^{-3}	421	(1964)
⁷ Be	S ⊥ c, c	1500-2000	53.4	5.8×10^{-5}	422	(1966)
⁷ Be	P	1100-1800	63.0	3.2×10^{-3}	423	(1966)

Tracer	Material	Temper- ature range (°C)	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Reference Year
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BISMUTH OXIDE, Bi₂O₃

²¹⁰ Bi	P	600-710	20.7	4.29×10^{-6}	424	(1963)
²¹⁰ Bi	P	710-780	66.0	0.45	424	(1963)

CALCIUM OXIDE, CaO

⁴⁵ Ca	P	900-1400	81.0	0.4	425	(1952)
⁴⁵ Ca	S	1000-1400	34.6	8.75×10^{-8}	426	(1967)

CHROMIUM OXIDE, Cr₂O₃

⁵¹ Cr	P	1000-1350	100	4000	427	(1956)
⁵¹ Cr	P	900-1100	22	4.29×10^{-8}	415	(1958)
⁵¹ Cr	P 99.0	1100-1550	61.0	0.137	428	(1961)
⁵⁹ Fe	P	900-1100	44	4.95×10^{-6}	415	(1958)

COBALT OXIDE, CoO

⁶⁰ Co	P 99.99	800-1350	34.5	2.15×10^{-3}	429	(1954)
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COPPER OXIDE, Cu₂O

¹¹⁰ Ag	S	800-1050 ***	27.63 ***	6×10^{-3}	430	(1960)
¹¹⁰ Ag	P	700-800	14.0	3.8×10^{-3}	430	(1960)
¹¹⁰ Ag	P	800-1000	28.27	5.6×10^{-3}	430	(1960)
⁶⁴ Cu	P	800-1050	36.1	4.36×10^{-2}	431	(1951)
¹¹⁴ In	S	800-1050	33.5	160	432	(1962)
¹¹⁴ In	P	600-780	12.4	2.4×10^{-8}	426	(1962)
¹¹⁴ In	P	780-1050	24.8	8.9×10^{-6}	432	(1962)
⁶⁵ Zn	P	600-900	9.0	1.7×10^{-8}	433	(1960)
⁶⁵ Zn	P	900-1050	30.9	5.2×10^{-4}	433	(1960)

IRON OXIDE, FeO

⁵⁹ Fe	P	700-1000	29.7	0.118	434	(1953)
⁵⁹ Fe	P	700-1000	30.2	0.014	429	(1954)

Tracer	Material	Temper- ature range (°C)	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Reference Year
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IRON OXIDE, Fe₂O₃

⁵⁹ Fe	P	760-1300	112	4×10^4	425	(1952)
⁵⁹ Fe	P	950-1050	100.2	1.3×10^6	426	(1962)

IRON OXIDE, Fe₃O₄

⁵⁹ Fe	P	750-1000	55.0	5.2	424	(1953)
⁵⁹ Fe	P	1000-1220	112	4×10^{-5}	424	(1953)
⁵⁹ Fe	P	770-1200	53.9	0.25	427	(1958)
⁵⁹ Fe	S	850-1075	84.0	6×10^5	428	(1960)
⁵⁹ Fe	P	850-1075	74.7	104	428	(1960)

LEAD OXIDE, PbO

²¹² Pb	P	400-590	66	10^5	429	(1952)
²¹⁰ Pb	P	600-680	64	—	430	(1965)

MAGNESIUM OXIDE, MgO

¹³³ Ba	S	1000-1725	77.75	0.07	441	(1967)
⁷ Be	S 99.99	1000-1700	36.8	1.41×10^{-5}	442	(1966)
⁴⁵ Ca	S 99.99	900-1700	49.0	2.95×10^{-5}	443	(1966)
Co	S	1000-1800	49.4	5.78×10^{-5}	444	(1962)
Fe	S	1050-1720	41.6	8.83×10^{-5}	444	(1962)
²⁸ Mg	S	1400-1600	79.0	0.249	445	(1957)
⁶³ Ni	P	1000-1800	48.3	1.8×10^{-5}	446	(1961)

NICKEL OXIDE, NiO

⁶³ Ni	P	900-1000	55	0.041	447	(1951)
⁶³ Ni	P	1140-1400	119.5	2.8×10^6	448	(1956)
⁶³ Ni	S	1000-1400	44.2	3.9×10^{-4}	449	(1957)
⁶³ Ni	P	1000-1400	44.2	5.0×10^{-4}	449	(1957)
⁶³ Ni	S,P	700-1400	56.0	1.7×10^{-2}	450	(1957)
⁶³ Ni	S	1300-1700	53.5	8.01×10^{-4}	451	(1960)
⁶³ Ni	S	1000-1400	45.6	1.83×10^{-3}	452	(1962)
⁶³ Ni	P 99.99	1200-1400	48.4	4.8×10^{-4}	453	(1962)

Tracer	Material	Temper- ature range (°C)	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Year
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NIOBIUM OXIDE, Nb₂O₅

⁹⁵ Nb	P	500-900	28.2	0.38	454	(1962)
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TIN OXIDE, SnO₂

¹¹³ Sn	P	1000-1260	118.7	10 ⁶	455	(1965)
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TITANIUM OXIDE, TiO₂

⁵⁹ Fe	P	770-1000	55.4	0.192	416	(1958)
⁵⁹ Fe	P	770-1000	55.0	0.0198	416	(1958)

THORIUM OXIDE, ThO₂

²³³ Pa		1800-2000	75.4	2.91 × 10 ⁻⁵	456	(1968)
²³⁰ Th		1600-2100	58.8	1.25 × 10 ⁻⁷	457	(1968)
²³⁷ U		1800-2000	76.4	1.10 × 10 ⁻⁴	458	(1968)

URANIUM OXIDE, UO₂

²⁴¹ Am	P	1200-1500	92.0	0.03	459	(1965)
²³⁷ Np	P	1200-1500	109.0	2.9	459	(1965)
Pa	P	1200-1500	107.6	2.5	459	(1965)
¹⁴⁷ Pm	P	1120-1410	56.8	3.5 × 10 ⁻⁶	460	(1961)
²³⁹ Pu	P	1200-1500	97.3	0.34	459	(1965)
Th	P	1200-1500	98	0.16	459	(1965)
²³³ U	P	1450-1785	88	4.3 × 10 ⁻⁴	461	(1961)
²³³ U	P	1300-1600	104.6	0.23	462	(1961)
²³³ U	P	1200-1500	104.0	0.9	459	(1965)
²³³ U	S,P	1450-1700	108.0	1.2	463	(1965)
²³³ U	P	1900-2150	72.7	5.82 × 10 ⁻⁵	464	(1966)
⁹¹ Y	P	1150-1450	46.4	6.8 × 10 ⁻⁸	461	(1961)
⁹⁵ Zr	P	1120-1419	59.2	1.6 × 10 ⁻⁶	461	(1961)

YTTRIUM OXIDE, Y₂O₃

⁹¹ Y	P	1400-1800	43.9	2.41 × 10 ⁻⁴	465	(1963)
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Tracer	Material	Temper- ature range (°C)	Activation energy, Q (kcal/mole)	Frequency factor, D ₀ (cm ² /sec)	Reference No.	Reference Year
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ZINC OXIDE, ZnO

⁶⁵ Zn	P	800-1330	74.0	1.3	466	(1952)
⁶⁵ Zn	S	850-940	20.0	3×10^{-9}	467	(1955)
⁶⁵ Zn	S	900-1025	73.0	4.8	468	(1955)
⁶⁵ Zn	S,P	910-1170	74.0	30	469	(1956)
⁶⁵ Zn	P	800-1300	89.0	0.1	470	(1957)
⁶⁵ Zn	P	1000-1200	44.0	1.3×10^{-5}	471	(1959)
⁶⁵ Zn	P	800-840	73.0	10	472	(1960)
⁶⁵ Zn	S	720-780	25.0	3×10^{-7}	473	(1961)

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Author Index

- Aaronson, H. I. 385
Abranyan, E. A. 33
Adda, Y. 2, 6, 158, 159, 161, 180, 191,
192, 409
Agarwala, R. P. 24, 165, 183, 185, 186,
187, 188, 189, 241, 273, 341, 343
Airoldi, G. 127
Akerstrom, A. 425, 427, 448, 450
Alcock, C. B. 463
Allison, H. W. 281
Amonenko, V. M. 61
Anand, M. S. 165, 183, 185, 187, 189,
241, 273, 341
Andelin, R. L. 156
Andriewski, A. I. 430
Andriewski, R. A. 346, 366
Andruszkiewicz, J. 147, 321
Anthony, T. R. 231, 254, 318
Anusavice, K. J. 212, 219
Archibald, T. F. 46
Arkhipova, N. K. 228
Arzhany, P. M. 408
Asaro, F. 200
Ascoli, A. 255
Askill, J. 19, 80, 263, 268, 287, 328
Aucouturier, M. 187, 240
Austern, A. B. 461
Austerman, S. D. 419, 420, 422
Austrumdal, S. 425
Averbach, B. L. 24, 40, 83, 173, 244,
300
Azzam, A. 38
Babad-Zachryapin, A. A. 436
Badrinarayanan, S. 184
Bakalar, I. D. 53
Baker, H. 94
Banks, F. R. 166, 167
Barbouth, N. 308
Barr, L. W. 104, 136, 215, 288
Bass, R. F. 227, 363
Batra, A. P. 338, 340
Belle, J. 461
Belokurova, I. N. 415
Bendazzoli, M. 409
Benediktova, G. P. 264
Berand, M. F. 465
Berkowitz, A. E. 350
Beyeler, M. 2
Bikov, V. N. 81, 176, 261, 267, 345,
412
Birchenall, C. E. 21, 23, 42, 51, 58,
64, 69, 272, 374, 434
Blinkin, A. M. 61, 342, 372
Blood, C. M. 423
Boas, W. 144
Bobleter, D. 414, 417
Bochvar, A. A. 160
Bogdanov, N. A. 16, 67
Bohmer, H. 349
Bokshtein, S. Z. 12, 15, 65, 78, 126,
265, 279, 329, 379
Boltaks, B. I. 108, 224, 293
Bonzel, H. P. 209, 211, 294
Borg, R. J. 58, 70, 193, 232, 383

- Borisov, V. T. 56, 243
 Borisov, Y. V. 77, 179, 344
 Bronfin, M. B. 78, 265
 Brown, S. 451
 Bruggeman, G. 247
 Buffington, F. S. 53, 59
 Bugai, A. A. 221
 Cabane, J. 308
 Calais, D. 107
 Carter, R. E. 429
 Castleman, L. S. 96
 Catalano, E. 135
 Cattaneo, F. 103
 Chatterjee, A. 270
 Cheek, C. 375
 Chemomorchenko, S. G. 154, 275
 Chinaev, A. I. 274
 Choi, J. S. 451, 452
 Chomba, W. 147, 321
 Chorna, L. F. 332
 Cohen, M. 24, 40, 44, 53, 59, 83, 173,
 186, 244, 300
 Cordes, H. 5
 Coston, C. 149
 Cramer, E. M. 106
 Cuddeback, R. B. 137
 Dahn, E. 238
 Danneberg, W. 79, 155
 Dasgupta, A. K. 424, 440
 De Bruin, H. J. 421, 423
 De Castro, R. 197
 DeHoff, R. T. 212, 219
 Dekhtyar, I. Y. 355, 356, 367, 390,
 394
 DeReca, N. E. W. 153, 395
 Dickey, J. E. 49
 Dolidze, V. M. 172
 Domain, H. A. 385
 Dorn, J. E. 87, 88, 92
 Douglass, D. L. 454
 Drickamer, H. G. 48, 137, 170
 Droniuk, M. I. 222, 432
 Dubinin, G. N. 264
 Duhl, D. 44
 Dupony, J. M. 6, 191, 192
 Dupuy, M. 107
 Dyment, S. F. 151
 Dyson, B. F. 254, 318, 319
 Dzantiev, B. G. 274
 Eager, R. L. 139
 Ebeling, R. 360
 Ebisuzaki, J. 451
 Eckert, R. E. 28, 360
 Edwards, G. R. 105
 Ee-Tsin, D. 433
 Emelyanov, V. S. 175
 Enqvist, O. 455
 Estulin, G. V. 393
 Evstyukhin, A. I. 344
 Fabian, D. J. 270
 Fairfield, J. M. 110
 Faulkenberry, B. H. 214
 Federer, J. I. 182, 348
 Federov, G. R. 90, 175, 178, 234, 271,
 391, 392
 Fedoseeva, N. P. 339
 Fensham, P. J. 144, 145
 Fiedler, W. 414, 417
 Finkelstein, B. N. 117
 Fock, M. 143
 Flubacher, P. 177
 Frantsevich, I. N. 387
 Furaya, H. 458, 464
 Gardner, A. B. 227, 363
 Gatos, H. C. 38, 39
 Geld, P. V. 99, 282, 285, 397
 Geodakyan, V. A. 55, 118
 Germagndi, E. 103, 127
 Gertsriken, S. D. 66, 119, 125, 128, 355,
 356, 367, 390, 394, 399, 402, 404
 Ghate, P. B. 3, 337
 Ghoshtagore, R. N. 138
 Gibbs, G. B. 325, 328, 398
 Gilder, H. M. 45
 Godin, Yu. G. 179, 346
 Golikov, V. M. 56, 243
 Gondolf, E. G. 14

- Gorbukov, N. S. 436
Gorbunova, K. M. 416
Grabtchak, V. P. 224
Graham, D. 60, 97, 262, 325, 398
Grasso, F. 103, 417
Graves, J. N. 194
Grigorev, G. V. 7, 249
Grinevich, G. P. 278, 280
Grum-Grzhimailo, N. V. 407
Gruzin, P. L. 13, 22, 54, 63, 77, 140,
175, 179, 233, 234, 236, 237, 245,
250, 271, 346, 357, 373, 377, 380,
391
Gulyakin, V. D. 178
Gunther-Mohr, G. R. 36
Gupta, D. 365
Gupta, Y. P. 426
Guy, A. G. 219

Hagel, W. C. 18, 428
Handler, G. S. 73, 101
Harding, B. C. 441, 442
Harkness, A. L. 162
Hassner, A. 4, 25, 148, 238
Hawkins, R. J. 463
Hevesy, G. von 71
Heumann, T. 349
Hilliard, J. E. 173
Hills, A. W. D. 463
Himmel, L. 434
Hino, J. 218
Hirai, T. 464
Hirano, K. 24, 44, 59, 186, 244, 305
Hirone, T. 201, 299, 304, 358
Hirsch, H. N. 121
Hirschwald, W. 10, 157
Hoffman, R. E. 82, 113, 302, 306, 406
Holloman, J. H. 305
Homan, C. G. 235
Huntington, H. B. 3, 8, 168, 169, 338,
342, 364
Huntz, A. M. 240

Ibraginov, N. I. 317
Ignatkov, V. D. 225, 415
Ihara, S. 283, 315

Ikushima, A. 206, 208
Imai, Y. 132
Inman, M. C. 215, 361
Isadzanov, E. A. 368
Ivanchev, N. P. 351
Ivanov, I. G. 93, 277, 372
Ivanov, L. I. 17, 33, 351
Ivantsov, I. G. 61
Izvekov, V. I. 416, 436, 437

Jagiela, J. 50
James, D. W. 62, 68
Jaumot, F. E. 20, 171, 297, 301, 312,
350
Johnson, R. D. 115, 200, 214
Johnson, W. A. 111
Johnston, D. 361

Kahn, M. 156
Kaigorodov, V. N. 133, 303, 311
Kalinovich, D. F. 95, 314, 386, 387,
389
Kamardin, F. 275
Kamel, R. 9
Kanter, M. A. 11
Kapman, M. G. 264
Karnik, F. 252, 370
Kazakova, V. A. 379
Keil, A. 71
Kennedy, J. 296
Kidson, G. V. 102, 181, 256
Kieszniewski, J. 248
Kim, K. 5
King, W. H. 46
Kingery, W. D. 413
Kirianenko, A. 158, 159, 161, 409
Kishkin, S. T. 12, 15, 65, 265, 279, 329,
379
Klokholt, E. 146
Klotsman, S. M. 133, 228, 314, 323, 359,
386, 387, 389, 438, 453
Komuta, S. 217
Komonyuk, I. F. 198
Kornev, Yu. V. 373
Kosenko, V. E. 220, 221, 225
Kostogonov, V. G. 233

- Kovalchuk, V. S. 216
 Kovenskii, I. I. 95, 196
 Krautz, E. 79
 Krikorian, O. 70
 Kriukov, S. N. 116
 Kruegar, H. 121
 Kucera, J. 131
 Kuliev, A. A. 226, 289, 316, 317
 Kumok, L. M. 367, 394
 Kunitake, T. 352
 Kunitomi, N. 201, 217, 358
 Kupalova, I. K. 384
 Kuper, A. 30, 362
 Kurdyumov, G. V. 373
 Kurtz, A. D. 39, 40
 Kuznetsova, E. V. 380
 Kuznetsova, V. G. 160
 Kuzmenko, P. P. 216, 278, 280
 LaChapelle, T. J. 291
 Lacombe, P. 57, 197, 240, 276
 Lai, D. Y. F. 70, 232, 383
 Landers, J. J. 451
 Lange, W. 4, 25, 148, 238, 382
 Langmuir, D. B. 139
 Larikov, L. M. 269, 332
 Lazarus, D. 45, 114, 307, 309, 362,
 365, 405
 Leak, G. M. 62, 68, 381
 LeClaire, A. D. 43, 230
 Letaw, H. 30, 34, 35
 Leymonie, C. 57
 Libanati, C. M. 151, 153
 Lieberman, D. S. 365
 Lindemer, T. B. 219
 Lindner, R. 252, 370, 425, 427, 435,
 439, 445, 448, 450, 455, 459, 460,
 462, 466
 Linnenbom, V. 375
 Litvin, D. F. 236, 250
 Liu, T. 170
 Lloyd, L. T. 162
 Logan, S. R. 451
 Lonsdale, H. K. 194
 Lowenberg, L. 259
 Lyubimov, V. D. 99, 282, 285, 397
 Lundy, T. S. 1, 47, 98, 141, 152, 163,
 182, 330, 348
 Lyashenko, V. S. 176, 412
 MacEwan, J. R. 85, 86
 MacEwan, J. U. 85, 86
 Machliet, C. A. 203
 Madatova, E. G. 367
 Maekawa, S. 295
 Mahmoud, K. A. 9
 Maier, M. S. 28
 Mairy, C. 158, 159
 Makin, S. M. 43
 Mallard, W. C. 227, 363
 Manning, J. 370
 Martin, A. B. 115, 200
 Masters, B. J. 110
 Mathers, H. B. 184
 Mathie, J. 6
 Matveeva, M. P. 17
 May, S. 180
 McGurn, J. 181
 McHargue, C. J. 98, 163, 331
 McKay, R. A. C. 37
 McKenzie, D. R. 193
 McNamara, P. 463
 Mead, H. W. 23, 42, 64, 374
 Meakin, J. D. 146
 Mehl, R. F. 51, 52, 434
 Mercer, W. L. 31, 361
 Meshcheryakov, G. Ya. 346, 366
 Meshkov, V. I. 140
 Messner, N. 87
 Mikhalev, V. S. 390
 Miller, J. W. 257
 Miller, N. C. 364
 Miller, P. H. 167
 Miller, R. C. 222
 Mills, B. 381
 Mirskii, L. M. 379
 Miselynuk, E. G. 221
 Mitchell, D. 451
 Miura, S. 304
 Miyake, M. 283, 315
 Miyazaki, T. 132
 Monma, K. 32, 210

- Moore, G. E. 281
Moore, W. J. 431, 447, 449, 451, 452,
 468, 471
Moroz, L. M. 12, 15, 65
Morozov, V. A. 17
Mortlock, A. J. 230, 324, 442, 443
Mote, J. 88
Movlanov, Sh. 316
Mundy, J. N. 104, 136, 259, 288
Munnich, F. 467
Mural, V. V. 245
Murarka, S. P. 165, 185, 187, 189, 273,
 341
Murdock, J. F. 1, 152, 330, 331
- Nachtrieb, N. H. 73, 74, 101, 124, 135,
 149, 258, 401
Naik, M. C. 191, 192
Nakonechnikov, A. Y. 261, 267
Naskidashvili, I. A. 172, 411
Nasledov, D. N. 289
Neiman, M. B. 274, 378
Nelson, H. R. 28
Nerses, V. 364
Neumann, G. M. 157
Newman, R. C. 292
Nix, F. C. 20, 27, 350
Norden-Ott, A. 260
Noskov, B. M. 357, 377
- Oikawa, H. 32, 210, 212
O'Keefe, M. 451
Okkerse, B. 41, 72
Ostrovskii, L. E. 216
Osvenskii, V. B. 329
Ott, A. 259, 260
Ouder, J. 308
Ovsienko, D. E. 190
- Paladino, A. E. 413
Palkar, G. D. 424, 440
Pampillo, C. 395
Panov, A. S. 266, 286
Parfitt, G. D. 445
Paul, A. R. 188, 343
- Pavlinov, L. V. 7, 13, 77, 81, 176, 249,
 261, 267, 327, 345, 347, 368, 412
Pavlyuchenko, M. M. 198
Pawel, R. E. 98, 141
Pawlicki, G. 50, 150
Paxton, H. W. 14, 195, 352, 369
P'dak, V. M. 222
Peart, R. F. 97, 109, 164, 326
Pelleg, J. 284
Peterson, N. L. 100, 174, 213, 262, 313,
 336
Petit, J. 124, 414
Pickering, M. E. 296
Pierce, C. B. 307
Pikus, F. W. 82
Pinajian, J. J. 212
Pinheiro, M. O. 197
Plachenov, B. T. 108
Platonov, P. A. 233
Pleteneva, N. A. 339
Polikarpov, Y. A. 234, 271
Portnoy, W. M. 34, 35
Prokoshkin, D. A. 17, 408
Pryanishnikov, M. P. 66, 119, 371
- Rabovskii, Ya. A. 303, 311
Rahan, J. J. 296
Raynor, C. L. 29
Redington, R. W. 416
Reimer, P. 134
Resing, H. A. 74, 258
Resnick, R. 96
Reynolds, J. E. 83
Rhines, F. W. 75
Richardson, F. D. 429
Roberts, J. 247
Roberts, J. P. 470
Rollin, B. V. 26
Roslowski, J. R. 3, 336
Ross, R. 102
Rothman, S. J. 162, 174, 313, 333, 334,
 335
Rousse, J. 29
Rowe, A. H. 43, 230
Rozycki, Z. 320

- Ruder, R. C. 21, 272
 Rungis, J. 443
 Ryabova, G. G. 175
 Rybak, V. M. 432
 Sakamoto, M. 201, 202, 358
 Sandulova, A. V. 222, 430, 432, 433
 Sano, T. 283, 315
 Santoro, C. J. 410
 Sata, K. 239
 Savitskii, A. V. 129, 130
 Sawatskii, A. 297, 301, 312, 322
 Schenck, H. 382
 Schmitz, F. 143, 459, 462
 Schoen, A. 400
 Schroedter, W. 10
 Secco, E. A.
 Seibel, G. 246, 253
 Seith, W. 71
 Selikson, B. 431
 Sergeev, V. S. 160
 Sevastianov, U. G. 7
 Seybolt, A. U. 428
 Shachtachinskii, M. G. 317
 Shcherbai, K. S. 432
 Shcherbedinskii, G. V. 242, 243, 264
 Shewmon, P. G. 76
 Shim, M. T. 449
 Shinyaev, A. Y. 89, 353, 354, 378, 392,
 396
 Shirn, G. A. 8, 142, 168, 169
 Shirokov, V. I. 377
 Shockey, W. 27
 Shumilov, M. A. 234
 Shuppe, G. N. 275
 Shuttleworth, R. 361
 Shveykin, G. P. 99, 285, 397
 Sinnott, M. J. 84, 207
 Sitharamarao, D. N. 424, 440
 Skatskii, V. I. 275
 Slifkin, L. 30, 34, 35, 114, 227, 298,
 309, 310, 363
 Smirnov, E. A. 33, 90
 Smirnov, V. P. 368
 Smith, A. F. 376
 Smith, F. A. 104, 136, 288
 Smith, F. M. 223
 Smith, R. L. 171
 Smolin, M. D. 95, 314, 386, 387, 388,
 389
 Sobaszek, A. 50, 320
 Son, P. 283, 315
 Sonder, E. 30, 120, 122, 310, 403
 Sozinov, I. I. 293
 Spicar, E. 469, 472, 473
 Staffansson, L. I. 69
 Stansbury, E. E. 152, 330
 Steigman, J. 27
 Struthers, J. D. 290
 Sutina, Ya. A. 285
 Suto, H. 32, 210
 Suzuoka, T. 251, 304
 Tagirov, V. I. 226
 Talinskii, V. K. 303, 311
 Tate, R. E. 105, 106
 Tetenbaum, M. 375
 Thomassen, L. 29
 Timofeev, A. N. 133, 228, 438, 453
 Tomilov, A. V. 242
 Tomizuka, C. T. 30, 114, 122, 199, 218,
 298, 309, 310, 362, 405
 Tomlin, D. H. 19, 60, 80, 97, 262, 324,
 325, 326, 398
 Tomono, Y. 204
 Trakhtenberg, I. Sh. 133, 228, 438, 453
 Tsitsiliano, D. D. 128, 402
 Turnbull, D. 112, 113, 231, 252, 305, 306,
 318, 406
 Tyshkevich, V. M. 332
 Tyutyunnik, A. D. 13, 393
 Upthegrove, W. R. 84
 Vandyshев, B. A. 266, 286
 Vasilev, V. P. 123, 154, 275
 Vasilov, T. 444, 446
 Vel'mozhnyi, Z. Ya. 397
 Volkova, R. M. 408
 Vorobiov, V. V. 342
 Wagner, J. W. 422

- Wajda, E. S. 8, 168, 169
Wakefield, J. 292
Walker, G. K. 381
Ward, R. A. 82
Watson, G. M. 421, 423
Wazzam, A. R. 88, 91, 92
Wever, H. 360
Wehrenberg, J. 124, 399
Weil, J. A. 135
Wert, C. 218
Wevrick, L. J. 426
Wheeler, C. 470
Widner, H. 36
Wilcox, W. R. 291
Wilder, D. R. 465
Williams, E. L. 471
Winslow, F. R. 47, 98
Wolfe, J. R. 193
Wolfe, R. A. 195, 369
Wuensch, B. J. 444, 446
Yaffe, L. 85, 86
Yajima, S. 464
Yamaki, H. 201
Yamamoto, H. 299
Yamashchikova, A. I. 117
Yanitskaya, M. E. 126
Yatsenko, T. K. 125, 399
Yemelyanov, V. S. 344
Yolokoff, D. 180
Yukawa, S. 207
Yurkevich, M. I. 430
Zagryazkii, V. N. 346, 368
Zasimchuh, I. K. 190
Zemskii, S. V. 384
Zhomov, F. I. 90
Zhukhovitskii, A. A. 55, 78, 116, 118,
126

General Index

- Activation energy, 9, 15
Alloys, 24
Arrhenius equation, 9, 27
Autoradiography, 7, 15

Boundary conditions, 2

Coefficient of linear expansion, 22, 26
Compressibility, 22, 26
Concentration gradient, 1
Cracks, 11
Crowdion mechanism, 14, 15

Diffusion, 1, 15
Diffusion coefficient, 1, 9, 15, 26
Diffusion flux, 1
Dislocations, 11, 14, 15

Elastic moduli, 20, 23
Empirical relations, 19
Exchange mechanism, 12

Fick's first law, 1, 15
Fick's second law, 2, 15
Frequency factor, 9, 15, 26

Grain boundary diffusion, 11, 14, 15
Gruzin method, 5

Heat of fusion, 20, 22, 26
Impurity diffusion, 2, 24, 25
Interchange, 12, 15
Interstitial mechanism, 12, 15
Interstitialcy mechanism, 14, 16

Lattice diffusion, 11
Mechanisms of diffusion, 11
Melting point, 20, 21, 23, 26
Methods of analysis, 4

Photographic density, 8
Self-diffusion, 1, 2, 9, 16, 28
Semi-empirical relations, 19
Serial sectioning, 4, 16
Surface decrease, 6, 16
Surface diffusion, 11

Residual activity, 5, 16
Ring mechanism, 12

Temperature dependence, 9

Vacancy, 11, 16
Valence, 24, 26