For symmetry C_{4v},

$$C_4: x\rightarrow y,\quad y\rightarrow -x,\quad z\rightarrow z;\quad \sigma_v: x\rightarrow y,\quad y\rightarrow x,\quad z\rightarrow z, \tag{5}$$

σ_v imposes four additional relations among the 16 coefficients (4):

$$C_{xxxxxy}=C_{yyyyxy},\quad C_{xxzzxy}=C_{yyzzxy},\quad C_{xxyzzx}=C_{yyyzzx},\quad C_{yzyzxy}=C_{zxzxxy}. \tag{6}$$

Thus, these 4 coefficients vanish (Table I). Symmetries $D_{4h}(C_{4v}\times i=D_4\times i=D_{2d}\times i)$, D_4 and D_{2d} are equivalent to C_{4v}.

For symmetry C_3,

$$C_3: x\rightarrow y,\quad y\rightarrow z,\quad z\rightarrow x, \tag{7}$$

there are 20 independent coefficients (Table I),[1] while for symmetry C_{3v},

$$C_3: x\rightarrow y,\quad y\rightarrow z,\quad z\rightarrow x;\quad \sigma_v: x\rightarrow x,\quad y\rightarrow z,\quad z\rightarrow y, \tag{8}$$

there are 14, since σ_v imposes six additional relations among the coefficients for C_3 (Table I). Symmetries $D_{3d}(C_{3v}\times i=D_3\times i)$ and D_3 are equivalent to C_{3v}.

For symmetry T,

$$C_3': x\rightarrow y,\quad y\rightarrow z,\quad z\rightarrow x;\quad C_3'': -x\rightarrow y,\quad y\rightarrow z,\quad z\rightarrow -x, \tag{9}$$

12 of the coefficients for C_3 vanish (Table I) owing to the additional relations imposed by C_3''. Symmetry $T_h=T\times i$ is equivalent to T.

For symmetry T_d,

$$C_3': x\rightarrow y,\quad y\rightarrow z,\quad z\rightarrow x;\quad C_3'': -x\rightarrow y,\quad y\rightarrow z,\quad z\rightarrow -x;\quad \sigma_d: x\rightarrow x,\quad y\rightarrow z,\quad z\rightarrow y, \tag{10}$$

only 8 of the relations imposed by C_3'' are distinct, owing to the relations imposed by σ_d: 8 of the 14 independent coefficients for C_{3v} vanish (Table I). Symmetries $O_h(T_d\times i=O\times i)$ and O are equivalent to T_d.

The writer wishes to thank Professor Bhagavantam and Mr. Hearmon for correspondence.

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[1] F. Birch, Phys. Rev. **71**, 809 (1947).

[2] S. Bhagavantam and D. Suryanarayana, Nature **160**, 750 (1947), have shown group-theoretically that Birch's number of coefficients for symmetry T_d($=8$) is in error; the correct number is 6, as was also confirmed by H. A. Jahn, Acta Cryst. **2**(1), 30 (1949). This result is actually obvious, even in more complete form, since symmetries T_d, O, and O_h ($T_d\times i=O\times i$) are equivalent for polar properties of even order.

[3] F. G. Fumi, Acta Cryst. (1951), to be published.

[4] After the writer had undertaken this work, he was informed by private communication that Mr. R. F. S. Hearmon, Physics Section, Forest Products Research Laboratory, England, had been applying to the third-order elastic tensor the direct method described in C. E. Love, *The Mathematical Theory of Elasticity* (Cambridge University Press, London 1927), Chapter VI.

Experimental Evidence for the Vacancy Mechanism in Diffusion in Metals and Alloys*

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THERE has been much discussion among the workers in the field of metallic diffusion as to the possibility of using an alloy system such as iron-aluminum, nickel-aluminum or cobalt-aluminum, near the fifty-fifty atomic percent composition, to test the vacancy theory of diffusion, but to our knowledge only one previous report[1] on experimental work has been given. FeAl,[2] NiAl,[3] and CoAl[4] are body-centered cubic with ordered structures at room temperature, aluminum atoms going to cube corners and the ferrous atoms to cube centers. The lattice spacings at the ideal composition (50–50 atomic percent) rise to a maximum. On the cobalt-rich side of the ideal composition (to take a specific example), the cobalt replaces aluminum, atom for atom, and a fall in the lattice spacing results from the replacement of large aluminum atoms by the smaller cobalt atoms. On the aluminum-rich side the number of atoms per unit cell is less than two.[4] For the ordered structure the cube corners are filled by aluminum atoms, but there are insufficient cobalt atoms to fill up the cube centers and the vacancies are not made up by the larger aluminum atoms to that there is a contraction in the cell dimensions. These vacancies have then been considered as a possible source of information on the vacancy mechanism of diffusion. Smoluchowski and Burgess[1] have raised doubt as to the ability of these vacancies to play a role in diffusion, due to their relatively small size compared to the size of an aluminum atom, in connection with an experiment on nickel-aluminum alloys. Their experiments seemed to uphold the arguments presented there, in that no increase in the diffusion coefficient was found for compositions on the aluminum-rich side in NiAl.

The arguments raised by Smoluchowski and Burgess are only applicable to a highly ordered structure and rapidly lose validity under the experimental conditions at elevated temperatures where the actual diffusion takes place. At these temperatures there must exist a considerable degree of disorder permitting vacancy diffusion to take place, where vacancies are distributed in a random fashion over lattice sites.

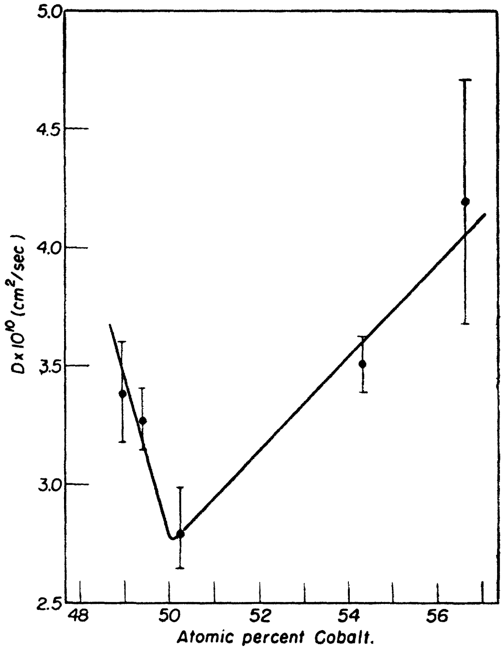

Fig. 1. Values of the diffusion coefficient of cobalt in cobalt-aluminum alloys as a function of cobalt concentration, at 1250°C.

Even though the ordered structure persists at elevated temperatures where the diffusion experiments were carried out, it seems highly unlikely, with such a large number of excess vacancies present, that they would not be of consequence in any process which took place as a result of vacancies. Even admitting that a cobalt or aluminum atom could not move into the cobalt vacancy created, as suggested by Smoluchowski and Burgess,[1] the sheer number of these vacancies would greatly increase the probability of a vacancy being adjacent to a normal lattice defect (e.g. a cobalt atom on a cube corner) or to a vacancy due to thermal excitation, and thus increase the mobility of the vacancies and consequently increase the diffusion coefficient.

We have investigated the diffusion of cobalt into five compositions of cobalt-aluminum alloys near the ideal composition, using radioactive Co^{60} as the diffusing atom. The experimental technique used was similar to that employed in our work on self-diffusion in cobalt.[5] The diffusion was carried out at three temperatures, 1050°C, 1150°C, and 1250°C. The preliminary results at all temperatures show a minimum in the diffusion coefficient at the ideal composition and a definite increase on the aluminum-rich side. Figure 1 shows this for diffusion at 1250°C, with the data spread indicated. The diffusion of cobalt in samples of the same composition at different temperatures follow the usual law

$$D = Ae^{-Q/RT},$$

thus allowing us to calculate the activation energies for the process at the various compositions of the alloy. The activation energy, as expected, drops off sharply on the vacancy-rich side of CoAl.

These preliminary results have large possible errors and do not determine the exact form of the curve of D as a function of composition. Consequently, the experiment is being continued using a greater number of compositions of the alloy and with emphasis on reducing the many possible errors involved.

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[†] This discussion is part of a dissertation by Frank E. Jaumot, Jr. presented to the Faculty of the Graduate School of the University of Pennsylvania in partial fulfillment of the requirements for the Ph.D. degree.

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Elastic Proton-Deuteron Scattering at 240 Mev[*]

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THE elastic proton-deuteron differential scattering cross section at 240 Mev has been measured for proton-scattering angles from 20.5° to 100° in the center-of-mass system. The internal proton beam of the Rochester synchrocyclotron strikes a thin target of heavy paraffin and coincidences between the scattered proton and recoil deuteron are observed using scintillation counters and conventional electronics. The incident beam is determined from the C^{11} beta-activity of the target produced by the reaction $C^{12}(p, pn)C^{11}$. The scattering apparatus, electronics, and beta-counting techniques will be described in detail in a paper to be published on proton-proton scattering performed with the same equipment.[1]

Several types of background coincidences are present. The chance coincidence background is measured by moving the target away from the position at which proton-deuteron coincidences are observed and measuring the coincidences at different beam intensities. The part which varies quadratically with the beam intensity, as monitored by the singles counts in either counter, is ascribed to chance. The linear term is due to events in the carbon in which two charged particles are emitted and reach the counters. For all of the measurements except that at 100° there was a background from inelastic proton-deuteron scattering. Only that portion of the inelastic process which results in a low energy neutron and two protons with approximately the same energy and angular relationship as in proton-proton scattering is observed. For small scattering angles proton-proton scattering from the hydrogen impurity in the target was an additional background. Scattering at 75° and 79° was observed at the same target position. It was not possible to completely separate the two effects. The cross sections at these two angles were obtained by splitting the total number of coincidences in such a way that the center-of-mass cross sections do not differ greatly.

The experimental values of the cross section are given in Fig. 1. The errors indicated at 20.5°, 31°, 42°, 54°, and 100° are the standard deviation in the coincidences. The error on the other points has been increased because of uncertainties in the background. The error in the calibration of the beta-counter is 5 percent. A value of 49 millibarns has been used for the $C^{12}(p, pn)C^{11}$ cross section.[2] The proton-proton scattering cross section at 90° in the center-of-mass system measured with the same apparatus is 4.9 millibarns.

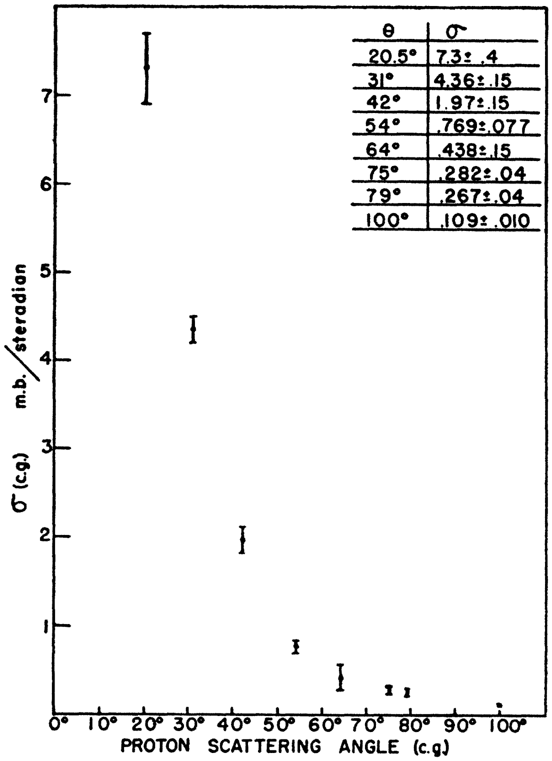

FIG. 1. Elastic proton-deuteron scattering cross section at 240 Mev.

Mr. T. Auerbach, of this laboratory, has calculated the cross section in the Born approximation[3] with the Serber mixture for the neutron-proton interaction and the three proton-proton interactions used by Gluckstern and Bethe.[4] The results of Auerbach's calculation and the experimentally determined cross sections are summarized in Table I. The experimental cross sections do not agree with any of these calculations, which is not surprising since the assumed forces do not explain the observed proton-proton scattering. Further theoretical calculations are clearly necessary.

TABLE I. Theoretical and experimental differential scattering cross sections.

Proton scatt. angle in c.m. system	Theoretical cross section, cm^2/sterad Direct	Pure exchange	Serber	Experimental cross section cm^2/sterad
20.5°	21×10^{-27}	6.0×10^{-27}	13×10^{-27}	$7.3\pm0.4\times10^{-27}$
31°	6.8	1.82	3.9	4.36±0.15
42°	1.95	0.55	1.06	1.97±0.15
54°	0.55	0.145	0.30	0.769±0.77
64°	0.24	0.052	0.112	0.44±0.15
75°	0.104	0.016	0.026	0.28±0.04
79°	0.083	0.010	0.017	0.27±0.04
100°	0.040	0.001	0.014	0.109±0.010

Some data have been obtained on the inelastic scattering mentioned above. These data will be published later with a more detailed discussion of the elastic scattering.

The author is indebted to Professor C. L. Oxley for his generous assistance on many phases of this investigation.

[*] Assisted by the joint program of the ONR and the AEC.

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