THE

PHYSICAL REVIEW

A Journal of Experimental and Theoretical Physics Established by E. L. Nichols in 1893

VOL. 53, NO. 3 FEBRUARY 1, 1938 SECOND SERIES

New Evidence as to the Nature of the Incoming Cosmic Rays, Their Absorbability in the Atmosphere, and the Secondary Character of the Penetrating Rays Found in Such Abundance at Sea Level and Below

I. S. BOWEN, R. A. MILLIKAN AND H. VICTOR NEHER
California Institute of Technology, Pasadena, California

(Received November 29, 1937)

The intensity of latitude-sensitive cosmic rays as would be measured by an electroscope placed just outside the atmosphere has been calculated. The ionization due to incoming electrons of 10 billion electron volts energy in this same electroscope placed 1/20th of an atmosphere beneath the top is found to be 13 times that outside. Electrons do not become penetrating by virtue of high energies even up to 17 billion electron volts. Neither protons nor other penetrating particles of any sort enter the atmosphere in significant numbers from outside the atmosphere. The observed penetrating particles and all other cosmic-ray effects, latitude-sensitive and non-latitude-sensitive, found in the lower atmosphere are practically all secondary effects—splashes from the absorption of electrons, or photons, or both taking place in the outer layers of the atmosphere.

I. EVIDENCE AS TO THE CHARACTER OF THE COSMIC RAYS AS THEY ENTER THE ATMOSPHERE

HAVING obtained[1] the nearly complete "depth-ionization" curve due to the band of charged particle rays of energy between 6.7×10^9 ev and 17×10^9 ev (weighted mean value 10×10^9 ev) which can break through the blocking effect of the earth's magnetic field between the magnetic equator and the magnetic latitude of San Antonio, Texas (mag. lat. 38° 30′) we are in position, by following the technique which we have already used[2] and which was also used still earlier by Millikan and Cameron[3] to compute the precise number of charged-particle-rays that enter the earth's atmosphere within this energy range. This is done as follows.

The total number of ions produced in a column of air 1 sq. cm in section and extending from the top of the atmosphere down to the lowest depth to which the ionizing influence of these rays extends, is obtained simply by a graphical integration of the area underneath the lower curve of Fig. 4, p. 83 of reference 1 and reproduced here as curve *A* of Fig. 1. This number comes out 2.80×10^7 ions.[4] This number represents the total effect in the production of ions of all the energy contained in these particular rays which enter each square cm of the earth's surface per sec. The number of ions which each of these 10×10^9 ev rays can produce, and must produce, since the whole energy is expended in

[1] Bowen, Millikan and Neher, Phys. Rev. **52**, 83 (1937).
[2] Bowen, Millikan and Neher, Phys. Rev. **44**, 252 (1933).
[3] Millikan and Cameron, Phys. Rev. **31**, 929 (1928).

[4] In the article in question we stated that in order to make the results comparable with those found in airplane flights with the use of thicker walled electroscopes we had added 10 percent to all the values obtained with the very thin walled (0.5 mm of steel) electroscopes used in our sounding balloon flights at San Antonio and Madras. The figures used above are those actually obtained in these thin-walled electroscopes rather than those corresponding to the graph given in Fig. 4, p. 83 of that paper, for the reason that for the purposes of the computation herein contained the extreme thinness of the electroscope wall is of vital importance.

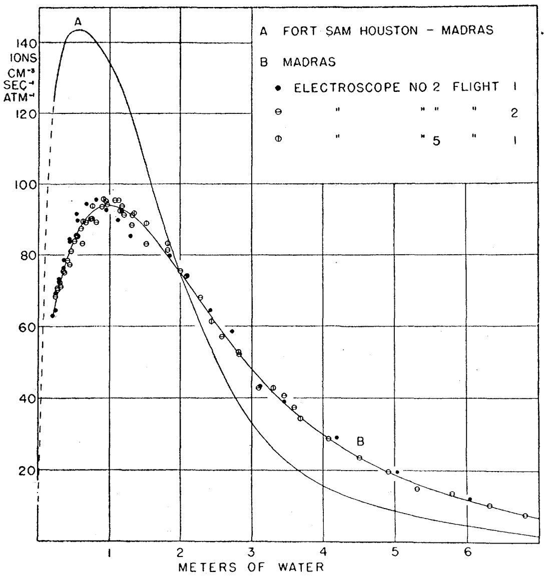

FIG. 1.

the production of ions, is $10\times10^9/32$ since each ion in air requires on the average 32 ev for its production; so that the number of these charged particle rays which fall per sec. on each square cm of the earth's surface is $2.80\times10^7\times32/10\times10^9=0.09$. Let us call this number N.

The problem which we then set ourselves is to find how much ionization these rays will produce in one of our thin-walled electroscopes when it is placed just outside the earth's atmosphere where it is exposed to all the rays coming in from all directions from the hemisphere above it but is screened off by the earth from the entrance of rays from the hemisphere below it.

Since N is the number of rays of the given energy passing through each sq. cm of surface, the total number passing through the electroscope of radius r is $2\pi r^2N$. These rays traverse every possible chord of the sphere of radius r, and the average length of these chords is $4r/3$. If now we make the assumption that, in view of the extreme thinness of the electroscope wall, the only ionizing effect produced in the air at atmospheric pressure within the electroscope (for all the readings obtained with our argon-filled electroscopes have been reduced to air at $p=76$ cm Hg, $t=23°C$) is found in the ions produced in the gas within the electroscope along the ion track, here taken as 60 per cm of length, then the expression for the number of ions per cc per sec. produced in the electroscope by the rays in question is

$$\frac{2\pi r^2N\times(4r/3)\times60}{4\pi r^3/3}=120N=11 \text{ ions per cc per sec.}$$

If the foregoing assumpton is a correct one, this value of 11 ions per cc/sec. should give us the intercept of the above curve on the ionization axis. We have in the figure extended a dotted line from the last observed point to that intercept, and thus obtained the complete curve to the top of the atmosphere of the ionization produced by all the incoming charged particles of energies between 6.7×10^9 and 17×10^9 electron volts.

Since the number of ions produced by these rays is seen from A, Fig. 1 to reach a maximum of 144 ion cc/sec. the multiplication of ions in penetrating 0.5 m of water is about 13-fold. This is not far from the multiplication computed by Carlson and Oppenheimer from the Bethe-Heitler theory of the absorption of the atmosphere for electrons of this energy. Their computed number for 10 billion volt electrons is 12.6. *This result constitutes a bit of new evidence that practically all the incoming latitude-sensitive rays are electrons, and that no appreciable number of protons or other penetrating particles are mixed with them.*

The only uncertainty that can inhere in the foregoing analysis lies in the assumption of the negligible effect of the thin wall on the ionization produced within the electroscope and in the choice of 60 as the most probable value of the ionization along the ion track of a 10×10^9 ev electron ray. As to this last it is larger than the mean of the direct counts of most of the observers who have directly attempted to count ions in high energy electron tracks, but it represents as fair a mean as we can find when the ions produced by the delta-rays are included. Even if it is in error, the foregoing reasoning is not seriously affected.

So far as the first assumption is concerned, if we rely upon Carlson and Oppenheimer's analysis as to how rapidly, according to the Bethe-Heitler theory, ionizing rays are multiplied by walls of given thickness and given materials as depicted in the curve which they give[5] walls of iron 0.5 mm thick, such as our electroscopes are made of, can contribute no appreciable new ionization.

[5] Carlson and Oppenheimer, Phys. Rev. **51**, 230 (1937).

The foregoing evidence as to very rapid absorbability obtained from a comparison of the ionizing power of the rays outside of the atmosphere and that found one-twentieth of the way through it, is merely confirmation of the evidence which we have already derived[6] from the ionization found as the rays penetrate below the first twentieth, for between this point and one-half the way through (5 meters of water) the ionizing power fell to 1/16th its maximum value (144 ions per cc/sec.), while at sea level it had dropped to 1/500th its highest value.

This demonstration of the very high absorbability of the incoming charged particles by the nuclei of the atoms of the atmosphere up to the huge value of 17 billion electron volts is in general accord with the requirements of the Bethe-Heitler theory, but it is completely irreconcilable with the absorbability of protons or any other particles too heavy to make radiative collisions, i.e., to produce "impulse radiation" or "*bremsstrahlung*." For the theory makes the rate of absorption vary inversely as the square of the mass, and the mass of a proton is two thousand times that of an electron. These experiments, therefore, force us to reaffirm the following conclusions: (1) *The latitude-sensitive rays contain no appreciable number of incoming protons or other penetrating particles* of any sort, since we find it impossible to build up the observed curve out of an appreciable mixture of incoming penetrating particles with highly absorbable particles (electrons). (2) *Electrons do not become penetrating by virtue of high energies*, at least up to 17 billion ev, as we ourselves and also Bethe-Heitler have heretofore assumed. Otherwise stated, these experiments remove what have been heretofore regarded as insuperable objections to the validity of the Bethe-Heitler theory *for electrons of very high energies*. They force the conclusion that the high energy penetrating particles definitely revealed in great numbers both by cloud-chamber photographs and by ion-counter experiments near the earth's surface are not ordinary electrons at all, though they carry the electronic charge and produce tracks thus far undifferentiable from electron tracks (+ and −). For they prove that, clear up to an energy of 17 billion ev, electrons *do* make radiative collisions, or at any rate are very rapidly absorbed. Certainly, then, observed penetrating particles of energies under 17 billion ev cannot be electrons. They must be either protons or else particles of mass intermediate between protons and electrons. If they are protons, since according to all observers they are nearly equally divided in sign between positive and negative, *the negative proton has been discovered*. In any case a new particle has come to light as Neddermeyer and Anderson have already announced[7] for another reason, namely, that they have actually observed a very considerable number of apparent electron tracks of the same curvature in a magnetic field but of entirely different penetrability and of too small ionizing power to be protons.

II. The Probable Origin of the Penetrating Particles Observed in the Lower Part of the Atmosphere

In the previous article we have shown that the top part of the latitude-sensitive curve (see Fig. 5,

[6] Bowen, Millikan and Neher, Nature **140**, 23 (1937).

[7] Neddermeyer and Anderson, Phys. Rev. **51**, 884 (1937). The history of this discovery is as follows: In 1934 it was pointed out by Anderson and Neddermeyer (Report of London Int. Conf. on Physics, Vol. I, Section on Nature of Cosmic-Ray Particles and footnote, page 182 (1934)) that there are serious difficulties in identifying the penetrating cosmic-ray particles at sea level with either electrons or protons. Further evidence of a new kind indicating the existence of particles of a new type was reported by them in the Phys. Rev. **50**, 270 (1936), captions under Figs. 12 and 13. In a colloquium on November 12, 1936 new evidence showing a difference in penetrability of single particles and shower particles was presented, in which the conclusion was reached that these data could be understood only in terms of a new type of particle. A brief report of this colloquium was published in Science, November 20, 1936, page 9 of the supplement. Further publication was withheld until a long series of careful measurements had been completed on 55 particles which showed that shower particles of a given curvature have an entirely different penetrability from nonshower particles of the same curvature. Further, practically all of these particles had much too small ionizing power to be protons. These results were reported in the Phys. Rev. **51**, 884 (1937). At practically the same time as this last publication Street and Stevenson, Abstract No. 40, Phys. Rev. **51**, 1005 (1937) presented data showing the existence of particles less ionizing than protons and more penetrating than electrons could be *on the assumption that the Bethe-Heitler law holds for high enough energies*. They thus confirmed the conclusion reached by Anderson and Neddermeyer in 1934 based on measurements reported to the London Conference at that time. That the Bethe-Heitler law does not break down at very high energies, as it had been assumed to do by Millikan, Bethe, Heitler, Oppenheimer and many others, was first shown in the San Antonio-Madras experiments published in Nature **140**, 23 (1937) and the Phys. Rev. **52**, 80 (1937).

p. 86 of reference 1) reveals if anything an even more rapid rate of absorption, or a lower penetrating power, than the Bethe-Heitler theory demands of incoming electrons, while the lower part of the curve corresponds, on the contrary, to a very considerably *higher* penetrating power than is predicted by this theory.

We conclude, therefore, that the incoming electrons, while mostly absorbed by the mechanisms assumed in the Bethe-Heitler theory, are yet able by some additional absorptive process to *produce* enough penetrating *secondaries* to give to the curve the increased absorption that it needs at the top and the more penetrating character which its lower half reveals.

The simplest assumption to account for these penetrating secondaries is merely that *a photon has the power not only of producing electron pairs, as Bethe-Heitler theory requires, but also, at much rarer intervals, of transferring its energy through a nuclear collision to a penetrating particle, which particle merely acts as an agent, or link, for carrying the energy downward*, but which may, through another collision, retransform its energy into electron-photon showers of the usual type.[8] It is assumed that it is through this mechanism that the incoming electrons of 6 billion electron-volts of energy are able to throw their influences down as far as to sea level, and thus produce there the cosmic-ray shelf, or diminution in sea-level intensity, which is found to set in at magnetic latitude 41°N, in spite of the fact that as already stated pure Bethe-Heitler theory does not permit even ten-billion volt electrons to produce one-thirtieth of the observed sea-level effect. It is also with the aid of these penetrating secondary links that we can explain the fact that showers some times representing a total energy of as much as several billion electron volts are found at sea level and below, as well as the observed fact that at least in the lower part of the atmosphere there is a strong Z component of absorption in substances of different atomic number Z, in spite of the fact that the Bethe-Heitler theory requires a Z^2 law, and that such a law actually appears in most shower experiments.

[8] We discussed this suggestion at length with the group at the Norman Bridge Laboratory as soon as, in February and March 1936, we had analyzed the results of the Madras flights made in October, 1935. Oppenheimer and Serber of this group have already published a brief note embodying this suggestion. (Phys. Rev. **51**, 1113 (1937).)

III. The Non-Field-Sensitive Cosmic Rays

The Madras curve reproduced in curve B represents all of the ionization produced by the non-field-sensitive cosmic rays. It is the background, present the world over, on which the ionizing effect of the latitude-sensitive rays is imposed. Its shape and its area give us at least some knowledge about the nature of these non-field-sensitive rays.

Its similarity of shape to curve A, particularly the fact that the maximum of ionization is reached so near the top of the atmosphere, namely, at 1/10th of the way through, instead of 1/20th as in the case of curve A, tells us at once that it is predominantly composed of highly absorbable rays (i.e., of electrons, photons, or both, for according to Bethe-Heitler these differ but little in absorbability), not of *penetrating* rays of any sort. This is our first bit of knowledge as to its composition.

Secondly, let us raise the following query: Can we admit in its constitution any significant ingredient of such incoming penetrating charged particles as the well-nigh universally accepted mode of treatment of the so-called "penetrating component" of the cosmic rays requires? Our own answer to that question is in the negative, but to show why we draw this conclusion we must compare the total areas of curves A and B. The latter's area, extended down to the lowest depths at which appreciable ionization can be observed at all, is a little larger than that of curve A, but when we add the latitude-sensitive rays found north of San Antonio, recently determined by us and soon to be published in detail, we find that the total energy represented by all latitude-sensitive rays is only a little larger than the energy represented in the area of curve A. For our present purposes we shall then treat curves A and B as of approximately equal area and as representing the respective energies of the latitude-sensitive and the non-latitude-sensitive components of the incoming cosmic radiation.

We have seen in §I that the average energy of the incoming rays responsible for curve A is 10 billion electron volts, since it is composed of the whole of the band of incoming charged particle rays (in this case electrons,—see §II) of energies between 6.7 billion electron volts and 17 billion electron volts. Even if the extreme and as yet wholly gratuitous assumption be made that curve B is due *entirely* to incoming charged particles—no photons at all—the average energy of these particles, no matter whether they are protons, electrons, or something of intermediate mass, must be above 17 billion electron volts, let us say *at the least* 20 billion, in order to enable the particles to get through the blocking effect of the earth's field and become a part of the non-field-sensitive component. It follows, then, from the mere equality in the areas of A and B that the number of *particle* rays responsible for B cannot at the most be more than half that responsible for A, since the same total energy combined with twice the individual energy means half the number. This tells us, then, something quite sharp and definite about the *distribution of energies* among the incoming charged particles. We may formulate it thus: *The great bulk of the incoming particle rays are in any case in the latitude-sensitive range of energies, i.e., in the band of energies between 6 and 17 billion electron volts.* Under the most extreme possible of assumptions there cannot be 1/10th that number of incoming particle rays of energies as high as 10^{11} electron volts, and probably not one-hundredth that number.

The third bit of knowledge about the non-field-sensitive component of the incoming cosmic rays is derived from the fact that 88 percent of the cosmic-ray ionization found at sea level is due to the background of non-latitude-sensitive incoming rays. This is evident from the fact that the maximum value of the equatorial dip—that found at Singapore—is 12 percent. Further, the cloud-chamber experiments at sea level show that by far the larger part of the tracks found there are those of *penetrating particles*.

The question to which we are now seeking an answer is "do these penetrating particles come in from outside or are they secondaries formed in our atmosphere?"[9] The most direct answer to that question is found in the original finding of Anderson,[10] confirmed by Kunze,[11] Anderson,[12] Anderson and Neddermeyer,[13] Blackett and Brode;[14] and recently notably extended by LePrince Ringuet and Jean Crussard,[15] that the penetrating particles actually found in cloud-chamber work at sea level are divided nearly equally between positives and negatives. In view of the fact that we know from the east-west effect that the *incoming* charged particles are predominantly positives, the near equality in the number of positives and negatives observed at sea level apparently means that these observed penetrating particles are not *the incoming particles at all*, at least to any significant degree, *but are secondaries produced in the atmosphere by incoming rays which have practically the same chance of transferring their energy directly or indirectly, in whole or in part, to a penetrating positive as to a penetrating negative.*

There is, however, a second mode of approach to the question as to whether the penetrating particles actually found near the earth's surface and below it are secondaries formed in the atmosphere or primaries coming in from outside. Remembering that only 12 percent of the sea-level ionization is due directly or indirectly to incoming latitude-sensitive rays and 88 percent to the non-latitude-sensitive component, we ask ourselves whether we can build up the observed curve B out of an appreciable mixture of incoming protons, or other penetrating rays, such as we actually find in cloud chambers, with highly absorbable rays which follow the Bethe-Heitler theory, as both electrons and photons are assumed to do. This is, in fact, the picture that is most in vogue among European physicists today, the penetrating particles being in general thought of simply as protons, the highly absorbable rays as electrons.

Here again the shapes and the areas of curves A and B seem to us to negate this assumption. For no matter whether these incoming particles are protons or electrons, in order to get through the blocking effect of the earth's field and become

[9] The suggestion that all the observed cosmic-ray effects found in the lower atmosphere might be secondary effects arising from the absorption of electrons in the outer layers of the atmosphere was made as early as 1928. See Nature **121**, 20 (1927), also **140**, 23 (1937). The secondary character of the great bulk of cosmic-ray effects was also strongly emphasized in December, 1932. See Phys. Rev. **43**, 664 (1933).

[10] Anderson, Phys. Rev. **41**, 405 (1932).
[11] Kunze, Zeits. f. Physik **80**, 559 (1933).
[12] Anderson, Phys. Rev. **44**, 406 (1933).
[13] Anderson and Neddermeyer, International Conference on Physics **1**, 171 (1934).
[14] Blackett and Brode, Proc. Roy. Soc. **154**, 573 (1936).
[15] LePrince Ringuet et Jean Crussard, Comptes rendus **204**, 112 (1937); also J. de phys. **8**, 213 (1937).

a part of the non-field-sensitive component they must have energies of around 20 billion electron-volts at the least, and, as already shown, their number must therefore be at the most half the number of latitude-sensitive electrons of mean energy 10 billion electron volts which are responsible for curve A. This small number, though they are practically all needed to explain the very large ionization in the upper portion of the atmosphere (for the area of curve B down to 5 meters of water is practically as large as that of curve A) must, according to our present hypothesis, be divided between penetrating particles and electrons in such a way as to enable the penetrating particles to produce all the ionization found in the lower atmosphere, for pure Bethe-Heitler electrons cannot throw any appreciable ionizing influences down anywhere near that far. Indeed, the idea of the admixture of penetrating particles was introduced just to "explain" the great preponderance of penetrating particles found below 6 meters of water in cloud chambers and in counter experiments. With this assumption of an admixture of incoming electrons and penetrating particles it is the latter that are just able to get through the atmosphere at an energy of 6 billion volts and thus cause the equatorial dip to set in at magnetic latitude 41°N, but because they are *penetrating* particles and do not make radiative collisions they cannot ionize appreciably more strongly in the upper air or anywhere on the way down than they do at sea level, so that there is no way whatever in which to account for the large increase in ionization actually found between sea level and say 5 meters below the top. This argument may be stated a little more quantitatively as follows:

Just how penetrating particles coming in from all directions do actually ionize as a function of depth was first pointed out by Bowen and later by Langer and Epstein, all of whom showed that the ionization produced by such rays of a given energy ionizing approximately uniformly along their paths produce within a constant pressure electroscope an ionization which varies linearly with the distance of the electroscope above the end of the range of the particles. Furthermore, since each of the hypothetical incoming penetrating particles with which we are here concerned must have an energy of at least 20 billion electron volts in order to get through the blocking effect of the earth's field, and must lose 5.7 billion electron volts in penetrating vertically through the atmosphere, this "range" is $20/5.7=3.5$ atmospheres, and the ionization at a depth of one atmosphere below sea level should be $1.5/2.5$ or 0.6 of the sea-level ionization, while the ionization at the top of the atmosphere should be $3.5/2.5=1.4$ times the sea-level ionization. But in fact the direct measurement of the ionization one atmosphere below sea level shows it to be but 0.35 of its sea-level value.[16] And the quantitative argument applied to a point a few meters of water *above* sea level is still more striking. Thus at say 6 meters (curve B)—a depth to which 20 billion volt Bethe-Heitler electrons cannot penetrate so as to produce, even if the incoming equatorial rays were all electrons more than 2.5 ions/cc sec. the observed ionization is some five times its value at sea level namely about 12 ions/cc sec. (see B), while that due to incoming penetrating particles alone should be $2.9/2.5$ or 1.15 that at sea level, so that the observed ionization is here more than twice at the least what the foregoing assumptions permit.

Another closely allied argument is as follows: As already stated, a mere mixture of penetrating particles with absorbable rays which follow the Bethe-Heitler theory requires all the ionization found in the lower part of the atmosphere to be due to the penetrating component. On the other hand, the non-field-sensitive rays in order to get through the blocking effect of the earth's magnetic field must have an entering energy of about 20 billion electron volts at least, and of this they will have retained about 14 billion electron volts even after they have penetrated to sea level. None of these 14 billion electron volt penetrating rays could be stopped by 10 cm of lead, which is equivalent to but one-ninth of an atmosphere. Therefore an electroscope shielded by 10 cm of lead at sea level should show practically as large an ionization as an unshielded electroscope, and if any secondaries at all are formed in the lead the shielded electroscope should show the larger discharge rate. In fact, however, the shielded electroscope shows about 67 percent of the ionization found in an unshielded one. This is inexplicable in terms of the foregoing picture.

[16] Millikan and Cameron, Phys. Rev. **37**, 244 (1931).

We conclude, therefore, (1) from reading of shielded and unshielded electroscopes in the lower atmosphere, (2) from the shape and area of curve B, and (3) from the near equality in the number of the high energy positives and negatives, *that incoming penetrating particles are not a significant factor in the near sea-level ionization*, that instead the observed penetrating particles are secondaries produced in the atmosphere.

In a word, they are the same "penetrating links" which we have already introduced to obtain a consistent interpretation of curve A.

The net result of all the considerations advanced thus far in this paper is contained in the statement that *practically all of the cosmic ray effects observed in the lower part of the atmosphere are secondary effects—splashes of various kinds—produced in the upper layers of the atmosphere by the inflow from outside of electrons (+ or −) or of electrons and photons combined, which no matter what their energy, cannot themselves penetrate through the upper layers because of the powerful barrier set by the laws of nuclear absorption.*

Our experiments thus far yield no crucial evidence as to the relative roles played by electrons and photons in producing the ionization due to the non-field-sensitive half, as measured by energies, of the incoming cosmic rays. A minor part of the incoming non-field-sensitive rays must in any case be electrons to account for the equatorial east-west effect. If they are all electrons, then in accordance with the reasoning in §I we may expect the intercept of curve B on the vertical axis to be at 5.5 (half of 11) or less; since the lower limit to the average energy of these hypothetical electrons cannot be placed at less than about 20 billion electron volts. If curve B should actually be found to cross the axis outside this range then something other than electrons or protons or penetrating charged particles of any sort must be a constituent of the incoming rays. We can probably follow the actual course of curve B farther to the left than we have yet done, though this is not a promising prospect for differentiating between incoming electrons and photons. With suitable *ad hoc* and as yet *unverifiable* assumptions, either hypothesis—electrons alone or a mixture of photons and electrons—can be made to work. The answer to this question, if found at all, will probably be found from more fundamental considerations as to the mode of origin of the rays rather than from a further study of curves A and B.

FEBRUARY 1, 1938 PHYSICAL REVIEW VOLUME 53

Neutrons from Lithium Plus Deuterons

W. E. Stephens
W. K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California
(Received December 13, 1937)

The energy distribution of the neutrons from the disintegration of lithium by deuterons has been measured by the method of α-recoils in a helium-filled high pressure cloud chamber. The stopping power was calibrated with thorium C′ α-particles in the chamber. Two distinct groups of neutrons were found with disintegration energies of 15.05 ± 0.2 Mev and 11.8 ± 0.4 Mev. The 15.05 Mev group is attributed to the formation of Be^8 in a normal state and the 11.8 Mev group to the formation of Be^8 in an excited state of about 3.3 Mev with a width at half-maximum of about 1.5 Mev. A more or less continuous distribution was observed from 9 Mev to 3 Mev (the limit of observation). These neutrons may come from higher wider states of Be^8.

Introduction

The neutrons resulting from bombardment of lithium with deuterons were first observed by Crane, Lauritsen and Soltan.[1] The neutron energy distribution was measured by Bonner and Brubaker[2,3] by the method of proton recoils in a methane filled high pressure cloud chamber[4] with a mica sheet to further

[1] Crane, Lauritsen and Soltan, Phys. Rev. **44**, 693 (1933).

[2] Bonner and Brubaker, Phys. Rev. **47**, 973 (1935).

[3] Bonner and Brubaker, Phys. Rev. **48**, 742 (1935).

[4] Brubaker and Bonner, Rev. Sci. Inst. **6**, 143 (1935).