Pis'ma v ZhETF, vol.70, iss.3, pp.171 - 174

ON A POSSIBILITY OF OBSERVATION OF NEUTRON ELECTRIC POLARIZABILITY

L.V.Mitsyna, A.B.Popov, G.S.Samosvat

Frank Laboratory of Neutron Physics, JINR
141980 Dubna, Moscow reg., Russia

Submitted 23 June 1999

A new method to set a lower or upper limit α_n^* of the neutron electric polarizability α_n is proposed. It is based on the fact that the real part of the s-wave scattering amplitude changes its sign near the s-wave neutron resonance at $E = E^*$. The methods consist of the observation of the energy behaviour of the forward - backward scattering asymmetry ω_1 that experiences a jump at $E = E^*$. If for the jump, $d\omega_1/dE > 0, \alpha_n > \alpha_n^*$, if $d\omega_1/dE < 0$, $\alpha_n < \alpha_n^*$ and $\alpha_n \sim \alpha_n^*$ if $d\omega_1/dE \sim 0$. Seven even-even nuclei are found with α_n^* from 0.5 to 3.1 in $10^{-3}\,\text{fm}^3$. Some details of a possible experiment with ^{182}W are described.

PACS: 28.20.-v

1. All methods that have been used up to now to evaluate the neutron electric polarizability α_n consist of the extraction of a very small α_n effect against a large background caused by the strong nuclear interaction. As a result, all of them are essentially quantitative methods. The method we have found is, in essence, a qualitative one though it is also connected with the observation of a very small effect.

As it is known [1 – 3] the α_n effect can be observed in the neutron energy (E) dependence of the forward-backward asymmetry coefficient

$$\omega_1 = \frac{\sigma(0) - \sigma(\pi)}{\sigma(0) + \sigma(\pi)}$$

($\sigma(\vartheta)$ is the differential scattering cross section) for neutron scattering by heavy nuclei at small E. The behavior of $\omega_1(E)$ is mostly determined by the interference between s- and p-waves and illustrated in Fig.1 where ω_1 is calculated for different α_n for the ^{238}U nucleus as if it had no neutron resonances. The discussed picture is obtained using the approximate expressions

$$\sigma(\vartheta) = (f_0 + f_1 \cos\vartheta)^2, \tag{1}$$

$$\omega_1 = 2f_1/f_0 \tag{2}$$

where f_0 is the s-wave scattering amplitude and

$$f_1 = f_1^N + f_1^{pol} \tag{3}$$

is the sum of nuclear and polarizability contributions to the p-wave amplitude. For ^{238}U, they are

$$f_0 = -9.4\ \text{fm}, \quad f_1^N = -1.09 \cdot 10^{-5} E\ \text{fm}, \quad f_1^{pol} = 5.05 \cdot 10^{-5} \alpha_n \sqrt{E}\ \text{fm} \tag{4}$$

(E is in eV, α_n is in 10^{-3} fm^3 here and below) and $\omega_1(E)$ is as in [1] and [3]. In Fig.1 the main peculiarity is that each $\alpha_n > 0$ curve intersects the abscissa at a certain energy

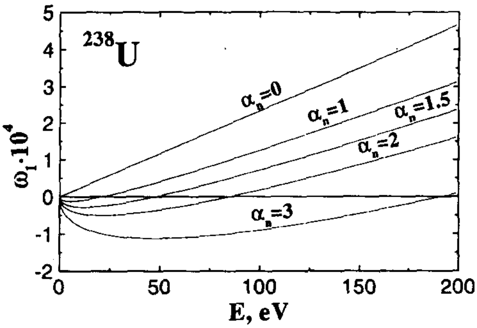

Fig.1. The ω_1 dependence on the neutron energy and α_n (in 10^{-3} fm^3) for ^{238}U nuclei without taking resonances into account

E'. It means that the p-wave amplitude f_1 changes its sign from positive at $E < E'$ to negative at $E > E'$ as soon as f_0 is simply a positive s-wave scattering radius R_0' taken with a minus sign.

In spite of a large α_n contribution to ω_1 at eV energies it is hardly possible to obtain experimentally the corresponding curve $\omega_1(E)$ because this requires not only the measurement accuracy $\sim 10^{-5}$ but also an equal degree of removal of various distorting effects.

2. Instead of measuring the whole curve $\omega_1(E)$ we think it is possible to evaluate α_n by investigating ω_1 only near s-wave resonances using their wonderful property. Such resonance with the energy E_0 on the even-even nucleus leads to that the total s-wave amplitude f_0 (potential – R_0' plus resonant) becomes zero at $E^* \cong E_0 - \Gamma_n/2kR_0'$ (k and Γ_n are the resonant values of the neutron wave number and neutron width) while at $E < E^*$, $f_0 < 0$ and at $E > E^*$, $f_0 > 0$. So according to (2), ω_1 also changes its sign at E^* from plus at $E < E^*$ to minus at $E > E^*$ if $f_1 < 0$. If $f_1 > 0$, the ω_1 situation is opposite. In its turn, the sign of f_1, as we have already seen, depends on α_n and E because f_1^N and f_1^{pol} in (3) have opposite signs and different E-dependences. Thus, observation of any changes in the sign of ω_1 at certain E^* from plus to minus or minus to plus gives as minimum an upper or lower limit of α_n, respectively.

3. All necessary calculations can be performed using instead of Eqs. (1) – (4) the following equations based on [4] :

$$\sigma(\vartheta) = B_0 + B_1 \cos\vartheta, \quad \omega_1 = B_1/B_0, \tag{5}$$

$$B_0 = \frac{1}{k^2}\left[\sin^2\delta_0 + 3\sin^2\delta_1 + \frac{1}{4}\frac{\Gamma_n^2}{\Delta E^2 + \Gamma^2/4} - \frac{\Gamma_n \sin\delta_0(\Delta E\cos\delta_0 + \Gamma\sin\delta_0/2)}{\Delta E^2 + \Gamma^2/4}\right], \tag{6}$$

$$B_1 = \frac{1}{k^2}\left\{6\sin\delta_0\sin\delta_1\cos(\delta_0 - \delta_1) - \frac{3\Gamma_n\sin\delta_1[\Delta E\cos(2\delta_0 - \delta_1) + \Gamma\sin(2\delta_0 - \delta_1)/2]}{\Delta E^2 + \Gamma^2/4}\right\}. \tag{7}$$

Here, the phase shifts are the sums of nuclear and polarizability terms

$$\delta_0 = -kR_0' + \frac{6}{5}k\frac{C}{R_q}, \quad \delta_1 = -\frac{1}{3}(kR)^2 kR_1' + \frac{\pi}{12}k^2 C, \tag{8}$$

where R_0' and R_1' are the s- and p-wave scattering radii, $R = 1.35\,\mathrm{A}^{1/3}$·fm and $R_q = 1.20\,\mathrm{A}^{1/3}$·fm are the channel and charge radii, $C = M_n\alpha_n(Ze/\hbar)^2$ is a constant, M_n is the neutron mass, Z is the charge number of the nucleus. Also Eqs. (6) and (7) contain the total width Γ of the resonance and $\Delta E = E - E_0$.

To choose a proper resonance which can give a suitably low limit for α_n, it is necessary to solve the equation $\delta_1 = 0$ at the energy E^* of this resonance. As a result, Eq.(8) gives

$$\alpha_n^* = 14.7\frac{A^{2/3}R_1'\sqrt{E^*}}{Z^2},$$

where R_1' is in fm and E^* is in eV. It is just the value of α_n for which one must not see any peaks of ω_1 around E^*. A ω_1 jump will be observed there with $d\omega_1/dE < 0$ if $\alpha_n < \alpha_n^*$ and with $d\omega_1/dE > 0$ if $\alpha_n > \alpha_n^*$.

4. Unfortunately, the even-even nuclei ^{238}U and ^{232}Th have a lot of p-wave resonances which make f_1 an irregular one and therefore, they are not suitable for our purpose. We find only seven suitable nuclei whose first s-wave resonances do not give too high α_n^* and have no known p-wave resonances at low energies. They are enumerated in Table together with the necessary parameters. The approximate values of R_1' are obtained for six nuclei from [5] by interpolation and for ^{182}W from [6, 7]. The scattering $\sigma_s = 4\pi B_0$ and capture σ_γ cross sections are given for $E = E^*$.

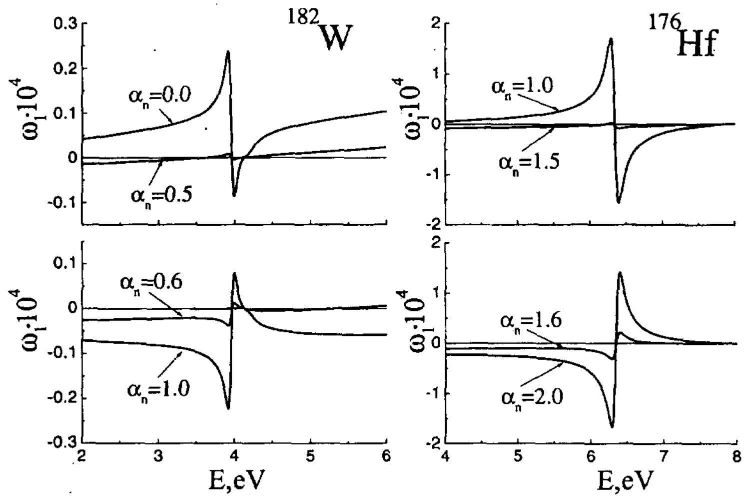

Fig.2. The singular pictures near resonances 4.16 eV of ^{182}W and 7.93 eV of ^{176}Hf for different α_n

Two most informative nuclei have been chosen to illustrate (see Fig.2) the proposed method of α_n observation. Doppler spreading is taken into account by the corresponding integration of (6) and (7) as well as of the cross sections σ_s and σ_γ in the Table.

Nucleus	R_0',fm	R_1',fm	E_0,eV	E^*,eV	α_n^*, 10^{-3}fm^3	σ_s, b	σ_γ, b
$^{198}_{80}$Hg	10.3	4.5	23.00	22.69	1.7	1.2	300
$^{188}_{76}$Os	9.3	6.0	38.73	37.37	3.1	0.072	35
$^{182}_{74}$W	9.0	3.0	4.16	3.94	0.5	0.23	260
$^{178}_{72}$Hf	7.5	6.8	7.78	2.29	0.9	0.0004	16
$^{176}_{72}$Hf	7.5	6.8	7.93	6.34	1.5	0.0076	33
$^{170}_{70}$Yb	7.3	8.0	8.13	7.95	2.1	0.67	380
$^{162}_{66}Dy$	7.5	10.0	5.44	2.71	1.6	0.0058	72

5. Turning to the question of the experiment we should emphasize in the first place that there is no need to try to obtain a "clean" picture of ω_1 like those in Fig.2 when

$\omega_1 \to 0$ (or small value) on both sides of E^*. The presence of some secondary effects, such as the scattering anisotropy in the laboratory system, different detectors at different angles, moderate backgrounds of various nature, etc., which cannot simulate a false ω_1 jump at E^* is quite permissible. This is the main advantage of our method.

At the same time, the realization of said method is connected with considerable difficulties. The principal one of them is the necessity to have a large amount of a high purity isotope for manufacturing a scatterer together with the necessity to accumulate very high statistics.

The isotope ^{182}W seems to be the most promising instrument to set the first experimental lower limit of α_n. The experiment can be carried out in Dubna on the 10 m flight path of the booster IREN under construction for the neutron intensity $2.7 \cdot 10^5 E^{-0.9}$ cm^{-2}·s^{-1}·eV^{-1} (E in eV). It is necessary to build a set-up consisting of an about 4 m aluminium vacuum tube and two identical detectors of many ^{3}He-counters. The neutron beam goes inside the tube and hits a scatterer whose plane is at the angle 45° to the beam. One of the detectors is situated around the tube and counts neutrons scattered backwards. Another detector is set near the tube and counts neutrons scattered around $\vartheta = 90°$. In order to distinguish with confidence a singular ω_1 picture of one type from another, it is sufficient to collect $\sim 5 \cdot 10^{10}$ counts in the area of a smaller ω_1 peak (negative if $\alpha_n < 0.5$, positive if $\alpha_n > 0.5$ or about zero if $\alpha_n > 0.5$) with the width ~ 0.18 eV. Using ~ 1000 g of an enriched to 99% isotope as a scatterer in the beam 40 cm in diameter one will have the average over peak outlet probability of neutrons $\sim 7 \cdot 10^{-3}$. The necessary statistics can be then reached in ~ 100 days, if each detector has the solid angle 10% of 4π and the efficiency 40%.

In conclusion, some additional difficulties that the experimentalist may face should be also mentioned. They are the background of delayed neutrons from the booster scattered by the target into the detectors and the background of fast neutrons scattered into the room and re-scattered to the detectors. Due to overload of electronics there may appear the necessity to unlock the detectors only for the investigated interval of the time of flight.

This work has been made with the RFBR support, grant 97-02-16213.

---

1. R.M.Thaler, Phys. Rev. **114**, 827 (1959).
2. Yu.A.Alexandrov, G.S.Samosvat, Zh.Sereeter, and Tsoj Gen Sor, Pis'ma ZhETF **4**, 196 (1966) [JETP Lett. **4**, 134 (1966)].
3. G.S.Samosvat, J.de Phys. **45**, C3-51 (1984).
4. J.M.Blatt and L.C.Biedenharn, Rev. Mod. Phys. **24**, 258 (1952).
5. G.S.Samosvat, Fiz. Elem. Chastits At. Yadra **26**, 1567 (1995) [Phys. Part. Nucl. **26**, 655 (1995)].
6. A.Langsdorf, Jr., R.O.Lane, and J.E.Monahan, Phys. Rev. **107**, 1077 (1957).
7. L.V.Kuznetsova, A.B.Popov, and G.S.Samosvat, JINR P3-87-393, Dubna, 1987 (in Russian).