Double gamma decay in ^{90}Zr

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In this work we observed a net peak corresponding to the double gamma decay in ^{90}Zr without any background subtraction. We set a value of $W_{\gamma\gamma}/W_{\rm tot}$ equal to $2.2(7)\times 10^{-4}$ assuming the resulting $\langle 2E1\rangle/\langle 2M1\rangle$ ratio of a recent experiment.

Many attempts have been made in the last 30 years to detect double photon transitions in atomic and nuclear systems.[1-6] In atomic physics the two-photon absorption and emission are very well-known processes and the theoretical predictions agree with the experimental results.[1] The situation is quite different in the nuclear case because two-gamma transitions have a very low probability to occur and consequently are difficult to observe. The most experimentally promising cases to study the double gamma decay in nuclei are to be found in transitions between two low-lying 0^+ states, usually in ^{16}O, ^{40}Ca, and ^{90}Zr, where there is no competition with single gamma transitions.

Double gamma decay in ^{90}Zr has been recently observed in an experiment[5] using the Heidelberg-Darmstadt "crystal-ball," where the first excited level [$0_2^+, E=1760.7$ keV, $T_{1/2}=61$ ns (Ref. 7)] of ^{90}Zr was populated by inelastic proton scattering (on-line experiment). Their authors set a double gamma decay branching ratio (double gamma decay rate/0_2^+ decay rate) equal to $1.8\ (2)\times 10^{-4}$ for a mixing of $2E1$ and $2M1$ transitions. In the literature there also exist two earlier experiments[3,4] that used samples of ^{90}Sr [$T_{1/2}=28.8$ y (Ref. 7)] which decay to ^{90}Zr via ^{90}Y (off-line experiments) and also obtained values for the double gamma decay branching ratio: $5.1(25)\times 10^{-4}$ by Nakayama[3] and $3.17(77)\times 10^{-4}$ by Asano and Wu,[4] both assuming a pure $2E1$ transition. Poor energy and time resolutions as well as background and statistical problems did not allow them to observe a clear peak corresponding to the double gamma decay in ^{90}Zr. In this Brief Report we present the results of our measurements based essentially on the same technique, but with an improvement in the experimental conditions that enabled us to observe a net double gamma peak.

To populate the 0_2^+ level of ^{90}Zr a sample of ^{90}Sr with an activity of 0.6 mCi was used. The only impurity found was ^{60}Co with 0.16 μCi. A lucite cylinder containing the ^{90}Sr sample was placed inside a lead cylinder of 2-mm wall thickness. Gamma rays were detected with two coaxial semiconductor detectors placed at 180° [53 cm^3 Ge(Li) and 104 cm^3 HPGe]. Their energy resolutions at 662 keV were 2.6 keV [Ge(Li)] and 1.8 keV (HPGe). An external lead shield was used to reduce the intensity of the 1764-keV gamma ray of ^{214}Bi. This gamma ray can be scattered by one detector and completely absorbed in the other detector, causing a peak in the sum-energy spectrum close to the 1761-keV double gamma decay peak.

Four measurements were carried out with two different data acquisition systems. In the first and second measurements the linear signals from the detectors were summed and the resulting signal, after being analyzed by a single analog-to-digital converter (ADC), was stored in a PDP-11/84 computer as one-parameter data. The ADC was gated by the logic signal from a fast coincidence circuit with a time resolution of 10 ns. With this one-dimensional data acquisition it was possible only to obtain information about the double gamma decay intensity. In the third and fourth measurements a two-parameter data acquisition system was used: two ADC's and a two-parameter synchronizing device were employed to register the linear signals of both detectors. By storing the data in a two-dimensional spectrum the double gamma decay energy distribution could, in principle, be obtained.

The first measurement consisted of 200 h of data acquisition. The double gamma peak at 1761 keV [Fig. 1(a)] appears in a doublet together with the 1764-keV peak from ^{214}Bi as a result of insufficient shielding. The continuous background comes mainly from the bremsstrahlung of the β^- particles emitted by the source. It was not possible to identify the peak at 1745 keV with any background event; it could be caused by the temporary presence of some gamma source in the neighborhood of the apparatus.

In the second measurement the 1764-keV peak from ^{214}Bi did not show up [Fig. 1(b)] because a larger shield was used. The continuous background is smaller because higher-energy thresholds (≈ 525 keV) were adopted. The smaller amount of events in the double gamma peak is caused by the shorter running time (42 h).

The same experimental setup was used in the third measurement, but with the two-parameter data acquisition system; the resulting double gamma peak is shown in Fig. 1(c). Although the running time was quite large (314 h) the double gamma peak has a small number of events. This is due to some change in the detector's position.

In the fourth measurement the efficiency was largely improved by approximating the detectors. After 204 h of data acquisition, the double gamma peak became evident [Fig. 1(d)].

It is important to note that in analyzing the data no background subtraction was necessary because the dou-

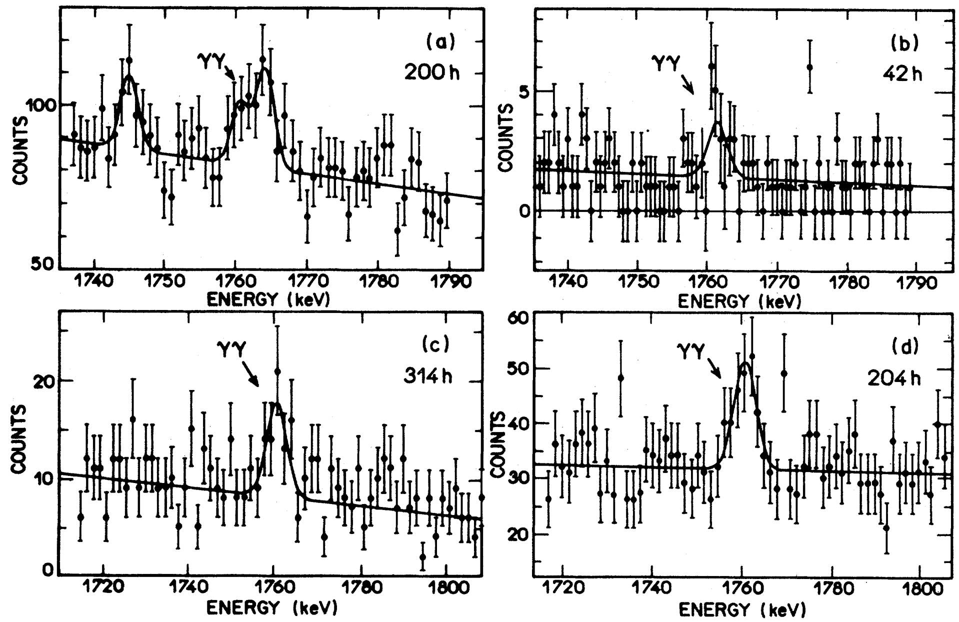

FIG. 1. Sum-energy spectra in the double gamma (1761 keV) region: (a), (b), (c), and (d) correspond to the first, second, third, and fourth measurements, respectively. The solid lines are adjusted peak functions with linear background.

ble gamma peak could be directly seen in all spectra. To obtain the spectra shown in Figs. 1(c) and 1(d) we projected the countings belonging to the same diagonal of constant sum energy. More details about the experiment and the data analysis can be found in Ref. 8.

In evaluating the double gamma branching ratio we initially supposed a double dipole emission with no mixing; Table I shows the four values obtained and also the adjusted mean value of $3.9(7)\times 10^{-4}$. The poor reduced χ^2 value, 2.7, may indicate the existence of some errors that were not taken statistically into account. In such a situation it is permitted to multiply the final standard deviation by the square root of the reduced χ^2.[9] This procedure leads to a double gamma branching ratio equal to

$$W_{\gamma\gamma}/W_{\rm tot}=3.9(12)\times 10^{-4} \; . \qquad (1)$$

This value is in agreement with the results set by Nakayama[3] and Asano and Wu.[4] In order to compare our result with the one reported by Schirmer and collaborators,[5] it is necessary to suppose a mixing between dipolar transitions. This comes from the fact that in studying the directional correlations of the double gamma decay in ^{40}Ca and in ^{90}Zr, they found an asymmetry around 90° interpreted as an interference between $2E1$ and $2M1$ transitions. If we assume this mixing and use their ratio $\langle 2E1\rangle/\langle 2M1\rangle$ in our branching calculations our final result became

$$W_{\gamma\gamma}/W_{\rm tot}=2.2(7)\times 10^{-4} \; , \qquad (2)$$

in close agreement with the result of Ref. 5.

The statistics in our third and fourth measurements were not high enough to let us get some new information

TABLE I. Results obtained in the four double gamma decay measurements assuming pure and mixed double dipole emission. The adjusted mean value and the reduced χ^2 are also indicated.

Measurement	Number of events	$W_{\gamma\gamma}/W_{\rm tot}$ ($2E1$ or $2M1$)	$W_{\gamma\gamma}/W_{\rm tot}$ ($2E1+2M1$ of Ref. 7)
1	60±23	$(5.9\pm 2.4)\times 10^{-4}$	$(3.3\pm 1.3)\times 10^{-4}$
2	13±5	$(7.7\pm 3.1)\times 10^{-4}$	$(4.3\pm 1.7)\times 10^{-4}$
3	33±10	$(2.6\pm 0.9)\times 10^{-4}$	$(1.4\pm 0.5)\times 10^{-4}$
4	84±20	$(7.3\pm 1.8)\times 10^{-4}$	$(4.0\pm 1.0)\times 10^{-4}$
Adjusted mean value		$(3.9\pm 0.7)\times 10^{-4}$	$(2.2\pm 0.4)\times 10^{-4}$
$\chi^2_{\rm red}$		2.7(4%)	2.7(4%)
Adjusted mean value		$(3.9\pm 1.2)\times 10^{-4}$	$(2.2\pm 0.7)\times 10^{-4}$
$\chi^2_{\rm red}$		1.0	1.0

about the double gamma decay energy distribution. The experimental data are compatible with a pure double dipole emission ($2E1$ or $2M1$) but do not exclude other possibilities.

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