out the l-dependent absorption is shown in Fig. 2 for the bombarding energy 12.0 MeV. With the l-dependence, χ^2 is about 5 and without, about 27. As the bombarding energy is increased, the improvement becomes more pronounced.

The statistical-model parameters which determine the incoherent compound-elastic-scattering term are modified by the introduction of the l-dependent absorption, but are still in reasonable agreement with those found by John et al. below 12 MeV. Again the maximum compound-elastic-scattering cross section is at a bombarding energy of about 9 MeV. The values and energy dependence of these parameters in the bombarding-energy range 5.5-12.5 MeV are consistent with the predictions of the Fermi-gas model.[6]

The authors wish to thank P. Robinson and J. John for the use of their data and W. Thompson for the use of the program BILSCAT. Special thanks are extended to D. Robson for helpful suggestions and informative discussions.

*Research supported in part by the Air Force Office of Scientific Research, Office of Aerospace Research, U. S. Air Force, under Grant No. AF-AFOSR-69-1674, and the National Science Foundation Grant No. NSF-GP-5114.

[1]C. P. Robinson, J. P. Aldridge, Joseph John, and R. H. Davis, Phys. Rev. 171, 1241 (1968).

[2]Joseph John, C. P. Robinson, J. P. Aldridge, and R. H. Davis, Phys. Rev. 177, 1755 (1969).

[3]R. A. Chatwin, J. S. Eck, A. Richter, and D. Robson, Phys. Rev. (to be published).

[4]P. Darriulat, G. Igo, H. G. Pugh, and H. D. Holmgren, Phys. Rev. 137, B315 (1965).

[5]D. Robson, private communication.

[6]K. A. Eberhard, A. E. Bisson, W. Thompson, and R. H. Davis, to be published.

ELECTROEXCITATION OF THE 10.8-MeV ($1^-; T=0$) LEVEL OF ^{12}C AND THE 7.12-MeV ($1^-; T=0$) LEVEL OF ^{16}O

Y. Torizuka, M. Oyamada, K. Nakahara, K. Sugiyama, Y. Kojima, T. Terasawa, K. Itoh, A. Yamaguchi, and M. Kimura

Laboratory for Nuclear Science, Tohoku University, Tomizawa, Sendai, Japan

(Received 3 October 1968)

Form factors for $E1$ ($\Delta T=0$) electroexcitation of the 10.8-MeV level of ^{12}C and the 7.12-MeV level of ^{16}O were obtained from inelastic electron scattering experiments. These form factors showed an anomalous q dependence relative to the usual $E1$ electroexcitation.

It has been shown that radiative electric dipole transitions with $\Delta T=0$ are forbidden by the isospin selection rule in self-conjugate nuclei. Eisenberg and Rose[1] have shown that the same rule can be applied to electroexcitation in the region $(qR)^2 \ll 1$, where q is the momentum transfer and R is the nuclear radius. They have also pointed out that in real nuclei the matrix element is nonvanishing because of (1) the presence of isospin impurity caused by Coulomb interactions and the neutron-proton mass difference, (2) the presence of higher order terms in $(qR)^2$, etc. From the second of these reasons it is supposed that inelastic scattering experiments using high-energy electrons may be useful in investigating the breakdown of the isospin selection rule of $E1$ $\Delta T=0$ transitions in $T_Z=0$ nuclei. On the basis of the particle-hole model, Seaborn and Eisenberg[2] have calculated the form factors for $E1$ $\Delta T=0$ transitions in ^{16}O. They have eliminated the effect of the spurious center-of-mass motion by carrying out the calculation using a set of basis vectors orthogonal to the spurious state. In this case the Coulomb radial reduced matrix element becomes

$$[f\|j_1(qr)\|i]=[f\|-(qr)^3/30+\cdots\|i],$$

where the first term ($\langle f\|qr\|i\rangle$) in the power series expansion of $j_1(qr)$ has been eliminated, since it corresponds to the spurious center-of-mass motion. Therefore, it is expected that the q dependence of $E1$ transitions with $\Delta T=0$ in $T_Z=0$ nuclei may show $E3$-like behavior.

Both the 10.8-MeV level in ^{12}C and 7.12-MeV level in ^{16}O have been assigned to be $1^-, T=0$[3]. The present paper reports the electroexcitation of these states. The experiments were performed using the electron beam of the Tohoku 300-MeV linear accelerator. The incident electron energies were chosen to be 183 and 250 MeV, and the scattering angles were varied in the range from 35 to 115°. The targets were 104-mg/cm^2 graph-

ite for ^{12}C and an 80-mg/cm^2-thick BeO disk for ^{16}O. A 390-mg/cm^2-thick Be target was used to estimate the contribution of the Be component in the BeO target. Scattered electrons were deflected by a double-focusing magnet ($r_0 = 100$ cm, $\theta = 169.7°$) and detected by a 12-channel detector ladder. Overall energy resolutions of the experimental data were ~0.25% in the case of the carbon target and ~0.1% for the BeO target, respectively. Typical energy spectra of scattered electrons from carbon and BeO are shown in Fig. 1. It is seen in this figure that the 10.8-MeV (1^-) level of ^{12}C is clearly observed in the display of the carbon spectrum, while the peak in the vicinity of 7 MeV in the BeO spectrum may be the doublet which corresponds to the well-known 6.92- (2^+) and 7.12-MeV (1^-) levels in ^{16}O. The doublet was decomposed into two peaks by a fitting procedure using the shape of elastic peak.

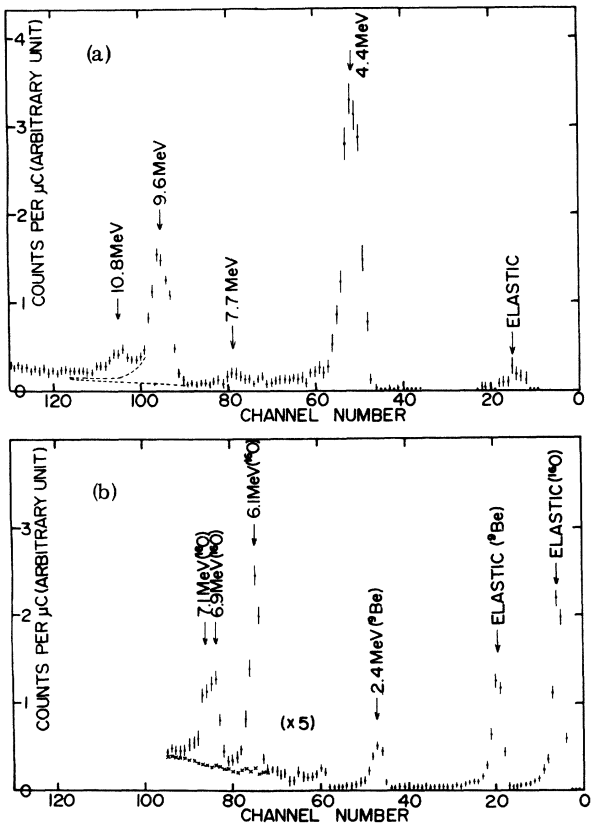

FIG. 1. Energy spectra of scattered electrons. (a) Carbon, $E_0 = 250$ MeV, $\theta = 85°$. The dashed lines are assumed to reproduce the 4.43-MeV peak shape for the 9.63-MeV peak. (b) Beryllium oxide, $E_0 = 183$ MeV, $\theta = 75°$. The crosses indicate the energy spectrum obtained for beryllium target. The 7-MeV peak was decomposed into two components by using shapes of other peaks.

The Be spectrum subtracted from that of BeO is also shown by crosses in Fig. 1(b). The experimental form factors were obtained by dividing the experimental cross sections by the Mott cross section. They are shown in Fig. 2, where 2(a) and 2(b) correspond to the squared form factors of ^{12}C and ^{16}O, respectively.

The experimental form factors for the 7.12-MeV (1^-) level in ^{16}O were compared with the theoretical prediction by Seaborn and Eisenberg,[2] although their calculated energy for the lowest $1^-, T = 0$ level in ^{16}O is 11.19 MeV. As can be seen in Fig. 2(b), their theoretical curve with a harmonic-oscillator length parameter of $b = 2.00$ F reproduces fairly well the q dependence of the experimental form factor of the observed 7.12-MeV level. The dashed curve in Fig. 2(b) corresponds to the Coulomb form factor alone, while the solid one corresponds to the sum of Coulomb and transverse components for $E_0 = 183$ MeV. The effects of the finite proton size and the center-of-mass correction for the shell model[4] were taken into account. The absolute value of their calculated form factor is smaller than the experimental one by a factor of 3. The difference of their calculated energy of the lowest 1^- level from that of the actual 1^- level and also the difference of their theoretical form factors from the experimental ones may be due to the one-particle, one-hole (1p-1h) configuration used in their calculation, since this level is generally supposed to contain a 3p-3h configuration.

Gillet and Vinh Mau[5] have also derived the wave functions of $1^-, T = 0$ states in ^{12}C and ^{16}O in the Tamm-Dancoff and random-phase approximations. Although the spurious components are almost all concentrated in the lowest states, the other states still have some spurious component. Therefore their wave functions are inadequate to calculate directly the inelastic electron scattering form factors.

In order to show clearly the difference of the q dependences between $\Delta T = 0$ and $\Delta T = 1$ $E1$ transitions, the Coulomb form factors of the transitions to the lowest $1^-, T = 1$ states calculated using wave functions of Gillet and Vinh Mau (random phase approximation)[5] are also shown in Fig. 2 (dotted curves).

It may be concluded that a feature of the breakdown of the isospin selection rule for $E1$ electroexcitation with $\Delta T = 0$ in $T_Z = 0$ nuclei is well described by the theory of Seaborn and Eisenberg.[2]

The authors wish to thank Professor S. Fujii and Professor T. Sasakawa for many valuable

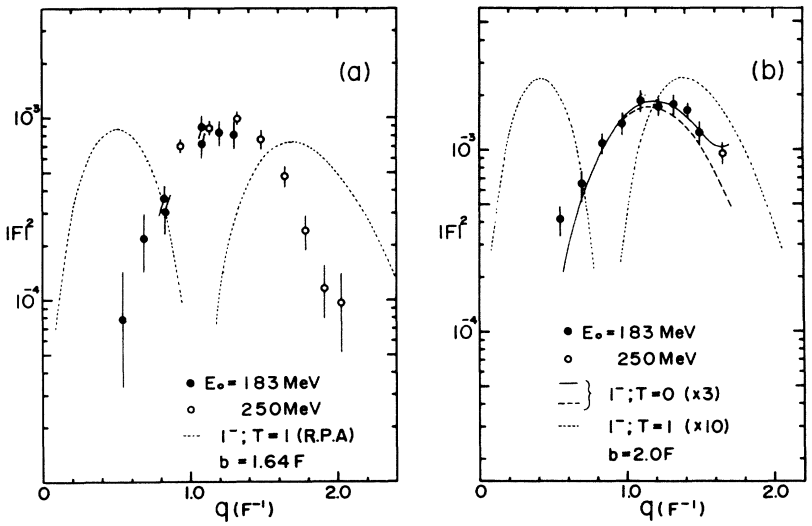

FIG. 2. Experimental and theoretical form factors squared. (a) The 10.8-MeV (1^-; $T=0$) level of ^{12}C and (b) the 7.12-MeV (1^-; $T=0$) level of ^{16}O. The dashed and solid curves in (b) are theoretical Coulomb and sum of Coulomb and transverse form factors for $E_0 = 183$ MeV, respectively, which have been calculated by Seaborn and Eisenberg (Ref. 2) in the 1p-1h model. They are multiplied by 3 in the figure. The dotted curves are $E1$ $\Delta T = 1$ form factors calculated using random-phase-approximation wave functions of Gillet and N. Vinh Mau [Nucl. Phys. 54, 321 (1964)].

discussions. They are also indebted to Professor J. M. Eisenberg who sent them the results of detailed calculations. Thanks are also due to the accelerator crew for their cooperation.

[1]J. M. Eisenberg and M. E. Rose, Phys. Rev. 131, 848 (1963).

[2]J. B. Seaborn and J. M. Eisenberg, Nucl. Phys. 70, 264 (1965).

[3]F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. 11, 1 (1959), and 114A, 1 (1968).

[4]R. S. Willey, Nucl. Phys. 40, 529 (1963).

[5]V. Gillet and N. Vinh Mau, Nucl. Phys. 54, 321 (1964).

LIFETIMES OF ROTATIONAL STATES FROM HEAVY-ION REACTIONS*

R. M. Diamond, F. S. Stephens, W. H. Kelly,† and D. Ward‡
Lawrence Radiation Laboratory, University of California, Berkeley, California 94720
(Received 23 January 1969)

The half-lives of several transitions in the ground-state collective bands of ^{160}Er, ^{158}Er, and ^{156}Er produced by (^{40}Ar, $4n$) reactions have been measured by a recoil-distance Doppler-shift method. These lifetimes are compared with those of several models. The mean time interval between the reaction and the population of the ground band was also determined.

The measurement of transition moments is an important method of testing nuclear models. In particular, the $E2$ moments of the $2 \rightarrow 0$ transitions in the ground-state collective bands of even-even nuclei have yielded much information on the nature of these bands. In the present work we have measured the $2 \rightarrow 0$ and several higher ground-band $E2$ moments (lifetimes) in each of three even-even Er nuclei, using a recoil-distance method. These nuclei were produced in the reactions ^{120,122,124}Sn(Ar, $4n$)^{156,158,160}Er.

The recoil-distance Doppler-shift method[1] is well suited to measure half-lives in the range 10^{-9}-10^{-12} sec.[2-5] Basically the method consists of stopping part of the excited nuclei recoiling from a thin target with a movable plunger placed closely behind the target. The fraction of the nuclei that live long enough to reach the plunger before emitting their radiation will yield a normal gamma-ray line, whereas the rest will decay in flight and yield a Doppler-shifted line. By varying the distance of the plunger from the target,