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Abstract. Spin polarization of beta-emitting fragment ^{23}Mg(I^π=3/2$^+$, $T_{1/2}$=11.3 s) produced through the projectile fragmentation process in ^{24}Mg + Au, Cu and Al collisions has been observed at 91 *A*MeV. General trend in the observed momentum dependence of polarization is reproduced well qualitatively by a simple fragmentation model based on the participant-spectator picture, for heavy and light targets. However the polarization behavior differs from this model in terms of zero crossing momentum, which become prominent in the case of Cu target, where the polarization is not monotone function of the fragment momentum.

INTRODUCTION

The technique of polarized radioactive nuclear beams is very useful for the study of nuclear structure. It has been applied for the measurement of nuclear moments(1-4). This technique can also be applied to the study of fundamental interactions. Precise measurement of the asymmetry parameter of ^{23}Mg beta decay, which discloses validity of Cabbibo universality(5), can be a good example of such a new application. In order to expand applicability of this technique, however, clear understanding of the polarization mechanism in heavy ion collisions in the intermediate energy region is crucial. Although the polarization mechanism has been studied using ^{14}N, ^{18}O, ^{40}Ca, and ^{46}Ti projectiles(1-4,6-9), the middle mass region in the sd shell has been missing. In the present experiment, spin polarization of beta-emitting fragment ^{23}Mg(I^π=3/2$^+$, $T_{1/2}$=11.3 s) produced through the projectile fragmentation process of ^{24}Mg has been observed at 91 *A* MeV.

EXPERIMENTAL PROCEDURE

The ^{24}Mg beam of 100 *A* MeV extracted from the RIKEN's *K*=540 ring cyclotron was used to bombard three kinds of targets (Au, Cu and Al). Energy loss of the beam in the target was 18 *A* MeV, so that the effective energy was 91 *A* MeV. ^{23}Mg fragments emerging from the target at a certain deflection angle were selected by a defining slit. They were then separated out from various fragments and were momentum analyzed by the RIPS (RIken Projectile fragment Separator). The separated ^{23}Mg nuclei were then implanted in a 50μm-thick Pt catcher placed in a strong magnetic field(4.0 kOe or 2.7 kOe) to maintain the polarization produced in the collision. The Pt foil was cooled to a low temperature(28K or 13K) to increase the relaxation time of the polarization. Beta rays emitted from the stopped nuclei were detected by two sets of plastic scintillation counter telescopes placed above and below the catcher relative to the polarization axis. The polarization was measured by means of counting asymmetry in these counters. For background rejection, a pulsed beam method was used, where the beam was on for 10 s in every 45 s and beta rays were observed in the following 35s of counting time. To obtain a reliable polarization, geometrical counter asymmetry was canceled by flipping the spin ensemble using the AFP(adiabatic fast passage) method in NMR in every other beam-count cycle.

RESULTS AND DISCUSSION

Spin polarization of ^{23}Mg was measured as a function of fragment momentum at a reaction angle of 2.0°. Fig. 1 shows the observed polarization together with the momentum distribution of ^{23}Mg for three targets. As expected from the participant-spectator picture of the collision at the present energy region, the observed fragment momentum shows a Gaussian distribution centered near the momentum corresponding to the beam velocity with a width close to that caused from the Fermi motion of a nucleon(10).

The polarization observed for the Au target is a monotone increasing function of momentum(Fig. 1-a), while the polarization for Al target is a decreasing function(Fig. 1-c), following the same trend observed in previous studies(6,7,9). As is shown by solid lines in Fig. 1, these momentum dependencies are reproduced well qualitatively by a simple fragmentation model(7, 11) based on the participant-spectator picture of the high energy heavy ion collision and the orbital deflection of projectiles caused by the combined Coulomb-nuclear potential to either positive(Au target) or negative (Al target) angles.

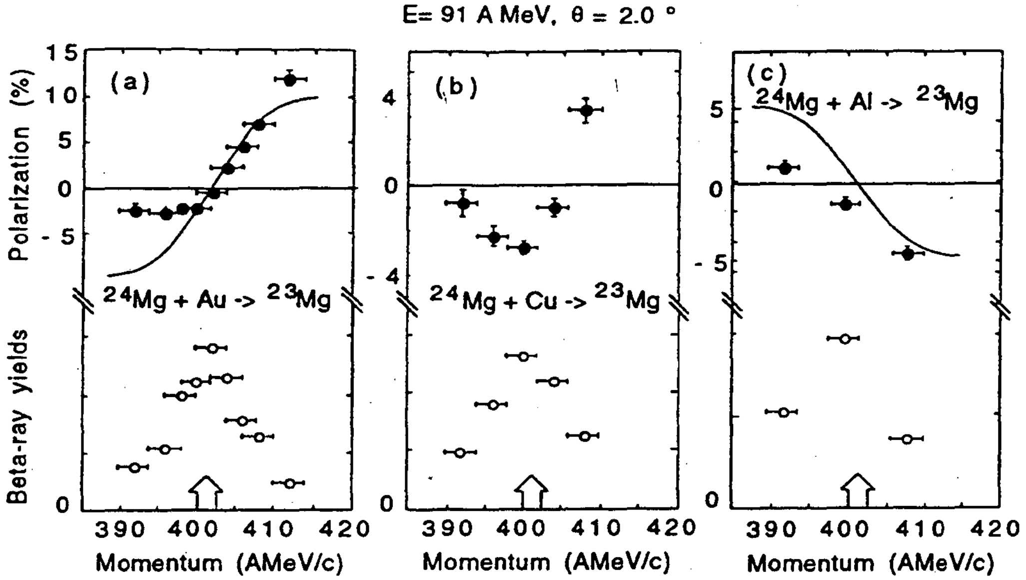

FIGURE 1. Momentum dependence of the polarization of ^{23}Mg. Closed and open circles are the polarizations and beta-ray yields, respectively. Arrows indicate the momentum corresponding to the beam velocity. Solid lines are the predictions from a simple polarization model, scaled down by 1/10 and 1/20 for Au and Al targets, respectively.

Although the general trend is well reproduced, details of the observed polarization differs from the above mentioned simple model. The predicted polarization is a monotone function crossing the momentum axis near the beam velocity and is anti-symmetric relative to the zero-crossing momentum. For the Au target the absolute polarization on the lower momentum side is significantly smaller than that on the higher momentum side; this effect has been seen in previous works. This trend may be caused from the unknown fraction of deep inelastic collisions (DIC) in the lower momentum region. The contribution from DIC to the polarization is not yet clear. For the Al target, the zero-crossing momentum is significantly lower than the beam velocity. This behavior may be understood by introducing a deceleration mechanism such as a nuclear frictional force. However, such a mechanism causes additional polarization.

In contrast to the polarization for heavy and light targets, the polarization for the Cu target has a minimum near the central momentum(Fig. 1-b) as was reported for light projectiles in ref. 2 and ref. 8. This trend is supposed to be a result of the mixing of deflection angles of both signs. However, this momentum dependence can not be reproduced by a simple extension of the above mentioned simple model.

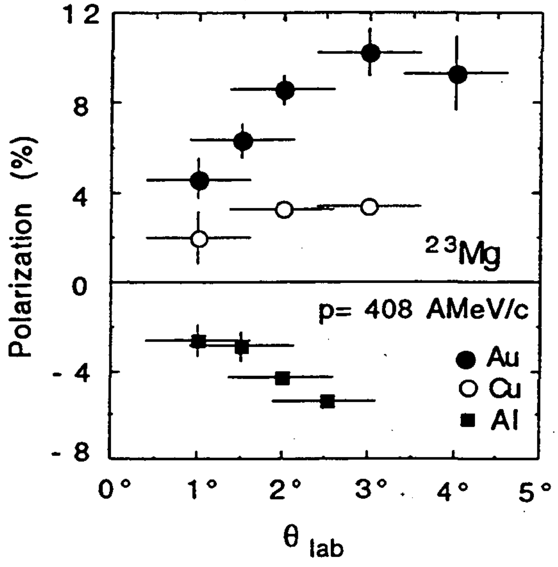

FIGURE 2. Reaction angle dependence of the polarization of ^{23}Mg. Closed circles, open circles and closed squares are the polarizations for Au, Cu and Al targets, respectively.

It can be reproduced only if there is some deceleration mechanism for the negatively deflected component. Instead of the deceleration mechanism, Okuno et al. recently introduced an idea of recession of the abrasion point(8). This mechanism introduces additional negative polarization for relatively large angles, resulting in the lowering of the zero-crossing momentum in the case of light targets. Although the recession necessary for explaining the data in ref. 8 seems too large compared with that expected from the finite mean free path of the abraded nucleons as is already discussed in the reference, it is worth trying to apply to the present data.

Spin polarization was also measured as a function of reaction angle at a momentum 1.7% higher than the beam velocity, as shown in Fig 2. For Au and Cu targets, the polarization increases as the angle and reaches a saturated value around 2°, which is explained well by the beam divergence due to the original beam emittance and multiple scattering of the beam in the target. On the other hand, the absolute polarization from the Al target keeps increasing in the observed range of reaction angle. Since multiple scattering of the beam is smaller in the light target, this angle dependence reflects the polarization mechanism. Thus the present behavior in angle dependence allow one to check the validity of the idea of recession of the abrasion point, since the additional polarization introduced by this new model changes its sign from positive to negative as the reaction angle increases.

There is another difficulty in understanding the polarization mechanism, i.e., the quenching of the absolute degree of polarization from the predicted polarization. This quenching, which is seen in all the present cases and in the previous works, can not be explained well by the depolarization in the implantation process, by the depolarization due to gamma transitions of the exited fragment nuclei, or by the mixing of the coulomb breakup together with the fragmentation process. This quenching may be caused by the coexistence of the positively and negatively deflected components even for both extreme cases where either of the components become dominant.

Once the polarization technique was established in ^{23}Mg, the technique can be applied to the study of beta decay. For further study, polarized ^{23}Mg nuclei produced at the angle of 2° at 1.7%-higher momentum from the beam velocity with Au target was used to maximize the figure of merit which is the yield rate times the square of the polarization. Study of the weak vector coupling constant G_V for mixed transitions like ^{23}Mg beta decay provides a sharp test for CVC(Conserved Vector Current) theory. G_V for the mixed transition is obtained from the asymmetry parameter as well as the half life of the transition. In the present experiment, a preliminary result for the asymmetry parameter of ^{23}Mg beta decay was obtained. A thin Pt catcher foil was further cooled down to 13 K. Polarization effects were measured by means of asymmetric beta-ray emission for both the ground state transition and the transition to the first excited state. The transition to the excited state was tagged by the 440 keV gamma rays.

Fig. 3 shows the obtained beta-ray asymmetries $\mathcal{A}P$ for beta-ray singles and beta-gamma coincidence events. Since the value $\mathcal{A}_{ex}$ is known to be -0.6, the ratio of two asymmetries, $\mathcal{A}_{ex}/\mathcal{A}_0'=0.90\pm0.19$, gives the asymmetry parameter for the ground transition as $\mathcal{A}_0=-0.65(13)$, which is in good agreement with the value -0.55 predicted from CVC. A more precise measurement is being planned in order to obtain the coupling constant G_V with an accuracy of about 1%.

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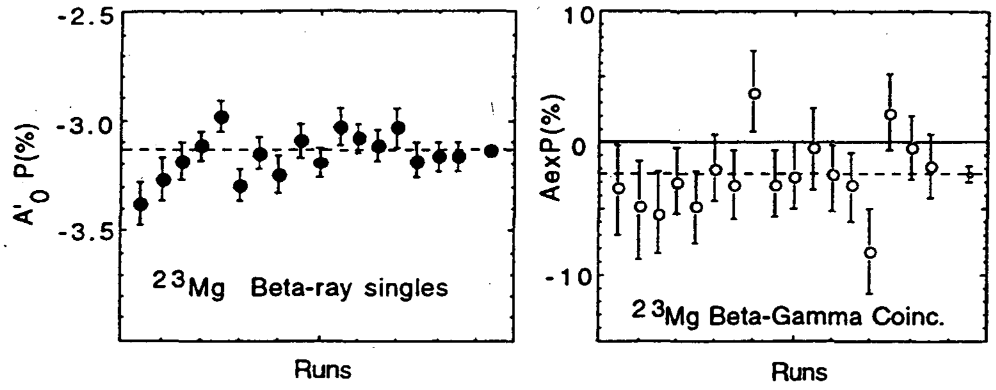

FIGURE 3. Beta-ray Asymmetries.
The last data points and the broken lines indicate average asymmetries.

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