USAGE OF THE FISSION REACTION FOR THE MEASUREMENT OF THE POLARIZATION DEGREE OF PHOTON BEAM

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The efficiency of photofission of ^{232}Th and ^{238}U for the measurement of the polarization degree of photon beam has been compared with the conventional reaction of the deuterium photodisintegration.

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1. INTRODUCTION

The experimental investigations of the photofission of even-even nuclei showed that its cross section value is sensitive to the direction of the polarization vector for photon energies $E_\gamma < 20$ MeV [1, 2, 3, 4]. Such result opens up possibility to use the photofission reaction for the measurement of the beam polarization degree [5].

In this work the comparison of the efficiency of photodisintegration of deuterium, which is usually used in this energy region, with photofission of ^{232}Th and ^{238}U was made.

2. PRECISION OF THE DETERMINATION OF THE POLARIZATION DEGREE

To evaluate the efficiency of one or other nuclear reaction in determination of the polarization degree (P) of the photon beam it is necessary to find the formula in which the precision the of the determination of P depends from the reaction characteristics - cross section (σ) and asymmetry (Σ) (in the case of photofission this quantity is called "analyzing power").

The polarization degree is usually defined as:

$$P = \frac{N_\parallel - N_\perp}{N_\parallel + N_\perp},$$

where $N_\parallel$ ($N_\perp$) - the number of photons with electric field vector parallel (perpendicular) to the reaction plane. At the same time the total number of photons passed through the target is $N_\gamma = N_\parallel + N_\perp$. In this case such formulas are true:

$$N_\parallel = \frac{N_\gamma}{2}(1+P),$$
$$N_\perp = \frac{N_\gamma}{2}(1-P). \quad (1)$$

The cross section asymmetry (analyzing power) associated with the change of the polarization direction is defined as:

$$\Sigma(\theta) = \frac{\frac{d\sigma_\parallel}{d\Omega}(\theta) - \frac{d\sigma_\perp}{d\Omega}(\theta)}{\frac{d\sigma_\parallel}{d\Omega}(\theta) + \frac{d\sigma_\perp}{d\Omega}(\theta)},$$

where $d\sigma_{\parallel,\perp}/d\Omega(\theta)$ - differential cross section of the reaction induced by photons with polarization parallel and perpendicular to the reaction plane. In this case the cross section with unpolarized photons is:

$$\frac{d\sigma}{d\Omega}(\theta) = \frac{\frac{d\sigma_\parallel}{d\Omega}(\theta) + \frac{d\sigma_\perp}{d\Omega}(\theta)}{2}.$$

For such definitions the given formulas are true:

$$\frac{d\sigma_\parallel}{d\Omega}(\theta) = \frac{d\sigma}{d\Omega}(\theta)(1+\Sigma(\theta)),$$
$$\frac{d\sigma_\perp}{d\Omega}(\theta) = \frac{d\sigma}{d\Omega}(\theta)(1-\Sigma(\theta)). \quad (2)$$

In the analysis of the experimental data the value of $\Sigma(\theta)$ is determined by the formulae:

$$\Sigma(\theta) = \frac{1}{P}\cdot\frac{Y_\parallel(\theta) - Y_\perp(\theta)}{Y_\parallel(\theta) + Y_\perp(\theta)},$$

where $Y(\theta)_{\parallel,\perp}$ - the reaction yield in the plane parallel and perpendicular to the polarization plane. In this case:

$$P = \frac{1}{\Sigma(\theta)}\cdot\frac{Y_\parallel(\theta) - Y_\perp(\theta)}{Y_\parallel(\theta) + Y_\perp(\theta)}.$$

Quantity $Y_\parallel(\theta)$ represent the sum of the reaction yields for photons with polarization parallel and perpendicular to the reaction plane:

$$Y_\parallel(\theta) = N_n \Delta\Omega\varepsilon(N_\parallel \frac{d\sigma_\parallel}{d\Omega}(\theta) + N_\perp \frac{d\sigma_\perp}{d\Omega}(\theta)),$$

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where N_n - the number of nuclei in the target, $\Delta\Omega$ - the solid angle of the detector, ε - detector efficiency. In the case of $Y_\perp(\theta)$ we have the similar formulae only $N_\parallel$ and $N_\perp$ change their places. For the reaction yield in the plane perpendicular to the polarization plane $N_\perp$ photons are parallel and $N_\parallel$ - perpendicular.

$$Y_\perp(\theta) = N_n\Delta\Omega\varepsilon(N_\perp\frac{d\sigma_\parallel}{d\Omega}(\theta) + N_\parallel\frac{d\sigma_\perp}{d\Omega}(\theta)).$$

Using (1) and (2) it is easy to obtain

$$Y_\parallel(\theta) = N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta)(1 + P\Sigma(\theta)),$$

and

$$Y_\perp(\theta) = N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta)(1 - P\Sigma(\theta)).$$

The relative error of the determination of the polarization value is:

$$\frac{\Delta P}{P} = \frac{1}{P\Sigma(\theta)}\Delta\left(\frac{Y_\parallel(\theta) - Y_\perp(\theta)}{Y_\parallel(\theta) + Y_\perp(\theta)}\right) = \frac{1}{P\Sigma(\theta)}\sqrt{\left(\frac{\Delta(Y_\parallel(\theta) - Y_\perp(\theta))}{Y_\parallel(\theta) + Y_\perp(\theta)}\right)^2 + \left(\frac{(Y_\parallel(\theta) - Y_\perp(\theta))\Delta(Y_\parallel(\theta) + Y_\perp(\theta))}{(Y_\parallel(\theta) + Y_\perp(\theta))^2}\right)^2} =$$

$$\frac{1}{P\Sigma(\theta)}\sqrt{\frac{(\Delta(Y_\parallel(\theta) - Y_\perp(\theta)))^2(Y_\parallel(\theta) + Y_\perp(\theta))^2 + (Y_\parallel(\theta) - Y_\perp(\theta))^2(\Delta(Y_\parallel(\theta) + Y_\perp(\theta)))^2}{(Y_\parallel(\theta) + Y_\perp(\theta))^4}}.$$

Using the obtained expressions for $Y_{\parallel,\perp}(\theta)$, and considering the error of $Y_{\parallel,\perp}(\theta)$ as a square root of its value we have:

$$Y_\parallel(\theta) + Y_\perp(\theta) = N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta)(1 + P\Sigma(\theta) + 1 - P\Sigma(\theta)) = 2N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta),$$

$$Y_\parallel(\theta) - Y_\perp(\theta) = N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta)(1 + P\Sigma(\theta) - (1 - P\Sigma(\theta))) = 2N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta)P\Sigma(\theta),$$

$$\Delta(Y_\parallel(\theta) + Y_\perp(\theta)) = \Delta(Y_\parallel(\theta) - Y_\perp(\theta)) = \sqrt{(\Delta Y_\parallel(\theta))^2 + (\Delta Y_\perp(\theta))^2} = \sqrt{Y_\parallel(\theta) + Y_\perp(\theta)} = \sqrt{2N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta)}.$$

Thus the relative error of measured polarization degree can be presented as:

$$\frac{\Delta P}{P} = \frac{1}{P\Sigma(\theta)}\sqrt{\frac{2N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta)(2N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta))^2 + (2N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta)P\Sigma(\theta))^2 2N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta)}{(2N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta))^4}} =$$

$$\sqrt{\frac{1 + P^2\Sigma(\theta)^2}{2N_n\Delta\Omega\varepsilon N_\gamma\frac{d\sigma}{d\Omega}(\theta)P^2\Sigma(\theta)^2}} = \frac{1}{\sqrt{2N_n\Delta\Omega\varepsilon N_\gamma P^2}}\sqrt{\frac{1 + P^2\Sigma(\theta)^2}{\frac{d\sigma}{d\Omega}(\theta)\Sigma(\theta)^2}}, \tag{3}$$

where information about the nuclear reaction is in the second factor only.

3. RESULTS AND DISCUSSION

It was shown in the experimental investigations [1, 2, 3, 4] of the fission of even-even nuclei with polarized photons that in the energy region $E_\gamma < 20$ MeV this process is described completely by the electric dipole excitation. In this case according to the equations of [6] the analyzing power of the photofission can be presented as:

$$\Sigma(\theta = 90°) = \frac{b}{a + b},$$

where a and b may be obtained from the analysis of the cross section angular distribution for unpolarized photons:

$$W(\theta) = a + b\sin^2(\theta).$$

To obtain the values of $d\sigma/d\Omega(90°)$ and $\Sigma(90°)$ the results of following works were used: [7, 8] - ^{232}Th, [8, 9] - ^{238}U, [10, 11] - ^{2}H. Numerical values were taken from the data base EXFOR (http://www-nds.iaea.org/exfor/exfor00.htm). To eliminate the fluctuations produced by the statistical dispersion of the data the approximation of the energy dependence of each experimental value with smooth curve was done. The example of such approximation for ^{232}Th is given in Fig.1.

As it is seen from formula (3) the precision of the determination of the polarization degree depends on $\Sigma(\theta)$ and product $d\sigma/d\Omega(\theta)\Sigma^2(\theta)$. For polarization $P \ll 1$ term $P^2\Sigma^2(\theta)$ in the numerator of the second factor became significantly smaller than 1. In this case the only value the relative error of P depends on is product $d\sigma/d\Omega(\theta)\Sigma^2(\theta)$:

$$\frac{\Delta P}{P} \sim \frac{1}{\sqrt{\frac{d\sigma}{d\Omega}(\theta)\Sigma^2(\theta)}}.$$

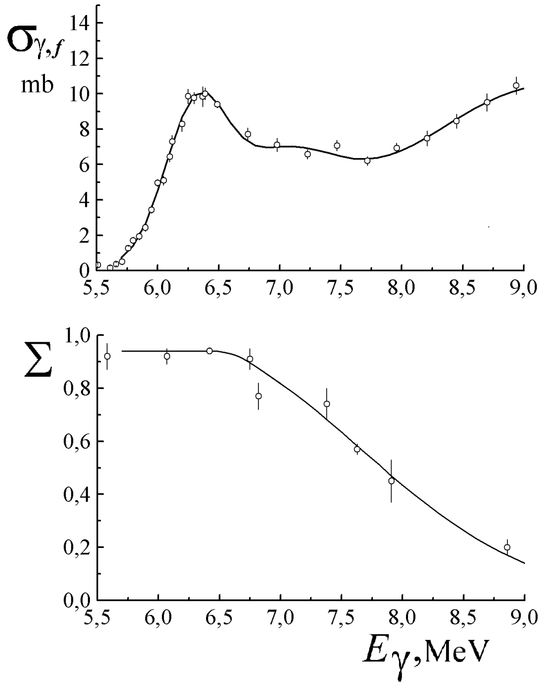

Fig.1. *Approximation of the cross section and analyzing power of* ^{232}*Th with smooth curves*

Fig.2 shows the energy dependence of $d\sigma/d\Omega(90°)\Sigma^2(90°)$ for ^{232}Th and ^{238}U photofission and photodisintegration of deuterium. Since the error is inversely as square root of this quantity it is evident that in the energy region $E_\gamma \sim 5.9\ldots6.4\,MeV$ for ^{238}U and $E_\gamma \sim 6.0\ldots7.3\,MeV$ for ^{232}Th the photofission reaction is preferable against the photodisintegration of deuterium. The usage of the photofission of ^{232}Th should give stronger positive effect and in broader energy region in comparison with ^{238}U.

To evaluate how the relative error depends on the value of the polarization itself in the case when it isn't possible to ignore the second term in the numerator of the formula (3) the calculations were carried out for polarization degree 10% and 100%. The result is present in Fig.3.

As it is seen from Fig.3 the usage of photofission of ^{232}Th is preferable for the measurements of polarization as compared with the photodisintegration of deuterium. But this advantage isn't big. The relative error can be reduced up to ∼25% for P = 10% and up to ∼30% for P = 100%. With the decrease of the polarization degree the energy region of the positive effect also became smaller from $E_\gamma \sim 6.0\ldots7.6\,MeV$ for $P = 100\%$ to $E_\gamma \sim 6.0\ldots7.3\,MeV$ for $P = 10\%$. The photofission of ^{238}U gives smaller effect not only in absolute value but in more narrow energy region also. But for the polarization close to 100% the new energy region of positive effect, that is absent in photofission of ^{232}Th, is opened - $E_\gamma \sim 7.6\ldots8.3\,MeV$.

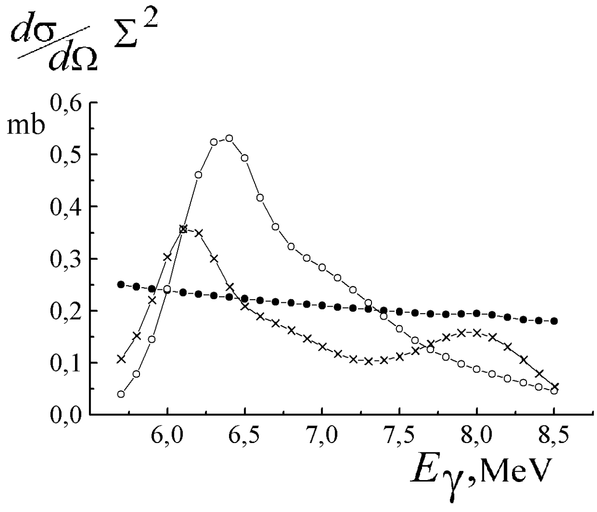

Fig.2. *Energy dependence of the product of cross section and square of asymmetry (analyzing power) for* $\theta = 90°$.
Solid circles - photodisintegration of deuterium.
Open circles - photofission of ^{232}*Th.*
Stars - photofission of ^{238}*U*

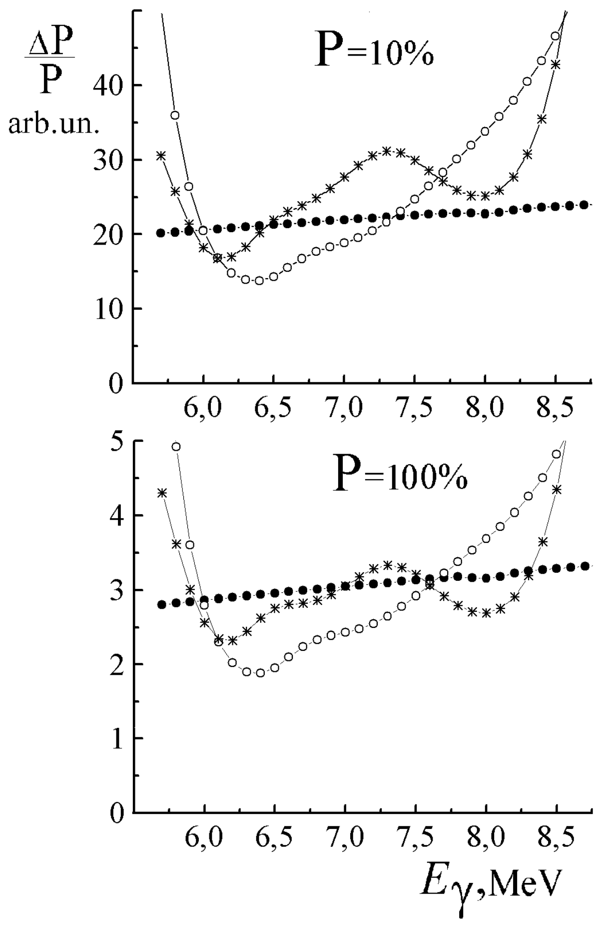

Fig.3. *Relative error of the polarization degree of photon beam.*
Solid circles - photodisintegration of deuterium.
Open circles - photofission of ^{232}*Th.*
Stars - photofission of ^{238}*U*

4. CONCLUSIONS

The carried out investigation shows that the usage of ^{232}Th and ^{238}U photofission for the determination of the polarization degree of the photon beam offers certain advantage compared with the conventional reaction of the deuterium photodisintegration. In spite of the fact that the positive effect doesn't exceed 30% these reactions are very perspective taking into account that the registration of the fission fragment is much easier task than the detection of the deuterium photodisintegration products. The essential weakness of the method is the impossibility of its usage for non-monochromatic photon beam.

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ИСПОЛЬЗОВАНИЕ РЕАКЦИИ ДЕЛЕНИЯ ДЛЯ ИЗМЕРЕНИЯ СТЕПЕНИ ЛИНЕЙНОЙ ПОЛЯРИЗАЦИИ ФОТОННОГО ПУЧКА

В.В. Деняк, В.М. Хвастунов, С.А. Пащук, У.Р. Счелин

В работе проведена оценка эффективности использования реакции фотоделения изотопов ^{232}Th и ^{238}U для измерения степени поляризации фотонного пучка по сравнению с традиционно применяемой реакцией фоторасщепления дейтерия.

ВИКОРИСТАННЯ РЕАКЦIЇ ПОДIЛУ ДЛЯ ВИМIРЮВАННЯ СТУПЕНЯ ЛIНIЙНОЇ ПОЛЯРИЗIЦIЇ ФОТОННОГО ПУЧКА

В.В. Деняк, В.М. Хвастунов, С.А. Пащук, У.Р. Счелiн

У роботi проведено оцiнку ефективностi використання реакцiї фотоподiлу iзотопiв ^{232}Th и ^{238}U для вимiрювання ступеня поляризацiї фотонного пучка у порiвняннi з традицiйно використовуємою реакцiєю фоторозщеплення дейтерiя.