Absolute K-conversion coefficients from the X-ray gamma ray summing in Ge(Li) detectors



1974 J. Phys. A: Math. Nucl. Gen. 7 2008

(http://iopscience.iop.org/0301-0015/7/16/005)

J. Phys. A: Math., Nucl. Gen., Vol. 7, No. 16, 1974. Printed in Great Britain. 

# Absolute K-conversion coefficients from the x ray gamma ray summing in Ge(Li) detectors

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Received 10 April 1974, in final form 15 July 1974

**Abstract.** A new method for the determination of absolute K-conversion coefficient is described. The K-conversion coefficients of the 569·7 keV and 1063·6 keV gamma rays in the decay of $^{207}$Bi (38 yr) and 316·5 keV gamma ray in the decay of $^{192}$Ir (74·2 d) are measured and they are found to agree with the reported data.

## 1. Introduction

Absolute measurements of internal conversion coefficients of gamma rays are of great importance in nuclear spectroscopy work. In addition to the identification of the multipolarities of the gamma rays involved, the conversion coefficients yield valuable information on the nuclear structure. For a radioactive decay having many gamma rays, the conversion coefficients are generally measured relative to the theoretical K-conversion coefficient ($\alpha_K$) of a gamma ray of known multipolarity. For example, in the decay of $^{152}$Eu, the 344·3 keV gamma ray corresponding to the transition $2^+$ to $0^+$ is taken from the computed data for the E2 transitions. The conversion coefficient of other gamma rays are then measured from the relative gamma-ray intensities and conversion electron intensities. One can measure (Hultberg and Stockendal 1959, Mukherjee 1960) the absolute conversion coefficients using the same source in a well calibrated beta and gamma ray spectrometer. But the method is time consuming and involves two sets of spectrometers. In the present study we present a new technique for the measurement of absolute K-conversion coefficient of gamma rays, which is less time consuming. It is expected that the present method will be extremely suitable for the study of short-lived radioisotopes.

## 2. Method and results

The method involves a careful study of the Kx-ray–gamma-ray sum spectra observed in a Ge(Li) detector. Since the K-conversion of gamma rays is followed by the emission of Kx-rays, the latter will be in coincidence with any subsequent gamma rays. If the K-conversion probability is appreciable, a prominent Kx-ray–gamma-ray sum peak can be readily observed in a close geometry set up. From an analysis of the area of the sum peak, together with a knowledge of the decay scheme, the K-conversion coefficient can be calculated from such spectra. In the present work we have measured the gamma-ray spectra in the decay of $^{207}$Bi and $^{192}$Ir whose decay schemes are well known.

We have used a 32·2 $cm^3$ Ge(Li) detector for the study of the gamma rays in the decay of $^{207}$Bi and $^{192}$Ir. The spectra are recorded in a 4096 channel analyser (Laben) and the gamma-ray peak areas are determined by graphical analysis.

### 2.1. $\alpha_K$ *of the 1063·6 keV transition in the decay of* $^{207}$*Bi*

The decay scheme of $^{207}$Bi (Rupnik 1972) is shown in figure 1. The sum peak $(569{\cdot}7+K_\alpha)$ keV (figure 2) arises due to the summing of the 569·7 keV gamma rays with (i) the Kx rays from the K conversion of the 1063·6 keV transitions, (ii) the Kx rays from

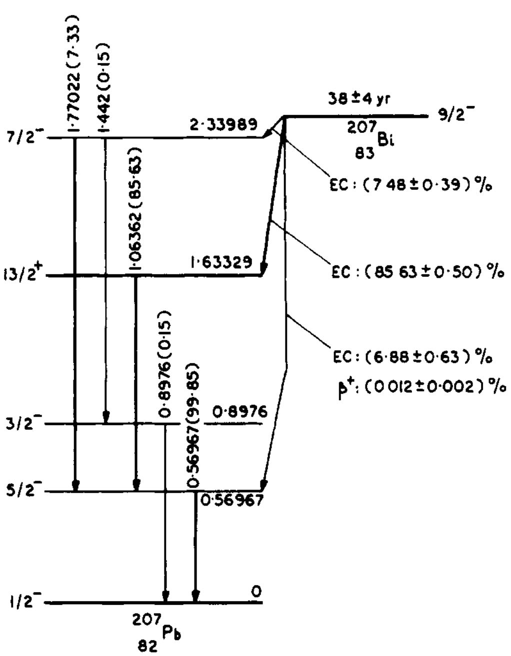
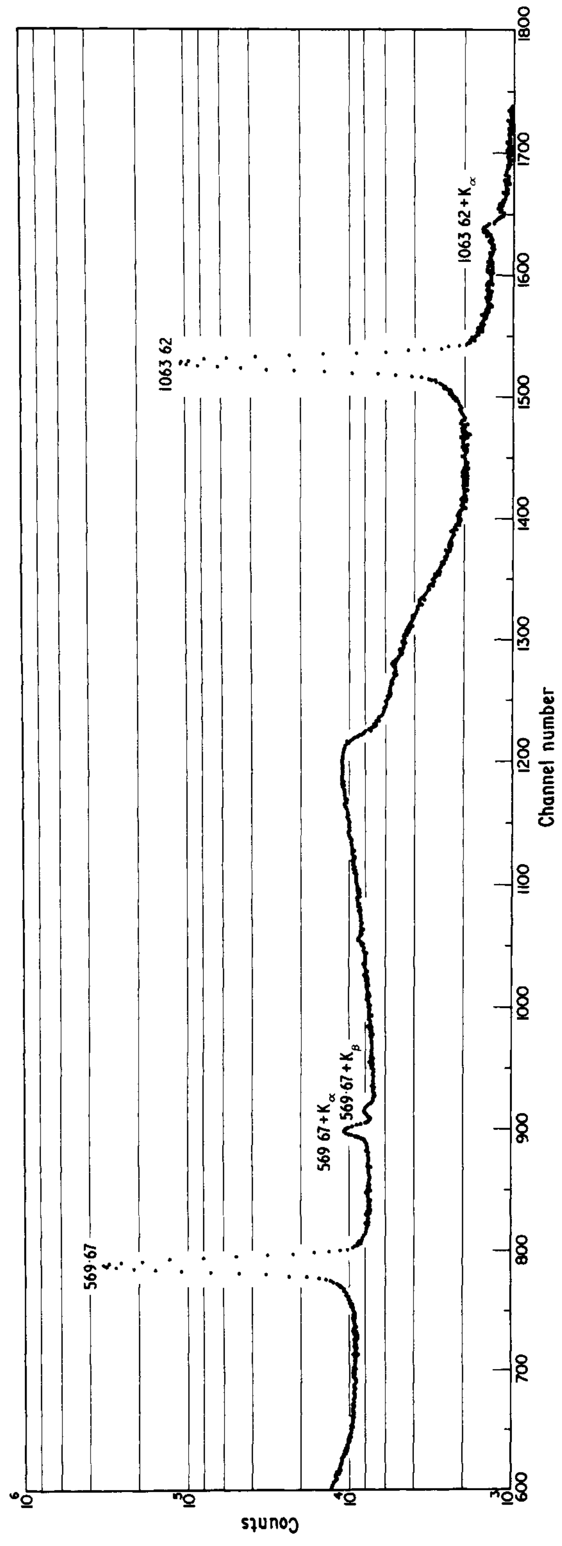



**Figure 1.** Decay scheme of $^{207}$Bi (Rupnik 1972).

the K conversion of the 1770·2 keV transition and (iii) the Kx rays following K capture to the 569·67 keV level. The second quantity can be neglected compared to the other two. Therefore, when the contribution of the last quantity is subtracted from the total sum-peak area, the $\alpha_K$ of the 1063·6 keV transition can be determined. For the determination of the last quantity a knowledge of $P_K$, the K-capture probability is necessary. In the absence of a reliable experimental estimate of $P_K$, we have utilized the theoretical expressions for $P_L/P_K$ and $P_{M+N+\dots}/P_L$ given in Nuclear Data Tables (1970) together with the $Q_{EC}$ value listed in Nuclear Data Sheets (1971). The theoretical estimate for $P_L/P_K$ and $P_{M+N+\dots}/P_L$ given in the Nuclear Data Tables (1970) is valid for allowed transitions, whereas the transition in $^{207}$Bi under our investigation is second forbidden. We have assumed, following Zyryanova (1968) that the capture ratio is not sensitive to the degree of forbiddenness.

The area under the sum peak $(569{\cdot}7+K_\alpha)$ keV can be expressed as

$$N^{\mathrm{sum}}_{569\cdot 7+\mathrm{K}_\alpha} = \omega_{\mathrm{K}} f_{\mathrm{K}_\alpha}\left(\frac{\epsilon_{\mathrm{K}_\alpha}}{\epsilon_{1063\cdot 6}}\alpha_{\mathrm{K}}^{1063\cdot 6} N^{\mathrm{sum}}_{569\cdot 7+1063\cdot 6} + b\epsilon_{\mathrm{K}_\alpha} N_{569\cdot 7}\right), \qquad (1)$$



569·67
569 67 + Kα
569·67 + Kβ
1063 62
1063 62 + Kα
Channel number
Counts
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800

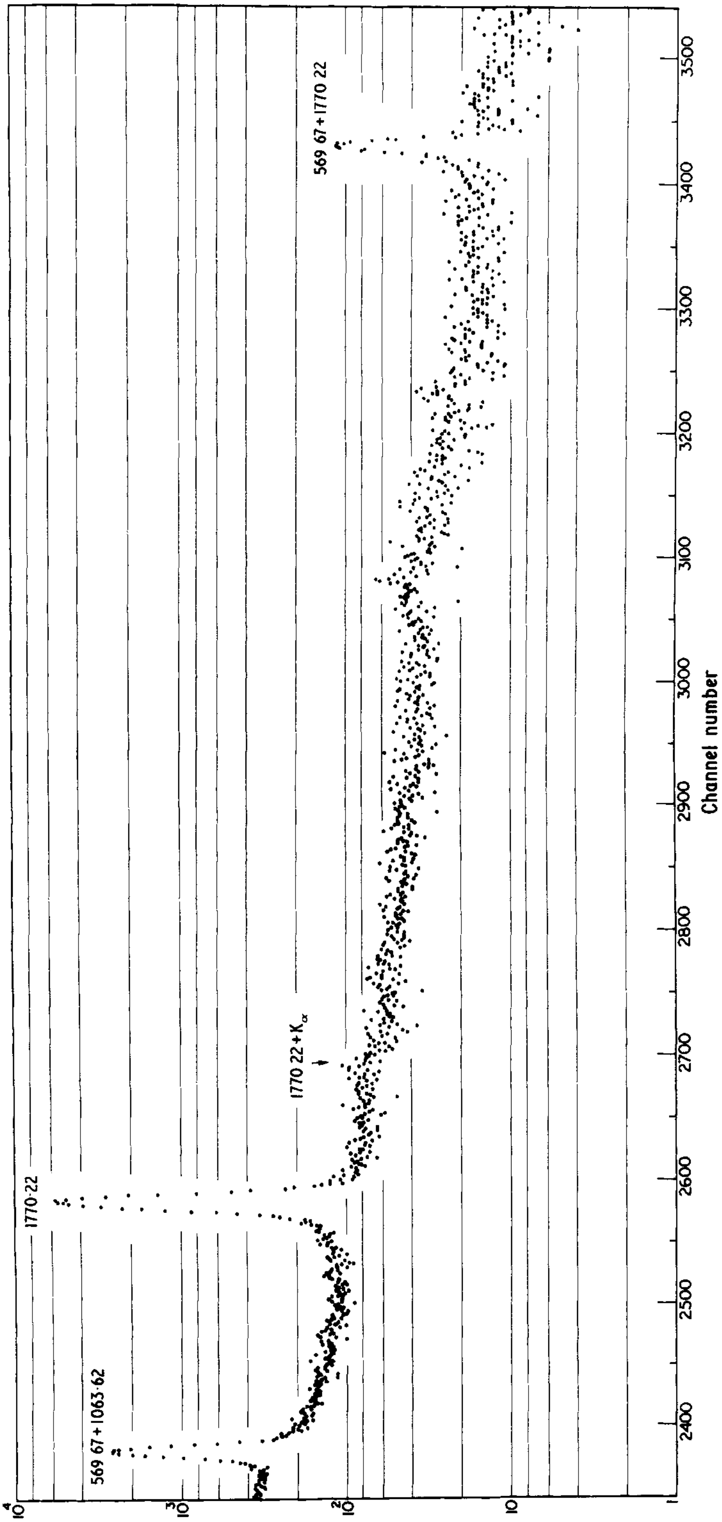



**Figure 2.** A typical gamma ray spectrum of $^{207}$Bi with the source on top of the 32·2 cm$^3$ Ge(Li) detector.

where $\omega_K$ is the K fluorescence yield and $f_{K_\alpha} = I_{K_\alpha}/(I_{K_\alpha}+I_{K_\beta})$, the values of which are taken from Bambynek *et al* (1972) and Hansen *et al* (1970) respectively, and $b$ is the number of the Kx rays in coincidence with 569·7 keV gamma, estimated from the $P_K$ and the known branching to the 569·67 keV level (figure 1). The possible angular correlation correction factor $W(\theta)$ in the above and the subsequent equations has been taken to be unity because of the small source-to-detector distance (Luukko and Holmberg 1968). The absolute efficiency $\epsilon_{K_\alpha}$ in equation (1) is determined from the absolute efficiency $\epsilon_{569\cdot7}$ measured from the analysis of the (569·7 + 1063·6) keV and (569·7 + 1770·2) keV sum peaks (Dasmahapatra and Mukherjee 1973) and the ratio $\epsilon_{K_\alpha}/\epsilon_{569\cdot7}$ from the relative efficiency curve of the detector in the close geometry set up (figure 3). From equation (1) our data yield

$$\alpha_K^{1063\cdot6} = 0\cdot095 \pm 0\cdot011$$

which agrees very well with the reported value 0·095 ± 0·014 (Nuclear Data sheets 1971).

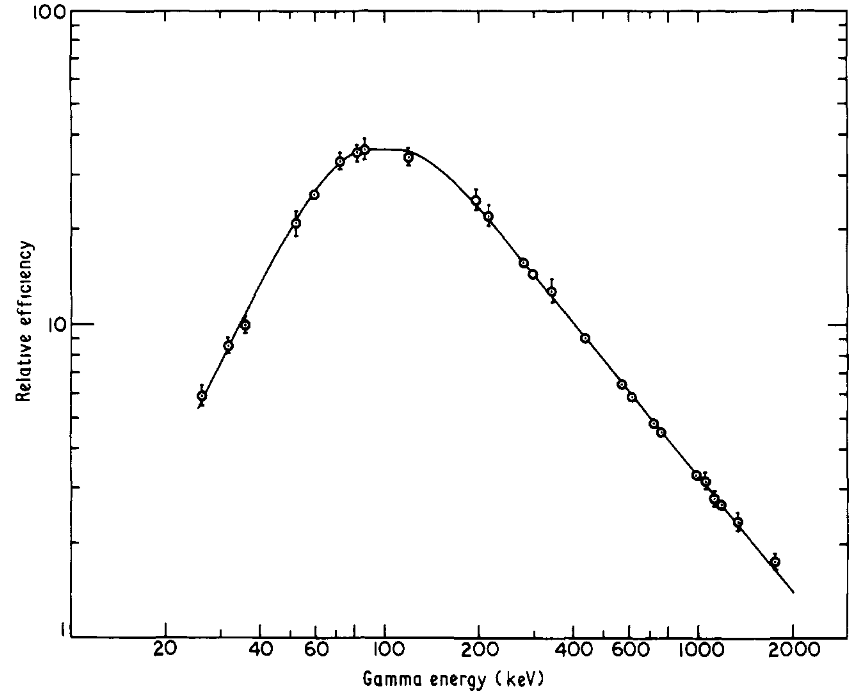



**Figure 3.** Relative efficiency of the 32·2 cm³ Ge(Li) detector in the close geometry set up.

### 2.2. $\alpha_K$ *of the 569·7 keV transition in the decay of* $^{207}Bi$

Since the 1633·29 keV state is metastable (half life = 0·8 s) there will not be any coincident summing of the capture Kx rays with the 1063·6 keV gamma transition. Thus the contribution to the sum-peak (1063·6 + $K_\alpha$) keV (figure 2) is solely due to the summing of the 1063·6 keV gamma rays with the Kx rays following the conversion of the 569·7 keV transition. The sum-peak area can be expressed as

$$N^{sum}_{1063\cdot6+K_\alpha} = \omega_K f_{K_\alpha} \frac{\epsilon_{K_\alpha}}{\epsilon_{569\cdot7}} \alpha_K^{569\cdot7} N^{sum}_{569\cdot7+1063\cdot6}. \qquad (2)$$

From the analysis of our data we find

$$\alpha_K^{569\cdot7} = 0\cdot023 \pm 0\cdot003.$$

The known value of $\alpha_K^{569\cdot7}$ is $0\cdot0159 \pm 0\cdot0005$ (Nuclear Data Sheets 1971). The results of the present investigation agree well with the $\alpha_K$ value ($0\cdot022 \pm 0\cdot001$) of Rizvi and Sen (1967) who measured the $\alpha_K$ from the $e^- - \gamma$ correlation. Unfortunately, the presence of a large background (figure 4) introduces an appreciable error in our measurement of $\alpha_K$ for this gamma ray. The random summing of two 569·7 keV gamma rays is found to be absent in our study after suitably suppressing the x rays in the decay of $^{207}$Bi. So its contribution to the sum-peak area is neglected.

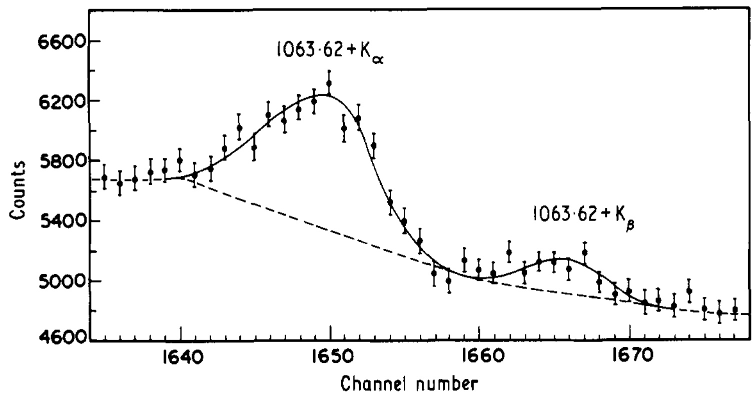



**Figure 4.** The $(1063{\cdot}62 + K_\alpha)$ keV sum peak in the decay of $^{207}$Bi showing the large background spectrum.

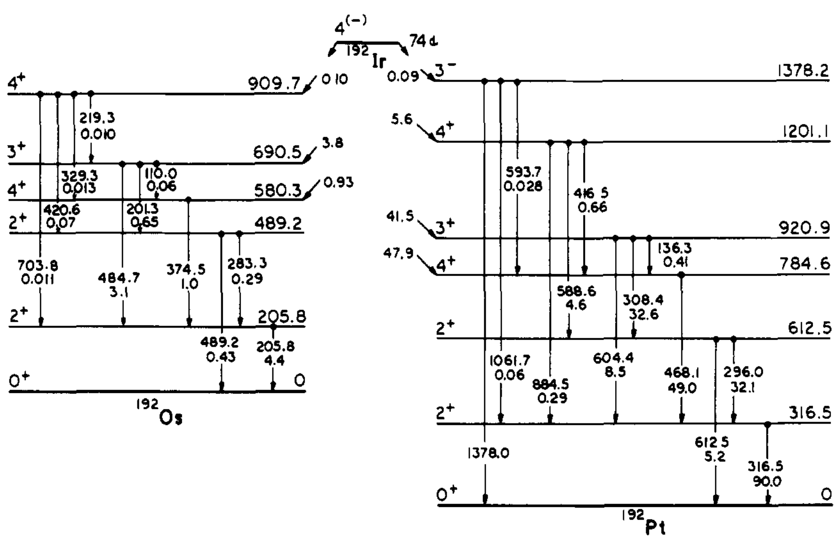
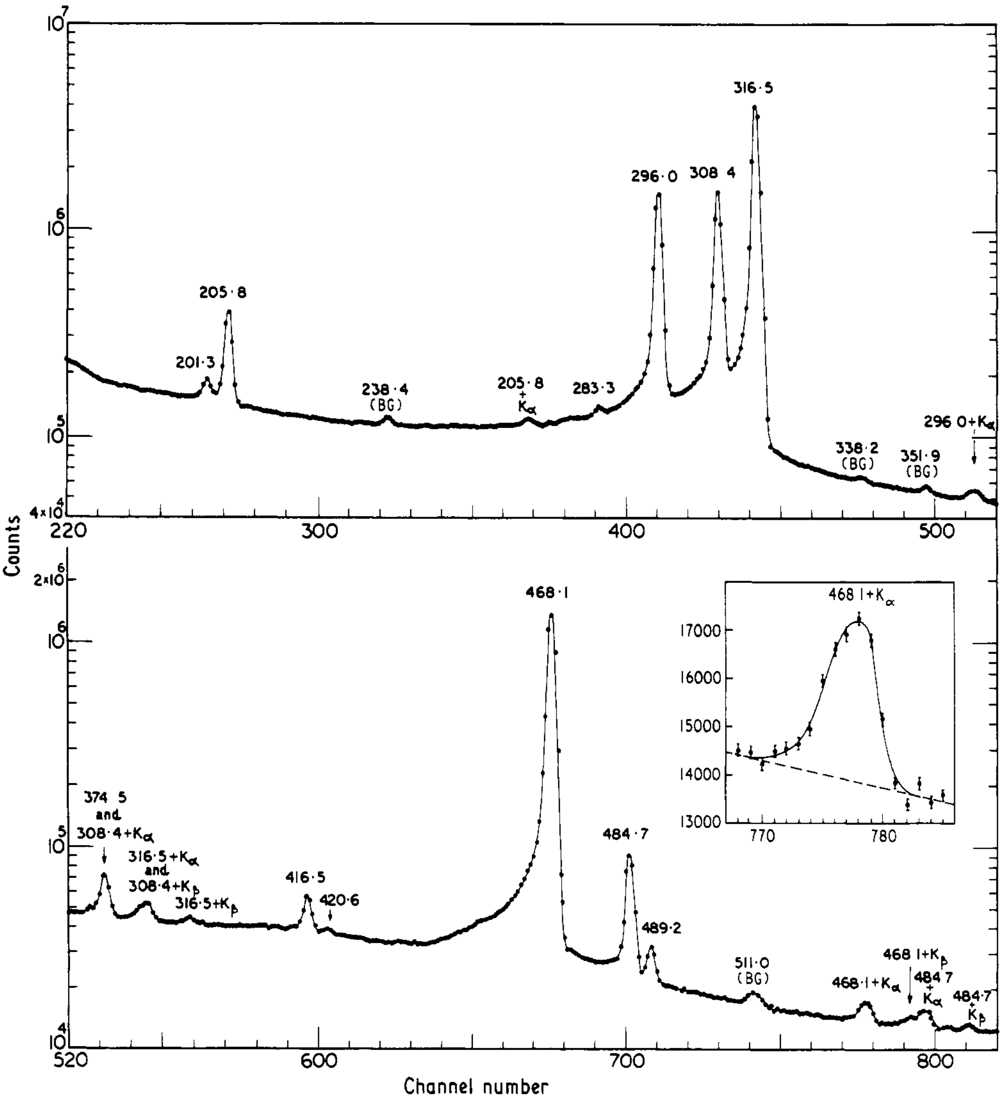



**Figure 5.** Decay scheme of $^{192}$Ir as determined in the present work. The gamma ray intensities are per 100 disintegrations with uncertainty 3% to 30% depending on the strength of the transitions.

### 2.3. $\alpha_K$ of the 316·5 keV transition in the decay of $^{192}Ir$

The decay scheme of $^{192}$Ir has very recently been investigated by us. The details of this work will be reported elsewhere. The revised decay scheme of this isotope is shown in figure 5. Figure 6 shows the gamma-ray spectrum of the $^{192}$Ir decay in the close geometry set up. Although we observe a number of $(Kx + \gamma)$ sum peak, due to the complex decay scheme of $^{192}$Ir only two sum peaks: $(468{\cdot}1 + K_\alpha)$ keV and $(604{\cdot}4 + K_\alpha)$ keV have been found to be suitable for the measurement of the $\alpha_K$ of the 316·5 keV transition. From the decay scheme of $^{192}$Ir (figure 5), it is observed that the sum peak $(468{\cdot}1 + K_\alpha)$ arises mainly due to the summing of the 468·1 keV gamma rays with the Kx rays following the K conversion of the 316·5 keV transition in cascade. The contribution from the other gamma rays in the cascade (136·3, 416·5 and 593·7 keV) can be nelgected, considering the intensity of these transitions relative to that of the 316·5 keV transition. This assumption



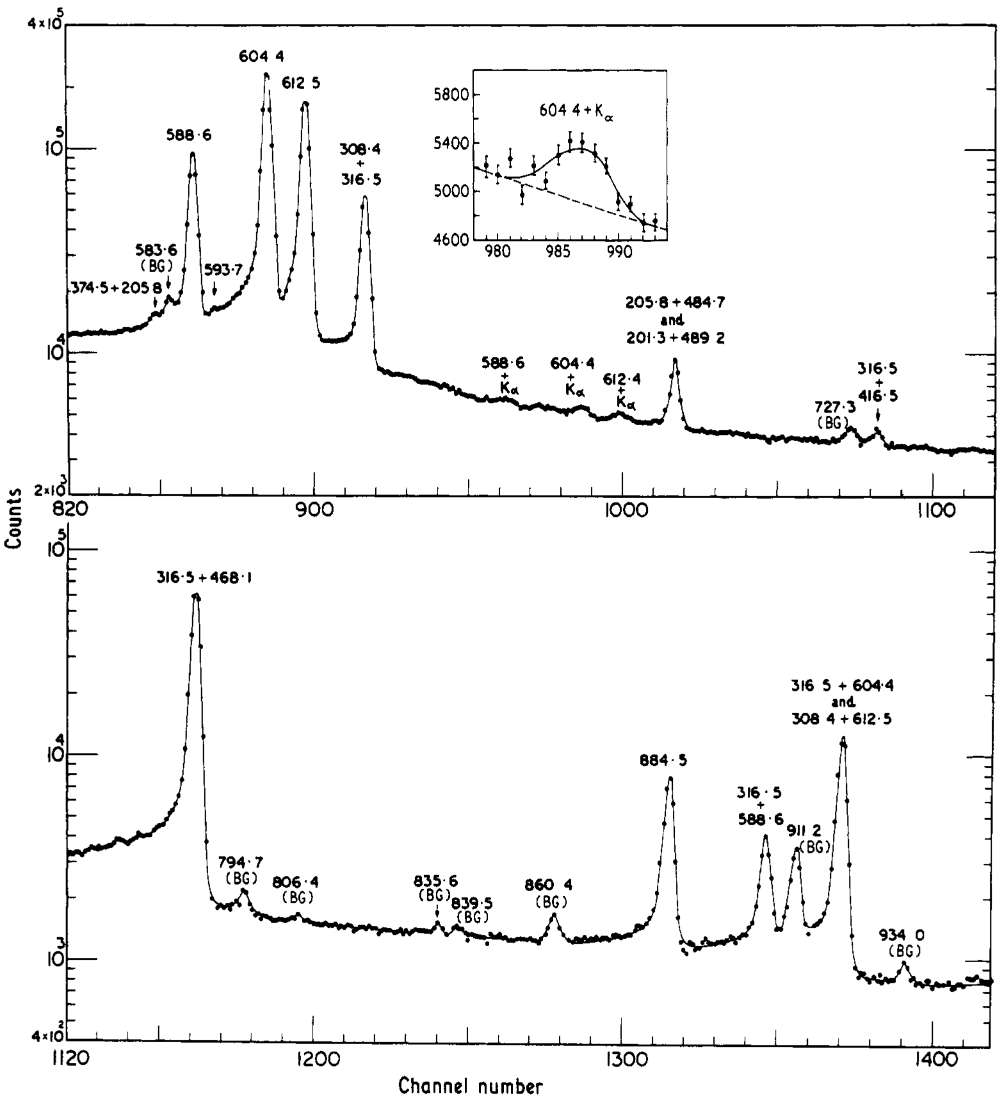



**Figure 6.** A typical gamma ray spectrum of $^{192}$Ir with the source on the top of the 32·2 cm$^3$ Ge(Li) detector.

is further supported from the area of the (136·3 + 316·5) keV and (416·5 + 316·5) keV sum peaks (figure 6).

Under this approximation the area under the sum peak (468·1 + $K_\alpha$) keV can be expressed as

$$N^{\text{sum}}_{468\cdot1+K_\alpha} = \omega_K f_{K_\alpha} \frac{\epsilon_{K_\alpha}}{\epsilon_{316\cdot5}} \alpha_K^{316\cdot5} N^{\text{sum}}_{316\cdot5+468\cdot1}. \tag{3}$$

The (604·4 + $K_\alpha$) keV sum peak arises from the summing of the 604·4 keV gamma rays with the Kx rays following the K conversion of the 316·5 keV transition. The area under this sum peak can be expressed as

$$N^{\mathrm{sum}}_{604\cdot4+\mathrm{K}_\alpha} = \omega_{\mathrm{K}} f_{\mathrm{K}_\alpha} \frac{\epsilon_{\mathrm{K}_\alpha}}{\epsilon_{316\cdot5}} \alpha_{\mathrm{K}}^{316\cdot5} N^{\mathrm{sum}}_{316\cdot5+604\cdot4}. \tag{4}$$

However, since the 920·9 keV state of $^{192}$Pt decays to the ground state via two dominant cascades: 604·4 keV–316·5 keV and 308·4 keV–612·5 keV, the total sum-peak area (figure 6) must be corrected for the contribution of the 308·4 keV–612·5 keV cascade. From the known branchings (figure 5) it is possible to extract the appropriate area for the (604·4 + 316·5) keV sum peak. From the analysis of our data the $\alpha_{\mathrm{K}}$ of the 316·5 keV transition is found to be $0{\cdot}052 \pm 0{\cdot}004$ and $0{\cdot}049 \pm 0{\cdot}007$ from equations (3) and (4) respectively. The comparatively greater uncertainty in the analysis of the (604·4 + $\mathrm{K}_\alpha$) sum peak is mainly due to the poor statistics of the above sum peak. The weighted average of these two values yield $\alpha_{\mathrm{K}}^{316\cdot5} = 0{\cdot}0513 \pm 0{\cdot}0035$, in good agreement with the theoretical E2 value 0·0539 (Hager and Seltzer 1968).

## 3. Conclusion

The present study indicates the possibility of a measurement of the absolute K-conversion coefficients of gamma rays from the study of a single gamma-ray spectrum. A clear advantage of this method is the determination of the $\alpha_{\mathrm{K}}$ from the ratios of the sum-peak areas and the efficiencies (equations (2)–(4)) and thus the accuracy in the measurement of the $\alpha_{\mathrm{K}}$ can be improved with good statistics. The method, however, is limited to the transitions having appreciable conversion probability and hence cannot be applied to the measurement of the $\alpha_{\mathrm{K}}$ of the weak transitions. The last mentioned disadvantage is also present in the other methods (Hultberg and Stockendal 1959, Mukherjee 1960). The present method is particularly advantageous for the short-lived isotopes, when a long time scanning of the conversion electron spectra becomes difficult.

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