separating the collector region C, taken to be n-type from the base B. This base-collector structure resembles an n-p-n transistor, similar to a p-n-p transistor. Holes arriving at M will be held by a "hook" in the potential energy curve and will bias the p-n junction M-C forward and provoke an electron flow from C into M. If M is thin, the electrons will diffuse through it and fall through the potential drop across B-M; B-M is an n-p junction biased in reverse by the collector voltage. The theory of p-n-p transistors can be applied to this process and it can be seen that very high values of α can arise in this way.

I am indebted to many of my colleagues for discussions of theories and experiments related to high values of α.

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[2] This reasoning is very similar to that of L. P. Hunter, Phys. Rev. **77**, 558 (1950).
[3] W. G. Pfann, personal communication.
[4] W. Shockley, Bell Sys. Tech. J. **28**, 435 (1949).

Internal Conversion Coefficients for Co^{60}

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RECENTLY several papers[1,2] have appeared in which the results of elaborate calculations of internal conversion coefficients are given. These are believed to be accurate to a few percent. It was our purpose in undertaking this investigation to attain sufficient accuracy in the experimental determinations to provide a significant test of the theory. For this reason we selected for our first experiments Co^{60} for which the gamma-rays are known to be quadrupole from angular correlation experiments.[3]

The measurements were made by means of a double-coil, thin-lens spectrometer in which considerable care had been taken to reduce the background due to scattering. For the setting used in these experiments the transmission was 2.40 percent and the half-width about 3.0 percent. Since it was necessary for us to use sources of slightly different diameters (ranging from 4.45 to 5.50 mm) we calibrated half-width against source diameter and found a slight increase with source diameter. Accurate knowledge of the half-width is essential to the integration of the β-spectrum. In measuring the transmission of the spectrometer we used the β-spectrum of several Co^{60} sources which had been calibrated by coincidence measurements. Because of window effects our data were not good below about 120 kev and we reconstructed the momentum plot by extrapolating to zero the straight Fermi plot (allowed) observed at higher energies. The end point for the β-spectrum was found to be 318.7±4.0 kev. The Co^{60} used was high specific activity material obtained from the Oak Ridge National Laboratory and was mounted on a 3-ply laminated backing (zapon-Formvar-zapon) and then covered with a single zapon film. Each of these films was less than 30 μg/cm^2. The three strongest sources were less than 0.20 mg/cm^2; the other three used, less than 0.016 mg/cm^2. Effects due to source charging were eliminated. The spectrometer was calibrated against the crystal spectrograph values[4] for the Co^{60} gamma-ray lines.

The values we obtain for the coefficients of conversion in the K, L, M shells together (unresolved) for the two gamma-rays from Co^{60} and the theoretical values[1] of the conversion coefficients for electric quadrupole radiation in the K shell are shown in Table I.

For all other types of radiation the conversion coefficients differ from those for EQ by a factor of at least two. Supposing the L+M conversion and screening effects to contribute about 10 percent, our results classify both gamma-rays as electric quadrupole. Com-

TABLE I. Internal conversion in excited states of Ni^{60}.

E (Mev)	$\alpha_{exp} \times 10^4$	Theoretical value: $\alpha_K{}^{(2)} \times 10^4$
1.1715	1.733 ±0.061	1.545
1.3316	1.286 ±0.035	1.175

parison with angular correlation measurements[3] then fixes the spins and parities of the three nuclear levels involved as: 0, 2, 4; same (even).

Although agreement between theory and experiment seems quite good, more exact comparison cannot be made until the theoretical values for the effects of L+M conversion and screening have been calculated. The present results are in agreement with those published by Deutsch and Siegbahn[5] within the relatively large error of the latter; however, the classification of both gamma-rays now seems unambiguous.

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[2] J. R. Reitz, Phys. Rev. **77**, 10 (1950).
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Comment on Mobility Anomalies in Germanium

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IT appears probable that the simple theory of spherical energy surfaces in the Brillouin zone for both holes and electrons in germanium may have to be modified in view of experimental results on mobility and magneto-resistance.

In this letter we shall quote the results of three methods of determining mobility:

Drift mobility. The technique of obtaining the mobility of injected current carriers in germanium by the direct measurement of their transit times over known distances and under the influence of known electric fields has been improved so that measurements with an error of less than 5 percent are obtained. This improvement over earlier equipment[1,2] consists largely in the substitution of pulse techniques for d.c. measurements leading to an unambiguous determination of transit time. The measurements include data on samples of both n- and p-type single crystals as well as on crystals grown by different techniques.

Hall mobility. Only under certain simplifying assumptions is $(8/3\pi)R\sigma$ theoretically equal to the mobility. We shall refer to the experimentally determined value of $R\sigma$ as the *Hall mobility*. Hall mobilities were obtained using the identical samples described above, excepting that the electron mobility values were obtained on n-type material and hole mobility on p-type, the reverse of the drift experiment. The most probable values for $(8/3\pi)$ times the Hall mobility are 1700 cm^2/volt-sec. for holes and 2600 cm^2/volt-sec. for electrons[3] although the experimental accuracy of this method is equal to that of the drift method, the spread in mobility values from sample to sample is much larger, being 1600 to 2200 cm^2/volt-sec. for holes and 2400 to 2900 cm^2/volt-sec. for electrons. (We do not find the large spreads or very high values reported by Dunlap.[4])

Conductivity mobility. Samples of germanium with radioactively determined concentrations of added antimony were found to have a conductivity which was linear in the added antimony and corresponded[5] to the mobility given in Table I. The experimental

TABLE I. Mobilities in cm^2/volt-sec. in germanium.

	$(8/3\pi) \times$Hall mobility	Drift mobility	Conductivity mobility
Electrons	2600 ±300	3600 ±180	3350 ±400
Holes	1700 +500 −100	1700 ±90	

uncertainty in this work was quite large, due in part to grain boundary effects for which corrections were attempted. Agreement between drift and conductivity mobility is to be expected unless electron-hole collisions are important or appreciable trapping is involved, neither of which is probable for germanium.

An interpretation, planned for later publication, of the Hall coefficient formula[5a] shows that the Hall mobility may be much

less than the drift mobility for re-entrant energy surfaces like those possible for degenerate energy bands[6] and, in fact, may even change sign.

Further evidence that the energy bands are not spherical is furnished by the large and anisotropic magneto resistance effects in germanium single crystals.[7]

We are indebted to Drs. J. Bardeen and F. Seitz for helpful discussions of the theory.

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[3] G. L. Pearson, Phys. Rev. 76, 179 (1949).
[4] W. C. Dunlap, Jr., Phys. Rev. 77, 759 (1950).
[5] Pearson, Struthers and Theuerer, Phys. Rev. 75, 344 (1949); 77, 809 (1950).
[5a] A. H. Wilson, The Theory of Metals (Cambridge University Press, London, 1936), Eq. (362).
[6] W. Shockley, Phys. Rev. 78, 173 (1950).
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l-Type Doubling in OCS and HCN

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THE two components of the rotation-vibration states of a linear molecule in an excited perpendicular vibration level are separated by l-type doubling, l being the quantum number of angular momentum so that $l = V$, $V-2$, $\cdots 0$ or 1). The doubling is predicted by theory[1] to be $\Delta\nu = qJ(J+1)$ where $q = q_0(V_s+1)$ $= (B_e^2/\omega_s)[1 + 4\sum_{s'} \xi_{ss'}^2 \lambda_s/(\lambda_{s'}-\lambda_s)](V_s+1)$ when $|l| = 1$, ω_s being the degenerate vibration frequency and $\xi_{ss'}$ the Coriolis coupling factors. Recent measurements by Shulman and Townes[2] have shown that q is, indeed, proportional to (V_s+1), thereby verifying one phase of the theory of l-type doubling. Calculations on the quantities q_0 for comparison with experimental values have been impeded largely because of the complicated nature of $\xi_{ss'}$. We shall report in this letter on the evaluation of q_0 for two molecules, namely OCS and HCN.

The quantities $\xi_{ss'}$ have been determined by A. H. Nielsen[3] for the linear XYZ molecule. He gives the following values

$$\xi_{21} = -[M_1 M_3/\sigma I^{(e)}]^{\frac{1}{2}}(Z_1^0 - Z_3^0)\cos\gamma - [M_2 \Sigma/\sigma I^{(e)}]^{\frac{1}{2}} Z_2^0 \sin\gamma$$

and

$$\xi_{23} = [M_1 M_3/\sigma I^{(e)}]^{\frac{1}{2}}(Z_1^0 - Z_3^0)\sin\gamma - [M_2 \Sigma/\sigma I^{(e)}]^{\frac{1}{2}} Z_2^0 \cos\gamma,$$

where M_2 is the central atom, $\sigma = M_1 + M_3$, $\Sigma = M_1 + M_2 + M_3$, Z_i^0, the equilibrium values of the coordinates and

$$\left.\begin{array}{l} \sin\gamma \\ \cos\gamma \end{array}\right\} = \pm 2^{-\frac{1}{2}}\{1 \pm [(k_1-k_3)^2(4k_4^2-(k_1-k_3)^2)]^{\frac{1}{2}}\}.$$

The constants k_i are defined as follows: $k_1 = \Re_1/\mu_1^{\frac{1}{2}}$, $k_3 = \Re_3/\mu_3^{\frac{1}{2}}$, $k_4 = \Re_4/(\mu_1\mu_3)^{\frac{1}{2}}$ with $\mu_1 = M_1 M_3/(M_1+M_3)$ and $\mu_3 = M_2\sigma/\Sigma$ and $\Re_1 = \{K_1(M_3/\sigma)^2 + K_2(M_1/\sigma)^2\}$, $\Re_3 = K_1 + K_2$, $\Re_4 = \{-K_1(M_3/\sigma) + K_2(M_1/\sigma)\}$, where K_i are the valence force constants of $2V = K_1\delta Q_1^2 + K_2\delta Q_2^2$ in which $\delta Q_1 = Z_2 - Z_1$, and $\delta Q_2 = Z_3 - Z_2$. One may, moreover, quickly show that $\sum_{s'} \xi_{ss'}^2 = 1$.

The force constants K_1 and K_2 used in this calculation have been taken from the tables of Herzberg[4] and are the following: $K_1 = 8\times10^5$ dynes/cm, $K_2 = 14.2\times10^5$ dynes/cm for OCS and $K_1 = 5.8\times10^5$ dynes/cm, $K_2 = 17.9\times10^5$ dynes/cm for HCN. Computation of the quantities $\xi_{ss'}$ for these molecules is now a simple matter. These in turn lead to values of $q_0 = 3.17$ Mc/sec. for OCS which is in complete agreement with the measured value[1] and $q_0 = 113.6$ Mc/sec. for HCN which is about 2 percent in excess of the measured value 111.8 Mc/sec. given by Shulman and Townes. When one considers that the K_1 and K_2 were determined from the band centers and not from the harmonic frequencies this agreement must be regarded as satisfactory.

Shulman and Townes have, moreover, reported a higher order effect in the l-type doubling of HCN. This manifests itself in a deviation of the quantity $q/J(J+1)$ which is proportional to J and of the order of magnitude $q(B_e/\omega_s)$. We have attempted to

calculate this effect which involves a fourth-order perturbation calculation. We find a correction to the $(l/l\pm2)$ components of the energy matrix of a little more than $2B_e(B_e/\omega_s)^3(V_s+1)J^2(J+1)^2$. The following argument which is of a symmetry nature, may be used to support this. The correction required must be a correction to the (l/l) or the $(l/l\pm2)$ elements, and since for linear molecules $l = K$, also to the (K/K) and $(K/K\pm2)$ elements of the energy matrix. The matrix components must contain terms proportional to J^3 if the deviation to $q/J(J+1)$ is to be proportional to J. Such terms can arise only from terms in the Hamiltonian of the molecule proportional to P_x and P_y to some odd power. Such terms have only $(K/K\pm1)$, $(K/K\pm3)\cdots$elements and, therefore, only $(l/l\pm1)$, $(l/l\pm3)\cdots$elements.

The differences between the deviations in the states $J = 8$ and $J = 10$, and $J = 10$ and $J = 12$ have been calculated by our method. One obtains 0.13 Mc/sec. and 0.16 Mc/sec. respectively compared to 0.18 Mc/sec. measured for both of these instances. While the data of Shulman and Townes certainly fit a linear relation better than the one derived here, it is suggested that the next approximation may bring the two into agreement and that to this approximation our expression is substantially correct.

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Proton Groups from the Alpha-Particles Bombardment of Beryllium*

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BOMBARDMENT of a 0.23 mg/cm^2 surface density metallic beryllium target with 21.94 Mev alpha-particles from the cyclotron has produced four proton groups. We have calculated Q-values for the reaction $Be^9(\alpha,p)B^{12}$ and three energy levels of B^{12} and have obtained a value for the mass of B^{12}.

Protons emerging from the target at 90° from the incident beam were counted by means of a dual proportional counter in a coincidence and discriminator circuit as described by Brolley, Sampson, and Mitchell.[1] The pulse discriminator was adjusted so that only pulses were counted which corresponded to the peak of the Bragg curve. Proton energies were calculated from aluminum absorption using unit absorber foils of 1.06 mg/cm^2 surface density. The alpha-particle beam energy was measured by aluminum absorption after scattering from a gold foil of 0.17 mg/cm^2 surface density. The residual range of the counter and the surface density of the beryllium target were measured with the aid of thorium C' alpha-particles. The beryllium target was prepared by vacuum evaporation from a tungsten filament. Smith's calculations[2] were used in determining proton energies from aluminum absorption.

Proton groups, relative intensities and calculated Q-values and excitations are given in Table I.

The -7.02 Mev Q-value of our end group gives a calculated atomic mass of 12.01839 for B^{12} which may be compared with the value 12.01827 ± 0.00009 calculated by Hornyak and Lauritsen.[3]

A low intensity proton group of 2.98 Mev energy was observed with variable intensity with different beryllium targets and is

TABLE I. Proton groups from $Be^9(\alpha,p)B^{12}$.

Proton energy Mev	Relative intensity	Q-value (Mev)	B^{12} energy level (Mev)
7.02	1	−7.02	0
6.06	2	−8.06	1.04
5.26	25	−8.93	1.91
3.25	40	−11.11	4.09