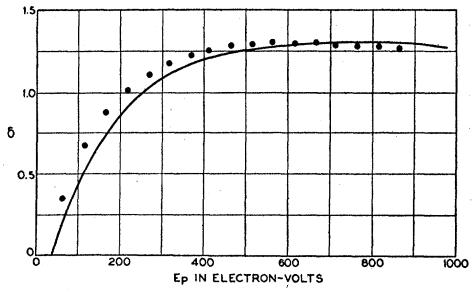

FIG. 1. Secondary yield *vs.* primary energy for nickel.

ured. Various auxiliary measurements fixed the uncertainty in the results at two percent or less. The system was thoroughly outgassed and evacuated before the metal was evaporated. The evaporation was carried out by heating a tungsten filament on which a small loop of nickel or cobalt wire had been hung. The measurements were made immediately after evaporation, during which time the pressure was less than 2×10^{-7} mm Hg, as indicated by an ionization manometer.

The experimental points are shown in Figs. 1 and 2.[2] The theoretically derived curves employed the following constants for the targets:

	Nickel	*Cobalt*
Atomic Volume[3]	11.0×10^{-24} cc/atom	11.0×10^{-24} cc/atom
Max. Fermi Energy[4]	11.6 ev	11.6 ev
Work Function[5]	5.0 ev	4.2 ev

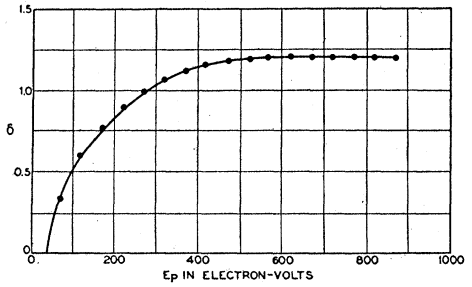

FIG. 2. Secondary yield *vs.* primary energy for cobalt.

The extent of the agreement between theory and experiment is as good as the approximations in the theory allow one to expect in the case of nickel. The extremely close agreement in the case of cobalt is probably fortuitous.

It is a pleasure to acknowledge the work of Mr. C. D. Hartman, who has been of great assistance in making the experimental measurements.

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[1] D. E. Wooldridge, Phys. Rev. **56**, 562 (1939).
[2] In these figures E_p is the energy, in electron-volts, of the primary particles just *after* they have penetrated the surface of the target. This exceeds the incident energy by about 16 ev, for nickel and cobalt.
[3] N. F. Mott and H. Jones, *Properties of Metals and Alloys* (Oxford, 1936), p. 318.
[4] Calculated on the assumption of two free electrons per atom. See, for example, reference 3, p. 54.
[5] A. L. Reimann, *Thermionic Emission* (John Wiley and Sons, 1934), p. 99.

Lattice Defects in Silver Halide Crystals

In a previous note[1] in this Journal, the writer pointed out that a value of the activation energy for the formation of lattice defects in ionic crystals could be obtained from a comparison of conductivity measurements at low and high temperatures. The value of the activation energy for silver bromide obtained with the use of this method was then employed in a simple theory to determine the actual number of lattice defects at various temperatures. The computed values were found to be so low even near the melting point as to make it seem unlikely that a comparison of density and lattice constant measurements could be used to decide whether or not the lattice defects consist (a) of pairs of vacancies in the positive and negative ion lattices, as in the alkali halides, or (b) of vacancies in the positive ion lattice and interstitial silver ions as suggested by Jost and Nehlep.[2] The basis for making an estimate of the accuracy of density measurements is provided by the work of Wagner and Beyer.[3]

Briefly, it was found that the ratio r of the number of lattice defect atoms to the number of normal atoms is given by the equation

$$r=\exp(-\epsilon/kT), \tag{1}$$

where ϵ was found to be about 0.36 ev for silver bromide. The principal assumptions made in deriving these results are that (a) the activation energy for ionic conductivity is smaller at low temperatures than at high temperatures because the number of defects becomes constant at low temperatures, and (b) the additional entropy of a crystal containing defects is simply a mixing entropy. If the same method is applied to silver chloride, it is found that the activation energy in (1) is about 0.50 ev.

Since the appearance of the preceding note, Wagner has pointed out to me that experiments carried on by him in cooperation with Koch[4] lead directly to values of the number of lattice defects. These workers have measured the conductivity of silver halide crystals containing small amounts of the corresponding lead halide, which is completely dissolved in the lattice of the silver salt. Since lead is divalent, each lead ion replaces two silver ions, thereby increasing the number of vacancies in the silver ion lattice. They then determine the conductivity associated with the silver ion vacancies from the measured increase of conductivity occurring with increasing lead concentration. This result is then used to determine the number of vacancies, and hence of lattice defects, in the pure crystal. The final expressions for r, the ratio of defect atoms to normal atoms, may be fitted closely with functions of the form

$$\begin{aligned} r(\mathrm{AgBr}) &= 29\exp(-5050/T),\\ r(\mathrm{AgCl}) &= 36\exp(-6250/T). \end{aligned} \tag{2}$$

The activation energies corresponding to the exponents in these expressions are 0.43 ev and 0.54 ev, respectively, which agree with the values 0.36 ev and 0.50 ev, determined above, as closely as may be expected when the difficulty of determining the low temperature activation energy of the conductivity is considered. The fact that the coefficients of the exponents are not unity, as in the simple theory

represented by Eq. (1), presumably indicates that the entropy associated with the lattice defects is not simply a mixing entropy, which is not at all surprising.

In conclusion, it may be said that the directly determined activation energies for the formation of lattice defects in the silver halides are in substantial agreement with those determined by the indirect method discussed in the reference of footnote 1.

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[1] F. Seitz, Phys. Rev. **54**, 1111 (1938).
[2] W. Jost and G. Nehlep, Zeits. f. physik. Chemie **B32**, 1 (1936).
[3] C. Wagner and J. Beyer, Zeits. f. physik. Chemie **B32**, 113 (1936).
[4] E. Koch and C. Wagner, Zeits. f. physik. Chemie **B38**, 295 (1938).

The Electric Quadrupole and Magnetic Dipole Moments of Li^6 and N^{14}

The nonspherically symmetric nuclear forces which are invoked in order to account for the existence of the electric quadrupole moment of the deuteron[1] present an opportunity to explain certain discrepancies between the theoretical and observed nuclear magnetic moments.[2] Of particular interest are the cases of Li^6 and N^{14}. On the assumption of intrinsic magnetic moments of the neutron and proton uninfluenced by binding forces one expected the magnetic moments of these nuclei to be equal to that of the deuteron. Such differences as are due to the effects of Coulomb forces and spin-orbit coupling are entirely negligible.[3] However, the observed values give $\mu(H^2)-\mu(Li^6)=0.03$ and $\mu(H^2)-\mu(N^{14})=0.45$ nuclear magnetons.[4]

The expectation of equality of the magnetic moments of H^2, Li^6 and N^{14} was based on the result following from the spherically symmetric force model that the ground state of all three nuclei were the same; *viz.*, $^3S_1$. But with angular dependent forces such as are presented by the meson field theory,[5] this is no longer valid and the ground states of these nuclei will be a mixture of $^3S_1$ and $^3D_1$ with differing amounts of the two. For the two heavier nuclei a greater admixture of the D function might be expected since the D term in Li^6 and N^{14} arises from the lowest configuration, in contrast to H^2, and there should be a smaller energy difference between the S and D levels in the unperturbed state.

It is easy to see that the effect of the D function is to decrease the calculated magnetic moments as experiment requires. In the absence of definite evidence to the contrary we may assume that the differences in magnetic moments are entirely due to the different admixtures of D function. Writing the ground state wave function as

$$\Psi=(1+\beta^2)^{-\frac{1}{2}}[\psi(^3S)+\beta\psi(^3D)] \tag{1}$$

we find

$$\beta=\left(\frac{\mu_{H^2}-\mu}{\mu-\mu'}\right)^{\frac{1}{2}}=\begin{cases}0.25 & \text{for } Li^6\\ 2.4 & \text{for } N^{14},\end{cases} \tag{2}$$

in which μ is the observed magnetic moment and $\mu'=\frac{3}{4}-\frac{1}{2}\mu_{H^2}$ is the magnetic moment associated with the D state. These values of β may be compared with the deuteron case where $\beta=0.07$ (neutral meson theory) and $\beta=0.21$ (symmetrical meson theory).[5] For N^{14} the large deviation from the deuteron moment resulting in the large value of β may be due in part to the fact that in the unperturbed state the spin-orbit splitting[6] brings the $^3D_1$ level closer to the $^3S_1$ level in N^{14} whereas in Li^6 the opposite is true. However, it is not likely that this is the sole factor and it is possible that either or both of the following is operative: (1) As the number of particles in the nucleus increases the angular dependent part of the forces becomes predominant or (2) the deviations from the deuteron moment are not entirely due to different admixtures of states with orbital momentum but other effects (influence of binding?) become more important for greater numbers of particles.

As a consequence of the angular dependence of the forces an electric quadrupole moment should be expected for both Li^6 and N^{14}. While no accurate calculation of the magnitude of these moments may as yet be made, approximate methods should be capable of giving the correct sign of the moments. If the Hartree model is used, and if the small effects due to excitation of the alpha-particle core are neglected so that we have essentially a two-body problem, the quadrupole moments calculated for the three nuclei all have positive sign. Part of the inaccuracies inherent in the model may be eliminated by comparing the ratios of the quadrupole moments. We find

$$Q/Q(H^2)=\begin{cases}27.5\beta^2/1+\beta^2 & \text{(neutral theory)}\\ 8.9\beta^2/1+\beta^2 & \text{(symmetrical theory).}\end{cases}$$

The use of these ratios and the observed value of $Q(H^2)$, together with the values of β determined above, amounts to an empirical determination of the fictitious potential used in the Hartree model. This, of course, depends on the validity of the assumption made above in regard to the source of the anomaly in the magnetic moments. If we use the neutral theory, which would be preferred if the deuteron moment is positive,[5] and with $Q(H^2)=2.5\times10^{-27}$ cm^2,[1] the values of β from (2) give $Q(Li^6)=4\times10^{-27}$ cm^2 and $Q(N^{14})=58\times10^{-27}$ cm^2. These values can at best be regarded as an order of magnitude estimate with considerable uncertainty prevailing in the case of the latter. However, a quadrupole moment increasing rather rapidly with increasing mass is to be expected.

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[1] J. M. B. Kellogg, I. I. Rabi, N. F. Ramsey and J. R. Zacharias, Phys. Rev. **55**, 318 (1939).
[2] M. E. Rose and H. A. Bethe, Phys. Rev. **51**, 205, 993 (1937). D. R. Inglis, Phys. Rev. **51**, 531 (1937); **53**, 822 (1938).
[3] D. R. Inglis, Phys. Rev. **55**, 329 (1939).
[4] J. M. B. Kellogg, I. I. Rabi, N. F. Ramsey and J. R. Zacharias, Phys. Rev. **55**, 595 (1939). I. I. Rabi, S. Millman, P. Kusch and J. R. Zacharias, Phys. Rev. **55**, 526 (1939). P. Kusch, S. Millman and I. I. Rabi, Phys. Rev. **55**, 1176 (1939).
[5] H. A. Bethe, Phys. Rev. **55**, 1261 (1939).
[6] D. R. Inglis, Phys. Rev. **50**, 783 (1936).