Investigation of $^{111}Cd(y,y')^{111m}Cd$ Average Cross Section

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Abstract:

A method for determining the photo excitation reaction cross section of $^{111}Cd(y,y')^{111m}Cd$ at ^{60}Co gamma energy is investigated. A HPCe detector is used to measure the absolute activity induced, producing a practical value for calculating the average cross section. Which is found to be (0.6683) ub matching the expected theoretical value.

This work may be considered of the pioneer measurements of such reaction cross – section.

Key words: Activity induced,Cross section, Gamma energy, H P Ge detector

دراسة معدل المقطع العرضي للتفاعل $^{111}Cd(y,y')^{111m}Cd$

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المستخلص:

بحثت طريقة لتحديد المقطع العرضي لتفاعل التهيج الفوتوني $^{111}Cd(y,y')^{111m}Cd$ عند طاقة كاما المنبعثة من نظير الكوبلت (٦٠) ، باستخدم عداد جرمانيوم عالي النقاوة لقياس مطلق النشاط الاشعاعي المستحث لتوفير قيمة عملية تستخدم في حساب معدل المقطع العرضي الذي وجد (٠،٦٦٨٣) مايكروبارن، بما يتلائم مع القيمة المتوقعة نظريا.

ربما يعد هذا العمل رائدا في قياسات المقطع العرضي لمثل هذا التفاعل.

الكلمات المفتاحية: النشاط الاشعاعي ، المقطع العرضي ، طاقة كاما ، عداد جرمانيوم عالي النقاوة .

Introduction:

The beginning of photonuclear research dated back to (1934), while the first analytical applications of photo reaction dates back to (1936). Nuclear reactions induced by electromagnetic radiation can be described - at least for sufficiently low photon energies - in terms of a two stage process.

Absorption of a photon leads to an intermediate highly excited state of the nucleus. The excitation energy of this so called compound nucleus can then be released by emission of photons, neutrons or charged particles[1].

A particular application of photon activation analysis is the use of (y, y') reaction as proposed by H. R. Lukens [2] . This method appears to be very interesting and useful for the non destructive determination of some elements in various matrices.

When the incident photon has an energy higher than the first excited state of the target nucleus excitation can occur. The emitted prompt gamma carries the energy difference between incident gamma and the energy of the first excited state of the nucleus. The latter returns to the ground state be emission of a gamma with an energy equal to difference of the two levels. When the half – life of the excited state is long enough to allow the counting of the products of DE excitation, application in activation analysis is possible[2].

Theory:

All gammas induced reactions are in fact threshold reactions. For $(\boldsymbol{y}, \boldsymbol{n})$ reactions, the threshold energies can be obtained from the mass difference method. Usually the thresholds have a value of $(7 \text{ to } 18)$ MeV. They decreased with increasing atomic number. In the case of charged particle emission, one has to take Coulomb barriers in to account , which increases rapidly with increasing Z.

The threshold for the (y, y') reaction on the other hand is only determined by the energy of the meta stable state of the nucleus and is usually well below (10) MeV.

Irradiation with photons with a maximum energy of (10) MeV for instance thus allows selective activation by the (y, y') reaction without interference of gamma particle reactions. The dominant feature in the interaction of photons with a nucleus is the giant resonance in the absorption process . This phenomenon occurs with all nuclei and corresponding cross – sections depend on the structure of the energy levels in the nucleus[2].

From the theory of the interaction between electromagnetic radiation and nuclei one obtains the following expression for the absorption cross – section of one individual nuclear level,[1]:

$$\sigma_a = \sigma_m \frac{0.25 \prod_a^2}{(E - E_a)^2 + 0.25 \prod_a^2}$$

Where:

σ_m = peak cross – section. It depends on the photon wavelength at resonance and the properties of the excited and the ground state of the nucleus.

E = energy of the incident photons.

E_a= resonance energy (energy of the excited state).

$\prod_a$ = total energy width of the excited state a, which is proportional to the transition probability from this lend to all other lower state.

For σ_m represents a resonance curve with a being its full width at half maximum. In general, according to the low energy width of nuclear levels (1 eV) the resonance is very sharp. Therefore, although the peak cross- section may exceed (10) barn, level is low . That's yields value of the order of magnitude of (micro barn)[1].

The differential reaction rate R(E) for a give gamma – energy (E) is giving by [2].

$$\boldsymbol{R(E) = \sigma_{(E)} \emptyset_{(E)}}$$

Where: $\sigma_{(E)}$ = the photon flux.

$\emptyset_{(E)}$= the cross – section as a function of photon energy.

Experimental:

Sample preparation:

A highly pure (99.99) foil of Cd with dimension $(6 \times 4 \times 0.1)cm$, and weight $(5.024)gm$ was rolled up in a uniform cylindrical shape of about (2) cm diameter and (4) cm height.

Irradiation equipment:

The gamma cell 220 irradiation unit (Atomic Energy of Canada Limited) was designed to provide a field of high intensity gamma irradiation. The Cobalt – 60 radioactive source consist of up to 48 linear source elements equally spaced in a stainless steel rack to form a radioactive cylindrical shell of annulus $(20 - 91)$ cm pitch circle diameter. (21.11) cm long. [3](of Fig.1).

Procedure:

The cylindrical shell of Cd is placed at the center of the radioactive cylindrical shell fot (4 h) . The induced activity was measured after (5.25 m) asa cooling time using a (96.1 cm) HPGe detector of resolution (2.3 KeV) at (1332 Kev) gamma lin, coupled to (4096) channel analyzer(IBM). The Cd-111 m spectrum obtained is shown in Fig. (2). The photo peak detection efficiency curve of the detector is represented by the relation:

$$\varepsilon = 2[2.47 \times 10^{-5} \ (E)^{-3.35} + 1.46(E)^{0.905}]^{-1}$$

Where :L the photon energy (E) in M eV , was for the particular counting geometry using different standard sources prepared and supplied By Amersham.

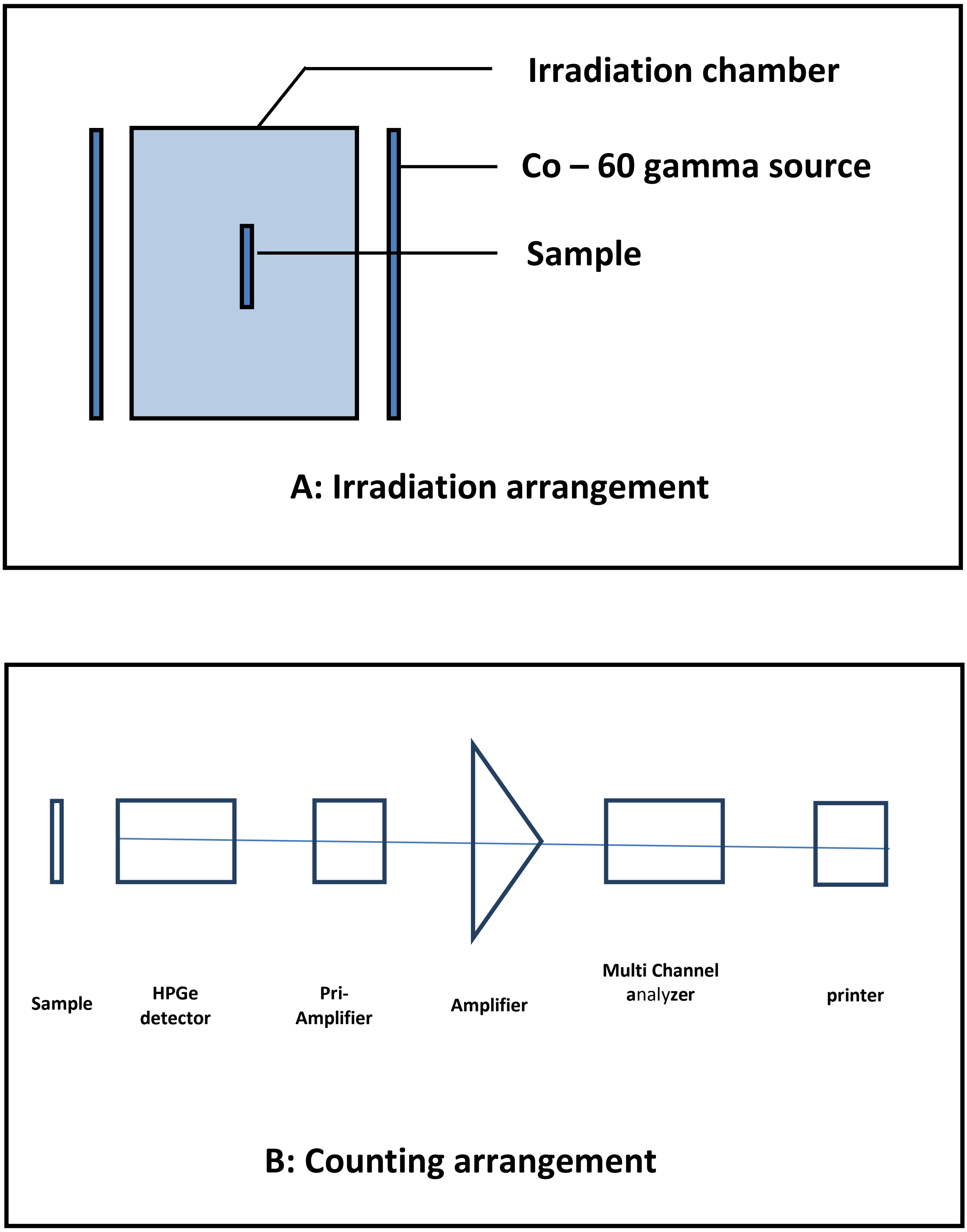

Fig.(1) Experimental setup

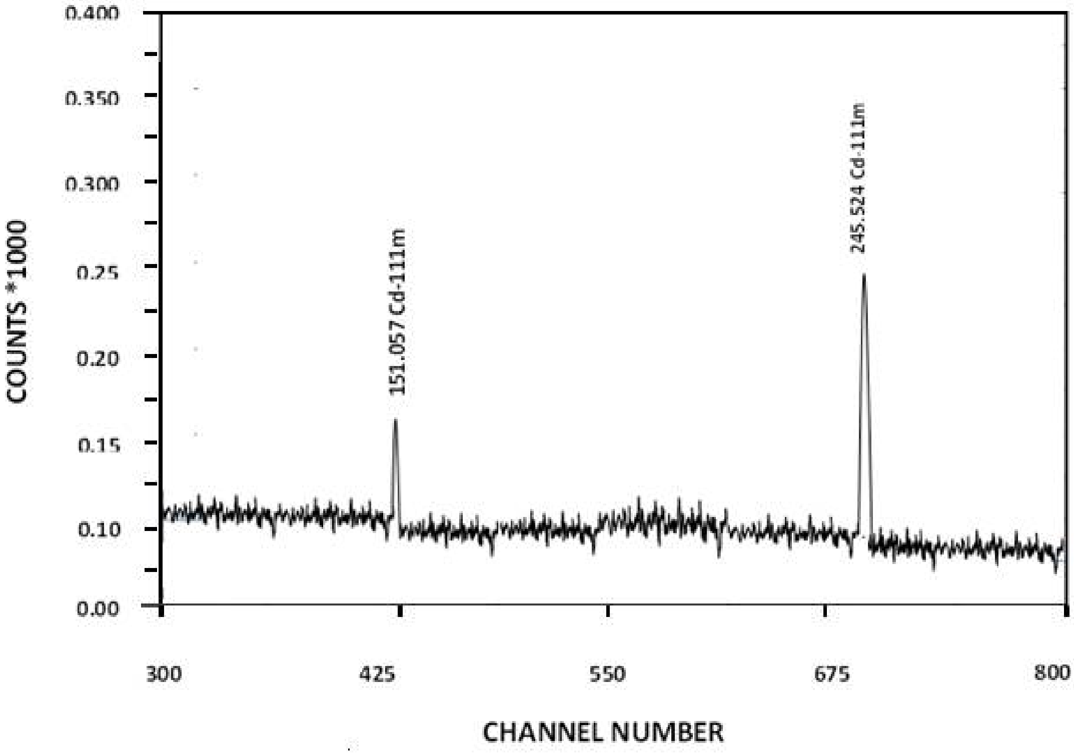

Fig.(2) Thee singles spectrum Cd-111m

Results and Discussion:

The requisite flux of Gamma photons was calculate at the irradiation position to be $(1.05 \times 10^{10}\ Y.cm^{-2}.sec^{-1})$.

Average cross – section value is obtained using the normal activation equation [4]:

$$A = N\sigma\emptyset\ (1 - e^{-\lambda t_i})e^{-\lambda t_d}(1 - e^{-\lambda t_c})\frac{I_\alpha - p}{\lambda}$$

Where:

A= measured absolute activity (CPR).

N= number of reactive nuclei

$$= \frac{W \times N_a \times a}{M}$$

W= weight in grams.

N_a = Avogadro's number

a = isotopic abundance

M= atomic weight.

$\boldsymbol{\sigma}$ = average cross – section (cm)

∅= photon flux (y. cm .s)

λ =decay constant (sec):

$$= \frac{in\ 2}{T_{\frac{1}{2}}}$$

$T_{\frac{1}{2}}$= half-life (sec)

$\mathbf{t}_{\boldsymbol{i}}$= irradiation time (sec).

t_d= decay or cooling time (sec).

$\mathbf{t}_{\boldsymbol{c}}$= counting time (sec) = detector efficiency at photo peak energy (%).

$\boldsymbol{I}_{\boldsymbol{\alpha}}$= gamma line intensity (%).

P= sample purity (%).

Using the characteristic data of the concerned reaction with the other requires ones:

$T_{\frac{1}{2}}$= 48.7 min

E_γ = 245.4 k.eV , I_γ = 94%

$$= \frac{W \times N_a \times a}{M}$$

$\boldsymbol{N}_{\boldsymbol{a}} = 6.023 \times 10^{23}$ Atoms/mole

a = 12.75 %

M= 112.41

∅= 1.05×10^{10} (y. cm^{-2} .s^{-1})

ε= 4.852 %

$\mathbf{t}_{\boldsymbol{i}}$= 4 h

t_d= 5.25 min

$\mathbf{t}_{\boldsymbol{c}}$= 1 h

P= 99.99 %

A= net area = 2387+ 60 counts , (Cross area = 3198 counts)

We get from the normal activation equation that :

$$\boldsymbol{\sigma} = 0.6683 \pm 0.0168\ \mu\, b$$

It is clear that this results provides a value of good as mentioned previously.[1].

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