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II.d. Nuclear Structure Studies with Polarized ^{207}Bi, ^{210}Bi(RaE) and Polarized ^{209}Bi Targets

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(Presented by K. Nagamine)

Studies of polarized radioactive Bi isotopes have been performed at low temperature in a ferromagnetic BiMn compound where Bi nuclei were found to feel a large hyperfine field around 1 MGauss. An application of the polarized ^{209}Bi target to the study of magnetic hfs in muonic atom is discussed.

Introduction

We have been performing low temperature nuclear orientation studies of Bi isotopes in the site of a chemical compound BiMn. The compound BiMn is ferromagnetic which contains Bi and Mn as a half and a half. The saturation magnetization is obtained by an external field of 7 KG. Recently by our nuclear orientation studies of ^{205,206}Bi isotopes, we found a large hyperfine field working on Bi nuclei amounting to around 1 MG.

Contrary to the case of ferromagnetic dilute alloys[1] we have Bi atoms in a macroscopic scale. Therefore we can use it not only as a host material which provides a hyperfine field on radioactive impurities but also as a target material.

Among our recent experiments using this compound, we present, in the following, two experimental results obtained by oriented radioactive Bi isotopes and in addition, one experimental proposal with polarized ^{209}Bi targets.

The E2 Effective Change in the $\nu f_{7/2}^{-1} \rightarrow \nu f_{5/2}^{-1}$ Transition in ^{207}Pb

Almost all our samples for radioactive studies were prepared as follows: the metallic Bi and Mn including radioactivities were mixed at 1000 C and reacted at 440 C. The BiMn compound was magnetically separated from unreacted background. The purity of our samples was estimated to be around 50% by magnetic susceptibility analysis. The powdered samples of 40-μm diameter were attached to the copper plate by Apieson N grease which was thermally connected to a dilution refrigerator or demagnetized CrK alum salt.

As a demonstration of the orientation effect using the BiMn compound, we show in Fig. 1, gamma-ray spectra from oriented ^{207}Bi which were detected by a NaI (Tl) coupled with a lucite light guide placed along the external field. The cool data was taken at demagnetization temperatures around 40 mK and warm data at liquid helium temperatures. We can see an anti-phase anisotropy between the 1063 keV transition ($i_{13/2}^{-1} \rightarrow f_{5/2}^{-1}$) and 1770 keV transition ($f_{7/2}^{-1} \rightarrow f_{5/2}^{-1}$), the former decays mainly by and M4 transition and the latter by the mixed transition of M1 and E2.

The mixing ratio in the 1770-keV transition is important in order to study neutron E2

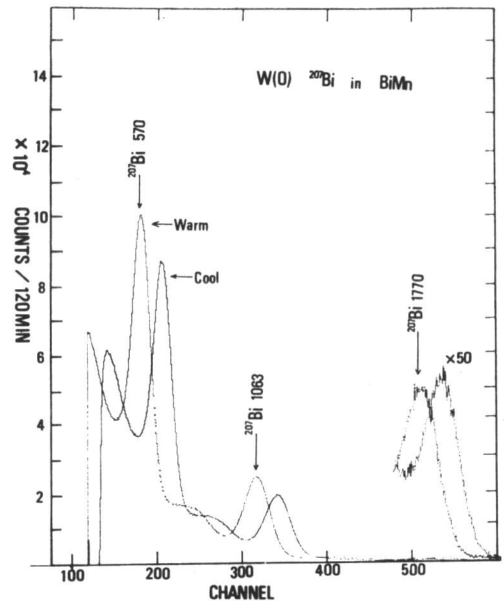

Fig. 1. Orientation effect in gamma spectra from ^{207}Bi in BiMn observed along polarization axis by a NaI (Tl) detector. Note that the rate of difference is reduced by the existence of free Bi background.

effective charge associated with a spin-flip E2 transition. We deduced this value taking the anisotropy of the 1063-keV transition as a reference. Since we have not yet measured the depolarization rate at the isomeric state of the $i_{13/2}^{-1}$ state, we can find only the lower limit on the E2/M1 mixing ratio as 0.08. This value is consistent with the recent data of angular correlation measurements by Bargholtz *et al.*[2] They reported the value of 0.085 ± 0.002 which gives us a somewhat smaller E2 effective charge in a spin-flip E2 transition ($f_{7/2}^{-1} \rightarrow f_{5/2}^{-1}$) than in a spin-non-flip case ($f_{7/2}^{-1} \rightarrow p_{3/2}^{-1}$).

The Signs of μ and Q of the 1^- State of ^{210}Bi (RaE)

As for the moments of the ground state of ^{210}Bi, Alpert *et al.*[3] determined in atomic beam experiment the absolute values of μ and Q and also relative sign of both moments and did not determine the sign of each moment.

On the other hand, Morita and Ohtsubo[4] contributed to this conference a paper describing theoretical calculation on the beta asymmetry from polarized RaE and pointed out importance of such a measurement in order to fix the parameters of beta matrix elements. Their calculation also shows a possibility to define the sign of the magnetic moment by observing the sign of polarization effect.

Although our final aim is to settle down the beta matrix elements, we are going to restrict our discussion to the sign determination since our data is only preliminary.

The nuclear polarization of RaE is difficult because of its small magnetic moment. With the aid of hyperfine field in the BiMn compound we tried to observe polarization effect using a dilution refrigerator which has been constructed in our laboratory and is working down to

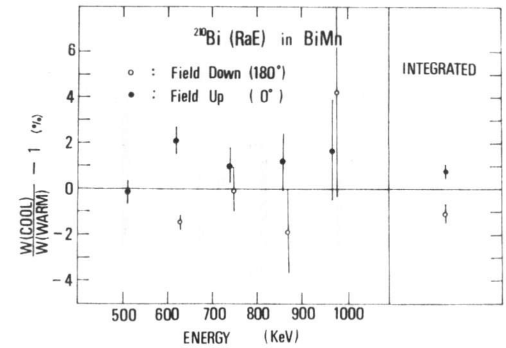

Fig. 2. Beta anisotropy from polarized ^{210}Bi(RaE) observed along the polarization axis. Closed circles represent the case of normal field direction (0°) and open circles represent the case of reversed direction (180°).

30 mK continuously. Experimental result is shown in Fig. 2 where we obtained a small but definite positive asymmetry with respect to the external field.

The asymmetry coefficient of the beta ray with respect to the spin direction is negative according to the theoretical calculation by Morita and Ohtsubo in which they considered all possible combinations of the beta matrix elements so as to fit the spectrum shape and the longitudinal polarization. The sign of the hyperfine field on Bi nuclei is estimated to be positive from the systematic trends of the hyperfine fields on As, Sb and Bi diluted in iron[5)] and the fields on the these nuclei in the manganese compounds.[6)] Therefore combined with the data of Alpert *et al.*[3)] we conclude that

$$\mu = -0.0442 \pm 0.0001 \text{ and } Q = +0.13.$$

These values can be compared with the shell-model predictions based on the empirical g-factors[7)] and E2 effective charge ($e_p = 1.5$, $e_n = 0.7$), $\mu = +0.07 \pm 0.04$ and $Q = +0.15$ for Kim-Rasmusson's wave function;[8)] $\mu = +0.00 \pm 0.04$ and $Q = +0.16$ for Kuo-Herring's wave function.[9)] Considering complex admixtures of various shell-model states into 1^- state, we can say that the agreement is good.

Application to the Precise Determination of Magnetic hfs in Muonic ^{209}Bi

The strong hyperfine field on the Bi nuclei in the BiMn compound leads us to a practical polarized ^{209}Bi targets.[10)] More than 90% polarization is obtained at 0.03 K where dilution refrigerator is very useful. Among the various experiments using polarized ^{209}Bi targets, we contributed to this conference a paper describing its application to the study of magnetic hyperfine structure in muonic atom.[11)]

Static magnetic moments in the closed shell region have revealed the anomalous orbital g-factor due to the mesonic exchange current.[12)] The magnetic hfs of muonic atoms especially of ^{209}Bi will give further information on the role of this effect.[13)] So far, the hfs coupling constants, A_1, for the muonic $1s_{1/2}$ and $2p_{1/2}$ states of ^{209}Bi have been measured[14)] but because of too small splitting they are not accurate enough. We propose an experiment using a polarized ^{209}Bi target and polarized muons where we want to populate selectively

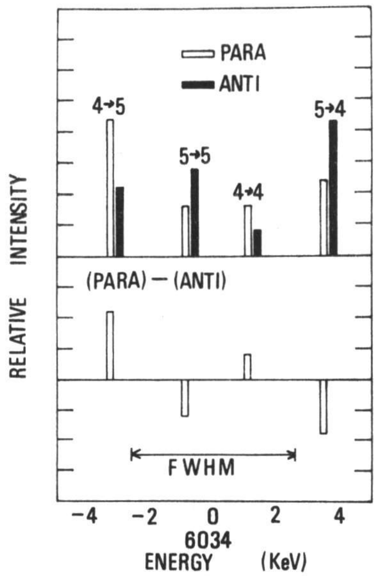

Fig. 3. Expected line profiles of the $2p_{1/2} \rightarrow 1s_{1/2}$ X-ray in ^{209}Bi in case of $A_1(1s_{1/2}) = 2.0$ keV and $A_1(2p_{1/2}) = 1.1$ keV.

one of the two F states by changing the relative polarization direction, and expect different profiles of the splitting in $2p_{1/2}$ to $1s_{1/2}$ transition.

We show in the upper part of Fig. 3 calculated line intensities in $2p_{1/2}$ to $1s_{1/2}$ transition where we assumed $A_1(1s_{1/2}) = 2.0$ keV and $A_1(2p_{1/2}) = 1.1$ keV and we did not take into account any nuclear excitations. $\langle$Para$\rangle$ means that target polarization is along the initial muon beam direction and $\langle$Anti$\rangle$ is the reversed case. If we do experiments according to $\langle$Para$\rangle - \langle$Anti$\rangle$ we have line intensities shown in the lower part. These lines must be folded by the counter resolution as indicated in the figure. Because of the large intensity difference we hope to obtain the coupling constant 4 times more precisely.

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Discussion

M. MORITA (Osaka): I would like to supplement the theoretical part of the problem of RaE. The asymmetry of beta rays from polarized RaE depends on three nuclear matrix elements. However, the beta-ray spectrum of RaE is strongly energy dependent, and the longitudinal polarization is about 75% of $-v/c$. These results can be explained by a cancellation among three parameters. Therefore, we have to be careful in order to predict the sign and magnitude of the asymmetry. We made a careful analysis of the beta-ray spectrum and *ft* value, from which we found the values of the nuclear matrix elements and then predicted the asymmetry. It comes out to be a negative quantity multiplied by $\langle m \rangle / j$. A shell model calculation also gives a consistent explanation of the nuclear matrix elements and the nuclear moment.

R. M. STEFFEN (Purdue Univ.): I have a question for Prof. Morita. In view of the strong cancellation of beta matrix elements in the RaE beta decay, higher order matrix elements may be important. Have these higher order matrix elements been taken into account in your calculation?

MORITA: We had a cancellation in our analysis but it is not too strong. And we obtained a better agreement with the beta spectrum than any other authors obtained previously. A large cancellation is unfavorable because it makes the *ft* value be unreasonably small. Higher order terms which come from the numerical solutions of the Dirac wave equation with the extended nuclear Coulomb potential were taken into account, but not additional nuclear matrix elements.

NAGAMINE: Is there any change of sign of the asymmetry caused by the cancellation?

MORITA: There might be if the cancellation is very strong. Fortunately, in our case we have a unique sign for all possible sets of nuclear matrix elements which are obtained from the beta spectrum analysis.