AD

Water Facility

RSIC-604

DETERMINATION OF THE DIFFUSION COEFFICIENTS IN ALLOYS WITH SEVERAL PHASES

by

V. T. Borisov
V. M. Golikov
G. N. Dubinin

Izvestiya, Akademii Nauk, SSSR, Metallurgiya i Gornoe Delo,
No. 4, 147-152 (1964)

Translated from the Russian by Harry Brooks

October 1966

PRICE $

PRICE(S) $

Hard copy (HC) 3.00

[illegible] .65

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

REDSTONE SCIENTIFIC INFORMATION CENTER

REDSTONE ARSENAL, ALABAMA

JOINTLY SUPPORTED BY

U.S. ARMY MISSILE COMMAND

GEORGE C. MARSHALL SPACE FLIGHT CENTER

FACILITY FORM 602

N67 16502	
(ACCESSION NUMBER)	(THRU)
13	/
(PAGES)	(CODE)
TMX-59320	17
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

FORM AMSMI-R-78, 1 NOV 65

27 October 1966

RSIC-604

DETERMINATION OF THE DIFFUSION COEFFICIENTS IN ALLOYS WITH SEVERAL PHASES

by

V. T. Borisov
V. M. Golikov
G. N. Dubinin

Izvestiya, Akademii Nauk, SSSR, Metallurgiya i Gornoe Delo,
No. 4, 147-152 (1964)

Translated from the Russian by Harry Brooks

DISTRIBUTION OF THIS
DOCUMENT IS UNLIMITED

Translation Branch
Redstone Scientific Information Center
Research and Development Directorate
U. S. Army Missile Command
Redstone Arsenal, Alabama 35809

Along with such widely known forms of thermo-chemical processing of alloys as cementation, nitridation, and cyanidation, certain new processes have acquired wide application in recent years. These include such processes of diffusion saturation of the surface of alloys as saturation with metals (aluminizing, chromizing, molybdenumizing, etc.) and saturation with metalloids (boronizing and siliconizing).

The extensive industrial use being made of these processes is due to the high grade of physico-chemical properties acquired by products as a result of diffusion saturation of their surfaces by metals, metalloids, or their compounds. Diffusion saturation of the surface of alloys with metals and metalloids is not only an effective means but, in many cases, the only possible means for solving such modern technological problems as the protection of the surface of alloys from oxidation at high temperatures, increasing their durability and resistance to corrosion, providing special electrical and magnetic properties on the surface, etc.

Despite the availability of a fairly extensive literature devoted to the study of individual questions of diffusion saturation of the surfaces of alloys with metals and metalloids (see, for instance, the Literature Cited[1,2,3,4,5]), much less attention has been paid to calculating the diffusion constants in chemico-thermal processing.

The most thorough investigations in this area are referenced[1,6,7,11] in the Literature Cited*. At the same time, a study of the laws of the diffusion of various elements when they are used to saturate the surface of metals and alloys makes it possible not only to broaden our understanding of the nature of phase transformations taking place in alloys during their processing, but also makes it possible to compute correctly the production rate of the diffusion saturation of the surface of alloys by means of metals and metalloids. Such computations are of special interest in connection with the increased use, in production, of vapor, gas, and liquid methods of saturating the surface of alloys by metals and metalloids since they make it possible to intensify the saturation process.

The diffusion constants for alpha-phase chromium used for the chromizing of iron in a gas medium have already been computed by

---

*Given the framework of the present article, we are not citing here the extensive literature available on general questions of diffusion. This can be had, for instance, from the bibliography cited by Gertsriken and Dekhtyar[8].

Hoar and Groom[9] while the corresponding figures for a liquid medium are given by Campbell et al[10]. However, the authors of these papers in using the basic diffusion equation

$$\xi = 2\nu\sqrt{Dt}$$

(where ξ is the thickness of the diffusion layer; ν, a constant which depends on concentration and temperature; t, the duration of the diffusion) conditionally accepted the value of ν as being equal to 1. The computed values of D and Q then become approximately as follows:

$$D_{\alpha}^{1100^\circ} = 14.7 \cdot 10^{-10}\,\mathrm{cm^2/sec},$$

$$Q = 57\ \mathrm{Kcal/g \cdot at} \quad \text{(Hoar and Groom}^{9}\text{)},$$

$$D_{\alpha}^{1100^\circ} = 25.5 \cdot 10^{-10}\,\mathrm{cm^2/sec},$$

$$Q = 58\ \mathrm{Kcal/g \cdot at} \quad \text{(Campbell et al}^{10}\text{)}.$$

Buckle[11], using a method he had worked out for computing the diffusion coefficient for a multiphase layer formed on the surface of a sample, utilized the data given by Galmiche[12] on the diffusion-chroming of iron in a gas medium, and computed the diffusion constant for the alpha- and gamma-phase of chromium, taking into account the concentration factor of the parameter of ν.

$$D_{\alpha}^{1100^\circ} = 50 \cdot 10^{-10}\,\mathrm{cm^2/sec},$$

$$D_{\gamma}^{1100^\circ} = 0.92 \cdot 10^{-10}\,\mathrm{cm^2/sec}.$$

The present article examines the method for determining the diffusion coefficient in cases when a multiphase diffusion layer is formed on the surface zone of the metal.

The calculation of the coefficient of diffusion was made by using as example the chromium-saturation of iron in a gas phase.

Figure 1 presents schematically the distribution of concentration in a sample when, in the process of diffusion, several different phases are formed, $k = 1, 2, \ldots n + 1$.

In determining the diffusion coefficients for various phases D_k in the form of a concentration curve, we shall assume that the coefficients are constants within the limits of their respective phase and that the concentration on the outer surface of sample z_0 is not dependent on time.

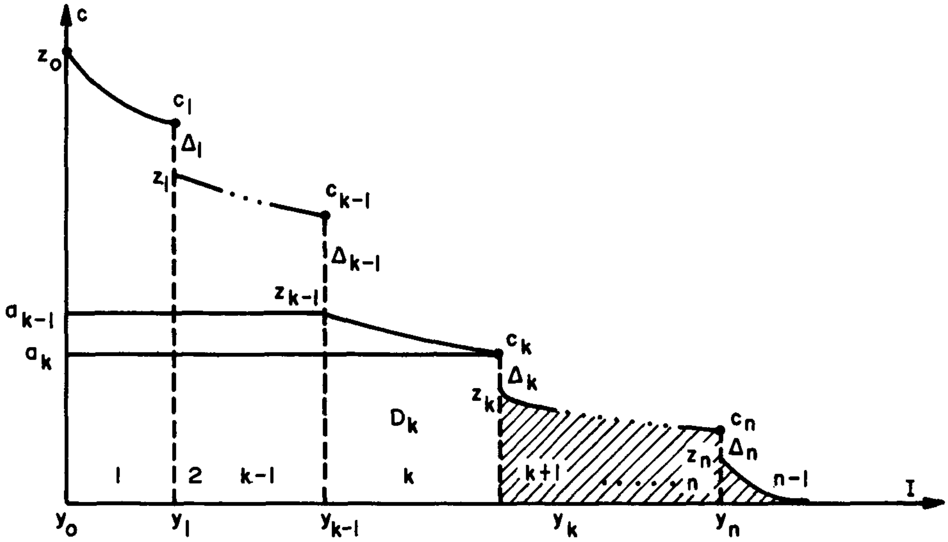

Figure 1. Schematic Distribution of Concentration of Diffusion in a Heterophase Medium

Concentrations z_{k-1} and c_k, on the phase boundaries, are also assumed to be known and not to be a function of time. These values can be determined in a diagram giving the state of the respective system if one assumes that the shift of phase boundaries occurs quasi-statically. Generally, the values of c_k, z_k, and values of the jumps or discontinuities $\Delta_k = c_k - z_k$ are determined experimentally. Thus, the concentration $c^k(x, t)$ within phase k satisfies the following equations:

$$\left.\begin{aligned} D_k c^k_{xx}(x, t) &= c^k_t(x, t) \\ y_{k-1}(t) \leqslant{} & x < y_k(t) \\ c^k\left[y_{k-1}(t), t\right] &= z_{k-1} \\ c^k\left[y_k(t), t\right] &= c_k \end{aligned}\right\} \qquad (1)$$

for which the following expression is the solution

$$c^k(x, t) = A_k \operatorname{erf}(x/2\sqrt{D_k t}) + B_k \qquad (2)$$

where

$$A_k = \frac{\delta_k}{\operatorname{erf}(b_{k-1}/\sqrt{D_k}) - \operatorname{erf}(b_k/\sqrt{D_k})},$$

$$B_k = \frac{c_k \operatorname{erf}(b_{k-1}/\sqrt{D_k}) - z_{k-1} \operatorname{erf}(b_k/\sqrt{D_k})}{\operatorname{erf}(b_{k-1}/\sqrt{D_k}) - \operatorname{erf}(b_k/\sqrt{D_k})} ,$$

$$\delta_k = z_{k-1} - c_k .$$

Within the limitations outlined above and in the presence of natural initial conditions $c^{n+1}(x, 0) = 0$, the boundaries separating the different phases shift—as we know—during the process of diffusion, according to the parabolic law.

It is, therefore, assumed in equations (1) and (2) that

$$y_k(t) = 2b_k\sqrt{t} . \tag{3}$$

The index k in equations (1) to (3) assumes the value of 1, 2, . . . n + 1, with $y_0(t) = 0$ ($b_0 = 0$); while when $k = n + 1$, we must regard $y_{n+1}(t) = \infty$ ($b_{n+1} = \infty$), $c_{n+1} = 0$ (see Figure 1). The mass balance on an arbitrary boundary, moving according to the law of $x = y(t)$, can be expressed by equation

$$dm/dt = -Dc_x\Big[y(t), t\Big] - c\Big[y(t), t\Big]dy(t)/dt \tag{4}$$

where dm/dt is the resulting flow across the phase boundary in question in the direction of an increase in the value of the coordinate x. The first and second terms on the right side of the above equation express, respectively, the pure diffusion flow and the flow resulting from the crossing of the phase boundary by the given substance because of the boundary shift. The quantity of matter m_k, which at a moment in time t is found beyond the border which separates phases k and k + 1, moving in accordance with the law of $x = y_k(t) = 2b_k\sqrt{t}$, can be computed by the following two methods (numerically, the value of m_k equals the shaded area in Figure 1):

$$\begin{aligned} m_k &= -D_k \int_0^t c_x^k\Big[y_k(t), t\Big]dt - c_k y_k(t) \\ &= -D_{k+1} \int_0^t c_x^{k+1}\Big[y_k(t), t\Big]dt - Z_k y_k(t) . \end{aligned} \tag{5}$$

The equivalence of the two methods is the result of the continuity of the flow across the phase borders.

Using equations (2) and (3), we can then compute the following:

$$\frac{m_k}{2\sqrt{t}} \sqrt{\frac{D_k}{\pi}}\, \delta_k \frac{\exp(-b_k^2/D_k)}{\operatorname{erf}(b_k/\sqrt{D_k}) - \operatorname{erf}(b_{k-1}/\sqrt{D_k})} - c_k b_k , \tag{6}$$

$$\frac{m_k}{2\sqrt{t}} = \sqrt{\frac{D_{k+1}}{\pi}}\,\delta_{k+1}\,\frac{\exp\left(-b_k^2/D_{k+1}\right)}{\operatorname{erf}\left(b_{k+1}/\sqrt{D_{k+1}}\right) - \operatorname{erf}\left(b_k/\sqrt{D_{k+1}}\right)} - z_k b_k\,. \quad (7)$$

By replacing k, in the last equation above, with k - 1, we get

$$\frac{m_{k-1}/2\sqrt{t} + z_{k-1}b_{k-1}}{m_k/2\sqrt{t} + c_k b_k} = \exp\left(\frac{b_k^2 - b_{k-1}^2}{D_k}\right) \quad (8)$$

which, solved for D_k, becomes

$$4D_k t = \left(y_k^2 - y_{k-1}^2\right)/\ln\left(\frac{m_{k-1} + z_{k-1}y_{k-1}}{m_k + c_k y_k}\right)\,. \quad (9)$$

This expression can be used for determining the coefficient of diffusion in various phases. To find the coefficient D_k, it is sufficient to know the position of a given phase boundary at any given point in time t, and the relationship of the integral diffusion flows across these boundaries as of that particular moment, $\theta_k = (m_{k+1} + z_{k-1}y_{k-1})/(m_k + c_k y_k)$.

According to Figure 1, the value of θ_k represents the relationship between the areas of sections of the diffusion zone lying below the a_{k-1} line and the a_k line, respectively. It can be calculated directly if the distribution concentration in the given sample has been determined experimentally.

Formula (9), which for an area adjacent to the surface of the sample (k = 1) takes the form of

$$4D_1 t = y_1^2/\ln\left(\frac{m_0}{m_1 + c_1 y_1}\right)\,, \quad (10)$$

can be utilized for determining the coefficient of diffusion in all zones except the last one, since when k = n + 1 (i.e., when $y_{n+1} \to \infty$ and $c_{n+1} \to 0$), expression (9) becomes identical. Formula (7) can be used to determine the value of D_{n+1}. With k = n, it gives

$$\sqrt{\pi}\,\xi e^{\xi^2}\operatorname{erfc}\xi = \frac{z_n y_n}{m_n + z_n y_n}\,,$$

$$\xi = \frac{y_n}{2\sqrt{D_{n+1}t}}\,. \quad (11)$$

The right side of this equation can also be determined graphically, if the course of the concentration curve in the last zone is known. The function $\sqrt{\pi}\, x \exp(x^2)$ erfcx is a monotone function, the value of which increases and tends to approach 1 for increasing values of x.

Following is a table of the values of this function, which can be used to find the required value of ξ in equation (11):

x	$\sqrt{\pi} \cdot xe^{x^2}$ erfcx	x	$\sqrt{\pi} \cdot xe^{x^2}$ erfcx	x	$\sqrt{\pi} \cdot xe^{x^2}$ erfcx	x	$\sqrt{\pi} \cdot xe^{x^2}$ erfcx
0.1	0.159	0.6	0.603	1.2	0.804	2.2	0.917
0.2	0.286	0.7	0.652	1.4	0.839	2.4	0.929
0.3	0.390	0.8	0.693	1.6	0.866	2.6	0.936
0.4	0.475	0.9	0.720	1.8	0.887	2.8	0.944
0.5	0.545	1.0	0.757	2.0	0.904	3.0	0.950

Expressions (6) and (7) can serve as a basis for another method of determining the diffusion coefficient of a multiphase medium. This method—unlike the one described above—does not require knowledge of the exact progress of concentration in the sample under investigation. Since expressions (6) and (7) are equal, we obtain the following recurrent equation

$$\delta_{k+1} \frac{2\sqrt{D_{k+1}t}}{y_k} \cdot \frac{\exp(-y_k^2/4D_{k+1}t)}{\operatorname{erf}(y_{k+1}/2\sqrt{D_{k+1}t}) - \operatorname{erf}(y_k/2\sqrt{D_{k+1}t})}$$

$$= \delta_k \frac{2\sqrt{D_k t}}{y_k} \cdot \frac{\exp(-y_k^2/4D_k t)}{\operatorname{erf}(y_k/2\sqrt{D_k t}) - \operatorname{erf}(y_{k-1}/2\sqrt{D_k t})} - \Delta_k , \qquad (12)$$

which makes it possible to determine the value of D_{k+1} if D_k has already been determined and if the position of the phase-boundaries at the time-instant t—as well as the concentration level at these points—is known. Thus, in order to find all the coefficients, it is sufficient—besides establishing the value of δ_k, Δ_k, and y_k, already mentioned—to know just the value of D_1.

To find D_1, convenient use can be made of the formula which determines the total mass m_0 of the substance which had diffused its way into the body of the sample. We must bear in mind, however, that in a number of cases it is possible to determine m_0 without defining the form of the concentration curve (e.g., by means of weighing the sample if saturation took place in a gas or liquid phase, or by measuring the total γ-radioactivity of the sample with the use of radioactive isotopes).

The equation for m_0 derived from formula (7) for the case when $k = 0$ has this form:

$$m_0 = 2\sqrt{D_1 t}\,\delta_1/\sqrt{\pi}\,\mathrm{erf}(y_1/2\sqrt{D_1 t}) \quad . \tag{13}$$

By using formula (12), the coefficients D_2, D_3, . . . D_{n+1} can be computed by the graphic method if we first draw up a family of functions $\exp(-x^2)/x(\mathrm{erf}\,\alpha x - \mathrm{erf}\,x)$ to determine the values of x and α at the intervals required ($x = y_k/2\cdot\sqrt{D_{k+1}t}$, $\alpha = y_{k+1}/y_k > 1$ for the left half of the equation, and $x = y_k/2\sqrt{D_k t}$, $\alpha = y_{k-1}/y_k^n \ll 1$ for the right).

By using the first of the methods described above, we were able, with the aid of formulas (9) to (11), to determine the coefficients for the diffusion of chromium in iron (with a 0.03% C content), for α and γ phases, saturating the iron with chromium in the gas phase[13].

Figure 2, below, shows the results of determining the concentration of chromium by layers in the diffusion zone at temperatures of 900°, 1000°, 1100°, and 1200°C—the duration of the process being 3 and 6 hours.

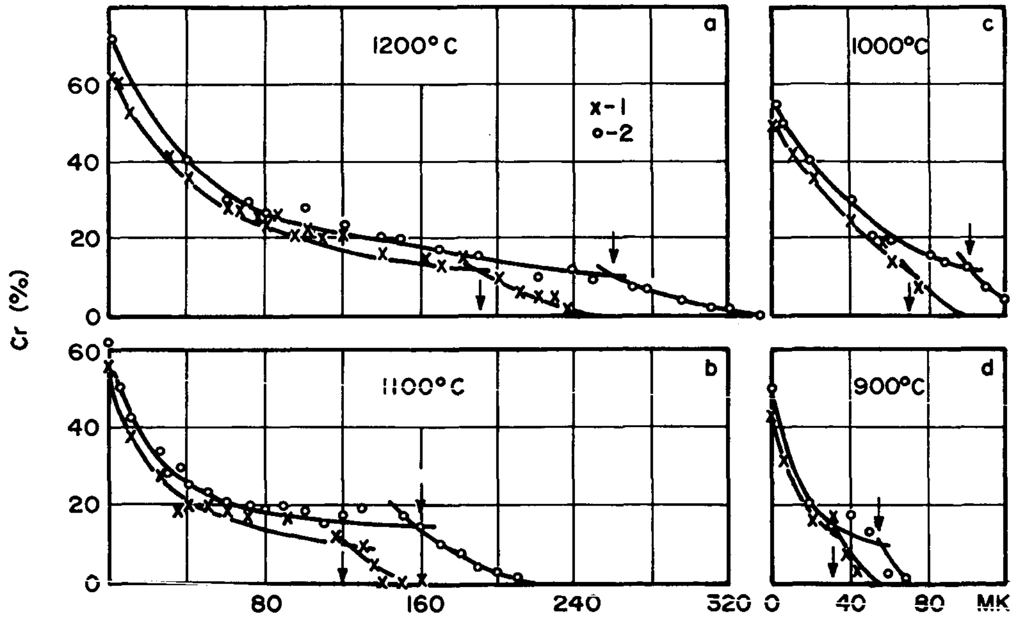

Figure 2. Changes in the Concentration of Chromium in the Surface Zones of Iron Which Underwent a Chromium Saturation Process in a Gas Medium at Temperatures from 900° to 1200°C for a Period of Three Hours (1) and Six Hours (2)

Chromium concentration by layers was determined by the spectral method[14]. The nodal points of the concentration curves (identified by arrows in Figure 2) correspond to the boundaries of $\gamma \rightarrow \alpha$ phase-transition at an isothermic point in the process. The upper part of the curve corresponds to chromium distribution in the α-phase, while the lower part corresponds to the γ-phase (at annealing temperature). Chromium concentration on the boundary of the α and γ phases, obtained as a result of these experiments, corresponds satisfactorily to the results shown in the diagram of the Fe = Cr system state[15].

The results of computing the chromium diffusion coefficient in the α and γ phases are shown in Figure 3, below.

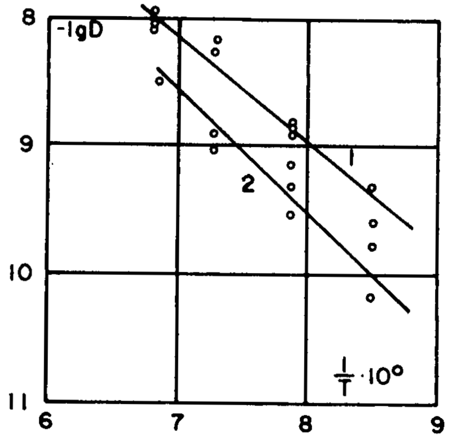

Figure 3. The Temperature Factor in the Coefficient of Diffusion (D, cm^2/sec) of Chromium in the α-State of Iron (Curve 1) and the γ-State (Curve 2)

Processing the experimental data makes it possible to present equations for the chromium diffusion coefficient in the α and γ phases in iron as follows:

$$D_{\alpha} = 1.55 \cdot 10^{-3} \exp\left(\frac{36,000}{RT}\right), \tag{14}$$

$$D_{\gamma} = 10^{-2} \exp\left(-\frac{44,000}{RT}\right). \tag{15}$$

Received for publication: 7 Oct 1963.

LITERATURE CITED

1. D. A. Prokoshkin, Diffusion of Elements in Solid Iron, Proceedings of the Moscow Steel Institute (Chemical and Thermal Methods for Processing Steel), ONTI, 1938.

2. A. N. Minkevich, Chemico-Thermal Processing of Steel, MASHGIZ, 1950.

3. N. S. Gorbunov, Diffusion-Plating of Iron and Steel, Publishing House of the Academy of Sciences, USSR, 1958.

4. G. N. Dubinin, Residual Tension in Surface Layers of Alloys Following Diffusion Saturation, Publishing House of the Academy of Sciences, Department of Technical Sciences, Metallurgy and Fuel, 1962, No. 4, 113.

5. G. N. Dubinin, Theory and Practice of Diffusion Saturation of Alloys with Metals (Investigation of Heat-Resisting Alloys), Proceedings of the Moscow Aviation Institute, 1960, Issue 123.

6. Yu. M. Lakhtin, The Physical Bases of the Nitrogenation Process, MASHGIZ, 1948.

7. A. A. Popov, Theoretical Bases of the Chemico-Thermal Processing of Steel, METALLURGIZDAT, 1962.

8. S. D. Gertsriken and I. Ya. Dekhtyar, Solid-Phase Diffusion in Metals and Alloys, FIZMATGIZ, 1960.

9. T. Hoar and P. Groom, Mechanism and Kinetics of the Chromizing of Mild Steel in an Atmosphere Containing Chromous Chloride, J. Iron Steel Inst., 1951, 169, 101.

10. I. E. Campbell, V. D. Borth, R. F. Hoeckelman, and B. W. Groaser, Transactions of the Electrochem. Soc., 1949, 96, 262.

11. H. Buckle, Note sur la chromisation du Fer, La Recherche Aéronautique, 1950, 61, No. 16. By the same author: 1949, 45, No. 12.

12. P. Galmiche, Nouveau procédé de chromage thermique et formation d'alliages mixtes de diffusion, Revue de Métallurgie, 1950, 47, 192. By the same author: Protection de métaux par diffusion de chrome, Comptes Rendus, 1950, 230, No. 1, 89.

13. G. N. Dubinin, Diffusion Chromizing of Steel, METALLURGIZDAT, 1950.

14. G. N. Dubinin, V. G. Koritskiy, and I. M. Veselovskaya, Diffusion of Chromium, Vanadium, and Manganese on the Surface of Steel in a Gas Medium, Journal of Tech. Physics, 1953, XXIII, Issue No. 10.

15. G. N. Dubinin, On the Nature of Surface Zones Arising in the Diffusion of Chromium in Iron, J. Tech. Physics, XXVI, Issue No. 6.

DISTRIBUTION

EXTERNAL

	No. of Copies
Air University Library ATTN: AUL3T Maxwell Air Force Base, Alabama 36112	1
U. S. Army Electronics Proving Ground ATTN: Technical Library Fort Huachuca, Arizona	1
U. S. Naval Ordnance Test Station ATTN: Technical Library, Code 753 China Lake, California 93555	1
U. S. Naval Ordnance Laboratory ATTN: Library Corona, California 91720	1
Lawrence Radiation Laboratory ATTN: Technical Information Division P. O. Box 808 Livermore, California	1
Sandia Corporation ATTN: Technical Library P. O. Box 969 Livermore, California 94551	1
U. S. Naval Postgraduate School ATTN: Library Monterey, California 93940	1
Electronic Warfare Laboratory, USAECOM Post Office Box 205 Mountain View, California 94042	1
Jet Propulsion Laboratory ATTN: Library (TDS) 4800 Oak Grove Drive Pasadena, California 91103	2
U. S. Naval Missile Center ATTN: Technical Library, Code N3022 Point Mugu, California	1
U. S. Army Air Defense Command ATTN: ADSX Ent Air Force Base, Colorado 80912	1
Central Intelligence Agency ATTN: OCR/DD-Standard Distribution Washington, D. C. 20505	4
Harry Diamond Laboratories ATTN: Library Washington, D. C. 20438	1
Scientific & Tech. Information Div., NASA ATTN: ATS Washington, D. C. 20546	1
U. S. Atomic Energy Commission ATTN: Reports Library, Room G-017 Washington, D. C. 20545	1
U. S. Naval Research Laboratory ATTN: Code 2027 Washington, D. C. 20390	1
Weapons Systems Evaluation Group Washington, D. C. 20305	1
John F. Kennedy Space Center, NASA ATTN: KSC Library, Documents Section Kennedy Space Center, Florida 32899	2
APGC (PGBPS-12) Eglin Air Force Base, Florida 32542	1
U. S. Army CDC Infantry Agency Fort Benning, Georgia 31905	1
Argonne National Laboratory ATTN: Report Section 9700 South Cass Avenue Argonne, Illinois 60440	1
U. S. Army Weapons Command ATTN: AMSWE-RDR Rock Island, Illinois 61201	1
Rock Island Arsenal ATTN: SWERI-RDI Rock Island, Illinois 61201	1
U. S. Army Cmd. & General Staff College ATTN: Acquisitions, Library Division Fort Leavenworth, Kansas 66027	1
Combined Arms Group, USACDC ATTN: Op. Res., P and P Div. Fort Leavenworth, Kansas 66027	1
U. S. Army CDC Armor Agency Fort Knox, Kentucky 40121	1
Michoud Assembly Facility, NASA ATTN: Library, I-MICH-OSD P. O. Box 29300 New Orleans, Louisiana 70129	1
Aberdeen Proving Ground ATTN: Technical Library, Bldg. 313 Aberdeen Proving Ground, Maryland 21005	1
NASA Sci. & Tech. Information Facility ATTN: Acquisitions Branch (S-AK/DL) P. O. Box 33 College Park, Maryland 20740	5
U. S. Army Edgewood Arsenal ATTN: Librarian, Tech. Info. Div. Edgewood Arsenal, Maryland 21010	1

	No. of Copies
National Security Agency ATTN: C3/TDL Fort Meade, Maryland 20755	1
Goddard Space Flight Center, NASA ATTN: Library, Documents Section Greenbelt, Maryland 20771	1
U. S. Naval Propellant Plant ATTN: Technical Library Indian Head, Maryland 20640	1
U. S. Naval Ordnance Laboratory ATTN: Librarian, Eva Liberman Silver Spring, Maryland 20910	1
Air Force Cambridge Research Labs. L. G. Hanscom Field ATTN: CRMXLR/Stop 29 Bedford, Massachusetts 01730	1
Springfield Armory ATTN: SWESP-RE Springfield, Massachusetts 01101	1
U. S. Army Materials Research Agency ATTN: AMXMR-ATL Watertown, Massachusetts 02172	1
Strategic Air Command (OAI) Offutt Air Force Base, Nebraska 68113	1
Picatinny Arsenal, USAMUCOM ATTN: SMUPA-VA6 Dover, New Jersey 07801	1
U. S. Army Electronics Command ATTN: AMSEL-CB Fort Monmouth, New Jersey 07703	1
Sandia Corporation ATTN: Technical Library P. O. Box 5800 Albuquerque, New Mexico 87115	1
ORA(RRRT) Holloman Air Force Base, New Mexico 88330	1
Los Alamos Scientific Laboratory ATTN: Report Library P. O. Box 1663 Los Alamos, New Mexico 87544	1
White Sands Missile Range ATTN: Technical Library White Sands, New Mexico 88002	1
Rome Air Development Center (EMLAL-1) ATTN: Documents Library Griffiss Air Force Base, New York 13440	1
Brookhaven National Laboratory Technical Information Division ATTN: Classified Documents Group Upton, Long Island, New York	1
Watervliet Arsenal ATTN: SWEWV-RD Watervliet, New York 12189	1
U. S. Army Research Office (ARO-D) ATTN: CRD-AA-IP Box CM, Duke Station Durham, North Carolina	1
Lewis Research Center, NASA ATTN: Library 21000 Brookpark Road Cleveland, Ohio 44135	1
Systems Engineering Group (RTD) ATTN: SEPIR Wright-Patterson Air Force Base, Ohio 45433	1
U. S. Army Artillery & Missile School ATTN: Guided Missile Department Fort Sill, Oklahoma 73503	1
U. S. Army CDC Artillery Agency ATTN: Library Fort Sill, Oklahoma 73504	1
U. S. Army War College ATTN: Library Carlisle Barracks, Pennsylvania 17013	1
U. S. Naval Air Development Center ATTN: Technical Library Johnsville, Warminster, Pennsylvania 18974	1
Frankford Arsenal ATTN: C-2500-Library Philadelphia, Pennsylvania 19137	1
Div. of Technical Information Ext., USAEC P. O. Box 62 Oak Ridge, Tennessee	1
Oak Ridge National Laboratory ATTN: Central Files P. O. Box X Oak Ridge, Tennessee	1
Air Defense Agency, USACDC ATTN: Library Fort Bliss, Texas 79916	1
U. S. Army Air Defense School ATTN: AKBAAS-DR-R Fort Bliss, Texas 79906	1

	No. of Copies
U. S. Army CDC Nuclear Group Fort Bliss, Texas 79916	1
Manned Spacecraft Center, NASA ATTN: Technical Library, Code BM6 Houston, Texas 77058	1
Defense Documentation Center Cameron Station Alexandria, Virginia 22314	20
U. S. Army Research Office ATTN: STINFO Division 3045 Columbia Pike Arlington, Virginia 22204	1
U. S. Naval Weapons Laboratory ATTN: Technical Library Dahlgren, Virginia 22448	1
U. S. Army Engineer Res. & Dev. Labs. ATTN: Scientific & Technical Info. Br. Fort Belvoir, Virginia 22060	2
Langley Research Center, NASA ATTN: Library, MS-185 Hampton, Virginia 23365	1
Research Analysis Corporation ATTN: Library McLean, Virginia 22101	1
U. S. Army Tank Automotive Center ATTN: SMOTA-RTS.1 Warren, Michigan 48090	1
Hughes Aircraft Company Electronic Properties Information Center Florence Ave. & Teale St. Culver City, California	1
Atomics International, Div. of NAA Liquid Metals Information Center P. O. Box 309 Canoga Park, California	1
Foreign Technology Division ATTN: Library Wright-Patterson Air Force Base, Ohio 45400	1
Clearinghouse for Federal Scientific and Technical Information U. S. Department of Commerce Springfield, Virginia 22151	1
Foreign Science & Technology Center, USAMC ATTN: Mr. Shapiro Washington, D. C. 20315	3

INTERNAL	No. of Copies
Headquarters U. S. Army Missile Command Redstone Arsenal, Alabama	
ATTN: AMSMI-D	1
AMSMI-XE, Mr. Lowers	1
AMSMI-XS, Dr. Carter	1
AMSMI-Y	1
AMSMI-R, Mr. McDaniel	1
AMSMI-RAP	1
AMSMI-RBLD	10
USACDC-LnO	1
AMSMI-RBT	8
AMSMI-RB, Mr. Croxton	1
National Aeronautics & Space Administration Marshall Space Flight Center Huntsville, Alabama	
ATTN: MS-T, Mr. Wiggins	5
R-P&VE-MMP, Dr. Roy	1

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Redstone Scientific Information Center Research and Development Directorate U.S. Army Missile Command Redstone Arsenal, Alabama 35809	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP N/A

3. REPORT TITLE
DETERMINATION OF THE DIFFUSION COEFFICIENTS IN ALLOYS WITH SEVERAL PHASES, Izvestiya, Akademii Nauk, SSSR, Metallurgiya i Gornoe Delo, No. 4, 147-152 (1964).

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Translated from the Russian by Harry Brooks

5. AUTHOR(S) *(Last name, first name, initial)*
Borisov, V. T., Golikov, V. M., and Dubinin, G. N.

6. REPORT DATE 27 October 1966	7a. TOTAL NO. OF PAGES 13	7b. NO. OF REFS 15

8a. CONTRACT OR GRANT NO. N/A b. PROJECT NO. N/A c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) RSIC-604 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* AD ______________

10. AVAILABILITY/LIMITATION NOTICES
Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES None	12. SPONSORING MILITARY ACTIVITY Same as No. 1

13. ABSTRACT

Investigated is the method for determining the diffusion coefficient in cases when a multiphase diffusion layer is formed on the surface zone of a metal. The calculation of the diffusion coefficient is made by using as an example the chromium-saturation of iron in a gas phase.

Author

DD FORM 1 JAN 64 1473

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Diffusion coefficient						
Phase boundaries						
Isothermic point						
Concentration curves						
Spectral method						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
____."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
____."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, *or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.