have to be greater than $m_\nu + m_\mu$. Using the values of the above example, we should have $m_\pi > 340 m_e > m_\mu$, an inequality which does not seem contradictory to present experience. While on this assumption the σ -meson could not spontaneously give rise to a pair of μ -mesons (charged and neutral), such a process would be possible in the field of a nucleus, if the energy is sufficient—as it might easily be under the Berkeley conditions. It is suggested that this may be the explanation of the comparatively large number of μ -mesons observed in the Berkeley plates. While the most probable process under those conditions seems to be the formation of σ -mesons by *Bremsstrahlung*, the observed cases of π -decay might on the above view be due to a break-up of nucleons, a process which would be expected to occur with measurable probability, the energy quantum (frequency multiplied by Planck's constant), corresponding to the collision time, being of the same order of magnitude as the assumed binding energy of the nucleon.

Without entering more closely on the consequences of the opposite assumptions—the identity of σ - and π -mesons—for the above considerations, I should like to state that in my view the interpretation of the μ -meson as an $\hbar/2$ -particle with an ordinary β -decay, which is, of course, independent of the hypothesis concerning nucleons and π -mesons, has not only a better foundation than the other assumptions of the above note, but also the more important bearing on the problem of the incorporation of meson theory in the general relativistic field theory. In this connexion it should perhaps be mentioned that the argument given in the note concerning the mass value of the electrophoton can only be expected to give the order of magnitude.

¹ Leprince-Ringuet, L., and L'Héritier, M., *J. Phys. Radium*, (8), 7, 66, 69 (1946). Rochester, G. D., and Butler, C. C., *Nature*, 160, 855 (1947).

² Weisskopf, V., *Phys. Rev.*, 72, 155 (1947). Pontecorvo, B., *Phys. Rev.*, 72, 246 (1947).

³ Klein, O., *Ark. and Mat. Astr. O. Fys.*, 34 A, No. 1 (1946).

⁴ Konopinski, *Rev. Mod. Phys.*, 15, 207 (1943).

EXCITATION CURVES FOR THE γ -RADIATION FROM LIGHT ELEMENTS BOMBARDED WITH α -PARTICLES FROM POLONIUM

By PROF. HILDING SLÄTIS
Nobel Institute for Physics, Stockholm

A LARGE number of investigations have been carried out on the disintegration of light nuclei bombarded with α -particles. In several cases excitation curves have been obtained for the γ -radiation as a function of the energy of the α -particles. (A review of earlier polonium α -particle bombardments of light elements, particularly those which may be of interest

Fig. 1. EMISSION OF γ -QUANTA ($\circ$) FROM LITHIUM, BERYLLIUM, BORON, FLUORINE, AND NEUTRONS (Δ) FROM BERYLLIUM AS A FUNCTION OF THE ENERGY OF THE BOMBARDING α -PARTICLES

for a possible γ -radiation, has been published by the present writer in *Arkiv. Mat., Ast. Fysik*, 35 A, No. 31; (1948). The results of different authors, however, are often inconsistent. For that reason I made use of an available polonium sample of about 40 mC. for observing the excitation functions of the γ -radiation from light elements bombarded with α -particles. The energy of the α -particles was varied by means of carbon dioxide.

Lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, sodium, magnesium, aluminium, silicon, phosphorus, sulphur, chlorine, potassium, calcium and lead were investigated. γ -Emission was observed from lithium, beryllium, boron, nitrogen, fluorine, sodium, magnesium and aluminium. The intensity of the γ -radiation was measured as a function of the energy of the α -particles for all these except nitrogen (Figs. 1–2). The α -particle threshold values for γ -emission and the relative intensities (as percentage of the measured polonium γ -radiation background) of the γ -quanta are given in the accompanying table.

Element	γ -Emission starts at the α -energy	Intensity of the γ -radiation for 5.3 MeV. α -particles
Li	MeV. 2.3	61
Be	1.7	340
B	3.7	9.0
N	—	2.7
F	3.1 (and 4.5)	9.0
Na	4.6	9.5
Mg	3.6	3.7
Al	4.1	7.9

The statistical errors are represented in all the diagrams except the γ -emission curves for lithium and beryllium, where the errors were too small to be

Fig. 2. γ -EMISSION FROM SODIUM, MAGNESIUM AND ALUMINIUM AS A FUNCTION OF THE ENERGY OF THE BOMBARDING α -PARTICLES

plotted ($\lesssim 1$ per cent of the polonium γ -radiation background).

The neutron-emission from beryllium was measured for α -particles of energies 4.3 and 5.3 MeV. The results and the statistical errors are plotted on an arbitrary scale in Fig. 1.

⁷Li. The γ -radiation is due to an excitation of the Li^7 -nucleus by inelastic collisions with α -particles, as quoted, for example, in the paper by Siegbahn and Slätis¹. The γ -radiation starts for α -particles of the energy 2.3 MeV., in agreement with the result of Schnetzler² but not with earlier investigations by Webster³ (1.9 MeV.), Curie and Joliot⁴ (3.1), Savel⁵ (2.8–3.0).

⁹Be. The γ -radiation maximum with 2.7 MeV. α -particles found by Becker and Bothe⁶ could not be confirmed, nor the starting point of the γ -emission for α -particles of the range 1.7 cm. (3 MeV.). The neutrons seem to be emitted simultaneously with the γ -quanta, as predicted by Chadwick⁷. The energy (1.7 MeV.) of the α -particles at which the γ -emission starts is the same as Chadwick found for the beginning of the neutron emission, and is in fairly good agreement with the starting points for the γ -emission found by Webster³ (1.9 MeV.) and by Szalay and Zimonyi⁸ (1.62 MeV.). Rasetti⁹ found 1.6 MeV. for the beginning of neutron emission and Curie and Joliot⁴ 1.3 MeV. for neutrons and γ -quanta.

⁵B. According to Becker and Bothe⁶, the γ -radiation begins at the same α -particle energy for which the second proton group starts (also in agreement with v. Baeyer¹⁰). The corresponding α -particle range was 2.90 cm. (4.4 MeV.). This is in agreement with the curve in Fig. 1, which starts at 3.7 MeV., or with the results of Webster³ (1.9 MeV.), or those of Szalay and Zimonyi⁸ (1.5 cm. = 2.7 MeV.), but in good accordance with Heidenreich¹¹ (3.6 MeV.) and Alichanow, Alichanian and Dzelepov¹² (2.1 cm. = 3.5 MeV.).

⁹F. The first proton pair found by Chadwick and Constable¹³ started at an α -range of 2.2 cm. (3.64 MeV.), the second pair at 2.7 cm. (4.2 MeV.).

This result is not in agreement with my observations; I find that (Fig. 1) the γ -radiation starts at 3.1 MeV. with clearly a second component at 4.5 MeV. energy of the α -particles. The starting point 0.9–1.2 MeV., found by Savel⁵, seems to be very improbable. Speh¹⁴ discovered that the γ -radiation consisted of two components. The harder one started at 3.1 cm. α -particle range (4.6 MeV.), which is in good agreement with the second starting point of the γ -radiation shown in Fig. 1.

¹¹Na. According to Fig. 2, γ -emission starts at an α -particle energy of 4.6 MeV. This agrees neither with Savel's⁵ result (3.7–4 MeV.) nor with Kovács's¹⁵ (2.7 MeV. and 3.5 MeV.). König¹⁶, however, found a proton resonance group, called B, which started at 4.8 MeV. This is in accordance with my result.

¹²Mg. Klarman's¹⁷ first proton group started at an α -particle energy of 3.26 MeV., which may agree with my value 3.6 MeV. for the beginning of the γ -radiation (Fig. 2). Savel⁵ found 4.3–4.5 MeV.

¹³Al. Pose's¹⁸ first proton group for an α -range of 2.50 cm. (4 MeV.) agrees well with the α -particle threshold value 4.1 MeV. for the γ -emission found by me (Fig. 2). Chadwick and Constable¹³ found for the first proton pair a threshold value 4.2 MeV. for the α -particle energy, also in good accordance with my result. Savel⁵ found 3–3.3 MeV. for the beginning of the γ -emission, Fahlenbrach¹⁹ 3 cm. (4.5 MeV.) for the starting point of the (α, p) -process, Alichanow, Alichanian and Dzelepov¹² 3.4 cm. (4.9 MeV.) for the (α, n) -process. For the same (α, n) -process Waring and Chang²⁰ obtained 3.4 MeV. Pollard, Schultz and Brubaker²¹ found possible resonance effects at 2.3 cm. (3.8 MeV.) and 4.8 cm. (6 MeV.). The former α -particle energy 3.8 MeV., as well as Fünfer's²² value 2.3 cm. (3.8 MeV.) and the starting point 2.4 cm. (3.9 MeV.) for the γ -radiation, found by Szalay and Zimonyi⁸, agree well with my α -particle energy value 4.1 MeV. for the beginning of the γ -radiation from aluminium.

¹ Siegbahn, K., and Slätis, H., *Nature*, **159**, 471 (1947); *Arkiv. Mat., Ast. Fysik*, **34** A, No. 15 (1947).

² Schnetzler, K., *Z. Phys.*, **95**, 302 (1935).

³ Webster, H. C., *Proc. Roy. Soc., A*, **136**, 428 (1932).

⁴ Curie, J., and Joliot, F., *C.R. Acad. Sci., Paris*, **196**, 397 (1933).

⁵ Savel, P., *Ann. de Phys.*, **4**, 88 (1935).

⁶ Becker, H., and Bothe, W., *Naturwiss.*, **20**, 349 (1932).

⁷ Chadwick, J., *Proc. Roy. Soc., A*, **142**, 1 (1933).

⁸ Szalay, A., and Zimonyi, J., *Z. Phys.*, **115**, 639 (1940).

⁹ Rasetti, Z., *Phys.*, **78**, 165 (1932).

¹⁰ v. Baeyer, H. J., *Z. Phys.*, **95**, 417 (1935).

¹¹ Heidenreich, F., *Z. Phys.*, **86**, 675 (1933).

¹² Alichanow, A. I., Alichanian, A. I., and Dzelepov, B. S., *Z. Phys.*, **93**, 350 (1935).

¹³ Chadwick, J., and Constable, J. E. R., *Proc. Roy. Soc., A*, **135**, 48 (1932).

¹⁴ Speh, K. C., *Phys. Rev.*, **50**, 689 (1936).

¹⁵ Kovács, M., *Phys. Rev.*, **70**, 895 (1946).

¹⁶ König, A., *Z. Phys.*, **90**, 197 (1934); *Naturwiss.*, **22**, 150 (1934).

¹⁷ Klarman, H., *Z. Phys.*, **87**, 411 (1934).

¹⁸ Pose, H., *Phys. Z.*, **30**, 780 (1929); *Naturwiss.*, **17**, 624 (1929).

¹⁹ Fahlenbrach, H., *Z. Phys.*, **94**, 607 (1935).

²⁰ Waring, I. R. S., and Chang, W. Y., *Proc. Roy. Soc., A*, **157**, 652 (1936).

²¹ Pollard, E., Schultz, H. I., and Brubaker, G., *Phys. Rev.*, **53**, 351 (1938).

²² Fünfer, E., *Ann. de Phys.*, **32**, 313 (1938).