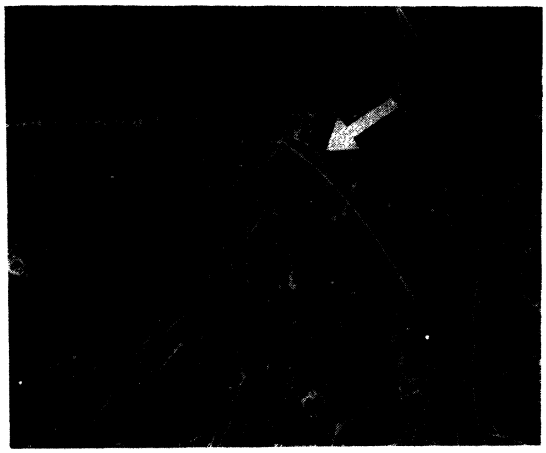

FIG. 2. Capture of a negative meson by a nucleus, presumably an argon nucleus. A star with two prongs may be seen.

both the top glass and the Lucite at the bottom of the chamber. Out of 100 photographs, seven examples have been found that are definitely the tracks of mesons of two or three Mev. They were all produced in either the top or bottom of the chamber; and in all cases but one, they were observed only to traverse the illuminated region. They have been identified by the fact that their radii of curvature are ~5 cm whereas a proton stops while its radius is larger than 10 cm. The meson tracks show ionization comparable to that of a slow proton. Figure 1 is a photograph of the first meson observed; its radius of curvature corresponds to a $\pi$-meson of 2.3 Mev or a $\mu$-meson of 3.0 Mev. Figure 2 shows the capture of a negative meson by a nucleus, presumably by an argon nucleus. The resulting star has two heavy fragments.

Another interesting group of tracks has been observed in the same film. They are particles that ionize near the minimum but are curved too much to be protons. They may be either fast electrons or fast mesons. Their curvatures correspond to electrons of about 150 Mev or mesons of about 70 Mev. If electrons, they may result from the bremsstrahlung of suddenly accelerated protons though there is no reason for not expecting to see mesons of this energy.

We wish to thank Professor E. O. Lawrence for his interest and encouragement. This work was done under the auspices of the AEC.

## Upper Limit for the $(d,H^3)$ Reaction in Phosphorus*

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SEVERAL cases of $(d,H^3)$ reactions have been reported. In spite of the fact that such a reaction is energetically possible, L. B. Borst mentioned in an abstract that he could not find it in $P^{31}$ with 7.5-Mev deuterons, but made no quantitative statement about the smallest cross section that could have been observed.[1] The search for this reaction has been repeated by bombarding elemental red phosphorus for periods of one minute with 7.5-Mev deuterons with an arrangement which would allow the detection of this process if the cross section were larger than $5\times10^{-30}$ cm$^2$.

The product nucleus which would occur in such a reaction is $P^{30}$, a positron emitter with a half-life of 150 seconds. Using a magnetic field to separate the positive and negative electrons only a positron radiation of approximately 72-second half-life was observed after bombardments. The major impurities in our samples determined by the manufacturer were approximately 130 p.p.m.$SiO_2$, 8 p.p.m.S, and a few p.p.m.Fe.[2] The oxidation in the form of phosphates which might have been incurred in handling before bombardment was determined by a phosphate-molybdate colorimetric test[3] to be less than 5 p.p.m. The bombardment of the impurities leads only in the case of oxygen to a positron-emitting product nucleus decaying with a half-life between one and three minutes, namely $F^{17}$ with a half-life of 70 seconds. The observed activity is thus due to the oxygen impurity. Assuming a cross section of $\approx1\times10^{-26}$ cm$^2$ for the $O^{16}(d,n)F^{17}$ reaction,[4] and assuming that a $P^{30}$ activity one-tenth as strong at the end of the bombardment could have been detected (especially in view of the fact that activity measurements were begun approximately 2.5 minutes afterwards) the above mentioned upper limit can be given. A rough check using the observed strength of the 72-second half-life activity leads to approximately the same amount of oxygen in the sample as specified by the manufacturer.

* Assisted by the joint program of the ONR and the AEC.
[1] L. B. Borst, Phys. Rev. **61**, 106A (1942).
[2] We wish to thank Dr. C. A. Stiegman of the Oldbury Electro-Chemical Company for the specially prepared sample of phosphorus and the above impurity analysis.
[3] This determination was made by Mr. George Herz using the method described in Snell's *Colorimetric Methods of Analysis*.
[4] H. W. Newson, Phys. Rev. **51**, 620 (1937).

## Cascade Theory*

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IN a recent paper[1] and in earlier papers, Bhabha and Chakrabarty have questioned the validity of the solutions of the diffusion equations as given by Serber[2] and myself.[3] Their objections were twofold. First, we used graphical interpolation methods for evaluating a function $K\mu(y, s)$ which satisfies a difference equation of the form

$$K\mu(y, s)=g(y, s-1)K\mu(y, s-1). \quad (1)$$

The function $K\mu(y, s)$ satisfies the condition $K\mu(y, 0)=1$. It is easy to compute the values of $K\mu(y, s)$ for integral values of $s$. From the values of $K\mu(y-y)$ for integral $y$ the values of this function were estimated for non-integral values of $y$ by interpolation. All the uncertainties thus engendered are overcome by a suitable solution of (1), namely

$$K_\mu(y, s) = K_\mu(y, t)g(y, t)^{s-t} \times \prod_{n=0}^{\infty}\left(\frac{g(y, t+n)}{g(y, s+n)}\left(\frac{g(y, t+n+1)}{g(y, t+n)}\right)^{s-t}\right). \quad (2)$$

The conditions that (2) shall be a solution of (1) are: (a) the infinite product in (2) converges; (b) $\lim_{N\to\infty}[g(y, s+N)/g(y, N)]=1$. Both of these conditions are satisfied for the particular $g(y, s)$ that comes from cascade theory.

Their second objection was that our solution did not satisfy the correct boundary conditions. This is true, but if $\beta \ll E_0$ the error introduced is negligible. In a paper which will be submitted for publication soon, a solution will be given which does satisfy the correct boundary conditions, a solution which can be reduced to the forms given by Bhabha and Chakrabarty. Also, the form of the energy spectrum will be given for low energies ($E<\beta$). My results do not agree with those of Bhabha and Chakrabarty[1] as given by their Eqs. (37), but do agree with those given earlier by Carlson and Oppenheimer[4] in their Eqs. (34).

* Research carried out at Brookhaven National Laboratory under the auspices of the Atomic Energy Commission.

[1] H. J. Bhabha and S. K. Chakrabarty, Phys. Rev. **74**, 220 (1937).
[2] R. Serber, Phys. Rev. **54**, 317 (1938).
[3] H. Snyder, Phys. Rev. **53**, 960 (1938).
[4] J. F. Carlson and J. R. Oppenheimer, Phys. Rev. **51**, 220 (1937).

## Electro-Disintegration of Nuclei

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IN recently reported experiments[1] the electron beam from the 22-Mev betatron activated a stack of thin, uniform foils by the reaction $A^z(e; e', n)(A-1)^z$. The activity in a foil was the sum of the activity from electro-disintegration, which was constant in each foil, and from photo-disintegration by bremsstrahlung produced by the incident electrons, which was a linear function of foil position.

The relative activities due to these two processes were estimated using the virtual quanta method[2] to obtain the electro-disintegration cross section and agreed closely with experiment. But since the virtual quanta method is not valid for energy transfers comparable to the incident electron energy, we have calculated the relative activities using more accurate expressions for the electro-disintegration cross section.

We assume that neither the electron beam nor the bremsstrahlung lose appreciable numbers or energy in traversing the foil and the bremsstrahlung is predominantly in the forward direction. Then we find

$$w_{pd} = Z^2 r_0^2 N a (n-\tfrac{1}{2}) F w_{el},$$

where $w_{pd}$ and $w_{el}$ are the activities in the $n$th foil from the photo- and electro-disintegration, respectively, due to the excitation of a single level, $Z$ is the atomic number, $N$ is number of nuclei/cc, $r_0=2.8(10^{-13})$ cm, $a$ is thickness of foil in cm, $F$ is a function only of the initial and final energies of the electron and of the kind of transition to the excited level, i.e., electric dipole, magnetic dipole, or electric quadrupole. The expression for $F$ involves the cross section for bremsstrahlung production,[3] the transition probabilities for photo-excitation, and the cross sections for electro-excitation.[4] At very low energy transfers, $F$ for electric and magnetic dipole transitions converges to the virtual quanta result, $8\pi/3$, while it vanishes for electric quadrupole transitions.

In the above equation we can interpret $w_{pd}$ and $w_{el}$ as the total activities, found by summing over-all excited levels leading to disintegration, if we replace $F$ by its average for energy transfers above disintegration threshold, $\bar{F}$. We find that $F$ is almost constant for energy transfers between disintegration threshold and 16 Mev, the incident electron energy, for the three reactions studied. Thus the manner in which $F$ is averaged is not very critical.

The comparison (Fig. 1) between calculated values of $F$ as a function of energy transfer and the experimental values of $\bar{F}$, seems to indicate that electric dipole transitions do not predominate. Theoretical and experimental uncertainties, however, make this judgment tentative. Further experiments with higher incident electron energies would be very informative, particularly with respect to the presence of electric quadrupole transitions.

The quadrupole curve was computed assuming that the invariant moment $(a|\Sigma r_i^2|b)$, discussed by Wick, vanishes. Since this moment contributes to electro-, but not to photo-transitions, its presence would further lower the quadrupole curve.

The angular distribution of inelastically scattered electrons is a marked function of the kind of nuclear transition. The presence, however, of electrons inelastically scattered in producing bremsstrahlung will make it necessary to use special techniques to investigate this effect.

We wish to thank Professor S. M. Dancoff for his guidance and Professors A. T. Nordsieck, A. O. Hanson, D. W.

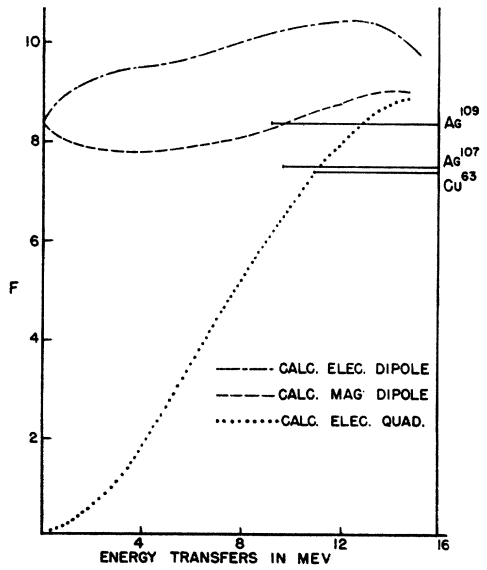


FIG. 1. Comparison of experimental $\bar{F}$ and calculated $F$ for 16-Mev incident electrons. Experimental values of $\bar{F}$ are drawn as straight lines extending over energy transfers above disintegration threshold.