LIFETIME MEASUREMENTS IN Sb^{121}

By M. K. Ramaswamy, F.A.Sc.

(Department of Physics, Karnatak University, Dharwar-3)

AND

B. A. Bishara

(Ohio State University, Columbus, O)

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Abstract

Employing delayed coincidence techniques lifetime measurements have been carried out in the decay of Te^{121} to decide between two alternative level schemes for Sb^{121}. Our results support the scheme proposed by Gupta which consists of excited levels in Sb^{121} at 70 and 576 KeV.

1. Introduction

The 17-day ground state of Te^{121} is known[1,2] to decay by electron capture to excited states of Sb^{121}, giving rise to electromagnetic transitions of 576, 506 and 70 KeV; the latter two are in coincidence. Excited states of Sb^{121} have been placed at 506 and 576 KeV[3] as shown in Fig. 1 *a*.

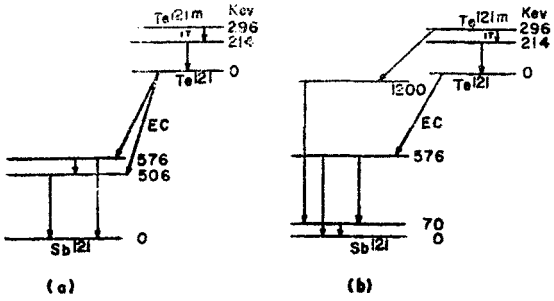

Fig. 1. The decay scheme of Te^{121}.

It was pointed out by Wapstra [4] from an examination of the systematics of the occurrence of $d_{5/2}$ and $g_{7/2}$ levels in isotopes of Sb and I that there may be a level at 70 KeV in the case of Sb_{121}. Recent coincidence studies by Gupta[5,6] suggest excited states at 70 and 576 KeV, *i.e.*, the 576 KeV level decays by 576 and 506 KeV gamma-rays to the ground state and the 70 KeV excited state respectively, as shown in Fig. 1 *b*. In addition, a level at 1200 KeV

populated from the decay of the 154-day isomeric state of Te^{121} was also proposed, the level de-exciting by an 1130 KeV gamma-ray *via* the 70 KeV level.

It is the object of the present investigation to establish the correct decay scheme by measuring the half-life of the different excited states. If the first decay scheme (Fig. 1 *a*) is correct, the lifetime of the 576 and 70 KeV transitions must necessarily be the same since they both originate from the same initial state, while the lifetime of the 506 KeV should be different. Alternately, if the second decay scheme (Fig. 1 *b*) is correct, the lifetime of the 576 and 506 KeV transitions must be the same, while that of the 70 Kev transition might well be measurably longer.

2. SOURCE PREPARATION AND EXPERIMENTAL RESULTS

Natural antimony, consisting of 57 per cent. Sb^{121} and 43 per cent. Sb^{121}, was bombarded with 6 MeV protons from the Ohio State University cyclotron. The tellurium isotopes of mass 121 and 123 ground state and isomeric state were produced.

The single gamma-ray spectrum was measured with a cylindrical NaI (Tl) crystal (1 inch diameter, and 2 inch height) optically coupled to an EMI 9536 B photomultiplier by means of silicone grease. A typical observed spectrum is shown in Fig. 2. The gamma-spectra from sources of Ba^{133}

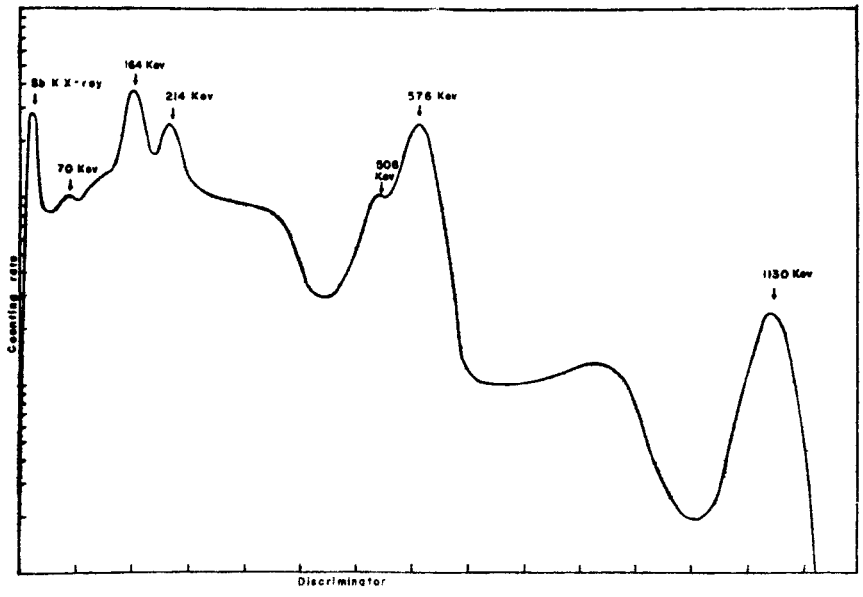

FIG. 2. Single gamma-ray spectrum of Te^{121} source.

(80 and 358 KeV), Na^{22} (1276 and 511 KeV), and Hg^{203} (74 and 280 KeV) were used for energy calibration; and from this the energies of the photopeaks shown in Fig. 2 could be assigned. One notes in addition to the Sb-K-X-ray that gamma-rays at 70, 164, 214, 506 and 1130 KeV are present. By following the half-life of the various photopeaks for about fifty days, the 70, 506 and 576 KeV gamma-rays could be attributed to the Te^{121} ground state decay; the 214 and 1130 KeV gamma-rays to the decay of the metastable state of Te^{121}; and the 164 KeV gamma-ray to the decay of the metastable state of Te^{123}.

Table I lists the various gamma-rays and their relative intensities determined after taking into account the variation of efficiency with energy and peak to total ratio, which have been empirically measured for the NaI crystal used in this study. It should be noted that the intensity of the 1130 KeV gamma-ray was different in the various sources which were prepared.

TABLE I

The relative intensity of γ-rays

γ-ray energy (KeV)	Intensity
70	1·5
214	5·3
506	21
576	100
1130	not constant

The gamma-gamma coincidences were measured by a conventional fast-slow coincidence circuit (Fig. 3) using two NaI (Tl) 1 inch by 2 inch scintillation detectors in both channels. The resolving time of the circuit (2τ) was about 16 nano-seconds.

To determine the " prompt " coincidence curve of the apparatus used, the annihilation radiation of Na^{22} is used and the 511–511 KeV prompt coincidence curve is measured (*see* Fig. 5). Upon comparing the slope of Fig. 4 with the prompt coincidence curve of Fig. 5 it is found that the two slopes are indistinguishable, which means that the decay of the 576 KeV state is " prompt " and the half-life is less than $1{\cdot}5\times10^{-9}$ seconds.

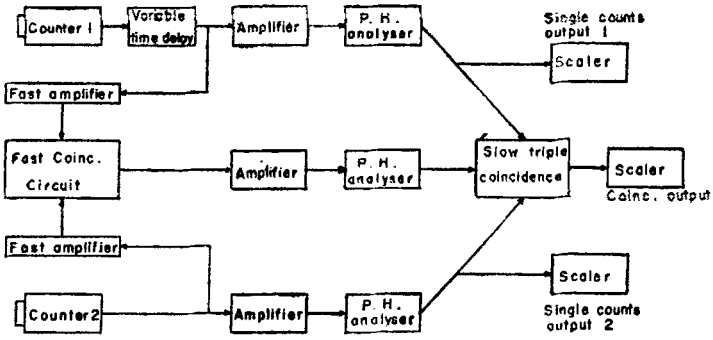

FIG. 3. Block diagram of experimental set-up indicating the electronic circuitry used.

The gamma-gamma coincidence results are essentially in agreement with the results of Gupta [6]; namely that both 506 and 1130 KeV gamma-rays are in coincidence with the 70 KeV gamma-ray and with the Sb-K-X-ray, while the 576 KeV gamma-ray is in coincidence only with the Sb-K-X-ray.

3. LIFETIME MEASUREMENTS

The half-lives of the excited states of Sb^{121} are measured by the delayed coincidence method,[7] using the fast-slow coincidence circuit shown in block diagram form in Fig. 3. By means of delay cables one could insert the desired additional delay (in units of 10^{-1} sec.) in one channel before the pulses are impressed in the coincidence circuit.

(*a*) *The half-life of the 576 KeV state.*—To measure the half-life of the 576 KeV state, counter No. 1 is set on the Sb-K-X-ray, while counter No. 2 is set on the 576 KeV photopeak (care being taken to exclude the unresolved 506 KeV gamma-ray). The X-ray pulses are delayed by a known time, and the coincidence counting rate is observed. The curve showing the coincidence counting rate as a function of delay is shown in Fig. 4.

The asymmetry of the curve in the X-ray side is a purely instrumental consequence of the low energy (28 KeV) of the X-ray radiation; it diminishes at higher energies.

(*b*) *The half-life of the 576 KeV state.*—The same experiment is repeated with the counter No. 1 set on the Sb-K-X-ray and counter No. 2 set on the 506 KeV photopeak. The curve obtained is also shown in Fig. 4; it is evident from the figure that the 506 KeV state is essentially prompt and its half-life is also less than $1{\cdot}5\times10^{-9}$ seconds.

In order to make sure that these results are correct, the same experiment was repeated with the counter No. 2 set on both the 506 and 576 KeV photo-

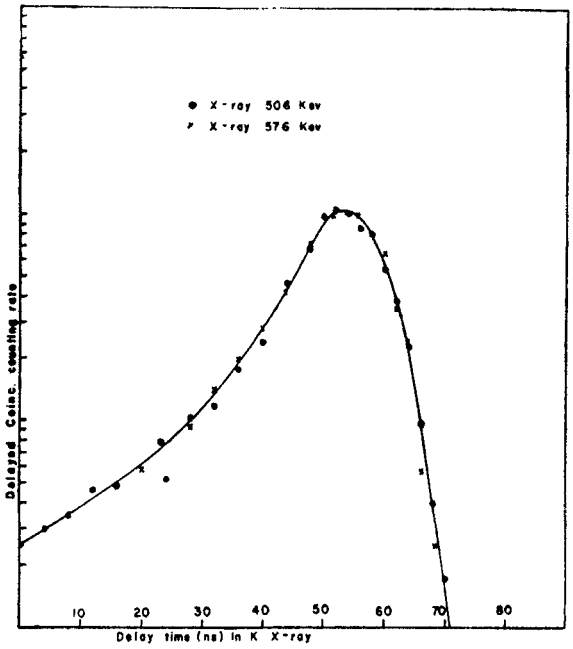

FIG. 4. Delayed coincidence curve with Te^{121}.

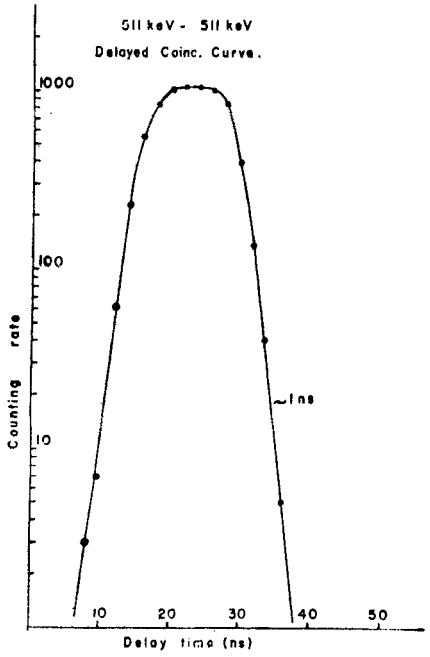

FIG. 5. Delayed coincidence curve using Na^{22} annihilation photon

peaks, if both really have a prompt lifetime, the curve obtained should have one slope; while if one does not have a prompt lifetime, the curve obtained should have two slopes.

The delayed coincidence curve of both the 506 and 576 KeV gamma-rays is shown in Fig. 6; it is observed to have only one slope, the same as that of Fig. 4. This result assures that both the 506 and 576 KeV gamma-rays are prompt transitions.

(*c*) *The half-life of the* 70 *KeV state.*—The 79 KeV level of Cs^{133} which has a half-life of 6×10^{-9} seconds[2], is used to calibrate the apparatus. Counter No. 1 is set on the 360 KeV gamma-ray (with the delay time inserted in this side), while counter No. 2 is set on the 79 KeV photopeak. The delayed coincidence curve of the 79 KeV level is measured (*see* Fig. 7) and it is found from the slope obtained that the half-life is $(6 \pm \cdot 5)\times10^{-9}$ seconds, which is in a good agreement with the previously reported value.

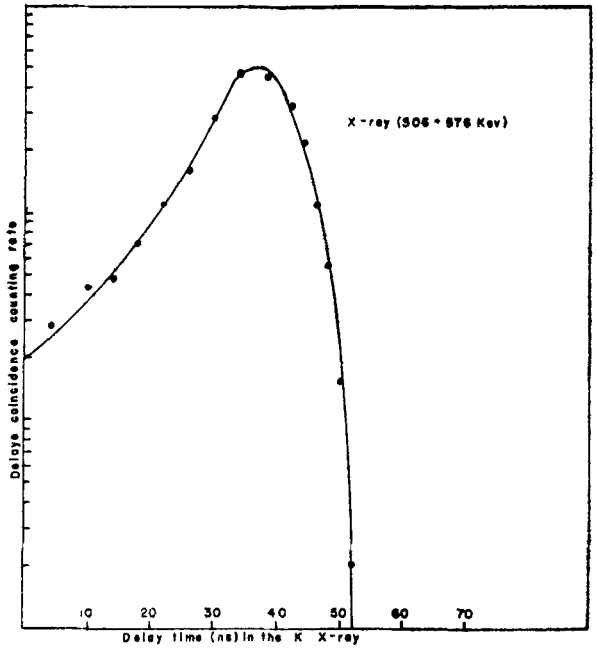

FIG. 6. **Delayed coincidence curve with Te^{131}.**

To measure the half-life of the 70 KeV gamma-ray counter No. 1 is set on the 506 KeV photopeak while counter No. 2 is set on the 70 KeV photopeak (care being taken to exclude the X-ray). The 506 KeV pulses are delayed, and

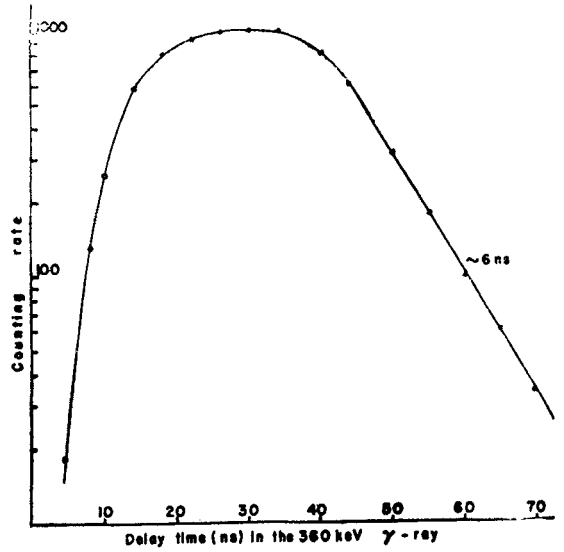

FIG. 7. Delayed coincidence curve for the 360-79 KeV gamma-cascade in Cs^{133}

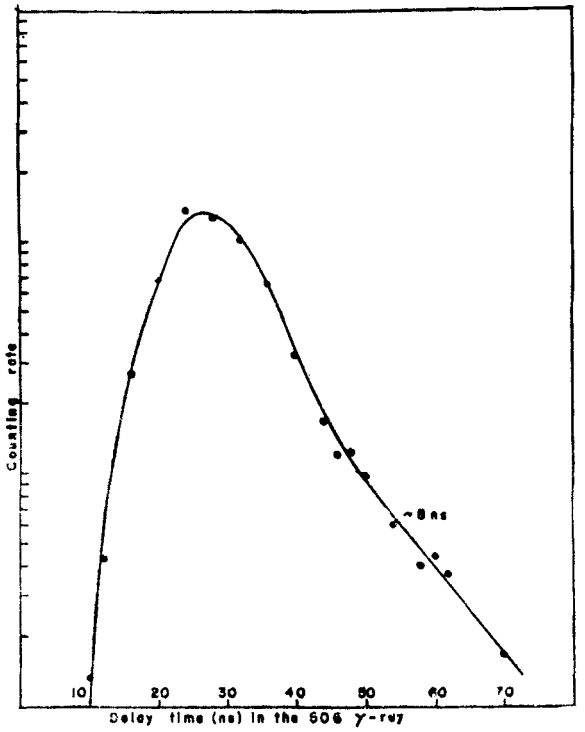

FIG. 8. Delayed coincidence curve with Te^{121} indicating the lifetime of the 70 KeV level

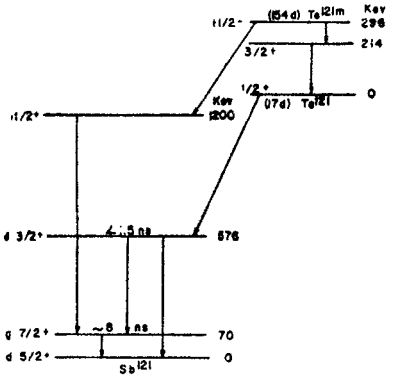

FIG. 9. Level scheme of Sb^{121} following this work.

the coincidence counting rate is observed. The delayed coincidence curve obtained is shown in Fig. 8; the half-life of the 70 KeV transition read from the slope of the curve is approximately 8×10^{-9} seconds.

The half-life of the 70 KeV gamma-ray is estimated to be $(8\pm1\cdot5)\times10^{-9}$ seconds, the error being largely due to calibration difficulties.

4. RESULTS AND DISCUSSION

The gamma-gamma coincidence experiments have confirmed the results of Gupta,[6] namely that both the 506 and the 576 KeV gamma-rays are in coincidence with the Sb-K-X-ray, but not in coincidence with each other; also that the 70 KeV gamma-ray is in coincidence with both the 506 KeV and the 1130 KeV gamma-rays, while it is not in coincidence with the 576 KeV gamma-ray.

The lifetime measurements, by the delayed coincidence method, showed that both the 576 KeV gamma-ray and the 506 KeV gamma-ray exhibit prompt decay (half-life less than $1\cdot5\times10^{-9}$ seconds), while the 70 KeV gamma-ray exhibits a longer half-life of $(8\pm1\cdot5)\times10^{-9}$ seconds.

These results contradict the decay scheme of Fig. 1 *a* which suggests that the 70 KeV and the 576 KeV gamma-rays should have the same lifetime.

The fact that the 576 KeV gamma-ray and the 506 KeV gamma-ray have half-lives shorter than $1\cdot5\times10^{-9}$ seconds, while the 70 KeV gamma-ray's half-life is $(8\pm1\cdot5)\times10^{-9}$ seconds, makes it likely that both the 576 and the 506 KeV gamma-rays originate from the same parent-excited state, while the 70 KeV gamma-ray originates from a different excited state. This is in agreement with the decay scheme suggested by Gupta[6] (*see* Fig. 1 *b*).

Figure 9 shows the decay scheme of Te^{121} resulting from the present work, together with spins and parities previously assigned[6] to the different states.

Considering that the Sb^{121} nucleus has 51 protons, *i.e.*, a single proton outside a closed shell of 50, the validity of the shell model can be assumed in this case. Using the order of energy states of the shell model, and the spins and parities previously assigned, a discussion could be carried on to assign the *l*-value of the various states of Sb^{121}, in a fashion consistent with the experimental results.

(*a*) *The ground state of* Sb^{121}.—The measured spin for the ground state of Sb^{121} is 5/2 and the parity is +. According to the shell model, in *l*-value equal to 2 could be assigned, *i.e.*, it is $d_{5/2}$ state.

(*b*) *The 70 KeV state.*—The spin and parity assigned to the 70 KeV state are 7/2+ from systematics. Since there is no change in parity, and the change in the angular momentum ∇ J = 1; the transition can be M1 or E2 or (M1 + E2).

Assuming that it is an M1 transition, the transition probability can be calculated from the single-particle formula[8]:

$$\lambda_j = (2{\cdot}8\times10^{13})\ E_j^{3}\ S\ \text{sec.}^{-1}$$

where E_j is the energy of the gamma-ray in MeV, and S is the statistical factor, which equals 9/7 in this case,

S (7/2→5/2)=9/7, *see* Ref. 8

The use of the single-particle formula may be justified here because we are dealing with the transition of a single proton outside of a closed shell. Then we get from the formula that $\lambda = \lambda_j\,(1 + \alpha_t) = (1{\cdot}23\times10^{10})\ (1 + 1{\cdot}587)$ $= 3{\cdot}2\times10^{10}$, sec.$^{-1}$ The half-life $T_{1/2} = 0{\cdot}693/\lambda_t = 0{\cdot}693/3{\cdot}2\times10^{10}$.

$$T_{1/2} = 2{\cdot}17\times10^{-11}\ \text{Sec. for M1 transition.}$$

It should be noted that the measured value of $T_{1/2}$ is about (365 $\pm$ 65) times larger than the calculated value under the assumption of no E2 admixture. The larger value of the measured half-life could be explaind if it is assumed that it is an *l*-forbidden M1 transition, where retardation factors of this order of magnitude are quite common.[9]

On the other hand, if the 70 KeV transition is assumed to be an E2 transition, the transition probability λ_j could be calculated from the single-particle formula: λ_j in sec.$^{-1}$ $= (1{\cdot}6\times10^{8})\ A^{4/3}\ E_j^{5}\ S$

where A is the atomic weight.

$$\lambda_j = (1\cdot6\times10^8)\ (121)^{4/3}\ (0\cdot070)^5\ 9/7$$
$$= 2\cdot08\times10^5\ \text{sec.}^{-1}$$

and

$$\lambda_t = (2\cdot08\times10^5)\ (1+1\cdot587)$$
$$= 5\cdot4\times10^5\ \text{sec.}^{-1}$$

thus

$$T_{1/2} = 1\cdot28\times10^{-6}\ \text{sec. for E2 transition.}$$

Here the calculated value of $T_{1/2}$ for E2 transition is (160 ± 25) times larger than the measured value.

The 70 KeV transition might well be a mixture of M1 and E2 transition; angular correlation measurements or nuclear alignment experiments are needed to determine the mixture of M1, E2.

(*c*) *The 576 KeV state.*—From angular correlation measurements in Te^{121m} the ground state of Te^{121} is known to be $S_{1/2}$ state. If we assume that the S_{112} ground state of Te^{121} decays 100 per cent. of the time to the 576 KeV excited state of Sb^{121}, which is assigned an angular momentum $3/2+$[6] from the study of systematics, the log *ft* value for the electron capture branch to the 576 KeV level—assuming the value of decay energy (Te^{121} Sb^{121}) from Way and Wood's estimate to be 1300 KeV—is approximately 6·7. Since $\triangle J = 1$ and there is no parity change, the transition is allowed; and since log *ft* is approximately 6·7, this suggests that it is probably an *l*-forbidden transition ($\triangle l = 2$). Then the *l*-value for the 576 KeV level could be set equal to 2, *i.e.*, it is a $d_{3/2}$ state.

Assuming that the 576 KeV state decays by a 576 KeV gamma-ray to the ground state, and by a 506 KeV gamma-ray to the 70 KeV level, we can calculate its lifetime.

The 576 KeV transition is M1 or E2 transition, since there is no change in parity and $\triangle J = 1$. For simplicity, we assume that it is a pure M1 transition, and use the single-particle formula:

$$\lambda_j = (2\cdot8\times10^{13})\ E_j^3\ S\ \text{sec.}^{-1}$$

where

$$E_j = 0\cdot576\ \text{MeV, and } S\ (3/2\rightarrow5/2) = 9/5^9$$

thus

$$\lambda_j = (2{\cdot}8\times10^{13})\ (0{\cdot}576)^8\ (9/5)$$
$$= 9{\cdot}54\times10^{12}\ \text{sec.}^{-1}$$
$$\lambda_t = (1+\alpha_t) = (9{\cdot}54\times10^{12})\ (1+0{\cdot}018)$$
$$= 9{\cdot}7\times10^{12}\ \text{sec.}^{-1}$$

The 506 KeV transition is E2 or M3 transition since there is no change in parity and $\triangle J = 2$. For simplicity, we assume that it is a pure E2 transition and use the single-particle formula for the E2 transition.

$$\lambda_j = (1{\cdot}6\times10^{8})\ A^{4/3}\ E_j^{5}\ S$$

where

$$S\ (3/2\rightarrow 7/2) = 18/7$$
$$= 8{\cdot}1\times10^{9}\ \text{sec.}^{-1}$$

If we take into consideration that the intensity of the 576 KeV transition is about five times larger than the intensity of the 506 KeV transition (*see* Table I), the average of the transition probability of the 576 KeV level would be about $8{\cdot}2\times10^{12}$ sec.$^{-1}$, and the calculated half-life of the 576 KeV state would be

$$T_{1/2} = 0{\cdot}693/\lambda = 8{\cdot}45\times10^{-14}\ \text{sec.}$$

This is a rough estimation of the half-life of this state because it is carried out under the assumption that the 576 KeV level is pure M1 transition while it actually could be a mixture of M1 and E2; also the 506 KeV transition is assumed to be pure E2 transition while it could be a mixture of E2 and M3. Angular correlation measurements are needed to determine the percentage of mixture in each case in order to make a better calculation of the half-life of this state.

5. Acknowledgments

One of us (M. K. R.) wishes to express his grateful thanks to Professor P. S. Jastram of Ohio State University for his hospitality.

6. References

1. Goldhaber, M. and Hill, R. D. *Revs. Mod. Phys.*, 1954, **26**, 321.

2. Strominger, D. and Hollander, J. M. *Nuclear Decay Schemes*, 1958, UCRL-8289.

3. Bhatki, K. S., Gupta, R. K., Jha, S. and Madan, B. K. — *Nuovo Cimento*, 1957, **6**, 1461.
4. Wapstra, A. H. .. *Physica*, 1953, **19**, 671.
5. Gupta, R. K., Jha, S. and Madan, B. K. — *Nuovo Cimento*, 1958, **9**, 1117.
6. Gupta, R. K. .. *Ibid.*, 1960, **17**, 665.
7. Bell, R. E. and Malmfors, G. — In *Beta and Gamma-ray Spectroscopy*, Ed. : Siegbahn, North Holland Publishing Co., 1955.
8. Moszkowski, S. A. .. Ch. 13 in *Beta and Gamma-ray Spectroscopy*, 1955.
9. Ramaswamy, M. K. — *Nuovo Cimento*, 1963, **27**, 1116.