Form Factors of the Monopole Transitions in ^{20}Ne by Inelastic Electron Scattering

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The inelastic-electron-scattering form factors in ^{20}Ne for the $E0$ transitions from the 0^+ ground to the 6.72- (0^+) and 7.20-MeV (0^+) states are presented. The monopole matrix elements and transition charge radii are extracted from the form factors.

Inelastic electron scattering provides the possibility of observing the monopole transitions between the ground 0^+ and excited 0^+ states. Such a transition is completely forbidden for γ-ray emission. The inelastic-electron-scattering form factor of the monopole transition is described by the operator $j_0(qr)-1$ from the requirement of the orthogonality of the nuclear wave functions.[1] This suggests that the monopole form factor in inelastic electron scattering is roughly similar to the quadrupole form factor.

Recently, theoretical and experimental interest has been concentrated on the nature of the 0^+ states in ^{20}Ne.[2,3] We have found the monopole form factors for the excitations to the 6.72- (0^+) and 7.20-MeV (0^+) states of this nucleus in the momentum-transfer range from 0.5 to 1.8 F^{-1}. Also the quadrupole form factors for the 7.43- (2^+) and 7.84-MeV (2^+) states were measured. It is known that these 7.43- and 7.84-MeV states belong to the members of the rotational bands starting from the 0^+ states at 6.72 and 7.20 MeV, respectively.[4]

The experiments were carried out using the Tohoku 300-MeV electron linear accelerator at incident electron energies of 120, 200, and 250 MeV and scattering angles between 35° and 90°. A stainless-steel cylinder 40 mm in diameter,

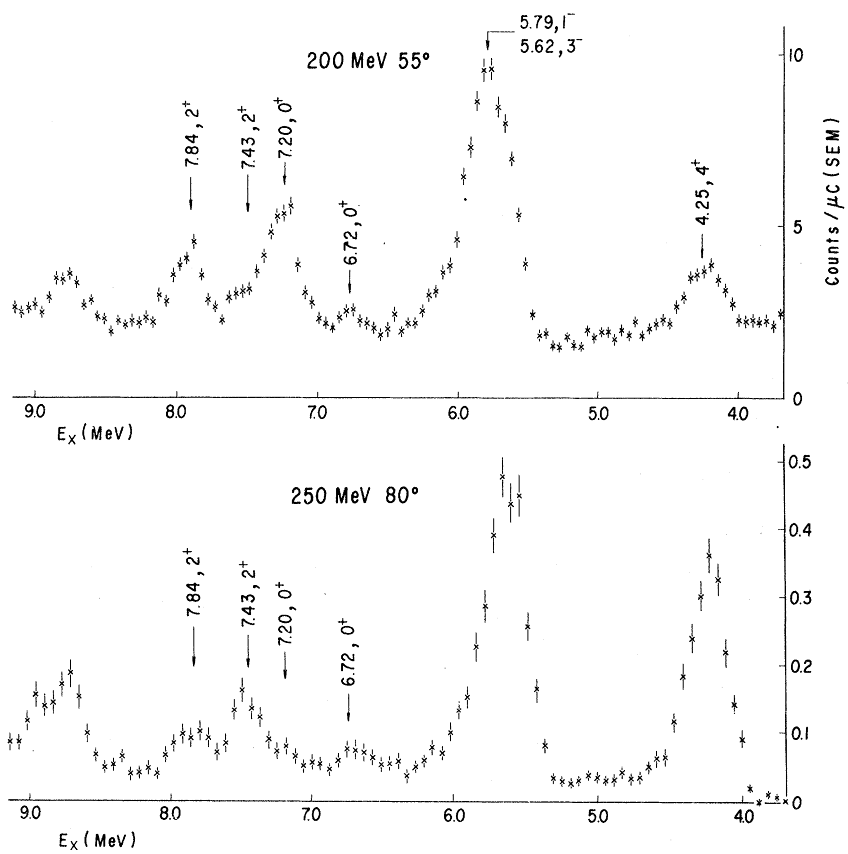

FIG. 1. Inelastic-electron-scattering spectra without radiative corrections. The momentum transfer of the upper spectrum is favorable to the excitations of the 0^+ state at 7.20 MeV and the 2^+ state at 7.84 MeV. The 7.43-MeV peak, not apparent in the upper part, appears distinctly in the lower part.

40 mm in height, and 0.12 mm in thickness was filled by natural Ne gas up to 21 kg/cm^2 pressure. Another cylinder of the same size was filled with ethane gas. Both gas holders were fitted to a target ladder located in a scattering chamber. The ladder also held a BeO screen for the beam monitoring. The spectrometer and detection apparatus have been described elsewhere.[5]

Figure 1 shows the raw spectra of inelastically scattered electrons in the region of ~4 to 9 MeV excitation. Each peak shows an experimental resolution of 0.13%. We have mainly investigated the peaks in the neighborhood of 7 MeV.[6] In the upper spectrum may be seen the peaks corresponding to the 6.72- (0^+), 7.20- (0^+), and 7.84-MeV (2^+) states. In the lower spectrum the 7.43-MeV (2^+) peak appears to be distinct as a result of the increased momentum transfer. The raw spectra were unfolded for the usual radiative effects, and then the area of the individual peak was estimated. The absolute cross section for ^{20}Ne was determined by comparing its yield with that of ^{12}C in the ethane target. The experimental form factors were obtained by dividing the experimental cross section by the Mott cross section ($Z=10$). The form factors obtained are displayed in Fig. 2 as a function of q_{eff}.[7] The 3^- (7.17-MeV) and 0^+ (7.20-MeV) states could not be resolved in the present measurement. However, the observed form factor is quite different from the usual $E3$ form factor related to the collective state.[8,9]

There may be seen marked differences in shape between the two $E0$ and also between the two $E2$ form factors. The first diffraction minimum of the 6.72-MeV (0^+) form factor lies at a lower momentum transfer than that of the 7.20-MeV (0^+) state. Furthermore, its second peak has a relatively high amplitude. The form factors for the $E0$ (7.20-MeV) and $E2$ (7.84-MeV) transitions are quite similar. This $E2$ form factor shows the usual shape which can be expected in terms of the collective model.[8,9] The $E2$ form factor of the 7.43-MeV (2^+) state shows anomalous shape which resemble the $E4$ form factor. It suggests that the corresponding radiative transition should be almost forbidden. The transition probabilities $B(EL)$ for the 2^+ states were extracted using the transition charge density of the Helm model,[9] with respect to which the parameters were varied to fit the experimental form factors. The results are tabulated in Table I. The marked difference between the $B(E2)$ values of the two 2^+ states will be referred to later.

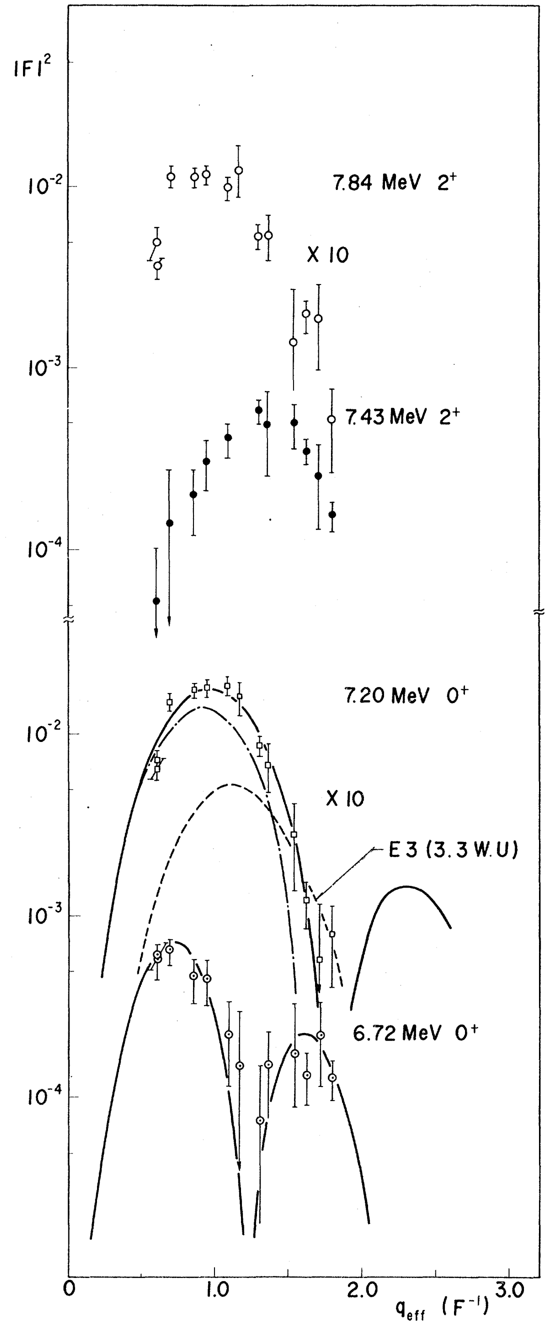

FIG. 2. Experimental form factors for the 6.72- (0^+), 7.20- (0^+), 7.43- (2^+), and 7.84-MeV (2^+) states, plotted against q_{eff}.

The monopole matrix element $M=\langle r^2\rangle_{tr}$ and transition charge radius $R_{tr}{}^2=\langle r^4\rangle_{tr}/\langle r^2\rangle_{tr}$ can be derived from the analysis of the present form factors. The transition charge density ρ_{tr} is assumed to be

$$\rho_{tr}=\left[\sum_{j=0}^{3}a_j\left(\frac{r}{b}\right)^{2j}\right]\exp\left(-\frac{r^2}{b^2}\right).$$

TABLE I. Matrix elements M, transition radii R_{tr}, and reduced transition probabilities $B(E2)$.

	E_x (MeV)	J^π	M (F^2)	$R_{tr}/A^{1/3}$ (F)	$B(E2)/B_{s.p.}$
^{20}Ne	6.72	0^+	7.37 ± 1.97	2.11 ± 0.48	
^{20}Ne	7.20	0^+	6.90 ± 1.44	1.69 ± 0.52	
^{28}Si	4.98	0^+	6.63 ± 2.43	1.81 ± 0.51	
			6.82 ± 0.52 [a]	1.86 ± 0.09 [a]	
^{20}Ne	7.43	2^+			0.13 ± 0.03
^{20}Ne	7.84	2^+			0.83 ± 0.13

[a] Ref. 12.

Since $\int \rho_{tr} r^2 dr = 0$, this kind of ρ_{tr} must have nodes.[10] The form factors for fitting the experimental data were searched with this form. The theoretical form factors obtained are shown in Fig. 2 and the corresponding ρ_{tr} are shown in Fig. 3. The M and R_{tr} obtained from the best fit ρ_{tr} are tabulated in Table I. In the same table we include the values for the 0^+ (4.98-MeV) state in ^{28}Si, which were extracted from the data of Nakada and Torizuka[11] by applying the same model-dependent analysis. These values may be compared with those determined from the model-independent method.[12] The results are in good agreement, as is seen in Table I. It is conspicuous that although the $E0$ strengths of the two 0^+ band-head states are almost the same, the $E2$ strength of the rotational 7.43-MeV state is much reduced by about an order of magnitude compared with that of the 7.84-MeV (2^+) state.

The 7.17-MeV (3^-) state is known to be the member of the rotational band starting at 5.79 MeV.[4] For the excitation of this sort of state, it is usual to consider a rather small amount of strength since the overlap between the cross-band states is probably small. However, the possibility of the $E3$ component, which may be included in the observed 7.20-MeV (0^+) form factor, was examined using the q dependence characterized by the multipole order. The same shape as for the 3^- (5.62-MeV) state was inserted into the graph, as indicated with the dashed curve. This curve is constrained to fit the observed minimum point. Nevertheless, while an $E3$ component with somewhat collective strength (3.3 Weisskopf units) was assumed, the observed 0^+ (7.20-MeV) form factor is not much reduced beyond the experimental error. With this modification, the corresponding M becomes 5.9 F^2, which however lies in the limit of the error indicated in Table I.

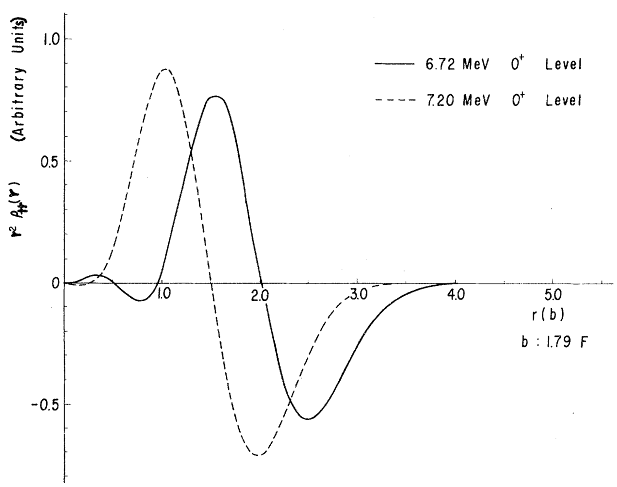

FIG. 3. Transition charge density for the 6.72- (0^+) and 7.20-MeV (0^+) states. The corresponding theoretical form factors are shown in Fig. 2 along with the experimental data.

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[1] L. I. Schiff, Phys. Rev. 96, 765 (1954).
[2] R. Middleton, J. D. Garrett, and H. T. Fortune, Phys. Rev. Lett. 27, 950 (1971).
[3] K. Nagatani, M. J. Le Vine, T. A. Belote, and A. Arima, Phys. Rev. Lett. 27, 1071 (1971).
[4] J. A. Kuehner and E. Almqvist, Can. J. Phys. 45, 1605 (1967); W. E. Hunt, M. K. Mehta, and R. H. Davis, Phys. Rev. 160, 782 (1967).
[5] M. Kimura *et al.*, Nucl. Instrum. Methods 95, 403 (1971).
[6] C. M. Lederer, J. M. Hollander, and I. Perlman, *Table of Isotopes* (Wiley, New York, 1967), 6th ed.
[7] D. G. Ravenhall, quoted in R. Hofstadter, Rev. Mod. Phys. 28, 214 (1956).
[8] T. de Forest and J. D. Walecka, Advan. Phys. 15, 1 (1966).
[9] R. Helm, Phys. Rev. 104, 1466 (1956).
[10] S. Fujii, Progr. Theor. Phys. 42, 416 (1969).
[11] A. Nakada and Y. Torizuka, J. Phys. Soc. Jap. 32, 1 (1972).
[12] P. Strehl and T. H. Schucan, Phys. Lett. 27B, 641 (1968).