TABLE I. Angular distributions of the 14-Mev and 17-Mev gamma-rays. Relative intensity $=I$. Ratio of relative intensity, $R=I_{17}$ Mev$/I_{14}$ Mev. Absolute intensity ratio, 17 Mev/14 Mev $=cR$.

Type of radiation	Angle in degrees	I_{14} Mev	I_{17} Mev	R	c*
440-kev resonance	0	1.00 ± 0.07	1.00 ± 0.07	1.00 ± 0.06	1.70 ± 0.20
radiation.	35	0.97 ± 0.07	1.03 ± 0.07	1.06 ± 0.06	
$E_p=0.50$ Mev	70	0.98 ± 0.07	0.99 ± 0.07	1.01 ± 0.06	
Nonresonant	0	1.00 ± 0.05	1.00 ± 0.05	1.00 ± 0.05	0.62 ± 0.07
radiation.	35	0.74 ± 0.06	0.69 ± 0.06	0.94 ± 0.08	
$E_p=1.15$ Mev	75	0.77 ± 0.05	0.56 ± 0.05	0.72 ± 0.05	

* The value of c, the ratio of absolute intensities in the forward direction, was obtained from a weighted average of the present data and earlier data of Walker and McDaniel. Corrections have been made for the variation with energy of the spectrometer detection efficiency. Resolution width, loss from vertical scattering, and pair cross section have been considered. Stated errors are standard deviations based on statistics and estimated accidental errors.

The nonresonant radiation is strongly anisotropic, and the angular distribution is clearly different for the two gamma-ray components.

Following Devons' arguments concerning the resonance radiation, one may suggest the following level assignments. Because of the isotropy of both components under resonance excitation, the resonance level is produced by s-protons and has an angular momentum $J=1$ and odd parity. Since the separate angular distributions of the two lines for nonresonant excitation are anisotropic and different from each other, it is likely, though not necessary, that the 2 lower states have different angular momenta. The long lifetime[7] of the Be^8 ground state would seem to favor the assignment of $J=2$, even, to that state and $J=0$, even, to the 3-Mev level. The separate angular distributions of the two components of the nonresonant radiation are not consistent with the angular distribution $(1+a\cos^2\theta)$ which would exist if p-protons alone caused this radiation. It is therefore likely that the s-protons which produce the resonant radiation, or d-protons forming some higher level, are interfering with the p-protons in producing the nonresonant radiation at these energies.

* Assisted by the ONR.
[1] S. Devons and M. G. N. Hine, Proc. Roy. Soc. (London) **A199**, 56 (1949).
[2] S. Devons and G. R. Lindsey, Proc. Phys. Soc. (London) **A63**, 1202 (1950).
[3] Nabholtz, Stoll, and Wäffler, Helv. Phys. Acta **23**, 858 (1950).
[4] E. R. Cohen, Phys. Rev. **75**, 1463A (1949).
[5] R. F. Christy, Phys. Rev. **75**, 1464A (1949).
[6] R. L. Walker and B. D. McDaniel, Phys. Rev. **74**, 315 (1948).
[7] C. H. Millar and A. G. W. Cameron, Phys. Rev. **79**, 182L (1950).

Microwave Collision Diameters and Associated Quadrupole Moments*

R. M. HILL AND WILLIAM V. SMITH
Department of Physics, Duke University, Durham, North Carolina
(Received February 23, 1951)

In recent papers[1,2] Smith and Howard reported an investigation of the broadening of the 3-3 inversion line of NH_3 by other gases. From the data obtained, they calculated a collision diameter for the NH_3-foreign gas collision. In the cases for which this diameter was markedly greater than that obtained from kinetic theory, the collision was ascribed to the interaction of the NH_3 dipole moment and a permanent electric quadrupole moment (averaged over the rotation)[2] of the foreign gas. The quadrupole moments for these gases were calculated.

Anderson[3] has since shown that the interaction of the quadrupole moment of NH_3, calculated from its structure, and the dipole induced in the foreign gas gives a collision diameter in good agreement with those molecules whose experimental collision cross sections approached kinetic theory values. However, for N_2 and others this diameter is too small, and the assignment of a permanent electric quadrupole to these molecules seems justified.

TABLE I. Collision diameters (b) of NH_3 with various colliding molecules.

Gas	$b\times10^8$ (cm) (microwave)	$b\times10^8$ (cm) (kinetic theory)	Polarization (α) $\times10^{24}$ [a]	$b\times10^8$ (cm) (Anderson)	Quadrupole moment (Q) $\times10^{16}$ (cm²)
C_2H_2	8.79		3.33	3.92	1.1
C_2H_4	6.67	4.79[b]	4.27	4.09	0.48
C_2H_6	5.64	4.86[b]	4.53	4.15	(0.28)
C_6H_6	9.76	4.50[c]	10.32	4.85	1.3
N_2O	7.32	4.35[d]	2.99	3.89	0.59
NO	5.64	3.90[d]	1.72	3.52	0.28
CO	5.97	3.96[d]	1.95	3.59	0.34

[a] H. A. Stuart, *Molekulstruktur* (Verlag. Julius Springer, Berlin, 1934).
[b] E. H. Kennard, *Kinetic Theory of Gases* (McGraw-Hill Book Company, Inc., New York, 1938), p. 149.
[c] Landolt-Bornstein, *Phys. Chem. Tab.*, Eg. I (a), p. 105.
[d] L. Loeb, *Kinetic Theory of Gases* (McGraw-Hill Book Company, Inc., New York, 1934), p. 651.

The NH_3 3-3 line breadth has been measured for mixtures of NH_3 with several more gases, using the same experimental technique as in reference 1. The results obtained are listed in Table I. For the gases investigated, either the dipole moment or its average over a collision was zero, and the collision may be described by an interaction other than dipole-dipole.

The diameters calculated from Anderson's formula are quite a bit lower than those found from broadening data, and except for C_2H_6 a quadrupole moment has been given. For C_2H_6 the microwave diameter is sufficiently close to the kinetic theory diameter that the quadrupole moment is given only as an upper limit.

For the C_2H_2, C_2H_4, C_2H_6 series the microwave diameter and associated quadrupole moment are seen to increase with the order of the C—C bond, indicating an increase in the asymmetry of the charge distribution. The moments obtained for NO and CO are very close to that for N_2 found by Smith and Howard, while the quadrupole moment for N_2O agrees very well with their values for COS, CS_2, and CO_2.

Further work in the interpretation of these data is in progress.

* The research reported in this document has been made possible through support and sponsorship extended by the Geophysical Research Directorate of the Air Force Cambridge Research Laboratories. It is published for technical information only and does not represent recommendations or conclusions of the sponsoring agency.
[1] R. R. Howard and W. V. Smith, Phys. Rev. **79**, 128 (1950).
[2] W. V. Smith and R. Howard, Phys. Rev. **79**, 132 (1950).
[3] P. W. Anderson, Phys. Rev. **80**, 511 (1950).

Survey Experiment on Elastic Scattering*

JACK W. BURKIG AND BYRON T. WRIGHT
Department of Physics, University of California, Los Angeles, California
(Received March 19, 1951)

USING cameras similar to those described by Fulbright and Bush[1] two survey experiments on the elastic scattering of protons have been performed.

In one, the angular dependence of the differential elastic cross section in the range 26° to 106° was measured at 15° intervals for the elements W, Pd, Ni, and Al. The proton beam energy, as determined from the magnetic field strength and the camera geometry, was 18.6 ± 0.4 Mev. The total energy spread at the half-maximum intensity of the incident beam was less than 1 Mev. The circulating beam was scattered by wires 0.001 in. in diameter.

The camera used in this experiment had three slits. In a single run the relative values of the elastic scattering at three angles could be obtained. The measurements were extended to other angles by overlapping sets of observations.

The relative values of the cross sections were then determined by counting the number of tracks per unit area in the elastic lines which appear on the developed film.

The results of this experiment are shown in Fig. 1. We have plotted $\ln(\sigma_o/\sigma_R)$ *vs* θ, where σ_o is the observed cross section, σ_R is that expected for Rutherford scattering, and θ is the angle

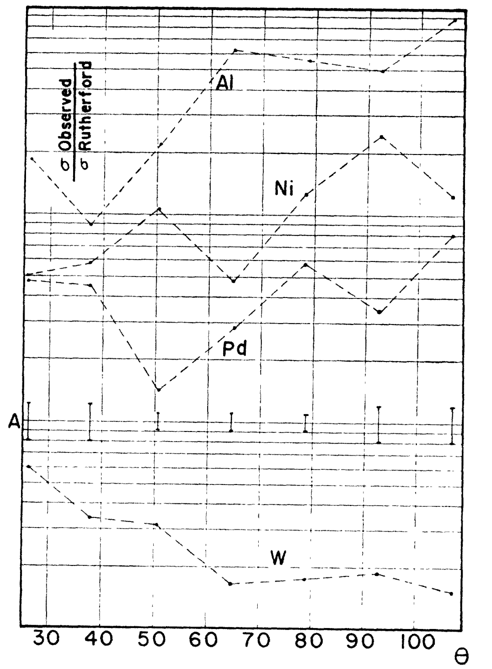

FIG. 1. A plot of the logarithm of the ratio of the observed elastic scattering to Rutherford scattering *vs* the scattering angle θ for 18.6-Mev. protons. The relative vertical position of the four curves has no significance.

through which the protons are scattered. No scale for the ordinates is indicated, since none would be significant. The relative vertical position of the four curves is not significant. They are presented on the same figure merely as a matter of convenience. The vertical lines along the horizontal line A indicate the probable errors in the various observations. The procedure of overlapping sets of observations leads to a larger probable error for the smallest and largest angles.

The W elastic scattering decreases monotonically below the Rutherford dependence; the Ni scattering has an average dependence the same as that expected for Rutherford scattering; and the Al definitely decreases less rapidly than would be expected for the case of Rutherford scattering. In addition, there are considerable deviations for Pd, Ni, and Al about their average angular dependence. A certain amount of progress has been made toward the description of the Al results in terms of a nuclear model which gives a sticking probability dependent on the angular momentum.[2]

By using a pair of cameras very near one another, the cross section for elastic scattering at 78.7±0.5° of a number of elements

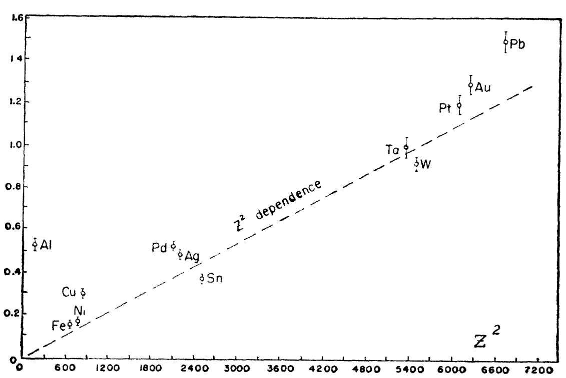

FIG. 2. For scattering at 78.7°, a plot of the ratio of the scattering by various elements relative to W *vs* the square of the atomic number Z.

relative to W was measured. The mass per unit length of the scattering wires was obtained with a quartz torsion microbalance. The reference wire was W in all cases except for four cross check runs. The results of this experiment are shown in Fig. 2. The ratios have probable errors varying from six to nine percent. In view of the marked angular dependence indicated in Fig. 1, the results of the scattering at a fixed angle, shown in Fig. 2, would appear to have little chance of interpretation at the present time.

* This work was supported in part by the joint program of the ONR and AEC.

[1] H. W. Fulbright and R. R. Bush, Phys. Rev. **74**, 1323 (1948).
[2] R. LeLevier and D. S. Saxon (private communication).

Relative Back-Scattering of Electrons and Positrons

WILLIAM MILLER
National Bureau of Standards, Washington, D. C.
(Received March 13, 1951)

RECENT measurements by Seliger[1] have indicated a significant difference in the back-scattering coefficients, β^- and β^+, for electrons and positrons. For isotropic sources of electrons and positrons with energies of the order of 0.5 Mev, and several scattering media with Z values ranging from 4 to 82, it was found that $\beta^-/\beta^+ \sim 1.3$.

Seliger suggested that this different behavior of electrons and positrons might result simply from their different cross sections for elastic single scattering at relativistic energies.[2] The ratio of the electron and positron cross sections for 90° scattering at 1.7 Mev is as large as 4, but the ratio approaches 1 at lower energies and for small angle scattering. The cumulative effect of small angle single scatterings constitutes the main source of the diffusion and back-scattering of electrons. Therefore, it is not immediately apparent that the difference of electron and positron scattering, while obviously in the right direction, is actually adequate to account quantitatively for the observed effect.

No detailed theory of back-scattering is available, but Bothe[3] has evaluated the back-scattering coefficient β approximately by considerations modeled on the neutron "albedo" theory. In the treatment of Bothe, the main parameter controlling the value of β is the ratio of the "true" range R of a particle in the scattering medium to the "scattering length" λ_s (inversely proportional to $\int_0^\pi \sigma(\theta)(1-\cos\theta)\sin\theta d\theta$), that is, $\beta=\beta(R/\lambda_s)$. Bothe computed λ_s from a nonrelativistic differential single-scattering cross section $\sigma(\theta)$, i.e., in essence a Rutherford cross section, equal for electrons and positrons.

A new evaluation based on relativistic cross sections has been made for the purpose of estimating the magnitude of the effect under consideration. The theoretical data of Bartlett, Watson, and Massey[2] on the cross section for single scattering of 500-kev electrons and positrons in mercury were inserted in the Bothe formulas. The λ_s values for electrons and positrons were calculated by approximating the $\sigma(\theta)$ by simple functions and doing the integral analytically. Since there is no reason to expect an appreciable difference in the ranges of the two types of particles, the range R for 500-kev electrons and positrons in mercury was taken as 0.030 cm.

The resulting values of R/λ_s for erectrons and positrons are 18.1 and 12.4, respectively. Table I shows a comparison of the values of λ_s, R, R/λ_s from the present calculation and of the corresponding values derived from Bothe's nonrelativistic for-

TABLE I. Comparison of calculated values with those of Bothe's theory.

		$1/\lambda_s$ (cm^{-1})	R (cm)	R/λ_s	β
Present calculation	Electrons	$605=1.39Z^2\rho/A$	$0.03=0.163A/Z\rho$	18.1	0.59
	Positrons	$414=0.95Z^2\rho/A$		12.4	0.51
Bothe		$(400/V)^2Z^2\rho/A$ $=0.64Z^2\rho/A$	$1.25\times10^{-6}V^2A/Z\rho$ $=0.31A/Z\rho$	$0.2Z$ $=16$	0.56