NUCLEAR DEALIGNMENT IN GASES

Zhu Shengyun (朱升云)* , M.H. Rafailovich, C. Alonso-Arias,
S. Vajda and G.D. Sprouse

(State University of New York, Stony Brook, New York 11794, USA)

(Received March 1993)

ABSTRACT

The nuclear dealignment is studied during the slowing down process and after thermolization in different gases by the time differential perturbed angular distribution method. A large fraction of the initial nuclear alignment following the nuclear reaction can be preserved in gases with large moments of inertia, but only a small fraction in monoatomic gases such as the noble gases. The plunger experiment shows that the nuclear dealignment occurs during the slowing down process and not after thermolization.

Keywords: Nuclear dealignment Gases Time differential perturbed angular distribution

1 INTRODUCTION

The previous experiment[1] has shown that a fraction of the initial nuclear alignment following nuclear reaction can be reserved for a long time in gases. This suggests that one can make use of gases for the measurement of nuclear moments of long-lived isomers and for the studies of yrast trap and optical pumping. The previous results have revealed that a larger fraction of the initial nuclear alignment is maintaned after thermolization in CO_2 than in noble gases and that the higher the gas pressure the larger fraction of the initial nuclear alignment is preserved. For effective use of gases as host materials in nuclear moment measurements *etc.*, it is helpful to understand the systematics and the nature of the nuclear dealignment in gases. To do that, the present experiment was motivated to make a thorough investigation of nuclear dealignment in gases after thermolization and during the slowing down time of recoil nuclei by the time differential perturbed angular distribution method.

2 EXPERIMENT

The $I = 19/2^-$ and $T_{1/2} = 0.45$ μs isomers in ^{43}Sc were used as probe nuclei to study

* Permanent address: China Institute of Atomic Energy, Beijing 102413

the nuclear alignment in gases. The isomers were populated and aligned by the fusion evaporation reaction $^{27}Al(^{19}F, 2np)^{43}Sc^*$ with a pulsed beam of a width of 2 ns and a repetition period of 2 μs, and the recoil momentum implanted the populated isomers into gas. The Al target foil was 1.6 mg/cm^2 thick with a chemical purity of 99.9 %. Before impinging onto the target, the incident ^{19}F beam passed through the Ni foil of 2 mg/cm^2 employed tc isolate the gas cell from the accelerator vacuum. The average energy of the beam was 46.5 MeV after the energy losses of the beam in both Ni and Al foils were taken into account. The nuclear alignment of the recoiled isomers in gas was measured by the time differential perturbed angular distribution method. A transverse magnetic field of 0.7 T was applied. In order to determine whether the loss of nuclear alignment takes place during the slowing down process or after thermolization a specially designed plunger gas cell was constructed and used. The distance between the Al target and the Ta catcher could be adjusted from 0 to 12 cm with an accuracy of 0.0006 cm. The Ta catcher of 0.025 cm thick was located at 12 cm from the target in the measurement of nuclear alignment after thermolization and at varying distances in the measurement of alignment as a function of recoil velocity during the slowing down process.

The γ-quanta depopulating the 3.1232 MeV $19/2^-$ level of the isomer[2] were detected by two identical 5 cm × 5 cm NaI(Tl) detectors at ± 135° to the beam direction. The energy windows were set such that the γ-rays of 1.158 MeV ($15/2^- — 11/2^-$) and 1.830 MeV ($11/2^- — 7/2^-$) were detected. This energy selection is permissible since the $15/2^- — 11/2^-$ and $11/2^- — 7/2^-$ γ-rays of the streched E_2 cascade have the same angular distribution coefficients as the $19/2^- - 15/2^-$ transition γ-rays. The time differential perturbed angular distribution method was used to perform the spin rotation measurement, which enables the nuclear alignment to be determined. In order to reduce the electronic dead time of the perturbed angular distribution spectrometer, two special techniques: fast-slow coincidence and passive delay, were used[3]. The background-subtracted time spectra from the two detectors were normalized and then used to form a standard ratio function $R(t)$:

$$R(t) = [I(t, +135°) - I(t, -135°)] / [I(t, +135°) + I(t, -135°)] \quad (1)$$

For the angular distribution of the delayed γ-rays with $K_{max} = 2$ and $A_2 << 1$, we have:

$$R(t) \approx -0.75\, A_2 G_2 \sin(2\omega_1 t - \phi) \quad (2)$$

where A_2G_2 are refered to as the amount of nuclear alignment in the system, ω_1 is the Larmor frequency and ϕ the phase depending on the detector angles, the $t=0$ determination and beam bending in the magnet. As an example, shown in Fig.1 are the time spectra from the detectors $I(135°, t)$ and $I(-135°, t)$ and the measured and fitted

ratio functions $R(t)$ in SF_6 at 10^5 Pa and Fig.2 the measured and fitted ratio functions in CO_2, Xe Ar, He and $0.9Ar+0.1CH_4$. The nuclear alignment, A_2G_2, was obtained simply by fitting Eq(1) to Eq(2). The corrections were applied to all data for the deviation at different stopping positions from the ideal 90° geometry of the two detectors.

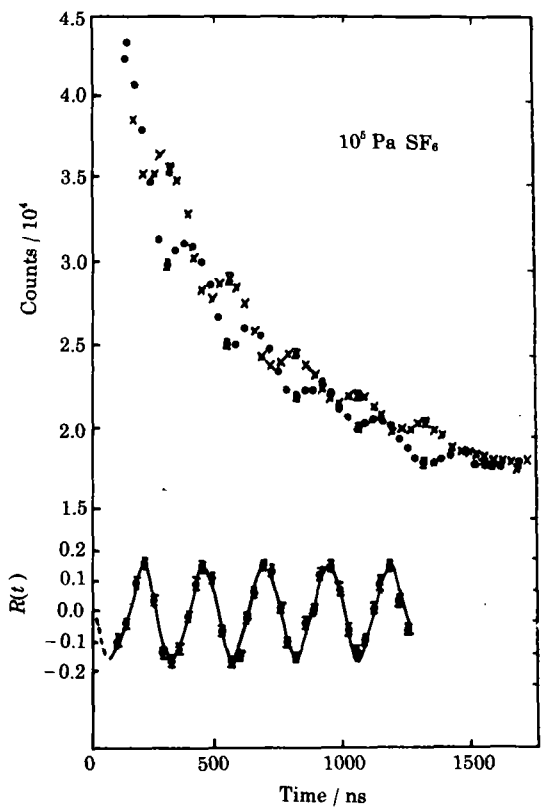

Fig.1 The measured time spectra of the delayed γ−rays $I(135°,t)$ (●) and $I(-135°,t)$ (×) (top) and the measured and fitted (—) ratio functions $R(t)$ in SF_6 at 10^5 Pa (bottom)

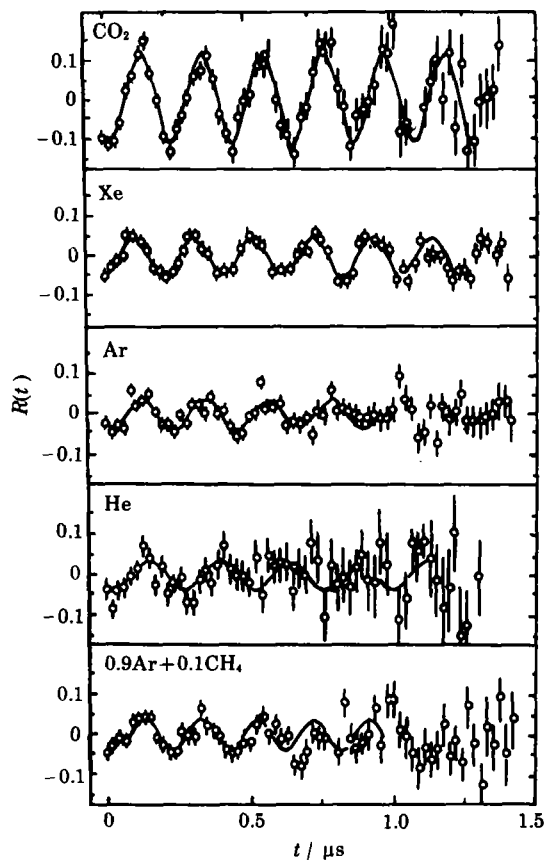

Fig.2 Ratio functions for ^{43}Sc $(19/2^-)$ in different gases at 10^5 Pa

3 RESULTS AND DISCUSSION

The dependence of the nuclear alignment remaining after thermolization on the rotational energy level spacing of the host gas at 10^5 Pa is shown in Fig.3. It can be seen from Fig.3 that, in general, gases which have large moments of inertia are good for preserving the nuclear alignment, while monoatomic gases such as the rare gases

are not good and severe nuclear dealignment occurs in them. In order to determine whether the loss of nuclear alignment takes place during the slowing down time or after thermolization, we did the plunger experiment in 5×10^{4} Pa of CO_2 and Xe, which allows the determination of the dependence of the nuclear alignment of the isomer on the velocity of the recoil nucleus during the slowing down process. Fig.4 illustrates the nuclear alignment observed as a function of recoil velocity in CO_2 and Xe. The dealignment is seen to take place during the slowing down time and not after

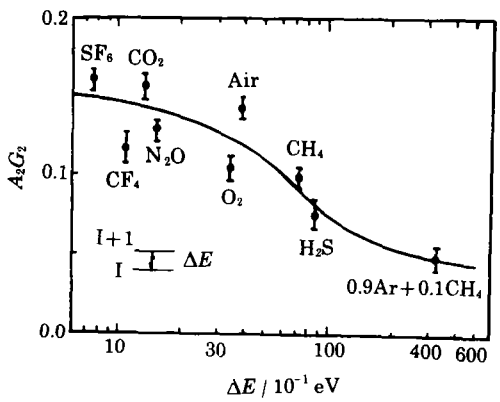

Fig.3 Anisotropy observed after thermolization in 10^5 Pa of different gases, plotted against the rotational excitation energy for each gas

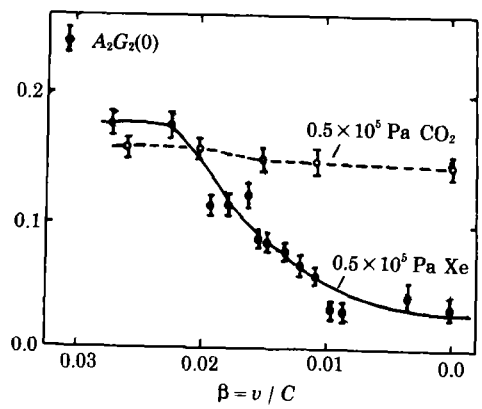

Fig.4 Anisotropy measured in the solid stopper as a function of the velocity when entering the stopper

thermolization. It can be also seen from Fig.4 that very less nuclear alignment is lost during the slowing down process for gases with large moment of inertia, while a large fraction of nuclear alignment is destroyed in monoatomic gas Xe. It is possible that the gases with larger moments of inertia have larger cross sections for collisions with the recoiling nucleus, thereby giving a shorter correlation time for dealignment. The ^{43}Sc nuclei recoil into gas from the Al target foil with the mean charge state of +11 and velocity of $\sim 10^9$ cm/s. They slow down first via charge exchange collision. Because of no hyperfine interaction Sc^{+1} and Sc^{+3} are favorable for preservation of the nuclear alignment. Strong hyperfine interaction destroys the nuclear alignment due to large correlation time. The difference of the electron capture cross section and the electron loss cross section were estimated for Xe and CO_2[4]. The difference is much larger in CO_2 with a large moment of inertia than in monoatomic gas Xe having a very small moment of inertia. Therefore, a plausible assumption can be made that soon after the highly stripped ^{43}Sc ions leave the Al foil, they rapidly attain to lower charge states in CO_2 gas, molecules of which contain more electrons resulting in a

larger moment of inertia and a smaller electro-negativity. The electrons contained in gas with large moment of inertia and small negativity are likely to be taken away easily by the highly stripped moving ions. Therefore, one can say that the charge exchange collision in CO_2 greatly favors the formation of $^{43}Sc^{+1,+3}$. As a result, a larger fraction of initial nuclear alignment is reserved in CO_2. In contrast to the case of CO_2, a large fraction of nuclear alignment is lost during the slowing down process due to strong hyperfine interaction.

No discernible relaxation of the precessing amplitude was observed over the full experimental time window. We also performed the measurement of the dependence of the nuclear alignment on the transverse magnetic field which produces the extranuclear perturbation. No dependence of the nuclear alignment on the applied magnetic field was observed.

In summary, we have studied by the time differential perturbed angular distribution method the nuclear dealignment of recoiling nuclei in different gases. The experimental results show that a large fraction of the initial nuclear alignment can be preserved in the gases with large moments of inertia. These gases can be well used for measurements of nuclear moments of long-lived isomers and for studies of yrast trap and optical pumping. The nuclear dealignment occurs in some gases such as monoatomic gases having very small moments of inertia during the slowing down process of recoils and not after thermolization.

REFERENCES

1 Sprouse G D, Rafailovich M H, Dafni E *et al.* Hyperfine Interactions, 1981; 9:213

2 Browne E, Dairiki J M, Doebler R E *et al.* In: Lederer G M, Shirley V S, eds. Table of isotopes. 7th ed. New York: A Wiley-Interscience Publication, John Wiley and Sons, Inc.

3 Dafni E, Rafailovich M H, Little W A *et al.* Phys Rev, 1981; 23C:90

4 Datz S. Physica Scripta, 1975; 11:149