so that finally we choose

$$\delta\kappa^2 = -(1/\pi i)Z_3^{-1}(f_1)\left[A''(f_1) - M_d(f_1)\int \Delta_{F1}'(t, f_1)dt\right].$$

This completes the proof.

On account of the results above regarding "final" M-divergences, it will be found expedient to associate basic momenta with nucleon rather with meson lines in graphs belonging to any category [n]. This choice will remove all the significant divergences with a single choice of basic variables.

The case of the meson self-energy has been treated at length because it will serve as a prototype for renormalization in other theories such as scalar electrodynamics, where both C and M parts are divergent and it is not possible to make an unambiguous insertion of S parts in meson or photon lines.

The general rule for the separation of divergences given in Sec. III will also apply to other theories such as scalar electrodynamics; but the considerations given in the remarks will not, because both C and M parts are divergent in that theory, leading to overlaps of considerably greater complexity. It is, in fact, in scalar electrodynamics that the power of the general rule formulated in Sec. III exhibits itself. General considerations on that problem will be published shortly.

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Emission of Protons from the Compound Nucleus F^{18*}

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The emission of protons from the reaction $N^{14}(\alpha,p)O^{17}$ was studied by photographic emulsion technique. Two groups of protons were observed, of Q values of about -1.16 Mev and -2.0 Mev for $E_\alpha = 3.6$ Mev and 4.2 Mev. The yield per million incident α-particles has been estimated at 0.348 and 0.409 for the two resonance levels, 3.6 Mev and 4.2 Mev, respectively. The angular distribution of protons in the CM system has a maximum at $\theta = 90°$ for the two ground states, and, for the excited states, it is isotropic.

I. INTRODUCTION

THE reaction $O^{16}(d,p)O^{17}$ and the reaction $N^{14}(\alpha,p)O^{17}$ both lead to the formation of the compound nucleus F^{18*}. It is known[1] that the former reaction yields two groups of protons. For $E_d = 0.575$ Mev, which corresponds to an excitation of 8 Mev in F^{18*}, these two groups had Q-values of 1.75 Mev and 0.8 Mev, according to the observation of Pollard and Davison.[2] At this excitation, which is provided by α-particles of energy about 3.6 Mev, only one group of protons has been observed in previous experiments for the second reaction, although two groups might be expected, unless forbidden by selection rule. The presence of two groups of protons in the reaction $N^{14}(\alpha,p)O^{17}$ has, in fact, been demonstrated by Pollard and Davison,[2] but in this case, the energy of the α-particles was about 5.2 Mev.

The purpose of the present experiment was to investigate, by emulsion technique; (A) the group structure of the protons, at low bombarding energies of the α-particles, arising from the reaction $N^{14}(\alpha,p)O^{17}$; (B) the yield of the process; and (C) the angular distribution of the protons.

[1] J. D. Cockroft and W. B. Lewis, Proc. Roy. Soc. (London) **A130**, 463 (1936). Guggenheimer, Heitler, and Powell, Proc. Roy. Soc. (London) **A190**, 196 (1947).

[2] E. Pollard and Perry W. Davison, Phys. Rev. **72**, 736 (1947).

II. EXPERIMENTAL DETAILS

The α-particles from polonium were channeled through a circular slit, the arrangement of which is shown in Fig. 1. It consists of two circular brass disks D, fitted with guard rings R, cut at sharp angles. The strength of the source is 1 mc deposited at one end of a wire W and introduced into the slit through the guide G which holds the source centrally between the two disks. The position of the source 0 can be viewed through holes H drilled at the center of each disk. The two supports S and the guide channel G subtend an equal angle at the center. This facilitated the calculation of the solid angle through which α-particles emerged.

TABLE I. Proton groups from $N^{14}(\alpha,p)O^{17}$.

E_α (Mev)	No. of protons	R_μ	E_p (Mev)	Q (Mev)	Ratio (II)/(I)
3.6	(I) 1986	54.5	2.45	(a) -1.15 ± 0.04	0.12
	(II) 245	28.5	1.60	(b) -2.0 ± 0.04	
4.2	(I) 2321	75	3.02	(a) -1.18 ± 0.04	0.12
	(II) 291	46.2	2.20	(b) -2.0 ± 0.04	

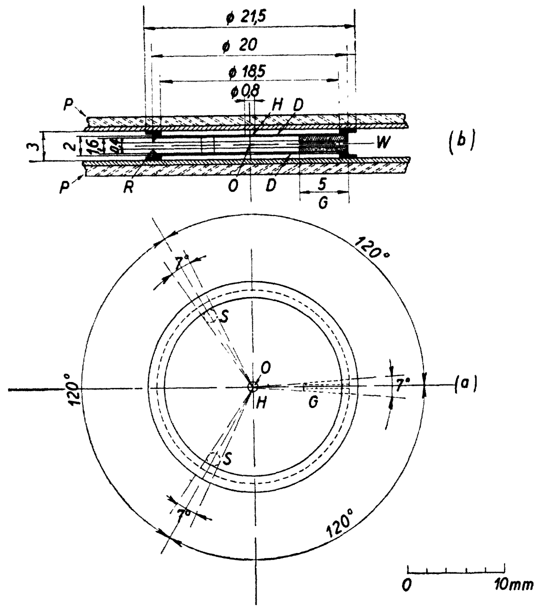

FIG. 1. (a) Sectional diagram of the slit arrangement together with the two plates P, one at the top, the other at the bottom of the slit. (b) Top view of the slit, the position of the supports S, the guide channel G, and the central hole H being indicated.

The angular dispersion of the α-beam calculated from the geometry of the slit was about 1°. This spread caused a dispersion in energy of the α-particles which was negligible in comparison with the width of the resonance levels investigated. The advantage of the slit was that, with the use of the two plates at each exposure, it permitted work with a low intensity source without sacrificing the yield. The location of the slit after development was possible because the geometry of the slit allowed α-particles from the source to strike the plates only through the central holes of the disks.

Ilford C2 50μ plates, 7 cm×5.5 cm, were used for the experiments and were exposed inside an airtight camera fitted with a manometer. Preliminary exposures were given in vacuum to study the effect of the slit and of the blackening of the plates due to γ-rays from the source, and, as a result, the upper time limit of exposure was fixed at 6 hours. However, in the final experiments an exposure of 2 hours was found sufficient to give the data required. The plates were developed by the discrimination method[3] in order to distinguish protons from any stray α-particles which might be present.

The measurement of angles was made by means of a goniometer calibrated at an interval of 0.5°. The total error in the measurement of angles, due partly to the small angular spread of the incident α-particles and partly to inaccuracy in measuring, was estimated to be less than 2°.

[3] M. Mortier and L. Vermaesen, Centre de Physique Nucléaire, Université Libre de Bruxelles, Note No. 5 (December, 1948).

III. RESULTS

(A) Structure of the Proton Groups

After measuring the coordinates, ranges, and angles of protons, it was found that there were altogether four groups of protons present; two for $E_\alpha=4.2$ Mev and two for $E_\alpha=3.6$ Mev. Protons originating from a disintegration must travel a certain distance in nitrogen before they strike the surface of the emulsion. This distance depends on the angle at which they are ejected with respect to the incident α-particles. In estimating the protons range this was taken into account. Table I gives the results.

It can be seen from Column 5 that the Q-value obtained for the ground state transition (a) is in agreement with the value -1.16 Mev derived from the mass data. The shorter range proton group from the excited state transition (b) gives a Q-value of -2.0 Mev for both the resonance levels. The ratio of the number of protons for the excited state and for the ground state is shown in the last column. The range of protons in micron is noted in Column 3 and its corresponding energy in Column 4.

(B) Yield of the Process

An estimate was made of the yield of protons per million incident α-particles for the two resonance levels. In order to calculate the yield, one must know how many protons are emitted for a given number of incident particles. The number of α-particles emerging from the slit during the course of the exposure was determined from the geometry of the slit and the strength of the source. Most of the disintegration protons were recorded, but some escaped through the gap between the two photographic plates. The number of these unrecorded protons was calculated according

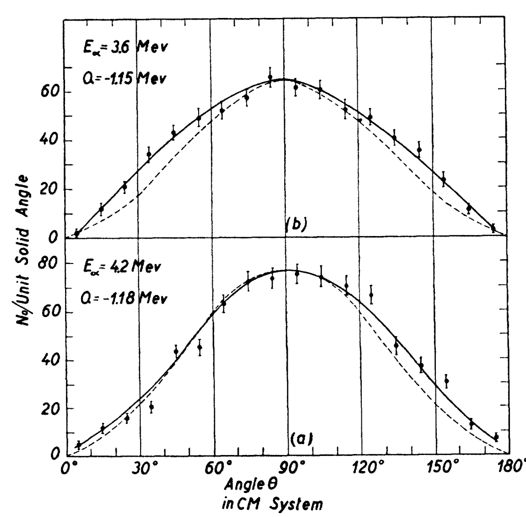

FIG. 2. (a) Angular distribution of the protons for the resonance level $E_\alpha=4.2$ Mev and $Q=-1.18$ Mev. The distribution shows a maximum at $\theta=90°$. (b) Distribution of the protons for the resonance level $E_\alpha=3.6$ Mev and $Q=-1.15$ Mev. The maximum of the curve is at $\theta=90°$.

to the method given in the Appendix. For $E_\alpha = 3.6$ Mev, the yield of protons for the ground and excited state transitions is 0.31 and 0.038, and for $E_\alpha = 4.2$ Mev it is 0.364 and 0.045.

(C) Angular Distribution

The angular distribution of protons for $E_\alpha = 3.6$ Mev and 4.2 Mev has been plotted in Figs. 2(a) and 2(b), respectively.

Both curves show a maximum at $\theta = 90°$ in the CM system. Figure 2(b) confirms the earlier observation of Champion and Roy,[4] who studied the angular distribution of protons from the reaction $N^{14}(\alpha,p)O^{17}$ for $E_\alpha = 3.6$ Mev by the cloud-chamber method. The experimental curves for the two ground state distributions can be fitted by the expression $1-\cos^2\theta$ (given in dotted lines).

Figures 3(a) and 3(b) illustrate the angular distribution of protons for the two excited states. No preferred direction in the emission of protons is evident. The curves are isotropic.

IV. CONCLUSIONS

The experimental results show the presence of two groups of protons for each resonance energy, 3.6 Mev and 4.2 Mev, corresponding to Q-values of about -1.16 Mev and -2.0 Mev. The difference between the Q-values, 0.84 Mev, reveals the presence of an excited level in O^{17}. This is approximately the value obtained from the reaction $O^{16}(d,p)O^{17}$ for the groups of protons at an excitation of 8 Mev above the ground state of the compound nucleus F^{18*}. The ratio of the number of protons from the two states is 0.12, which is smaller than the value 0.3 obtained by Pollard and Davison for the same reaction but with a higher incident energy of the α-particles. This difference might be explained by assuming that the yield from the excited state increases with increasing energy of incidence. The angular distribution of the ground state groups suggests that the probable value for the angular momentum is unity. It would seem that the P-wave is involved in this disintegration process.

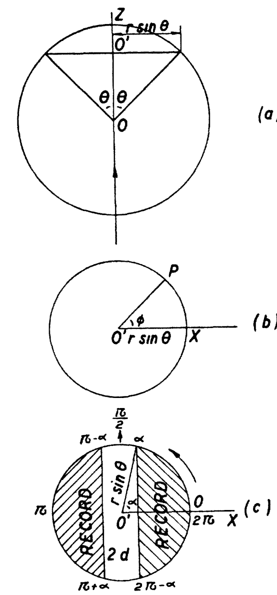

FIG. 4. Geometrical conditions of the experiment.

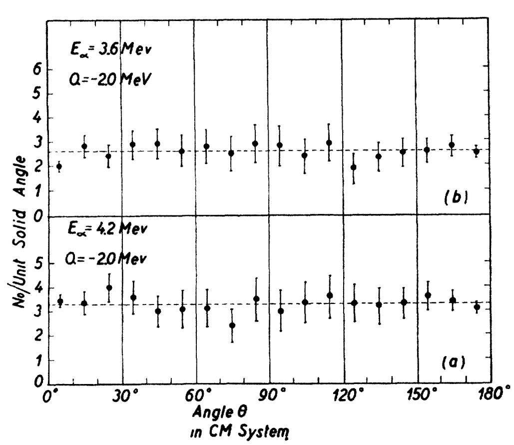

FIG. 3. Distributions for the two excited states, $E_\alpha = 4.2$ Mev and $E_\alpha = 3.6$ Mev, which are isotropic.

[4] F. C. Champion and R. R. Roy, Proc. Roy. Soc. (London) **A191**, 269 (1947).

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APPENDIX

Method of Calculating the Total Number of Protons

Let r be the range of a proton ejected at an angle θ with the direction of incidence OZ. The protons will lie on a circle of latitude of the sphere, center O (the point where the disintegration occurs) and radius r. The vertical section can then be represented as in Fig. 4(a). All protons will be distributed on the circumference of the horizontal circle of latitude [Fig. 4(b)], which has a radius $r\sin\theta$. In Fig. 4(b), $O'X$ is any reference line drawn in the plane, and the point P on the circumference is specified by the angle ϕ made by $PO'X$. It is assumed that the intensity is independent of ϕ. If the total of the disintegrated protons be N, the number per unit angle of ϕ will be $N/2\pi$. Conversely, if we know the number of disintegrated particles over some definite range of ϕ, for instance β, then the total over the whole range will be

$$(2\pi/\beta)\times\text{no. of disintegrated particles in range } \beta. \qquad \text{(I)}$$

If $2d$ be the distance between the two plates, the particles whose paths end within the range of $2d$ are not recorded. The horizontal section in the plane of latitude is then represented as in Fig. 4(c). It can be seen from the figure that the particles are recorded for a range of ϕ which is 4α radians; those not recorded are of $(2\pi-4\alpha)$ radians. From the figure, we see that

$$\cos\alpha = d/r\sin\theta. \qquad \text{(II)}$$

Therefore, if, in (I), n be the number of particles recorded from the experiment, the total number present was $2\pi n/4\alpha$, where α is given by (II).