JOHN E. EDWARDS ACCELERATOR LABORATORY

Ohio University

Athens, Ohio 45701

Differential Cross Section and Polarization
for 2.63-MeV Neutrons Scattered from ^{12}C

H. D. Knox, J. M. Cox, R. W. Finlay and R. O. Lane

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Differential Cross Section and Polarization for 2.63 MeV
Neutrons Scattered from $^{12}\text{C}^*$

H. D. Knox[†], J. M. Cox, R. W. Finlay and R. O. Lane
Ohio University, Athens, Ohio

Abstract: The differential cross section and differential polarization of 2.63 MeV neutrons scattered from ^{12}C have been measured at eight angles between 17° and 118° in the laboratory system. By simultaneously fitting the cross section and polarization data, a set of scattering phase shifts was obtained. The values of the resulting d-wave phase shifts were larger than those of other existing sets of phase shifts in the energy region. A subsequent R function analysis, reflecting these larger d-wave phase shifts, gave excellent fits to other experimental data below 3 MeV neutron energy region. The influence of narrow states at 7.50 and 7.55 MeV excitation energy in ^{13}C is discussed.

NUCLEAR REACTIONS $^{12}\text{C}(n,n)^{12}\text{C}$, $E = 2.63$ MeV; measured total σ , $\sigma(\theta)$, polarization. Deduced phase shifts.

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[†] Present address: Rensselaer Polytechnic Institute, Troy, New York.

1. Introduction

Recent interest in the scattering of neutrons from ^{12}C has to some extent been generated by suggestions as to the possible use of carbon as both a cross section standard below 2 MeV and as a polarization analyzer above 2 MeV. The use of carbon in either of these applications requires accurate knowledge of the scattering phase shifts. Below 2 MeV, two existing sets of phase shifts, those of Lane et al.¹ from an R - function calculation and those of Reynolds et al.^{2,3} from a coupled - channels calculation, seem to accurately represent both the differential cross section and polarization data existing in this energy region. In the 2-4 MeV region, in addition to the phase shifts from the coupled channels calculation, there exist two sets of experimentally determined scattering phase shifts, those by Meier et al.⁴ and those by Wills et al.⁵ These latter two sets are traditionally used to determine the analyzing power of carbon in this energy region. Both of these sets were obtained by the authors fitting only angular distribution data of their own experiments. The polarizations predicted by these sets differ, and this has led to a running discussion for several years as to which set is more nearly correct. In addition to these four sets of phase shifts, the recent work of Leung and Koshel⁶ using a unified reaction formalism resulted in still another set.

By fitting both differential cross and differential polarization data, one places severe restrictions on the allowed values of the phase shifts. These stringent checks are generally not possible with existing $n + ^{12}\text{C}$ data in the 2-3 MeV neutron energy region since most of the differential cross section and polarization data in this energy region were obtained under different

experimental conditions and at different incident neutron energies. The purpose of the present experiment was to measure the differential cross section, differential polarization and total cross section of 2.63 MeV neutrons scattered from ^{12}C . By simultaneously fitting these data, a consistent set of scattering phase shifts could be obtained. Sensitive checks of the existing sets of phase shifts could then be made at this incident neutron energy.

In order to obtain the differential polarization from asymmetry data, the source polarization, P_1 , of the neutron producing reaction must be known. In the case of the $\text{D(d,n)}^3\text{He}$ reaction, the neutron source used here, there is some controversy as to the value of P_1 especially near the incident deuteron energy in the present experiment, $E_d = 120$ keV. More will be said of this in Sections III and V. Rather than use some previously determined value of P_1 , the source polarization was included as a variable in the fitting program along with the phase shifts and an independent determination of P_1 was made.

Repeated references will be made here to the work of Lane et al.¹, Reynolds et al.^{2,3}, Meier et al.⁴ and Wills et al.⁵. For simplicity these works will hereafter be referred to as "Lane", "Reynolds", "Meier", and "Wills".

II. Experiment

A beam of 120 keV deuterons from the Ohio University Cockcroft-Walton accelerator was incident upon a thick, pure (99.999%) aluminum drive-in target. Neutrons from the $D(d,n)^3\text{He}$ reaction emitted at 50° to the incident deuteron beam passed through a long air-core, 90° spin-precision solenoid and were then scattered from a 0.749 cm. thick reactor grade carbon plate scattering sample. The scattered neutrons were detected by two detectors in the vertical plane located 45 cm. from the scattering sample. These detectors could be positioned at scattering angles between 17° and 118° in the laboratory system from the incident deuteron beam. The two detectors were RCA 8575 photomultiplier tubes with NE218 scintillators. Pulse shape discrimination was used with these detectors.

Associated-particle time-of-flight (TOF) was used for all measurements. The start signal for timing was obtained by the detection of the ^3He particles associated with the neutrons emitted at 50° . The associated-particle detector was a 50mm^2 , 300 μ depletion depth, silicon surface-barrier detector. In order to prevent deuterons elastically scattered from the aluminum target from reaching the detector, a $100\text{ }\mu\text{g}/\text{cm}^2$ Parylene N (a trademark of Union Carbide Corporation) film with a $10\text{ }\mu\text{g}/\text{cm}^2$ layer of aluminum evaporated on it and a very thin aluminized Formvar (a trademark of Shawinigan Resins Corporation) film were placed between the target and detector. The solid state detector (SSD) was centered at an angle of about 121° from the incident deuteron beam to maximize the number of "tagged" neutrons incident on the scattering sample. With this configuration, deuterons scattered from the target

were stopped in the foils, while ^3He particles reached the detector with an energy of about 225 keV when the incident deuteron energy was 120 keV.

Because of finite geometry effects, there is not a one-to-one correspondence between the number of ^3He particles detected and the number of "tagged" neutrons incident on the scattering sample. At best only a relative normalization is possible and this only when adequate precautions are taken. If the deuteron beam spot on the target should move or if the effective deuterium distribution inside the target should change due to, perhaps, local heating or a buildup of contaminants on the target face, even a relative normalization is invalid. Rather than rely on a relative ^3He normalization, the differential cross section and asymmetry data were normalized to the number of time-of-flight neutrons transmitted by the scattering sample and detected by a monitor detector located 2.7 meters from the drive-in target. This detector was a 17.8 cm. diameter by 2.5 cm. thick NE102 scintillator bonded to a tapered light pipe and mounted on an Amperex 58AVP photomultiplier tube.

In order to normalize the data in this manner, the transmission of the scattering sample must be known. The transmission was measured using the monitor detector and normalizing the number of ^3He detected but taking special precautions so that the relative ^3He normalization would be valid. Since transmission measurements require a relatively short time, changes in the actual deuterium distribution inside the drive-in target should be negligible provided that other related effects (i.e. beam spot movement, good target cooling, etc.) are stable. By using small collimators to limit beam spot movement, allowing adequate time for the neutron yield from the drive-in target to stabilize, allowing adequate time for the accelerator, itself, to stabilize and by using a

long series of short alternate sample-in and sample-out runs, the relative normalization to ^3He counting rate was felt to be adequate. The transmission of the carbon sample, which was inclined at an angle of 45° to the incident neutron beam, was determined to be 0.8438 ± 0.0027 . Since only elastic scattering is possible for carbon at this neutron energy, the total elastic cross section, σ_t , determined from this transmission measurement was $\sigma_t = 1.714 \pm 0.032$ barns.

The relative efficiencies of the neutron detectors were determined by scattering neutrons from hydrogen in the form of a polyethylene scattering sample. The contribution of carbon to the scattering was determined by replacing the polyethylene sample by a carbon scattering sample. The efficiency data was normalized in the same manner as the asymmetry and cross section data and the transmissions of the polyethylene and carbon samples used in the efficiency measurements were determined to be 0.9166 ± 0.0026 and 0.9184 ± 0.0027 , respectively. These thin samples were used in order that multiple scattering corrections would be negligible. For each detector, the number of neutrons scattered from hydrogen was measured at three scattering angles (neutron energies). Using the known cosine dependence of the hydrogen cross section on scattering angle and the $\cos^2$ dependence of the neutron energy on scattering angle, the relative efficiency of each detector as a function of neutron energy was determined.

The asymmetry and cross section were measured at 8 scattering angles between the limits mentioned earlier. The relative differential cross section, as determined from the angular distribution and relative efficiency of the neutron detectors, was normalized to agree with the total elastic cross section ob-

tained from the transmission data. Multiple scattering and finite geometry corrections were necessary for both the asymmetry and differential cross section measurements. The multiple scattering correction to the differential cross section was done using the Monte Carlo calculation of Lane and Miller⁷. An approximate correction⁸ using the same Monte Carlo code was made to the asymmetry data. A special code⁹ was written to correct for the finite geometry effects. This code was necessary to account for the effects that arise in using the associated particle time-of-flight method. With the finite geometry code, the average energy of the "tagged" neutrons incident on the scattering sample was computed to be 2.63 MeV with a full width at half maximum of 76 keV. The final corrected data are given in Table I. The errors quoted in Table I contain the effects of counting statistics only.

III. The Scattering Phase Shifts

Instead of fitting only $\sigma(\theta)$, $P_2(\theta)$, and σ_T , the program was designed to include the source polarization, P_1 , as a variable in the search procedure so that $\sigma(\theta)$, $\epsilon(\theta)$ (the asymmetry), and σ_T were all fitted simultaneously. There have been several previous measurements of P_1 for the $D(d,n)^3\text{He}$ reaction but three problems exist with these measurements. First, there is disagreement around 100 keV incident deuteron energy as to the value of P_1 . Some experiments¹⁰⁻¹² show a resonance-like behavior in P_1 as a function of deuteron energy while others¹³⁻¹⁴ do not. Second, thick targets or targets of intermediate thickness were used in all of these experiments. Depending on the experiment, then, P_1 is given as a function of either average deuteron energy, average neutron energy, maximum neutron energy or incident deuteron energy. For one to obtain a value of P_1 for a particular target material and experiment, an average energy calculation must be done. This calculation must rely upon thin target yields of the $D(d,n)^3\text{He}$ reaction and low energy stopping cross section for the target material, neither of which is well known. The third difficulty in using previously measured values of P_1 is that in several instances, carbon was used as an analyzer and the phase shifts of either Wills or Meier were used to compute the analyzing power. Since one of the goals of the present experiment was to provide a check on these two sets of phase shifts, use of a value of P_1 obtained in this manner would not be appropriate. The inclusion of P_1 as a variable in the fitting program would bypass all of these problems.

The phase shifts were obtained by minimizing the function

$$\chi^2 = \sum_{i=1}^8 \left(\frac{\sigma^c(\theta_i) - \sigma(\theta_i)}{\Delta\sigma(\theta_i)} \right)^2 + \sum_{i=1}^8 \left(\frac{\epsilon^c(\theta_i) - \epsilon(\theta_i)}{\Delta\epsilon(\theta_i)} \right)^2 + \left(\frac{\sigma_T^c - \sigma_T}{\Delta\sigma_T} \right)^2$$

with respect to each of the phase shifts and P_1 . The superscript c implies a

computed value, while $\sigma(\theta_i)$, $\epsilon(\theta_i)$ and σ_T are measured values. The calculated differential cross section and asymmetry can be written as

$$\sigma^c(\theta_i) = \sum_{L=0}^4 B_L P_L(\cos\theta_i) \quad \text{and} \quad \epsilon^c(\theta_i) = P_1 \frac{\sigma_p^c(\theta_i)}{\sigma^c(\theta_i)} = P_1 \frac{\sum_{L=1}^4 C_L P_L^1(\cos\theta_i)}{\sum_{L=0}^4 B_L P_L(\cos\theta_i)}$$

and $\sigma_c^c = 4\pi B_0$. The relationships between the phase shifts and the B_L and C_L are given by Blatt and Biedenharn¹⁵ and Simon and Welton¹⁶, respectively. The number of terms included in the series expansions for $\sigma(\theta)$ and $\sigma_p(\theta)$ was determined by applying F-tests to successive fits using increasing numbers of terms.

Five phase shifts (through $l=2$) were used in fitting the data. Both Wills and Meier found f-wave phase shifts were not necessary to fit $n + {}^{12}\text{C}$ angular distribution data in this energy region. More recently Galati *et al.*¹⁷ found that f-waves were necessary only above 4.6 MeV.

Two methods were used to minimize the function χ^2 above and both methods converged to the same final values. One method was the use of the computer code STEFIT¹⁸, a direct numerical search for minimizing a function. The other method was the Newton-Raphson method¹⁹ for the solution of a system of non-linear equations. The condition that χ^2 be a minimum requires that the derivatives of χ^2 with respect to each of the phase shifts and P_1 equal zero. These six conditions result in six simultaneous non-linear equations in six unknowns.

Table II gives the final values of the phase shifts and source polarization obtained by this search and the predictions of Wills, Meier and Reynolds at 2.63 MeV. The errors given for the phase shifts and P_1 obtained in the present phase shift analysis correspond to an increase of one in χ^2 .

Comparisons of the value of P_1 obtained here ($P_1 = -11.2 \pm 1.1\%$) with other measurements is somewhat difficult because of the previously mentioned

problems with average energy calculations. The present result falls midway in the field of numbers obtained by other experimenters and can be considered as an appropriate value of P_1 for use in this analysis.

The resulting differential polarization at 2.63 MeV is given in Table III. During the course of this experiment and analysis, two other measurements of the polarization of neutrons scattered from ^{12}C were reported. In the 2-3 MeV neutron energy region, measurements of the differential polarization were done by Drigo *et al.*²⁰ at 2.4 and 2.8 MeV and by Holt²¹ at 2.2, 2.3, 2.4, 2.5 and 2.6 MeV. The polarization measured in the present experiment is in better agreement with the results of Drigo *et al.*²⁰. The values of the polarization measured by Holt²¹ are, in general, smaller than those obtained both by the present work and by Drigo *et al.*²⁰ which might be attributed to the lack of multiple scattering calculations in the work of Holt.

Direct comparisons of the various sets of phase shifts at 2.63 MeV can be made from Table II. Plots of the measured differential cross section and polarization, fits by the phase shifts obtained directly from the data of the present experiment and the predictions of Wills, Meier and Reynolds are shown in Figures 1 and 2. As seen in Table II, the phase shifts obtained from the analysis of the present experiment differ from the generally accurate values of Reynolds mainly in the d-wave phase shifts. The differential cross section measured in the present work shows a "flattening" at forward angles that was not observed by either Wills or Meier since neither of them measured farther forward than 37° while in the present work $\sigma(\theta)$ was measured at $\theta_{\text{cm}} = 18.4^\circ$. The "flattening" of the differential cross section and the large differential polarization measured here are the primary causes of the larger d-wave phase shifts obtained in the analysis.

IV. R-Function Analysis and Conclusions

An R-function calculation of $n + {}^{12}\text{C}$ was undertaken to see if other experimental data in this energy region could be accurately described by a model which contained the enhanced d-wave contributions suggested by the present experiment. Since ${}^{12}\text{C}$ has zero spin, only one channel spin is present for neutrons scattered from carbon. Below about 4.4 MeV, only elastic scattering is possible and capture is negligible. The application of R-matrix^{26,27} theory is, then relatively easy since the R-matrix reduces to an R-function.

In the present analysis, the program COMBO²⁸ was used to compute $\sigma(\theta)$, $P(\theta)$, R_L and C_L from R-function parameters. In this program, the multi-level R-function is approximated by a two level R-function.

$$R_{\ell J}(E) = \sum_{\lambda=1}^2 \left(\frac{\gamma_{\lambda}}{E_{\lambda} - E} \right)_{\ell J} + R_{\ell J}^0$$

where γ_{λ}^2 and E_{λ} are the reduced width and characteristic energy, respectively, for the λ^{th} state of a given ℓJ . The effect of distant levels is included as a constant background term $R_{\ell J}^0$.

Data from four different experiments were used in this analysis: the differential cross section and differential polarization data of Lane below 2 MeV, the differential cross section data of Wills between 1.5 and 4.0 MeV, the differential cross section data of Galati *et al.*¹⁷ between 3 and 5 MeV and the data of the present experiment at 2.63 MeV. Comparisons of the predictions of this analysis with the differential cross section data of Meier were also made.

All levels in ${}^{13}\text{C}$ up to an excitation energy of about 10 MeV except the ones at 0, 3.86, 7.50 and 7.55 MeV were included specifically as levels in this

analysis. The final parameters for the fit are given in Table IV. For all lJ , the nuclear radius was chosen to be $3.72R$. Fits to the B_L and C_L coefficients of the four experiments are shown in Figure 3 and 4.

The data of the present experiment for the differential cross section and polarization at 2.63 MeV as well as that predicted by the R-function calculation are shown in Figure 5. The values of the $s_{1/2}$, $p_{1/2}$, and $p_{3/2}$ phase shifts from this R-function calculation are -99.1° , -12.9° and -9.1° , respectively, and are in agreement with those of Reynolds and with those obtained directly from the phase shift analysis of the present experimental data. The values of the $d_{3/2}$ and $d_{5/2}$ phase shifts are 21.7° and -6.7° , respectively. From Table II, it can be seen that these values fall between the predictions of Reynolds and those obtained directly from the present data. The value of χ^2 for the R-function fits to the present data are 77.5 for the differential cross section and 5.5 for the differential polarization. In the case of the cross section, this is about a factor of 3 better than the fit obtained using the phase shifts of Reynolds.

Comparisons of the predictions of this analysis to the experimental data of Lane below 2 MeV are shown in Figure 6. The final R-function parameters of Lane were used as the starting values for the present work. The differences between these two calculations which affect the predictions below 2 MeV are mainly in the calculations of $R_{d_{5/2}}$ and $R_{s_{1/2}}$. In the present calculation, the bound $d_{5/2}$ state at -1.093 MeV was included specifically as a level, whereas the effects of this state were included as a background $R_{d_{5/2}}^0$ in the calculation by Lane. The present calculation included a small positive $R_{s_{1/2}}^0$ in the calculation of $R_{s_{1/2}}$. Both of these changes improved the fits to Lane's

data below 2 MeV.

The motivation for adding the background term in the R-function calculation for the $s_{1/2}$ case was to bring the total cross sections below 2 MeV predicted by this analysis more in line with the recommended values of Francis et al.²⁹ who made a careful study of existing experimental data in this energy region. Values of σ_t predicted by the present calculation agree with these recommended values to within 2%.

Comparisons of the predictions of this analysis to the data of Wills, Meier, and Galati et al.¹⁷ are shown in Figures 7, 8 and 9, respectively. Fits to the data above 4 MeV by the present analysis are not as good as the fits by the phase shifts of Reynolds. The inability of the phase shifts of the present analysis to fit data above 4 MeV is due to the opening of the inelastic channel in $n + {}^{12}\text{C}$ scattering. However, in the 2-3 MeV region the fits to the data of Wills and Meier by the phase shifts of the present R-function analysis are typically better than fits by Wills and Meier to their own data and are as good as the fits obtained by Reynolds' phase shifts to these data. Unless further experimental work is done to clarify the question of enhanced d-wave phase shifts, either the present analysis or that of Reynolds can be used as an adequate representation of $n + {}^{12}\text{C}$ scattering phase shifts.

V. The Levels at 7.50 and 7.55 MeV in ^{13}C .

Boersma²² and Hänsen²³ have suggested that the two levels at $E_x = 7.50$ MeV ($E_n = 2.75$ MeV) and $E_x = 7.55$ MeV ($E_n = 2.82$ MeV) in ^{13}C might be the cause of the resonance-like behavior of the asymmetry as measured in an experiment somewhat similar to the present one. The measurement of Hänsen et al.¹⁰ of the asymmetry of the $\text{D(d,n)}^3\text{He}$ reaction showed a resonance occurring at about 100 keV incident deuteron energy. In these measurements, carbon was used as the polarization analyzer and the phase shifts of both Wills and Meier were used to calculate the analyzing power of carbon. The observed resonance was first attributed to a virtual level in ^4He but the existence of such a level is now doubtful since its effects have not been observed in two other similar experiments^{13,14} or in other reactions, e.g. the $\text{T(p,n)}^3\text{He}$ reaction²⁴. Boersma²² first suggested that the resonance was due to the levels at 7.50 and 7.55 MeV in ^{13}C and not due to a level in ^4He . Since neither the phase shifts of Wills nor those of Meier reflects the presence of these levels, the use of either set of phase shifts to predict P_2 could erroneously show a resonance in the resulting value of P_1 . If these two levels are, in fact, the cause of the resonance-like behavior measured by Hänsen et al.¹⁰, they might also have some effect on the present experiment.

Of the two levels in question, only one has been given a definite spin and parity assignment. This is the level at 7.55 MeV and the assignment is $5/2^-$. Only recently has this level been observed in high resolution total cross section experiments. The level at 7.50 MeV has never been observed in a neutron scattering experiment. No definite spin or parity assignment has been made to this level although Hänsen²³ proposes that the level is $7/2^+$.

This possible assignment is made because of the existence of a $7/2^+$ level in the mirror nucleus ^{13}N .

Using the R-function formalism described above, the possible effects of these two levels on both the experiment of Hånsen et al.¹⁰ and the present one were studied. In this calculation, it was assumed that the total widths of the 7.50 and the 7.55 MeV levels were 1 and 2 keV, respectively. Present estimates of the actual width of the 7.55 MeV level are that it is less than 0.5 keV, while the width of the 7.50 MeV level is even smaller. Thus, this calculation represents a "worst possible" situation. The 7.50 MeV level was assumed to be $7/2^+$.

Figure 10a shows the results of this calculation. Any effects of the lower level would be noticeable only if the neutron energy were greater than 2.74 MeV. Thus the effects of these levels on the present experiment are completely negligible because the energy spread of the "tagged" neutron beam limits neutron energies to values well below 2.74 MeV. From kinematics, 2.74 MeV neutrons are produced at 50° from the $\text{D}(\text{d},\text{n})^3\text{He}$ reaction when the incident deuteron energy is 120 keV. Thus, Hånsen et al.¹⁰, using thick targets and no associated particle techniques should only begin to see any effects of these resonances above $E_d = 120$ keV. Furthermore, the use of thick targets would average out the resonance-like effects of these levels. Using the "thin target" values of P_2 shown in Figure 10b and assuming a neutron flux^{26,10} given by

$$N(E_d) \propto e^{-48E_d^{-1/2}},$$

where E_d is the incident deuteron energy, a calculation of the polarization $\bar{P}_2$ that would be measured in an experiment using a thick neutron producing target was made, where:

$$\bar{P}_2 = \int P_2(E_n) N(E_n) dE_n / \int N(E_n) dE_n.$$

The results of this calculation are shown in Figure 10b. The values of P_2 measured using a thick target would show only a small plateau occurring at energies above 120 keV. The values of P_2 on this plateau are about 3% higher than the values of P_2 obtained assuming the two narrow levels are not present.

Using "worst possible" assumptions about the widths of the two levels at 7.50 and 7.55 MeV, the calculations described here show these levels should have no effect on the present experiment. Also, the resonance-like behavior of the asymmetry observed by Hånsen et al.¹⁰ could not have been caused by the existence of these levels in carbon.

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TABLE CAPTIONS

Table I: Differential cross Section and Asymmetry for 2.63 MeV neutrons scattered from ^{12}C .

Table II: A comparison of the various sets of phase shifts. All phase shifts are in degrees. The errors on the phase shifts of the present work correspond to an increase in χ^2 of 1.

Table III: Differential polarization of 2.63 MeV neutrons scattered from ^{12}C . These values were obtained from the asymmetries listed in Table I and $P_1 = -11.2 \pm 1.0\%$.

Table IV: R-function parameters for $^{12}\text{C} + n$ scattering with an interaction radius $A = 3.72\text{F}$ for all ℓJ .

FIGURE CAPTIONS

- Figure 1. Fits to the present experimental data by the phase shifts of Wills and Meier. The solid line is the fit obtained by the phase shift analysis described in Section III.
- Figure 2. Fits to the present experimental data by the phase shifts of Reynolds. The solid line is the fit obtained by the phase shift analysis described in Section III.
- Figure 3. R-function analysis fits to B coefficients of the data of Lane (o), Wills (*), Galati (x) and the present experiment (Δ).
- Figure 4. R-function analysis fits to C coefficients of Lane (o) and the present experiment (Δ).
- Figure 5. Fits to the present experimental data by the phase shift analysis described in Section III and the R-function calculation described in Section IV.
- Figure 6. Fits to the data of Lane by the present R-function calculation.
- Figure 7. Comparisons of the fits to Wills' data by the phase shifts of Wills and those of the present R-function analysis.
- Figure 8. Comparison of the fits to Meier's data by the phase shifts of Meiers and those of the present R-function analysis.
- Figure 9. Fits to the data of Galati by the present R-function analysis.
- Figure 10a). Results of the R-function calculation of the analyzing power of carbon at $\theta_n = 50^\circ$ with and without the resonances at $E_x = 7.50$ and 7.55 MeV assuming a monoenergetic neutron beam incident on the carbon.
- b). Results of the R-function calculation of the analyzing power of carbon at $\theta_n = 50^\circ$ with and without the resonances at $E_x = 7.50$ and 7.55 MeV assuming a thick neutron producing target.

TABLE 1

CORRECTED DIFFERENTIAL CROSS SECTION AND ASYMMETRY

C.M. Angle (degrees)	Cross Section (b/sr)	Asymmetry (%)
18.41	0.1897 ± 0.0075	5.60 ± 1.20
32.41	0.1940 ± 0.0077	7.89 ± 1.50
48.41	0.1569 ± 0.0059	10.58 ± 1.60
64.17	0.1087 ± 0.0039	12.36 ± 1.60
79.66	0.0634 ± 0.0022	4.63 ± 2.10
94.82	0.0560 ± 0.0019	-3.97 ± 2.00
109.26	0.1027 ± 0.0034	-10.65 ± 1.50
122.26	0.1664 ± 0.0057	-10.07 ± 1.50

TABLE 2

COMPARISON OF PHASE SHEETS

	Present Work	Meier	Wills	Reynolds
$\delta_s \ 1/2$	-99.7 ± 5.1	-72.0	-101.0	-95.1
$\delta_p \ 1/2$	-9.9 ± 9.4	-9.5	-7.0	-15.8
$\delta_p \ 3/2$	-4.0 ± 7.8	-1.0	-3.5	-8.9
$\delta_d \ 3/2$	24.4 ± 2.5	32.0	27.0	19.2
$\delta_d \ 5/2$	-10.6 ± 2.5	-2.0	-1.5	-5.3
$P_1(\%)$	-11.2 ± 1.0			

TABLE 3

DIFFERENTIAL POLARIZATION

C.M. Angle (Degrees)	Differential Polarization (%)
18.41	-50.0 ± 11.6
32.41	-70.4 ± 14.7
48.41	-94.5 ± 16.4
64.17	-101.4 ± 17.3
79.66	-41.3 ± 19.1
94.82	35.4 ± 18.1
109.26	95.1 ± 15.8
122.26	89.9 ± 15.5

TABLE 4

LEVELS IN ^{13}C				R-FUNCTION PARAMETERS			
ℓJ	E_{ex} (MeV)	E_{cm} (MeV)	E_{lab} (MeV)	E_{r} (MeV)	γ_{λ}^2 (MeV)	R_0	$b_{\ell J}$
0 1/2	3.09	-1.86	--	-1.86	4.0	0.075	-1.035
1 1/2	8.86	3.91	4.26	3.911	0.0834	0.1	-0.293
1 3/2	9.90	4.95	5.38	4.953	0.0103	0.25	-0.247
	9.52	4.50	4.94	4.560	0.002		
2 3/2	7.68	2.73	2.95	2.734	0.212	0.107	-1.368
	8.25	3.30	3.58	3.537	2.50		
2 5/2	3.85	-1.09	--	-1.093	1.80	0.0	-2.213
	6.86	1.92	2.08	1.959	0.075

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

APPENDIX

The following is a table of the phase shifts for 0.01-4.00 MeV neutrons scattered from ^{12}C obtained from the R-function analysis described in Chapter VI. For completeness, Table 6-1, the final R-function parameters, is included in this Appendix.

FINAL R-FUNCTION PARAMETERS

LEVELS IN ^{13}C				R-FUNCTION PARAMETERS			
ℓJ	E_{ex} (MeV)	E_{cm} (MeV)	E_{lab} (MeV)	E_{λ} (MeV)	γ_{λ}^2 (MeV)	R_0	$b_{\ell J}$
0 1/2	3.09	-1.86	--	-1.86	4.0	0.075	-1.035
1 1/2	8.86	3.91	4.26	3.911	0.0834	0.1	-0.293
1 3/2	9.90	4.95	5.38	4.953	0.0103	0.25	-0.247
	9.52	4.50	4.94	4.560	0.002		
2 3/2	7.68	2.73	2.95	2.734	0.212	0.107	-1.368
	8.25	3.30	3.58	3.537	2.50		
2 5/2	3.85	-1.09	--	-1.093	1.80	0.0	-2.213
	6.86	1.92	2.08	1.959	0.075		

C-12 PHASE SHIFTS FROM E=0.01 TO 4.0 MEV

(PHASE SHIFTS IN DEGREES)

E MEV	S 1/2	P 1/2	P 3/2	D 3/2	D 5/2
0.010	-7.16019	-0.00542	-0.00297	0.00000	-0.00003
0.020	-10.11624	-0.01530	-0.00639	0.00003	-0.00012
0.030	-12.37789	-0.02803	-0.01538	0.00009	-0.00033
0.040	-14.27906	-0.04304	-0.02365	0.00018	-0.00067
0.050	-15.94925	-0.05999	-0.03299	0.00032	-0.00116
0.060	-17.45496	-0.07864	-0.04331	0.00051	-0.00181
0.070	-18.83571	-0.09883	-0.05440	0.00075	-0.00264
0.080	-20.11731	-0.12042	-0.06647	0.00105	-0.00365
0.090	-21.31770	-0.14330	-0.07919	0.00142	-0.00485
0.100	-22.44994	-0.16738	-0.09261	0.00185	-0.00626
0.110	-23.52393	-0.19259	-0.10668	0.00235	-0.00788
0.120	-24.54733	-0.21886	-0.12136	0.00293	-0.00971
0.130	-25.52629	-0.24612	-0.13664	0.00358	-0.01175
0.140	-26.46574	-0.27433	-0.15247	0.00432	-0.01402
0.150	-27.36981	-0.30343	-0.16883	0.00514	-0.01652
0.160	-28.24191	-0.33339	-0.18571	0.00606	-0.01925
0.170	-29.08496	-0.36416	-0.20309	0.00706	-0.02221
0.180	-29.90144	-0.39572	-0.22094	0.00816	-0.02541
0.190	-30.69350	-0.42803	-0.23924	0.00937	-0.02884
0.200	-31.46298	-0.46105	-0.25799	0.01066	-0.03252
0.210	-32.21158	-0.49477	-0.27716	0.01207	-0.03644
0.220	-32.94070	-0.52915	-0.29675	0.01359	-0.04059
0.230	-33.65166	-0.56417	-0.31673	0.01522	-0.04498
0.240	-34.34558	-0.59981	-0.33711	0.01696	-0.04963
0.250	-35.02353	-0.63605	-0.35787	0.01883	-0.05452
0.260	-35.68642	-0.67286	-0.37899	0.02079	-0.05967
0.270	-36.33507	-0.71023	-0.40047	0.02290	-0.06505
0.280	-36.97029	-0.74813	-0.42230	0.02514	-0.07066
0.290	-37.59277	-0.78656	-0.44447	0.02750	-0.07654
0.300	-38.20316	-0.82549	-0.46697	0.03001	-0.08264
0.310	-38.80200	-0.86491	-0.48979	0.03264	-0.08899
0.320	-39.38989	-0.90481	-0.51293	0.03541	-0.09560
0.330	-39.96732	-0.94516	-0.53637	0.03833	-0.10244
0.340	-40.53471	-0.98597	-0.56012	0.04138	-0.10954
0.350	-41.09256	-1.02720	-0.58416	0.04459	-0.11686
0.360	-41.64122	-1.06886	-0.60849	0.04795	-0.12444
0.370	-42.18108	-1.11094	-0.63311	0.05147	-0.13224
0.380	-42.71246	-1.15340	-0.65799	0.05513	-0.14030
0.390	-43.23575	-1.19626	-0.68314	0.05897	-0.14857
0.400	-43.75121	-1.23949	-0.70857	0.06295	-0.15711
0.410	-44.25911	-1.28309	-0.73425	0.06711	-0.16586
0.420	-44.75978	-1.32705	-0.76018	0.07144	-0.17486
0.430	-45.25342	-1.37135	-0.78636	0.07596	-0.18407
0.440	-45.74030	-1.41599	-0.81280	0.08063	-0.19352
0.450	-46.22061	-1.46096	-0.83946	0.08549	-0.20321
0.460	-46.69461	-1.50626	-0.86637	0.09053	-0.21312

0.470	-47.16249	-1.55186	-0.89350	0.09575	-0.22326
0.480	-47.62442	-1.59778	-0.92086	0.10115	-0.23364
0.490	-48.08060	-1.64398	-0.94845	0.10677	-0.24421
0.500	-48.53119	-1.69048	-0.97625	0.11256	-0.25502
0.510	-48.97638	-1.73726	-1.00427	0.11856	-0.26605
0.520	-49.41629	-1.78431	-1.03250	0.12475	-0.27730
0.530	-49.85112	-1.83163	-1.06093	0.13115	-0.28878
0.540	-50.28098	-1.87922	-1.08957	0.13776	-0.30045
0.550	-50.70599	-1.92706	-1.11841	0.14459	-0.31234
0.560	-51.12631	-1.97515	-1.14745	0.15162	-0.32445
0.570	-51.54207	-2.02348	-1.17668	0.15887	-0.33676
0.580	-51.95337	-2.07205	-1.20610	0.16633	-0.34930
0.590	-52.36032	-2.12085	-1.23572	0.17405	-0.36201
0.600	-52.76305	-2.16988	-1.26551	0.18196	-0.37495
0.610	-53.16165	-2.21913	-1.29549	0.19012	-0.38809
0.620	-53.55621	-2.26859	-1.32565	0.19852	-0.40142
0.630	-53.94684	-2.31826	-1.35598	0.20714	-0.41496
0.640	-54.33365	-2.36813	-1.38649	0.21601	-0.42871
0.650	-54.71672	-2.41821	-1.41716	0.22513	-0.44263
0.660	-55.09613	-2.46848	-1.44801	0.23450	-0.45675
0.670	-55.47194	-2.51894	-1.47902	0.24411	-0.47108
0.680	-55.84427	-2.56959	-1.51020	0.25399	-0.48558
0.690	-56.21317	-2.62042	-1.54154	0.26413	-0.50026
0.700	-56.57872	-2.67142	-1.57303	0.27452	-0.51515
0.710	-56.94099	-2.72259	-1.60468	0.28520	-0.53021
0.720	-57.30006	-2.77394	-1.63648	0.29614	-0.54546
0.730	-57.65599	-2.82545	-1.66844	0.30736	-0.56088
0.740	-58.00887	-2.87711	-1.70054	0.31886	-0.57647
0.750	-58.35873	-2.92894	-1.73280	0.33064	-0.59225
0.760	-58.70561	-2.98092	-1.76520	0.34270	-0.60821
0.770	-59.04968	-3.03304	-1.79774	0.35508	-0.62432
0.780	-59.39087	-3.08532	-1.83042	0.36772	-0.64063
0.790	-59.72926	-3.13773	-1.86325	0.38069	-0.65708
0.800	-60.06493	-3.19028	-1.89620	0.39394	-0.67373
0.810	-60.39790	-3.24296	-1.92930	0.40752	-0.69051
0.820	-60.72827	-3.29578	-1.96253	0.42142	-0.70746
0.830	-61.05606	-3.34871	-1.99589	0.43562	-0.72458
0.840	-61.38139	-3.40178	-2.02938	0.45015	-0.74185
0.850	-61.70416	-3.45497	-2.06300	0.46501	-0.75927
0.860	-62.02448	-3.50828	-2.09675	0.48018	-0.77686
0.870	-62.34244	-3.56169	-2.13062	0.49572	-0.79459
0.880	-62.65805	-3.61522	-2.16461	0.51158	-0.81247
0.890	-62.97131	-3.66886	-2.19872	0.52779	-0.83050
0.900	-63.28233	-3.72261	-2.23296	0.54435	-0.84868
0.910	-63.59111	-3.77646	-2.26731	0.56128	-0.86698
0.920	-63.89771	-3.83041	-2.30179	0.57856	-0.88544
0.930	-64.20210	-3.88445	-2.33637	0.59620	-0.90405
0.940	-64.50438	-3.93859	-2.37107	0.61421	-0.92278
0.950	-64.80464	-3.99283	-2.40588	0.63261	-0.94165
0.960	-65.10277	-4.04715	-2.44081	0.65139	-0.96064
0.970	-65.39886	-4.10156	-2.47584	0.67055	-0.97977
0.980	-65.69301	-4.15605	-2.51097	0.69010	-0.99904
0.990	-65.98517	-4.21063	-2.54622	0.71005	-1.01841

1.000	-66.27542	-4.26528	-2.58158	0.73041	-1.03792
1.010	-66.56372	-4.32001	-2.61703	0.75117	-1.05754
1.020	-66.85020	-4.37481	-2.65258	0.77235	-1.07728
1.030	-67.13483	-4.42969	-2.68824	0.79395	-1.09714
1.040	-67.41760	-4.48463	-2.72400	0.81598	-1.11710
1.050	-67.69856	-4.53964	-2.75986	0.83843	-1.13719
1.060	-67.97784	-4.59472	-2.79582	0.86133	-1.15738
1.070	-68.25537	-4.64985	-2.83186	0.88467	-1.17767
1.080	-68.53114	-4.70506	-2.86801	0.90847	-1.19806
1.090	-68.80522	-4.76031	-2.90425	0.93272	-1.21856
1.100	-69.07767	-4.81563	-2.94059	0.95743	-1.23915
1.110	-69.34846	-4.87100	-2.97701	0.98260	-1.25986
1.120	-69.61769	-4.92642	-3.01353	1.00827	-1.28064
1.130	-69.88527	-4.98189	-3.05014	1.03442	-1.30150
1.140	-70.15131	-5.03741	-3.08683	1.06104	-1.32247
1.150	-70.41577	-5.09297	-3.12361	1.08821	-1.34347
1.160	-70.67871	-5.14858	-3.16048	1.11585	-1.36459
1.170	-70.94017	-5.20423	-3.19743	1.14400	-1.38580
1.180	-71.20010	-5.25993	-3.23447	1.17268	-1.40705
1.190	-71.45856	-5.31565	-3.27158	1.20189	-1.42837
1.200	-71.71559	-5.37142	-3.30879	1.23164	-1.44977
1.210	-71.97121	-5.42723	-3.34607	1.26192	-1.47124
1.220	-72.22540	-5.48305	-3.38344	1.29275	-1.49277
1.230	-72.47812	-5.53892	-3.42088	1.32414	-1.51434
1.240	-72.72957	-5.59481	-3.45840	1.35612	-1.53595
1.250	-72.97961	-5.65074	-3.49600	1.38866	-1.55763
1.260	-73.22835	-5.70668	-3.53368	1.42180	-1.57933
1.270	-73.47575	-5.76266	-3.57145	1.45551	-1.60110
1.280	-73.72186	-5.81865	-3.60926	1.48963	-1.62289
1.290	-73.96666	-5.87467	-3.64717	1.52476	-1.64471
1.300	-74.21008	-5.93070	-3.68514	1.56032	-1.66652
1.310	-74.45242	-5.98676	-3.72319	1.59652	-1.68839
1.320	-74.69339	-6.04282	-3.76130	1.63333	-1.71027
1.330	-74.93315	-6.09890	-3.79949	1.67081	-1.73214
1.340	-75.17172	-6.15498	-3.83774	1.70891	-1.75404
1.350	-75.40913	-6.21111	-3.87609	1.74773	-1.77592
1.360	-75.64525	-6.26719	-3.91446	1.78719	-1.79779
1.370	-75.88031	-6.32333	-3.95294	1.82736	-1.81966
1.380	-76.11414	-6.37945	-3.99146	1.86821	-1.84151
1.390	-76.34685	-6.43559	-4.03006	1.90980	-1.86331
1.400	-76.57837	-6.49171	-4.06872	1.95208	-1.88508
1.410	-76.80879	-6.54784	-4.10744	1.99512	-1.90679
1.420	-77.03816	-6.60398	-4.14623	2.03888	-1.92849
1.430	-77.26636	-6.66009	-4.18507	2.08341	-1.95008
1.440	-77.49350	-6.71623	-4.22399	2.12869	-1.97164
1.450	-77.71960	-6.77235	-4.26296	2.17475	-1.99312
1.460	-77.94463	-6.82846	-4.30200	2.22161	-2.01449
1.470	-78.16853	-6.88456	-4.34109	2.26929	-2.03575
1.480	-78.39153	-6.94067	-4.38024	2.31777	-2.05692
1.490	-78.61343	-6.99676	-4.41946	2.36710	-2.07796
1.500	-78.83429	-7.05281	-4.45871	2.41723	-2.09886
1.510	-79.05417	-7.10887	-4.49804	2.46824	-2.11962
1.520	-79.27312	-7.16492	-4.53743	2.52014	-2.14019

1.530	-79.49103	-7.22094	-4.57686	2.57290	-2.16060
1.540	-79.70795	-7.27695	-4.61636	2.62656	-2.18080
1.550	-79.92395	-7.33294	-4.65591	2.68113	-2.20081
1.560	-80.13896	-7.38890	-4.69551	2.73663	-2.22056
1.570	-80.35306	-7.44485	-4.73517	2.79309	-2.24006
1.580	-80.56621	-7.50076	-4.77487	2.85049	-2.25929
1.590	-80.77844	-7.55666	-4.81464	2.90889	-2.27820
1.600	-80.98969	-7.61250	-4.85443	2.96825	-2.29679
1.610	-81.20016	-7.66836	-4.89431	3.02864	-2.31504
1.620	-81.40965	-7.72415	-4.93421	3.09005	-2.33290
1.630	-81.61823	-7.77993	-4.97417	3.15250	-2.35033
1.640	-81.82596	-7.83567	-5.01418	3.21599	-2.36734
1.650	-82.03282	-7.89137	-5.05423	3.28059	-2.38383
1.660	-82.23892	-7.94704	-5.09434	3.34629	-2.39978
1.670	-82.44400	-8.00266	-5.13449	3.41307	-2.41516
1.680	-82.64839	-8.05828	-5.17470	3.48102	-2.42991
1.690	-82.85191	-8.11382	-5.21494	3.55011	-2.44397
1.700	-83.05452	-8.16933	-5.25523	3.62038	-2.45727
1.710	-83.25633	-8.22479	-5.29555	3.69185	-2.46975
1.720	-83.45746	-8.28022	-5.33594	3.76452	-2.48136
1.730	-83.65756	-8.33559	-5.37636	3.83843	-2.49198
1.740	-83.85696	-8.39091	-5.41683	3.91362	-2.50151
1.750	-84.05560	-8.44619	-5.45734	3.99010	-2.50987
1.760	-84.25346	-8.50143	-5.49791	4.06787	-2.51693
1.770	-84.45045	-8.55659	-5.53850	4.14694	-2.52256
1.780	-84.64684	-8.61172	-5.57914	4.22741	-2.52663
1.790	-84.84236	-8.66678	-5.61981	4.30925	-2.52893
1.800	-85.03719	-8.72180	-5.66053	4.39248	-2.52929
1.810	-85.23116	-8.77675	-5.70128	4.47720	-2.52745
1.820	-85.42451	-8.83165	-5.74209	4.56335	-2.52320
1.830	-85.61716	-8.88649	-5.78294	4.65090	-2.51631
1.840	-85.80894	-8.94124	-5.82380	4.74004	-2.50624
1.850	-86.00005	-8.99595	-5.86471	4.83076	-2.49268
1.860	-86.19052	-9.05058	-5.90566	4.92302	-2.47519
1.870	-86.38014	-9.10515	-5.94664	5.01691	-2.45314
1.880	-86.56906	-9.15965	-5.98766	5.11239	-2.42591
1.890	-86.75743	-9.21409	-6.02873	5.20957	-2.39262
1.900	-86.94502	-9.26844	-6.06982	5.30842	-2.35234
1.910	-87.13200	-9.32274	-6.11095	5.40904	-2.30376
1.920	-87.31821	-9.37694	-6.15212	5.51138	-2.24541
1.930	-87.50371	-9.43107	-6.19330	5.61558	-2.17526
1.940	-87.68866	-9.48512	-6.23454	5.72156	-2.09098
1.950	-87.87291	-9.53910	-6.27580	5.82943	-1.98927
1.960	-88.05663	-9.59301	-6.31711	5.93930	-1.86587
1.970	-88.23949	-9.64681	-6.35844	6.05102	-1.71509
1.980	-88.42180	-9.70053	-6.39980	6.16476	-1.52888
1.990	-88.60341	-9.75416	-6.44119	6.28059	-1.29587
2.000	-88.78448	-9.80772	-6.48263	6.39848	-0.99931
2.010	-88.96617	-9.86155	-6.52438	6.51935	-0.60986
2.020	-89.14600	-9.91494	-6.56588	6.64156	-0.09058
2.030	-89.32513	-9.96819	-6.60739	6.76595	0.63520
2.040	-89.50363	-10.02136	-6.64892	6.89262	1.70939
2.050	-89.68159	-10.07445	-6.69050	7.02163	3.44211

2.060	-89.85893	-10.12742	-6.73210	7.15299	6.65924
2.070	-90.03557	-10.18029	-6.77374	7.22672	14.47306
2.080	-90.21175	-10.23307	-6.81540	7.42299	50.49655
2.090	-90.38737	-10.28577	-6.85711	7.56182	-37.50793
2.100	-90.56230	-10.33832	-6.89882	7.70315	-19.26857
2.110	-90.73669	-10.39076	-6.94055	7.84718	-13.89557
2.120	-90.91046	-10.44312	-6.98234	7.99390	-11.59767
2.130	-91.08368	-10.49534	-7.02412	8.14341	-9.95964
2.140	-91.25629	-10.54743	-7.06594	8.29568	-9.03879
2.150	-91.42850	-10.59944	-7.10779	8.45091	-8.40204
2.160	-91.60008	-10.65134	-7.14968	8.60915	-7.95919
2.170	-91.77097	-10.70307	-7.19155	8.77036	-7.59044
2.180	-91.94147	-10.75471	-7.23348	8.93477	-7.32055
2.190	-92.11134	-10.80623	-7.27542	9.10233	-7.10754
2.200	-92.28076	-10.85762	-7.31740	9.27315	-6.93685
2.210	-92.44955	-10.90885	-7.35937	9.44731	-6.79847
2.220	-92.61787	-10.95998	-7.40140	9.62493	-6.68533
2.230	-92.78558	-11.01095	-7.44342	9.80611	-6.59227
2.240	-92.95282	-11.06181	-7.48549	9.99092	-6.51556
2.250	-93.11960	-11.11253	-7.52757	10.17942	-6.45219
2.260	-93.28581	-11.16310	-7.56968	10.37181	-6.39992
2.270	-93.45151	-11.21352	-7.61179	10.56800	-6.35703
2.280	-93.61656	-11.26379	-7.65393	10.76828	-6.32205
2.290	-93.78131	-11.31393	-7.69609	10.97273	-6.29384
2.300	-93.94553	-11.36391	-7.73830	11.18138	-6.27151
2.310	-94.10918	-11.41373	-7.78048	11.39439	-6.25427
2.320	-94.27238	-11.46340	-7.82271	11.61191	-6.24152
2.330	-94.43510	-11.51292	-7.86496	11.83411	-6.23261
2.340	-94.59721	-11.56223	-7.90719	12.06089	-6.22719
2.350	-94.75902	-11.61144	-7.94948	12.29281	-6.22486
2.360	-94.92027	-11.66047	-7.99179	12.52968	-6.22531
2.370	-95.08090	-11.70928	-8.03409	12.77167	-6.22821
2.380	-95.24121	-11.75797	-8.07643	13.01910	-6.23334
2.390	-95.40100	-11.80646	-8.11877	13.27210	-6.24046
2.400	-95.56038	-11.85478	-8.16114	13.53078	-6.24945
2.410	-95.71922	-11.90290	-8.20351	13.79525	-6.26008
2.420	-95.87776	-11.95087	-8.24591	14.06597	-6.27229
2.430	-96.03575	-11.99862	-8.28833	14.34285	-6.28586
2.440	-96.19319	-12.04617	-8.33074	14.62626	-6.30065
2.450	-96.35025	-12.09356	-8.37319	14.91646	-6.31672
2.460	-96.50684	-12.14071	-8.41564	15.21360	-6.33379
2.470	-96.66304	-12.18769	-8.45812	15.51806	-6.35194
2.480	-96.81879	-12.23445	-8.50060	15.82993	-6.37100
2.490	-96.97412	-12.28102	-8.54311	16.14964	-6.39092
2.500	-97.12894	-12.32736	-8.58563	16.47733	-6.41168
2.510	-97.28334	-12.37348	-8.62815	16.81345	-6.43319
2.520	-97.43738	-12.41937	-8.67068	17.15833	-6.45539
2.530	-97.59093	-12.46505	-8.71323	17.51227	-6.47825
2.540	-97.74409	-12.51051	-8.75581	17.87578	-6.50177
2.550	-97.89680	-12.55572	-8.79837	18.24905	-6.52586
2.560	-98.04912	-12.60070	-8.84096	18.63284	-6.55050
2.570	-98.20105	-12.64544	-8.88356	19.02734	-6.57564
2.580	-98.35243	-12.68992	-8.92616	19.43311	-6.60130

2.590	-98.50343	-12.73415	-6.96878	19.85078	-6.62762
2.600	-98.65419	-12.77815	-9.01141	20.28111	-6.65598
2.610	-98.80441	-12.82186	-9.05404	20.72444	-6.68093
2.620	-98.95416	-12.86532	-9.09668	21.18173	-6.70328
2.630	-99.10368	-12.90853	-9.13935	21.65367	-6.73604
2.640	-99.25273	-12.95144	-9.18202	22.14107	-6.76415
2.650	-99.40160	-12.99409	-9.22470	22.64478	-6.79264
2.660	-99.54959	-13.03642	-9.26737	23.16605	-6.82139
2.670	-99.69756	-13.07851	-9.31007	23.70604	-6.85051
2.680	-99.84499	-13.12027	-9.35277	24.26570	-6.87990
2.690	-99.99210	-13.16174	-9.39547	24.84680	-6.90957
2.700	-100.13881	-13.20291	-9.43820	25.45094	-6.93950
2.710	-100.28514	-13.24373	-9.48089	26.07953	-6.96973
2.720	-100.43109	-13.28428	-9.52363	26.73506	-7.00016
2.730	-100.57664	-13.32447	-9.56635	27.41977	-7.03086
2.740	-100.72189	-13.36434	-9.60910	28.13618	-7.06179
2.750	-100.86674	-13.40390	-9.65185	28.88748	-7.09300
2.760	-101.01172	-13.44307	-9.69460	29.67728	-7.12434
2.770	-101.15529	-13.48192	-9.73736	30.50977	-7.15593
2.780	-101.29906	-13.52039	-9.78011	31.38950	-7.18772
2.790	-101.44243	-13.55849	-9.82286	32.32303	-7.21963
2.800	-101.58551	-13.59625	-9.86565	33.31702	-7.25185
2.810	-101.72810	-13.63359	-9.90841	34.37970	-7.28416
2.820	-101.87039	-13.67058	-9.95119	35.52202	-7.31670
2.830	-102.01245	-13.70716	-9.99397	36.75624	-7.34939
2.840	-102.15398	-13.74331	-10.03674	38.09857	-7.38218
2.850	-102.29526	-13.77907	-10.07952	39.56874	-7.41523
2.860	-102.43614	-13.81440	-10.12230	41.19319	-7.44837
2.870	-102.57680	-13.84932	-10.16512	43.00542	-7.48166
2.880	-102.71700	-13.88378	-10.20789	45.04915	-7.51513
2.890	-102.85687	-13.91777	-10.25067	47.38518	-7.54867
2.900	-102.99644	-13.95132	-10.29347	50.09540	-7.58240
2.910	-103.13564	-13.98440	-10.33625	53.29477	-7.61626
2.920	-103.27451	-14.01700	-10.37904	57.14641	-7.65023
2.930	-103.41292	-14.04908	-10.42182	61.88782	-7.68431
2.940	-103.55116	-14.08070	-10.46461	67.86145	-7.71857
2.950	-103.68903	-14.11178	-10.50739	75.54903	-7.75289
2.960	-103.82657	-14.14234	-10.55018	85.56570	-7.78736
2.970	-103.96390	-14.17239	-10.59297	-81.53835	-7.82196
2.980	-104.10081	-14.20189	-10.63577	-65.87283	-7.85665
2.990	-104.23737	-14.23078	-10.67855	-48.92110	-7.89143
3.000	-104.37367	-14.25913	-10.72132	-33.06729	-7.92632
3.010	-104.50958	-14.28688	-10.76409	-19.90021	-7.96130
3.020	-104.64528	-14.31403	-10.80687	-9.60831	-7.99636
3.030	-104.78049	-14.34055	-10.84963	-1.66080	-8.03158
3.040	-104.91556	-14.36646	-10.89240	4.56033	-8.06683
3.050	-105.05031	-14.39172	-10.93516	9.54799	-8.10223
3.060	-105.18468	-14.41629	-10.97791	13.65472	-8.13771
3.070	-105.31880	-14.44020	-11.02066	17.12274	-8.17328
3.080	-105.45247	-14.46339	-11.06339	20.11958	-8.20892
3.090	-105.58591	-14.48588	-11.10613	22.76344	-8.24464
3.100	-105.71918	-14.50765	-11.14888	25.13806	-8.28045
3.110	-105.85207	-14.52865	-11.19158	27.30421	-8.31633

3.120	-105.98465	-14.54890	-11.23433	29.30699	-8.35229
3.130	-106.11691	-14.56833	-11.27701	31.18024	-8.38836
3.140	-106.24895	-14.58697	-11.31974	32.95041	-8.42447
3.150	-106.38060	-14.60476	-11.36241	34.63666	-8.46070
3.160	-106.51193	-14.62162	-11.40510	36.25581	-8.49694
3.170	-106.64311	-14.63776	-11.44779	37.81978	-8.53331
3.180	-106.77390	-14.65290	-11.49046	39.33853	-8.56975
3.190	-106.90445	-14.66714	-11.53313	40.82021	-8.60625
3.200	-107.03462	-14.68038	-11.57574	42.27122	-8.64274
3.210	-107.16472	-14.69270	-11.61841	43.69739	-8.67939
3.220	-107.29434	-14.70397	-11.66102	45.10207	-8.71608
3.230	-107.42372	-14.71417	-11.70363	46.48915	-8.75283
3.240	-107.55289	-14.72334	-11.74624	47.86194	-8.78965
3.250	-107.68173	-14.73143	-11.78884	49.22224	-8.82653
3.260	-107.81027	-14.73835	-11.83141	50.57201	-8.86352
3.270	-107.93857	-14.74411	-11.87397	51.91275	-8.90051
3.280	-108.06664	-14.74867	-11.91652	53.24548	-8.93757
3.290	-108.19432	-14.75197	-11.95905	54.57115	-8.97467
3.300	-108.32178	-14.75401	-12.00157	55.89037	-9.01183
3.310	-108.44907	-14.75476	-12.04409	57.20367	-9.04911
3.320	-108.57590	-14.75411	-12.08658	58.51086	-9.08638
3.330	-108.70264	-14.75207	-12.12906	59.81270	-9.12372
3.340	-108.82899	-14.74858	-12.17150	61.10808	-9.16115
3.350	-108.95520	-14.74361	-12.21395	62.39801	-9.19859
3.360	-109.08110	-14.73709	-12.25637	63.68132	-9.23613
3.370	-109.20668	-14.72897	-12.29879	64.95834	-9.27368
3.380	-109.33203	-14.71919	-12.34117	66.22789	-9.31126
3.390	-109.45715	-14.70772	-12.38354	67.48994	-9.34895
3.400	-109.58195	-14.69446	-12.42587	68.74419	-9.38665
3.410	-109.70660	-14.67938	-12.46821	69.98975	-9.42444
3.420	-109.83095	-14.66244	-12.51051	71.22617	-9.46223
3.430	-109.95497	-14.64351	-12.55279	72.45255	-9.50006
3.440	-110.07893	-14.62258	-12.59507	73.66881	-9.53800
3.450	-110.20241	-14.59951	-12.63730	74.87383	-9.57592
3.460	-110.32574	-14.57426	-12.67951	76.06769	-9.61390
3.470	-110.44884	-14.54678	-12.72171	77.24942	-9.65198
3.480	-110.57170	-14.51692	-12.76388	78.41841	-9.69005
3.490	-110.69426	-14.48463	-12.80601	79.57431	-9.72816
3.500	-110.81657	-14.44980	-12.84814	80.71648	-9.76631
3.510	-110.93866	-14.41233	-12.89023	81.84430	-9.80452
3.520	-111.06059	-14.37213	-12.93230	82.95744	-9.84281
3.530	-111.18221	-14.32909	-12.97435	84.05615	-9.88110
3.540	-111.30360	-14.28306	-13.01636	85.13914	-9.91944
3.550	-111.42474	-14.23392	-13.05833	86.19344	-9.95782
3.560	-111.54567	-14.18157	-13.10028	87.22222	-9.99623
3.570	-111.66628	-14.12585	-13.14219	88.22747	-10.03469
3.580	-111.78673	-14.06661	-13.18407	89.20860	-10.07318
3.590	-111.90695	-14.00373	-13.22593	89.68680	-10.11173
3.600	-112.02695	-13.93701	-13.26777	89.70157	-10.15027
3.610	-112.14662	-13.86627	-13.30955	87.73326	-10.18888
3.620	-112.26622	-13.79136	-13.35130	86.78207	-10.22755
3.630	-112.38551	-13.71205	-13.39302	85.84781	-10.26620
3.640	-112.50456	-13.62815	-13.43471	84.93057	-10.30494

3.650	-112.62331	-13.53941	-13.47635	-84.03043	-10.34368
3.660	-112.74190	-13.44564	-13.51795	-83.14731	-10.38249
3.670	-112.86034	-13.34656	-13.55953	-82.28081	-10.42131
3.680	-112.97838	-13.24187	-13.60105	-81.43152	-10.46015
3.690	-113.09634	-13.13136	-13.64254	-80.59851	-10.49903
3.700	-113.21408	-13.01465	-13.68398	-79.78249	-10.53796
3.710	-113.33150	-12.89143	-13.72538	-78.98248	-10.57691
3.720	-113.44878	-12.76137	-13.76674	-78.19891	-10.61593
3.730	-113.56581	-12.62404	-13.80304	-77.43105	-10.65489
3.740	-113.68260	-12.47907	-13.84930	-76.67923	-10.69397
3.750	-113.79926	-12.32604	-13.89054	-75.94304	-10.73309
3.760	-113.91566	-12.16445	-13.93171	-75.22205	-10.77219
3.770	-114.03185	-11.99378	-13.97284	-74.51630	-10.81138
3.780	-114.14780	-11.81350	-14.01392	-73.82536	-10.85054
3.790	-114.26350	-11.62299	-14.05493	-73.14944	-10.88975
3.800	-114.37906	-11.42165	-14.09590	-72.48740	-10.92898
3.810	-114.49438	-11.20868	-14.13681	-71.83995	-10.96826
3.820	-114.60956	-10.98345	-14.17767	-71.20595	-11.00757
3.830	-114.72443	-10.74508	-14.21845	-70.58598	-11.04686
3.840	-114.83913	-10.49262	-14.25920	-69.97920	-11.08625
3.850	-114.95367	-10.22517	-14.29989	-69.38535	-11.12563
3.860	-115.06790	-9.94161	-14.34050	-68.80450	-11.16508
3.870	-115.18207	-9.64073	-14.38106	-68.23579	-11.20451
3.880	-115.29591	-9.32128	-14.42154	-67.67982	-11.24398
3.890	-115.40961	-8.98188	-14.46199	-67.13570	-11.28350
3.900	-115.52315	-8.62085	-14.50235	-66.60333	-11.32299
3.910	-115.63646	-8.23651	-14.54263	-66.08238	-11.36256
3.920	-115.74945	-7.82696	-14.58284	-65.57278	-11.40212
3.930	-115.86229	-7.39010	-14.62299	-65.07408	-11.44176
3.940	-115.97496	-6.92348	-14.66304	-64.58607	-11.48138
3.950	-116.08757	-6.42454	-14.70305	-64.10867	-11.52105
3.960	-116.19978	-5.89039	-14.74295	-63.64143	-11.56074
3.970	-116.31177	-5.31759	-14.78277	-63.18402	-11.60039
3.980	-116.42375	-4.70256	-14.82253	-62.73657	-11.64016
3.990	-116.53543	-4.04122	-14.86219	-62.29861	-11.67990