presented in Fig. 3(b).

Weber and Seavey[6] have measured the uniform resonance nuclear relaxation rates in $RbMnF_3$ over the dc field range of 6-23.5 kOe at $T=4.2$°K. They observed a similar frequency dependence of these rates to the dependence shown in Fig. 3(a), namely, a decrease in magnitude with increasing magnon frequency. By extrapolating their results to the frequency range presented in the figure, values are obtained which are higher than our values by two orders of magnitudes. The difference between their values and ours can probably be attributed safely to strain inhomogeneous broadening to which the uniform resonance linewidth, electronic as well as nuclear, is particularly sensitive.

Hinderks[7] has recently measured a nuclear relaxation rate of ~0.3 MHz for $RbMnF_3$ at 1.15°K by employing a photon pump at a frequency of 888 MHz. Since a decrease in the value of the relaxation rate with frequency is expected, this measured value is considered in good agreement with our results. Recent measurements by Hinderks[7] and by Seavey[8] on $CsMnF_3$, also employing photon pumping, indicate a nuclear relaxation rate lower by an order of magnitude than the relaxation rate of $RbMnF_3$. Phonon–nuclear-magnon interaction experiments could therefore be conducted on $CsMnF_3$ at a much reduced acoustic power.

We would like to thank N. F. Foster of Bell Telephone Laboratories for providing the transducers.

---

†Research supported by the Advanced Research Project Agency under Contract No. SD-90.

[1]A. Platzker and F. R. Morgenthaler, Phys. Rev. Lett. 22, 1051 (1969).

[2]A. Platzker, thesis, Massachusetts Institute of Technology, 1970 (unpublished).

[3]H. Suhl, Phys. Rev. 109, 606 (1958).

[4]T. Nakamura, Progr. Theor. Phys. 20, 542 (1958).

[5]P. M. Richards, Phys. Rev. 173, 581 (1968).

[6]R. Weber and M. H. Seavey, Solid State Commun. 7, 619 (1969).

[7]L. W. Hinderks, thesis, University of Kansas, 1970 (unpublished).

[8]M. H. Seavey, J. Appl. Phys. 40, 1597 (1969).

Nuclear Fermi Momenta from Quasielastic Electron Scattering

E. J. Moniz
Institute of Theoretical Physics, Department of Physics, Stanford University, Stanford, California 94305*

and

I. Sick† and R. R. Whitney
High Energy Physics Laboratory and Department of Physics, Stanford University,‡ Stanford, California 94305

and

J. R. Ficenec, R. D. Kephart, and W. P. Trower
Physics Department, Virginia Polytechnic Institute and State University,§ Blacksburg, Virginia 24061
(Received 12 January 1971)

The cross sections for quasielastic electron scattering from nine target nuclei from lithium to lead have been measured for an electron incident energy of 500 MeV and a scattering angle of 60°. The data are interpreted in terms of a Fermi gas model, yielding the nuclear Fermi momentum as a function of atomic number. The Fermi momentum increases from lithium to calcium and remains roughly constant at about 260 MeV/c from nickel to lead.

The quasielastic peak directly measures the single-particle structure of the nucleus and dominates the spectrum of high-energy electrons inelastically scattered from nuclei.[1] In addition, quasielastic scattering provides information on nucleon-nucleon correlations[2] and must be understood if one is to examine the usual nuclear sum rules[3,4] or to use nuclear targets in tests of quantum electrodynamics.[5] Nevertheless, because of the difficulty in making radiative corrections to deep inelastic electron-scattering data and in estimating the contribution from pion electroproduction, experimental work in the quasielastic region has been scarce. Our experiment represents the first investigation of the systematics of quasielastic scattering from a whole series of nuclei. The cross sections $d^2\sigma/d\Omega d\epsilon$ were measured for fixed electron incident energy (500 MeV) and scattering angle (60°) on nine target nuclei ranging in atomic number from lithium to lead. The radiatively corrected spectra are interpreted in terms of the nuclear Fermi gas model of Moniz.[6] This model retains the full relativistic nucleon electromagnetic vertex and provides a good description of the data.[7] The analysis is used to extract the nuclear Fermi momentum[1] and average nucleon interaction energy as a function of atomic number.

The experiment was performed on the Stanford Mark III linear electron accelerator. Except for a change in the detector discriminator settings needed to improve pion rejection, the experimental apparatus and techniques used are identical to those of several recent elastic-scattering experiments and are discussed elsewhere.[8] For each nuclear target, positron and positive-pion spectra were measured by reversing the spectrometer field. These counts, which never constituted more than 3% of the electron spectrum for electron energy loss less than 300 MeV, were subtracted from the data.

The radiative correction procedures followed were basically those of Mo and Tsai,[9] which are believed good to better than 3%. Their expressions were modified to include effects arising from multiple-photon emission in the target, as worked out by Miller.[10] In making radiative corrections to inelastic data, one must in principle know the cross section (at the same angle) for all lower incident energies down to the scattered-electron energy under consideration. In this experiment, we measured the cross sections at an angle of 60° for incident energies of 500, 440, 380, and 320 MeV and for secondary electron energies from the elastic peak down to at least 260 MeV. For incident energies not actually measured, we interpolated from the measured spectra along lines of constant excitation energy.[11] This interpolation procedure introduces an uncertainty of less than 1% in the final 500-MeV data points. Also, since the most uncertain part of the radiative correction formulas is that which increases with target thickness, we used very thin targets of less than 0.01 radiation lengths in all cases. The target-thickness part of the radiative correction was never more than 20% of the total correction to any data point, which in turn was never more than 30% of the original

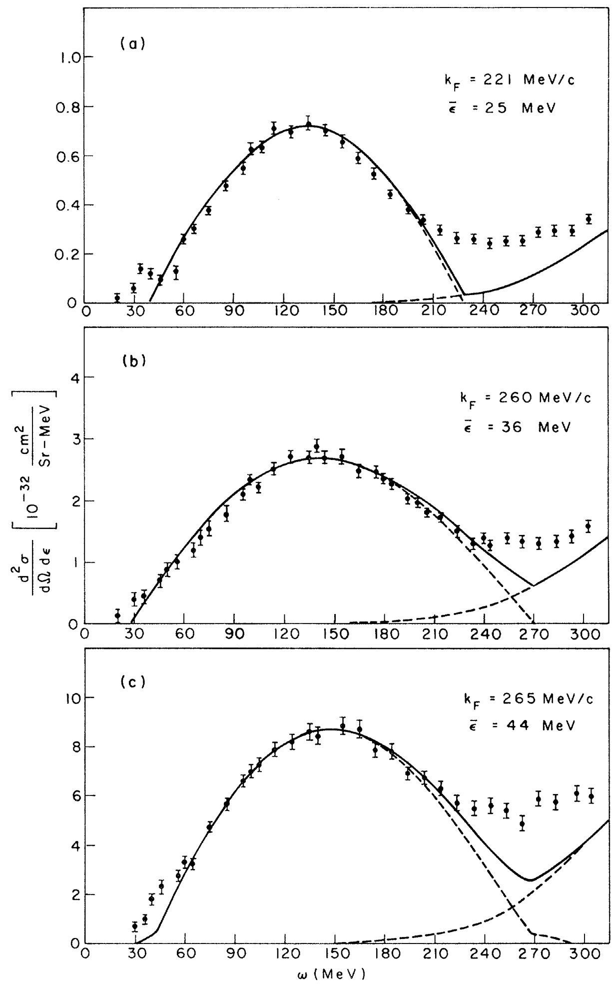

Fig. 1. Cross sections $d^2\sigma/d\Omega d\epsilon$ versus electron energy loss $\omega = \epsilon_1 - \epsilon_2$ for inelastic scattering of 500-MeV electrons at 60° from (a) carbon, (b) nickel, and (c) lead. Solid lines are the results of the Fermi-gas calculation with the nuclear parameters indicated on the figure.

number of counts. In Fig. 1 we present the cross sections, after radiative correction, for carbon, nickel, and lead targets.

We have compared our data with the Fermi-gas model of Moniz,[6] treating the nuclear Fermi momentum, k_F,[12] and the average nucleon interaction energy, $\bar{\epsilon}$, as variable parameters. The width of the quasielastic cross section is directly proportional to k_F, while $\bar{\epsilon}$ is determined from the location of the peak. More precisely, the energy-conserving δ function involved in computing the cross section [see Eq. (7) of Ref. 6] is written $\delta(\omega + (k^2/2M - \bar{\epsilon}) - (\vec{k}+\vec{q})^2/2M)$, where ω is the energy loss and $\vec{q}$ is the momentum transfer. The constant $\bar{\epsilon}$ shifts the peak position and is interpreted as the average nucleon interaction energy.

Since the data extend well beyond pion threshold, an estimate of the pion electroproduction cross section is included in the calculations. This is also computed in the nuclear Fermi-gas model and has been taken as the sum of two contributions. First, s-wave production is calculated following the method of Czyż and Walecka,[13] the only improvement being that the pion is not assumed to be close to threshold in the integration over pion coordinates. Second, pion production proceeding through excitation of the first nucleon resonance is computed using the isobar model of Moniz[6] with a realistic line shape for the 3-3 resonance folded in. The interference term between s-wave and resonant production has been neglected[14] and coherent π^0 production has been found to be negligible even for lead.

A minimization program was used in comparing our data with the Fermi-gas calculation in order to obtain best-fit values for k_F and $\bar{\epsilon}$. No overall normalization factor has been employed and consequently, once the peak position is fixed, the single parameter k_F is varied to fit both the height and width of the quasielastic peak. The results of this fitting procedure are given in Table I for the nine nuclei studied and the best-fit curves are shown in Fig. 1 for three cases. The model provides a surprisingly good description of the data in both shape and magnitude.[15] The nuclear Fermi momentum is roughly constant at 260 to 265 MeV/c for the target nuclei from nickel through lead, while it is increasing from lithium up through calcium. This behavior is a reflection of the saturation of nuclear forces in nuclei; that is, nuclear densities are roughly constant for the heavier nuclei and decrease as one goes to lighter nuclei. From elastic electron scattering, we infer a nuclear matter density $\rho \approx 0.17$ fm^{-3}, giving an equivalent Fermi momentum $k_F = (3\pi^2\rho/2)^{1/3} = 270$ MeV/c. The small difference between this and our extracted Fermi momentum for lead, 265 MeV/c, can be attributed to a lower "local Fermi momentum" in the nuclear surface. The main point is that this method provides a determination of k_F completely independent of that obtained from the ground-state density as measured in elastic electron scattering. This is a dynamical determination of the Fermi momentum and the agreement with the values obtained from the static ground-state densities confirms the essential validity of this simple picture of the nucleus.

Finally, we note that the Fermi-gas calculation systematically underestimates the cross section at very large electron energy loss. Several improvements in the theoretical calculations should be incorporated and may account for at least part of this difference. For example, one should retain a reasonable single-particle potential in the energy-conserving δ function, use a more realistic momentum distribution for the target nucleons (including the effects of finite size of nuclei and of nucleon-nucleon short-range correlations), and make a local Fermi-gas model which better treats the nuclear surface. Nevertheless, we again point out that the systematics of the quasielastic region can be understood remarkably well in terms of a very simple nuclear model.

Table I. Nuclear Fermi momentum k_F and average nucleon interaction energy $\bar{\epsilon}$ determined by least-squares fit of theory to quasielastic peak.

Nucleus	k_F (MeV/c)[a]	$\bar{\epsilon}$ (MeV)[b]
$_3Li^6$	169	17
$_6C^{12}$	221	25
$_{12}Mg^{24}$	235	32
$_{20}Ca^{40}$	251	28
$_{28}Ni^{58.7}$	260	36
$_{39}Y^{89}$	254	39
$_{50}Sn^{118.7}$	260	42
$_{73}Ta^{181}$	265	42
$_{82}Pb^{208}$	265	44

[a]The fitting uncertainty in these numbers is approximately ±5 MeV/c.

[b]The fitting uncertainty in these numbers is approximately ±3 MeV. Simple estimates for $\bar{\epsilon}$ give numbers in reasonable agreement with those in the table.

The idea of using quasielastic electron scattering to determine the nuclear Fermi momentum was first discussed in Ref. 1. We thank Professor J. D. Walecka for suggesting this experiment and for many helpful discussions during the analysis. The Virginia Polytechnic authors thank Professor Maurice Goldhaber for independently encouraging them to study the systematics of the extracted Fermi momentum and Professor R. Hofstadter, Director of the High Energy Physics Laboratory, for the hospitality extended them during their visit. We also thank Professor Hofstadter and Professor M. R. Yearian for their support, and the operating crew of the Stanford Mark III accelerator for their capable assistance.

*Work supported in part by the U. S. Air Force Office of Scientific Research, under AFOSR Contract No. F44620-68-C-0075.

†Present address: Centre d'Etudes Nucléaires de Saclay, B. P. No. 2, 91 Gif-sur-Yvette, France.

‡Work supported in part by the National Science Foundation and Office of Naval Research under Contract No. Nonr 225(67).

§Work supported in part by a grant from the Petroleum Research Fund of the American Chemical Society.

[1]J. D. Walecka, *High Energy Physics and Nuclear Structure*, edited by S. Devons (Plenum, New York, 1970), p. 1.

[2]W. Czyż and K. Gottfried, Ann. Phys. (New York) 21, 47 (1963).

[3]S. D. Drell and C. L. Schwartz, Phys. Rev. 112, 568 (1958).

[4]K. W. McVoy and L. Van Hove, Phys. Rev. 125, 1034 (1962).

[5]S. D. Drell and J. D. Walecka, Ann. Phys. (New York) 28, 18 (1964).

[6]E. J. Moniz, Phys. Rev. 184, 1154 (1969).

[7]The analysis in this paper uses nonrelativistic kinematics for the recoiling nucleon. The use of relativistic kinematics increases the cross section at the peak by a few per cent.

[8]I. Sick and J. S. McCarthy, Nucl. Phys. A150, 631 (1970).

[9]L. W. Mo and Y. S. Tsai, Rev. Mod. Phys. 41, 205 (1969).

[10]G. Miller, thesis, Stanford University, 1970 (unpublished).

[11]D. B. Isabelle and J. Berthot, in Proceedings of the NATO Institute on Electron Scattering and Nuclear Structure, Cagliari, Italy, 1970 (to be published).

[12]The neutron and proton Fermi momenta were taken as $k_F^n = (2N/A)^{1/3} k_F$ and $k_F^p = (2Z/A)^{1/3} k_F$, respectively. The implication here is that, for a given k_F, the density of nuclear matter is constant irrespective of the ratio of neutrons to protons. This assumption is supported by elastic electron-scattering data, which show that the nuclear half-density radii vary with $A^{1/3}$ and that $A\rho_0/Z$, where ρ_0 is the proton central density, is roughly constant for heavy nuclei.

[13]W. Czyż and J. D. Walecka, Nucl. Phys. 51, 312 (1964).

[14]This is a very good approximation for the conditions of our experiment, since the s-wave and resonant amplitudes for production on a nucleon are completely out of phase at the resonance. This can be seen in the results of Ref. 13.

[15]Coulomb corrections have not been included in the calculations, but simple estimates based upon the eikonal approximation indicate that they are only a few percent even for lead.

Isospin Purity at High Excitation Energies as Evidenced by Cross Correlations of Mirror-Channel Fluctuations*

C. Détraz,† C. E. Moss, C. D. Zafiratos, and C. S. Zaidins
Nuclear Physics Laboratory, Department of Physics and Astrophysics, University of Colorado, Boulder, Colorado 80302

(Received 13 January 1971)

The Ericson fluctuations of the mirror decays $^{15}O + ^{7}Li$ and $^{15}N + ^{7}Be$ of a ^{22}Na compound state near 53-MeV excitation energy are found to be correlated, providing evidence that isospin is a good quantum number at this high excitation energy.

For low-lying energy levels, isospin has been shown to be a good quantum number. With increasing excitation energy, though, the overlap of states with different T increases since the average width Γ of the levels becomes larger than their average separation distance D. The extent to which isospin is a good quantum number is accordingly predicted to deteriorate.[1] However, at still higher excitation energies, Γ becomes so large that it even exceeds the value of the isospin-mixing Coulomb matrix element $\langle H_c \rangle$. In other words, the half-life of the level becomes too short to let the Coulomb forces mix the isospin which should therefore again be a good quantum number.[1,2]

Experimental confirmation of good isospin purity of highly excited levels is rather limited. It consists largely of a trend for isospin-nonconserving nuclear reactions [such as $\Delta T = 1$ (d, α) reactions] to decrease in cross section with increasing bombarding energy.[3] However, the interpretation of these results in terms of isospin purity of an intermediate compound state is confused by the increasing role of direct mechanisms at higher bombarding energies. We wish to report what we think is experimental evidence of isospin purity for the overlapping levels of ^{22}Na near 53-MeV excitation energy.

In a study of the four-nucleon transfer reactions $^{19}F(^{3}He, ^{7}Li)^{15}O$ and $^{19}F(^{3}He, ^{7}Be)^{15}N$ near 40-MeV bombarding energy,[4] compound-nucleus effects were found to dominate at backward angles, as evidenced by a strong energy dependence of the cross sections. Figure 1 shows excitation