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Nuclear Resonance Fluorescence in Te^{122}†

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The mean life of the 564-keV excited state in Te^{122} has been determined by the nuclear-resonance-fluorescence method using a gaseous source of Sb^{122} in the form of antimony trihydride. The value $\tau=(1.05\pm0.16)\times10^{-11}$ sec was obtained for the mean life of the 564-keV state.

I. INTRODUCTION

IN the course of some preliminary measurements in an experimental investigation of the beta-neutrino angular correlation in a first-forbidden nonunique beta decay using nuclear resonance fluorescence, we have measured the mean life of the 564-keV excited state in Te^{122} by the resonance scattering method[1] using a gaseous source of Sb^{122} (half-life 2.8 days). The recoil energy losses accompanying emission and absorption of a gamma ray are compensated by the Doppler shift given to the gamma ray on recoil from the preceding β-ν emission having an end-point energy 1.4 MeV (Fig. 1). The radioactive Sb^{122} was used in a gaseous form, so that the recoil momentum imparted to the nucleus by the β-ν emission was unaltered in the period before gamma emission. The compound used was antimony trihydride (stibine) which has the advantage that it is gaseous around room temperature, and that its molecular weight is only slightly greater than that of the metal.

The cross section for resonance nuclear scattering for the case where direct gamma decay to the ground state is the only mode of de-excitation, is given, for a gamma ray of energy E, as[2]

$$\sigma(E)=\frac{\lambda_0^2}{8\pi}\frac{2J_1+1}{2J_0+1}\frac{\Gamma^2}{(E-E_0)^2+\frac{1}{4}\Gamma^2}, \qquad (1)$$

λ_0 being the wave length for a γ ray of energy E_0 (E_0 is the energy of the nuclear excited state) and J_1 and J_0 being the nuclear spins in the excited and ground states, respectively. Γ is the natural width of the state E_0. Since the incident spectrum stretches to either side of the value E_0, an average cross section σ_{av} for nuclear scattering can be obtained by integrating over the whole spectrum. In this procedure, one has also to take into account, along with $\sigma(E)$, the effect of thermal motion of the nuclei in the scatterer. However, since the width of the γ spectrum is far larger than Γ, the integration can be carried out in a straightforward manner.[2] One

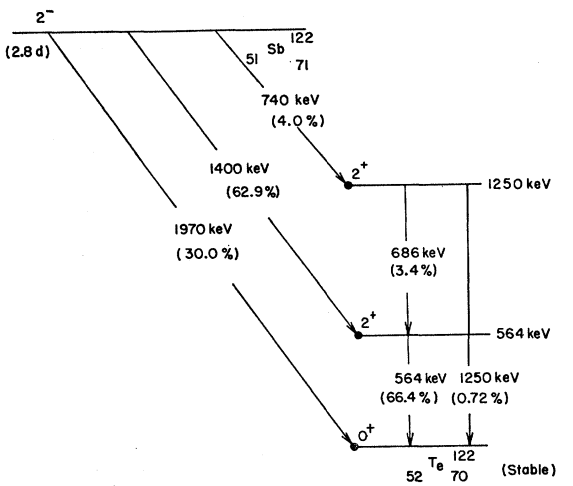

FIG. 1. Decay scheme of Sb^{122} according to *Nuclear Data Sheets* compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington 25, D. C., 1960), NRC 60-4-85. The gamma-ray-intensity values are based on the data published by B. Farrelly, L. Koerts, N. Benezer, R. van Lieshout, and C. S. Wu, Phys. Rev. **99**, 1440 (1955).

† Supported by the National Science Foundation.
[1] F. R. Metzger, Phys. Rev. **110**, 123 (1958).
[2] F. R. Metzger, in *Progress in Nuclear Physics*, edited by O. R. Frisch (Pergamon Press, Inc., New York, 1959), Vol. 7.

then obtains

$$\sigma_{av}=\frac{N(E_0)}{N_{total}}\frac{\lambda_0^2}{8\pi}\frac{2J_1+1}{2J_0+1}2\pi\Gamma, \quad (2)$$

where $N(E_0)$ is the number of gamma rays per unit energy at $E=E_0$. The detailed microspectrum has been worked out for this case by Shubnyi[3] and the value for $N(E_0)/N_{total}$ given as (0.080 ± 0.005) eV^{-1}. This estimate has been obtained assuming that an allowed beta-neutrino angular-correlation form, $W(\theta_{\beta\nu})=1+\lambda(v/c)\cos\theta_{\beta\nu}$, is a valid approximation for the present case of a first forbidden ($2^-\rightarrow 2^+$) transition (Fig. 1). The values $\lambda=+1$, and $\lambda=-\frac{1}{3}$ for the vector and the axial vector interactions, respectively, were applied in deducing the limits of $N(E_0)$. The β-γ angular correlation[4] is expected to have only a minor effect on $N(E_0)$ and has been ignored. Having thus obtained a value of $N(E_0)/N_{total}$, an experimental determination of σ_{av} leads to a value for Γ and hence τ, the mean life of the 564-keV state.

II. EXPERIMENTAL METHOD

1. Source Preparation

The antimony hydride was prepared in a Pyrex apparatus by treating a neutron-irradiated pellet of 98.4% enriched Sb^{121} (10 mg) and Mg(20 mg) in 12% hydrochloric acid at 0°C.[5] The pellet was first produced by induction melting of the metals in a small boron nitride crucible in an atmosphere of hydrogen. Later, it was irradiated for one day in the Oak Ridge Research Reactor at a flux of 2×10^{14} neutrons/cm^{2}sec. Within hours after the irradiation, all radioactivity due to Mg died out. The pellet was then introduced into a bulb of the stibine preparation apparatus, containing frozen acid (Fig. 2). The apparatus was then evacuated and sealed with a flame. Next the acid bulb was warmed to 0°C and the reaction proceeded releasing free hydrogen and stibine. Stibine was condensed and frozen into a second small bulb of the apparatus by cooling this bulb with liquid nitrogen. The hydrogen was then pumped off and the stibine bulb sealed and removed for use.

2. Procedure

In two separate measurements, we prepared gaseous sources of about 16 mCi and 4 mCi, and each time data were collected for approximately 10 h. The pressure inside the bulb was of the order of a tenth of an atmosphere so that the thermal collision frequency was of the order of 10^9/sec. By blowing a jet of nitrogen vapor against the source bulb, the gas was kept at approximately −10°C, to minimize decomposition into antimony metal and free hydrogen. The detector used was a $4\frac{1}{2}$-in. diam×4-in.-long NaI(Tl) scintillation crystal, shielded from the direct gamma rays by an 11-in.-thick lead cone (Fig. 3). Two scatterers, one of natural tellurium containing 2.47% Te^{122} and a comparison scatterer of tin (a material close to Te in atomic number) having almost the same mass and shape were used alternately exchanging at intervals of 10 min. Ten such runs were made with each scatterer. The scattered gamma spectra were analyzed in a 512-channel Nuclear Data analyzer, in groups of 128 channels.

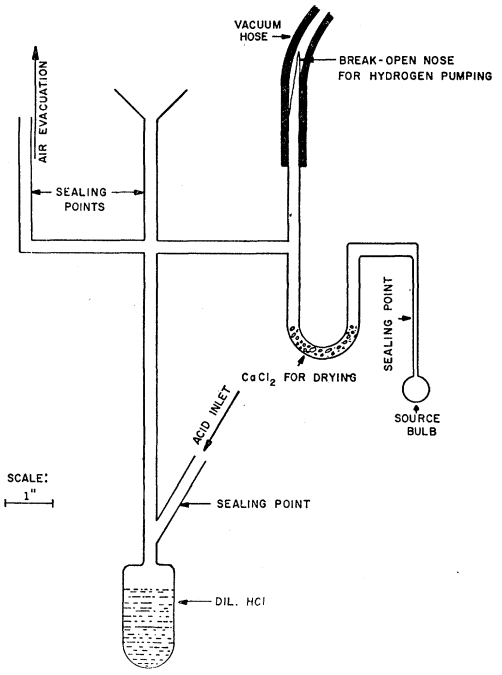

FIG. 2. Apparatus used in preparation of stibine.

An experimental determination of σ_{av} [Eq. (2)] requires taking into account the gaseous source strength, the geometry of the scatterer, the geometry and efficiency of the detector and the electronic absorption and scattering in the scatterer. The effect of selective absorption within the scatterer[1] is found to be small. Direct and separate determinations of the source strength, detector geometry and efficiency were avoided by comparing the resonance fluorescence photopeak with a weighted mean of the photopeaks in the spectra from a weak solid source when placed in positions within the space occupied by the scatterer. The strength of this weak source was determined relative to the gaseous source. The procedure was as follows:

At the end of the runs, the source bulb was broken inside a jar filled with liquid carbon disulfide. The bulk of the gaseous antimony hydride was thus dissolved in the liquid CS_2. The nondissolved activity due to metal

[3] Yu K. Shubnyi, Zh. Eksperim. i. Teor. Fiz. **45**, 460 (1963) [English Transl: Soviet Phys.—JETP **18**, 316 (1964)].
[4] R. M. Steffen, U.S. Atomic Energy Commission Report AECU 4185, 1959 (unpublished), p. 23.
[5] J. W. Mellor, in *A Comprehensive Treatise on Inorganic and Theoretical Chemistry* (Longmans Green and Company, Ltd., London, 1929), Vol. IX.

deposits on the walls of the source bulb from decomposed stibine was collected and the activity was compared to the total activity before the source bulb was broken. The area of the 564-keV photopeak was used for such comparison. Thus, the fraction of the gaseous source that had decomposed during the experiment was known. Also the fraction of the gaseous activity dissolved in the liquid was determined by a similar comparison method. After correction for self-absorption in the liquid, it was found in the case of both mean-life measurements that approximately three-fourths of the nondecomposed gaseous radioactive stibine was dissolved in the carbon disulfide. The liquid carbon disulfide was thoroughly mixed and its volume measured (approximately 200 cm^3 in both cases). A thin solid source of approximately 1/200 the strength of the original gaseous source was prepared and compared to the activity of 1 cm^3 of the CS_2 solution. Therefore, the exact relative strength of the weak solid source with respect to the original gaseous source was known.

A weighted photopeak area was obtained from the photopeaks corresponding to the various positions of the solid source within the space of the scatterer by weighting each photopeak in proportion to the relative contribution to the nuclear resonance photopeak from corresponding volume elements within the Te scatterer. By obtaining the ratio of this weighted photopeak area to the nuclear resonance photopeak area one could eliminate the source strength, photopeak efficiency of the crystal and the geometry of the crystal from the computation of σ_{av}. The electronic absorption of the resonance-scattered γ rays on the return path within

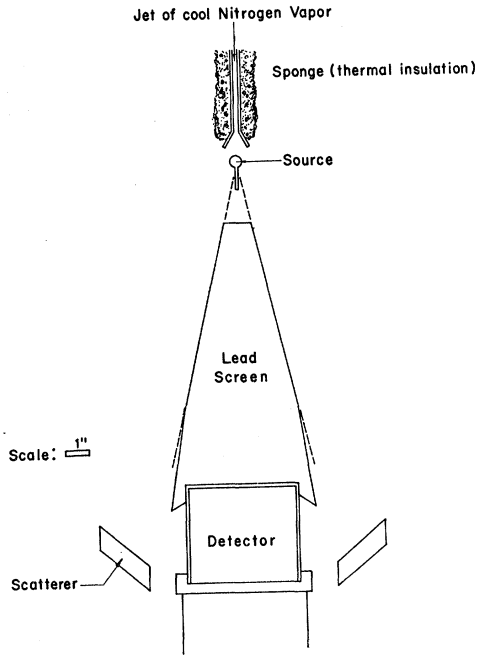

FIG. 3. The nuclear resonance fluorescence apparatus.

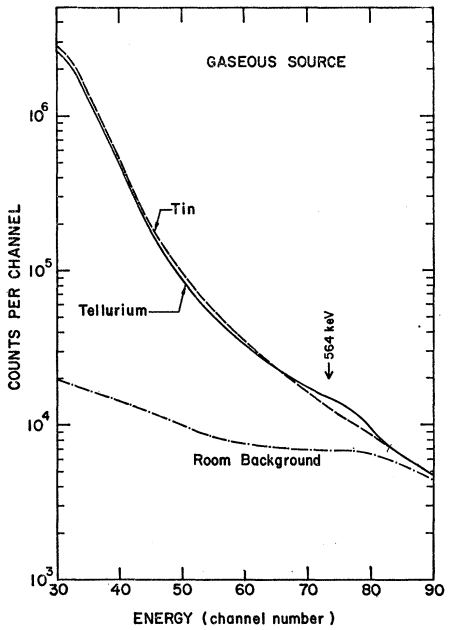

FIG. 4. Uncorrected pulse-height spectra for the gaseous source (second measurement).

the scatterer was determined empirically. For this, corresponding to the various positions at which the weak solid source was placed as above, a second run was made with a layer of tin of known thickness d (measured in g/cm^2) placed just above the source, parallel to the top surface of the scatterer. The thickness d for each such run was equal to the depth of the source position with respect to the top surface of the scatterer. Hence, the required gamma-ray absorption factor for the various scattering elements within the scatterer was obtained from the attenuation of the photopeak area due to the tin layer. The only additional factor to be obtained for evaluating σ_{av} is the solid angle subtended by the scatterer at the source position, which in this setup was simple enough to be easily computed.

III. RESULTS AND DISCUSSION

The spectra obtained with Te and Sn scatterers were identical in shape except for the 564-keV resonance peak in the case of Te (Fig. 4). Subsequently, when a solid source was employed, the two gave nearly identical spectral shapes (Fig. 5). The Sn and Te nonresonant background scattering spectra are expected to be alike but for slight differences in differential scattering cross sections of the γ rays, and in geometry of the scatterers. Both of these factors were taken into account by using the Te and Sn scattering spectra from a solid source for the purpose of normalization (Figs. 6 and 7).

In the first measurement, it was found that 48% of the gaseous source decomposed during the observations. A relatively large error is quoted to account for the un-

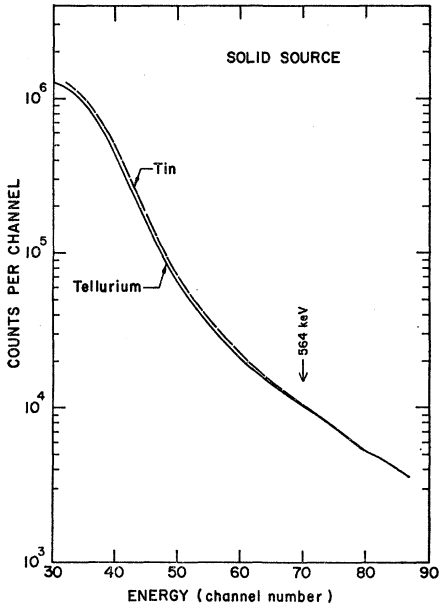

FIG. 5. Uncorrected data for solid source.

certainty in the time dependence of this decomposition during the running period, i.e., the lower and upper limits correspond, respectively, to all the observed de-

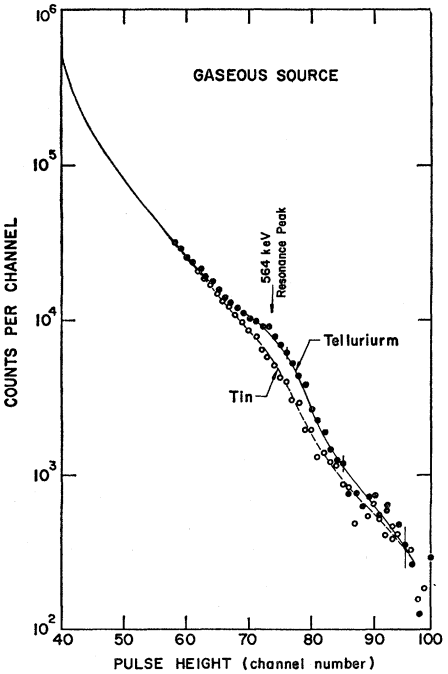

FIG. 6. Gamma-ray spectra, corrected for room background and geometrical effects.

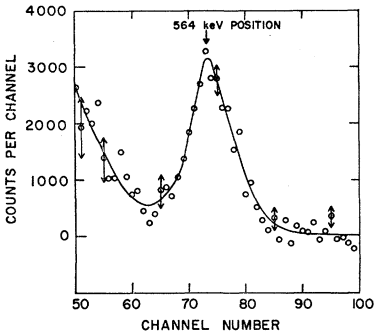

FIG. 7. Resonance-scattered γ spectrum. The position and shape of the peak were identical to a direct 564-keV photopeak of Sb^{122}.

composition occurring before and after taking data. From the first measurement[6] we obtained $\tau=(1.12\pm0.5)\times10^{-11}$ sec for the mean life of the 564-keV state in Te^{122}. The second measurement gave $\tau=(1.04\pm0.17)\times10^{-11}$ sec. Here the percentage error attributed to the experimental uncertainty is less owing to the smaller decomposition (only 8%) of the gaseous source during the experiment. The weighted mean value of the two measurements is $\tau=(1.05\pm0.16)\times10^{-11}$ sec. Also, σ_{av} was found to be $(0.30\pm0.05)\times10^{-24}$ cm^2. These values are consistent with earlier published results. On the basis of Coulomb excitation measurements, Temmer and Heydenberg[7] reported $\tau=1.4\times10^{-11}$ sec, and Stelson and McGowan[8] reported $\tau=1.1\times10^{-11}$ sec. Other values, namely, $\tau=(1.2\pm0.3)\times10^{-11}$ sec and $\tau=(1.32\pm0.33)\times10^{-11}$ sec were quoted by Shubnyi[3] and Zimmerman,[9] respectively, from nuclear resonance fluorescence measurements. It should be pointed out that in the present work, a more prominent nuclear resonance effect as well as a higher counting rate per mCi source were achieved because of more favorable geometry.

ACKNOWLEDGMENTS

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[6] The value, $\tau=(6.1\pm2.5)\times10^{-12}$ sec previously quoted by the author in Bull. Am. Phys. Soc. **9**, 499 (1964) was based on this first measurement, and was incorrect due to error in calculation.

[7] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **104**, 967 (1956).

[8] P. H. Stelson and F. K. McGowan, Oak Ridge National Laboratory Report, ORNL 2610, 1958 (unpublished), p. 11.

[9] W. Zimmerman, Ann. Physik **12**, 45 (1963).