Bull. Inst. Chem. Res., Kyoto Univ., Vol. 60, No. 2, 1982

A Plunger System for the Recoil-Distance Doppler-Shift Life-Time Measurements of Nuclear Excited States

Toshiyasu HIGO†, Yoshihisa IWASHITA and Seishi MATSUKI

Received March 31, 1982

A plunger system for the recoil-distance Doppler-shift life-time measurements was constructed. The distance between a target and a stopper can be varied by driving a micrometer with a pulsed motor from the outside of a vacuum chamber in a precision of 1 μm. All the system is controlled automatically from a remote station. The system detail, performance and some examples of life-time measurements are presented.

KEY WORDS: Recoil-distance Doppler-shift/ life times of high-spin states/ plunger system/

I. INTRODUCTION

The importance of the electromagnetic transition probabilities of the nuclear excited states to understand nuclear structures has been recognized for a long time. Recently the property of the high-spin states of collective nature has been more and more investigated to discriminate various theoretical models, and thus the life-time measurements for the high-spin states become one of the most important techniques. Radiative life-time of excited nuclear states in the $10^{-15} \sim 10^{-9}$ sec range can be measured by Doppler-shift methods, *i. e.* the recoil distance plunger method (RDDS) and Doppler-shift attenuation method (DSAM).[1)]

The two methods both rely on the Doppler effect, *i. e.*, the shift in energy of a γ-ray when it is emitted from a moving source. In the RDDS, the nuclei excited by a reaction recoil freely in a vacuum untill they are quickly stopped in $\sim$0. 5 psec by a movable stopper. Since the energies of the γ-rays emitted by the stopped and moving nuclei are different, it is possible to know the time the nuclei takes to reach the stopper, and thus to obtain the life-times in the range $10^{-9} \sim 10^{-12}$ sec. The DSAM makes use of the fact that the nuclei recoiling from a nuclear reaction are slowed down in about 0. 5 psec in a solid material, thus the Doppler-shifted energy profile of emitted γ-rays depends on the nuclear life time in the range of $10^{-12} \sim 10^{-15}$ sec.

The development of high-resolution Ge(Li) detectors has brought extensive applications of the RDDS and DSAM techniques to the measurement of nuclear life-time up to $\sim 10^{-15}$ sec.[1)] The Chalk River group[2)] especially developed a method of RDDS technique which is termed now the plunger technique, firstly suggested by A. E. Litherland.[1)]

肥後寿泰, 岩下芳久, 松木征史: Laboratory of Nuclear Reaction, Institute for Chemical Research, Kyoto University.

† present address: National Laboratory for High Energy Physics, Tsukuba, Ibaraki.

In part of series of investigations for the nuclear structure of transitional nuclei around A=70~90 such as even Se, Kr and Sr,[3] we have developed a simple and versatile plunger system to study life-times of collective nuclear excited states. We have particularly measured the life-times of the high-spin states of ^{80}Sr up to the 8^+ in the ground state band with the RDDS and DSAM method.[4] In the present plunger system we used a micrometer in which the position can be read out by an attached optical rotation-encorder with the precision of 1 μm. This system offers an especially simple and still very accurate measuring apparatus for the RDDS method. In this paper the plunger system is described in somewhat detail and the performance of the system is presented and discussed.

II. THE APPARATUS

II. 1. General

An overall view and a schematic diagram of the plunger system are shown in Figs. 1 and 2, respectively.

A stopper frame is mounted on sliding stage of a digimatic micrometer[†] which can be driven by a pulsed motor from the out side of a vacuum chamber. The moved distance

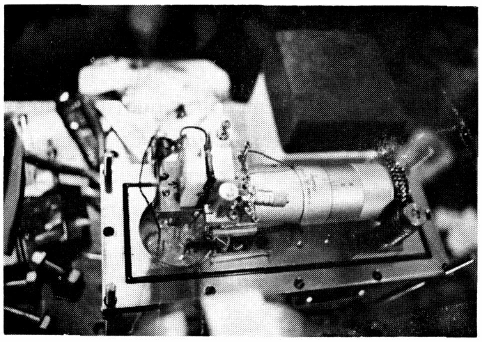

Fig. 1. An overall view of the plunger system.

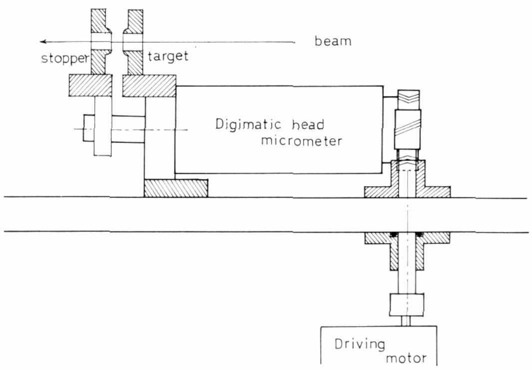

Fig. 2. A schematic view of the present plunger system.

[†] made by Mitsutoyo Seiki Co. Ltd.

of the micrometer can be read out by an optical rotation encorder attached to the micrometer with an accuracy of 1 μm.

A target frame is mounted on a flat stage which is fixed on the base plate of the micrometer. The absolute distance between the target and the stopper is monitored by measuring capacity between them. The vacuum chamber is made of acrylic acid resin to reduce the absorption of emitted γ-rays.

II. 2. Target and stopper assembly

A target foil is mounted on a target frame as shown in Fig. 3. The present method for stretching the target foil is similar to the double stretching technique of Jones et al.[5] The inner ring made of teflon is pushed outside to stretch the foil further with a guide pin thus avoiding mechanical stress to the foil. The whole assembly was made of teflon except a screw for stretching and the flat stage for mounting the assembly. The stopper assembly is almost the same as the target assembly.

The target and the stopper foils are adjusted to be parallel within 0.06 degrees with an Ar laser beam; Firstly the laser beam is reflected from the stopper foil without mounting the target foil and the reflected beam-spot is marked onto a screen which is enough far away (further than 5 m) from the foil to get the accuracy of the parallel adjustment. Then the target assembly is mounted and the laser beam is then reflected by the target foil. The position of the target assembly is then adjusted with two tensioned micrometer adjuster so that the reflected laser-beam spot coincides with the previous spot with the stopper foil reflection. In the actual trial, the spot size of the reflected laser-beam on a screen was about 3 mm in diameter and thus the parallelism between the stopper and the target was estimated to be within 0.06 degrees.

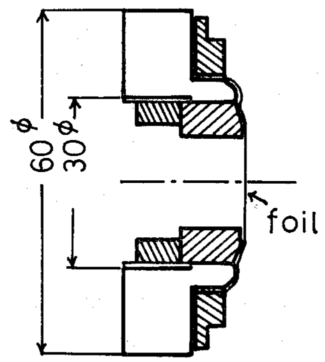

Fig. 3. A target assembly for double-stretching.

II. 3. Capacity measurement

Capacity between the target and stopper foils can be used to know the absolute distance between them. In the present plunger system, the measuring circuit incorporated into a small circuit board was put into the vacuum chamber, near to the target and stopper assembly, thus reducing the effect of unwanted stray capacities. The block diagram of the circuit for the capacity measurement is shown in Fig. 4. The principle

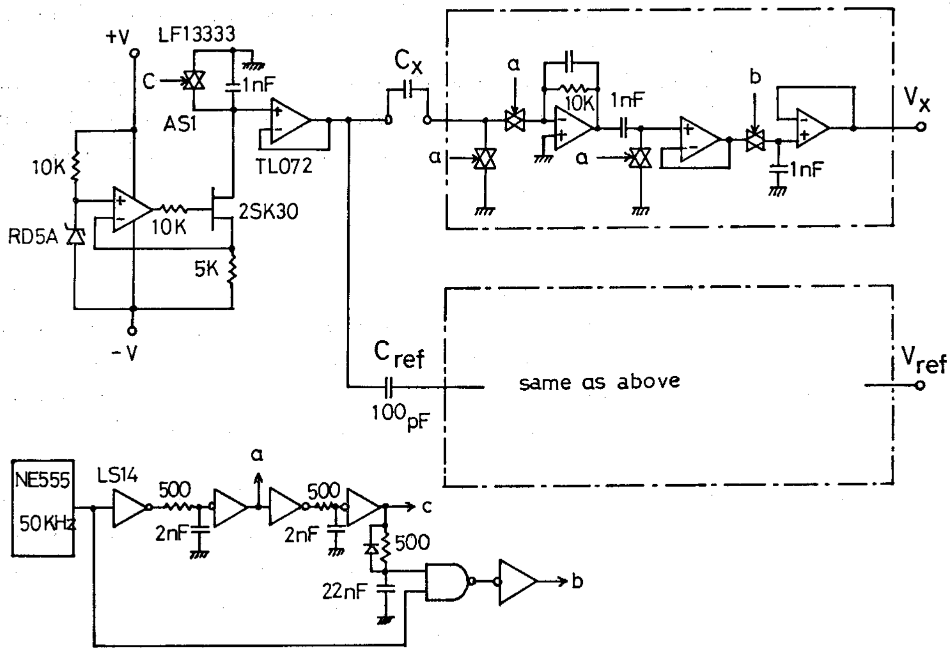

Fig. 4. A schematic blockdiagram of the electronic system for the capacity measurements.

of the circuit operation is as follows; Timing control pulses, a, b and c, of 50 kHz repitition, are produced with a NE 555 (Texas Instruments) timing circuit. Saw-tooth wave of the same repitition rate, produced with a constant current source, a capacitor and an analog switch AS1, is applied to the capacitor C_x, the capacity of which is to be measured. The resulting voltage is sampled and holded (V_x) and then fed to an analog-to-digital-converter (ADC) of $3^1/2$ digit. The output of the ADC is displayed with 7-segment display-tubes in the unit of pF. The capacitor C_x can be replaced by a 100 pF capacitor, thus enabling a test of the accuracy of the whole measuring system.

III. PERFORMANCE

III. 1. Absolute recoil distance

The absolute recoil distance between the target and stopper was determined by the capacity measurements in a case of a ^{66}Zn target foil and a Pb stopper. The target foil of about 3 mg/cm^2 thickness with the backing foil of natural Pb($\sim$1 mg/cm^2) was made with the evaporation method. The stopper thickness was about 30 mg/cm^2. The inverse of the measured capacity, $1/C_x$, is plotted as a function of the micrometer reading with the optical rotation-encorder as shown in Fig. 5. From the extraporation of the linear portion of the plot, the zero point of the distance can be determined in terms of the micrometer reading.

III. 2. Life-time measurements of the $(2_g^+\to0_g^+)$ and $(4_g^+\to2_g^+)$ transitions in the ground state band of ^{80}Sr.

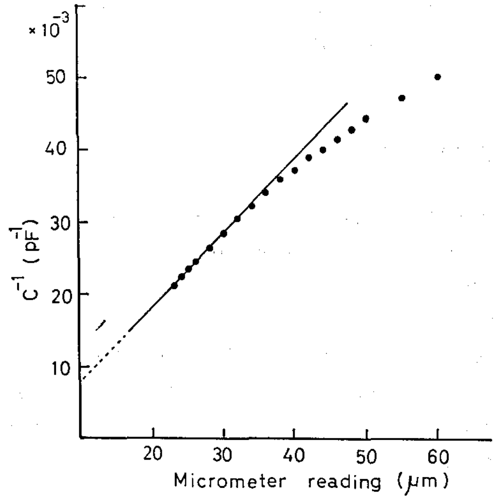

Fig. 5. The inverse of the measured capacity C^{-1} versus the micrometer reading for a ^{66}Zn target and a Pb stopper system.

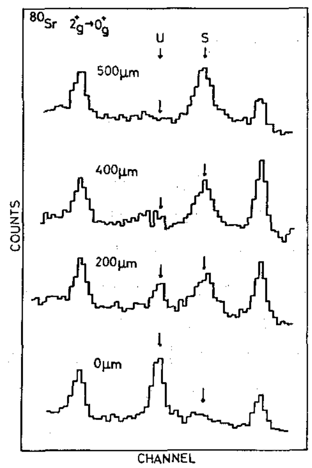

Fig. 6. A portion of the γ-ray spectra in the vicinity of the 385.7 keV $2_g^+ \to 0_g^+$ transition in ^{80}Sr with various recoil distances.

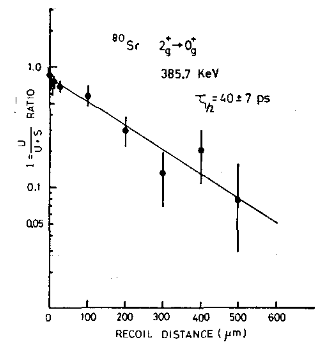

Fig. 7. The ratio I of unshifted versus sum of the shifted and unshifted peak yields for the 385.7 keV $2_g^+ \to 0_g^+$ transition in ^{80}Sr.

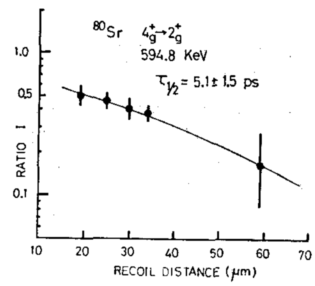

Fig. 8. The ratio I for the 594.8 keV $4_g^+ \to 2_g^+$ transition in ^{80}Sr.

The ^{16}O beam of 55 MeV from the INS SF-cyclotron was used to bombard enriched ^{66}Zn target and γ-rays from the ^{66}Zn(^{16}O, $2n\gamma$)^{80}Sr reaction were measured with a 60 cm^3 Ge(Li) detector at 0° with respect to the beam direction.[5] The target was made by evaporating metalic Zn on natural Pb backing and doubly stretched as described in the preceding section.

Typical γ-rays spectra in the vicinity of 385.7 keV γ-ray corresponding to the ^{80}Sr($2_g^+ \to 0_g^+$) transition are shown with various recoil distances in Fig. 6. The deduced ratio of unshifted peak yield to the sum of unshifted and shifted peaks, $I = U/(U+S)$, is plotted as a function of the target-stopper distance in Fig. 7. After correcting the feeding time from higher excited 4_g^+ state, the resulting life-time of the 385.7 keV 2_g^+ state was determined to be 40 ± 7 psec. This value is in good agreement with the result by Nolte et al.[6] The ratio I for the $4_g^+ \rightarrow 2_g^+$ transition (594.8 keV) is also shown in Fig. 8. Preliminary result of the life-time for this transition is estimated to be 5.1 psec from this ratio.

IV. DISCUSSION

When the ^{16}O beam was on the target in the above mentioned life time measurements, the capacity between the target and stopper slightly increased in short distances. This may be due to thermal expansion of the target and/or stopper. No critical examination of this problem, however, has yet been tried.

The main cause of the finite limit of the close distance between the target and stopper is due to local contacts which may arise from local irregularity of the surface of the foils or from the attaohed dust. It is thus important to refine further the method of stretching the foil in order to get more close distance easily.

ACKNOWLEDGEMENTS

The authors would like to thank Prof. T. Yanabu for his interests and continuous encouragement throughout this work.

REFERENCES

(1) T.K. Alexander and J.S. Forster, in "*Advances in Nuclear Physics*" **10**, 197 (1978) and references cited therein.
(2) T.K. Alexander and K.W. Allen, *Can. J. Phys.* **43**, 1563 (1965).
(3) S. Matsuki *et al.*, *Nucl. Phys.* **A370**, 1 (1981) and references cited therein; T. Higo, S. Matsuki and T. Yanabu, to be published.
(4) T. Higo, T. Shiba, T. Ohsawa, S. Matsuki, K. Ogino and T. Tanabe, to be published.
(5) K.W. Jones, A.Z. Schwerzschild, E.K. Warburton and D.B. Fossan, *Phys. Rev.*, **178**, 1773 (1969).
(6) E. Nolte *et al.*, *Z. Phys.* **26B**, 267 (1974).