states. The present result could be the first observation of such resonances as final states in a multiparticle transfer reaction and could prove new insights into the reaction $^{12}C(^{16}O, \alpha)^{24}Mg$ mechanism as well as the structure of the states in ^{24}Mg. Again a systematic study of the $^{12}C + ^{12}C$ decay following $^{12}C(^{16}O, \alpha)^{24}Mg$ population of these states would be an important extension of the present work.

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Elastic Electron Scattering from ^{3}He and ^{4}He at High Momentum Transfer

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Experimental values of ^{3}He (^{4}He) elastic structure functions up to momentum transfer $q^2 = 4.0$ (2.4) (GeV/c)^2 are presented. They are compared to calculations using three- and four-body wave functions and to asymptotic models.

We present data on elastic electron scattering from ^{3}He and ^{4}He that extends the information from previous experiments[1] into the unexplored region of momentum transfer $q^2 > 0.8$ (GeV/c)^2. This complements the large-q^2 measurements of electromagnetic structure functions already available for the dueteron[2] and may allow a better understanding of the failure of microscopic calculations[3-11] to explain existing data near $q^2 = 0.8$ (GeV/c)^2. Large-q^2 data also will be important for an understanding of the asymptotic behavior of the structure functions. For example, in the dimensional-scaling quark model (DSQM), the structure functions at large q^2 are predicted[12] to decrease according to a power of q^2 determined by the number of elementary constituents. Of particular interest is the determination of the momentum transfer of the onset of this scaling. A large-q^2 experiment therefore may investigate the region of the transition from nuclear to elementary-particle physics.

The experiment was performed at the Stanford Linear Accelerator Center (SLAC) using high-pressure gas targets and the 20- and 8-GeV spectrometers to detect the scattered electrons and the recoil nuclei in coincidence.[13] The target cells were operated at high, uniform density with high heat-extraction rates and had a thin window in the direction of the recoiling He nuclei. A 42-cm-long cell with 0.4-mm Al windows was used at 50 atm pressure. The gaseous He was circulated through a heat exchanger cooled with liquid hydrogen to remove the 150 W deposited by the 15-μA average beam current. This target system contained a total of 2000 liters (STP) of ^{3}He (isotopic purity 98.2% with 1.8% ^{4}He) yielding a total target thickness of 3 g/cm^2. A 10-atm target cell with 0.094-mm Al windows was used for the lowest-q^2 points.

The scattered electrons of 6 to 15 GeV were detected at 8° in the SLAC 20-GeV spectrometer. Electrons were identified and measured by three plastic scintillators, a total-absorption shower counter, a nitrogen-gas Cherenkov counter, and by five planes of proportional wire chambers. Separation of the slow, highly ionizing, helium nuclei from the high flux of π, p, and d was made by measuring energy loss in and time of flight between two planes of scintillator counters placed in the 8-GeV spectrometer. This experimental arrangement allowed a measurement free of background even in regions of extremely small cross section. A liquid-hydrogen target was used to calibrate the entire system against the world e-p cross sections.

The cross section for e-^{3}He scattering is written

$$\frac{d\sigma}{d\Omega}=\sigma_M\frac{F_{ch}^2+F_{mag}^2\mu^2\tau[1+2(1+\tau)\tan^2(\theta/2)]}{1+\tau}$$

$$=\sigma_M[A(q^2)+B(q^2)\tan^2(\theta/2)]$$

and for ^{4}He

$$d\sigma/d\Omega=\sigma_M F_{ch}^2=\sigma_M A(q^2),$$

where σ_M is the Mott cross section for scattering from a spinless point nucleus, F_{ch} and F_{mag} are the charge and magnetic form factors, θ is the electron scattering angle, $\tau=q^2/4M^2$, M is the target mass, and $\mu=-3.2\mu_N$ is the nuclear magnetic moment. We will assume that at our scattering angle of 8°, the cross section for ^{3}He is entirely due to the $A(q^2)$ term. The $B(q^2)$ term would contribute less than 1.0% for $F_{ch}=F_{mag}$.

The numerical results for our experiment are listed in Table I and plotted in Figs. 1 and 2. The errors quoted are statistical error plus 5% systematic error added linearly. For ^{3}He at momentum transfer above 2,5 (GeV/c)^2, it is not clear whether we observe a diffraction feature or not; at a cross section of 5×10^{-39} cm^2/sr ($A^{1/2}=3\times10^{-5}$) we have reached our level of sensitivity of 1 event in 5 Coulombs (about 6 days of running). An empirical fit to the data for $q^2\geq0.7$ (GeV/c)^2 using $A^{1/2}(q^2)=a\exp(-bq^2)$ gives $a=0.034\pm0.004$ and $b=2.72\pm0.09$ with a reduced χ^2 of 1.03 indicating that the new data are compatible with the absence of a diffraction feature.

The ^{4}He charge form factor is quite smaller and falls off more quickly than that for ^{3}He with increasing q^2. A fit using the exponential function for $q^2\geq0.8$ (GeV/c)^2 gives $a=0.15\pm0.03$ and $b=4.0\pm0.2$ with a reduced χ^2 of 1.15. The steepening decline of F_{ch} near $q^2=1.8$ and the worse fit

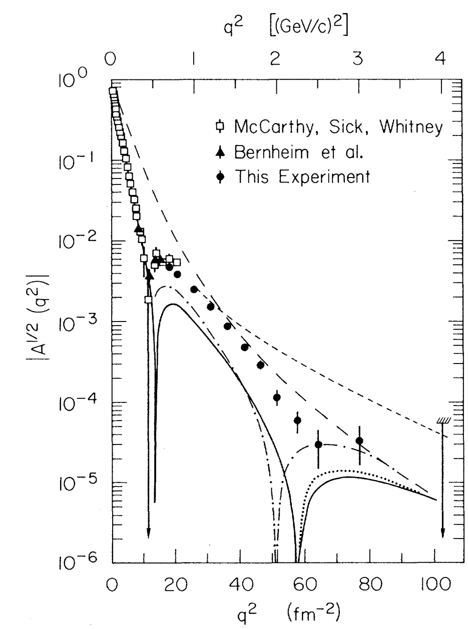

FIG. 1. Results of this and previous experiments for ^{3}He structure function $A^{1/2}$ displayed with theoretical predictions of F_{ch} and $A^{1/2}$. The curves (described in the text) are as follows: solid, F_{ch} Faddeev (Ref. 14); dotted, F_{ch} Faddeev (Ref. 15); dot dashed, sum of Faddeev one-body (Ref. 14) plus MEC (Ref. 9); small dashed, $A^{1/2}$ DSQM (Ref. 12); large dashed, $A^{1/2}$ relativistic impulse approximation (Ref. 18).

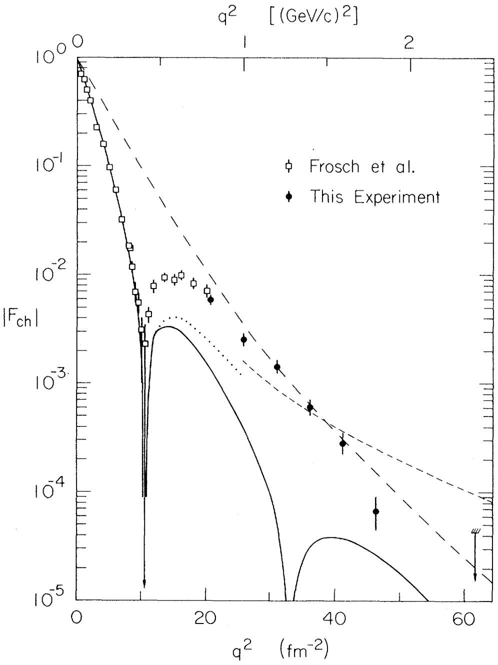

FIG. 2. Results of this and previous experiments for ^{4}He charge form factor F_{ch} displayed with theoretical predictions. The curves (see text) are as follows: solid, F_{ch} Gaussian one-body with Jastrow correlation plus MEC (Ref. 9); dotted, F_{ch} FBHF plus MEC (Ref. 11); small dashed, $A^{1/2}$ DSQM (Ref. 12); large dashed, a relativistic impulse approximation (Ref. 18).

suggests the presence of a second diffraction minimum, but we have not been able to measure a value for F_{ch} at the momentum transfer $q^2 = 2.4$ $(\text{GeV}/c)^2$ which we conjecture to be the position of the next diffraction maximum.

Figure 1 shows calculations of F_{ch} and $A^{1/2}$ for ^{3}He from various microscopic and asymptotic models. The solid curve is the one-body form factor F_{ch} from a Faddeev calculation[14] in momentum space. The result from a Faddeev calculation[15] in configuration space, shown by the dotted curve, is almost indistinguishable from the solid curve up to $q^2 = 2.2$ $(\text{GeV}/c)^2$. Both of these calculations used the Reid soft-core (RSC) interaction for the nucleon-nucleon force, and nucleon form factors from Blatnik and Zorko.[16] The calculation of Ref. 5 is also very similar up to $q^2 = 2.0$ $(\text{GeV}/c)^2$. The dot-dashed curve represents the sum of the one-body form factor[14] F_{ch} plus contributions due to meson exchange currents (MEC)[9]. A calculation (not shown)[17] using a different one-body density and MEC gives results up to $q^2 = 2$ $(\text{GeV}/c)^2$ which are about a factor of 1.4 to 2 higher than the dot-dashed curve

TABLE I. Structure function results for ^{3}He and ^{4}He.

q^2 $(\text{GeV}/c)^2$	^{3}He $10^3 \times \lvert A^{1/2} \rvert$	^{4}He $10^3 \times \lvert F_{ch} \rvert$
0.7	4.57 ± 0.59	...
0.8	3.56 ± 0.32	5.49 ± 0.60
1.0	2.28 ± 0.23	2.65 ± 0.24
1.2	1.42 ± 0.13	1.36 ± 0.19
1.4	0.818 ± 0.073	0.579 ± 0.098
1.6	0.456 ± 0.045	0.273 ± 0.063
1.8	0.275 ± 0.039	0.065 ± 0.025
2.0	0.108 ± 0.025	...
2.25	0.056 ± 0.017	...
2.4	...	≤ 0.043
2.5	0.028 ± 0.015	...
3.0	0.032 ± 0.018	...
4.0	≤ 0.057	

from $q^2 = 0.6$ to 2.0 $(\text{GeV}/c)^2$. The short-dashed curve is a prediction[12] for $A^{1/2}$ based on the DSQM obtained using constituent interchange with binding corrections necessary in the preasymptotic region. The pure DSQM is expected to work for truly asymptotic q^2 where it predicts the shape $A^{1/2}(q^2) \propto (q^2)^{1-3A}$ but not the normalization. The long-dashed curve represents $A^{1/2}$ from a calculation[18] that uses a relativistic impulse-approximation model; it has the same asymptotic falloff as the DSQM and also gives a good fit to the deuteron structure function and many other inclusive high-energy nuclear reactions.

Without experimental measurements[19] or theoretical calculations[20] of F_{mag} for $q^2 \gtrsim 0.8$ $(\text{GeV}/c)^2$, it is difficult to test the Faddeev calculations for F_{ch}. If those calculations are correct, $F_{mag} \approx 4F_{ch}$ would be necessary to give the measured value of $A^{1/2}$ near $q^2 = 1.5$ $(\text{GeV}/c)^2$ and F_{mag} could fill in the second diffraction minimum in F_{ch}. If we assume F_{mag} is small, the old discrepancy for the Faddeev calculations in the height of the second maximum in the region of $q^2 = 0.8$ $(\text{GeV}/c)^2$ is seen to continue at about the same level out to $q^2 = 2.0$ $(\text{GeV}/c)^2$. The apparent disagreement in the region of $q^2 = 2$ $(\text{GeV}/c)^2$ is due to a complicated mixture of many effects, and interpretation of this region will take more careful study.

The DSQM prediction falls more slowly than the data as a function of q^2. This indicates that even with the mass correction employed, scaling sets in at a q^2 considerably larger than expected. The lower limit for the onset of scaling in this form is $q^2 \approx 2.2$ $(\text{GeV}/c)^2$. The relativistic impulse approximation of Ref. 18 does not attempt to describe the diffractive structure at low q^2, but it seems to agree fairly well with the data in the preasymptotic region.

Theoretical calculations of F_{ch} for ^{4}He are shown in Fig. 2. The dotted curve[11] is a calculation based on Faddeev-Bruckner-Hartree-Fock (FBHF) theory employing the RSC interaction, and includes MEC contributions. The solid curve has been obtained[9] using a simplified one-body wave function of Gaussian form with Jastrow correlation factors in order to study the effect of MEC contributions. The short-dashed curve[12] and the long-dashed curve[18] in Fig. 2 are the scaling predictions analogous to the ones discussed above for ^{3}He. The theoretical description of ^{4}He is not as fully developed as that for ^{3}He; however, the discrepancies between the curves presented in Fig. 2 and the new data are similar to that observed for ^{3}He.

The new data on helium form factors at large q^2 indicate that the existing microsocpic calculations of the wave functions are missing an important ingredient. The comparison with the scaling predictions shows that, until now, only the preasymptotic region of the structure functions has been explored. For large q^2, both theoretical predictions and experimental measurements of E_{mag} for ^{3}He are called for.

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