Lifetime of the 78-keV Level of ^{32}P†

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A mechanical-recoil method has been used to measure the lifetime of the 78-keV first excited state of ^{32}P. This state was populated near threshold by the $^{29}Si(^4He,p)^{32}P$ reaction, using an enriched $^{29}SiO_2$ target on the down-beam side of a thin copper backing, so that the ^{32}P nuclei recoiled into vacuum. The 78-keV γ rays were detected, after passing the edge of a movable absorber, by a narrow rectangular Ge(Li) detector ($2\times2\times20$ mm). From the exponential curve of count rate vs absorber displacement, a value of $\tau = 402 \pm 13$ psec is found for this level. A similar measurement, using the $^{19}F(^4He,n)^{22}Na$ reaction, gave an upper limit of $\tau \le 26 \pm 6$ psec for the 74-keV $M1$ transition from the 657-keV excited state of ^{22}Na.

INTRODUCTION

A number of previous experiments have established the spins of the ground and first excited states of ^{32}P to be 1^+ and 2^+, respectively.[1] The 78-keV first excited state decays to the ground state by γ-ray emission with a mean life known to be <40 nsec at the start of this work, and from this and the decay energy it may be inferred that the transition is principally $M1$ in character. In order to determine the radiative transition probability between these levels, we have measured the lifetime of the first excited state by means of a mechanical-recoil method[2] and the $^{29}Si(^4He, p)^{32}P$ reaction.

A similar measurement of the $^{19}F(^4He, n)^{22}Na$ reaction permits an upper limit of $\tau \le 26 \pm 6$ psec to be placed on the 74-keV transition from the 657-keV 0^+ state to the 583-keV 1^+ state of ^{22}Na.

EXPERIMENTAL PROCEDURE

To populate the first excited state of ^{32}P, a target of $^{29}SiO_2$, 29-$\mu g/cm^2$ thick and enriched to 95%, was exposed to a beam of 4.52-MeV ^4He particles, produced by the Office of Naval Research–California Institute of Technology tandem accelerator. The $^{29}SiO_2$ was evaporated onto a backing of 150-$\mu g/cm^2$ copper and bombarded through the backing, with a resulting beam energy at the target of 4.46 MeV. This was the energy of the first large resonance for the production of 78-keV γ rays observed in the excitation function for the $^{29}Si(^4He, p)$-^{32}P reaction. [The target thickness was subsequently measured at the 3-MV accelerator by observing the width of the 698-keV resonance in the excitation function for the $^{29}Si(p, \gamma)^{30}P$ reaction.]

The target geometry is illustrated in Fig. 1. The excited ^{32}P nuclei recoiled into vacuum, and if they survived past the absorber edge, the deexcitation γ rays were observed at 90° by means of a narrow Ge(Li) detector, 2-mm wide by 20-mm long and drifted to a depth of 2 mm. The maximum ^{32}P recoil angle was 16.5° at the bombarding energy used. In Fig. 1, the long axis of the counter is perpendicular to the plane of the figure. The γ-ray absorber was composed of 0.19-mm-wall Ta tubing surrounded by a 0.56-mm-wall cast-Sn cylinder. The attenuation of 78-keV γ rays by the Ta was 93%, while that of the Ta-Sn

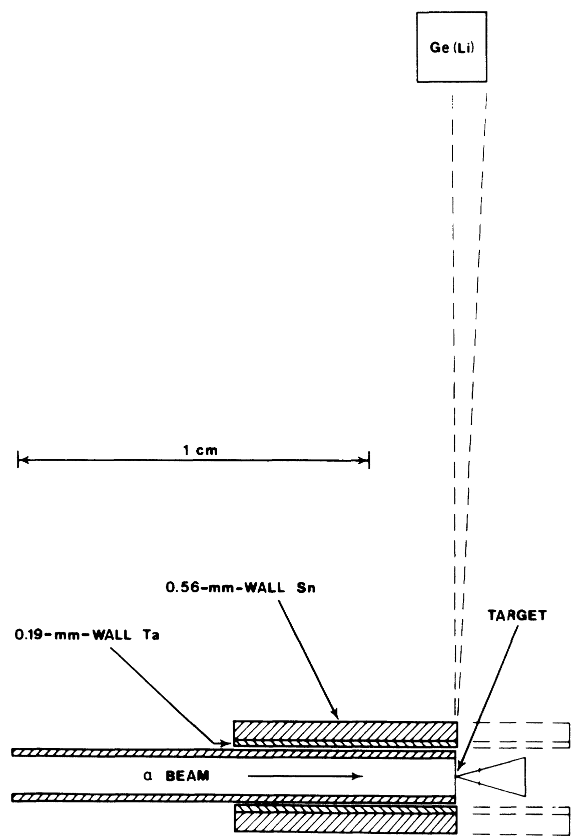

FIG. 1. The target geometry for the recoil-distance lifetime measurements. The triangle downbeam from the target indicates the maximum kinematic recoil angle.

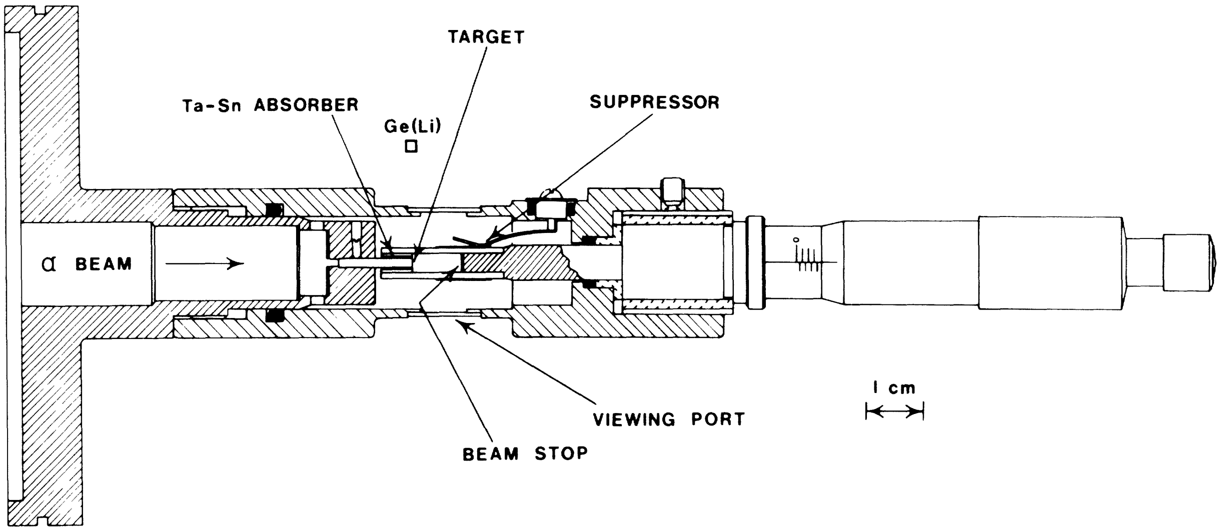

FIG. 2. The complete recoil-distance apparatus.

combination was 98%.

Between successive runs, the target was held fixed and the absorber was advanced by means of a micrometer screw. Since the velocity of the recoils can be deduced, the lifetime measurement reduces to a measurement of the exponential rate of fall of γ-ray yield versus absorber position. The geometrical resolution of the apparatus, using the configuration of target, absorber, and counter as indicated in Fig. 1, was 0.04 mm. The complete assembly is shown in Fig. 2. The ^{4}He beam, typically about 0.4 μA, was collimated prior to entering the stainless-steel tube onto which the target foil was cemented. The Ta-Sn absorber was attached to the micrometer screw by means of a short piece of Pyrex glass tubing, around which was painted a ring of conductive paint, held at a potential of −300 V to serve as an electron suppressor. The beam was stopped by a 0.25-mm-thick copper disk attached to the

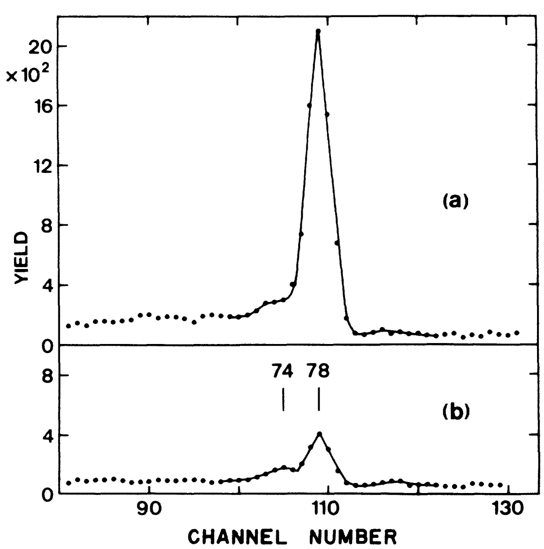

FIG. 3. Two of the ^{32}P γ-ray spectra obtained in the Ge(Li) detector for typical absorber positions. The spectrum (a) illustrates the yield of 78-keV γ rays when there is no attenuation by the absorber, while (b) illustrates the yield when the absorber has been advanced to a position 1.6 mean lives downstream from the target.

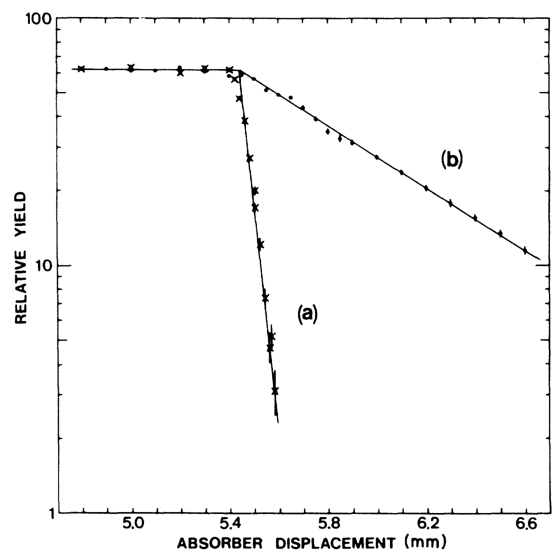

FIG. 4. Relative yield of 78-keV γ rays from ^{32}P versus absorber position. The errors indicated are statistical errors only. The circular data points (b) denote the yield of 78-keV γ rays when the ^{32}P nuclei are permitted to recoil into vacuum, while the crosses (a) denote the yield when the recoils are stopped in a layer of copper. The resolution of the apparatus is found from the mean recoil distance in curve (a) to be 54 μm. The solid lines are least-squares fits to an exponential function.

micrometer end and maintained at a potential of +300 V. The micrometer was insulated from the main apparatus by means of Lucite and epoxy to facilitate beam-current integration.

As a monitor of the target thickness and the current integration, a 7.6-cm by 7.6-cm NaI(Tl) crystal was installed at 90° and 2.5 cm from the beam axis to observe the 2.24-MeV γ rays from the first excited state of ^{32}S produced by the $^{29}Si(^{4}He, n)^{32}S$ reaction.

Essentially the same procedure and geometry were also used with the $^{19}F(^{4}He, n)^{22}Na$ reaction. In this case the target was 50-μg/cm^2 CaF_2 on 0.5-mg/cm^2 Cu foil, and the beam energy was 3.87 MeV. The yield of the 1.27-MeV γ rays from $^{19}F(^{4}He, p)^{22}Ne$ served as monitor.

RESULTS

Two of the ^{32}P γ-ray spectra obtained in the Ge(Li) detector for typical absorber positions are shown in Fig. 3. The resolution of the detector was about 2.5 keV. In addition to the γ-ray peak at 78 keV, there was a small contaminant peak at 74 keV, attributed to the $^{19}F(^{4}He, n)^{22}Na$ reaction on residual fluorine in the Cu beam stop from prior measurements with CaF_2. By comparison with the well-known γ rays from ^{57}Co and ^{241}Am, the energy of the 78-keV transition was determined to be 78.2 ± 0.1 keV.

The results of one series of runs are shown in Fig. 4. The yield of 78-keV γ rays has been corrected for target deterioration by normalizing to the NaI(Tl) monitor-counter yield. It has also been corrected for geometrical effects arising from the nonzero diameter of the absorber cylinder and for its $2 \pm 1\%$ transmission. A least-squares fit with an exponential function gives a mean recoil distance $x_m = 0.70 \pm 0.02$ mm. The data indicated by crosses, which exhibit the position resolution of the apparatus, were taken with a layer of copper, sufficiently thick (600 μg/cm^2) to stop the recoils, evaporated onto the target used in the lifetime run. The resolution of the apparatus is found from the mean recoil distance in curve (a) to be 54 μm. Figures 5 and 6 illustrate similar measurements for the ^{22}Na case, except that no measurement was made for the stopped recoils, and only an upper limit for the lifetime is assigned.

In order to convert the ^{32}P measurements into a lifetime, the mean recoil velocity of the ^{32}P nuclei along the beam direction must be determined. Towards this end, the angular distribution of the proton group populating the 78-keV state was measured in 10° steps from 10 to 150° using the 61-cm-radius magnetic spectrometer with a position-sensitive detector at the focal

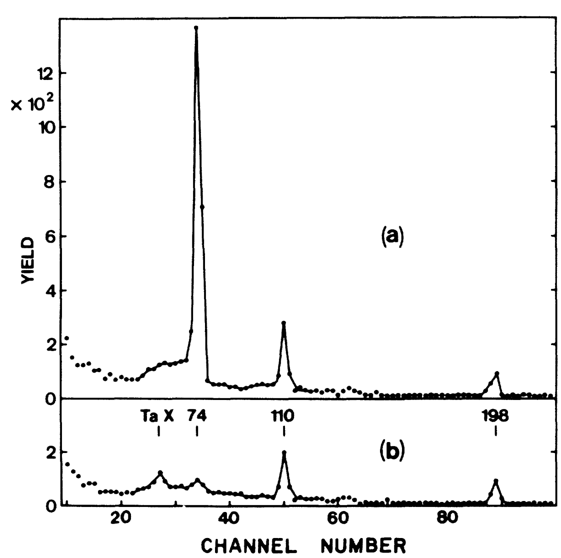

FIG. 5. Typical spectra of the 74-keV γ ray from ^{22}Na, taken at (a) 4.08- and (b) 4.40-mm displacement (see Fig. 6). The peaks in channels 50 and 89 are from $^{19}F(\alpha, \alpha')$.

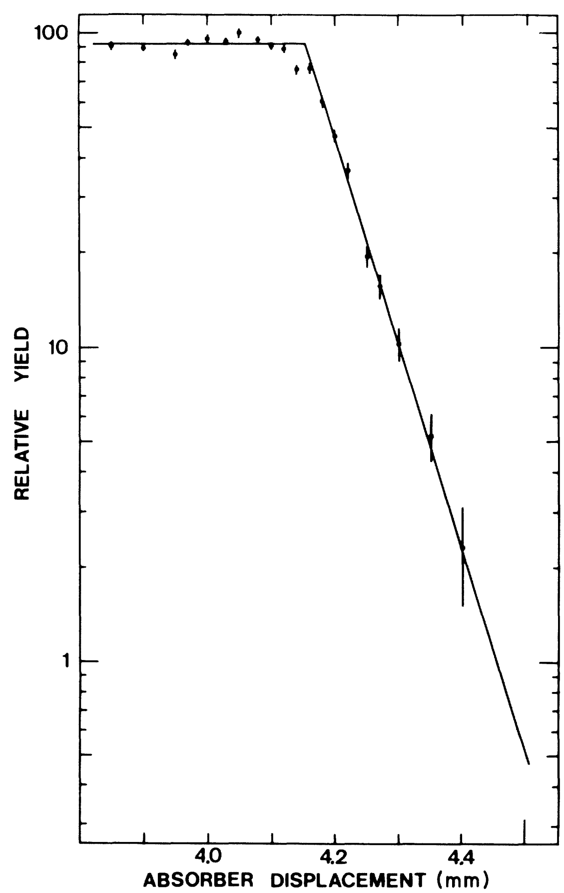

FIG. 6. Relative yield of 74-keV γ rays from ^{22}Na versus absorber displacement.

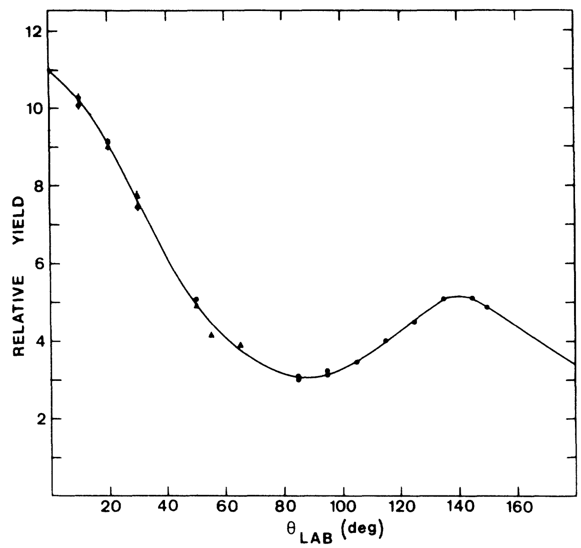

FIG. 7. The angular distribution of protons populating the 78-keV level of ^{32}P by the $^{29}Si(^4He,p)^{32}P$ reaction. The statistical errors are within the size of the data points unless otherwise indicated. The smooth curve shown is that used in deducing the mean recoil velocity for the ^{32}P nuclei. The circular and triangular data points indicate two separate runs.

plane. A NaI(Tl) detector monitored the 2.24-MeV γ radiation from ^{32}S as before. The observed laboratory angular distribution is shown in Fig. 7. From this distribution and the reaction kinematics, the mean recoil velocity of ^{32}P along the beam axis was calculated to be 1.82 ± 0.03 mm/nsec, which is about 1.6% less than the value calculated for an isotropic center-of-mass proton distribution. The uncertainty in the recoil velocity is due principally to uncertainties in the extrapolation of the distribution to 0 and 180°.

The velocity was then corrected, using the methods of Lindhard, Scharff, and Schiøtt,[3] for the mean energy lost by the ^{32}P in leaving the target, amounting to about 10% of their initial energy. The corrected mean recoil velocity for the data of Fig. 4 is $\bar{v}_z = 1.73 \pm 0.04$ mm/nsec.

From the above values, the mean lifetime of the 78-keV state is found to be $\tau = x_m/\bar{v}_z = 405 \pm 15$ psec. A second run with a thinner target yielded a mean distance $x_m = 0.71 \pm 0.04$ mm and a mean recoil velocity $\bar{v}_z = 1.80 \pm 0.03$ mm/nsec, which lead to a lifetime $\tau = 394 \pm 24$ psec. The weighted average of these results is $\tau = 402 \pm 13$ psec. This result is in agreement with the value $\tau = 365 \pm 36$ psec found by Boulter and Prestwich,[4] but disagrees with the value $\tau = 520^{+90}_{-50}$ psec found by Mendelson and Carpenter.[5] Both the above authors used an electronic-timing technique.

The Weisskopf estimate for this lifetime is 67 psec, about $\frac{1}{6}$ of the observed value. Mendelson and Carpenter[5] have calculated a lifetime for this state to be 44 psec, assuming an $M1$ transition between ^{32}P states describable as two j-j coupled nucleons outside closed shells. However, Glaudemans, Endt, and Dieperink[6] have computed the lifetime of this state to be 490 psec, using modified-surface-δ-interaction shell-model calculations and incorporating effective g factors and charges as well as experimental transition energies. This is in fair agreement with the observed value.

For the ^{22}Na case, the data of Fig. 6 show a mean recoil distance of 66 ± 6 μm, which is close to the expected resolution (viz., 54 μm in Fig. 4). Further measurements with this apparatus were not pursued, in view of the successful determination of the lifetime by another method in this laboratory. Thus, using a calculated ^{22}Na mean recoil velocity of 2.1 mm/nsec (for isotropic c.m. neutrons), we cite merely the upper limit $\tau \leq 26 \pm 6$ psec for the lifetime of the 657-keV state. This is consistent with the value 20 ± 3 psec found[7] from a subsequent Doppler-shift-attenuation measurement, and the large $M1$ strength $\Gamma = 4.0\ \Gamma_w$ is compatible with the strength[8] of the analogous Gamow-Teller branch in the β decay of ^{22}Mg, for which $|\int\sigma|^2 = 0.80 \pm 0.08$.

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