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INTERNAL BREMSSTRAHLUNG (IB) FROM ^{210}Bi RADIONUCLEI

SALAH EL-KONSOL, ABDEL-MOHSEN BASHA,
NABILA SHAMS EL-DIN and SAYED A. GAAFAR

Reactor and Neutron Phys. Dept., Nuclear Research Centre, Atomic Energy Establishment, Cairo, Egypt

and

Phys. Dept., Faculty of Science, Cairo University, Cairo, Egypt

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The *IB* spectrum from ^{210}Bi radionuclei has been measured with the aid of a NaI (Tl) scintillation spectrometer. The spectrum was analysed into its constituting gamma lines by using the variable width peeling off method. The analysed *IB* spectrum was then corrected with all the proper corrections. The *IB* probability per disintegration per m_0c^2 was compared with the theoretical calculations based on the Knipp and Uhlenbeck theory, Bloch theory, Coulomb corrected theories of Lewis and Ford and of Nilsson, and Ford and Martin's theory in which the detour transition is considered. A new theoretical approach is presented in this work. The comparison of the measured *IB* probability with that calculated on the basis of this approach shows a satisfactory agreement between theory and experiment.

1. Introduction

Studies on internal bremsstrahlung (*IB*) accompanying β-decay are not only of theoretical interest but also of practical importance. Theoretical analysis[1,2] of *IB* have been performed for both allowed and forbidden β-transitions. Further studies were carried out in which the Coulomb effects were taken into account[3,4].

In case of forbidden β-decay the *IB* may be accompanied by radiation produced as a result of detour transition which is negligible in case of allowed β-decay. Ford and Martin[5] considered the detour transition in their calculations and showed that it can play a significant role in case of forbidden β-decay.

Several experimental investigations have been carried out on the *IB* associated with the β-decay. There is, however, lack of agreement among various experimental results as well as between experiment and theory, particularly at high photon energies. On the other hand, most of works[6-10] done so far on the *IB* measurements from ^{210}Bi were restricted to energies below 250 keV and the agreement with the theoretical calculations is good. It would be very interesting to know whether or not the same agreement between experiment and theory in the low energy region will be obtained also at the high-energy part of the *IB* spectrum.

2. *Experimental details*

The ^{210}Bi source was supplied by the Radiochemical Centre, Amersham. Its activity was 0.82 μCi. No conversion electrons were observed. ^{210}Bi is a β--emitter with $E_\beta(\max) = 1.17$ MeV with a half-life of 5 days. Being a β-transition with $\Delta I = 2$ and parity change (a $h_{9/2} \rightarrow d_{5/2}$ transition), having a $\log ft = 8.8$, it was classified as a non-unique first forbidden transition[11].

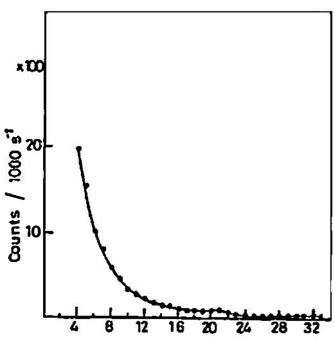

Fig. 1. The typical *IB* spectrum of ^{210}B radionuclei.

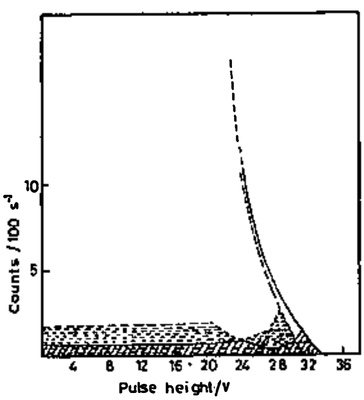

Fig. 2. Illustration of the variable width peeling off method of analysis.

The *IB* spectrum of ^{210}Bi radionuclei was measured by a scintillation spectrometer using a NaI (Tl) crystal of 1 inch diameter and 3/4 inch high. The source to crystal distance was 5 cm. An aluminium absorber of 1.9 mm thickness was mounted between the source and the crystal to minimize the external bremsstrahlung (*EB*) contribution. The experimental arrangement has been previously explained in details[12,13]. Fig 1. shows the typical *IB* spectrum of ^{210}Bi radionuclei. In this figure one can observe a hump at the 760 keV photon energy. (This hump may be from the effect of pile-up). When the pile-up was determined, it was found to be less than 3% and was neglected. The hump was found to be due to the laboratory background. After subtracting this background which was measured under the conditions of the *IB* spectrum measurements, the hump disappeared. The pure *IB* spectrum was then analysed into its constituting gamma lines. This analysis was achieved by employing the so-called *variable width-peeling-off method*[12-14]. Fig. 2 illustrates this method of analysis. The *IB* spectrum was corrected with all the proper corrections such as the crystal efficiency[15], iodine K-X ray escape, back-scattering, external bremsstrahlung (*EB*), solid angle and absorption of radiation in the beta stopper (Al-absorber)[12,13].

3. *Results and discussion*

Fig. 3 shows the experimental *IB* probability in comparison with that theoretically calculated on the basis of Knipp and Uhlenbeck[1] and Bloch[2] theories (*KUB*) as well as on the basis of the Coulomb corrected theory by Lewis and Ford[4] and modified *KUB* theory by Nilsson[3]. The measured *IB* probability was normalized to the theoretical one at 409 keV photon energy. This normalization enables us to eliminate the uncertainty in the determination of the absolute β strength of the source. In addition, the absolute determination of *IB* probabilities in the low

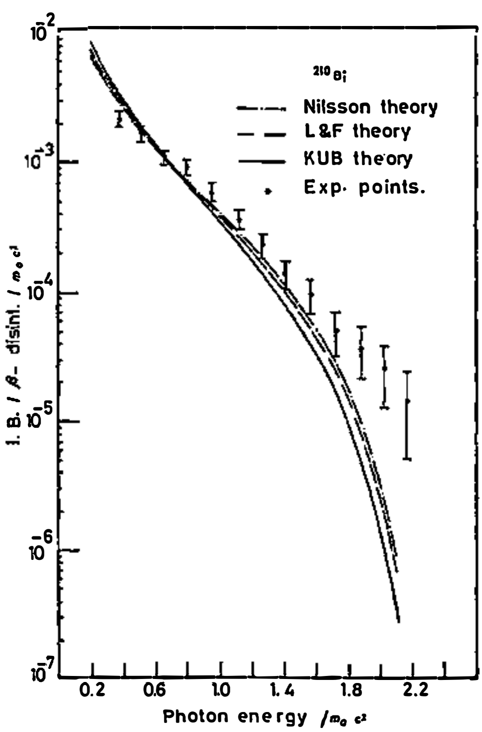

Fig. 3. The experimental *IB* probability in comparison with the calculated *IB* probabilities according to *KUB*, modified *KUB* and Lewis and Ford theories.

energy region has shown insignificant differences when compared to the calculated *IB* probabilities[16]. It is clear from this figure that the experimental values are in agreement with those calculated theoretically on the basis of the aforementioned theories up to 870 keV. A similar agreement was obtained by Murty and Jnanananda[11] who did their measurement up to 550 keV photon energy. It can also be noted that the deviations from the predictions of *KUB*[1,2] theory are larger than those registered in case of Nilsson[3] and Lewis and Ford[4] theories. Such an improvement with the latter two theories is due to the consideration of the Coulomb effect.

In spite of the improved agreement of Lewis and Ford[4] and Nilsson[3] theories, a disagreement still exists particularly at high photon energies. This disagreement can be attributed to the fact that the comparison has been carried out with the theories applicable to of the allowed β-decay, while the β-transition of ^{210}Bi source is classified as a non-unique first forbidden. Consequently, Fig. 4 shows the comparison between the experimental values and values calculated from the theory of Lewis and Ford[4] (direct). It can be seen in this figure that there is no significant improvement between the theory and experiment. When the comparison of the experimental results was done with values calculated according to the Ford and Martin[5] theory in which the detour transition is taken into

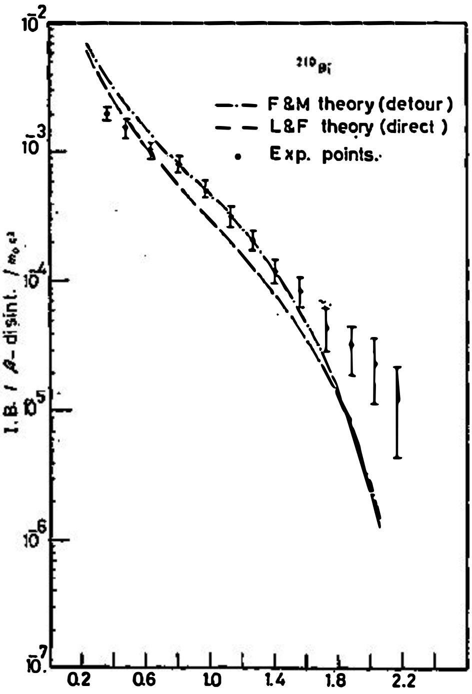

Fig. 4. The experimental *IB* probability in comparison with the calculaed *IB* probabilities according to Lewis and Ford theory, for forbidden β-transition (direct) and Ford and Martin (detour) theory.

account, a significant improvement was obtained particularly in the middle energy region (see Fig. 4). An excess of the experimental values at high photon energy still persisted.

This may lead to the conclusion that Ford and Martin[5] as well as Lewis and Ford[4] theories are inadequate in explaining the experimental results in the high photon energy region. Such conclusion has been also obtained by Beattie and Byrne[17].

As it was previously mentioned[3] the modified *KUB* theory seems to be suitable for comparison with the experimental results of the allowed β-transitions. Therefore, a new theoretical approach has been developed in the present work. This approach is based on the modified *KUB* theory by Nilsson[3] after applying the shape correction factor (C_1) deduced by Konopinski und Uhlenbeck[18,19] for first forbidden transitions

$$C_1 \cong p^2 + q^2 \cong (W^2 - 1) + (W_0 - W)^2$$

where p and q are the momenta of the associated electron and neutrino, respectively, W is the energy of the electron and W_0 is the total energy release in units of m_0c^2.

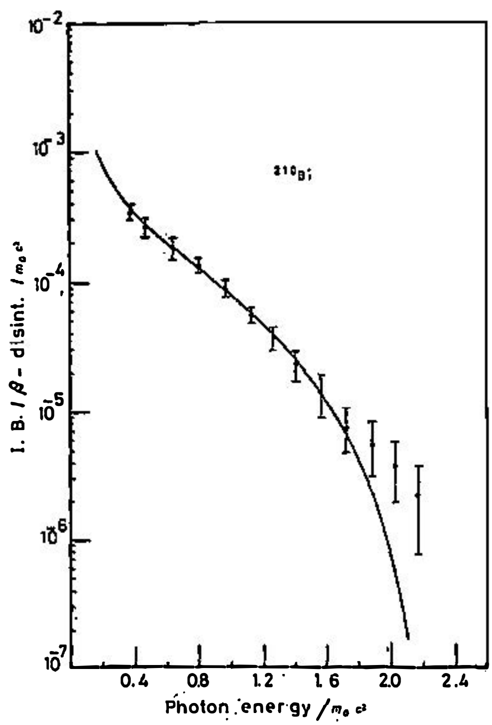

Fig. 5. The experimental *IB* probability in comparison with the calculated *IB* probabilities according to the shape factor corrected modified *KUB* theory.

Fig. 5 shows the comparison between the experimental results and the value calculated according to the shape corrected modified *KUB* theory. It can be seen from this figure that a much better agreement between the experiment and theory has been achieved. To illustrate the improvement between experiment and theory, the ratios between the experimental results and those calculated according to the shape corrected modified *KUB* theory (R_1) and Ford and Martin theory (R_2) for different photon energies were determined as shown in Fig. 6. It is clear from this figure that the former ratios (R_1) are much closer to unity than the latter ones (R_2) up to 900 keV photon energy.

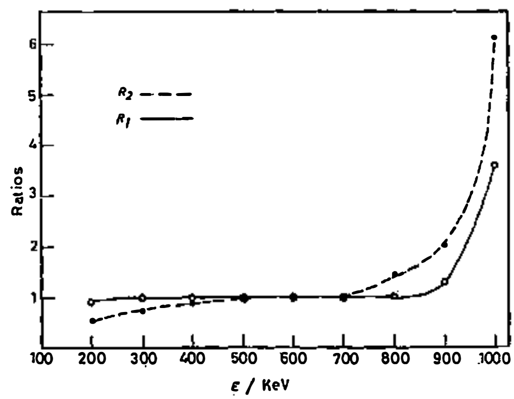

Fig. 6. The ratios between the experimental *IB* probabilities and the calculated *IB* probabilities according to the shape factor corrected modified *KUB* theory (R_1) and Ford and Martin theory (R_2).

Therefore, one may conclude that, in case of forbidden β-transitions, if the Coulomb correction factor, degree of forbiddeness and detour transition effect are taken into account in a more refined manner than those in the aforementioned theories[3,4,5], an agreement between experiment and theory can be obtained up to the end point energy.

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UNUTRAŠNJE ZAKOČNO ZRAČENJE IZ ^{210}Bi RADIONUKLIDA

SALAH-EL-KONSOL, ABDEL-MOHSEN BASHA,

NABILA SHAMS EL-DIN i SAYED A. GAAFAR

Reactor and Neutron Phys. Dept., Nuclear Research Centre, Atomic Eenergy Establishment, Cairo, Egypt

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Phys. Dept., Faculty of Science, Cairo University, Cairo, Egypt

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Pomoću NaI(Tl) scintilacijskog spektrometra izmjeren je spektar zakočnog zračenja iz ^{210}Bi radionuklida. Izmjereni spektar analiziran je primjenom metode odbijanja funkcije odgovora detektora s promjenljivim razlučivanjem. Zatim su izvršene sve potrebne korekcije spektra. Postignuti rezultati za vjerojatnosti zakočnog zračenja po m_0c^2 uspoređeni su s teorijskim proračunima provedenim prema teoriji Knippa i Uhlenbecka, teoriji Blocha, prema teorijama Lewisa i Forda te Nilssona, u kojima su uključene Coulombske korekcije, te prema Fordovoj i Martinovoj teoriji koja uključuje neizravne prijelaze. U ovom radu izlažu se također rezultati novog teorijskog pristupa. Rezultati tih proračuna pokazuju dobro slaganje s izmjerenim vjerojatnostima zakočnog zračenja.