EXCITATION OF INDIUM 113 BY X-RAYS†

By J. V. DUNWORTH and B. PONTECORVO

Received 15 February 1946

Introduction

The production by X-rays of nuclear isomers, or metastable states of stable isotopes, was first observed in indium (1). It was found that the period of the metastable state was about 4 hr. (1, 2), and it was proved with certainty that the nucleus excited was In^{115*} (2, 3).

The decay period of In^{115*} is given to-day in the literature as: $T = 4{\cdot}1$ hr. (see, for example, Seaborg's Table of isotopes (4)) or $T = 4{\cdot}5$ hr. (see, for example, Cork's table of induced radioactivities (5)). It occurred to us that this discrepancy might be due to errors caused by the presence of a second metastable state. Actually element indium consists of two isotopes: indium 115 (95·5 %) and indium 113 (4·5 %), each of them having spin 9/2; in addition, both indium 115 and indium 113 are known to have a metastable state (the period for In^{113*} is 104 min. (6)). In^{113*} had never been observed as the result of X-ray bombardment of indium. We describe in this paper some experiments which show that In^{113*} may be formed by X-ray irradiation of indium.

The method

The 2 MeV. X-ray equipment (7) built by G.E. was a modification of their standard 1 MeV. a.c.-operated unit. The maximum current was 1·5 mA.

Under these circumstances the X-ray spectrum is rather complicated. In order to give an idea of the intensity of hard X-rays we can state that the initial saturation count of In^{115*} which we obtained when a thick indium foil of ~ 10 cm.^{2} was placed as close as possible to the tungsten target and then wrapped around a 0·15 mm. aluminium counter, was about 15,000 pulses/min. The problem consists in detecting a very weak activity of about 104 min. period in presence of a very strong one of about 4·5 hr. period. In order to emphasize as much as possible the shorter period, various methods may be considered:

(i) The thresholds for the production of the two metastable states are certainly different and so are the corresponding excitation curves. We were not able to use this method because, unfortunately, it is impossible to change the voltage applied to the X-ray tube without a serious loss in current.

(ii) The mass absorption coefficient (nuclear) in metallic indium of the radiation which produces In^{115*} should be much higher than the one corresponding to the radiation which produces In^{113*}; this method fails however, because the nuclear absorption coefficients turn out to be much smaller than the Compton scattering coefficients, the Doppler widths being larger than the natural widths, as discussed, for example, in (8).

† These experiments were finished in December 1944.

(iii) Because of the difference in the decay period, the shorter period will be emphasized by using short-time irradiations. In practice, when statistical errors are considered, the best time of irradiation in our conditions turns out to be about 50 min.

(iv) Some discrimination between the two periods can be obtained because of the difference in the quality of the radiations emitted. The radiations emitted by In^{115*} and In^{113*} have been very carefully studied by Lawson and Cork (3). Table 1 summarizes their findings.

Table 1

	In^{115*}	In^{113*}
Energy of radiation (MeV.)	0·338	0·393
Internal conversion coefficient	$0·5 \pm 0·1$	$0·7 \pm 0·1$

In our experiments we have irradiated the indium sample for about 50 min. and discriminated the radiation of In^{113*} and In^{115*} by absorption methods, since a more accurate β-ray spectrometer investigation was not possible for intensity reasons.

RESULTS

The first experiments we performed consisted of irradiating at the same time two indium foils 100 mg./cm.^{2} thick, and counting them on two different counters. The first counter was cylindrical, had an aluminium wall about 40 mg./cm.^{2} thick. The second one had a mica window 6 mg./cm.^{2} thick. Two of our typical decay curves are shown in Fig. 1 curve (a) and Fig. 2 curve (a). It is seen that a shorter period superimposed on the In^{115*} is obvious in the decay curve obtained with the aluminium counter (40 mg./cm.^{2}), while it is almost non-observable in the decay curve obtained with the mica counter (6 mg./cm.^{2}). The In^{113*} period is emphasized in the aluminium counter because the electron conversion radiation of In^{113*} is slightly more penetrating than the electron radiation emitted by In^{115*}. Similar experiments with the two different types of counters were repeated several times, yielding the same results. Of course the presence of the In^{113*} could easily be observed also in the mica window counter when the decay curve was taken by placing in front of the window an aluminium absorber 40 mg./cm.^{2} thick.

It should be noticed that from a study of the decay curves extending to only 7 or 8 hr. after the end of irradiation, one could arrive at the conclusion that only one period of the order of 4 hr. exists. This explains the discrepancy in the literature mentioned above.

From the analysis of all our curves the period of In^{115*} is found to be $4·50 (\pm 0·02)$ hr. The period of In^{113*} could be measured roughly by subtracting from the observed decay curves in In^{115*} curve extrapolated back to zero time (Fig. 1, curve (b)); we find as an average of all our determinations the value 96 min. in good agreement with the more precise value 104 min. found by Barnes (6). In order to measure the ratio of the cross-sections for the production of In^{115*} and In^{113*} by X-rays of 2 MeV., we have irradiated a thick indium sample (3·2 g./cm.^{2}) and measured the γ-radiation in the aluminium counter, using a filter of copper 300 mg./cm.^{2} thick to absorb the β-radiation. From

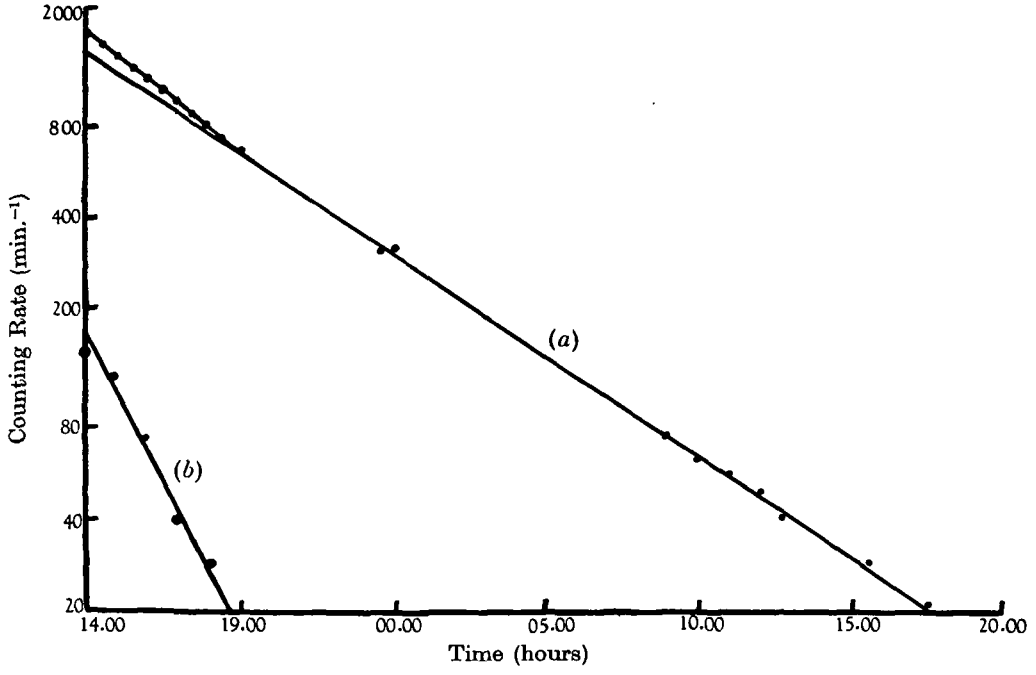

Fig. 1. Activity measured with aluminium counter of wall thickness 40 mg./sq.cm. Curve (*a*). Observed total activity due to In^{113*} and In^{115*}. Curve (*b*). In^{113*} activity obtained from curve (*a*) by subtraction.

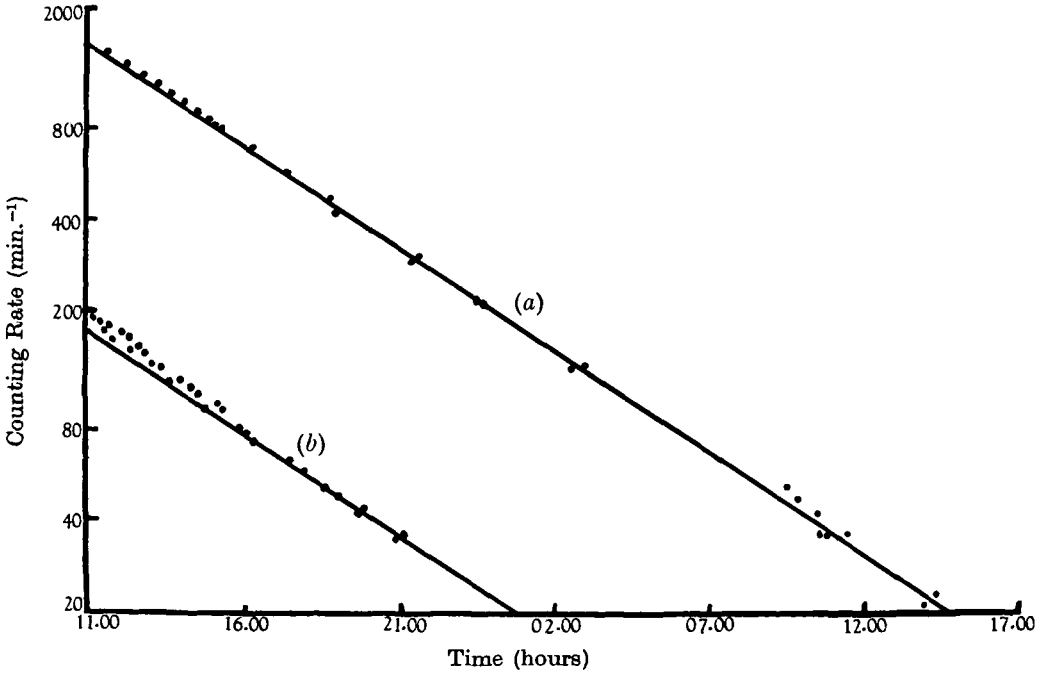

Fig. 2. Curve (*a*). Total activity measured with mica window counter—6 mg./sq.cm. Line corresponds to In^{115*} activity. Curve (*b*). Total activity measured with thick-walled γ-counter. Line corresponds to In^{115*} activity.

this experiment, of which the corresponding decay curve is shown in Fig. 2, curve (*b*), we obtain for the ratio of the initial intensities of In^{115*} and In^{113*} the value 6·7. Taking into account the difference in saturation of the two periods due to the finite time of irradiation, the relative abundance of indium 113 and indium 115 in the element indium, the difference in the internal conversion coefficients of the radiations of In^{113*} and In^{115*} we arrive at the result that the cross-sections for the formation of In^{113*} and In^{115*} are about equal. Because of the various errors involved, we believe that the cross-section for the excitation of the two isomers with the X-ray spectrum we have used do not differ by more than a factor of 2.

SUMMARY

It is shown that In^{113*} can be obtained by nuclear excitation of indium by X-rays. The cross-section per nucleus for the production of In^{113*} with 2 MeV. X-rays is of the same order as the cross-section for the production of In^{115*}. The decay period of In^{115*}, for which some discrepancy was apparent in the literature, was definitely proved to be 4·5 hr.

Our thanks are due to the National Research Council of Canada, Dr J. D. Cockcroft (Director of the Montreal Laboratory), Dr H. H. Halban, and Dr B. W. Sargent, for permission to undertake this work and for access to the two Million Electron Volt G.E. X-ray Unit.

REFERENCES

(1) PONTECORVO and LAZARD. *C.R. Acad. Sci., Paris*, 208 (1938), 99.
COLLINS, WALDMAN, STUBBLEFIELD and GOLDHABER. *Phys. Rev.* 55 (1939), 507.
(2) GOLDHABER, HILL and SZILARD. *Phys. Rev.* 55 (1939), 47.
(3) LAWSON and CORK. *Phys. Rev.* 57 (1940), 982.
(4) SEABORG. *Rev. Mod. Phys.* 16 (1944), 1.
(5) *Handbook of Chemistry and Physics*, 319.
(6) BARNES. *Phys. Rev.* 56 (1939), 414.
(7) CHARLTON and WESTENDORP. *Electronics* (Dec. 1944).
(8) GUTH. *Phys. Rev.* 59 (1941), 325.

NATIONAL RESEARCH COUNCIL
MONTREAL, P.Q.
CANADA