more metals than had been supposed until now. It will be interesting to see whether this material is superconducting.[1] E. A. Wood has identified our material with that of Pietrokowsky,[2] who determined that its structure was the cubic $MgCu_2$ structure.

[1] V. L. Ginzburg, Zhur. eksptl. i teort. Fiz. **31**, 202 (1956) [translation: Soviet Phys. JETP **4**, 153 (1957)].

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Vacancy Diffusion in Binary Ordered Alloys

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SLIFKIN and Tomizuka[1] have suggested that vacancy diffusion in certain well-ordered binary alloys should lead to equal self-diffusion coefficients for the two components of the alloy. It was assumed, as it will be in all that follows, that (1) the lattice of the alloy may be subdivided into two sublattices such that nearest neighbor sites of a site on one sublattice all lie on the other sublattice, the state of perfect order of the AB alloy being such that each sublattice is occupied by atoms of one kind, and (2) the only mechanism for atom interchange is by vacancy jumps from a site to a nearest neighbor site. The argument is simply that, in the course of $2m$ vacancy jumps through the well-ordered AB lattice, m A atoms and m B atoms are each displaced an equal distance: it is inferred that the self-diffusion coefficients of the two components of the alloy are equal.

This suggestion has been criticized by Lidiard[2] who points out that such vacancy tracks do not satisfy the equilibrium requirements for the alloy. There are, however, as has been remarked by Huntington,[3] certain cyclic vacancy tracks which could produce diffusion without creating disorder. Although such highly correlated processes might seem at first sight very improbable, we shall show that, at sufficiently low temperatures, they provide the dominant mechanism for diffusion.

Consider a vacancy supposed initially to be at an a site in an otherwise perfectly ordered body-centered cubic AB crystal. A jump of the vacancy into one of the nearest neighbor b sites disorders a B atom with consequent increase in configuration energy and, for temperatures low compared to the critical temperature, will almost always be followed by a jump of the vacancy back into its original position. Two successive jumps of the vacancy away from the original position, involving the disordering of two atoms and consequently a greater increase in configurational energy, will occur much less frequently and such jumps also will tend to be immediately retraced: the vacancy is strongly bound to its initial position. It follows that a configuration in which a vacancy has a perfectly ordered local environment is, at sufficiently low temperatures, very stable. Further, none of these processes involving jumps away from the initial position followed by retracing of these jumps give rise to net diffusion.

Eventually the vacancy will, in some series of jumps, either return to its initial stable position by a process not depending on retracing of jumps, or escape to a different stable position. Either process results in net displacements of the atoms of the alloy. In fact, the escape to a new stable position is the most probable process. The vacancy will be in a position to escape from an initial stable position if it makes three successive jumps around a square of four nearest neighbor sites in a (111) plane: the vacancy is then just as likely to make a further forward jump around the square as a backward jump. If the vacancy makes the forward jump, however, it will then be bound to a *new* stable position at the site on the square diagonally opposite the initial site. In going from the initial to the final stable configuration, the vacancy makes six jumps around the sides of the square. The net result so far as diffusion is concerned is that if the initial vacancy site was an $a(b)$ site, two $B(A)$ atoms will have interchanged places, so that each has been displaced a distance equal to the diagonal of the square considered, and one $A(B)$ will have moved the same distance. No net disordering occurs.

In order to execute any other nontrivial series of jumps starting and ending in a stable state, the vacancy must pass through a configuration of higher energy than any occurring in the six-jump process described. Moreover, the increase in the number of equivalent processes will not compensate for this increase in configurational energy at sufficiently low temperatures. At sufficiently low temperatures, then, we may regard diffusion as taking place solely by the six-jump process described. It should be noted here, however, that although other cyclic processes make no appreciable contribution to diffusion, they constitute mechanisms by which semi-permanent local regions of disorder may be created and destroyed and hence play a part in maintaining the equilibrium disorder. Since it may be shown that Bardeen-Herring type correlations between successive jumps of A and B atoms are approximately the same, the mean square displacement of $B(A)$ atoms due to an $a(b)$ vacancy making a series of six-jump processes will be approximately twice that of $A(B)$ atoms. At sufficiently low temperatures, then, we expect the value of the ratio of self-diffusion, G, of A to B atoms to lie between 2 and $\frac{1}{2}$, the precise value being given by

$$G = D_B/D_A = (2n_a w_a + n_b w_b)/(2n_b w_b + n_a w_a),$$

where n_a and n_b are equilibrium concentrations and w_a and w_b are frequencies for the six-jump process for the two kinds of vacancy.

It is probable that diffusion will be too small to be measured at temperatures where processes other than the simple six-jump process may be ignored. The more complicated processes which will come into play at slightly higher temperatures would not, however, be expected to change the ratio G very greatly. We may therefore reasonably expect that, at low temperatures, the two diffusion constants will lie within a factor of two or three of one another and this expectation is borne out by the experimental results.[4]

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Effective Nuclear Spin Interactions in Ferromagnets

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THIS note is to draw attention to a type of nuclear spin-spin interaction which may be at the root of the difficulty of observing nuclear resonance of the metal nuclei in ferromagnetic and antiferromagnetic insulators.

The interaction takes place as follows: Each nuclear spin sees the electronic spin on its own ion, through the effective hyperfine coupling $A\mathbf{I}\cdot\mathbf{S}$. The electronic spins of all the ions are coupled by exchange interaction. An interaction of the nuclei therefore arises via the low-lying excited states (spin waves) of the electronic system as intermediate states.[1–4] That is to say, a nuclear spin excites a spin wave through the hyperfine coupling, and another nuclear spin causes it to be reabsorbed through its hyperfine coupling. For a cubic ferromagnet, summation of this process over all the possible virtual spin-wave states leads to a nuclear interaction of the form

$$\mathfrak{H}_{\text{eff}}=-\frac{A^2S}{8\pi g\mu_B H_{\text{ex}}}\sum_{i\neq i}\frac{a}{r_{ij}}\exp\left[-\left(\frac{H_{\text{int}}}{H_{\text{ex}}}\right)^{\frac{1}{2}}\frac{r_{ij}}{a}\right]I_i^-I_j^+, \tag{1}$$

where r_{ij} is the distance between sites i and j, a the lattice spacing, A the hyperfine coupling constant, S the ionic spin, H_{ex} an effective exchange field, H_{int} the effective dc field (i.e., the applied steady field minus the demagnetizing field). $I_i^{\pm}$ stands for $I_i^x \pm iI_i^y$, where I_i^x, I_i^y are the nuclear spin components in a plane normal to the quantization direction, which is taken to be the direction of H_{int}. Demagnetization effects (other than in H_{int}) were neglected, the energy of a spin wave quantum of wave number k being taken in the form $\hbar\omega_k=g\mu_B(H_{\text{int}}+H_{\text{ex}}a^2k^2)$. If demagnetization effects are included, interactions of the form $I_i^+I_j^+$ and $I_i^-I_j^-$ will also occur, leading to satellite lines. The self-energy term $i=j$, which has been omitted from (1), gives a small shift in the nuclear resonance frequency, and, if $I>\frac{1}{2}$, also a small quadrupole effect.

The interaction (1) will lead to a nearly Gaussian line profile,[5] with root-mean-square width given by Van Vleck's formula.[6] Since the range of the interaction is rather long (about 30 lattice spacings for $H_{\text{ex}}\sim10^6$ oe and $H_{\text{int}}\sim10^3$ oe), the sum in Van Vleck's formula[6] may be replaced by an integral, with the result

$$(\langle\Delta\nu^2\rangle)^{\frac{1}{2}}=S\left[\frac{I(I+1)}{24\pi}\right]^{\frac{1}{2}}\left(\frac{H_{\text{ex}}}{H_{\text{int}}}\right)^{\frac{1}{4}}\left(\frac{A}{h}\right)\left(\frac{A}{g\mu_B H_{\text{ex}}}\right). \tag{2}$$

For example, in the Mn^{++} ion, with $S=\frac{5}{2}$, $A=10^{-2}\,\text{cm}^{-1}$, $I=\frac{5}{2}$, and $H_{\text{ex}}/H_{\text{int}}=1000$, the line width will be about 0.14 Mc/sec.

Formula (2) is very similar [aside from the factor $(H_{\text{ex}}/H_{\text{int}})^{\frac{1}{4}}$] to the result of Moriya[7] applicable in the paramagnetic regime. Thus, the hope that ferromagnetic ordering of electron spins might make observation of nuclear resonance easier than it is in the disordered state does not appear to be justified.

The same process also occurs in antiferromagnetic materials such as MnF_2 and affects the resonance of the nuclei of both the magnetic and nonmagnetic ions. The result is much the same as (2) with the anisotropy field replacing H_{int}. This, and related topics, will be discussed in a forthcoming paper.

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[1] Other cases of interaction of nuclei via electrons have been described in the literature, e.g., in references 2, 3, and 4.
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[6] Y. H. Van Vleck, Phys. Rev. **74**, 1168 (1948).
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Possible Method for Determining the Intrinsic Parity of the K Meson*†

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AS a consequence of the nonconservation of parity in the weak interactions, including decays not involving the emission of neutrinos, there is no possibility of determining the intrinsic parity of a K meson or hyperon by observations on its decay.[1] However,