Fermi National Accelerator Laboratory

FERMILAB-Pub-85/101-E
7420.545
7420.053

A COMPARISON OF CROSS SECTIONS FROM DEEP INELASTIC NEUTRINO SCATTERING ON NEON AND DEUTERIUM*

J. Hanlon, R. A. Burnstein, and H. A. Rubin
Illinois Institute of Technology, Chicago, IL 60616 USA

and

M. Kalelkar, E. B. Brucker, P. F. Jacques, E. L. Koller, R. J. Plano, and P. E. Stamer
Rutgers, The State University, New Brunswick, NJ 08903 USA

and

C. Y. Chang, S. Kunori, G. A. Snow, D. Son, P. H. Steinberg, and D. Zieminska
University of Maryland, College Park, MD 20742 USA

and

T. Kafka, W. A. Mann, A. Napier, and J. Schneps
Tufts University, Medford, MA 02155 USA

and

T. Kitagaki, S. Tanaka, H. Yuta, K. Abe, K. Hasegawa, A. Yamaguchi, K. Tamai, Y. Otani, H. Hayano, H. Sagawa, and Y. Yanokura
Tohoku University, Sendai 980, Japan

*Submitted to Physical Review D

A Comparison of Cross Sections from Deep Inelastic Neutrino Scattering on Neon and Deuterium

J. Hanlon,* R. A. Burnstein, and H. A. Rubin
Illinois Institute of Technology, Chicago, Illinois 60616

M. Kalelkar, E. B. Brucker,† P. F. Jacques,
E. L. Koller,† R. J. Plano, and P. E. Stamer§
Rutgers University, New Brunswick, New Jersey 08903

C. Y. Chang, S. Kunori, G. A. Snow, D. Son,**
P. H. Steinberg, and D. Zieminska††
University of Maryland, College Park, Maryland 20742

T. Kafka, W. A. Mann, A. Napier, and J. Schneps
Tufts University, Medford, Massachusetts 02155

T. Kitagaki, S. Tanaka, H. Yuta, K. Abe, K. Hasegawa, A. Yamaguchi,
K. Tamai, Y. Otani, H. Hayano, H. Sagawa, and Y. Yanokura
Tohoku University, Sendai 980, Japan

*Present address: Fermi National Accelerator Laboratory, Batavia, Illinois 60510

†Permanent Address: Stevens Institute of Technology, Hoboken, New Jersey 07030

§Permanent address: Seton Hall University, South Orange, New Jersey 07079

**Present address: Columbia University, New York, New York 10027

††On leave from the University of Warsaw, 00-681 Warsaw, Poland

ABSTRACT

We compare cross sections derived from deep inelastic neutrino scattering on neon and deuterium targets. Systematic effects are minimized by imposing identical analysis criteria on two experiments in the same detector with similiar incident neutrino spectra, and by using variables independent of the beam energy estimate. Our results favor a previously observed dependence of nucleon structure functions on the target nucleus (the EMC effect), but do not require the existence of this phenomenon.

We present a comparison of neutrino-neon and neutrino-deuterium deep inelastic scattering cross sections. Recent results from deep inelastic scattering experiments on nuclear targets have shown the nuclear structure functions to depend on the nucleus, contrary to most expectations. The experimental situation is far from clear, and there is no single accepted theoretical explanation for this phenomenon.

This effect was first observed by the European Muon Collaboration (EMC) in a comparison of structure functions derived from muon scattering on iron and deuterium,[1] where the structure function in iron was found to be enhanced at small Bjorken-x values and depleted at large x relative to that in deuterium, a phenomenon contrary to that expected to result from the effects of target Fermi motion.[2]

This so-called "EMC effect" was reported at large x in a comparison of iron and deuterium cross sections from a SLAC electro-production experiment,[3] while a comparison of electro-production data on aluminum and deuterium[4] failed to show the small x enhancement, and was interpreted as a possible "shadowing" effect of the virtual photon at the low Q^2 values of the electro-production experiment. Further work at SLAC revealed the deep inelastic scattering cross section ratio to decrease logarithmically with target nucleus atomic weight (A) in the region $0.3 < x < 0.8$, and the most recent electro-production results suggest that an A dependence of $R = \sigma_L/\sigma_T$ could resolve the small x discrepancies between the electron and muon scattering data.[5]

A comparison of neon structure functions from neutrino scattering with an isoscalar structure function by the BEBC TST collaboration[6] showed results consistent with the electro-production data, as did the data from the BEBC antineutrino neon/deuterium comparison.[7] This latter experiment, however, reports results which disagree with the rise in the cross section ratio at small x observed in the EMC data.

There has appeared a wide range of speculation as to the nature of this effect, and the reader is referred to the literature[8] for discussions of possible theoretical explanations.

We extend the range of the previous studies by investigating the cross sections derived from neutrino scattering on neon and deuterium. The data are from two similiar exposures of the Fermilab 15-foot bubble chamber to wide-band neutrino beams. Systematic effects are minimized in our comparison by applying identical selection criteria to the data from the two experiments.

The neon-target data[9] are from exposures of the chamber filled with a 62% (atomic) Ne-H_2 mixture to neutrinos produced by 400 GeV/c protons. Part of the neon data was obtained with a double-horn focusing system; the remainder with a single-horn system. The deuterium data[10] are from an exposure of the deuterium-filled chamber to a single-horn focused neutrino beam produced by 350 GeV/c protons.

The events selected for analysis are produced by incident neutral particles in a 15.6 m^3 fiducial volume. We accept only events with two or more charged tracks, and require that all charged tracks be well-reconstructed using the geometric reconstruction program TVGP. Topology-dependent weights are applied to the data to account for those events failing geometrical reconstruction.

The film from the deuterium exposure was scanned twice, and scanning efficiency weights, as a function of topology, are applied to the deuterium data. The neon film has only been scanned once, and we apply the single-scan efficiencies determined from the deuterium experiment to the neon data. We do not expect the scanning efficiency to depend strongly on the liquid in the chamber, and the results we present are insensitive to the scanning efficiency weights applied.

We use a kinematic technique which utilizes only the measured momenta of the charged particles to select a sample of charged-current events. Only events which have $\Sigma p_L > 5$ GeV/c, where p_L is the component of laboratory momentum in the beam direction and the sum is taken over all charged particles, are included in the analysis. The muon candidate is chosen to be that negative track in the event with the largest component of momentum transverse to the incident neutrino direction. We accept as charged-current events those in which the component of the μ^- candidate's momentum transverse to the vector sum of the momenta of the other charged particles in the event is greater than 1.0 GeV/c.

The incident neutrino energy for the selected charged-current events is estimated using transverse momentum balance: $E_\nu = p_L^\mu + p_L^H + |\bar{p}_T^\mu + \bar{p}_T^H| p_L^H/p_T^H$, where the symbols p^μ and p^H refer to the muon momentum and the vector sum of the charged hadron momenta, respectively, and p_T is the component of laboratory momentum transverse to the incident neutrino direction. The kinematic variables x, y, and W are calculated using the measured muon momentum and this estimate of the neutrino energy. Only events with $E_\nu > 10$ GeV and $W > 1.5$ Gev are accepted for analysis.

The efficiency of the above selection criteria is determined from the neon-target experiment, where an independent method of charged-current identification based on the hadron interaction rate in neon is possible[7]. On this basis, our kinematically selected charged-current sample is determined to contain 91% of the charged-current events with $E_\nu > 10$ Gev, and to contain a 6% background of neutral-current and antineutrino events. We expect this background to be the same in the two experiments, and it should not affect the ratios we present.

The selected sample consists of 11 113 ν-d and 2 792 ν-Ne events. Since we wish to present results representative of isoscalar targets, we correct the data for the excess number of protons in the target liquids (2% in the deuterium experiment and 5% in the neon) by adding to the distributions from each experiment the appropriate fraction of a ν-n distribution. The ν-n distributions are obtained from the ν-d events[10] with spectator-proton momentum less than 0.2 GeV/c (including invisible spectator protons). The results we present are insensitive to this correction.

Distributions of neutrino energy E_ν from the two experiments are shown in Fig. 1. When we present ratios of other distributions from the two experiments, we weight each ν-Ne event by the ratio of the E_ν distributions for the particular value of E_ν of that event. This has the effect both of correcting the data for the slightly different E_ν distributions in the two experiments and of normalizing the data such that the average value of the ratios is 1.0. The mean value of Q^2 in both experiments is about 7 $(\mathrm{GeV/c})^2$.

Fig. 2 shows the ratio of the distributions of the momentum component transverse to the incident neutrino direction both for the muon and for the vector sum of the charged hadrons. The ratio of the p_T^μ distributions is consistent with unity, having a χ^2 of 17.8 for 14 degrees of freedom for this hypothesis. A linear least squares fit in the region $p_T^\mu < 3.0$ GeV/c gives a slope of $+0.03 \pm 0.04$, with a χ^2 of 17.0 for 13 degrees of freedom.

The ratio of the p_T^H distributions, however, is observed to decrease monotonically for $p_T^H < 1.0$ GeV/c. A linear least squares fit in this region gives a slope of -0.45 ± 0.13 with a χ^2 of 0.34 for three degrees of freedom. Since this quantity, p_T^H, enters directly into our neutrino energy correction a comparison of kinematic variables which depend on E_ν is valid only if our neutrino energy estimate accurately corrects for the different p_T^H distributions in the two experiments.

Our Monte Carlo simulation of the effects of the correction to the neutrino energy is sensitive to both the distribution of produced hadrons (including neutral hadrons) and the rescattering process within the neon nucleus which is responsible for the different p_T^H distributions observed. We believe that our knowledge of these processes, in particular of intra-nuclear rescattering, is insufficient to confidently correct for their effects. Consequently, we limit our comparison to muon variables which are independent of the neutrino energy.

We present in Fig. 3 the neutrino-neon/neutrino-deuterium cross section ratio as a function of $v = xy = (E^\mu - p_L^\mu)/M_N$, which depends only on the measured muon momentum. The data show a negative slope in the region $v < 0.4$ consistent with the EMC data. A linear least squares fit of the data in this region gives a slope of -0.53 ± 0.22, with a χ^2 of 1.7 for 5 degrees of freedom. However, the hypothesis that the ratio is equal to unity in this region also gives a satisfactory fit to the data, with a χ^2 of 9.5 for 6 degrees of freedom.

This result may be compared with that of the BEBC anti-neutrino neon/deuterium comparison,[7] where a fit of the data over the correlated p_T^μ - v plane to a flat line representing no nuclear effects gives χ^2 of 34 for 30 degrees of freedom. Both data sets are reasonably represented by this null hypothesis.

In conclusion, our observed values of the nucleon cross section ratio $\sigma(\nu\text{-Ne})/\sigma(\nu\text{-d})$ derived from deep inelastic neutrino scattering favors a systematic decrease with increasing $v = xy$ for $v < 0.4$, consistent with the EMC observations. However, given the substantial statistical uncertainties, the data are also consistent with a cross section ratio of unity.

REFERENCES

1. J. J. Aubert et al., Phys. Lett. 123B, 275 (1983).

2. A. Bodek and J. L. Richie, Phys. Rev. D 23, 1070 (1980); ibid. D 24, 1400 (1981).

3. A. Bodek et al., Phys. Rev. Lett. 50, 1431 (1983).

4. A. Bodek et al., Phys. Rev. Lett. 51, 534 (1983).

5. R. G. Arnold et al, Phys. Rev. Lett. 52, 727 (1984).

6. M. A. Parker et al., Nucl. Phys. B232, 1 (1984).

7. A. M. Cooper et al., Phys. Lett. 141B, 133 (1984).

8. For theoretical interpretations, see for example:

   R. L. Jaffe, Phys. Rev. Lett. 50, 228 (1983);

   C. H. Llewellyn Smith, Phys. Lett. 128B, 107 (1983);

   M. Ericson and A. W. Thomas, Phys. Lett. 128B, 112 (1983);

   F. E. Close, R. G. Roberts, and G. G. Ross, Phys. Lett. 129B, 346 (1983);

   E. L. Burger et al., Phys. Rev. D 29, 398 (1984);

   R. L. Jaffe, F. E. Close, R. G. Roberts, and G. G. Ross, Phys. Lett. 134B, 449 (1984);

   S. J. Wimpenny, CERN-EP/84-115.

9. C. Baltay et al., Phys. Rev. Lett. 39, 62 (1977).

10. J. Hanlon et al., Phys. Rev. Lett. 45, 1817 (1980).

    T. Kitagaki et al., in Proceedings of the International Conference on Neutrino Physics and Astrophysics ν '81, ed. by R. J. Cence, E. Ma, and A. Roberts, Maui, Hawaii (1981), vol. 2, p.97.

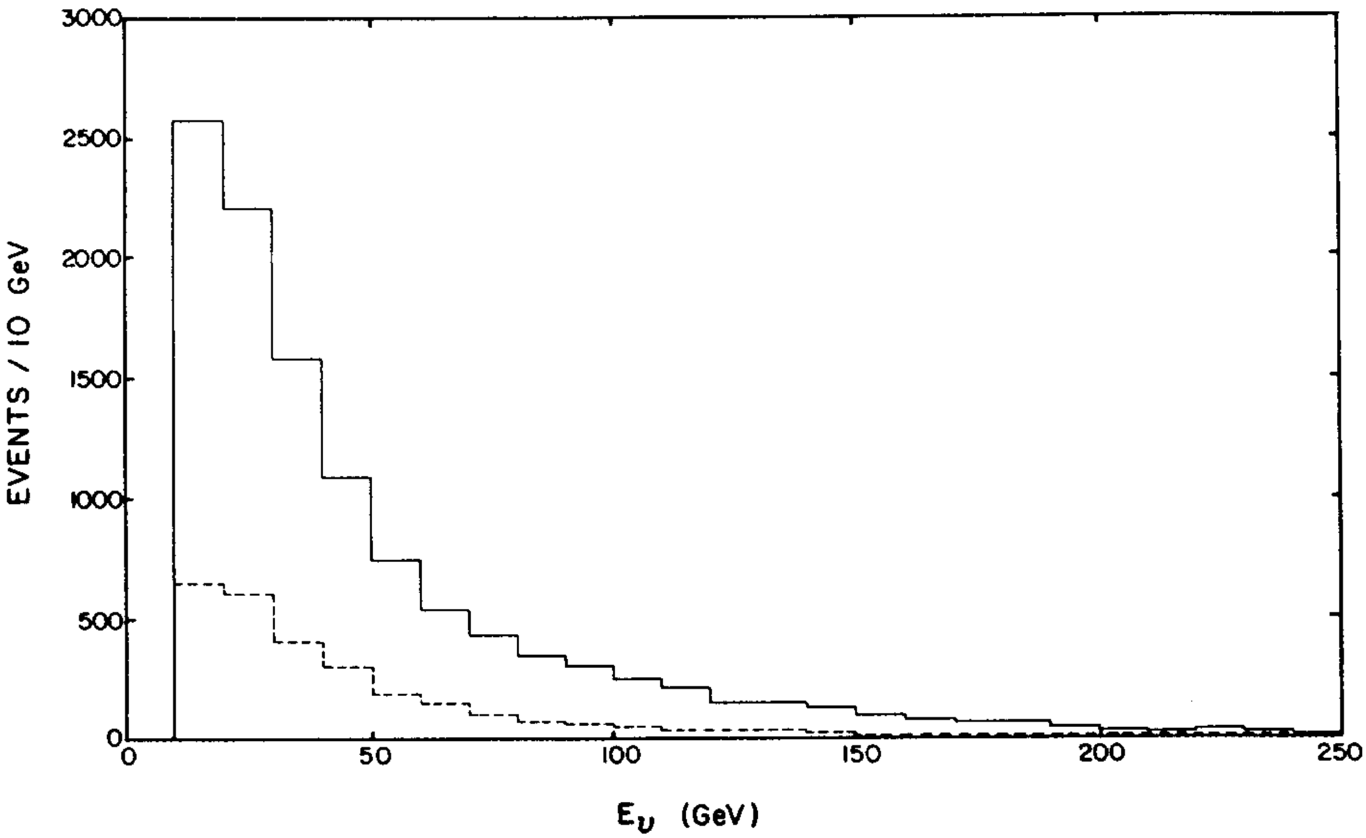
    T. Kitagaki et al., Phys. Rev. Lett. 49, 98 (1982).

FIGURE CAPTIONS

Fig. 1. Distribution of neutrino energy for the ν-d (solid line) and ν-Ne (dashed line) data.

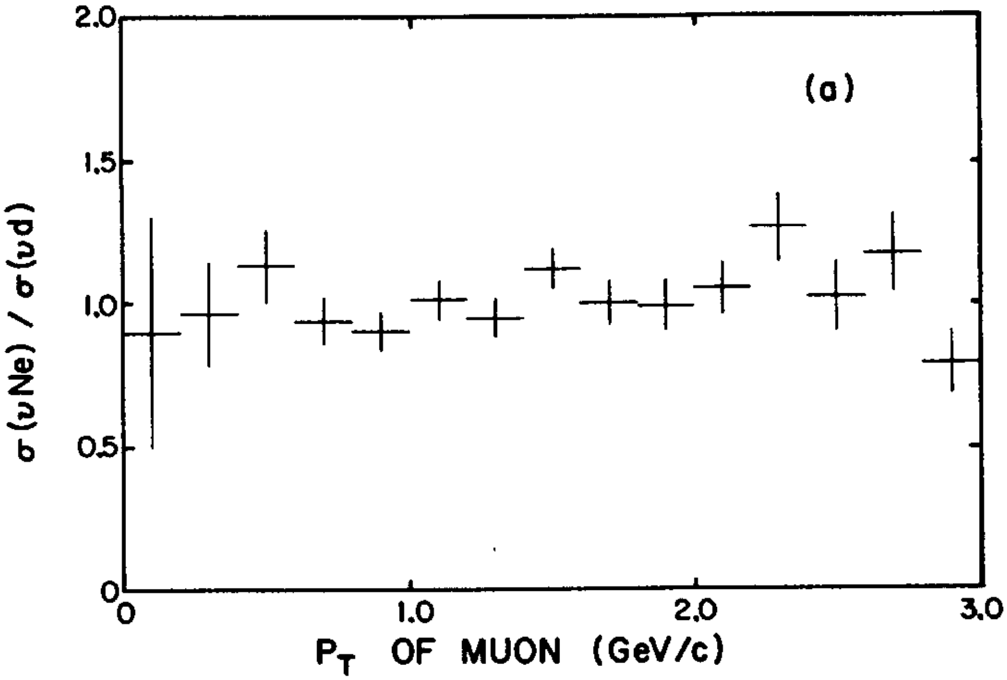
Fig. 2. Ratio of ν-Ne to ν-d cross sections as a function of momentum component transverse to the incident neutrino direction for (a) the muon and (b) the charged hadron system. The data are normalized such that the average ratio is 1.0.

Fig. 3. Ratio of ν-Ne to ν-d cross sections as a function of $v = xy$ normalized such that the average ratio is 1.0. The solid line represents a linear fit in the region $0.0 < v < 0.4$. The dashed line indicates a ratio of 1.0 for comparison.



3000
2500
2000
1500
1000
500
0
EVENTS / 10 GeV
0
50
100
150
200
250
E_ν (GeV)

Figure 1


2.0
1.5
1.0
0.5
0
σ(νNe) / σ(νd)
(a)
0
1.0
2.0
3.0
P_T OF MUON (GeV/c)

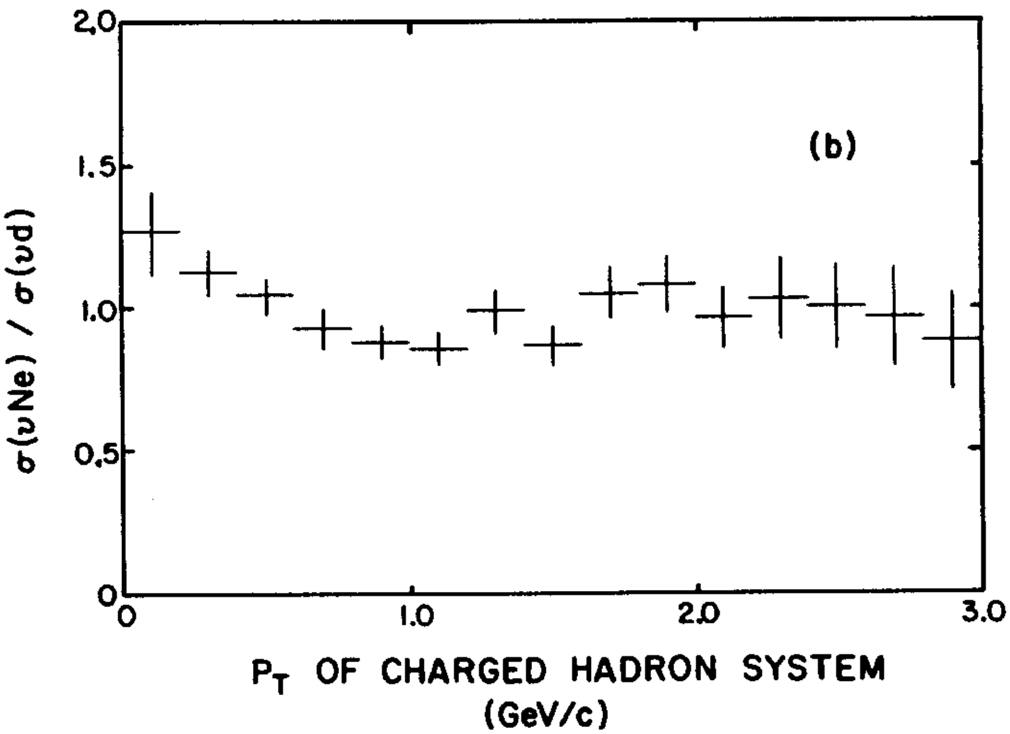

2.0
1.5
1.0
0.5
0
σ(νNe) / σ(νd)
(b)
0
1.0
2.0
3.0
P_T OF CHARGED HADRON SYSTEM (GeV/c)

Figure 2

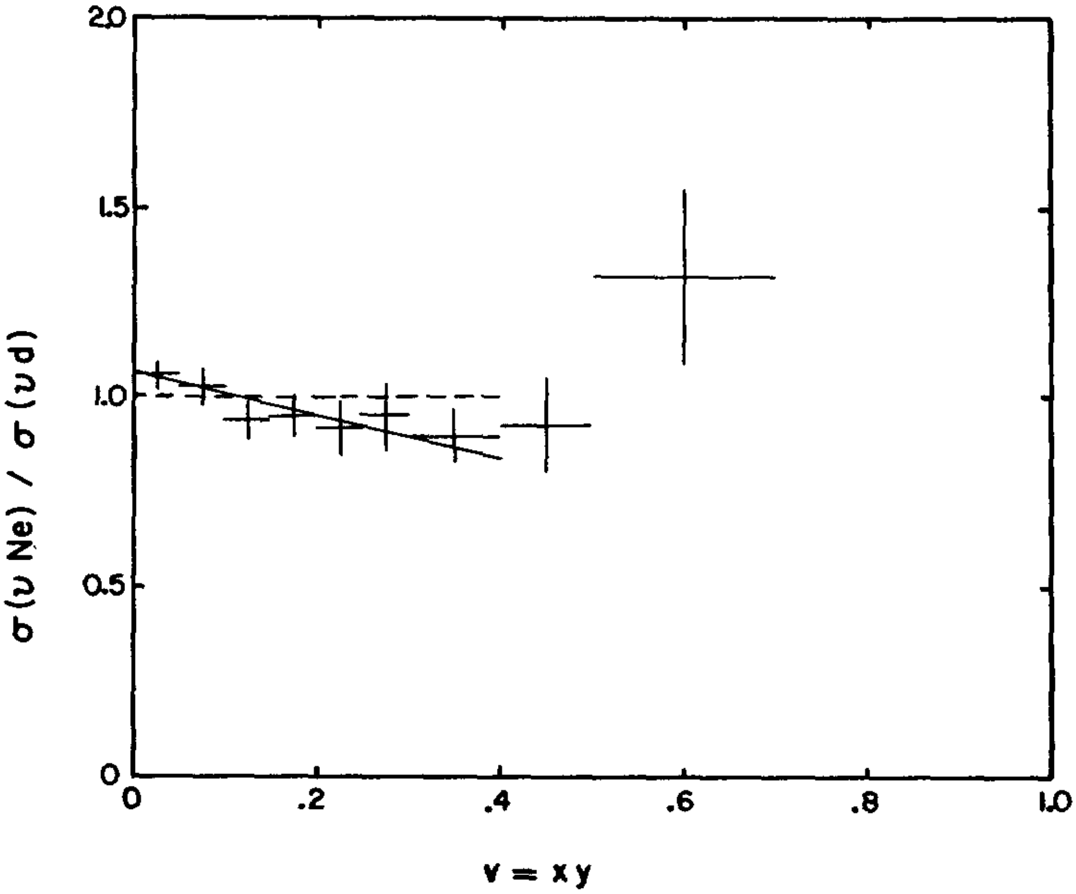


Figure 3