Properties of Low-Lying Levels in Sb^{121}†

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(Received 10 July 1963)

Resonance fluorescence in Sb^{121} has been observed with Te^{121} as the source of the exciting gamma radiation. A comparison of the pulse-height distribution of the resonance scattered radiation with that of the incident radiation showed unambiguously that the 506- and the 576-keV gamma rays emitted in the decay of 17-day Te^{121} are the ground-state transitions from two separate levels in Sb^{121}. The angular distribution of the resonance radiation was studied with the resonant gamma rays from a gaseous source of Te^{121}. On the basis of this angular distribution, the most probable spin assignments are $\frac{3}{2}$ for the 506-keV level, and $\frac{1}{2}$ for the 576-keV level. The transition probabilities of these levels were determined using the centrifuge method of compensating for the recoil energy losses. Assuming a branching of $\Gamma_0/\Gamma=0.96$, the partial width for the 576-keV $E2$ transition was found to be $\Gamma_0(576)=(5.4\pm0.6)\times10^{-5}$ eV. For the mixed $M1+E2$ 506-keV transition, using $\Gamma_0/\Gamma=0.90$, the partial width was determined to be $\Gamma_0(506)=(2.2\pm0.2)\times10^{-4}$ eV. While the single-particle model predicts the observed spin sequence, it fails to account for the observed transition probabilities. Wave functions obtained recently by Kisslinger and Sorensen, and representing a combination of quasiparticle and phonon excitations, predict the observed transition probabilities rather well.

I. INTRODUCTION

OUR knowledge of the position and the properties of the excited states of Sb^{121} is rather poor. There is general agreement that a 506–70-keV γ-γ cascade is present in the decay of 17-day Te^{121}. Based on the systematic trend[1] of the $g_{7/2}$ level in neighboring nuclei, several authors[2–4] placed the 70-keV level near the ground state of Sb^{121}. This scheme obtained further encouragement through the observation[3,5] of 1130–70 keV coincidences following the decay of the 154-day isomer of Te^{121}. On the other hand, this level sequence was somewhat unsatisfactory because the intensity of the 70-keV radiation appeared[3,5,6] to be considerably smaller than the intensity of the 506-keV transition populating the suggested 70-keV level. This difficulty was avoided by a scheme[7] which, ignoring the 1130–70 keV coincidences, featured levels in Sb^{121} at 506- and 576-keV excitation energy. The additional objection to this solution, namely the absence of a low-lying state in Sb^{121}, has been eliminated by a very recent study[8] of the 154-day isomer, in which evidence for a 37-keV first excited state in Sb^{121} has been obtained.

Coulomb excitation experiments and/or resonance fluorescence studies could easily distinguish between the two schemes mentioned above. The only Coulomb excitation experiments reported to date,[9] carried out on separated Sb^{121} with 5.2-MeV alpha particles, did not reveal any radiation which could be conclusively attributed to that isotope. This in itself was surprising since the spin of the Te^{121} ground state is most probably[10] $\frac{1}{2}$, and consequently the spin(s) of the excited state(s) fed in the 17-day decay are smaller than $\frac{5}{2}$, making the ground-state transition(s) dipole or quadrupole.

Resonance fluorescence experiments had not been performed with Sb^{121}. Recent advances in rotor design and in rotor materials have brought even the 576-keV transition in Sb^{121} into the range of the centrifuge method, i.e., the resonance fluorescence method using mechanical motion as the means of producing a sufficiently large Doppler shift. An estimate[4] of the electron capture energy of 17-day Te^{121} made it probable that the neutrino recoil would also be sufficient to compensate for the gamma recoil energy losses. On the basis of this favorable information it was decided to study the resonance fluorescence from the Sb^{121} levels.[11]

The centrifuge method was used for the determination of the level widths, the gaseous source method (neutrino recoil) for the investigation of the angular distribution of the resonance radiation. This division of labor was chosen because, with the limited activity available, the low counting rates observed with the centrifuge would not have allowed good statistics for the angular distribution study. On the other hand, the uncertainty in our knowledge of the electron capture energy, and the complications arising from the use of molecular Te_2, would have made a determination of the widths with the gaseous source method inaccurate, but did not affect the measurement of the angular distributions.

† Supported by a grant from the National Science Foundation.
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[2] R. K. Gupta, S. Jha, and B. K. Madan, Nuovo Cimento **9**, 1117 (1958).
[3] R. K. Gupta, Nuovo Cimento **17**, 665 (1960).
[4] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington 25, D. C., 1958 and 1962).
[5] R. Bhattacharyya and S. Shastry, Nucl. Phys. **41**, 184 (1963).
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[7] R. D. Hill, P. Axel, and A. W. Sunyar (private communication) quoted by J. M. Hollander, I. Perlman and G. T. Seaborg, Rev. Mod. Phys. **25**, 469 (1953).
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[10] N. Goldberg and S. Frankel, Phys. Rev. **100**, 1350 (1955).
[11] A preliminary report of this work was presented at the 1963 Washington, D. C., meeting of the APS: Bull. Am. Phys. Soc. **8**, 332 (1963).

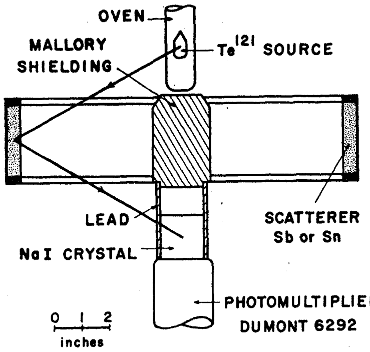

FIG. 1. Typical arrangement of source, scatterer and detector for the scattering experiments with the gaseous Te^{121} source.

A description of the experiments performed with the gaseous source will be followed by a report on the studies carried out with the centrifuge. The experimental results will then be evaluated in terms of the properties of the excited states of Sb^{121}.

II. GASEOUS SOURCE EXPERIMENTS

Approximately 1 mg of Te metal containing 10 mCi of Te^{121} was distilled into a quartz ampoule of 2 cm^3 volume which was then sealed off. As expected, the entire activity was in the gaseous phase as soon as the temperature of the ampoule exceeded 950°C. In the source,[12] which had been produced by the reaction Sb(p,n)Te, the 17-day activity was initially several times stronger than the 154-day activity from the isomer Te^{121m}.

The resonance scattering for different scattering angles was determined in conventional ring geometries of the type shown in Fig. 1. A twenty-channel pulse-height analyzer sorted the pulses from the NaI(Tl) scintillation detection system. A typical pulse-height distribution of the resonance radiation is compared in Fig. 2 with the pulse-height distribution of the incident radiation. If the 506–70-keV cascade proceeded through an excited state at 70 keV, i.e., if both 506- and 576-keV gamma rays originated from a single level at 576-keV, the two pulse-height distributions of Fig. 2 should be identical in shape. The fact that they differ drastically immediately excludes the first decay scheme. The shape of the pulse-height distribution of the resonance radiation agrees with that expected for a mixture of 506- and 576-keV gamma rays. However, the presence of up to 10% of a transition with between 430 and 500 keV energy cannot be excluded.

Since $\frac{1}{2}$ and $\frac{3}{2}$ are the only likely spin assignments to the levels fed from the spin $\frac{1}{2}$ ground state of Te^{121}, the angular distribution of the resonance radiation will be of the form $W(\theta)=1+A_2P_2(\cos\theta)$. If such a distribution is fitted to the angular distribution data, the coefficients are

$$A_2(506)=+0.17\pm0.07,$$
$$A_2(576)=-0.05\pm0.07.$$

[12] Obtained from the Nuclear Science and Engineering Corporation, Pittsburgh, Pennsylvania.

In order to take into account uncertainties in the evaluation of the different geometries and in the matching of the scatterers, the errors quoted above are twice as large as the statistical (counting) uncertainties.

The evaluation of the scattering results in terms of the widths of the excited Sb^{121} states is rather uncertain because it depends on the knowledge of the energy distribution of the emitted gamma lines. Specifically, the scattering is proportional to the fraction $N(E_R)/N$ of the gamma rays falling into a unit energy interval at the resonant energy E_R. This fraction depends on the neutrino recoil and its effect on the Te_2 molecule. While it is likely that the recoil is not large enough to break up the molecule, it will leave it in a state of high excitation. No attempt was made to evaluate the effect of this excitation on the value of $N(E_R)/N$ except to show, after the results of Sec. III became available, that, with reasonable assumptions concerning the excitation of the Te_2 molecule, $N(E_R)/N$ would fall into the desired range.

A self-absorption study[13] with the gaseous source could, in principle, have yielded the desired widths. However, such a measurement would have been very inaccurate for the 576-keV line since the expected effect for a 10 g/cm^2 Sb absorber was smaller than 1%. The determination of the widths was, therefore, left to the centrifuge method.

III. CENTRIFUGE EXPERIMENTS

In contrast to the situation with the gaseous source, the shape of the emission line for a solid source is well known, provided the lifetime of the excited state under study is longer than a few times 10^{-12} sec. For shorter lifetimes, the Maxwellian shape of the emission line will be modified since the recoil of the radiation that populated the level will not have been completely dissipated.

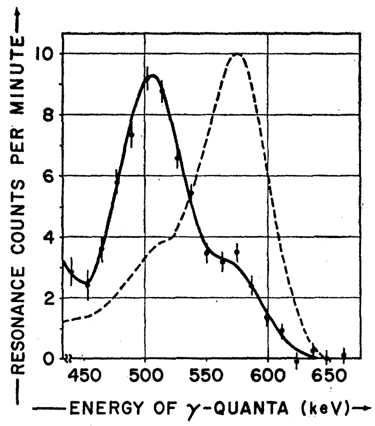

FIG. 2. Pulse-height distributions obtained in the experiments with the gaseous Te^{121} source. The dashed curve is the distribution for the incident gamma radiation, the fully drawn curve refers to the scattered resonance radiation (counting rate from comparison scatterer subtracted as background).

[13] See, for instance, F. R. Metzger, Phys. Rev. 103, 983 (1956).

In this case, the lack of knowledge of the electron capture energy and the complexity of the slowing-down processes create uncertainties akin to those encountered with the gaseous source.

In the absence of any influences of the preceding radiation on the shape of the emitted line, the cross section for resonance scattering, averaged over the incident line, is given by

$$\sigma_{av}=\frac{g_2c^2h^2}{g_1 4\pi^{1/2}E_\gamma^3}\frac{\Gamma_0^2}{\Gamma}\left[\frac{Mc^2}{2k(T_1+T_2)}\right]^{1/2}\times\exp\left[-\frac{M(E_\gamma/Mc-u)^2}{2k(T_1+T_2)}\right], \quad (1)$$

where g_2 and g_1 are the statistical weights of excited state and ground state, respectively; c is the velocity of light, h Planck's constant; E_γ is the energy of the excited state; Γ_0 is the partial width for the ground-state transition, Γ is the total width of the level; M is the mass of the recoiling nucleus; k Boltzmann's constant, u is the relative speed of source and absorber, and T_1 and T_2 are the absolute effective temperatures of source and scatterer obtained from the actual temperatures by taking into account the effects of the binding[14,15] in the source and scatterer material. An effective temperature of 325 deg absolute was used for the source, and a temperature of 307 deg for the scatterer.

The velocities needed for the Sb^{121} experiments were beyond the "safe" range[16,17] of the existing titanium alloy rotors. However, by reducing the size of the rotor tips, it was possible to increase the operational source speed by 15% to 1.3×10^5 cm/sec. This improvement in the operating speed increased the overlap of emission and absorption line for the 576-keV level more than threefold to 40% of the maximum overlap. The main disadvantage that had to be accepted was a reduction of the volume available for the source to 10^{-3} cm³. In the case of Te^{121}, this did not restrict the usable activity, but it made the loading of the source material into the tip a difficult operation. Approximately 5 mCi of Te^{121} activity were placed into a $\frac{1}{32}$-in. diam. hole near the end of one of the rotor tips and the hole sealed with an aluminum plug and epoxy resin.

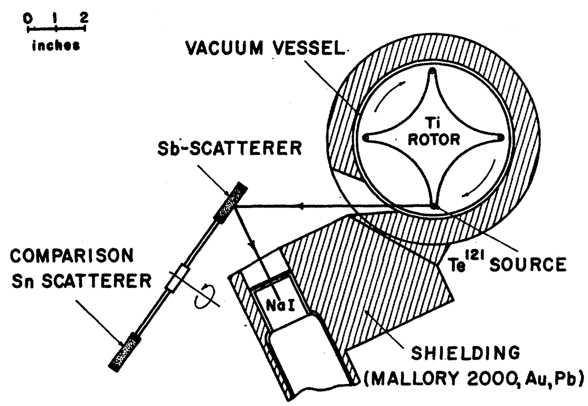

FIG. 3. Experimental arrangement for the scattering experiments with the centrifuge method.

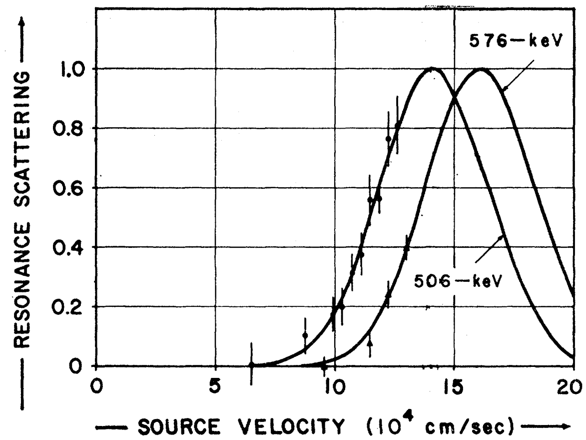

FIG. 4. Centrifuge method. Dependence of the resonance scattering on the source velocity. Circles refer to the 506-keV radiation, triangles to the 576-keV radiation. The curve labeled "506-keV" represents the velocity dependence which any radiation produced through excitation of the 506-keV level should exhibit. The curve labeled "576 keV" has the same significance for the 576-keV level. If both gamma rays originated from the 576-keV level, all the experimental points should fall on the curve labeled "576 keV."

The geometrical arrangement of rotor, scatterer, detector and shielding material is depicted in Fig. 3. A scattering angle of 115° was used. The scintillation counter system was connected to either a 400-channel analyzer or a single-channel analyzer. The analyzers were gated everytime the source moved into the region where the direction of emission of the gamma rays striking the scatterer subtended an angle of less than ±30 deg with the tangent to the source path. The gate was initiated by a light beam reflected into a photomultiplier tube by a mirror mounted on the drive shaft of the centrifuge. A properly placed second photomultiplier turned off the gate. The gated pulse-height distributions of the radiation scattered from an antimony scatterer and from a tin comparison scatterer were measured at a considerable number of rotor speeds. At each speed, the difference of the two pulse-height distributions was attributed to resonance scattering from Sb^{121}.

In Fig. 4, the resonance counting rates for the 506- and 576-keV lines are plotted versus the source speed. It is evident that the two lines differ in their velocity dependence. The curves drawn through the experimental points were calculated under the assumption that levels at 506- and 576-keV excitation energy are responsible for the resonance scattering. In view of the

[14] W. E. Lamb, Phys. Rev. **55**, 190 (1939).
[15] See, for instance, F. R. Metzger, *Progress in Nuclear Physics*, edited by O. R. Frisch (Pergamon Press, Inc., New York, 1959), Vol. 7.
[16] F. R. Metzger, Phys. Rev. **127**, 220 (1962).
[17] F. R. Metzger, Phys. Rev. **128**, 2332 (1962).

good agreement of the experimental and theoretical excitation curves, Fig. 4 may be considered to be the final proof for the existence of two levels in Sb^{121} at 506- and 576-keV excitation energy.

In fitting the cross section given by Eq. (1) to the experimental points, the ratio $g\Gamma_0^2/\Gamma$ was the only free parameter. Of course, Eq. (1) had to be averaged over the path covered by the source while the gate was open, and the angular distribution of the resonance radiation had to be taken into account. The best fit to the experimental data then yielded

$$(g\Gamma_0^2/\Gamma)_{506}=(1.33\pm0.13)\times10^{-4}\text{ eV},$$
$$(g\Gamma_0^2/\Gamma)_{576}=(1.73\pm0.20)\times10^{-5}\text{ eV}.$$

The expected branching from the 506-keV level to the 37-keV level has recently been observed,[8] the 469-keV gamma line being approximately ten times weaker than 506-keV ground-state transition. However, the presence of a 469–37-keV cascade does not affect the value given above for the ratio $(g\Gamma_0^2/\Gamma)_{506}$.

It had been pointed out in a previous paper[16] that increased rotor speeds will render feasible transmission type experiments with the centrifuge compensation method. For the 506-keV transition in Sb^{121} this is indeed the case, and a transmission experiment was carried out in a geometry similar to that given in Ref. 16. At a source speed of 1.3×10^5 cm/sec, the resonance absorption for a 15.2 g/cm^3 Sb absorber amounted to $11\pm3\%$. The resonance absorption for the 576-keV transition was $-0.5\pm1.5\%$.

IV. DISCUSSION

The results of the resonance fluorescence experiments described in the preceding sections may be summarized as follows:

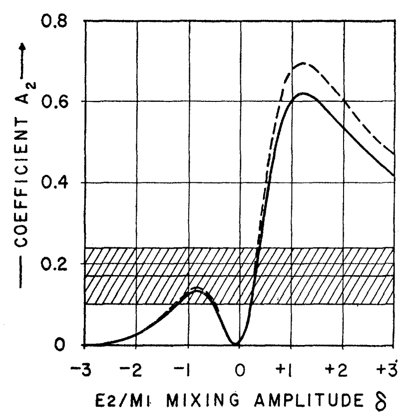

FIG. 5. Comparison of the experimental range (shaded area) for the coefficient A_2 in the angular distribution function $W(\theta)=1+A_2P_2(\cos\theta)$ for the 506-keV transition with the theoretical values. The fully drawn curve refers to a 10 to 1 mixture of $\frac{5}{2}$ (mixed) $\frac{3}{2}$ (mixed) $\frac{5}{2}$ and $\frac{5}{2}$ (mixed) $\frac{3}{2}$ (pure quadrupole) $\frac{7}{2}$; the dashed curve was calculated for the spin sequence $\frac{5}{2}$ (mixed) $\frac{3}{2}$ (mixed) $\frac{5}{2}$ alone.

(a) The decay of 17-day Te^{121} populates directly two excited states in Sb^{121} at 506- and 576-keV excitation energy.

(b) The angular distributions of the resonance radiation have the form $1+A_2P_2(\cos\theta)$, with

$$A_2(506)=+0.17\pm0.07,$$
$$0\leq A_2(576)\leq0.02.$$

(c) The expressions $g\Gamma_0^2/\Gamma$ for the two levels have the values

$$(g\Gamma_0^2/\Gamma)_{506}=(1.33\pm0.13)\times10^{-4}\text{ eV},$$
$$(g\Gamma_0^2/\Gamma)_{576}=(1.73\pm0.20)\times10^{-5}\text{ eV}.$$

(d) Any transition from the 506-keV level to a level which lies some 30 to 80 keV above the ground state of Sb^{121}, if it is present, must be at least ten times weaker than the ground-state transition.

Statement (a), placing the 70-keV transition on top of the 70–506-keV cascade rather than at the bottom, unambiguously chooses between the two reported decay schemes. As far as the spins of the two excited states of Sb^{121} are concerned, the observed anisotropy (b) of the 506-keV resonance radiation rules out spin $\frac{1}{2}$ for the 506-keV level, and the isotropic distribution of the 576-keV radiation makes spin $\frac{1}{2}$ the most likely assignment to the 576-keV excited state. With the assignment[10] of spin $\frac{1}{2}$ to the ground state of Te^{121}, and with an estimated[4] $\log ft$ value of 6.3, a spin of $\frac{3}{2}$ is the only possible assignment to the 506-keV state.

In Fig. 5, the dashed curve indicates the behavior, as a function of the $E2/M1$ mixing amplitude δ, of the theoretical value of the coefficient A_2 for the spin sequence $\frac{5}{2}$ (mixed) $\frac{3}{2}$ (mixed) $\frac{5}{2}$ with the same δ for both transitions. Since the experimental angular distribution of the 506-keV radiation contains an admixture of the 469-keV branch to the 37-keV $\frac{7}{2}+$ level, the solid curve, corresponding to the spin sequence $\frac{5}{2}-\frac{3}{2}-\frac{5}{2}$ with a 10% admixture of the $\frac{5}{2}$ (mixed) $\frac{3}{2}$ (pure quadrupole) $\frac{7}{2}$ sequence, is more appropriate for the comparison with the experimental result. Best agreement with the experiment (shaded area) is obtained for positive δ values: $\delta=+0.29\pm0.09$, corresponding to an $E2/M1$ mixing ratio of $0.08_{-0.04}^{+0.06}$. Negative δ values ranging from -0.5 to -1.3 cannot be excluded on the basis of the angular distribution measurements. Recent internal conversion data[8] agree with the predominance of the $M1$ transition indicated by the range of small positive δ values. Large positive values of δ would give rise to an unreasonable enhancement of the $E2$ transition probability. They, too, are excluded by the internal conversion data.[8]

The result of the angular distribution measurement involving the 576-keV transition was stated in (b) in a form differing from the experimental result since, for resonance scattering, the coefficients A_2 are squares of real numbers, hence cannot be negative. A spin of $\frac{3}{2}$ cannot be excluded on the basis of (b), since for -0.25

TABLE I. Summary of the presently available information concerning the electromagnetic transitions between the states of Sb^{121} which are populated in the decay of 17-day Te^{121}. The ratio of the observed $E2$ transition probability to the Weisskopf estimate (See Ref. 20) with $R=1.2A^{1/3}\times10^{-13}$ cm is listed in column 6. The last column presents the corresponding ratio for the $M1$ transitions.

E_γ (keV)	Transition initial final states	γ-Intensity (rel.)	τ_γ(sec)	$E2/M1$	$\frac{T(E2)}{T(E2)_W}$	$\frac{T(M1)}{T(M1)_W}$
576	$576\rightarrow0$	100	1.2×10^{-11}	∞	30	$\cdots$
70	$576\rightarrow506$	2 ± 0.7	6×10^{-10}	$\ll1$	$\cdots$	0.17
506	$506\rightarrow0$	~20	3×10^{-12}	$0.08_{-0.04}^{+0.06}$	18	0.09
469	$506\rightarrow37$	~2[a]	3×10^{-11}	∞	23	$\cdots$
37	$37\rightarrow0$	~2[a]	6×10^{-8}[a]	$\ll1$	$\cdots$	0.012

[a] See Ref. 8.

$<\delta<0$ and $-6<\delta<-2$ the A_2 coefficients do reach the low values required by the experiment. Measurements of the conversion coefficients[8] indicate that the 576-keV transition is predominantly $E2$; thus, they rule out the first of the two δ intervals given above. The second interval cannot be ruled out by the conversion measurements. This means that the spin of the 576-keV level could be $\frac{3}{2}$. For the future discussions we shall, however, assume that the spin of the 576-keV state of Sb^{121} is $\frac{1}{2}$.

With a spin of $\frac{3}{2}$ for the 506-keV level, and a spin of $\frac{1}{2}$ for the 576-keV level, the expressions (c) may be reduced to

$$(\Gamma_0^2/\Gamma)_{506}=(2.0\pm0.2)\times10^{-4}\text{ eV}$$

$$(\Gamma_0^2/\Gamma)_{576}=(5.2\pm0.6)\times10^{-5}\text{ eV}.$$

For the branching of the 506-keV level a value $\Gamma_0/\Gamma=0.90$ will be used, since branching to the 37-keV level is now thought to be of the order of 9%,[8] and the total interval conversion coefficient[18] is $\alpha_T\approx0.8\%$. For the 576-keV level one has, in addition to 0.5% conversion, the branching to the 506-keV state. The gamma intensity of the 70-keV transition has been reported[3,5,6] as two percent of the 576-keV gamma line. To be able to compete to this degree with the 576-keV transition, the 70-keV transition must be predominantly $M1$. The total conversion coefficient is then $\alpha_T=1.7$, making the contribution of the 70-keV branch to the total width $\Gamma(576)$ 3.4%. A value $(\Gamma_0/\Gamma)_{576}=0.96$ seems then to represent the situation properly.

With these branching ratios, the partial widths Γ_0 of the two levels become $\Gamma_0(506)=2.2\times10^{-4}$ eV and $\Gamma_0(576)=5.4\times10^{-5}$ eV. The corresponding mean lives are

$$\tau_\gamma(506)=(3.0\pm0.4)\times10^{-12}\text{ sec},$$

$$\tau_\gamma(576)=(1.22\pm0.15)\times10^{-11}\text{ sec}.$$

At this point one may compare the results of the scattering experiment with those of the transmission study mentioned at the end of Sec. III. For the partial widths Γ_0 given above, the expected absorptions for the 506- and the 576-keV transitions are $9.3\pm1\%$ and $0.34\pm0.04\%$. The agreement with the experimental results is satisfactory. It is gratifying that, when the branching to the 37-keV state is taken into account, the agreement for the 506-keV transition is even better than without the assumption of such branching.

In Fig. 6, the most probable decay scheme for the 17-day ground state of Te^{121} is shown. It might be mentioned that the observed coincidences[3,5] between 1130-keV gamma rays and 70-keV radiation could be explained as coincidences of the high energy gamma ray from 154-day Te^{121} with the sum peak of K x rays accompanying electron capture and the 37-keV gamma rays or the x rays accompanying their conversion.

As far as the positron spectrum reported by Ref. 5 is concerned, it can only be said that a γ-γ coincidence experiment, with counters alternately at 90° and 180°, indicated that less than 0.1%, if any, of the disintegrations of the 17-day Te^{121} proceed by positron decay.

On the basis of the decay scheme shown in Fig. 6 and of the lifetimes reported in this paper, one would expect Coulomb excitation of the 506- and 576-keV levels in Sb^{121} to be observable. It has come to our attention[19] that excitation of the 5–600-keV level(s) has been achieved in a hitherto unreported experiment. The earlier negative result, must, therefore, be attributed to unfavorable experimental conditions (background). A report of the results of Coulomb excitation experiments with the two

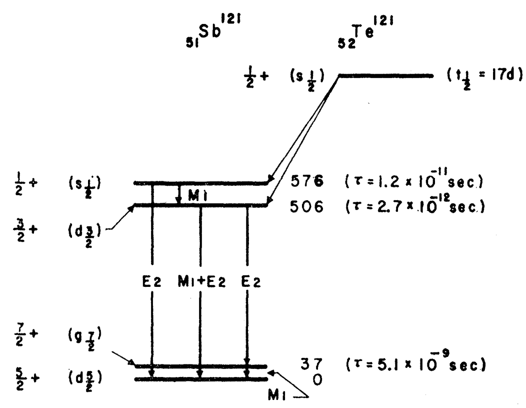

FIG. 6. Most probable decay scheme for 17-day Te^{121}. The mean lives of the levels are given in parentheses.

[18] L. A. Sliv and I. M. Band, Acad. Sci. USSR (Moscow, Leningrad, 1956), issued in the United States as report 57 ICC KI, Physics Department, University of Illinois (unpublished).

[19] P. H. Stelson (private communication).

TABLE II. Wave functions of the first four levels in Sb^{121} according to Kisslinger and Sorensen (See Ref. 21). $C_{j'nJ}{}^{j}$ is the amplitude, in the total wave function with angular momentum j, of the combination of a quasiparticle configuration with angular momentum j' and n phonons coupled to angular momentum J. (Only $n=0$, 1 are shown.)

Excitation energy (keV)	Single particle assignment	$C_{5/2(00)}{}^{5/2}$	$C_{7/2(00)}{}^{7/2}$	$C_{3/2(00)}{}^{3/2}$	$C_{1/2(00)}{}^{1/2}$	$C_{5/2(12)}{}^{j}$	$C_{1/2(12)}{}^{j}$	$C_{3/2(12)}{}^{j}$	$C_{1/2(12)}{}^{j}$
0	$d_{5/2}$	+0.82	···	···	···	+0.46	−0.19	+0.09	−0.17
37	$g_{7/2}$	···	+0.88	···	···	+0.11	+0.41	−0.14	···
506	$d_{3/2}$	···	···	−0.36	···	+0.24	+0.79	−0.14	−0.14
576	$s_{1/2}$	···	···	···	+0.41	+0.78	···	+0.23	···

levels would be very useful, especially if angular distribution information was obtained.

One would expect the single-particle model to provide a fairly good description of the states of Sb^{121} since this nucleus has just one proton outside the closed $Z=50$ shell. As far as the spin sequence (Fig. 6) is concerned, this is indeed the case. However, the electromagnetic transition probabilities, which are compared in Table I with the Weisskopf estimates,[20] exhibit appreciable deviations from the expected behavior. Within the single particle description it is disturbing to find that, while the l-forbidden 37-keV $g_{7/2}-d_{5/2}$ $M1$ transition is somewhat retarded as expected, the other l-forbidden transition, the 70-keV $s_{1/2}-d_{3/2}$ transition, is as fast or even faster than the 506-keV spin flip transition $d_{3/2}-d_{5/2}$. On the basis of this evidence one would conclude that the spin $\frac{1}{2}$ and spin $\frac{3}{2}$ states are quite far from being pure single-particle states.

As far as the electric quadrupole transitions are concerned, Table I shows that they are considerably enhanced, the enhancement being somewhat intermediate between that of the two neighboring even-even nuclei.

It is interesting to note that the observed behavior of the transitions in Sb^{121} is rather well described by the wave functions obtained by Kisslinger and Sorensen[21] with a combination of quasiparticle and phonon excitations. Table II, which lists these wave functions, shows that the deviations from the pure single-(quasi-)particle description are large for the $\frac{3}{2}+$ and $\frac{1}{2}+$ states which contain a substantial amount of phonon excitation coupled to the $d_{5/2}$ and $g_{7/2}$ quasiparticle states.[22] The two low lying states, on the other hand, are fairly pure quasiparticle states. As may be seen by inspection of Table II, the fast $E2$ transitions are understandable, although one might, for instance, expect the 469-keV transition to be more favored over the 506-keV transition then the observations seem to indicate. With the wave functions of Table II, the behavior of the $M1$ transitions is rather well explained, preliminary calculations giving agreement within a factor of about two for all transitions. The considerable presence, in the 506- and 576-keV states, of one-phonon excitations based on the $d_{5/2}$ and $d_{3/2}$ quasiparticle states, accounts for the "violation" of the l-selection rule for the 70-keV transition, and the small $C_{3/2(00)}{}^{3/2}$ amplitude accounts for the retardation of the l-allowed 506-keV transition (contributions of the other components of the wave function turn out to be small).

ACKNOWLEDGMENTS

The authors are indebted to Professor Sorensen for providing them with additional information concerning the wave functions of some of the states in Sb^{121} and for helpful discussions. They thank Dr. S. Fallieros for many stimulating discussions, and Dr. S. Monaro for the communication of experimental results prior to publication.

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