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SECOND CLASS CURRENTS AND THE β-PARTICLE ASYMMETRY AT THE DECAY OF ORIENTED ^{24m}Na NUCLEI

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1. Introduction

In last years the question of the possible existence of the second class currents (SCC) [1] in the weak interaction has again become more interest. Recently, for example, the observation (although there is contradiction) of τ-lepton decay channels due to SCC in the experiments at colliding e^+e^--beam, has been reported [2,3]. But a more accurate analysis of the data on the τ-lepton decay has only led to establishment of the upper limits for the decay channel induced by SCC [4]. Earlier attempts of the experimental search for SCC in the nuclear β-decay [5] did not allowed an unambiguous solution of this problem as well. More efficient experiments on the measurement of the β-particle asymmetry also happened to be impossible due to technical difficulties connected with the preparation of the polarized β-active nuclei, localised in small volumes and sufficiently pure of other activities. At present, because of the implementation of the laser technique for the preparation of oriented ensembles [6] of short-lived β-active nuclei, the possibility of performing these experiments at a higher accuracy and in a wider region of nuclei has emerged.

As a first candidate for these investigations a short-lived nucleus ^{24m}Na is proposed. On the one hand, the ^{24m}Na nucleus is convenient from the point of view of the search for SSC, since it decays through the allowed Gamow-Teller ($1^+ \to 0^+$) β-transition into ^{24g}Mg and has enough decay energy ($Q_\beta = \Delta E = 5.5$ MeV). On the other hand, in its atomic spectrum there are energy levels necessary to achieve a high degree of polarization and alignment of nuclei in the given direction. Furthermore, ^{24m}Na is the daughter nucleus in the decay of ^{24}Ne (see Fig. 1).

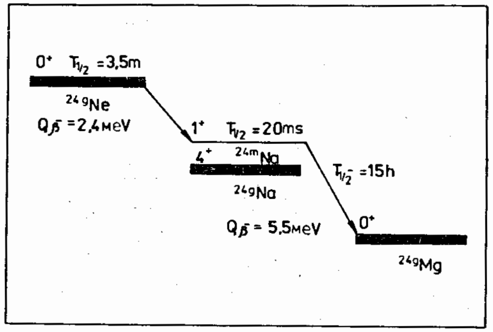

Fig. 1. Scheme of the decay $^{24g}\mathrm{Ne} \to {}^{24m}\mathrm{Na} \to {}^{24g}\mathrm{Mg}$.

The latter fact, as it will be clear below in the description of the experimental set-up, is decisive in the possibility of carrying out the experiment.

The aim of the present paper is to investigate theoretically the influence of SCC on the energy dependence of the asymmetry coefficient of the β-particle emission with respect to the spin orientation of the ^{24m}Na nucleus in the process

$$^{24m}\mathrm{Na} \longrightarrow {}^{24g}\mathrm{Mg} + e^- + \tilde{\nu}_e \qquad (1)$$

and to discuss the possibilities of measuring this dependence in a concrete experimental set-up.

2. Theoretical investigation

The spin orientation of the initial nucleus taken into account, the differential rate of process (1) in the non-relativistic limit ($v/c \ll 1$) [7], is given by [8]:

$$dW = N\, dE_e d\Omega_e d\Omega_\nu p_e p_\nu E_e E_\nu\, F(E_e, \theta, \theta^*, \varphi^*). \qquad (2)$$

Here $N = G_F^2/(2\pi)^4$ and the function $F(E_e,\theta,\theta^*,\varphi^*)$ is

$$F(E_e,\theta,\theta^*,\varphi^*) = (F^5_{L1})^2\{\xi^2(1+\frac{1}{2}AP_2(\cos\theta^*))(f_1+ 2qf_2\varkappa_2) + (1-AP_2(\cos\theta^*))(f_3-2qf_4\varkappa_1) + \xi A[P_2^1(\cos\theta^*)\cos\varphi^*(f_6+qf_7\varkappa_2-qf_8\varkappa_1) + \frac{1}{4}\xi P_2^2(\cos\theta^*)\cos 2\varphi^* f_{10}] + 3\xi P[\frac{1}{2}\xi P_1(\cos\theta^*)(f_2 + 2qf_1\varkappa_2) + P_1^1(\cos\theta^*)\cos\varphi^*(f_7+qf_6\varkappa_2-qf_9\varkappa_1)]\}, \qquad (3)$$

where $\varkappa_1 = \frac{1}{2MF_A}(F_A-2MF_T)$; $\varkappa_2 = \frac{1}{2MF_A}(F_1+2MF_2)$; $\xi = F^5_{E1}/F^5_{L1}$; the leptonic functions f_i ($i = 1, 2, \ldots, 10$) are defined in [8]; $A = 1-3a_0$ and $P = a_1-a_{-1}$ are the alignment and polarization of the ^{24m}Na nucleus, a_λ ($\lambda = 0, \pm 1$) are the relative populations of magnetic substates; $P_L^M(\cos\theta^*)$ are the associated Legendre Polynomials; θ^* and φ^* are the angles describing the spin orientation axis of the ^{24m}Na nucleus; F^5_{E1} and F^5_{L1} are the matrix elements of the transverse electric and longitudinal spin multipole operators [9]; F_A, F_1, and F_2 are the form factors of the first class currents; F_T is the form factor of the SCC [1].

From eq. (2) it follows that all information on the nuclear structure is contained in the parameter ξ. In the long-wave-length limit $\xi = \sqrt{2}$. In the case of the decay of nuclei, oriented along the electron momentum $\cos\theta^* = (\beta_e E_e + \beta_\nu E_\nu \cos\theta)/q$, $\varphi^* = 0$, where β_e (β_ν) and E_e (E_ν) are the velocity and energy of the electron (antineutrino), θ is the angle between the electron and antineutrino momenta, q is the momentum transfer. Then the differential decay rate of (1) summed over the spin states of the leptons and integrated over the solid angle of the antineutrino emission is given by

$$dW(\vec{s}_n \,||\, \vec{p}_e) = 4\pi\, N\, dE_e d\Omega_e\, p_e p_\nu E_e E_\nu \{3 + 2\beta_e^2 E_e(\varkappa_1 - 2\varkappa_2) + 2\beta_\nu^2 E_\nu(\varkappa_1 + 2\varkappa_2) - 2A\beta_e^2 E_e(\varkappa_1 + \varkappa_2) - 3\lambda\beta_e P[1 - 2\varkappa_2 E_e + \frac{2}{3}\beta_\nu^2 E_\nu(\varkappa_1 + 2\varkappa_2)]\}. \qquad (4)$$

Parameter λ takes the values of +1 for $\vec{s}_n \uparrow\uparrow \vec{p}_e$ and -1 for $\vec{s}_n \uparrow\downarrow \vec{p}_e$.

The asymmetry coefficient of the electron emission with respect to the nuclear spin is defined by

$$A_e = \frac{dW(\vec{s}_n \uparrow\uparrow \vec{p}_e) - dW(\vec{s}_n \uparrow\downarrow \vec{p}_e)}{dW(\vec{s}_n \uparrow\uparrow \vec{p}_e) + dW(\vec{s}_n \uparrow\downarrow \vec{p}_e)}. \qquad (5)$$

For A_e from eq. (2) we obtain the expression

$$A_e \cong -\beta_e P\{1 + \frac{4}{3}(\beta_e^2 E_e - \beta_\nu^2 E_\nu)\varkappa_2 - \frac{2}{3}\beta_e^2 E_e \varkappa_1 + \frac{2}{3}\beta_e E_e A(\varkappa_1 + \varkappa_2) - 2\varkappa_2(E_e - \frac{2}{3}\beta_\nu^2 E_\nu)\}, \qquad (6)$$

which, after neglecting the terms of order $m_e\varkappa_1$ and $m_e\varkappa_2$, takes a simple form:

$$A_e \approx -\beta_e P[1 - \frac{2}{3} E_e(1-A)(\varkappa_1 + \varkappa_2)]. \qquad (7)$$

The behaviour of the coefficient A_e versus the energy of the decay electrons for various values of the form factor F_T is shown in Fig. 2. The solid

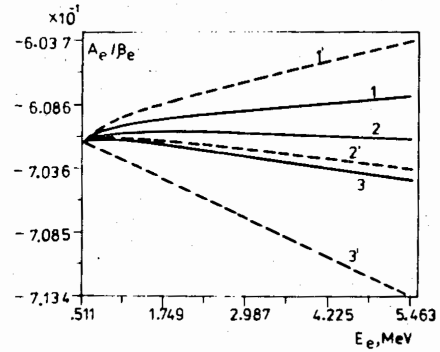

Fig. 2. The energy dependence of the coefficient A_e (normalized to β_e) at $P = 0.6$. Solid curves (1, 2, 3) belong to the case of $A = 0.6$ and the dashed curves (1′, 2′, 3′) – to the case of $A = 0.01$.

curves (1, 2, 3) belong to the case of alignment A = 0.6, and the dashed curves (1′, 2′, 3′) – to the case of A = 0.01. Curves 1 (1′), 2 (2′) and 3 (3′) belong to the cases of form factor MF_T = -5, 0 and +5, respectively. From Fig. 2, it is seen that measurement of the energy dependence of the coefficient A_e in the high electron energy region at small alignments ($A \ll 1$) will give information on the value of the form factor F_T.

3. Possible experiment

The scheme of the set-up to perform the experiment on measurement of the effects calculated in Sec. 2 is shown in Fig. 3. ^{24}Ne (used as a generator of ^{24m}Na) mixed with a noble gas of stable isotopes of Ar is transported to the spectrometer chamber

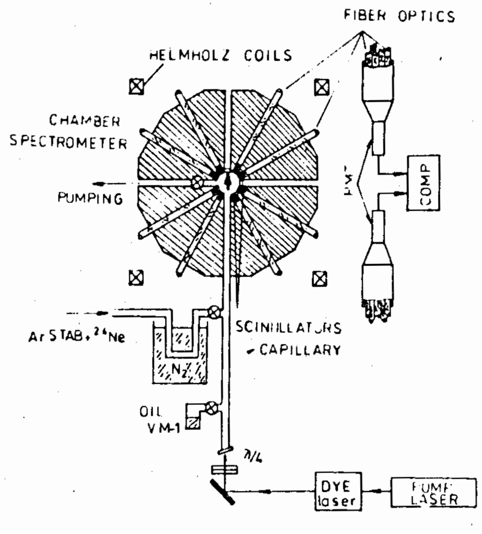

Fig. 3. Experimental lay-out for the measurement of the asymmetry of β-particle emission with respect to the nuclear spin.

through a thin capillary. Since both gases are inert, the coefficient of their passing through the capillary may be more than 90%. The transportation time through the capillary several meters long is less than one second, which is small against the half life of ^{24}Ne which is 3.5 minutes. Therefore, the loss of ^{24}Ne, when transporting, may be practically neglected. According to the ISOLDE data of 6.06.85 [10], the yield of ^{24}Ne in the nuclear reaction of deep spallation of MgO-target of 3 g/cm^2 thick by 600 MeV protons of 1 mkA after the electromagnetic mass-se-

paration is 1.64×10^6 atoms per second. It should be noted that the small branching of β^--decay of ^{24m}Na is an unpleasant fact. It will decrease the speed of counting. Nevertheless, there is a real possibility of increasing it by higher proton current and thickness of the target. With aguerus solutions of Mg salts as a target, its thickness may be increased up to several hundreds of g/cm^2, which will allow the ^{24}Ne yield to be raised by two orders of magnitute.

^{24}Ne was additionally purified of possible disturbing admixtures coming from the capillary walls by the freezing in the nitrogen trap (see Fig. 3) before letting it enter into the spectrometer chamber. The spectrometer is preliminarily pumped out to a high vacuum and its inner walls are oiled by VM-1, the vapors of which are supplied by a special tube. This procedure fully eliminates the physical adsorption of ^{24m}Na on the chamber walls [11], which highly reduces the loss of sodium atoms on the spectrometer chamber walls. Thus, in the spectrometer chamber one can achieve not less than 10^6 ^{24}Ne decays per second, which finally defines the quantity of ^{24m}Na nuclei. In the experiment the β-particles resulted from the decay of ^{24m}Na are to be detected. The spectrometer chamber has the geometry near to 4π, as seen from Fig. 3, where its section is shown in the diametric plane. β-particles are registered by two scintillation spectrometers, each controlling the upper and lower semi-spheres consisting of the face plates of the scintillators. The scintillator fluorescence resulted from the β-particles, goes to the input of the photomultipliers through the fiber optics lightguides. Polarization [6] of ^{24m}Na atoms in the spectrometer chamber is achieved by bombarding them by the resonanse and circular polarized laser beams from a dye-laser. In order to avoid destruction of polarization by possible presence of the background magnetic fields and to have the nuclear spins aligned along the given direction, the chamber is surrounded by the Helmholz coils, giving a homogeneous magnetic field of several Gauss in its centre, which is collinear to the orientation axis of ^{24m}Na. The polarization time of sodium is of the order of 10^{-8} second [6], therefore, the ^{24m}Na isomers, have enough time to be polarized before the decay ($T_{1/2}$(^{24m}Na) = 20 ms). Depolarization is mainly defined by the collisions of the ^{24m}Na atoms with the noble gas atoms and with the spectrometer chamber walls. Nevertheless, since the nuclear spins of Ar and ^{24}Ne isotops are zero, polarization is not lost in collisions (there is no polarization exchange), and the small free path length (with respect to the size of the spectrometer chamber) at the sufficient density of the noble gas and the small half-life of ^{24m}Na, guarantees a neglegiably small number of collisions with the chamber walls and thus decreases the depolarization effects.

The measurement are supposed to be cyclic. For a few minutes ^{24}Ne is accumulated. Then it is transported to the spectrometer chamber, preliminarily pumped out to a high vacuum. Further, for the same period of time (≈ 10 minutes) the measurements of

the asymmetry are carried out with the simultaneous accumulation of the next portion of ^{24}Ne. And so the cycle is repeated many times. For the additional increament of the ^{24m}Na concentration and for its localization in the centre of the spectrometer chamber the phenomenon of the light-induced drift of the sodium vapor in noble gases [12] is used. To remove the false asymmetry due to inaccuracy in the construction of the spectrometer chamber and due to the difference in the efficiencies of the β-particle detection by the upper and lower β-channels, the measurements are carried out for two directions of polarization, and the results are summed. The asymmetry coefficient is calculated by

$$A_e = \frac{W_1(\vec{s}_n\uparrow\uparrow\vec{p}_e)+W_2(\vec{s}_n\uparrow\uparrow\vec{p}_e)-W_1(\vec{s}_n\uparrow\downarrow\vec{p}_e)-W_2(\vec{s}_n\uparrow\downarrow\vec{p}_e)}{W_1(\vec{s}_n\uparrow\uparrow\vec{p}_e)+W_2(\vec{s}_n\uparrow\uparrow\vec{p}_e)+W_1(\vec{s}_n\uparrow\downarrow\vec{p}_e)+W_2(\vec{s}_n\uparrow\downarrow\vec{p}_e)}, \quad (8)$$

where W_1 and W_2 are the counts in detectors 1 and 2 for various spin orientations (up or down) of ^{24m}Na. For the number of β-decays of the order of 10^4 per second and 100% efficiency of β-particle detection, the statistics may become more than 10^8 counts for 10 hours of measurement. This statistics is "good" for finding the effects of the order of 10^{-3}. Using a high difference in the decay energies of ^{24}Ne and ^{24m}Na (see Fig. 1) and the fact that the effects due to second class currents are manifest themselves in the high energy region of the β-spectrum (see Fig. 2), one may exclude the background β-particles from the decay of ^{24}Ne, setting a detection threshold at 2.5 MeV.

Thus, we see it possible to carry out the described experiment at the proton accelerator of the Laboratory of Nuclear Problems (LNP) of the Joint Institute for Nuclear Reaserch (JINR), having the proton energy of 660 MeV and the current of a few μA. This experiment is planned to be carried out in this and next years at the newly constructed laser set-up in the LNP of JINR.

4. Conclusion

In conclusion we shall note that the method of having a polarized ensemble of sodium nuclei as well as other nuclides using lasers opens up a possibility of carrying out a number of correlation experiments. For example, the study of not only the double correlation discussed here, but also the triple correlation at the decay of oriented ^{24m}Na nuclei, measuring, apart from the momentum of β-particles, the momentum of recoil nuclei. Experiments of this sort may shed some light on the question of the violation of the T-invariance in β-decay. Furthermore, valuable information on the nuclear structure may be obtained, if γ-rays emitted after the decay of oriented nuclei are studied. The experiments on the scattering of various accelerated particles by the polarized gas targets are interesting as well. Here the laser method may be indispensable and promising for the preparation of these targets.

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Катхат Ч.Л., Солнышкин А.А., Усман М.А. E6-89-411
Токи второго рода и асимметрия β-частиц при распаде ориентированных ядер ^{24m}Na

В рамках оболочечной модели ядра теоретически исследован и оценен возможный вклад токов второго рода в коэффициент асимметрии β-частиц (A_e) при распаде ориентированных ядер ^{24m}Na. Показано, что при $E_T \approx 10^{-3}$ МэВ$^{-1}$ эффект составляет $\approx 10^{-3}$. Обсуждена возможность конкретной реализации опыта по измерению энергетической зависимости коэффициента A_e с помощью лазерной методики. Предложена схема эксперимента.

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Kathat C.L., Solnyshkin A.A., Ousmane M.A. E6-89-411
Second Class Currents and the β-Particle Asymmetry at the Decay of Oriented ^{24m}Na Nuclei

The possible contribution of second class currents to the β-particle asymmetry coefficient (A_e) at the decay of oriented ^{24m}Na nuclei is theoretically investigated and estimated in the framework of the nuclear shell model. For $F_T \approx 10^{-3}$ MeV^{-1} the effect is shown to be $\approx 10^{-3}$. A possibility of an experiment to measure the energy dependence of the coefficient A_e using the laser method is discussed. A scheme of the experiment is proposed.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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