Secondary Electrons Produced by Mesons

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IN a recent paper[1] Nassar and Hazen have measured the number of secondary electrons in equilibrium with the meson beam at sea level. In particular, they find the number of electrons with energy greater than 10^7 ev to be about 2 percent of the total number of mesons, and state this result to be in disagreement with an early measurement of my own[2] which is quoted to be 4.8 percent of electron secondaries of energy greater than 10^7 ev. This discrepancy arises from a misreading of my paper, in which the incident mesons were divided into two categories, with momenta respectively greater and less than 3×10^9 ev/c, which were considered separately.

The mesons of the high momentum group, comprising about 44 percent of the whole meson beam, were accompanied by about 4.4 percent (of their own number) of electrons; those of the lower momentum group, comprising the remaining 56 percent, were accompanied by only 0.4 percent of electrons. The measurement by Nassar and Hazen is to be compared with the mean value over both groups, taken together, that is, with $(0.44\times4.4+0.56\times0.4)$ percent or 2.2 percent, and not with $(4.4+0.4)$ percent. There is thus no significant discrepancy between the two sets of observations.

[1] S. Nassar and W. Hazen, Phys. Rev. **69**, 298 (1946).
[2] J. G. Wilson, Nature **142**, 73 (1938).

The Hyperfine Structure and Nuclear Moments of Chlorine*

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TWO of us[1] have recently reported an atomic-beam magnetic resonance experiment, in which the hyperfine structure splittings of the ground states of the natural isotopes of potassium were separately observed, with a mass spectrograph supplementing the usual hot wire detector. In the experiments herein reported, a discharge tube, previously used to supply atomic hydrogen, was used to provide a beam of chlorine atoms. To detect the beam, a fraction of the Cl atoms and the Cl_2 molecules are converted to negative ions on evaporation from the usual hot tungsten filament despite its high work function. These ions are then analyzed by the mass spectrograph. We have, therefore, been able to measure the hyperfine structure splittings of the $^2P_{3/2}$ ground states of Cl^{35} and Cl^{37}.

Townes, Holden, Bardeen, and Merritt[2] as well as Gordy, Simmons, and Smith[3] have shown that for Cl^{35} and Cl^{37} the nuclear spin $I=\frac{3}{2}$ and that various molecules exhibit large electric quadrupole interactions. Townes[4] has estimated the nuclear electric quadrupole moments Q from such data.

The energy level system for an atom of nuclear spin $I=\frac{3}{2}$ and electronic state $J=\frac{3}{2}$ is sketched in Fig. 1. The

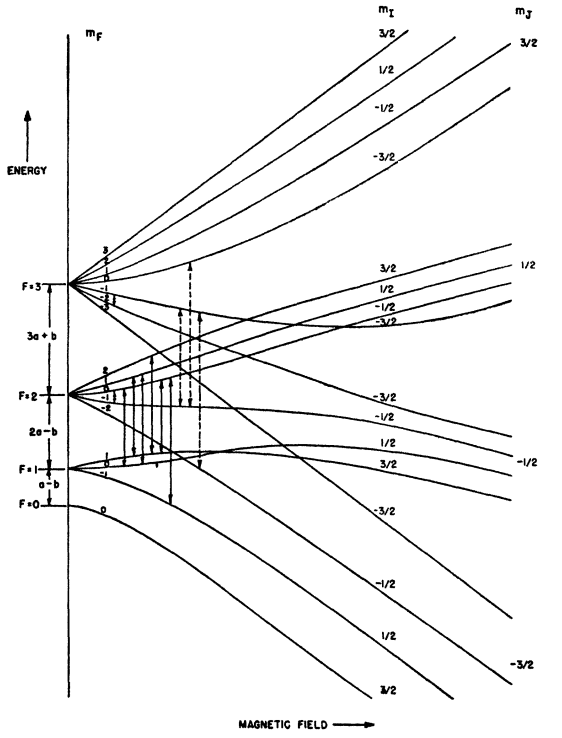

FIG. 1. A rough plot of the h.f.s. level energies as a function of applied magnetic field for a nucleus of $I=3/2$ in an atom with $J=3/2$, derived from the Hamiltonian

$$H=aI\cdot J+b\left\{\frac{3/2(I\cdot J)^2+3/4I\cdot J-\frac{1}{2}I(I+1)J(J+1)}{I(2I-1)J(2J-1)}\right\}+\mu_0 g_J J\cdot H-\mu_0(m/M_P)g_I I\cdot H,$$

for small b/a and $a>0$. The abscissa runs from $x=0$ to ~6, where $x=\mu_0 g_J H/a$.

vertical lines between levels show transitions which can be observed in this apparatus,[5] which requires, for proper refocusing, that m_J change sign. Of the eleven such transitions which obey selection rules $\Delta F=\pm1,0$ $\Delta m_F=\pm1.0$, we have observed 8; 2 for $\Delta F=0$ and 6 for $\Delta F=1$, between $F=2$ and $F=1$. For Cl^{35} these observations were made in the h.f.s. Zeeman region and in the region of intermediate coupling; for Cl^{37}, only in the Zeeman region. A set of lines typical of Cl^{35} at fixed intermediate field is:

$$\begin{aligned}\nu(3,-1\leftrightarrow3,-2)&=35.414\pm0.02\text{ mc/sec.},\\ \nu(2,0\leftrightarrow2,-1)&=36.890,\\ \nu(2,0\leftrightarrow1,1)&=336.266,\\ \nu(2,0\leftrightarrow1,0)&=340.075,\\ \nu(2,1\leftrightarrow1,1)&=368.066,\\ \nu(2,1\leftrightarrow1,0)&=371.872,\\ \nu(2,2\leftrightarrow1,1)&=395.702.\end{aligned}$$

Assuming the hyperfine structure to be given by a magnetic dipole interaction constant a and an electric quadrupole interaction constant b, we can draw the following conclusions:

(1) Both isotopes have nuclear spins $I=\frac{3}{2}$;

(2) the separations $\Delta\nu_{2,1}=2a-b$ are: $(\Delta\nu^{35}{}_{2,1})=355.231\pm0.02$ mgc/sec. and $(\Delta\nu^{37}{}_{2,1})=298.116\pm0.02$ mgc/sec.;

TABLE I.

Isotope	a(mgc/sec.)	b(mgc/sec.)	$Q(10^{-26}$ cm$^2)$ (DFZZ)	$Q(10^{-26}$ cm$^2)$ (Townes)
Cl^{35}	205.2±4.6	55.2±1.2	−7.95±0.2	−6.7
Cl^{37}	170.6±3.9	43.1±1.0	−6.20±0.2	−5.1

(3) $(b/a)^{35}=0.269\pm0.006$;

(4) by observing the trajectory of the atoms giving rise to the line $(2, 0)\rightarrow(1, -1)$ we conclude that the magnetic moment of Cl^{35} is positive, confirming the observation of Kusch and Millman;[6]

(5) assuming their[6] value of $g^{35}/g^{37}=1.203\pm0.005$ to give a^{35}/a^{37}, we obtain the a and b values of Table I.

From atomic h.f.s. measurements of this sort, it is possible to obtain accurate values of the nuclear quadrupole moment Q, without resorting to fine structure data and estimates of an effective nuclear charge Z_i, since both the magnetic dipole and electric quadrupole interactions have the same r dependence on the electronic wave functions. From the formulae for a and b given by Casimir[7] neglecting relativity corrections, we obtain, in an obvious notation:

$$Q=-(b/a)g_I(\mu_0^2/e^2)(m/M_p)(L+1)(2L+3)/J(J+1),$$

and we get the Q values of Table I. The Q values given by Townes[4] are included for comparison.

In view of the fact that Q values can be determined quite accurately, we believe that the significance of these values lies not in the fact that they disagree with the estimates of Townes, but rather that, when combined with microwave spectroscopy measurements of $eQ\partial^2V/\partial z^2$, they provide a method of actually measuring $\partial^2V/\partial z^2$ at the position of the halogen nucleus in a wide variety of molecules.

Values for a and b of considerably greater accuracy can be obtained when the transitions $\Delta\nu_{3,2}=3a+b$ are found. We plan to apply this method to other halogens, including radioactive ones, and to measure the interaction constants to higher precision than the present apparatus can achieve. We believe that ultimately this method is suitable for observing these atomic interactions to a few cycle/sec., for atoms in concentration of less than 10^{-5}.

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[1] L. Davis, Jr. and J. R. Zacharias, Bull. Am. Phys. Soc. **22**, No. 6, B2 (1947).
[2] C. H. Townes, A. N. Holden, J. Bardeen, and F. R. Merritt, Phys. Rev. **71**, 644 (1947).
[3] W. Gordy, J. W. Simmons, and A. G. Smith, Phys. Rev. **72**, 344 (1947).
[4] C. H. Townes, Phys. Rev. **71**, 909 (1947).
[5] J. R. Zacharias, Phys. Rev. **61**, 270 (1942).
[6] P. Kusch and S. Millman, Phys. Rev. **56**, 527 (1939).
[7] H. B. G. Casimir, *On the Interaction Between Atomic Nuclei and Electrons* (Teyler's Tweede Genootshap, Amsterdam, 1936).

Instantaneous Rates of Grain Growth

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PREVIOUS work[1,2] showed that the isothermal increase of the average grain size (D) with the annealing time (t) in high purity aluminum follows the relation

TABLE I. Heat treatment and grain size of specimens.

Specimen No.	Heat treatment	D mm
1	125 min. at 400°C	0.235
2	125 min. at 400°C and 120 min. at 450°C	0.340
3	5 min. at 450°C	0.230
4	125 min. at 450°C	0.344

$$D=K\cdot t^n, \qquad (1)$$

where K and n are parameters depending on the temperature. The exponent n increases from 0.056 at 350°C to 0.32 at 600°C. From (1) the instantaneous rate of growth is

$$dD/dt=nK\cdot t^{n-1}. \qquad (2)$$

Since $n<1$, dD/dt decreases with continued annealing. The absolute value of the negative exponent $n-1$ and, therefore, the rate of decay of dD/dt is increasing with decreasing temperature.

More recent experiments demonstrated that the rate of grain growth in high purity aluminum after 33 percent reduction of area by rolling depends only on the instantaneous grain size and on the temperature, but that it is independent of the particular prior heat treatment used to produce the instantaneous grain size considered. A typical experiment was the following. Four specimens 0.020 in. thick, from ingot No. 18 (see reference 2), were annealed at the temperatures and for the periods given in Table I. The table also gives the average grain sizes obtained.

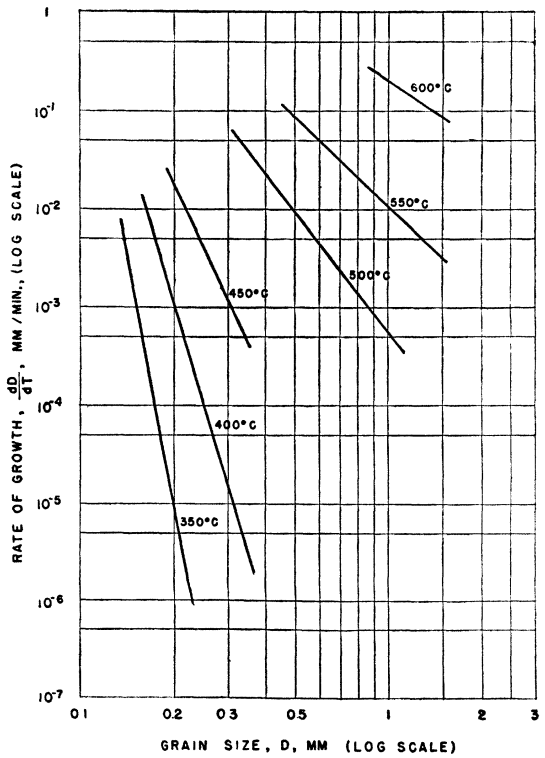

FIG. 1. Rate of grain growth as a function of grain size for aluminum.