THE DECAY OF THE 7·68 MeV STATE IN ^{12}C

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Summary

A polonium-beryllium source has been used to investigate the radiations in coincidence with the 4·43 MeV γ-ray leading to the ground state of ^{12}C. The coincident radiation consisted of a continuum due to neutrons and a γ-ray of energy 3·05 MeV and intensity 0·12–0·08 that of the 4·43 MeV γ-ray.

This indicates that the 7·68 MeV state of ^{12}C decays principally by cascade γ-emission.

I. Introduction

The second excited state of ^{12}C at 7·68 MeV has recently become the subject of considerable interest owing to the importance of the ^{8}Be(α,γ)^{12}C reaction in those hot stars which have largely exhausted their central hydrogen. Under this condition the core is expected to contract and the central temperature to rise until thermonuclear reactions with the helium occur. Hoyle explains the original formation of elements heavier than helium by this process and concludes from the observed cosmic abundance ratios of ^{16}O : ^{12}C : ^{4}He that there should be a level in ^{12}C in the region of 7·6 MeV, that is, the ^{8}Be$+\alpha$ reaction should have a resonance at about 0·25 MeV. Several reactions indicate the existence of a ^{12}C level in this region, the most recent and accurate measurement being from the ^{14}N(d,α)^{12}C* reaction which places the level at 7·68$\pm$0·03 MeV above ^{12}C ground state (Dunbar *et al.* 1953). With the existence of the level confirmed it is important to know the relative probabilities of the different modes of decay which are energetically possible, namely,

(i) decay to ^{8}Be$+\alpha$,

(ii) decay direct to ^{12}C ground state by γ-radiation or pair emission,

(iii) cascade γ-decay to the ground state of ^{12}C.

Although the decay of the 4·43 MeV state of ^{12}C by γ-radiation is well known, no γ-radiation from the 7·68 MeV state to ground has been observed, and a lower intensity limit to the ratio of these two γ-rays has been given as 2500 : 1 (Beghian *et al.* 1953). The apparently forbidden nature of such a transition can be explained by both the 7·68 MeV state and ground state of ^{12}C having spin zero. Decay of this excited state by nuclear pair emission, however, has been reported by Harries and Davies (1952) who observed seven such pairs in cloud chamber measurements.

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Beghian *et al.* (1953) have reported the existence of a 3·16 MeV γ-ray in the γ-ray spectrum from a polonium-beryllium source. Using a thick beryllium target, the intensity of the 3·16 MeV γ-ray was only 1 : 30 that of the 4·43 MeV γ-ray.

In the present paper the γ-ray cascade has been observed in the reaction $^{9}Be(\alpha,n)^{12}C^{*}\gamma,\gamma^{12}C$. From the results it is possible to make an estimate of the relative probability of the decay of $^{12}C^{*}$ by this γ-ray cascade.

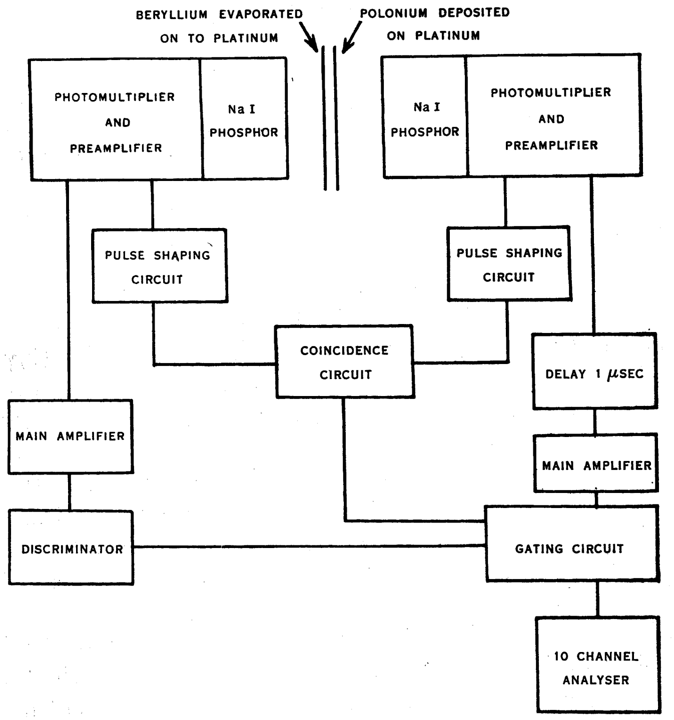

Fig. 1.—Block diagram of apparatus.

II. Experimental

The detection of a 4·43 MeV γ-quantum in one scintillation counter has been used to gate the output of a second scintillation counter so that the gated output consists essentially of pulses due to radiations in coincidence with the 4·43 MeV γ-ray. These radiations are :

(*a*) neutrons (approx. 3 MeV) from $^{13}C^{*}$ to 7·68 MeV state in ^{12}C,

(*b*) γ-radiation (approx. 3 MeV) from 7·68 MeV state in ^{12}C to 4·43 MeV state,

(*c*) neutrons (approx. 6 MeV) from $^{13}C^{*}$ to 4·43 MeV state in ^{12}C.

The experiment therefore reduces to the problem of detecting radiation (*b*) in the presence of (*a*) and (*c*), where the relative intensities $a : b : c$ may be expected to be $1 : \leqslant 1 : 8$ (Guier, Bertini, and Roberts 1952). This is achieved through the differential amplitude distribution of pulses from the detector because the inelastic scattering of neutrons in the above energy region is expected to give rise to a continuum which is approximately logarithmic, decreasing to zero at an energy rather below the neutron energy. On the other hand γ-radiation at the above energy may be expected to give rise to peaks at energies corresponding to pair energy ($E_\gamma - 2m_0c^2$) and pair energy plus the capture of one annihilation quantum ($E_\gamma - m_0c^2$).

A block diagram of the detecting and analysing apparatus is shown in Figure 1. A 40 mc polonium-beryllium source was used, the polonium being deposited on a 1 cm diameter area on a platinum disk. Measurements were made with both thick and thin beryllium targets opposite the polonium and distant 0·020 in. from it. The thick target was a 0·010 in. thick beryllium disk while the thin target was made by evaporating beryllium on to a platinum disk to give a target approximately 200 keV thick.

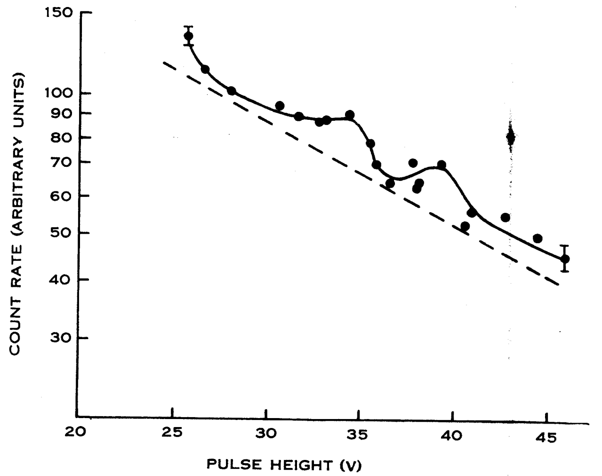

Fig. 2.—Typical pulse height distribution due to radiation in coincidence with 4·43 MeV γ-rays. Probable error has been indicated on two typical points.

Two scintillation counters (with sodium iodide crystal phosphors $1\frac{1}{2}$ in. diameter by 1 in. long) were used to detect the emissions. These counters were both placed as close as possible to the source. The output of a 0·2 μsec coincidence circuit between the two counters triggered a gate which passed on any pulses in counter *A* which were in coincidence with a 4·4 MeV γ-ray in counter *B*. These gated pulses were analysed on a 10 channel pulse amplitude analyser. The observed true to random ratio was 100 : 1 when using the thin target.

III. Results and Discussion

Several measurements of the amplitude distribution of the gated pulses were made for each beryllium target. With the thick target the number of 6 MeV neutrons compared with the number of 3 MeV neutrons is estimated to be 30 : 1 while with the thin target the ratio is approximately 8 : 1. Therefore any features of the coincidence pulse distribution which are emphasized in the thick target runs are due to neutrons, while any showing more distinctly in the thin target runs are due to γ-radiation.

The thick target runs give a smooth distribution with energy which is nearly exponential.

A typical pulse distribution due to radiation in coincidence with the $4 \cdot 4$ MeV γ-ray from a thin target is shown in Figure 2. The bumps in the curve which are evident at 34 and 39 V occurred in all thin target runs.

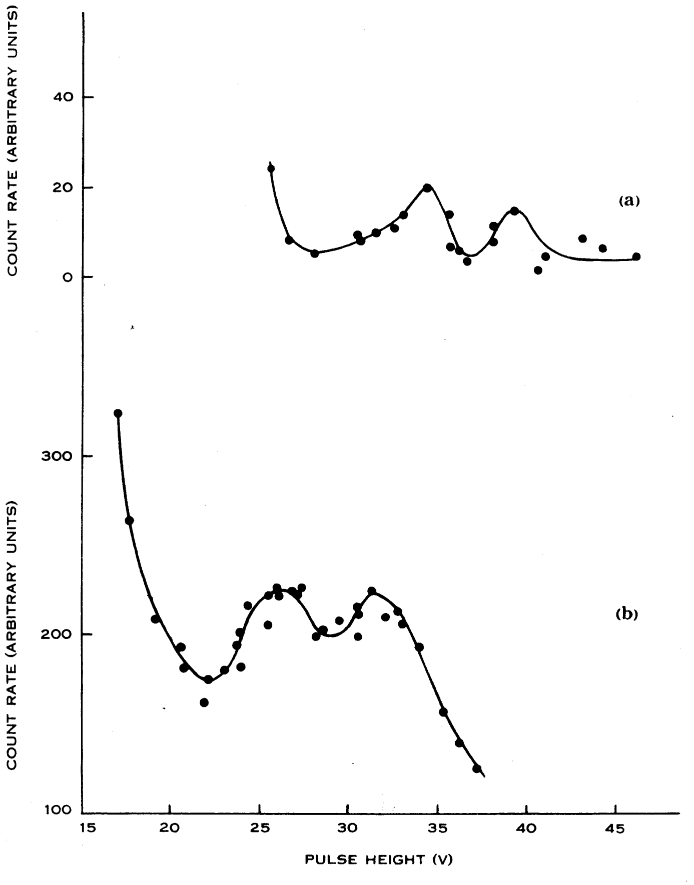

Fig. 3 (a).—Data shown in Figure 2 after background subtracted.
Fig. 3 (b).—Distribution of pulses due to $2 \cdot 62$ MeV γ-radiation from ThC″.

When an exponential function similar to the thick target pulse distribution (represented by the straight line below the curve in Figure 2) is subtracted from the thin target measurement we obtain the curve shown in Figure 3 (a).

By comparison with the ThC″ pulse distribution (Fig. 3 (b)) the difference curve is seen to represent a single γ-ray line of energy approximately $3 \cdot 0$ MeV. Only the pair and pair-plus-one peaks appear because of the relatively poor resolution of the crystal used.

Using the ThC″ γ-radiation and the polonium-beryllium $4 \cdot 43$ MeV γ-ray pair peak for calibration the energy of the coincident γ-ray is estimated at $3 \cdot 05 \pm 0 \cdot 1$ MeV. This value of $0 \cdot 1$ MeV for the assigned error has been assessed from the repeatability of the pair peak in the several thin target runs and takes no account of errors in calibration. The energy, $3 \cdot 05$ MeV, found from the peak is lower than the measurement by scintillation counter pair spectrometer (Beghian *et al.* 1953) mentioned earlier and is also lower than the value required by the difference in energy of the two levels concerned. Because of uncertainties in the calibration, however, no significance is attached to this discrepancy.

From the peak to trough ratios in Figure 3 the fraction of counts due to $3 \cdot 1$ MeV γ-rays under the curve of Figure 2 may be estimated and from this figure and the geometry of the source and counters the ratio of $3 \cdot 1$ MeV γ-rays to $4 \cdot 4$ MeV γ-rays from the polonium-beryllium source has been calculated. This ratio lies between $0 \cdot 08$ and $0 \cdot 12$. Comparing these values with the photographic plate determination of the ratio of the number of neutrons leading to the excited states in ^{12}C as $1 : 8$ (Guier, Bertini, and Roberts 1952), it appears that the decay of the state at $7 \cdot 68$ MeV is principally by cascade γ-emission.

IV. Acknowledgments

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