TABLE I. Mass of air contained in a column of unit cross section from outside the earth's atmosphere to a specific station within the atmosphere z kilometers above the surface along a path of zenith angle ξ.

z km	$M(z,\xi)$ g/m^2 $\xi=0°$	30°	60°	75°	80°	85°	87.5°	90°	Max ξ	$M(z,\xi_{max})$
0	1.07×10^7	1.24×10^7	2.13×10^7	4.07×10^7	5.95×10^7	1.09×10^8	1.78×10^8	3.74×10^8	90°	3.74×10^8
5	5.73×10^6	6.61×10^6	1.14×10^7	2.18×10^7	3.20×10^7	5.90×10^7	9.72×10^7	2.14×10^8	92°16.3′	6.45×10^8
10	2.81×10^6	3.24×10^6	5.58×10^6	1.07×10^7	1.57×10^7	2.90×10^7	4.82×10^7	1.10×10^8	93°12.5′	7.07×10^8
15	1.30×10^6	1.50×10^6	2.60×10^6	4.97×10^6	7.28×10^6	1.35×10^7	2.24×10^7	5.16×10^7	93°55′	7.32×10^8
20	5.93×10^5	6.84×10^5	1.18×10^6	2.26×10^6	3.31×10^6	6.11×10^6	1.01×10^7	2.33×10^7	94°32′	7.41×10^8
30	1.32×10^5	1.53×10^5	2.64×10^5	5.04×10^5	7.37×10^5	1.35×10^6	2.22×10^6	4.96×10^6	95°33′	7.47×10^8
40	3.54×10^4	4.09×10^4	7.06×10^4	1.35×10^5	1.97×10^5	3.59×10^5	5.82×10^5	1.24×10^6	96°24.5′	7.48×10^8
50	1.05×10^4	1.21×10^4	2.08×10^4	3.98×10^4	5.81×10^4	1.06×10^5	1.73×10^5	3.70×10^5	97°9.5′	7.48×10^8
60	3.00×10^3	3.46×10^3	5.99×10^3	1.14×10^4	1.67×10^4	3.07×10^4	5.02×10^4	1.09×10^5	97°50′	7.48×10^8
70	770	890	1.54×10^3	2.93×10^3	4.30×10^3	8.00×10^3	1.34×10^4	3.13×10^4	98°27.5′	7.48×10^8
80	141	163	282	538	789	1.47×10^3	2.49×10^3	5.97×10^3	99°2′	7.48×10^8
100	5.92	6.82	11.8	22.5	32.9	60.2	98.5	222	100°5′	7.48×10^8
120	0.539	0.622	1.08	2.03	2.94	5.25	8.25	16.4	101°2′	7.48×10^8
150	0.0493	0.0569	0.0907	0.184	0.264	0.455	0.680	1.21	102°19′	7.48×10^8

90 km. This factor would be reflected in the total air mass beginning gradually at stations somewhat below 50–60 km.

The mass $M(z,\xi)$ of a column of unit cross section of air in a given direction ξ degrees from the zenith above a station z kilometers above the surface of the earth is

$$M(z,\xi)=\int_z^\infty \rho(y)dy \Big/ \left[1-\left(\frac{R+z}{R+y}\right)^2 \sin^2\xi\right]^{\frac{1}{2}},$$

where $\rho(y)$ is the density at each altitude y along the given path as seen in Fig. 1. R, the radius of the earth was taken to be 6368 km. In this calculation the upper limit of integration was 220 km, the last altitude for which Havens quoted a density. For $\xi<75°$, relatively no error is involved in assuming a flat earth such that

$$M(z,\xi)=\sec\xi M(z,0°).$$

At $\xi=85°$ this method gives about an 11 percent error. Table I gives mass in grams per meter squared for various stations above the earth for several zenith angles—including the value of ξ for which the path is tangent to the earth. In all the large angle cases, and especially for the maximum angle cases, the path traverses latitudes and longitudes quite far away from White Sands, where presumably different atmospheric conditions prevail. The effect on $M(z,\xi)$, however, should be within the accuracies quoted, these being based upon the accuracy claimed by Havens. Figure 2 shows, for a station at z kilometers altitude, the ratio of mass at various zenith angles to vertical mass.

Computation error up to 100 km is estimated to be not greater than 2 percent. In his density data, Havens claims an error of less than 5 percent up to 40 km and less than 10 percent up to 70 km.

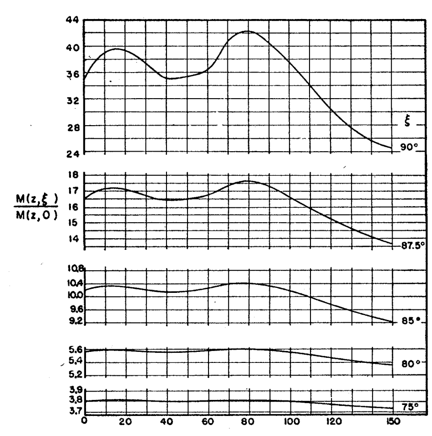

FIG. 2. Air mass ratio. ξ = zenith angle; z = altitude of observation point above the surface of the earth; $M(z,\xi)$ = mass of air in direction ξ between the observation point and outer space in a column of unit cross section; $M(z,0)$ = mass of air vertically above observation point.

Values above 80 km are based on fewer measurements. A check was made using data on pressures, densities, and temperatures in the upper atmosphere by the Rocket Panel.[4] In general the air mass obtained from that atmosphere is slightly lower than that obtained here, but the difference is well within the limit of error stated above.

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The Electric Scattering of Deuterons*

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A LETTER on the above subject by French and Goldberger[1] which has recently appeared in the *Physical Review* was apparently written without the authors' knowledge of the existence of a letter on the same subject by one of us[2] a year earlier. As a result, there is one difference in the conclusions of the two articles which arises from the invalidity of one of their approximations in some cases. In particular, French and Goldberger conclude that there should be simple Rutherford scattering by $n=Ze^2/\hbar v\gg1$, whereas in Ramsey's[2] earlier paper a small departure is predicted.

This discrepancy arises from the approximations used by French and Goldberger being just such as to conceal the non-Rutherford scattering which arises from the distortion of the deuteron by the electric field, i.e., from the polarizability of the deuteron. Their conclusion about the Rutherford nature of the scattering for $n\gg1$ is based on an analysis of their Eq. (4) which is only an approximation to their earlier Eq. (3). The exact wave function of the deuteron in the process of the scattering is replaced by a wave function whose dependence on the deuteron's internal coordinates is just that of the ground state of the deuteron in the absence of any strong electric field. Then, because of the spherical symmetry of the latter state, it is argued that the average value of $[1/|\mathbf{R}-\frac{1}{2}\mathbf{s}|-1/R]=0$ except for $R\leqslant\frac{1}{2}s$ and that this high penetration of the deuteron is improbable for large n.

However, the use of the ground-state wave function for the deuteron is only approximately valid in the presence of the strong electric field of the scattering nucleus, and higher deuteron states must be included. The admixture of the higher states corresponds to a distortion or polarization of the deuteron by the electric field of the scattering nucleus. When these terms are included, the bracketed quantity above no longer equals zero when $R>\frac{1}{2}s$ and the disagreement with Ramsey's[2] conclusions disappears. That there should be considerable admixture of higher states is apparent from the fact that the electric field at the deuteron multiplied by the product of the deuterons charge and diameter is comparable to the binding energy of the deuteron.

Experiments with $n \gg 1$ have the advantage[2] that then the circumstances can sometimes be such that the Coulomb barrier prevents appreciable overlap of the nuclei and all departures from the Rutherford scattering law must be attributed to the distortion of the deuteron by the electric field in scattering. On the other hand, under the conditions of the French and Goldberger[1] theory, the calculated departure from Rutherford scattering due to the deuteron structure occurs along with a large and unknown departure due to nuclear forces; the separation of the two effects experimentally would be very difficult. The importance of direct nuclear interaction is apparent from the fact that in their example of 14-Mev deuterons on aluminum the classical distance of closest approach of these nuclei considered as point charges is 1.34×10^{-13} cm which is much less than the radius of either the deuterium or the aluminum nucleus, so that large effects from nuclear forces should occur.

We have calculated the polarizability of the deuteron quantum mechanically, and we have interpreted the polarizability scattering by a classical approximation. The validity of the calculations are limited by the assumptions that the Coulomb field is adiabatically applied and that $n \gg 1$. In so far as these assumptions hold for the scattering of 8-Mev deuterons on bismuth, we find approximately a 3 percent departure from Rutherford scattering in the backward direction.

* This work was partially supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
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Search for "*T*-Tracks" in Photographic Plates

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BLAU and Salant[1] have reported evidence for a type of event observed in photographic plates, which they called a *T*-track and tentatively interpreted as the break-up of a heavy particle at, or near, the end of its range into two fast, singly charged particles. Their evidence is based on the fact that *T*-tracks appeared to be more frequent than could be explained by the chance passing of a light track by the end of a black track.

In the last month we have scanned 112 cm² of 400 μ G-5 emulsion that was exposed vertically for about 10 hours at 90 000 ft and geomagnetic latitude of 41°N.

To find *T*-tracks, all stars with three or more prongs and with at least one prong longer than 100 μ were analyzed, and all the prongs ending in the emulsion were examined for minimum ionizing tracks passing at distances up to 5 μ. The minimum ionizing tracks were required not to scatter appreciably within 500 μ; this condition eliminates electrons of energy smaller than about 20 Mev.

A total number of 2191 stars were found, with 4246 prongs ending in the emulsion; of these, 335 had minimum ionizing tracks within 5 μ, subdivided as shown in Table I.

To determine the expected number of chance coincidences between the endings of the heavy tracks and tracks of minimum ionization, we have measured the number of minimum ionizing tracks crossing unit surfaces of developed emulsion, N_v in the vertical planes and N_h in the horizontal planes containing the shrunken coordinate.

It was found that $N_h \simeq N_v = 1.0\times10^{-3}\mu^{-2}$, which indicates an isotropic distribution of the minimum ionizing tracks. It follows that the expected number of chance *T*-tracks within a distance r is

$$n_{\mathrm{ch}} = 2\pi\times0.86\times N_h\times r^2\times\text{No. of track endings observed.}$$

The factor 0.86 arises from taking into account that the emulsion has shrunk, after development, by a factor of about 2.5, so the sphere of developed emulsion was originally a prolate ellipsoid.

The estimated backgrounds are given in the lowest row of Table I. It seems that the observed number of *T*-tracks within 1 μ is well accounted for by chance coincidences.

TABLE I. Observed and expected track distributions.

Distances within which the minimum ionizing particles were found, in μ	0–1	1–2	2–3	3–4	4–5
No. of observed cases	19	47	86	87	96
Expected chance coincidences	22	66	110	156	198

The fact that the number of expected chance coincidences is higher than the observed coincidences at the larger distances is thought to be the result of a decrease in the efficiency of the scanner when looking at regions not very close to the end of the heavy track.

We did not try to subdivide further the 19 cases classified within 1 μ, as we felt very uncertain in determining the distances when they were smaller than this limit. One reason for this is that many of the minimum ionizing tracks are steep, and the distance from the end of the heavy track can be estimated by utilizing only a few of their grains. These are not enough to determine the trajectory of the fast particle within much less than 1 μ, as the grains may be displaced from the true trajectory by distances of the order of the dimension of a grain, i.e., by several tenths of a micron. Another reason is that it is often difficult to tell whether a grain is the last grain of the heavy track or a grain belonging to the light track. Finally, depths of field much less than the wavelength of the light (0.5 μ) cannot be realized, and this puts a limit on the precision of the depth measurements.

If we try to select among the 19 close cases the one which appear as "perfect *T*-tracks," three give unmeasurable distances. The value of r which corresponds to three chance coincidences is 0.37 μ, in reasonable agreement with the resolving power of the microscope.

We are thus led to the conclusion that, in order to explain the occurrence of the *T*-tracks observed in our plates, it is not necesto postulate the existence of any special particle.[2]

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1 M. Blau and E. O. Salant, Phys. Rev. **88**, 945 (1952); we are grateful to Dr. Blau and Dr. Salant for communicating to us their results before publication.
2 In a private communication, Dr. Salant has stated to us that the number of *T*-tracks they observe within 1 μ is four times the calculated random background. Since in our plates the background of light particles is larger by about a factor four than that quoted by Blau and Salant, the detection of *T*-particles would be more difficult in our case.

The Lattice Expansion of Quartz Due to Fast Neutron Bombardment

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THE progressive anisotropic expansion of α-quartz irradiated with increasing dosages of fast neutron flux has been observed and measured by x-ray and density methods of analysis. Bombardment produced by a neutron source that gave a total integrated neutron flux of 6.6×10^{19} *nvt* resulted in a density change of $(\Delta\rho/\rho)\times100=3.5\pm0.1$ as measured by the hydrostatic weighing method. The density change measured by the x-ray method gave $(\Delta\rho/\rho)\times100=4.8\pm1.5$. The crystal temperature was approximately 100°C during irradiation.

X-ray diffraction data taken from Debye-Scherrer, Laue, and precession photographs show that the expanded lattice belongs to the trigonal system. In addition, it appears likely that this lattice has the same space group, D_3^4 or D_3^6, as the nonirradiated crystal. The expanded lattice constants are $a_0=5.01\pm0.01$A and $c_0=5.41\pm0.02$A, as compared with the nonirradiated quartz $a_0=4.903$A and $c_0=5.393$A.