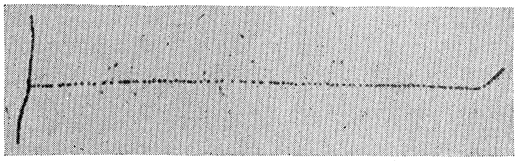

FIG. 1. Ternary fission: third fragment—mass≈9, range = 17 cm air equivalent.

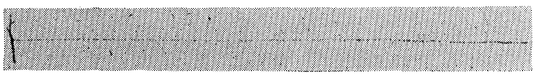

FIG. 2. Ternary fission: third fragment—mass≈6, range = 44 cm air equivalent. The two branches on one of the heavy fragments are caused by nuclear collisions.

1 and 2). Precise analysis, based on the conservation of momentum, shows that it is impossible to describe all of them as branches caused by a collision of the fission fragment at the beginning of its range, with a known nucleus contained in the emulsion (such as H, C, N, O, Br, and Ag). It seems more plausible to conclude that these are fissions of uranium into three charged fragments (ternary fission).

Taking account of the measured angles and ranges, and of the velocity-range relation of heavy ions,[4] and requiring conservation of momentum, we can determine the mass and energy of each fragment. The distribution of masses of the three fragments is shown in Fig. 3: the two heavy fragments have average masses of 99 and 131, respectively, the third fragment seems to have two probable values, one about 5 or 6, the other about 9.[5] The average total kinetic energy of ternary fission is 165 Mev, slightly higher than that of binary fission. If the total internal excitation energy is about the same for binary and ternary fission fragments, the agreement between the observed kinetic energy and the theoretical value may be regarded as satisfactory.

The ratio of ternary fission to binary fission is 0.003 ± 0.001. This value may be regarded as the lower limit, because certain cases with a heavier third fragment are discounted from the statistics owing to the possibility of attributing them to nuclear collisions.

(*B*) *Quaternary fission.* Besides those of ternary fissions, we have observed some cases which cannot be explained otherwise than by fission into four charged fragments (quaternary fission). One of these has already been described in detail (Fig. 4).[6] It seems interesting to indicate that the observed ternary fissions are almost all of the same type, i.e., two heavy, and one light; whereas the

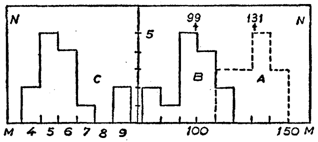

FIG. 3. Distribution of masses of ternary fission fragments.

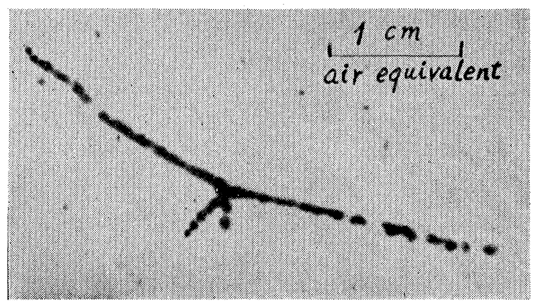

FIG. 4. Quaternary fission.

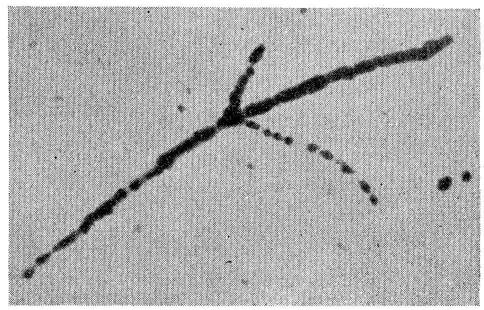

FIG. 5. Quaternary fission. (In same scale as Fig. 4.)

quaternary fissions may occur in various fashions: (1) two heavy, and two relatively light (Fig. 4), (2) three heavy, and one light (Fig. 5). If the total internal excitation energy is about the same for binary and quaternary fission fragments, the mean observed kinetic energy for the latter, about 110 Mev, is in good agreement with that estimated by Bohr and Wheeler.[1,5] The ratio of quaternary fission to binary fission is 0.0003 ± 0.0002.

The detailed report of this work will be published shortly in *Journal de Physique et le Radium.*

[1] N. Bohr and J. A. Wheeler, Phys. Rev. **56**, 426 (1939). R. D. Present, Phys. Rev. **59**, 466 (1941).
[2] C. F. Powell, C. P. S. Occialini, D. L. Livesey, and L. V. Chilton, J. Sci. Inst. **23**, 102 (1946).
[3] Tsien San-Tsiang, R. Chastel, Ho Zah-Wei, and L. Vigneron, Comptes rendus **223**, 986 (1946).
[4] J. K. Bøggild, K. J. Brostrøm, and T. Lauristen, Kgl. Danska Vid. Sels. Math.-Fys. Medd **18**, 1 (1940). O. J. Knipp and E. Teller, Phys. Rev. **59**, 659 (1941). F. Joliot, Comptes rendus **218**, 488 (1944).
[5] Tsien San-Tsiang, Ho Zah-Wei, R. Chastel, and L. Vigneron, Comptes rendus **224**, 272 (1947).
[6] Ho Zah-Wei, Tsien San-Tsiang, L. Vigneron, and R. Chastel, Comptes rendus **223**, 1119 (1946). In the table of this article, the data under the columns M_3 and M_4 should be exchanged. Similarly, those under E_3 and E_4 should also be exchanged.

Microwave Absorption Frequencies of $N^{14}H_3$ and $N^{15}H_3$

W. E. GOOD AND D. K. COLES
Westinghouse Research Laboratories, East Pittsburgh, Pennsylvania
February 19, 1947

FIFTY microwave absorption lines of $N^{14}H_3$ and $N^{15}H_3$ have been observed in the region between 19,000 and 26,000 mc/s.[1–5] We have now remeasured the frequencies of all of these lines with a precision of better than one part

TABLE I. Microwave absorption frequencies in ammonia.

J	K	$N^{14}H_3$	$N^{15}H_3$
1	1	23,694.49 mc/s	22,624.96 mc/s
2	2	23,722.63	22,649.85
2	1	23,098.79	22,044.28
3	3	23,870.13	22,789.41
3	2	22,834.17	21,783.98
3	1	22,234.53	21,202.30
4	4	24,139.41	23,046.10
4	3	22,688.29	21,637.91
4	2	21,703.36	20,682.87
4	1	21,134.29	—
5	5	24,532.98	23,421.99
5	4	22,653.00	21,597.86
5	3	21,285.27	20,272.04
5	2	20,371.46	—
6	6	25,056.02	23,922.32
6	5	22,732.43	21,667.93
6	4	20,994.61	—
6	3	19,757.57	—
7	7	25,715.17	24,553.42
7	6	22,924.94	21,846.41
7	5	20,804.83	—
8	8	—	25,323.51
8	7	23,232.24	22,134.89
8	6	20,719.21	—
9	8	23,657.48	22,536.26
9	7	20,735.44	—
10	9	24,205.29	23,054.97
10	8	20,852.51	—
11	10	24,881.90	—
11	9	21,070.70	—
12	11	25,695.23	—

in a million. The standard frequency transmissions of the National Bureau of Standards Station, WWV, were used as the basis of these measurements in order to obtain the necessary precision. These absorption lines should now provide excellent secondary frequency standards in the region mentioned.

Harmonics, from a 240 mc/s crystal controlled oscillator, falling in the above region were used as frequency markers. Interpolation between the markers was done with a calibrated communication receiver. It is estimated that the values in Table I are accurate to ±0.02 mc/s.

[1] B. Bleaney and R. P. Penrose, Nature **157**, 339 (1946).
[2] W. E. Good, Phys. Rev. **70**, 213–218 (1946).
[3] C. H. Townes, Phys. Rev. **70**, 665 (1946).
[4] D. K. Coles and W. E. Good, Phys. Rev. **70**, 979 (1946).
[5] Dailey, Kyhl, Strandberg, Van Vleck, and Wilson, Phys. Rev. **70**, 984 (1946).

Proton-Proton Scattering at 10 Mev

ROBERT R. WILSON*
Harvard University, Cambridge, Massachusetts
February 23, 1947

THE 10-Mev protons available from the sixty-inch cyclotron at the Radiation Laboratory of the University of California have been used for studying the scattering of protons by protons. Coincidences between the scattered and recoil protons were measured as a function of the angle of the scattered protons utilizing the same method and equipment which had been developed at Princeton University[1] for use with 8-Mev protons.

A scattering foil of Nylon $(C_{12}H_{22}N_2O)_x$ about 2×10^{-4} cm thick was placed at the center of the scattering chamber such that the normal to the plane of the scattering foil made an angle of 30° with the direction of the incident proton beam which was 2.0 mm in diameter. The scattered protons were counted with a proportional counter, the "defining counter," which had a circular aperture of 1.65 mm diameter 7.8 cm from the center of the scattering foil. Another proportional counter, the "monitor counter," was mounted such that it received the recoil protons at 90° with respect to the defining counter. It had an oval aperture $\frac{3}{16}''$ wide and $\frac{3}{8}''$ high and was only 3.7 cm from the scattering foil. Coincidences between the defining counter and the monitor counter were registered. The solid angle of the monitor counter was large to insure that the recoils of all protons entering the defining counter would also enter the monitor counter.

The proton integrator consisted of a 2.10 mf condenser which was connected between the Faraday collector cup and ground. The charge collected on the condenser during a ten-minute run was measured at the end of each run using a ballistic galvanometer.[2] The system was not accurately calibrated since all the measurements were relative. It was not convenient to vary the magnetic field or frequency of the sixty-inch cyclotron, which customarily accelerates deuterons of α-particles, so molecular hydrogen ions of unit charge were accelerated to 20 Mev, thus giving the equivalent of 10-Mev protons. This energy was determined by accurate range measurements made on the scattered protons. Thus the protons scattered at 30.5° had a mean range of 0.097 mg/cm² in aluminum, corresponding to an energy of 7.35 Mev or 9.9[4] Mev for the incident protons.

At each angle of scattering a counting plateau was established by measuring the number of coincidences per incident proton as a function of the discriminator biases. Good plateaus were found for all angles except 12° where it was necessary to extrapolate to zero bias, thereby introducing a correction of 9 percent. The accidental

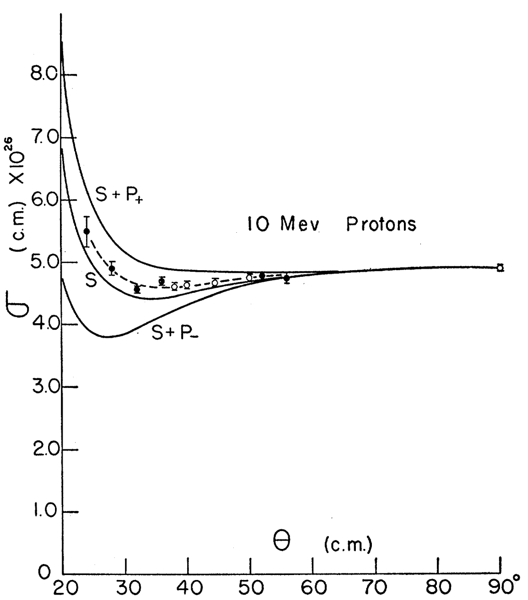

FIG. 1. The cross section per unit solid angle in the center of mass system as a function of the scattering angle in the center of mass system. All the data are relative.