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Short Range Alpha-Particles from Fluorine and Lithium Bombarded by Protons

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IN a recent paper Walker and McDaniel[1] report on measurements of the energy of the gamma-radiation emitted in the bombardment of fluorine and lithium by protons. The radiation from fluorine was found to consist of two lines of energies 6.13 ± 0.06 and 6.98 ± 0.07 Mev; similar results have been reported by Rasmussen, Hornyak, and Lauritsen.[2] The 6-Mev radiation has been shown to come from an excited O^{16} nucleus formed in the reaction:

$$F^{19}+H^1 \rightarrow O^{16*}+He^4,$$

and the alpha-particles (α_1) produced in this reaction have been detected.[3,4]

We have now observed alpha-particles (α_2) corresponding to the emission of the 7-Mev gamma-radiation. These particles were resolved magnetically from protons scattered from the target and were detected by a fluorescent screen and photoelectric multiplier. Figure 1 shows the number of alpha-particles observed from a thin calcium fluoride target as a function of analyzer magnet current. The magnetic analyzer was calibrated by means of the particles from the well-known reactions[5] $Be^9(p\alpha)Li^6$ and $Be^9(pd)Be^8$ and the Q values deduced for the alpha-particle groups from fluorine are shown in Table I, together with values obtained by range comparisons. The errors stated represent the uncertainty in setting the magnetic field and in the range determinations (0.05 Mev) together with an allowance of 0.03 Mev for possible systematic errors in calibration. The mean Q for the group α_1 (1.93 ± 0.06 Mev) is higher than that found earlier,[4,6] but the sum of this value and the corresponding gamma-ray energy is 8.06 ± 0.08 Mev which is consistent with the energy of 8.12 ± 0.24 Mev available from the mass change.[7] The Q for the group α_1 is independent of proton energy, in agreement with previous work.[3,4]

The difference between the Q for the reaction $F^{19}(p\alpha_2,\gamma)O^{16*}$ at 867 kev and at the other tabulated resonances exceeds the experimental error. This suggests that the excited state in which the O^{16} nucleus is left in this reaction is not the same at all resonances; the results could be explained by the existence in the oxygen nucleus of levels at 6.94 and 7.15 Mev above the ground state, in addition to previously known levels at about 6.00 (pair emitting level) and 6.13 Mev.[2,6] If this is so, the energy of the gamma-radiation observed at the 932- and 665-kev resonances should be 7.15 Mev and that of the gamma-radiation at the 867-kev resonance should be 6.94 Mev. The thick target observations of Walker and McDaniel are not inconsistent with this hypothesis.[8]

The ratio of intensities α_1/α_2 of the two groups of alpha-particles (observed at 83° with the proton beam) is given in Table II for the more prominent resonances below 950 kev, together with the

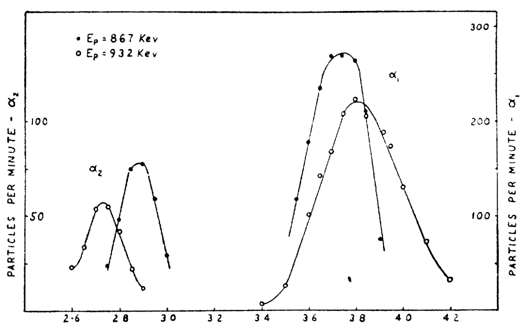

FIG. 1. Alpha-particles from the $F^{19}(p\alpha,\gamma)O^{16*}$ reaction for proton energies of 867 and 932 kev. Angle of observation $=104°$.

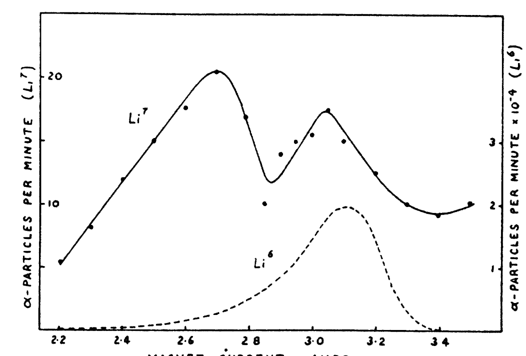

FIG. 2. Alpha-particles from lithium isotopes bombarded with 440-kev protons. Angle of observation $=104°$.

[1] R. L. Walker and B. D. McDaniel, Phys. Rev. **74**, 315 (1948).
[2] Rasmussen, Hornyak, and Lauritsen, Phys. Rev. (to be published).
[3] W. E. Burcham and S. Devons, Proc. Roy. Soc. **A173**, 555 (1939).
[4] Becker, Fowler, and Lauritsen, Phys. Rev. **62**, 186 (1942).
[5] Tollestrup, Lauritsen, and Fowler, Phys. Rev. (to be published).
[6] J. M. Freeman and A. S. Baxter, Nature **162**, 696 (1948).
[7] H. A. Bethe, *Elementary Nuclear Theory* (John Wiley & Sons, Inc., New York, 1947).
[8] Measurements of the gamma-ray energies at the 867- and 932-kev resonances, kindly communicated to us by Professor Lauritsen, are also in agreement with the suggestion of a higher energy at the latter resonance.

TABLE I. Q values for the alpha-particle groups from fluorine.

Proton Energy (kev)	Group α_1 932	867	665	Group α_2 932	867	665
Q by magnetic deflection (Mev)	1.95	1.94	1.97	0.96	1.19	0.98
Q by range (Mev)	1.88	1.92	1.93	—	1.17	0.96
Mean Q (Mev)	1.92	1.93	1.95	0.96	1.18	0.97
Error (Mev)		±0.08			±0.08	

TABLE II. Ratio of the intensities $^{\alpha}1/\alpha_2$ of the two alpha-particle groups and the gamma-ray intensity ratio observed by Rasmussen, Hornyak, and Lauritsen.

Proton Energy (kev)	343	594	665	867	932
$^{\alpha}1/\alpha_2$	50	>60	6	3.0	3.7
$^{\gamma}1/\gamma_2$				2.5	3.3

gamma-ray intensity ratio observed by Rasmussen, Hornyak and Lauritsen.[2] The variation in $^{\alpha}1/\alpha_2$ with proton energy is predicted by the varying penetrability of the barrier of the O^{16*} nucleus for the two alpha-particle groups except in the case of the 594-kev resonance, for which the α_2 group could not be distinguished above background and appears to be forbidden.

In the work with lithium, Walker and McDaniel show that there are gamma-ray lines of energies 14.8 and 17.6 Mev, and give evidence that these lines correspond to transitions in the excited Be^8 nucleus formed in the reaction

$$Li^7+H^1\rightarrow Be^{8*}\rightarrow Be^8+\gamma.$$

The emission of a 17-Mev gamma-ray leaves the Be^8 nucleus in its ground state, while that of a 14-Mev gamma-ray could leave the nucleus in the well-known 2.8-Mev excited state, which has been observed in several other reactions and is known to break up into two alpha-particles.[9] We have observed these particles by bombarding a thick target of the Li^7 isotope (oxidized by exposure to air) with 440-kev protons. Figure 2 shows the distribution of alpha-particles emitted from this target, together with a curve taken with a Li^6 target under the same conditions. The alpha-particles from the excited state of Be^8 form a group centered at an energy of 1.38±0.08 Mev. This group was found to have an excitation function agreeing exactly with that of the gamma-radiation for proton energies between 350 and 700 kev. The energy of the excited state of Be^8 from these measurements is 2.6±0.2 Mev, and the width is 0.9±0.1 Mev. The higher energy group shown in Fig. 2 (Li^7) could be due to contamination of the target by Li^6 and check experiments showed that the number of particles in this group was only about twice that expected from the contamination; within the limits of accuracy of the comparison, the whole of the second group could be ascribed to the $Li^6(p\alpha)He^3$ reaction.

[9] Bonner, Evans, Malich, and Risser, Phys. Rev. **73**, 885 (1948).

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Photograph of a Shower Produced by a π-Meson and a π-μ-Decay

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THE production of multiple heavy particles by the interaction of π-mesons with nuclei has been definitely established by the recent investigation with photographic plates by the Bristol school.[1] So far little evidence of such interactions has been obtained from Wilson Chamber photographs. We reproduce herewith a photograph of a shower which appears to be produced by the interaction of a π-meson with a nucleus; the particles emitted are not heavy in character, neither have they short ranges like the particles recorded in photographic emulsions (see Fig. 1). The photographs are stereoscopic and careful reprojection shows that the shower starts from a point in the gas of the chamber about 1.5 cm below the second lead plate (thickness 2.5 cm). Altogether seven particles are present in the shower and the two horizontal particles ejected towards the left start from the same point as the other five particles contained in the downward cone. These five particles pass out of the third lead plate (thickness 1 cm) with only one more secondary particle as the numbering of the tracks will show. The track No. 7 is an old track which is easily recognized from its diffused nature.

The first interesting point about the shower is its generation in the gas apparently from a point and the emission of the two particles toward the left without any apparent emission on the right

[1] Lattes, Occhialini, and Powell, Nature **160**, 486 (1947).