Observation of a giant Gamow-Teller resonance in the compound nucleus ^{118}Sb

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A new approach to the study of Gamow-Teller resonances based on the observation of these resonances in *compound* nuclei has been tested experimentally on the reaction $^{117}\mathrm{Sn}(p,n)^{117}\mathrm{Sb}$. A resonance found in the excitation function $\sigma_{pn}(E_p)$ has parameter values ($E_R = 7.17$ MeV, $\Gamma = 0.99$ MeV, $\Gamma_p = 50$ keV) close to those expected for a 1^+ Gamow-Teller resonance in the compound nucleus ^{118}Sb.

1. The search for isobaric collective 1^+ states similar in structure to the analog 0^+ states led to the observation of Gamow-Teller resonances in the state spectra of the *final* nuclei formed in direct charge-exchange reactions at $E_p = 25$–200 MeV (Ref. 1). With increasing proton energy and with decreasing neutron emission angle, the contribution of the Gamow–Teller resonance to the spectrum of excited collective states increases. The broad Gamow-Teller peak ($\Gamma \simeq 2$–4 MeV) lies above a narrow analog resonance on the excitation-energy scale; the distance (gap) between the two features decreases with increasing A and N–Z.

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The possibilities of studying Gamow-Teller resonances in direct *pn* reactions at large values of E_p are seriously limited because of the complexity of measuring the partial widths and the degradation of the energy resolution, which is $\Delta E \simeq 1.3$ MeV at 200 MeV.

In this letter we wish to discuss an alternative method for studying Gamow-Teller resonances, based on the observation of these resonances in the excitation function of a *pn* reaction, i.e., as a resonance of a *compound* nucleus which lies above the analog resonance on the proton-energy scale by an amount equal to the gap. By measuring the excitation function on a tandem electrostatic accelerator with a resolution $\Delta E_p \leqslant 10$ keV, one can study the structure of the fragmented Gamow-Teller resonances and distinguish the contributions of the narrow analog resonances from the background of the broad Gamow-Teller resonance. In this approach, not only the total widths but also the partial widths of the neutron and proton decay of the Gamow-Teller resonance can be determined by a simple procedure. We have no other information on the latter widths.

According to the estimate of Ref. 2, the proton widths of a Gamow-Teller resonance and an analog resonance are close in order of magnitude, but the total width of a Gamow-Teller resonance is roughly 60 times that of an analog resonance. We would thus expect the cross section ($\sigma_{\rm res}$) at the peak of the 1^+ Gamow-Teller resonance to be about 20 times smaller than that for a 0^+ analog resonance at the same proton energy. The ratio of $\sigma_{\rm res}$ of a 1^+ Gamow-Teller resonance to the nonresonant cross section for the *pn* reaction, σ_{pn}, is estimated to be ~ 0.05 for nuclei with $A \simeq 120$.

2. We have searched for a 1^+ Gamow-Teller resonance in the excitation function of the reaction $^{117}\mathrm{Sn}(p,n)^{117}\mathrm{Sb}$, which we chose because of the following circumstances. In the compound nucleus $^{118}\mathrm{Sb}$, the first 0^+ analog resonance is comparatively low, at $E_p = 4.491$ MeV. According to the systematics of Ref. 3, the gap between the analog resonance and the Gamow-Teller resonance in $^{118}\mathrm{Sb}$ is 2.479 MeV. The expected position of the resonance is $E_{\rm GT} = 6.99 \pm 0.25$ MeV, so that it can be studied over a rather broad range of energies which are accessible under the operating conditions of the ÉGP-10 accelerator. The population of the 1^+ Gamow-Teller resonance in $^{118}\mathrm{Sb}$ from the ground state of the target nucleus, $^{117}\mathrm{Sn}(1/2^+)$, can occur in a single-step process only if induced by protons with $l = 0$, for which the attachment coefficients $T_{pl}(E_{\rm GT})$ are sufficiently large.

The integral yield of neutrons from a thin ($d = 0.27$ mg/cm^2), self-standing target with a $^{117}\mathrm{Sn}$ abundance of 89.3% was measured from 4 to 11 MeV with a highly efficient 4π detector consisting of a cylindrical paraffin block (530 mm in diameter, $h = 425$ mm) with 40 apertures for $^3\mathrm{He}$ proportional counters. The target was placed at the axis at the center of the detector inside an ion duct. The monitoring was carried out on the basis of the charge Q in a Faraday cup, which was measured by a current integrator. Two semiconductor counters were used to measure the constancy of the effective thickness of the target. These counters measured the flux density of Coulomb-scattered protons at two angles from the beam axis, $\pm 20°$. The statistical error of the measurements of the neutron yield, N_n/Q, and of the proton flux density, N_p/Q, was less than 1%. In analyzing the excitation functions, we took into account the contributions from impurities of other tin isotopes in the target and also the neutron background from protons scattered by the wall of the ion duct. Comparison of the data on $\sigma_{pn}(E_p)$ with the published data[4] reveals a good agreement in the region $E_p \leqslant 6.3$ MeV.

3. The cross section $\sigma_{pn}(E_p)$ for the reaction ^{117}Sn(pn, n)^{117}Sb increases rapidly with increasing energy because of the penetrability factor of the Coulomb and centrifugal barriers. This trivial dependence can be eliminated by a conversion to the ratio $\sigma_{pn}(E_p)/\sigma_R(E_p)$, which is shown in Fig. 1. For the normalization we used values of σ_R calculated with an optical potential with the parameters found previously in a description of data on tin isotopes.[5]

Shown along with the group of narrow resonances, which are analogs of excited levels of ^{118}Sn ($E_x = 1.23$–3.06 MeV, $I^\pi = 0^+, 1^+, 2^+$), in Fig. 1, are two broad resonances, at $E_p \simeq 7$ and 10 MeV. The position of the first of these two resonances agrees well with that expected from the systematics of Ref. 3 for a 1^+ Gamow-Teller resonance in ^{118}Sb. We describe this resonance by the method of undetermined coefficients with two approximating functions: a Breit-Wigner formula and a formula which has been used to describe an asymmetric resonance.[6] In the latter case we found a better (in terms of min χ^2) description with the following parameters for the resonance: $E_R = 7.173 \pm 0.057$ MeV, $\Gamma = 0.99 \pm 0.12$ MeV, $\Gamma_p = 50$ keV $\pm 15\%$, an asymmetry parameter $\Delta = 170$ keV $\pm 26\%$, a symmetry parameter $\epsilon = 687$ keV $\pm 12\%$, and a mixing phase $\phi_c^R = 16° \pm 4°$. For the second resonance, the better description was

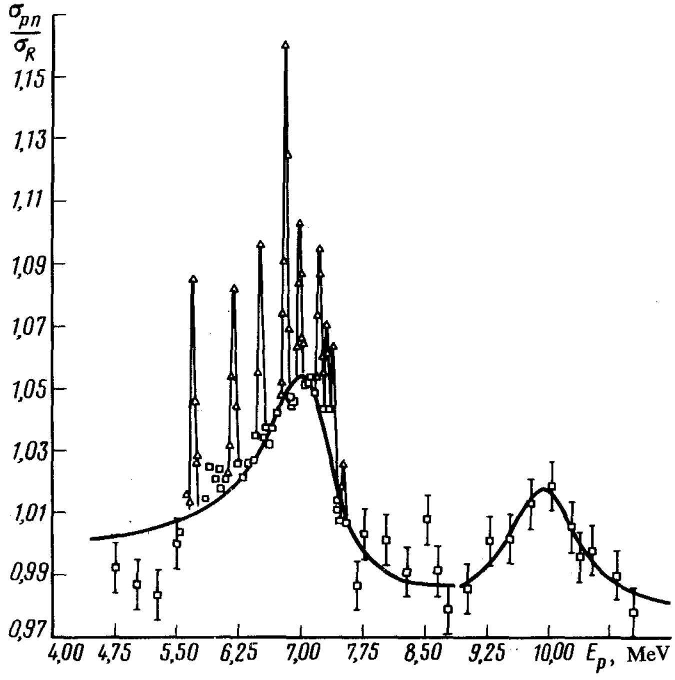

FIG. 1. The ratio σ_{pn}/σ_R versus the proton energy. Squares—experimental points used to generate the description of the Gamow-Teller resonance; solid curves—results of the description; triangles—experimental points pertaining to narrow analog resonances.

found with the Breit-Wigner formula with the parameters

$$E_R = 9{,}927 \pm 0{,}064\ \text{MeV},\quad \Gamma = 1{,}09 \pm 0{,}42\ \text{MeV},\quad \Gamma_p = 125 \pm 64\ \text{keV}.$$

The total widths of the two resonances are identical but roughly 3.5 times smaller than the widths of the Gamow-Teller resonances found in the nuclei ^{116,120}Sb in an experiment[7] with $\Delta E_n = 0.6$ MeV. The proton widths of the two resonances calculated for $I^\pi = 1^+$ are approximately equal to the corresponding widths, $\Gamma_p = 41$ and 115 keV, for the 0^+ analog resonance which were found by converting the known value $\Gamma_p = 1.8$ keV at $E_R = 4.491$ MeV (Ref. 8) to $E_R = 7.173$ and 9.927 MeV, respectively, on the basis of a Coulomb-penetrability function for $l = 0$. The mixing phase for the first resonance has the same sign but is two or three times smaller in magnitude than the phase for the analog resonance of the same energy.[6]

Parameter values have been predicted theoretically[2] for a 1^+ Gamow-Teller resonance in ^{118} Sb: $E_R = 6.4$ MeV, $\Gamma = 0.84$ MeV, and $\Gamma_p = 22.1$ keV. A conversion to $E_R = 7.173$ MeV yields $\Gamma_p = 38$ keV. The experimental and theoretical results on the total width and the proton width of the Gamow-Teller resonance are thus approximately equal.

The second resonance is similar to the first in terms of the total and proton reduced widths but lies 2.75 MeV higher. It may be that this is a second fragment of the Gamow-Teller resonance, corresponding (in contrast with the first) to a two-step excitation of the resonance through an inelastic proton entrance channel. In the first step there is a transition from the $s_{1/2}^{-1}$ ground state to the $d_{3/2}^{-1}$ excited state of the target nucleus, and in the second step there is a capture of the proton by the excited ^{117}Sn nucleus, accompanied by the formation of a Gamow-Teller resonance in the compound nucleus ^{118}Sb. An estimate of the inelastic proton width on the basis of Ref. 2 yields for $E_R = 9.93$ MeV the value $\Gamma_p(d_{3/2}^{-1}) = 107$ keV, which is comparable to the experimental value. The large total widths of the Gamow-Teller resonances in the nuclei ^{116,120}Sb (Ref. 7) are apparently due to a distribution of the strength of the Gamow-Teller transition different from that of the nucleus ^{118}Sb. It can be concluded from these results that the relaxation width of the individual fragments of the Gamow-Teller resonance in ^{118}Sb is about 1 MeV. The observation of large widths in experiments with a poor resolution ($\Delta E \sim 1$ MeV) can be attributed to the merging of several fragments into a broad common "resonance" with $\Gamma = 2$–4 MeV because of the intrinsic width of the fragments and ΔE.

The observation of a Gamow-Teller resonance in a compound nucleus opens up some new possibilities for studying the partial decay widths and the distribution of the strength of fragmented Gamow-Teller resonances. It would therefore be worthwhile to pursue this new approach in experiments on electrostatic accelerators.

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