SCATTERING OF C^{13} FROM O^{16}

by

ROBERT LOUIS PHILLIPS

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Approved by:

James C. Legg
Major Professor

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INTRODUCTION

Resonance phenomena have been observed in nuclear processes for many years. Until 1960, however, the only cases that had been observed involved light particles (A less than 5) interacting with heavy nuclei. These could be explained as the population of individual levels in the resulting compound nucleus. They were characterized by their relatively low excitation energies (about 4-10MeV)in the compound nucleus and their involvement in only a few reaction cross sections.

In 1960 a very different class of resonances was discovered in a system involving two heavy ions, ^{12}C on ^{12}C (1). They are special because they involve very high excitation energies in the compound nucleus (about 20MeV) and they manifest themselves in many exit channels.

To explain this phenomenon it is necessary to postulate the formation of a special state of the compound nucleus. This state must be formed with a very high excitation energy and must have some width for decay into many available reaction channels. These states are termed nuclear molecular states. The behavior that is envisioned by this term is that the two colliding nuclei will remain in close proximity to each other while still retaining the basic character of two independant nuclei. In short a molecule but with nuclear forces providing the binding energy instead of electrostatic forces.

Today there is an abundance of experimental and theoretical work available on this phenomenon. Table 1 (page 2) gives a partial listing of the experiments performed to attempt to locate resonances. This particular table was adapted from

TABLE 1.

reaction	relative level density	relative number of open channels	exit channels observed	resonances observed (a)	reference
$^{9}Be + ^{12}C$	3.3	7.	p, α	No	17,3
$^{10}B + ^{12}C$	15	14	gamma	No	18
$^{11}B + ^{12}C$	11	14	gamma	No	18
$^{10}B + ^{14}N$	100	350	α, ^{12}C	No	19
$^{12}C + ^{12}C$	1	1	γ, p, n, α, ^{8}Be, ^{12}C	Yes	1,4,20,21,11
$^{12}C + ^{13}C$	7.1	13	gamma.p. α, ^{13}C	No Yes	19,22 2 ,24
$^{13}C + ^{13}C$	36	48	gamma	No	22
$^{12}C + ^{14}C$	13	12	d, t, α	Yes	25
$^{12}C + ^{14}N$	23	13	p, α , gamma	No	18,26,27
$^{12}C + ^{16}O$	3.8	3.9	p, α	Yes	5
$^{14}N + ^{14}N$	110	300	γ, p, d, α	No	3,17,28,29
$^{13}C + ^{16}O$	59	125	gamma, ^{13}C	No	present work
$^{12}C + ^{19}F$	350	1800	γ	No	26
$^{12}C + ^{20}Ne$	43	75	γ	No	26
$^{16}O + ^{16}O$	22	34	γ, p, n, d,	No	1,21
$^{16}O + ^{20}Ne$	450	1500	gamma	No	26

Table 1. Information on subCoulomb structure and resonances in heavy ion interactions. A more complete table can be found in Hanson et.al. (ref. 3). This reference also contains the details of the calculations of the level densities and open channel numbers.

(a) The word No is used in several cases where there is some structure in the excitation functions. However positive results are ascribed only to those cases where the structure found is subCoulomb barrier and of the same type as the carbon-12 on carbon 12 resonances.

one found in Hanson et.al. (3) and definitions as well as calculational details can be found there.

Of the many theories that deal with resonances as something other than statistical fluctuations only three have received major attention or belief. They have been formulated at various times and not all of them listed were formulated to explain the entire table presented in this paper.

One of the first and simplest models introduced to explain the existence of resonances in the $^{12}C+ {}^{12}C$ system was first postulated almost simultaneously by Vogt et.al.(4) and by D.A.Bromley et.al. (1)(6) in 1960. This model proposed the existence of a secondary minimum in the effective potential of the combined system for at least some values of angular momentum.

This minimum arises from the decrease in the surface energy of the combined system resulting from the two particles joining together at one surface point during a grazing collision. Thus the two nuclei, fixed on a surface point, are free to vibrate along their molecular axis. This binding is the mechanism responsible for the extended lifetime of the system.

An important detail of this process is that it requires one or both of the colliding nuclei to be relatively soft and easily deformed. This deformation is the process that makes it possible for them to fasten together at distances large enough for the effect to take place outside of the Coulomb barrier.

This requirement was formulated so that this model could explain the existence of resonances in the $^{12}C+ {}^{12}C$ system and also their absence in the $^{16}O+ {}^{16}O$ system.

Another problem that had to be overcome was that this model seems to predict that any system of particles where one or both

of the incident nuclei are not closed-shell nuclei will show resonant behavior. To remove this difficulty the further requirement that the two incident particles be composed of whole numbers of alpha particles was imposed.

This model has lost much of its popularity mainly because the branching ratios and the cross-sections it predicts are smaller than those measured. In fact, for the case of $^{12}C+ ^{12}C$ the reaction particle cross-sections predicted are somewhere between a factor of 4 and 10 too small at the lower energies.

Another popular, and commonly used, explanation was pioneered by B. Imanishi in 1968 (7)(8). According to this model the mechanism responsible for the resonances and structure found in the excitation functions involves having one of the two colliding nuclei undergo a transition to an excited state. If this state is at a sufficiently high energy that the system loses an appreciable amount of its kinetic energy, as well as **orbital angular momentum, then this loss will cause it to occupy a quasi-bound state of the system.**

The quasi-bound nature of this state gives rise to the extended lifetime of the system. And, of course, it is this extended lifetime that characterizes resonant systems. The basic requirement, then, for a system to display resonant behavior in this model is that it possess high first excited states in both colliding nuclei. Both must be relatively high since the system will tend to selectivly populate the lowest excited states and if one of the states is too low the effect will not be seen. Experimental evidence places a lower limit on the value of the first excited state at about 2-3 MeV. Below this value the energy lost in exciting the state is not sufficient for the binding to last long enough for

resonance effects to be observed.

Although Imanishi's original publications dealt only with the $^{12}C+ ^{12}C$ system and only reproduced the first three resonances (8) below the coulomb barrier, his work was later extended by Kondo et. al.(among others) to include many more of the resonances.(9) It was also extended to explain the super-Coulomb-barrier structure found in the $^{16}O+ ^{16}O$ system(9). Here the calculations were performed by W. Greiner et.al. and the experiments done by research teams at Yale. (10)

The third of the three major theories was championed by Michaud and Vogt. This theory calls for the formation of what are termed "intermediate states". This terminology arises because they are supposed to be populated between the time that the system is in the two separate particle configuration and the formation of the true compound nucleus. These states are formed when one of the two colliding nuclei disintegrates into smaller, identical, particles. The interaction of these particles with the intact nucleus is then expected to show behavior much more complex than simple two-body motion.(2)(12)(13)

As described for the case of $^{12}C+ ^{12}C$ (2) the proposed structure has one of the two carbon nuclei fragment into three alpha particles. These then interact with the intact nucleus in much the same manner as the three hydrogen atoms interact with the nitrogen atom in the ammonia molecule. The difference is that the ammonia molecule is bound by electrostatic forces while the nuclear"nolecule" is bound by nuclear forces. This alpha particle molecule, as it is sometimes refered to, can then exist for a finite period of time before it either has one or more of the

semi-free alpha particles are captured or released.

Once any of the particles escape or are captured the system will immediately collapse into a compound nucleus state. Also in order for more than one alpha particle to escape they must combine. This is necessary for them to have sufficient energy to do so. Thus there is some width for the escape of ^{12}C or ^{8}Be from the resonating state.

It can be readily understood that this state is at a very high excitation energy, particularly if it is viewed as an excited state of the resulting compound nucleus, in this case ^{24}Mg. Thus it has a rather short lifetime. This leads us to the conclusion that the addition of even a single non-identical particle in the orbit of the fragments will perturb the system sufficiently to eliminate the long-lifetime intermediate state altogether. Thus the requirement that the nucleus which fragments be composed of a whole number of alpha particles is imposed.

Using this theory and appling several different optical model potentials, as well as an alpha-alpha potential, Michaud and Vogt were able to satisfactorily reproduce most of the structure in the elastic scattering cross-section excitation functions fairly well.(12) Unfortunately their work has not, at present, been extended to other systems. It is thus difficult to determine if the absence of structure in the $^{12}C+ {}^{20}Ne$ system is explained by it or if it is a difficulty that it must face.

In an attempt to add to the available body of experimental evidence an investigation was done on the $^{13}C+ {}^{16}O$ system. There were several reasons for its choice.

Imanishi's theorem calls for high first excited states in the colliding nuclei. This criterion is satisfied by this system.

The disintegration into alpha particles that is called for in the alpha particle molecule model is not likely to occur. The only way for this system to produce three or four alpha particles would be for the oxygen nucleus to break up. It is far more likely that the carbon will fragment long before the more stable, closed-shell oxygen nucleus.

Thus the results of the experiment can be used to select between these two models. The discovery of resonances lends some credibility to the theorem of Imanishi while non-discovery will add support to the model proposed by Michaud and Vogt.

A further consideration in this choice is the energy level density. A large value for this number indicates that the resonance lifetimes will be short. The short lifetime tends, according to conventional wisdom, to broaden the resonance as well as to decrease its magnitude. Finding resonances or structure in this system would have the effect of raising the upper bound on this number.

APPARATUS

All of the experimental work for this project was performed using beams accelerated with the K.S.U. 6 MV tandem Van de Graff generator. The carbon-13 beams were produced in the High Voltage diode ion source.(14) This unit has several means for producing this particular beam. For example, beams of CH, CH_4, C and CN anions have all been obtained by bleeding methane gas mixed with nitrogen gas into the arc region. The problem encountered with all of the lighter anions is that the intensities produced do not suffice for this type of work. Any of these beams can be produced in quantities of only 1-10 nA. It was therefore decided to use as the anion beam the CN radical produced by bleeding a 1:2 mixture of methane and nitrogen gas into the arc. This method is capable of producing source beam currents of up to 20 microamps. This amount is far more than adequate for any studies involved in this report. In fact, the usual source beam current used was only about 3 microamps. This gives about 600nA of beam on the target using the 3+ charge state for energies between 12 and 20MeV.

This anion, of course, does not allow the optimum beam energy to be obtained. The average charge state of the beam after gas stripping at the terminal is only about 3.4. Thus for beam energies less than 21MeV the 3+ charge state is used. For energies up to 27MeV the 4+ charge state beam is employed and the loss in beam current of 60%-90% must be accepted. This compares to final energies available using a C anion of 24 and 30MeV using the 3+and4+ charge states respectively. Once it became clear that all of the structure of interest was in the 11-14MeV beam energy range it was obvious that the correct choice was the beam with greatest intensity.

The K.S.U. tandem facility has two scattering chambers devoted to heavy ion nuclear studies. Both were employed for taking data in this report. For data that does not involve measuring or recording gamma rays the chamber used is the 24" stainless steel chamber. This unit was designed for the facility by Erich Feldl.

This chamber is at present wired to handle up to eight separate detectors. The mounting system uses three concentric rings each of which has mounting locations spaced at 30° intervals. Tracks are then placed at selected locations on these rings. The detectors and collimators are then mounted on these tracks. Each of the rings can be separately rotated from outside of the chamber without breaking the vacuum. Locations of the detectors, using the existing calibrations, is $\pm.1^{\circ}$(nominal). The chamber is fitted with target handling systems so that up to five targets can be kept inside. These can be removed, if nescessary, without letting the chamber up to air pressure by means of an air lock fitting.

The target handling equiptment is capable of selecting one of the five targets, rotating it 360° with respect to the beam axis and adjusting its vertical location with respect to the beam center. This also can be done with the entire chamber still under vacuum.

To avoid the effects of beam spot motion a system of two collimator slits was employed. The closer slit was usually placed about 12-13cm from the target while the more distant slit was placed about 30cm away. The effect of these slits was that if the beam was steered in any direction the ratio of counts in any peak to integrated beam current would not vary by more than 1-2%.

When the particular measurement being taken involved gamma rays, the other chamber was employed. This device, named the "mixing-bowl" chamber, was manufactured at the facility. One side of it is a hemispherical shell made of .375mm thick stainless steel. The other side is a flat plate of .625mm thick stainless steel. This side has an inset in it to permit a gamma detector to be placed within 2cm of the target. The chamber has provisions to hold up to three targets. These can be selected from without having to pressurize the chamber to air pressure. To facilitate angular correlations they can also be rotated 360° with respect to the beam axis.

In addition there is a mounting bracket inside of the chamber. This is used to mount a particle detector which is used to monitor either elastic or reaction particles. For most of the studies involved in this report this mount was used to hold a .1mm particle detector that was used to normalize the data.

With both chambers individual data points were timed using a current integrator. This unit was connected to either the Faraday cup of the large chamber or to the target of the smaller one. This proved to be unsatisfactory as a means of normalizing the data, however. Thus for normalization a particle detector at a far forward angle was used. This angle varied from one run to another but was held fixed for any one excitation function. It was in any case always between 9° and 25°. The carbon-13 scattered into this detector from the heaviest component ir the target could then be assumed to be purely from Rutherford scattering. In this way plots of cross section as ratio to Rutherford could be easily obtained.

Data taking was accomplished using only three basic types of detectors; silicon surface barrier detectors, lithium-silicon proton detectors, and a lithium-drifted germanium gamma ray detector.

The silicon detectors were used to obtain most of the particle data. Three different varieties were employed. These were 0.1mm and 1mm Ortec and 0.1mm Princeton Gamma Tech. They are operated by placing a bias voltage of 15-250V across the active surface layer. When the biased detector is struck by a charged particle, it gives off a signal which has a peak current proportional to the energy the particle lost in the active region of the detector. This loss can range from 100% for heavy ions (carbon for example) in any detector to as low as 10% for fast protons in one of the thinner units. Thus to measure alpha spectra the thicker model of detector is mandatory.(16)

Figure 1 shows two typical spectra from this type of detector. The middle spectrum was taken by a 1mm unit using an aluminum shield to screen out all of the heavy particles. All of the counts in this spectrum are thus due to alphas striking the surface of the detector. Unfortunately all of the large, intense lines in the spectrum have been identified as resulting from reactions between carbon-13 and carbon-12 from the surface layer on the target.

The bottom spectrum was taken using a 0.1mm detector. The narrow line at the left is caused by protons. These do not give up all of their energy and thus the detector cannot tell their true energy. The large broad line just to the right of the proton peak is the result of recoiling iron atoms. The apparent doublet is actually due to a combination of elastically scattered carbon-13

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

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THE FOLLOWING PAGES ARE BADLY SPECKLED DUE TO BEING POOR QUALITY PHOTOCOPIES.

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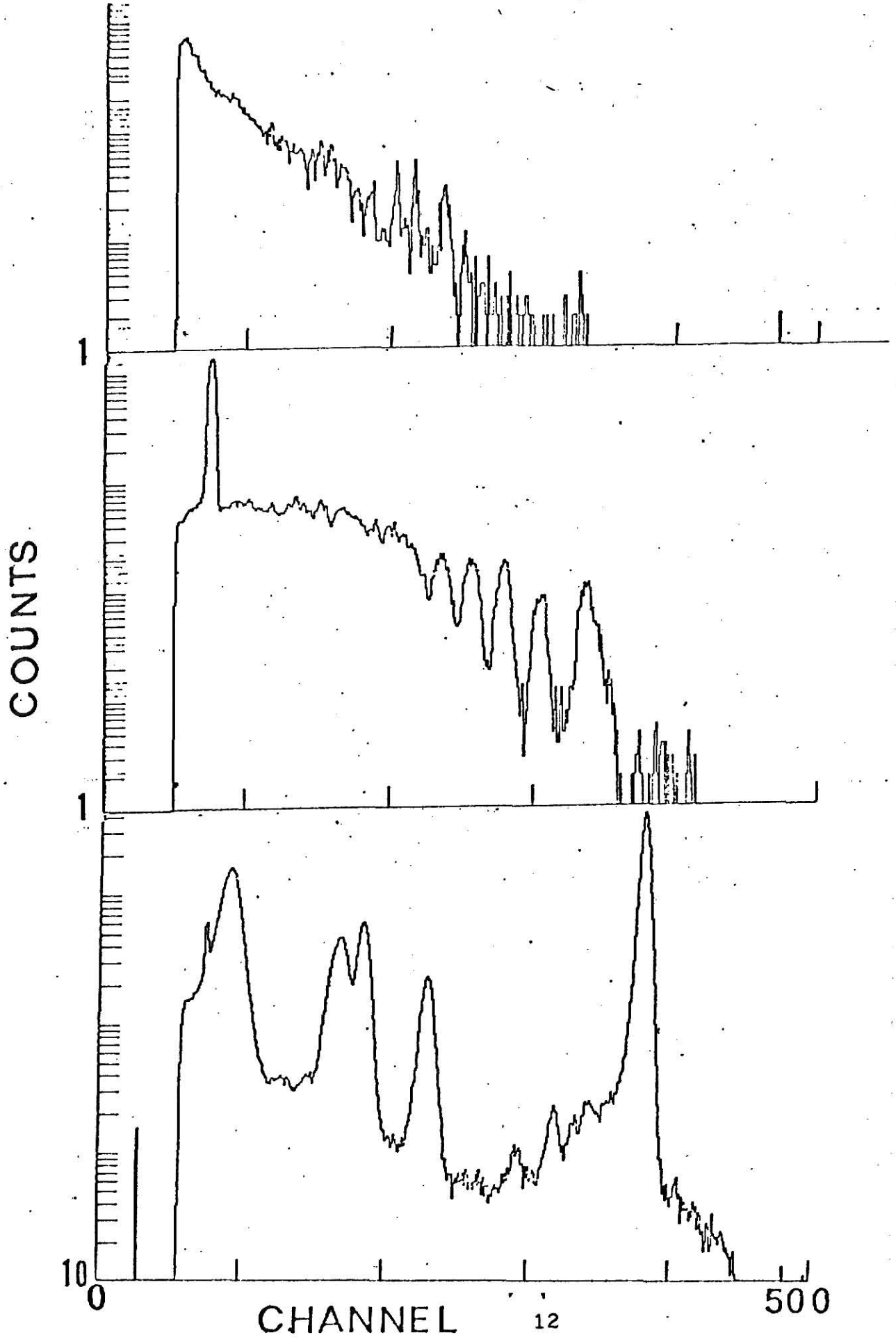
Figure 1. Typical Spectra from Heavy Ion Detectors



($^{12}C(^{13}C,^{13}C)^{12}C$) and the recoiling oxygen and carbon-12. The two large lines on the right are due to carbon-13 ions scattered from the Fe in the target (this line is on the far right) and from the oxygen-16 in the target(this is located at about channel 225). The other, smaller, lines are due to a variety of causes. Most of the lines are the result of inelastic scattering of ^{13}C from iron.

For recording spectra of protons the lithium-silicon detector gave the best results. The upper spectrum of figure 1 is a typical example. The problem with this data is that all of the broad, intense lines are identified as resulting from carbon-carbon reactions. The small number of counts at the far right may or may not be due to reactions of carbon on oxygen. The number present in that area is so amall that there is no real way to tell with any ceartainty.

The final detector type employed is the 90cc Princeton Gamma Tech Lithium drifted germanium detector. This device is capable of resolution on the order of 2KeV using the 1.332MeV line of ^{60}Co as a reference. It has a counting efficiency of better than 19%. Unfortunately this was not sufficient to resolve more than two of the resulting gamma ray lines from our reactions. The chief reason for this problem is again the carbon layer that invariably built up on the target.

Whichever detector (or mix of detectors) was employed in a given run the electronics used were about the same. Figure 2 illustrates the schematics of the basic data recording hook up. The signal from the detector is routed to a preamplifier which, in turn, is connected to a spectroscopy amplifier (Ortec 451 or equivalent). This signal is sent to a mixer and router which is

Figure 2 Typical electronics schematic diagram.

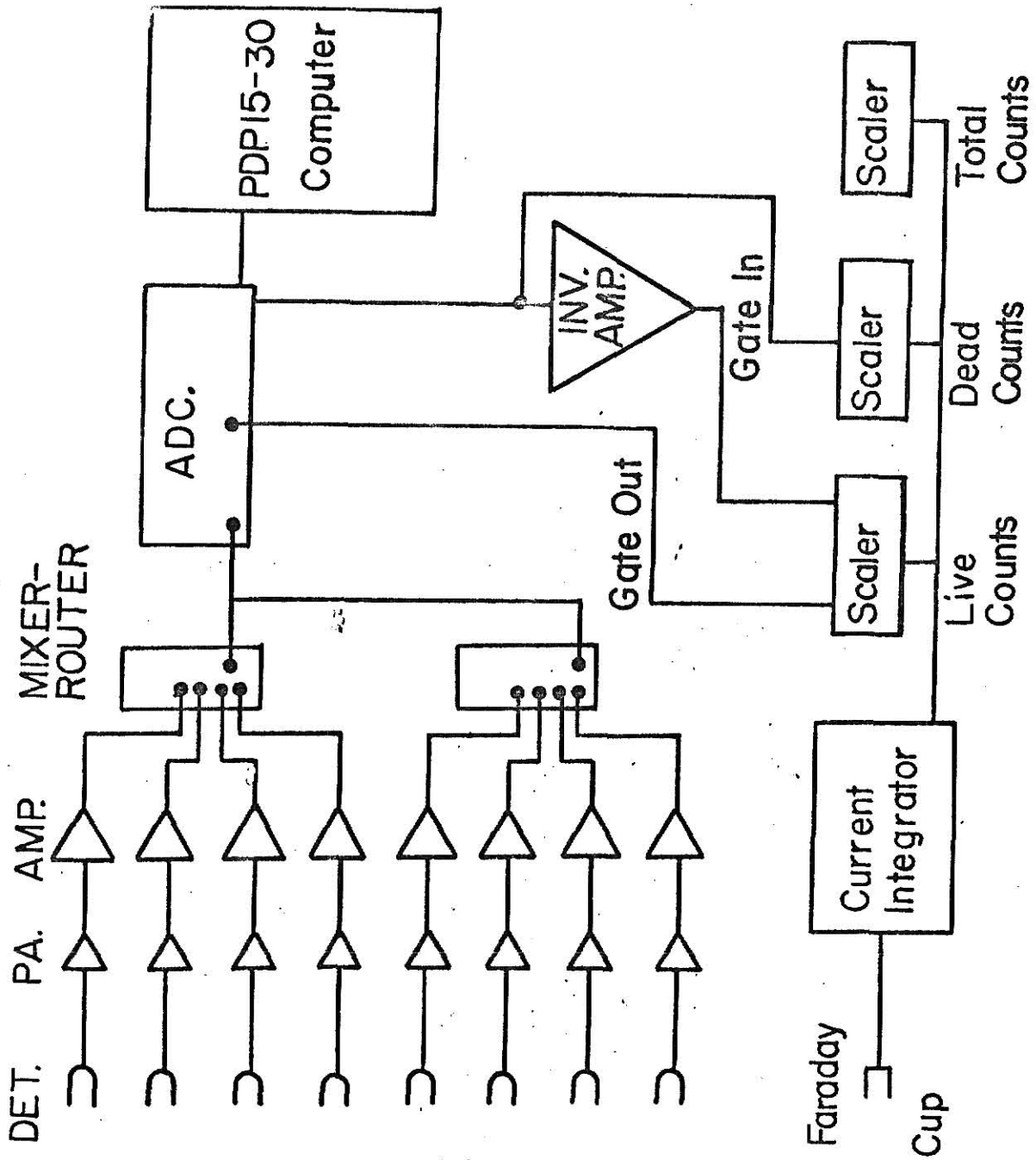


FIGURE 2

combined with an analogue-to-digital converter. This assembly outputs a signal containing two pieces of information: The amplitude of the input pulse (energy of the incedent particle, gamma) and which of the several detectors in use produced the signal. The signal, now in digital form, is then entered into the computor and stored first in memory while the spectrum is accumulated and later on magnetic tapes for later analysis.

To extract the data used in the plotted excitation functions two methods of curve fitting were employed. Both involve the use of the PDP-Digital computor in the laboratory. The first (and simplest) involves fitting the background in the area of the peak of interest to a polynomial. This program uses the method of least-squares. The intrapolated curve is then subtracted point-by point from the data. The integrated difference was taken to be the "true" area of the peak.

The second method involves fitting the peak to a given shape. This shape was usually a Gaussian but a Lorentzian shape was also tried. If the background is also fitted at the same time to a straight line then the parameters of the fitted curve give the area of the peak in question. This method of fitting uses the technique of parameter search. This method will even give fairly reliable data even if the peak of interest slightly overlaps with another peak.

The general rule for selection between the two methods was to employ that method that best reduced the scatter of the resulting excitation function. A further consideration was that the resulting background or fitted curve had to be a reasonably close to the original data curve.

The programs from which the actual data reduction programs were

adapted all appear in Bevington's book (31). Most of the adaptation done concerened itself with making the programs fit or work in the computor in the laboratory. Also much investigation was done to fit other curves than the original programs were written to work on.

Each point was then normalized to the number of carbon-13 ions scattered into a detector at a far forward angle(9^{o}-25^{o}). This produces immediately a plot of cross section as a ratio to Rutherford (in arbitrary units).

The final item of interest is the targets. These definitely gave the most problems of any item in the experiment. Many dif ferent types of target materials were tried. The list includes, but is not limited to, SiO and SiO_2 self-supporting targets, TiO and FeO self supporting, TiO on Ti, FeO and CaO on carbon backing and CaO on Ti backing.

The silicon targets were ruled out because they produced inelastic peaks from the silicon that interferred with the oxygen data. They also produced reaction particles that made data from carbon-oxygen reactions impossible to separate out. The pure titanium and iron oxides could not be floated properly and so could not be used as targets. The CaO on Ti backing targets produced disintegrated when the beam struck them. Apparently the alloy formed during the evaporation was too brittle to take the heat of the beam.

The TiO on Ti backing targets produced some of the best elastic scattering data obtained. The reason that they were discarded was that they tended to build up a layer of carbon-12 on the surface facing the beam. This layer produced reaction particles that made it impossible to sort out reaction data. Since it was

moreover impossible to get the oxide layer very thick the improved statistics desired later were impractical. Thus for the later runs where the reaction data was essentially written off targets of iron and calcium oxides evaporated onto carbon backings were employed.

They were made by evaporating thin layers of Ca or Fe onto a self-supporting carbon-12 backing. As long as the layer of metal was kept below 10-20μgm/cm^2 the stopping power effects on the structure were found to be minimal. An iron oxide layer about 100μgm/cm^2 thick was made. It broadened the structure so much that it virtually disappeared.

Oxidation was accomplished for the Fe targets by heating them in an oxygen atmosphere at about 20 millitorr O_2 . The Ca layer could be satisfactorily oxidized by exposure to air for several minutes.

ANALYSIS

Figures 3 and 4 show the resulting excitation functions for elastically scattered ^{13}C from ^{16}O. Figure 3 was obtained by analyzing spectra from three essentially identical TiO on Ti targets. The stopping power of the oxide layer on all three targets was 40-60KeV at 13MeV lab energy. This was one of the "survey" excitation functions, taken to obtain preliminary data on the existence and location of interesting structure. The dashed lines drawn on the plots indicate the location of the structure later given more through study.

Figure 4 shows some of the results of one of these investigations. This excitation function was measured from spectra taken using a target composed of a 10μgm/cm^2 carbon backing onto which a 14μgm/cm^2 layer of iron had been evaporated. This iron layer was then heated in an oxygen atmosphere until it was about 80% FeO. The stopping power of this layer was calculated to be about 70KeV in the energy region of this graph. A third layer of carbon-12 was deposited onto the face of the target due to the action of the beam. Its thickness cannot be determined with much precision but an estimate based upon visual inspection places its thickness as being on the order of 10μgm/cm^2. This adds an additional stopping power of 60-70KeV. Thus the total stopping power of this target for computing the effects on the oxygen data is about 140KeV. Notice that the peaks on the excitation functions have shifted about 100-200KeV higher and are about 100KeV wider.

Data was also obtained for two reaction channels using gamma ray dection. The two lines that were analyzible in the spectra were the 1.779MeV line of ^{28}Si produced in the reaction $^{16}O(^{13}C,n)^{28}Si$, and the .843MeV line of ^{27}Al. The latter was produced in a reaction

Figure 3. Elastic scattering excitation function 13-20 MeV

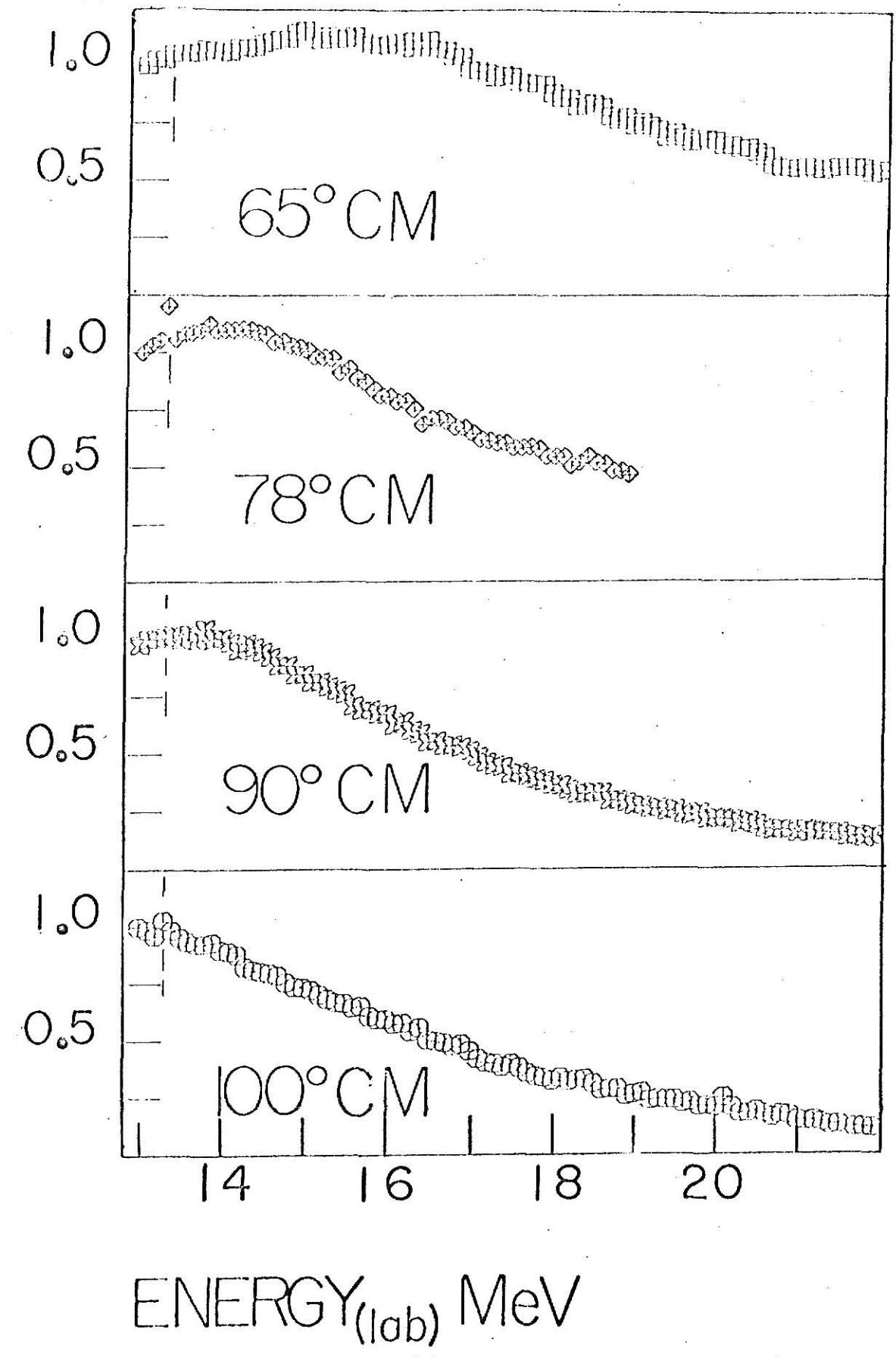
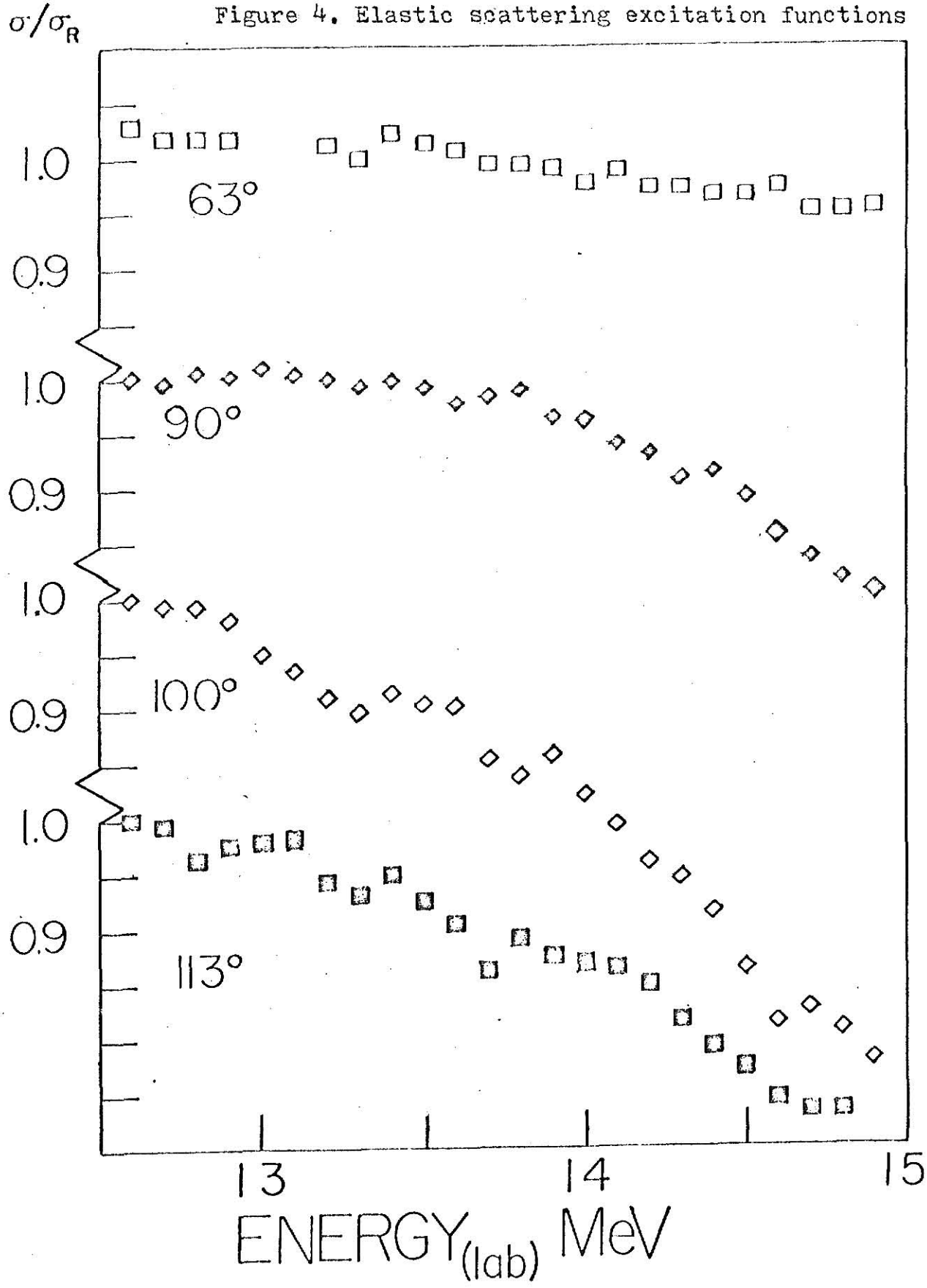


Figure 4. Elastic scattering excitation functions



of the form (C,d) , (C,n,p) or (C,p,n). Since the (C,p) reaction product ^{28}Al is not observed via its gamma rays, the (C,p,n) reaction is unlikely. Because no deuterons are observed in any of the particle detectors the (C,d) reaction also seems to be unlikely. Thus, the assumption favored is that the reaction involved is the (C,n,p) reaction.

Both of the reaction excitation functions are plotted as the nuclear structure factor(32). This quantity is defined as

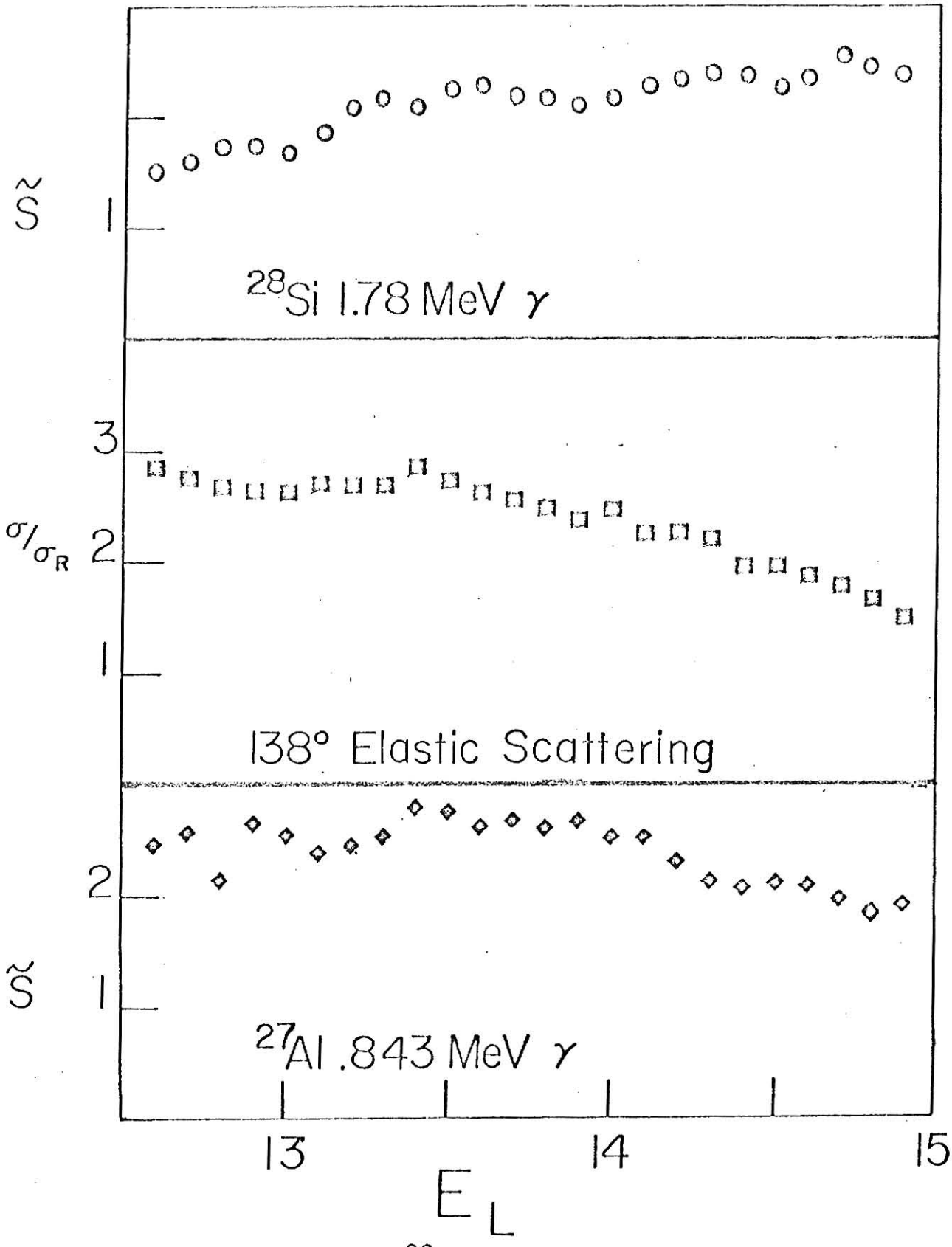
$$S(E)=\sigma(E)*E* \exp\left|\frac{4Z_1Z_2e^2}{h\,v}\right| \arccos(T/B)^{\frac{1}{2}}-(T/B)^{\frac{1}{2}}(1-T/B)^{\frac{1}{2}}\Big|\Big|.$$

Where $B= Z_1Z_2e^2/R$ is the electrostatic energy at the radius of the Coulomb barrier (R). T is the kinetic energy of the incident particles in the center of mass system. Finally, $\sigma(E)$ is the cross section at energy E. Plotting the data in this form factors out the effects of Coulomb barrier penetration.

In both cases the resulting excitation functions are smooth. The apparent structure in the .843 MeV gamma data is the result of poor counting statistics, not a resonance. The conclusion is that the mechanism responsible for the effect seen in the elastic scattering data affects these channels much less, if at all.

Attempts to verify these results in other reaction channels have so far met with uniform failure. The principle reason for this is the buildup of carbon layers on the surface of every target used in the study. The reaction particles produced in this layer are so numerous that they totally wash out the effects of those produced in the ^{13}C on ^{16}O reactions. Since the thickness of this layer changes in an apparently random manner subtraction and folding-out methods are found to be completely unworkable.

Figure 5. Gamma ray excitation functions 12.5-15 MeV



CONCLUSIONS

The main conclusion of this experiment is that there is no structure in the ^{13}C on ^{16}O system of the type found in the ^{12}C on ^{12}C system. There is a small anomaly at one energy in the elastic scattering channel. Since this anomaly is not correlated with structure in the reaction channels it is probably due to some type of single level resonance. The available data is not sufficient to further categorize it.

This finding presents a severe difficulty to the two theories involving single particle mechanisms. Both appear to predict the existence of the same type of structure that is found in the ^{12}C on ^{12}C system. Thus, we conclude that we cannot support the theories of Imanishi or Vogt-McMannus.

The theory that does predict correctly the results of this experiment is the alpha particle molecule model proposed by Vogt-Michaud. Because it correctly predicts the results of the experiment this is the model the experiment supports.

A further conclusion from this experiment pertains to the resonance structure found in the ^{13}C on ^{12}C system. There are two explanations resulting from this experiment regarding the location of the extra neutron in this system compared to the ^{12}C on ^{12}C system. One of the explanations hypothesizes that the extra neutron is stripped off before the resonance process occurs. The other model views the neutron as a spectator in the core (unaffected) nucleus. The latter is indicated by this experiment. The former predicts that the ^{13}C on ^{16}O system will show the same resonance structure (almost) as the ^{12}C on ^{16}O system.

REFERENCES

1. E. Almquist, D.A.Bromley, and J.A.Kuehner in Proceedings of the Second Conference on Reactions Between Complex Nuclei, Gatlinburg, Tennessee,1960 (Wiley, New York, 1960), p.151 and p.282.

2. H.Voit,P.Duck,W.Galster,E.Haindl,G.Hartmann,H.-D. Helb,F.Siller and G.Ischenko Phys. Rev. C 10 No.4 (1974) 1331.

3. D.L.Hanson, R.G.Stokstad,K.A.Erb, C.Olmer, M.W.Sachs, and D.A.Bromley. Phys. Rev. C 9 No.5(May, 1974) 1760.

4. E.Vogt and H.McManus Proceedings of the Second Conference on Reactions Between Complex Nuclei, Gatlinburg, Tennessee, 1960 (Wiley, New York, 1960) p.291.

5. J.R.Patterson, B.N.Nagorcka, G.D.Symons, and W.M. Zuk Nucl.Phys A165,545(1971);B.N.Nagorcka, G.D.Symons,W.M.Zuk and J.R.Patterson, Nature Phys. Sci. 231 (No. 18),17(1971); H.Voit,G.Hartman,H.-D.helb, G.Ischenko,and F.Siller, Z.Phys.255,425(1972);M.L.Halbert,F.E. urham and A.van der Woude, Phys.Rev.162,899(1967); G.E.Groce and G.P.Lawrence, Nucl.Phys.67,277(1965).

6.E.Almquist,D.A.Bromley and J.A.Kuehner, Phys.Rev.Lett.4,515(1960)

7. B.Imanishi, Phys.Letters 27B,267 (1968)

8. B.Imanishi, Nucl. Phys. A125,33(1968)

9. Other sources for carbon-12 data are; Y.Kondo,T.Matsuse and Y.Abe also J.J.Castro and P.Federman in papers delivered at the Second International Conference on Clustering Phenomena in Nuclei,Maryland, April 21-25,1975.
The calculations for oxygen-16 structure appeared in Phys.Rev. Letters 25,176(1970) in an article by W.Scheid,W.Greiner and R.Lemmer.

10. R.H.Siemssen,J.V.Maher,A.Weidinger and D.A.Bromley, Phys.Rev. Letters 19,369(1967),and 20,175(1967); J.V.Maher,M.W.Sachs, R.H.Siemssen, A.Weidinger and D.A.Bromley, Phys.Rev. 188,1665(1969).

11. J.R.Patterson, H.Winkler and C.S.Zaidens, Ap.J. 157,367(1969).

12. G.Michaud and E.W.Vogt, Phys. letters 30B,85 (1969).

13. G.Michaud and E.W.Vogt, Phys. Rev. C5,350(1972).

14. G.W.Hartnell, J.C.Legg, J.R.Macdonald, and G.G.Seaman, Atomic and Nuclear Physics Studies with Accelerators, p.86 Kansas State University Nuclear Laboratories publication.

15. E.J.Feldl, ibid. p.96.

16. Full details of this instrument can be found in ref. 1 as well as ORTEC Instruction Manual for Surface Barrier Detectors, ORTEC inc. 100 Midland Road, Oak Ridge, Tenn. 37830.

17. Hanson, C. Olmer, K. Erb, M. W. Sachs, R. Stokstad and D. Bromley, Bull. Am. Phys. Soc. 18,566(1973).

18.R. Dayras, Z. Switkowski, R. Wieland, and R. G. Stokstad, Bull. Am. Phys. Soc., Washington meeting, 1974
B. N. Nagorka and J. O. Newton, Phys. Letters 41B,34(1972).

19. H. Voit, G. Ischenko, F. Siller and H.-D. Helb, Nucl. Phys. A179,23 (1972).

20. M. Nazarakis and W. E. Stephens, Ap. J. 171, 197 (1972); Phys. Rev. C7, 1280 (1973).

21. H. Spinka and H. Winkler, Ap. J. 174, 455 (1972).

22. M. L. Halbert and K. Nagatani, Bull. Am. Phys. Soc. 17, 530 (1972).

23. D. J. Crozier and J. C. Legg, Bull. Am. Phys. Soc.II19, 548 (1974).

24. D. J. Crozier and J. C. Legg, Phys. Rev. Letters 33, 782 (1974).

25. M. Feil, W. von Oertzen, H. G. Bohlen, A. Gamp, R. L. Walter and B. Kohlmeyer, Z. Phys. 260, 271(1973).

26. E. Almquist, D. A. Bromley and J. A. Kuehner, in Proceedings of the Second Conference on Reactions Between Complex Nuclei, Gatlinburg, Tennessee 1960 (Wiley, New York, 1960) p.282.

27. J. A. Kuehner and E. Almquist, Phys. Rev. 134, B1229 (1964).

28. E. Almquist, D. A. Bromley andJ. A. Kuehner, Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, 1960, edited by D. A. Bromley and E. W. Vogt (North-Holland, Amsterdam, 1960), p.258.

29. R. G. Stokstad, Z. Switkowski, and R. Wieland, Bull. Am. Phys. Soc. 18,1596 (1973).

30. J. C. Legg , Private communications.

31. P. R. Bevington, Data Reduction and Error Analysis for the Physical Sciences, (McGraw-Hill, New York 1969).

32. P. Marmier and E. Sheldon Physics of Nuclei and Particles Volume 1 (1969 published by Academic Press, Inc.) page316-317.

SCATTERING OF C^{13} FROM O^{16}

by

ROBERT LOUIS PHILLIPS

B.S. University of Nebraska at Lincoln, 1973

AN ABSTRACT OF A MASTER'S THESIS

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An investigation was made of the $^{13}C + ^{16}O$ system. The primary aim of this investigation was to determine if there are resonances in this system that are similiar to those found in the $^{12}C + ^{12}C$ system. Two exit channels were investigated: elastic scattering and gamma rays from two different daughter nuclei. Despite the presence of a slight anomaly in the elastic channels no evidence for correlated structure was discovered.

Thus the conclusion is made that no such structure exists in this system.