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THE $^{7}Li+p\gamma$-RADIATION AS A TOOL FOR THE DETECTION OF NUCLEAR CROSS-SECTION FLUCTUATIONS

by

M. MANDÒ

(Istituto di Fisica dell'Università - Firenze)

1963

Work performed by Istituto Nazionale di Fisica Nucleare - Sottosezione di Firenze under the Euratom contract No. 001-60-12 MPAI

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The ^{7}Li+p γ-Radiation as a Tool for the Detection of Nuclear Cross-Section Fluctuations (*).

M. MANDÒ
Istituto di Fisica dell'Università - Firenze
Istituto Nazionale di Fisica Nucleare - Sottosezione di Firenze

(ricevuto l'1 Ottobre 1962)

The importance, for the compound nucleus theory, of fluctuations in the nuclear cross-section when the excitation energy is varied has been recently emphasized by T. ERICSON (1,2); the most important information is obtained when the compound nucleus is brought in the region of overlapping levels and the energy spread ΔE of the bombarding particles is kept small compared to $\Gamma = \hbar : \tau$, τ being the characteristic half-life of the compound nucleus; in fact in this case the fluctuation width in energy allows a determination of τ.

Very few experimental results exist, however, on this point, owing to the stringent requirements on energy resolution (L. COLLI and coll. (3) and bibliography therein).

This paper points out the advantages offered by the γ-radiation from the ^{7}Li+p reaction, when used as a projectile, to study the above mentioned fluctuations and discusses some specific experiments, which have been started at Florence and Bologna.

The main idea is to exploit the well known resonance of the ^{7}Li+p reaction, at a proton energy of 441 keV (laboratory system) to get a fairly intense beam of nearly monochromatic γ-rays and to use the Doppler shift at different angles of observation to vary its energy within a range, which is admittedly small, but seems however sufficient, at least in some cases, for the purpose at hand. Let us now consider the γ source from ^{7}Li+p in detail:

1) if protons of energy slightly above the resonance are made to impinge on a thick target of lithium, a high proportion of the whole radiation will be emitted by resonance and will consist of a beam of the 17.64 resonance radiation, with an energy spread of ±6 keV corresponding to the resonance half width; a smaller contribution to any reaction yield will come from the weaker component at 14.8 MeV; since, however, this component is the result of a transition from the 17.64 MeV level to a very broad 2.9 MeV level of ^{8}Be, quite

(*) Work presented at the XLVIII S.I.F. Conference in a session of September 13, 1962.

(1) T. ERICSON: *Phys. Rev. Lett.*, 5, 430 (1960).

(2) T. ERICSON: *Adv. in Phys.* (Supplement to the *Phil. Mag.*), 9, 425 (1960).

(3) L. COLLI, U. FACCHINI, I. IORI, M. G. MARCAZZAN, M. MILAZZO, E. SAETTA-MENICHELLA and F. TONOLINI: *Energia Nucleare*, 9, 439 (1962).

apart from intensity consideration, its contribution will be averaged over a large energy interval and will produce only an additional uniform background, which will not cause serious trouble for most of the experiments to be considered below;

2) the excitation energy is not very high but is probably sufficient to bring many nuclei in the interesting region of overlapping levels;

3) the range of energy, around 17.64 MeV, which can be covered by exploiting the Doppler shift, is ± 67 keV; this is small but it should be sufficient to observe, at least in some cases, the effect predicted by Ericson;

4) the angular distribution of 17.6 γ-rays is known to be isotropic (to a few percent) at resonance ([4]); a small amount of anysotropy would not cause trouble in many types of relative measurement; if need be, it could be eventually taken into account.

Possible experiments fall in two classes:

a) (γ, p) or (γ, α) reactions in which the charged products are detected and their energy is measured; this allows to pick up single (or small multiplicity) final states; the fluctuations are expected to be very great in size, so that their widths, when the energy is varied, can be easily measured. Simultaneous observation of transitions to different final levels and relative intensity measurements may allow further simplification of the experimental set-up, by dispensing with an accurate monitoring system;

b) activation measurements of a given nuclear cross-section at different γ-energy; by this method, fluctuations can be expected much smaller in size, since detection of the «end» product, which can result from many transitions followed by γ disexcitation, is equivalent to averaging over many «final» states («n» in Ericson's formulae of the order of, perhaps, 10^3 or more); since, however, it allows more rapid collection of higher statistics and leaves ample choice of target elements it is also worth of consideration.

Let us now consider the two classes of experiments in more detail.

Class *a*) experiments, to get sufficient intensity and the necessary good angular resolutions, restrict possible targets to elements which can be made part of the detector itself; this also seems to rule out gaseous detectors. The next possible choice appears to be solid state detectors, and especially the widely used silicon detectors. In the case of silicon one may hope to observe (γ, p) and (γ, α) reactions in ^{28}Si (92.18% isotopic abundance) with fairly good statistics and in a reasonable time, by using the biggest available sensitive volume (0.1 cm^3) and a proton beam of some hundred μA on the lithium target, (a tentative cross-sections of 1 mb was assumed for this calculation). Preliminary experiments in this laboratory ([5]) appear to confirm the possibility of observing at least the proton transitions to the fundamental and to the two first excited states of ^{27}Al and the α-transition to the ^{24}Mg ground state.

Needless to say, other less common types of solid state detectors (Germanium, Gallium Arsenide, etc.) may also provide suitable target-detectors, for our particular purpose.

The next possible choice for target-detectors in class *a*) experiments is offered by inorganic scintillators, especially NaI and KI, which can be used to detect proton or α-transitions to diffe-

([4]) See, for instance, V. MEYER, H. MÜLLER, H. H. STAUB and R. ZURHMÜHLE: *Nucl. Phys.*, **27**, 284 (1961); H. NEUERT and TH. RETZ-SCHMIDT: *Zeits. f. Naturfor.*, **13**, 829 (1958).

([5]) P. G. BIZZETI, A. M. BIZZETI-SONA, M. BOCCIOLINI and G. DI CAPORIACCO: private communication.

rent levels of the final nucleus, in Na(γ, p), K(γ, p), Na(γ, α) and K(γ, α) reactions. Here the γ-radiation shows a distinct advantage over fast neutrons as a projectile.

In fact the scintillators do not respond equally to protons, α's and recoil nuclei of the same energy; therefore in fast neutron (n, p) and (n, α) reactions on the light elements, neighbouring levels which would be clearly separated in the center-of-mass system, do easily overlap instrumentally in the laboratory system, owing to the different amount of energy which can go to the recoil nucleus. In the case of (γ, α) and (γ, p) reactions, however, the momentum carried out by the γ radiation is so small that the effect of the recoil can easily be accounted for. In fact proton groups corresponding to different final levels have been clearly separated in Na(γ, p) and K(γ, p) by using scintillators (6).

The main difficulty with scintillators arises from the strong electron and γ background; to reduce it various methods can be devised. Among them the recently introduced technique of (pulse shape discrimination (see *e.g.* (7) and bibliography therein) seems to be most promising; its effectiveness under working conditions is being checked in this laboratory.

Other less common and (generally speaking) less efficient scintillators may possibly allow a more ample choice of targets, but a preliminary experimental investigation of their properties is needed before any experiment can be started with them.

The main difficulty with class *b*) experiments seems to lay on the small expected amplitude. There is, however, an experiment which was carried out, as far ago as 1954, by BUNBURY (8) with a different purpose in view and it seems to point out towards the feasibility of the experiment. He investigated the (γ, n) reaction in ^{63}Cu, ^{64}Zn and ^{109}Ag; the results appear to show fluctuations of the order of a few percent with a recurrence of some tens of keV. It is a pity that Zn and Ag results were affected, as stated by the author in the caption of the figure, by some bigger systematic error, so that results cannot be considered as a completely sound evidence for our purpose; it seems, however, that the experiment is worth repeating.

It is clear from what precedes that (^{7}Li+p) γ-radiation is not only just another method of attack to the experimental problem of Ericson's fluctuations; in some cases it may compare favourably with any other method; as a matter of fact the small intensity of the source, as compared to charged particle sources is more apparent than real when the energy definition is kept the same, because charged particles require very thin targets, while similar or perhaps more stringent geometrical limitations arise during the detection of product particles. With fast neutrons (*e.g.* D+T neutrons) a similar energy resolution would also entail some difficulty and a drastic reduction of the yield, while other advantages of γ radiation have already been pointed out.

In conclusion it seems justified to state that ^{7}Li+p γ-radiation at the 441 MeV resonance may provide a quite useful tool to investigate nuclear cross-section fluctuations and related phenomena.

* * *

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(6) R. T. OPHEL and I. F. WRIGHT: *Proc. Phys. Soc.*, A **71**, 389 (1958); A **72**, 321 (1958).

(7) P. G. BIZZETI, A. M. BIZZETI-SONA and M. BOCCIOLINI: *Nucl. Phys.*, **36**, 38 (1962).

(8) D. ST. P. BUNBURY: *Proc. Phys. Soc. London*, A **67**, 1106 (1954).

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