Alpha decay of giant resonances in Ni^{58} nuclei

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Cross sections have been measured for $Ni^{58}(e,e'p)$ and $Ni^{58}(e,e'\alpha)$ reactions. Virtual photon spectra calculated in the distorted wave Born approximation have been used to analyze the experimental results. An electric quadrupole ($E2$) giant resonance has been found which decays principally by the emission of α-particles.

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The study of decay paths for giant multipole resonances gives important information concerning the discharge mechanism for the collective excitation of nuclei. In this work we study proton and α-particle decay channels for giant resonances in Ni^{58} nuclei excited by electrons.

We measured cross sections for the $Ni^{58}(e,e'p)$ and $Ni^{58}(e,e'\alpha)$ reactions for electrons in the range 12–35 MeV. Figure 1a,b shows the cross sections for the $(e,e'p)$ and $(e,e'\alpha)$ reactions, respectively, as a function of electron energy (circles). It is well-known that the electronuclear reaction cross sections $\sigma_{e,x}(E_0)$ are related to the corresponding photonuclear reaction cross sections $\sigma^{\lambda L}_{\gamma,x}(E_\gamma)$ by the following equation:

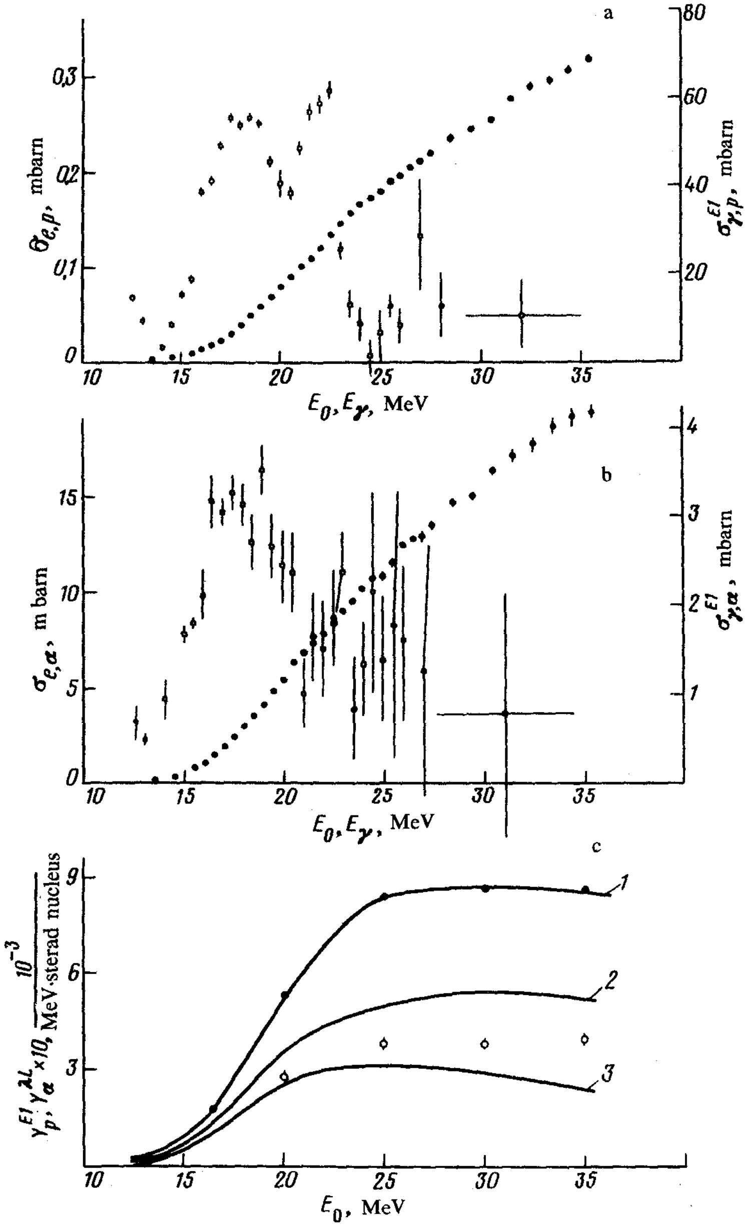

FIG. 1. a–Cross section for the $Ni^{58}(e,e'p)$ reaction (circles) and the $Ni^{58}(\gamma,p)$ reaction under the assumption that all the transitions are $E1$ transitions (squares); b–same as Fig. 1a, but for the $Ni^{58}(e,e'\alpha)$ and $Ni^{58}(\gamma,\alpha)$ reactions; c–measured emission of protons (dark circles) and α-particles (open circles) correspondingly in the $Ni^{58}(\gamma,p)$ and $Ni^{58}(\gamma,\alpha)$ reactions. Curves 1 and 2 are the expected emission respectively of protons and α-particles under the assumption of $E1$ transitions. Curve 3 is the same as curve 2, but under the assumption of $E2$ transitions. The measured proton emission is normalized to curve 1 at an arbitrary point.

$$\sigma_{e,x}(E_0) = \int_{E_{th}}^{E_0 - m_0 c^2} \sum_{\lambda L} \sigma_{\gamma x}^{\lambda L}(E_\gamma) N_V^{\lambda L}(E_0, E_\gamma) E_\gamma^{-1} dE_\gamma, \quad (1)$$

where $N_V^{\lambda L}(E_0,E_\gamma)$ is the virtual photon multipole spectrum λL which we computed according to Ref. 1, E_{th} is the kinematic threshold for the reaction, and E_0 is the electron energy.

The contribution of transitions of different multipolarity to the $(e,e'\alpha)$ reaction cross section is unknown *a priori*. It may be determined by comparing the measured $\sigma_{e,x}(E_0)$ with the measured integral photonuclear reaction cross sections:

$$Y_{\gamma,x}(E_0) = \int_{E_{th}}^{E_0 - m_0 c^2} \sum_{\lambda L} \sigma_{\gamma,x}^{\lambda L}(E_\gamma) \frac{dN_{br}(E_0, E_\gamma)}{dE_\gamma} dE_\gamma, \quad (2)$$

where $dN_{br}(E_0,E_\gamma)/dE_\gamma$ is the bremsstrahlung spectrum. The expected values $Y_{\gamma,x}^{\lambda L}(E_0)$ calculated using the $\sigma_{\gamma,x}^{\lambda L}(E_\gamma)$ values obtained according to Eq. (1) under the assumption that all transitions in $(e,e'x)$ reactions are either $E1$ (squares in Fig. 1a–$\sigma_{\gamma,p}^{E1}(E_\gamma)$, Fig. 1b–$\sigma_{\gamma,\alpha}^{E1}(E_\gamma)$), or $E2$ transitions shown in Fig. 1c (1–$Y_{\gamma,p}^{E1}(E_0)$, 2–$Y_{\gamma,\alpha}^{E1}(E_0)$, 3–$Y_{\gamma,\alpha}^{E2}(E_0)$).

The problem of determining the contribution of the $E1$ and $E2$ transitions to the $(e,e'\alpha)$ reaction cross section is substantially simplified, since it is known with an accuracy of $\sim 1\%$ that $(e,e'p)$ and $(e,e'n)$ reactions take place due to the exchange of virtual $E1$ photons at least on light and medium nuclei,[2,3] i.e., with the indicated accuracy $Y_{\gamma,p}(E_0) \approx Y_{\gamma,p}^{E1}(E_0)$. Because of this we may restrict ourselves only to relative measurements of $Y_{\gamma,p}(E_0)$ and $Y_{\gamma,\alpha}(E_0)$. In Fig. 1c the dark circles show the measured $Y_{\gamma,p}(E_0)$ normalized to curve 1 at an arbitrary point; the open circles (whose positions are uniquely determined by the indicated normalization of the $Y_{\gamma,p}(E_0)$) are the measured $Y_{\gamma,\alpha}(E_0)$ values.

The measurements clearly indicate that the $(e,e'\alpha)$ reaction is not due to only $E1$ transitions. The contribution of the $E1$ and $E2$ transitions to the $(e,e'\alpha)$ reaction cross section was determined by using the standard technique of parameter selection for the assumed (Lorentz) curves for the $\sigma_{\gamma,\alpha}^{E1}$ and $\sigma_{\gamma,\alpha}^{E2}$ cross section of the $(e,e'\alpha)$ and the yield (γ,α) of the reactions. The resonance parameters are the position ω_0, the width at half height Γ, and the integral cross sections and their ratios S to the cross sections obtained from the corresponding sum rules ($\sigma_0^{E1} = 60\ ZN/A$ MeV mbarn and $\sigma_{-2}^{E2} = 0.22\ Z^2/A^{1/3}$ MeV. μbarn), given in Table I. Also given in the table is the integral cross section for the $Ni^{58}(\gamma,p)$ reaction.

It follows from the data given in the table that we have found an $E2$ giant resonance in the α-particle decay path for giant resonances of Ni^{58} nuclei, whose strength which is concentrated near an excitation energy of 16 MeV makes up 35–60% of the total strength of the isoscalar $E2$ transitions. For an excitation energy of 19 MeV corresponding to $E1$ transitions the ratio of $\sigma_{\gamma,\alpha}^{E1}$ to the total photoabsorption cross section is 1.5%. This ratio remains approximately the same for $E1$ excitation even for

TABLE I.

$Ni^{58}(\gamma, p)$			$Ni^{58}(\gamma, \alpha)$		
$\int_0^{30} \sigma(E_\gamma)dE_\gamma$ MeV·mbarn	multi-polarity	ω_0 MeV	Γ MeV	$\int\sigma(E_\gamma)dE_\gamma$ MeV·mbarn	S %
539 ± 33	$E1$	19,1 ± 1,0	4,6 ± 0,4	15,9 ± 2,3	1,8 ± 0,3
570 ± 60 [4]	$E2$	16,0 ± 1,0	2,5 ± 0,5	5,4 ± 1,4	47 ± 12

$E_\gamma = 16$ MeV, i.e., even in this region of excitation energies the number of open proton and neutron decay channels is significantly larger than for α-particles. At the same time, the ratio of $\sigma_{\gamma,\alpha}^{E2}$ to the total photoabsorption cross section for $E2$ transitions at $E_\gamma = 16$ MeV is about 50%. Such a large relative intensity for the α-decay of the $E2$ giant resonance apparently suggests a nonstatistical mechanism for the emission of α-particles and indicates the predominance of semidirect and direct mechanisms.[5,6] At the present time analogous measurements for Ni^{60} nuclei have been processed.

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[1]W.W. Gargaro and D.S. Onley, Phys. Rev. **C4**, 1032 (1971).
[2]W.C. Barber, Phys. Rev. **111**, 1642 (1958).
[3]E. Wolynec, G. Moscati, *et al.*, Phys. Rev. **C11**, 1083 (1975).
[4]B.S. Ishkhanov, I.M. Kapitonov, *et al.*, Yad. Fiz. **11**, 485 (1970) [Sov. J. Nucl. Phys. **11**, 272 (1970)].
[5]L.A. Sliv, Phys. Lett. **58 B**, 266 (1975).
[6]N. Shikazano and T. Terasawa, Nucl. Phys. **A250** (1975).