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Quasielastic Electron Scattering and Giant Multipole Resonances in ^{116}Sn

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Electron-^{116}Sn scattering spectra were obtained over an excitation energy range of about 100 MeV. The experimental transverse spectrum is in good agreement with the Fermi-gas model, but not the longitudinal spectrum. The quasielastic contribution was then obtained from the shape of the transverse spectrum. The residual amount interpreted to be the resonance part was divided into many multipoles.

Inelastic scattering of electrons and hadrons from the nuclear continuum for a wide range of nuclei has revealed the existence of giant multipole resonances (GMR).[1] The GMR appear as bumps riding on a large continuous background. Accordingly major uncertainties in the GMR data arise from the approximations used for the background. In order to estimate this background, as a first step, the procedure of subtracting the contributions due to the electrons degraded through radiative effects is used. Then the quasielastic-electron-scattering contributions arising from electron collisions with the individual nucleons in the nucleus must be subtracted. However, since the same processes are involved in the GMR as for quasielastic scattering these two effects have not been considered to be distinct.[2,3]

Quasielastic electron scattering (QES) is a simple knockout reaction, which involves the proton and neutron form factors. In this process the longitudinal (charge) and transverse (magnetic) form factors are therefore comparable in magnitude, while in the collective electric multipole excitations the transverse form factor is reduced approximately to a fraction $(\omega/q)^2$ of the longitudinal form factor, where ω is the excitation energy and q is the momentum transfer.

According to the result[4] of 180° electron scattering from ^{197}Au in which only transverse terms contribute, the $M1+M3$ peak with a width of ~ 3 MeV has been observed at ~ 8 MeV while no indications have been found at the expected energies of the GMR. We infer that the transverse form factor is the sum of the individual excitations with rather single-particle character. Therefore the transverse form factor obtained from a Rosenbluth plot, or a 180°-scattering experiment, is confined to QES in the zeroth order and it may be used to determine the spectral shape for QES. The residual form factor is then interpreted as the resonance part and may be compared with the theoretical form factors obtained from the hydrodynamical model[5,6] to resolve the possible multipolarities of the various GMR.

Inelastic electron scattering from ^{116}Sn was measured with use of the beam of the Tohoku University 300-MeV electron linear accelerator at an overall resolution of 0.15%. The experiments were carried out at incident energies and angles of 150 MeV, 25°–35°; 183 MeV, 35°; 215 MeV, 35°; 250 MeV, 25°–75°; and 130 MeV, 155°. A range of about 100 MeV in excitation energy E_x was covered. The experimental arrangement has been described elsewhere.[7] We employed two 96%-enriched ^{116}Sn self-supporting targets of 92 and 124 mg/cm^2. The thicker one was used for experiments at 250 MeV, 65° and 75°, and at 130 MeV, 155°. The cross sections were normalized to elastic and inelastic electron-carbon cross sections. The spectra corrected for the radiative effects are displayed in Fig. 1. We have attempted the unfolding somewhat phenomenologically by varying the effective target thickness so as to achieve the fit in the region of the discrete levels. We believe that this method may be useful up to the region of the GMR; however, it becomes uncertain in the high-E_x side of QES. The negative value in the high-E_x region implies partly that the assumed energy dependence of the elastic and inelastic form factors may not be adequate.

The obtained cross-section spectra were divided by the Mott cross section and the form-factor spectra thus defined are shown in Fig. 1. Besides a broad bump of QES, peaks are evident around 5, 15, and 25 MeV in the low-q spectra. Roughly the QES peak for $q \geq k_F$ appears at $q^2/2M^*$ with a width of qk_F/M^*, where M^* is the effective nucleon mass and k_F the Fermi momentum. For $q < k_F$ the cross section is restricted by the Pauli principle and the peak deviates from $q^2/2M^*$. The obtained spectra are compared with the Fermi-gas model[8] at nonzero temperature ($T = 0.2$) where M^* is taken to be $0.8M$ and $k_F = 260$ MeV/c, which are consistent with the values so far known. The predicted curves fit the high-q spectrum, but disagree at low q, indicating an enhanced structure which overshoots the

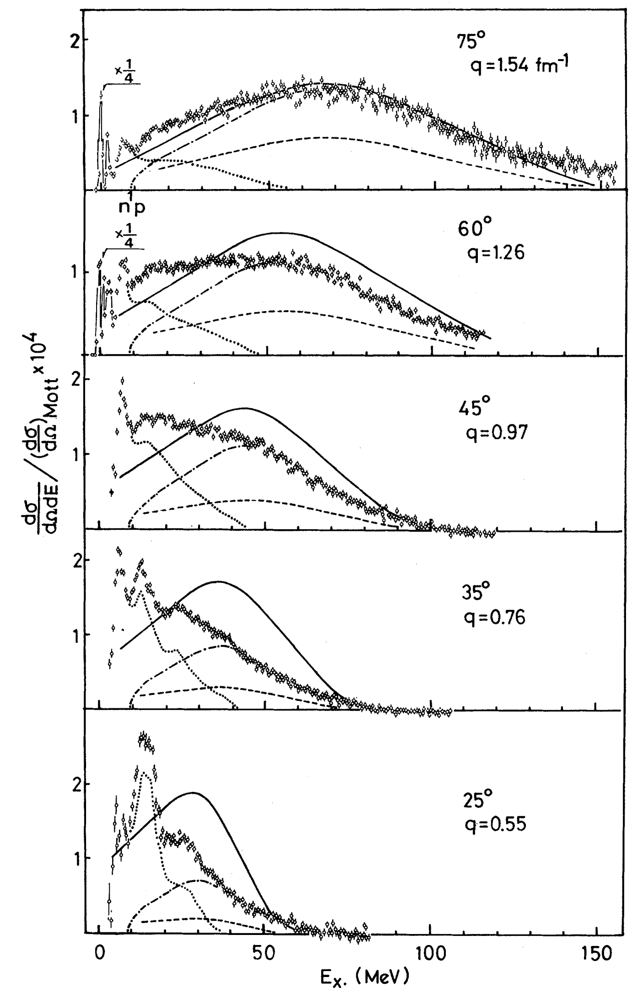

FIG. 1. The form-factor spectra at 250 MeV and 25°, 35°, 45°, 55°, 60°, and 75°. The total (full line) and transverse form factors (dashed line) are obtained from the Fermi-gas model. The spectra are divided into quasielastic (dash-dotted line) and resonance (dotted line) parts.

predicted curve at low excitation energies. This implies that the excess scattering results from excitation of the GMR and involves the residual interaction which has been neglected in the simple QES model. The Fermi-gas–model transverse form factors are also shown in Fig. 1.

The contributions of the longitudinal form factor F_L^2 and transverse form factor F_T^2 can be separated by making a plot of

$$F^2 = F_L^2 + (\tfrac{1}{2} + \tan^2\tfrac{1}{2}\theta)F_T^2,$$

versus $\frac{1}{2} + \tan^2\frac{1}{2}\theta$. Such a procedure was performed as a function of E_x for two spectra at 250 MeV, 60°, and at 130 MeV, 155°, which corre-

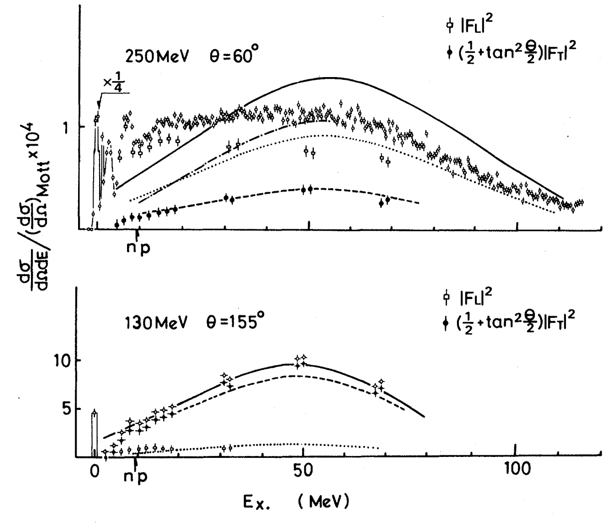

FIG. 2. The spectra at 250 MeV, 60°, and at 130 MeV, 155°, are separated into the $F_L{}^2$ and $(\frac{1}{2}+\tan^2\frac{1}{2}\theta)\times F_T{}^2$ terms. The F^2 (full line), $F_L{}^2$ (dotted line), and $(\frac{1}{2}+\tan^2\frac{1}{2}\theta)F_T{}^2$ (dashed line) were obtained from the Fermi-gas model. The quasielastic contribution (dash-dotted line) was determined to be $\alpha(\frac{1}{2}+\tan^2\frac{1}{2}\theta)F_T{}^2$.

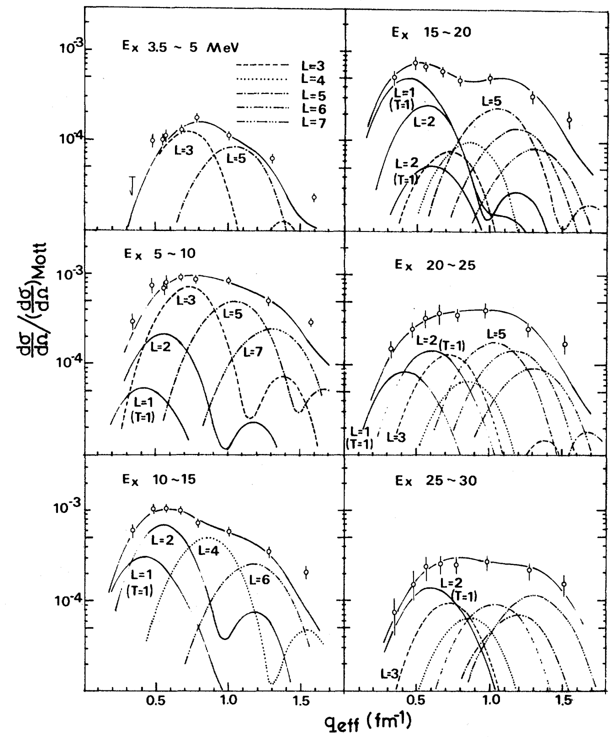

FIG. 3. The form factors for the resonance part are compared with combinations of multipoles.

spond to the same $q_{\rm eff}=1.25\ {\rm fm}^{-1}$ at the point $E_x=15$ MeV. The result is shown in Fig. 2. Also shown is the theoretical F^2 and $(\frac{1}{2}+\tan^2\frac{1}{2}\theta)F_T{}^2$ obtained with the Fermi-gas model. This model is in good agreement with the experimental $F_T{}^2$ but not with the experimental $F_L{}^2$. The QES part may be approximated to be $\alpha(\frac{1}{2}+\tan^2\frac{1}{2}\theta)F_T{}^2$ as shown in Fig. 2 where $\alpha=3$ is determined to fit the spectrum at high E_x.

The QES effect was determined (a) by assuming that the location of the peak is given by the Fermi-gas model, (b) by assuming that beyond the peak there are no resonance effects, and (c) by using the proton separation energy as the threshold energy. The QES rises in the manner $(E_x-E_{x\,\rm thresh})^{1/2}$ and matches in to the straight line beginning at $E_x=0$ as shown in Fig. 1. $F_T{}^2$ below the proton threshold energy in Fig. 2 seems to be related to the magnetic multipole excitations.

The resonance part at low q is consistent with the known GMR at 12 MeV ($E2$, $T=0$), 16 MeV ($E1$, $T=1$), and 25 MeV ($E2$, $T=1$) which exhaust the corresponding energy-weighted sum rule. The 7-MeV peak which appears in all spectra is a complex of many narrow excitations with no single multipolarity. In Fig. 3 the summed form factors for the resonance part in the specific ranges 3.5–5, 5–10, 10–15, 15–20, 20–25, and 25–30 MeV are compared with conceivable combinations of multipoles. The form factors for the known GMR with $T=1$, $E1$, and with $T=1$, $E2$, were obtained from the Steinwedel-Jensen-Jensen model.[6] The other multipole excitations were regarded as $T=0$ and their form factors were obtained from the Tassie model.[5] The 3.5–5-MeV form factor is reproduced with the sum of $E3$ and $E5$. For the 5–10-MeV form factor, since we expect a group of excitations across one major shell ($1\hbar\omega$), only odd-parity states are introduced. The 10–15-MeV range involves the excitations of two major shells ($2\hbar\omega$) and the $E1$, $T=1$ giant resonance. In the ranges 15–20, 20–25, and 25–30 MeV the form factors are compared with multipoles from $E1$ to $E7$. In Table I the transition strengths obtained are indicated with percentages of the corresponding energy-weighted sum rule.

The anomalous structure around 7 MeV which we claim to be a complex of $E3$, $E5$, and $E7$ has also been observed in the other reactions.[1] The disagreement between the QES model and the observed spectra arises mainly from the longitudinal part, indicating the excitations of many electric GMR. The lower-multipole strength is concentrated in a narrow region, while the higher-

TABLE I. The percentages of the energy-weighted sum rule.

E_x (MeV)	$E1$, $T=1$	$E2$, $T=0$	$E2$, $T=1$	$E3$, $T=0$	$E4$, $T=0$	$E5$, $T=0$	$E6$, $T=0$	$E7$, $T=0$
0–3.5		5		10	8	2		
3.5–5				4		3		
5–10	3	14		39		34		26
10–15	25	65			47		38	
15–20	50	20	11	10	12	37	29	21
20–25	10	7	13	24	10	35	35	29
25–30			16	20	12	26	20	46

multipole strength is fragmented in accord with recent theoretical results.[9-11]

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Mirror γ Decays in ^{13}C and ^{13}N†

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We have measured the γ-ray branching ratios of the lowest $T=\frac{3}{2}$ levels in ^{13}C and ^{13}N, and the absolute strength of the γ_0 transition in ^{13}N. The mirror electromagnetic selection rule is obeyed by the $M1$ (γ_0 and γ_2) transitions. However the $E1$ (γ_1) transitions exhibit a surprisingly large charge asymmetry. Charge-dependent differences in the radial wave functions do not account for a similar asymmetry in strong $T=\frac{1}{2}\rightarrow T=\frac{1}{2}$ $E1$ transitions in mass 13.

Isovector γ-ray decays between corresponding levels of mirror nuclei are expected to be of equal strength.[1] This follows from two assumptions—that the nuclear levels involved obey charge symmetry, and that the electromagnetic current contains only isoscalar and isovector components. Hence a precise experimental comparison of the reduced strengths of mirror $\Delta T=1$ transitions can reveal asymmetries caused either by a failure of exact symmetry in the nuclear wave functions, or by the existence of an exotic (isotensor) electromagnetic current.

The mirror selection rule for $\Delta T=1$ electromagnetic transitions is not well verified.[2] Blin-Stoyle has used the $T=\frac{3}{2}\rightarrow T=\frac{1}{2}$ $M1$ transitions in ^{13}C and ^{13}N to derive an upper limit of ~10% for the ratio of the isotensor to isovector amplitudes.[3] We have improved upon previous data[4,5] concerning the mirror $\Delta T=1$ γ decays in mass 13 by significantly increasing the precision of the comparison of the ground-state and second-excited-state $M1$ transition strengths. We have also ex-