DIRECT AND COMPOUND GAMMA DECAY OF THE GIANT QUADRUPOLE RESONANCE OF ^{208}Pb

J.R. BEENE

Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

G.F. BERTSCH, P.F. BORTIGNON [1,2,3]

Department of Physics & Astronomy, University of Tennessee, Knoxville, TN 37996-0154, USA and Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

and

R.A. BROGLIA

The Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen Ø, Denmark and Department of Physics & Astronomy, University of Tennessee, Knoxville, TN 37996-0154, USA

Received 1 August 1985

The gamma decay of the giant quadrupole resonance in ^{208}Pb is estimated to have comparable probability through the compound nucleus as by direct decay. Measurements are suggested where the giant resonance is expected to display mainly a direct gamma branch.

We have recently investigated the properties of the giant quadrupole resonance (GQR) of ^{208}Pb by measurements [1] and calculations [2] of gamma decays. These papers discuss primarily the direct decays from the resonance and leave the impression that this is the only important decay mode.

We wish to show here that compound decay can be significant and even mask the direct decays, depending on the specific systems studied.

The quantity measured is the gamma branching ratio P, which we may express as a sum of a direct component and a compound component,

$$P = P_d + P_c = \Gamma^{\gamma}_{GR}/\Gamma^{\downarrow} + \langle \Gamma^{\gamma}_c/\Gamma_c \rangle. \qquad (1)$$

Here Γ^{γ}_{GR} is the direct gamma decay width of the giant resonance, $\Gamma^{\downarrow}$ is the spreading width of the resonance, and Γ^{γ}_c and Γ_c are the gamma width and total width of an individual compound state. Eq. (1) assumes that the decay width is small compared to the total width of the resonance, which is well satisfied for the GQR. Numerically, for the GQR in ^{208}Pb, we have [1,3] $\Gamma^{\downarrow} \approx 2.5$ MeV. The Γ^{γ}_{GR} is estimated from the isoscalar energy-weighted sum rule [4] to be $\Gamma^{\gamma}_{GR} \approx 175$ eV.

The average gamma width of the compound $\langle \Gamma^{\gamma}_c \rangle$ can be calculated from the strength function associated with the GR,

$$S(E) = (\Gamma^{\gamma}_{GR}/2\pi)\, \Gamma^{\downarrow} / [(E - E_a)^2 + (\Gamma^{\downarrow}/2)^2]\,. \qquad (2)$$

At resonance this relation reads

$$\langle \Gamma^{\gamma}_c \rangle\, \rho(2^+; 11\ \text{MeV}) = (2/\pi)\, \Gamma^{GR}_{\gamma}/\Gamma^{\downarrow} \approx 10^{-4}, \qquad (3)$$

* This work was supported in part by the US Department of Energy under contract DE-AC05-840R21400 with Martin Marietta Energy Systems, Inc., and in part by the National Science Foundation.

[1] On leave from Dipartimento di Fisica Galileo Galilei, Università di Padova, Padua, Italy.

[2] INFN, Legnaro, Italy.

[3] Supported by MPI, Italy.

0370-2693/85/$ 03.30 © Elsevier Science Publishers B.V. (North-Holland Physics Publishing Division)

Table 1
Estimate of neutron decay width of compound states at ≈ 11 MeV excitation in ^{208}Pb.

l	j	$S_l \times 10^4$	Number of transitions to ^{207}Pb	$\langle v_l (K/1\text{ eV})^{1/2}\rangle \times 10^{-3}$	$\rho\Gamma_c^l$
0		0.9 [6]	1	0.99	0.09
1	1/2	0.42 [7]	2	1.52	0.13
	3/2	0.28 [7]	4	1.42	0.16
2		0.9	5	0.31	0.14
3		0.35	7	0.54	0.13
4		0.9	1	0.17	0.02
				total	$\rho\Gamma_c = 0.67$

where ρ is the density of compound levels in the GQR region. Using a constant temperature model [5], we estimate about 10^3 $J^\pi = 2^+$ per MeV at 11 MeV of excitation. Thus $\langle\Gamma_c^\gamma\rangle \approx 0.1$ eV.

The neutron decay of the compound levels dominates their total width Γ_c. In the compound nucleus model the average Γ_c is related to the partial wave neutron strength function S_l by

$$\rho\Gamma_c = \sum_i\sum_l (2l+1)\, S_l v_l^{(i)} (K^{(i)}/1\text{ eV})^{1/2}. \qquad (4)$$

Here i labels final states in the A^{-1} nucleus, and the sum over neutron angular momentum l includes all values allowed by the spins of the initial and final states. The energy of the neutron above threshold is denoted by K. The v_l are the centrifugal barrier penetration factors defined in ref. [6], with $v_0 = 1$ and $v_l \approx (kR)^l/[(2l-1)!!]^2$ for large l. In table 1 we display the evaluation of eq. (4) using refs. [6,7] for measured S_l and assuming the same values for higher angular momenta. The v_l were computed using a nuclear radius of $R = 8$ fm. With a level density of $\rho \approx 1000$/MeV, the compound decay width is $\langle\Gamma_c\rangle \sim 0.7$ keV.

Inserting the estimates for the various widths in eq. (1), we obtain

$$P \approx 175\text{ eV}/2.5\times 10^6\text{ eV} + 0.1\text{ eV}/700\text{ eV}$$

$$\approx 10^{-4} + 10^{-4}. \qquad (5)$$

The observed gamma-branching ratio GQR → gs is $\approx 3\times 10^{-4}$, which is 3 times larger than allowed by energy-weighted sum-rule arguments, if only direct decay is considered. The result (5) shows that, in principle, there is no contradiction between theory and experiment.

In ref. [2] it was stated that Γ_c^γ is negligible compared to Γ_{GR}^γ for a particular transition to an excited state. While true, this is irrelevant because its contribution to the experimental ratio (1) depends on the ratio of Γ_c^γ to Γ_c, rather than on the relative magnitude of Γ_c^γ and Γ_{GR}^γ.

The above result shows that while the experimental ratio P of eq. (1) can be used to measure the E2 resonance strength, the result depends on estimates of the average total widths of compound states. However, in the light of this result, it is easy to find situations which reduce the compound decay background to a negligible level.

For example, if the experiment reported in ref. [1] was repeated using a ^{209}Bi target, the neutron decay daughter would be ^{208}Bi, which has an order of magnitude larger density of transition channels from the ^{209}Bi compound state.

The nucleus $^{90}_{46}$Zr turns out to also be a favorable case to study. Although the density of states in the $N = 49$ neutron system is not particularly high, the p-wave strength function is very large because of a single-particle p-wave resonance near threshold.

Gamma decay studies of the isovector quadrupole would have a low background. The direct decay frame $\Gamma_{GR}^\gamma/\Gamma^\downarrow$ is roughly the same, whereas $(\Gamma_c^\gamma/\Gamma_c)$ is much smaller because of the large density of final states available to the neutron decay. These isovector states would be particularly interesting to study [2,8] because the associated E1 decays would not be quenched as they are in the decay of the isoscalar GQR.

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