DETOUR TRANSITIONS IN THE INTERNAL BREMSSTRAHLUNG SPECTRUM OF ^{91}Y

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ABSTRACT

The IB spectrum from ^{91}Y is measured in the energy region from 100–1250 keV by using a multichannel NaI (Tl) scintillation spectrometer with a standard geometrical arrangement. After effecting all the necessary corrections, the spectral shape, the total yields of intensity and of energy of IB are determined and compared with the corresponding thecretical (detour and direct) values of Ford and Martin in the energy region investigated. The present experimental results are in excess over the direct theory in the entire energy region investigated while they almost coincide with the detour theory in tne energy region from 200 to 600 keV. Again below 200 keV and above 650 keV, the experimental results are deviating positively from even this detour theory. Above 650 keV the divergence between experiment and theory is found to increase with increasing energy.

I. INTRODUCTION

THE survey of Persson[1] in the field of IB reveals that there is a lack of agreement between theory and experiment in the majority of cases so far studied. The situation seems to be still worse for the case of forbidden beta decaying isotopes; always the experiment is exceeding the theory, the excess being higher the greater the photon energy. Several theories[2–10] of IB were developed and all of these earlier theories were found to be inadequate to explain the observed large experimental IB excess over theory. Of late, we find in the literature, attempts being made to explain the observed experimental IB excess over theory in terms of the so-called detour transitions[11–16]. Detour transitions are those in which the parent nucleus undergoes a virtual beta transition to a level of higher energy in the daughter nucleus which then decays to the ground state with emission of gamma radiation or *vice versa*. In these detour transitions the nucleus rather than the electrons radiate the photons unlike in direct transitions in which the photon is emitted by the outgoing (beta particle) electrons. Since the energy is not conserved in the intermediate state, the gamma spectrum is continuous. Ford and Martin[14] developed in detail, the theory of IB, taking into account the so-called detour transitions for the case of unique first forbidden beta decay.

To find out the importance of the detour transitions which are expected to be significant in forbidden beta decays, the investigation of IB from ^{91}Y was undertaken, since in this particular case, the earlier measurements[17–20] indicated a large discrepancy between theory and experiment. Further, in this case no attempts have so far been made to calculate in detail the detour effect and ascertain whether or not, it can account for the observed experimental excess over KUB theory.

II. EXPERIMENTAL DETAILS

The isotope ^{91}Y was obtained from the Bhabha Atomic Research Centre, Trombay, India, as carrier free solution with the least possible amounts of solids in it. In this isotope, it was found that there is a weak (0·3%) beta transition of energy 0·33 MeV which is followed by a gamma ray of energy of 1·2 MeV. Except for this gamma line, the source was found to be free from any other mono-energetic gamma rays or beta impurities when tested with a Ge (Li) detector (having a FWHM of 3·7 keV for 662 keV gamma rays from ^{137}Ba) and anthracene crystal.

The preparation of IB sources, the measurement, the method of analysis and the evaluation of various errors in the measurement as well as in the calculation of various correction factors were the same as those found in our earlier publication[20] except for the following improvements and differences.

To eliminate the air disturbances in the low energy region, the column between the detector and the source was evacuated and maintained at a pressure of 1 mm of mercury. Secondly, the single channel analyser employed in the earlier study was replaced by a 512 channel analyser of ND 1100 system along with a non-overloading amplifier of type PA 563 which facilitated collection of larger counts resulting in better statistical accuracy.

The overall error in the present investigation was estimated as the r.m.s. value of the different possible errors in the measurement of IB as well as in the calculation of various correction factors. The total r.m.s. error thus arrived at is of the order of 7% at 1000 keV and also it was found that this error decreases with decreasing energy being 6·08% at 700 keV and 2·74% at 200 keV.

III. Results and Conclusions

The theoretical IB distributions (as probability for bremsstrahlung per mc^2 energy interval per beta *disintegration)* for both the direct and detour transitions were calculated using the theory of Ford and Martin[14]. After effecting all the necessary corrections the final experimental distributions were all obtained as number of photons per mc^2 energy interval per beta disintegration.

^{91}Y is an unique first forbidden beta decaying isotope having an end point energy of 1545 keV and a half-life of 58·5 days. In this case, the comparison between the present experimental results of IB and the corresponding theoretical distributions in the region from 100 keV to 1250 keV is shown in Fig. 1. From this figure it is seen that the present experimental results are almost coinciding with the detour corrected theory due to Ford and Martin[14] *from 200 to 650 keV, the* experiment is deviating positively from even the detour theory. The experimental excess over detour theory at 800 keV is 75% and at 900 keV is 120%.

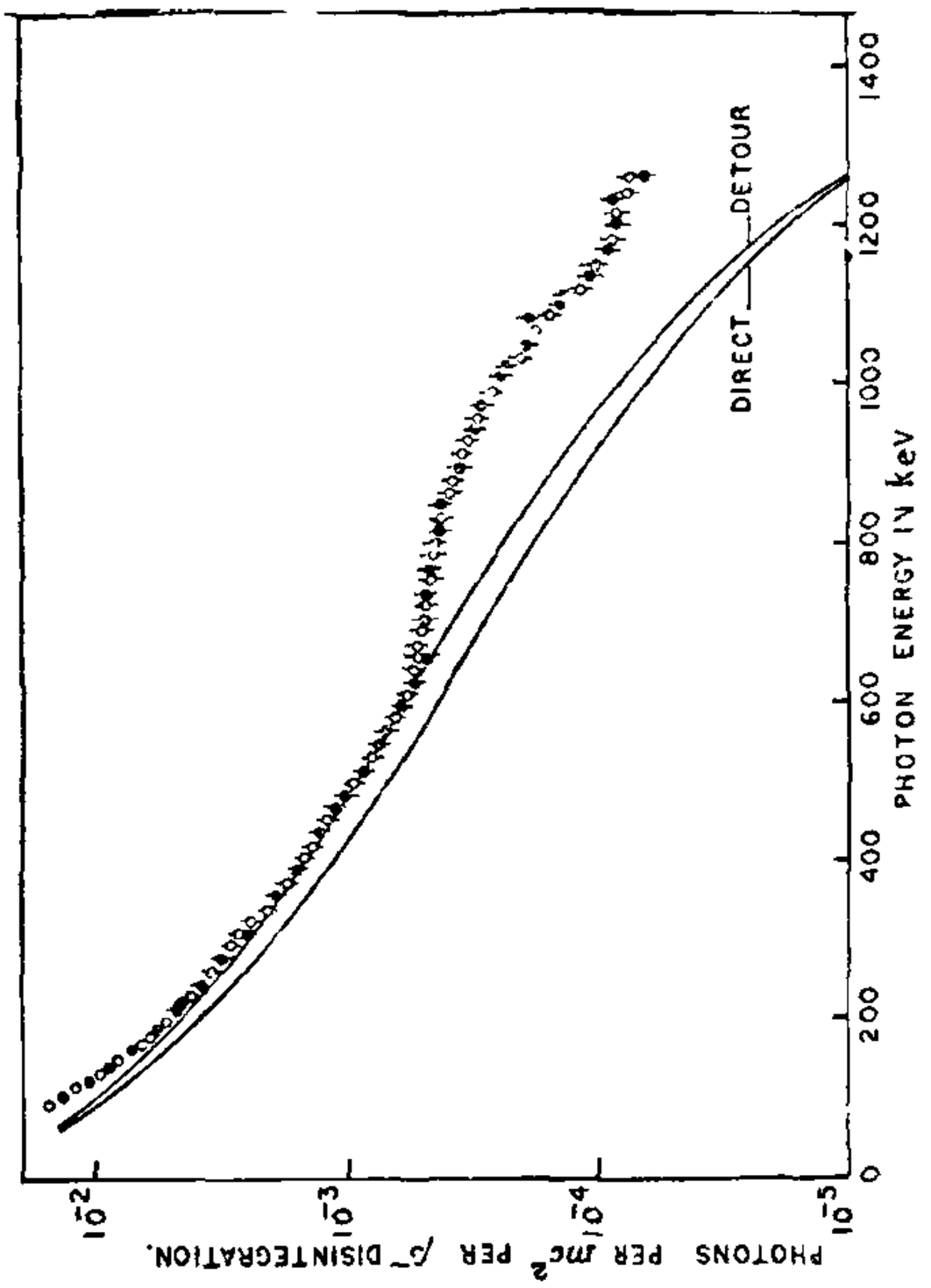

Fig. 1. ^{91}Y Internal bremsstrahlung Intensity Spectrum, O Experimental data with different source strengths ranging from 50 to 150 micro Curies.

Abscissa—Photon energy in keV.
Ordinate—Photons per mc^2 per beta disintegration.

The IB from this isotope was hardly studied previously. Even in the relatively few earlier investigations available for this case, the contribution of detour transitions to IB was not considered. In the first measurement due to Bolgiano *et al*[19] which was confined only to a very small energy region from 20 to 150 keV, there was good agreement between experiment and theory (KUB). Subsequently, two more measurements[17,20] were made of IB from the same isotope which covered the high energy as well, upto 1000 keV. These two later studies, namely, the differential measurements of IB due to Persson[17] at large angles between the emitted electrons and the accompanying IB photon as well as the integral *(single counter)* measurements of Narasimha Murty *et al.*[20] represent similar trends of the experimental results of IB with respect to Coulomb corrected KUB theory, in the sense that in both of them, there was experimental excess over theory throughout the investigated energy region from 100 to 1000 keV, the experimental excess over theory increasing with increasing photon energy.

When the present results are compared with those of Persson and of Narasimha Murty *et al.*, it is seen that the present experimental values are also having similar behaviour in respect of deviating from the direct theory throughout the investigated energy region. But, the extra finding that can be claimed in the present study is the successful applicability of the detour theory in the photon *energy region from 100 to 650 keV as can be seen* from Fig. 1.

An attempt to improve the agreement between the theory and experiment even at high energies, by assuming the amplitudes of detour matrix elements to be twice or thrice as large as the direct matrix elements instead of equal magnitude, was also made in the present investigation and found to be unsuccessful since such an assumption resulted in increasing the detour contribution to a greater extent, once again, only at the middle energy region.

In Fig. 1., the small vertical lines over each experimental point are a measure of the total r.m.s. value of the error involved in the experimental measurements at that energy. For the experimental points for which no limits of error are given, it is implied that the limits lie within the symbols. The total yields of intensity and of energy of IB from this isotope in the investigated energy region of 100 to 1250 keV is determined to be $3·809 \times 10^{-3}$ $(2·569 \times 10^{-3}; 2·994 \times 10^{-3})$ and $2·146 \times 10^{-3}$ $(1·395 \times 10^{-3}; 1·741 \times 10^{-3})$ respectively. The values in the brackets represent the corresponding quantities for direct and detour theories respectively for the same energy region.

Finally, it is concluded that throughout the investigated energy region, the experimental results are deviating positively from the direct theory and this positive deviation is found to be increasing with increasing energy. But the detour theory is found to be successful in explaining the experimental excess over the theory only in the middle energy region. It is therefore desirable to develop new theories by taking into account new effects if there are any, which were ignored in the existing theories and which are likely to augment the IB intensities especially at high photon energies.

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EXPLOSIVE PHASE TRANSFORMATION IN $Sm_{0\cdot8}$ $Tb_{0\cdot2}$ S

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WE recently reported the thermo-power study of the isostructural electronic phase transition in SmS which occurs around 6·5 Kbar pressure[1]. The semiconductor to metal transition manifests itself as a dramatic drop in thermo-power (Q) followed by a change of sign. After the phase transition, Q increases anomalously over a narrow pressure range. It is well known that the high pressure phase of SmS is in a mixed valance or inter-configurational fluctuation state[2] (ICF). Further the effect of pressure can be simulated by substituting smaller trivalent ions like Tb^{3+}, Gd^{3+}, Y^{3+}, etc., for the larger divalent Sm ions in the SmS lattice[3,4]. Thus the critically doped and 'Chemically collapsed' systems like $Sm_{0\cdot8}$ $Tb_{0\cdot2}$ S, $Sm_{0\cdot84}$ $Gd_{0\cdot16}$ S, etc., exhibit properties which are similar to the high pressure phase (metallic phase) of SmS.

In this communication we report some new data on the thermoelectric behaviour of the chemically collapsed $Sm_{0\cdot8}Tb_{0\cdot2}S$ system in the temperature range $-200°$ C to $+200°$ C. Further this study gives evidence that the black phase obtained after the explosive phase transformation[3,5] at $-170°$ C (B'-Phase) is quite distinct from the normal black phase (B-phase).

Figure 1 gives the temperature-concentration diagram[3] of a typically doped material like Sm_{1-x} Gd_xS. For concentrations less than the critical value the material will be in the B–Phase (FCC) which is the normal semiconducting phase. For concentrations greater than a critical value and for temperatures above 100° K, the black phase undergoes an isostructural first order phase transformation to a metallic phase (M). This metallic phase on cooling undergoes an explosive phase transformation to the B'–phase, near liquid nitrogen temperature. There is evidence to indicate that this is also an isostructural transformation[3]. As mentioned earlier this study clearly shows that B and B' are electronically distinct phases.

Figure 2 presents the variation of Q with temperature ranging from $-200°$ C to $+200°$ C for $Sm_{0\cdot8}Tb_{0\cdot2}S$. The most notable feature is the change of sign of Q at lower temperatures followed by very large increase in its magnitude ($Q \approx -40$ $\mu v/°$ C at $-150°$ C). The explosive phase transformation from the metallic to the B'-phase is seen by the large discontinuity in Q occurring near $-170°$ C. The sign of Q is *positive in the B'–phase. From* our earlier studies[1], we note that Q is negative in the B–phase