about 2×10^{-4} for the quadripole gamma-ray of Th C″, $\gamma\leqq2.6\times10^6$ volts.

The application of (2) to the absorption of cosmic rays is in some respects illuminating. For as the energy of the gamma-ray is increased, the absórption by the production of pairs becomes relatively more important than the absorption by Compton effect. This would account for Anderson's observation that among high energy particles the numbers of positives and negatives are roughly equal; and it would increase the energy of the gamma-rays as estimated from their absorption coefficients. Further (2) gives a limiting penetration, which is of the same order for water as that observed for the hardest cosmic rays. Nevertheless (3) is here in definite disagreement with experiment, in that a penetration in water twice as great as that predicted by (2) has been observed by Regener, and further in that (2) predicts serious deviations from the mass absorption law which are certainly not found experimentally. It appears that deviations from the Coulomb law for the nuclear fields could not sensibly affect our result; and one is tempted to see in this discrepancy a failure of the theory when applied to radiation whose wave-length is of the order of the critical distance e^2/mc^2 which marks the limit of applicability of classical electron theory. But we must emphasize that (2) was derived by the use of approximations which may be unsound; just in the range of high energies and large atomic numbers their validity appears doubtful; and we believe that no conclusions may justly be drawn until this purely analytical point is settled. Even for light elements the use of (2) for γ greater than 10^8 volts appears to us questionable.

On the present simple theory there is no place for the simultaneous production of large numbers of pairs. The fast electrons and positives, however, will themselves tend to produce further pairs; and although this point too wants much closer investigation, it is possible that one may so be able to account for the multiple tracks observed.

We want to express our profound thanks to Professor Bohr, who has helped us to understand the essential consistency of the theory which we have here applied.

J. R. Oppenheimer
M. S. Plesset*

California Institute of Technology,
Pasadena, California,
June 9, 1933.

* National Research Fellow

The Emission of Alpha-Particles from Various Targets Bombarded by Deutons of High Speed

Using a sample of hydrogen containing 50 percent of the heavy isotope, H^2, in our apparatus for the multiple acceleration of ions we have given to the ions H^1H^{2+} energies of 2,000,000 volts. These ions striking any target immediately yield 660,000 volt-protons and 1,330,000 volt H^2 nuclei which we call deutons. We have directed these particles against various targets.

It was of particular interest to study elements of the nuclear type $4n+2$ in order to ascertain whether these would yield nuclei of type $4n$ and α-particles. As a matter of fact the two targets which were most striking because of the range and number of emitted α-particles were NH_4NO_3 and LiF, which contained the nuclei N^{14} and Li^6. Experience with other targets containing O, H and F shows that most of the effects observed were due to N and Li. N yielded about 100 α-particles per 10^9 deutons all apparently homogeneous with a range of 6.8 cm. The minimum deuton energy at which we observed this disintegration was 600,000 volts. The energy of the α-particles obtained in this disintegration is only about one-half of that which should be set free in the process $N^{14}+H^2\rightarrow C^{12}+He^4$.

With Li a large number of α-particles of range 8.2 cm were obtained which are very likely due to the accompanying protons. In addition there are about one-tenth as many with the great range of 14.5 cm corresponding to an energy of 12,500,000 volts. No other known natural or artificial disintegration has yielded particles of so great energy. If we assume the process $Li^6+H^2\rightarrow 2He^4$ and take for He the mass 4.0022 and for H^2 and Li^6 the most recent values of Bainbridge, which he has kindly communicated to us, the values 2.0136 and 6.0145, respectively, and take account of the kinetic energy of the deuton (1,300,000 volts), we find 23,400,000 volts as the total energy set free. If this energy is equally divided between the two α-particles, each would have 11,700,000 volts, whereas, from the observed range we find 12,500,000 volts. This calculation of the energy from the range is a wide extrapolation, with the use of the 3/2 power voltage range relation, and the agreement between the observed and calculated values is well within the limits of uncertainty because of this and other causes. An alternative, but less likely hypothesis, that the process involves Li^7 with the emission of a neutron, happens to agree equally well with the observations if the mass of the neutron has the low value (about unity) that we discuss later.

With the Be target α-particles were obtained of the same range (3.3 cm) as those obtained in this laboratory in similar experiments with high speed protons. But the number of disintegrations per deuton was at least 100 times as great as the number per proton. The identity of the two ranges strongly suggests that the bombarding particle merely causes the disintegration of the unstable Be nucleus; in other words, that we have disintegration without capture. This is a process which has already been suggested by Bainbridge[1] for the disintegration of Be by α-particles. If we take Bainbridge's value for the mass of Be, 9.0155, our value for the kinetic energy of the α-particles and Chadwick's[2] for the kinetic energy of the neutron, the mass of the neutron would come out as a little less than unity, which tends to confirm the estimate of the mass of the neutron (following communication) which we have obtained from quite different experiments.

Of the remaining targets studied, Al and Mg gave a small

[1] Bainbridge, Phys. Rev. **43**, 367 (1933).

[2] Chadwick, Proc. Roy. Soc. **A136**, 692 (1932).

number of α-particles of about 6 cm range when the deuton had an energy of at least 1,200,000 volts. B_2O_3 also yielded α-particles which may however have been produced by the protons rather than the deutons. CaF_2 and NaCl gave a small number of particles of 3.8 and 2.8 cm range, respectively, but these also require further investigation. The remaining targets SiO_2, $NaPO_3$, C, CuS, $Ca(ClO_3)_2$, Au, Pt, brass and mica gave no detectable α-particles.

We are indebted to Dr. M. C. Henderson, who constructed the linear amplifier used in these experiments and who has kindly helped us in many other ways. We are also indebted to the Research Corporation and the Chemical Foundation for their support.

Gilbert N. Lewis
M. Stanley Livingston
Ernest O. Lawrence
Radiation Laboratory, Department of Physics,
Department of Chemistry,
University of California,
June 10, 1933.

The Emission of Protons from Various Targets Bombarded by Deutons of High Speed

Deutons (nuclei of H^2) with energies ranging from 600,000 to 1,330,000 volts have been directed against the following targets: carbon, gold, platinum, lithium fluoride, silicon dioxide, sodium phosphate, calcium chlorate, copper sulphide and brass (the backing of the other targets). In addition to the emission of alpha-particles, which we have already reported in the preceding communication, we have observed the emission of protons in large numbers, with various ranges up to more than forty centimeters.

Every target, including gold and platinum which could hardly be expected to suffer nuclear disintegration, yielded protons of about 18 cm range in air. We have been unable to account for this group of protons common to all targets except on the hypothesis that the deuton itself is breaking up, presumably into a proton and a neutron. This assumption implies a lower value for the mass of the neutron than that of Chadwick[1] whose value, however, rests on the assumption that in the disintegration of B^{11} by α-particles, to form N^{14} and a neutron, there is no γ-radiation.

To examine this hypothesis of the instability of the deuton we have observed the relation between the range of the emitted protons and the energy of the bombarding deutons. In the case of gold we observed that when the deuton energy was increased from 1,000,000 to 1,330,000 volts the maximum range of the protons increased approximately from 16.7 cm to 17.9 cm, corresponding to an increased energy of 160,000 volts. This is in accord with the assumption that the proton and neutron fly apart with equal kinetic energies. Realizing that all of these assumptions may be modified by later work, we may nevertheless make a tentative calculation of the mass of the neutron. From the masses of H^1 and H^2 and from the measured energies of the deuton and the emitted proton, the mass of the neutron appears very close to unity. In the case of carbon the change in the energy of the proton was found to be approximately equal to the change in the energy of the deuton which suggests, if our hypothesis is at all correct, that in addition to the dissociation of the deuton there is a change in the carbon nucleus itself.

Aside from this group of protons common to all targets we have observed large numbers of protons from silica and sodium phosphate with ranges in the neighborhood of 12 cm and which were not obtained with the other targets. The investigations have not yet been carried below this range. On the other hand, sodium phosphate and lithium fluoride yielded protons of very high energy. In the former case two long range groups were observed, one of 26 cm and one of 35 cm. Lithium fluoride was not so carefully investigated but protons with ranges as great as 40 cm were observed.

A study of the relation between the number of emitted protons and the energy of the deuton shows that in all cases the emission of protons becomes unobservable when the deuton energy falls below 800,000, and at least in the case of the group common to all targets, there seems to be a very sharp threshold.

We are again indebted to Dr. M. C. Henderson who constructed the linear amplifier used in these experiments and who has kindly helped us in many other ways. We are also indebted to the Research Corporation and the Chemical Foundation for their support.

Ernest O. Lawrence
M. Stanley Livingston
Gilbert N. Lewis
Radiation Laboratory, Department of Physics,
Department of Chemistry,
University of California,
June 10, 1933.

[1] Chadwick, Proc. Roy. Soc. **A136**, 692 (1932).

The Masses of the Lithium Isotopes

The mass of Li^6 referred to O^{16} was measured as 6.0145 $\pm$0.0003 from five spectra by comparison with $H_3{}^2$ by the "doublet" method. The mass of Li^7 was measured from the same spectra as 7.0146$\pm$0.0006. The lithium ions were obtained from a heated spiral of flat tungsten strip coated with spodumene. Simultaneously a discharge was run in hydrogen containing a high concentration of the heavy isotope. The hydrogen had been put at the disposal of the writer through the kindness of Professor G. N. Lewis.

Fig. 1 illustrates two $Li^{6+}-H_3{}^{2+}$ doublets.[1] The upper spectrum is one of the five used in the mass determinations. The mass of H^2 had previously been accurately determined