On the Possible Mechanism of Interaction of High-Energy Particles with Nuclei

Mirzajan A. Asimov and Takhir R. Akhmedov

333 S. Webster Ave., Suite 4, Norman, OK 73069, USA. E-mail: TakhirAkhmedov@yandex.ru

Based on an analysis of classical views stating that a charged particle creates certain magnetic field around its trajectory, we draw a conclusion about possible polarization of target nuclei within the magnetic field of approaching charged particle.

1 Introduction

While studying of scattering of electrons and neutrons by nuclei Mott [1] and J. Schwinger [2] suggested the mechanism of interaction of the scattering particle's magnetic moment with Coulomb field of a nucleus. Such scattering has been known as Mott-Schwinger interaction. Polarization of scattered particles is considered within the framework of this interaction [3].

In the present study, the interaction of the magnetic field of the scattering charged particles with the magnetic moment of nuclei is investigated.

It was demonstrated earlier that within the framework of this interaction the nucleus is also polarized. Spin of the nucleus interacting with the fast-moving (primary) charged particle orient itself in the plane perpendicular to the direction of the primary particle's momentum.

2 Magnetic field of the charged particle

The charged particle moving with the velocity v induces magnetic field H wrapped around its path. H depends on the distance from the charged particle as follows [4]:

$$H = \frac{e\,v \sin\theta}{r^2}\,, \qquad (1)$$

where e is the charge of the scattered particle, r is the distance from the particle, and θ is the angle between the direction of the particle's velocity and r. Using this expression, one can calculate the intensity of the magnetic field H as a function of r and the speed of the particle with $\beta \sim 1$. It is assumed that laws of electromagnetism apply for small distances down to 10^{-13} cm. The calculations are presented in Table 1.

The numbers in the Table 1 indicate that pretty strong fields still not achieved by any experimental instrument. As it is known the magnetic field of a single charged particle has rotational characteristics.

3 Interaction of the magnetic field of the charged particle with the magnetic field of the nucleus

Magnetic charge of the scattering particle functions as an external magnetic field in respect to the nucleus. However, specific characteristic of the rotational magnetic field must be accounted for. Magnetic intensity lines are in the plane that is perpendicular to the direction of the particle's velocity. At the same time the vector of the magnetic field H at any arbitrary point on that plane at the distance r from the path of the particle is tangential to the circle of the radius r, and the direction of H is determined by the right-hand screw rule.

Let's consider that the nucleus is not exactly in the center of such a circle, but instead at some distance r from it. One can estimate the energy of interaction of the magnetic moment of the nucleus, μ, and the field H at distance r:

$$U = \mu H\,. \qquad (2)$$

One has to take into consideration that magnetic moment acts like a top, and, in non-relativistic case, precession of the nucleus is simple Larmor precession. Relativistic case was described by Bargman et al [5].

Following Bargman, one can consider the case when the angle between the spin of the nucleus and magnetic field H is close to $\frac{\pi}{2}$. The spin will start precessing around the magnetic field H with the frequency

$$\Omega = \omega L \left(\frac{g}{2} - 1\right), \qquad (3)$$

where $\omega L = \frac{e}{m\gamma} H$ is the frequency of Larmor precession, g is gyromagnetic ratio, and $\gamma = (1–\beta^2)–2$. It follows that

$$\Omega = \frac{eH}{m\gamma}\left(\frac{g}{2} - 1\right). \qquad (4)$$

As Ω can be expressed as $\Omega = \frac{2\pi}{t}$ and for those nuclei whose spin satisfies the condition of $\frac{g}{2} \neq 1$ the spin of the target nucleus will precess in the magnetic field of the incoming particle. Forced polarization appears while turning the direction of the spin by $\frac{\pi}{2}$.

Time necessary for the turn is determined by

$$t = \frac{m\pi\gamma}{eH}\,(g-2)\,, \qquad (5)$$

where m is the mass of the nucleus. For $\gamma = 10$, $m = 50$ a.m.u., we have $(g-2) \sim 1$, and $\mu = 1$ (nuclear magneton). Other examples in Table 2 demonstrate some interesting faces of the interaction.

Figures in Table 2 demonstrate that during the interaction of a fast moving charged particle with a nucleus (at $r \sim 10^{-12}$ cm) the orientation of the spin of the target nucleus takes as little time as $\sim 10^{-26}$ seconds. During this time interval the fast moving charged particle covers only 3×10^{-16} cm. This allows drawing a conclusion that right at the beginning of the interaction the nucleus target has time to orient its spin and further interaction takes place with the already polarized nucleus.

r, cm	10^{-13}	10^{-12}	10^{-11}	10^{-10}	10^{-9}	10^{-8}
H, Ersted	4.8×10^{16}	4.8×10^{14}	4.8×10^{12}	4.8×10^{10}	4.8×10^{8}	4.8×10^{6}

Table 1: The magnetic field intensity H as a function of r and the speed of the particle with $\beta \sim 1$.

r, cm	10^{-13}	10^{-12}	10^{-11}	10^{-10}	10^{-9}	10^{-8}
T, sec	10^{-28}	10^{-26}	10^{-24}	10^{-22}	10^{-20}	10^{-18}
$l = ts$, cm	3×10^{-18}	3×10^{-16}	3×10^{-14}	3×10^{-12}	3×10^{-10}	3×10^{-8}
$U = \mu H$, eV	1.5×10^{5}	1.5×10^{3}	15	0.15	1.5×10^{-3}	1.5×10^{-5}

Table 2: During the interaction of a fast moving charged particle with a nucleus (at $r \sim 10^{-12}$ cm), the orientation of the spin of the target nucleus takes as little time as $\sim 10^{-26}$ seconds.

4 Evaluation of energy required to change orientation of the nuclear spin within the external magnetic field

In known experiments of Dr. Wu et al [6], Co-60 nuclei were polarized at $T \sim 0.003$ K and the parity conservation was tested. Low temperatures were achieved by adiabatic demagnetization of Cerous Magnesium Nitrate. The energy of the effect can be estimated to be < 2.5 eV. Energy of the interaction of Co-60 nucleus magnetic moment with the outside magnetic field of a few hundred oersteds is negligible.

Therefore, the condition $\mu H \gg \kappa T$ is satisfied entirely (see Table 2): $\mu H \sim 10^3$, $\kappa T \sim 10^{-2}$.

Submitted on May 26, 2015 / Accepted on May 28, 2015

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