NEUTRON CAPTURE IN THE GIANT DIPOLE RESONANCE REGION OF ^{14}C

by

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Date: June 24, 1983

Approved:

N. Russell Roberson, Supervisor

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Physics in the Graduate School of Duke University

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Abstract

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The ninety-degree absolute cross section of the $^{13}C(n,\gamma_0)^{14}C$ reaction was measured in 200 keV steps at neutron energies ranging from 5.6 to 13 MeV and at selected energies between 13 and 17 MeV. The angular distributions of cross section and analyzing power were measured at 7.75, 9.2, 10.0, 10.2, 11, 12, and 13 MeV over an angular range of 30^{o} to 150^{o}. Ninety-degree analyzing powers were measured at 17 energies from E_n = 7.75 MeV to E_n = 15 MeV. Fore-aft asymmetries were measured at 7 energies from E_n = 10.2 MeV to E_n = 17 MeV.

The giant dipole resonance in ^{14}C was found to be split into two components at excitation energies of 15.45 and 17.85 MeV and with widths of 1.5 and 1.75 MeV, respectively. Two-level doorway state calculations agree well with the measured a_2 and b_2 coefficients and indicate that it is resonable to parameterize the giant dipole resonance as two different levels of the same spin and parity. After detail balance conversion to photoneutron cross section, the integrated E1 yield exhausted 14 % of the classical dipole sum rule in the (γ,n_0) channel in the region of 13.4 to 24 MeV excitation energy. A model independent E1 transition matrix analysis of the data yielded two solutions, one where the $d_{3/2}$ matrix element accounted for about 85 % of the E1 cross section, the other where the $d_{3/2}$ element accounted for about 30 % of the E1 cross section. Direct-semidirect model calculations indicate the dominant

$d_{3/2}$ solution to be the physical one.

The E1-E2-M1 transition matrix element analysis showed that the E2 strength was less than 2 % of the total cross section and that the M1 strength could not be determined by examination of a single angular distribution. The observed E2 strength exhausts 2.8 ± 0.6 % of the isoscalar E2 energy weighted sum rule. The data show little evidence for collective E2 strength in the (γ, n_0) channel.

Structure in the 90° analyzing power and in the Legendre coefficient b_1 near 9.2 and 10.2 MeV neutron energy suggests the existence of narrow M1 resonances at these energies. A direct-semidirect model calculation was in good overall agreement with all of the experimental data when it included two M1 resonances at excitation energies 16.7 and 17.5 MeV, with strengths 0.24 and 0.17 μ_0^2, and widths less than the 300 keV energy spread of the neutron beam.

ACKNOWLEDGEMENTS

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I would like to thank Dr. Tom Clegg for his help with the polarized ion source and its microprocessor, and Dr. Jim Jury for the use of the ^{13}C target. I am indebted to Sidney Edwards for many discussions of computers and electronics, and to Mike Bailey for her help with the preparation of the figures.

Most of all, I thank my parents, Harvel and Carleta, and my sister, Nancy, for their support and encouragement throughout all of my 22 years of schooling.

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1 Introduction

The dominant features of the photonuclear reaction in the excitation energy region of a few MeV up to about 50 MeV are the giant resonances. They are characterized by a peak in the yield curve of the order of 5 MeV wide. The magnitude of the integrated cross section of the individual peaks is, in general, a large fraction of the appropriate sum rule (Fuller, 1981). The giant resonance can be labeled by the angular momentum L of the absorbed γ ray. The order of the γ-ray multipolarity is given by 2^L so that if, for example, L = 1, 2, or 3, the absorbed γ radiation is dipole, quadrupole, or octupole, respectively. If the parity change of the nucleus is $(-1)^L$, the multipolarity is classified as electric; if the parity change is $(-1)^{L+1}$, the classification is magnetic. In this way, the multipolarity of a giant resonance can be written by XL, where X = E for electric and M for magnetic, and L is the angular momentum of the absorbed γ ray. For example, the giant electric quadrupole resonance is referred to as a giant E2 resonance.

The most prominent and well studied giant multipole resonance is the one associated with electric dipole transitions. The peak of the giant dipole resonance occurs near $80\ A^{-1/3}$ MeV in medium and heavy nuclei and at about 20 MeV in light nuclei. Resonances of higher multipolarities have recently been observed and are of current experimental interest (Bertrand, 1976). Giant resonance cross section measurements have been carried out by a variety of methods including

electron scattering, inelastic proton and alpha particle scattering, and photon scattering and absorption (Bertrand, 1980).

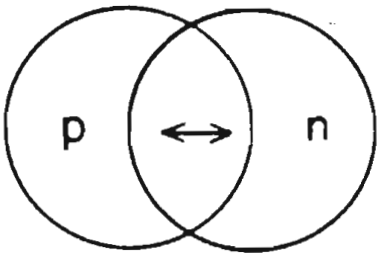
The giant resonances of a nucleus "A" can also be excited by nucleon capture into the nucleus "A-1". The principle of detail balance can be applied to infer the inverse photonuclear cross section. The capture reaction has many attractive features (Hanna, 1979). By measuring the cross sections and analyzing powers as a function of energy, complete knowledge can, in many cases, be obtained of a single decay channel. The measurements often allow the various multipoles involved in the reaction to be identified with a high degree of certainty. In addition, capture reactions are the only technique for studying giant multipole resonances built on excited states. Particle beams of high intensity and small energy spread are generally easier to produce and manipulate than γ-ray beams.

The modes of vibration of the nucleus for some of the lower order resonances are illustrated in Figure 1-1. In isoscalar electric modes, the nucleus as a whole vibrates. In isovector electric modes, the protons vibrate out of phase with the neutrons. In the isovector magnetic modes, protons with spin up and neutrons with spin down oscillate against protons with spin down and neutrons with spin up, respectively.

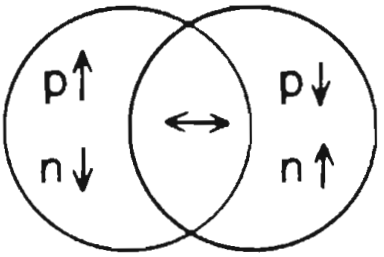
The direct-semidirect model (DSD) has been successful in describing the radiative capture process (Brown, 1964, and Clement *et al.*, 1965). The capture reaction is separated into two components,

Figure 1-1 Schematic representations of some of the lower order modes of nuclear giant resonance oscillation.

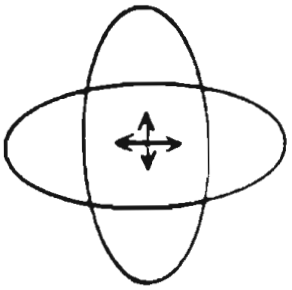
ISOVECTOR
E1



ISOVECTOR
M1



ISOSCALAR
E2



the direct and the semidirect. Direct capture corresponds to the incident nucleon emitting the γ ray as it is captured directly to the final state of the residual nucleus. Semidirect capture corresponds to the incident nucleon exciting the nucleus into a collective state which decays to the final state through the emission of the γ ray. The lifetime of the collective state is longer than the time of a direct reaction but is shorter than the lifetime of a compound nuclear state. The direct capture cross section is proportional to the square of the recoil effective charge, ε_L (Hayward, 1970). The effective charges for E1 and E2 radiation from proton and neutron capture are given by

$$\varepsilon_{1,p} = \frac{N}{1 + A} \tag{1-1}$$

$$\varepsilon_{1,n} = \frac{-Z}{1 + A}$$

$$\varepsilon_{2,p} = \frac{(A^2 + Z)}{(1 + A)^2}$$

$$\varepsilon_{2,n} = \frac{Z}{(1 + A)^2}$$

where A and Z refer to the mass and charge of the target nucleus. For E1 radiation the effective charges are about equal, but for quadrupole radiation the neutron effective charge is less than the proton effective charge by a factor $(A^2 + Z) / Z$. Collective E2 strength should be much more easily observed with neutron capture than with proton capture since the direct E2 contribution to the cross section will be significantly reduced.

This work presents a continuation of the investigation of the giant resonance region of ^{14}C by the radiative capture group at the Triangle Universities Nuclear Laboratory (TUNL) using the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. No previous published data existed for this nucleus due to the difficulty of producing a ^{14}C target for the (γ,n) measurements that are more commonly used to study giant resonances. The spin one half ground state of the ^{13}C target along with the spin zero ground state of the ^{14}C residual nucleus imply that it is possible, in principle, to perform a model-independent transition matrix analysis of the data (see chapter 6). The results of the transition matrix analysis are used to determine the multipolarity of the γ radiation, as discussed above. The small quadrupole recoil effective charge of the neutron means that the direct E2 radiation from neutron capture should be reduced by more then a factor of 1000 compared to proton capture. The previous TUNL data (Jensen, 1981) showed evidence for collective E2 strength at the highest energies measured but was not of sufficient quantity or statistical accuracy to unambiguously demonstrate the existence of a collective E2 resonance.

2 Experimental Equipment

2.1 Overview

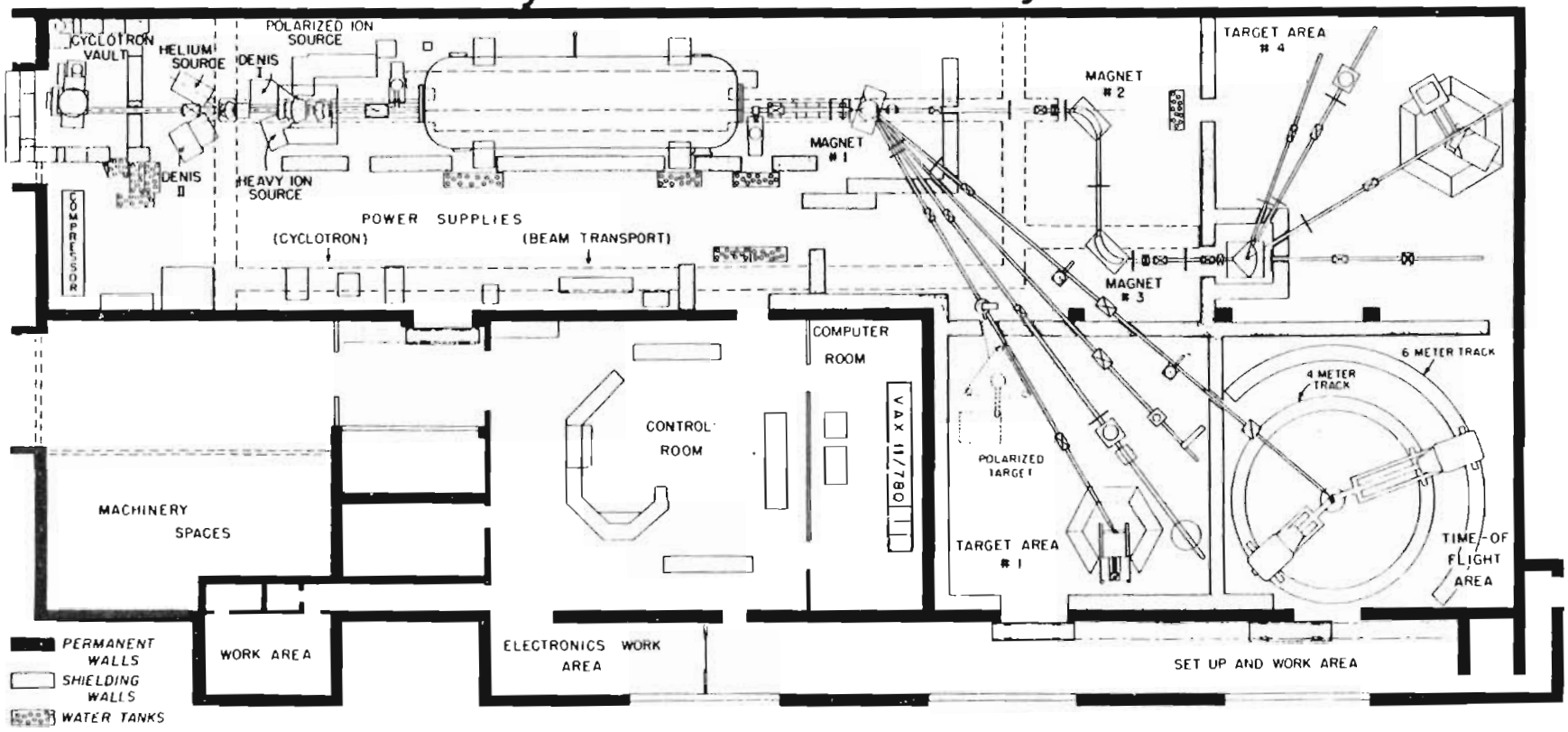
Neutrons are electrically neutral and so do not respond to the Coulomb force. This makes them useful theoretically for understanding the nuclear force but difficult to use experimentally. Neutrons cannot be produced in ion sources and accelerated directly as can charged particles but must be produced by the nuclear reaction of some charged particle with a stable nucleus. As a result, neutron beams are generally much less intense than charged particle beams and have poorer energy and spatial resolution characteristics. Because neutrons react weakly with matter, targets and detectors must be large and detectors are generally low in efficiency. Time consuming finite geometry and multiple scattering corrections must be applied to the data. Background problems arise from many sources. Despite massive shielding, neutrons scattered from walls, floors, air and anything else in the target room may enter the detector. In the case of γ-ray spectroscopy, neutrons scattered by the target itself also present a background problem. Target out background measurements are often required but provide only an estimate of the true background.

2.2 Beam

A floor plan of the TUNL Van de Graaff laboratory is shown in Figure 2-1. A direct extraction negative ion source was used to produce

Figure 2-1 TUNL Van de Graaff laboratory.

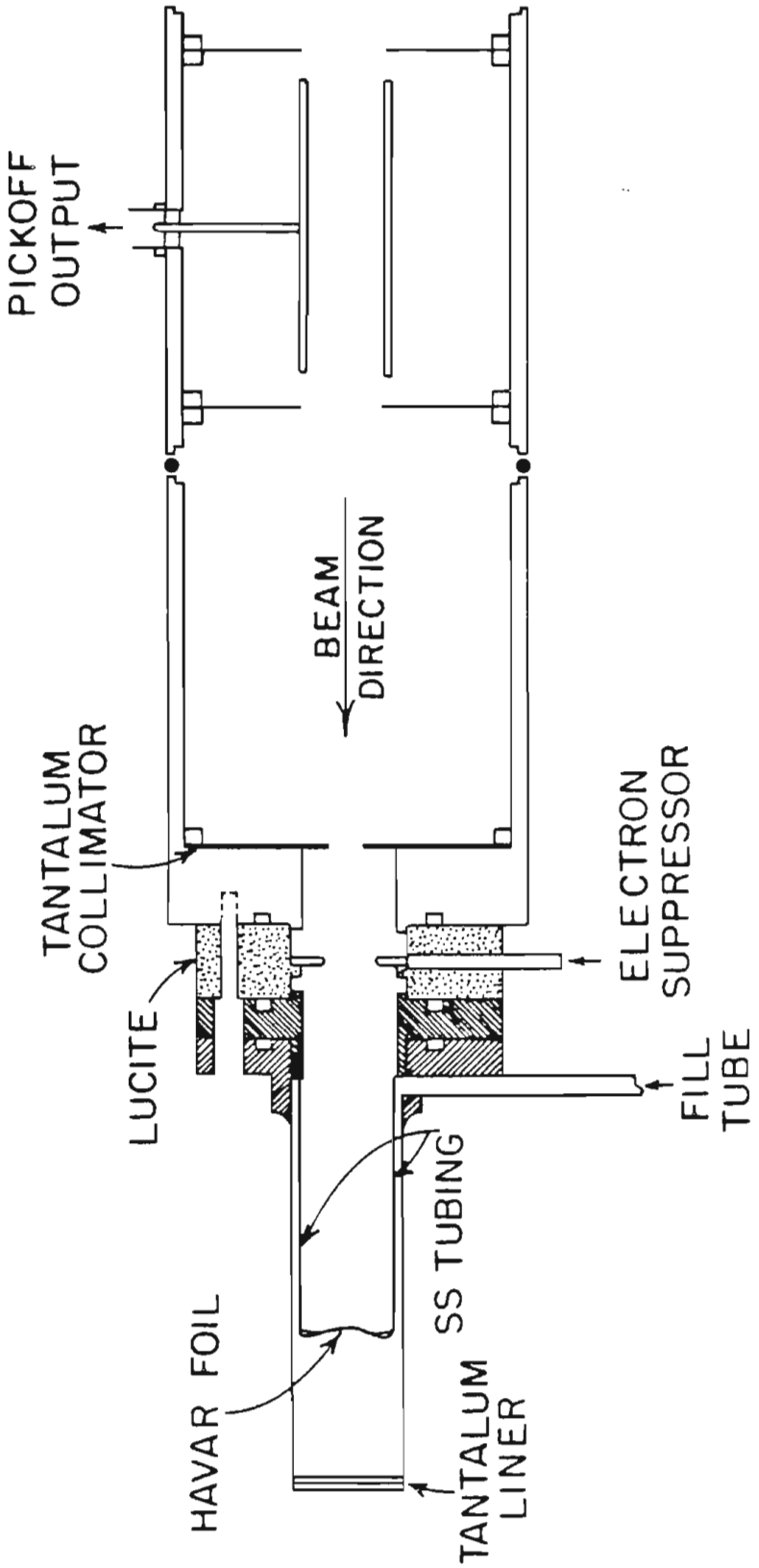
Cyclo-Graaff Laboratory



an unpolarized deuteron beam (labeled DENIS II in Figure 2-1). The beam was passed through a radio frequency chopper and a double drift klystron buncher. The pulsing system produced beam bursts of 2 nsec on target with a repetition rate of 2 MHz. For this work, beam currents on target were typically 350 nA. The polarized beam was produced by a Lamb shift polarized ion source (Clegg et al., 1970). The beam was ramped, bunched and chopped to produce 2 nsec beam bursts with a repetition rate of 4 MHz (Wender et al., 1980). Approximately 70% of the DC beam from the source could be bunched into the pulsed beam. Typical beam currents were 90 nA. The polarization of the deuteron beam was measured using the quench ratio method (Trainor et al., 1974) and was typically 0.65. The beams from the ion sources were injected into a tandem Van de Graaff accelerator with a maximum terminal voltage of 8 MV. The beam was then momentum analyzed by two 90° bending magnets (see Figure 2-1).

Neutrons were produced by sending the beam through a 5.6 μm Havar foil into a 2.5 cm gas cell filled with 6 atm of deuterium. Figure 2-2 shows a diagram of the gas cell, collimator, and time pickoff assembly. The $^{2}H(d,n)$ reaction produced the neutrons. The $^{2}H(d,n)$ reaction has a cross section which is forward peaked so that most of the neutrons lie in a 20° cone centered about the beam direction. A computer program was used to calculate the incident deuteron energy needed to produce outgoing neutrons of the desired energy at the center of the gas cell allowing for energy loss in the entrance foil and target gas. For neutron energies less than 9.2 MeV, the pressure in the gas cell was reduced to 5 atm to narrow the energy spread of the neutron beam. The

Figure 2-2 Deuterium gas cell.


PICKOFF
OUTPUT
BEAM
DIRECTION
TANTALUM
COLLIMATOR
LUCITE
ELECTRON
SUPPRESSOR
FILL
TUBE
SS TUBING
HAVAR FOIL
TANTALUM
LINER

energy spread of the neutrons leaving the gas cell ranged from 400 KeV at E_n = 7.75 MeV to 180 KeV at E_n = 17.0 MeV and is shown in Figure 2-3. The interior of the gas cell was lined with tantalum. The amount of beam used in the experiment was determined by integrating the charge deposited in the gas cell. The deuteron beam was collimated at the entrance to the gas cell by passing it through a 0.4 cm hole in a tantalum disk. Current on the collimator was keep below 1 nA. In front of the collimator was a 7.6 cm long by 1 cm diameter copper tube that served as a capacitive pickup to determine the arrival time of a beam burst at the gas cell.

Polarized neutrons were produced using a polarized deuterium beam and the excellent polarization transfer characteristics of the $^2H(\vec{d},\vec{n})$ reaction (Lisowski, 1973). The source was operated so that the vector and tensor deuteron polarizations were equal. For this case, and for the neutron energies used in this work, the neutron polarization P_n is given by

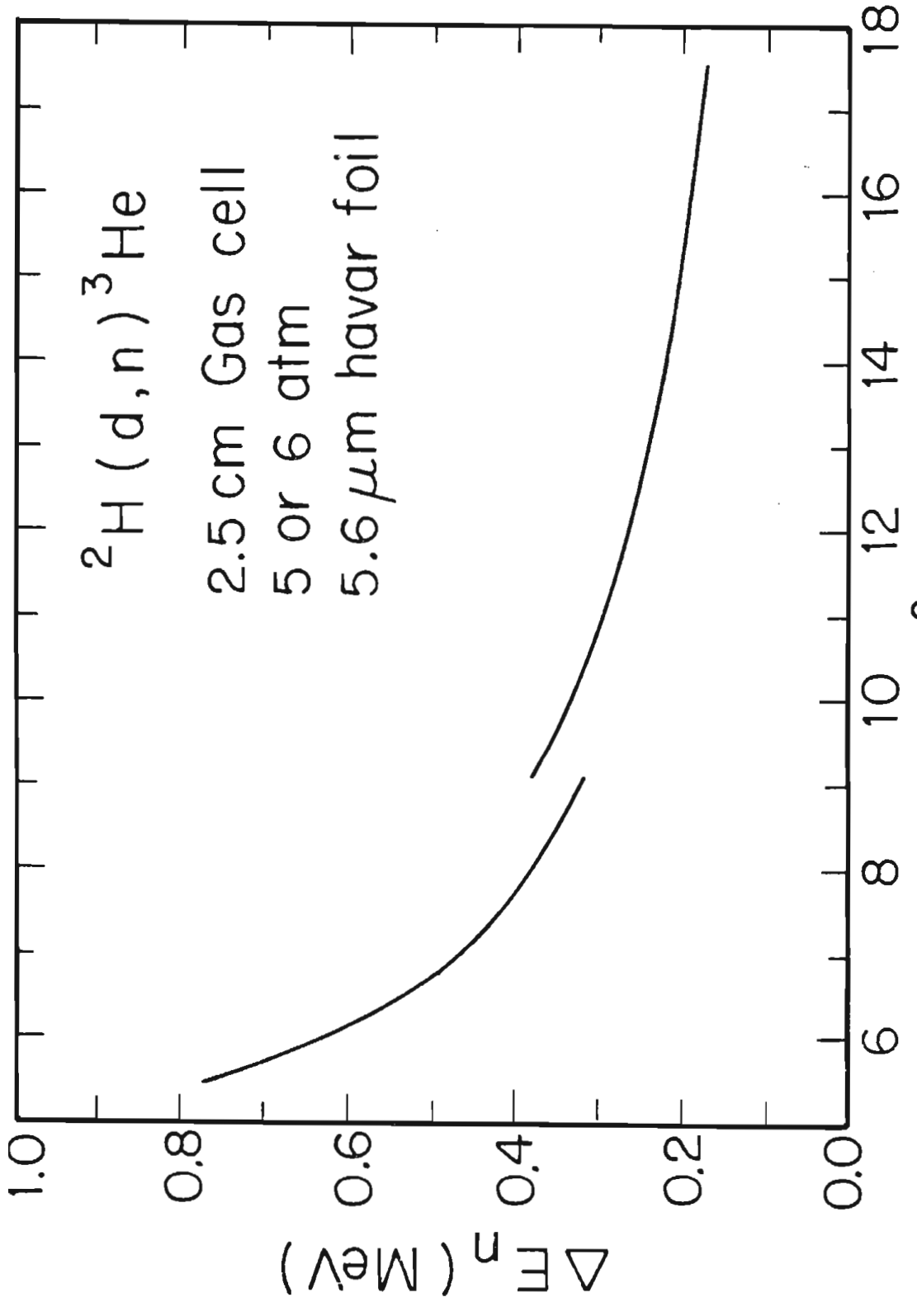
$$P_n = \frac{0.95}{0.12 + P_d^{-1}} \qquad 2\text{-}1$$

where P_d is the polarization of the deuteron beam. The cross section for production of neutrons from the $^2H(\vec{d},\vec{n})$ reaction is larger for tensor polarized deuterons than for unpolarized deuterons and is given by

$$\sigma(0^\circ) = \sigma_u(0^\circ)\,[\,1 + 0.12\,P_d\,]\,. \qquad 2\text{-}2$$

The parameters in Equation 2-1 and Equation 2-2 were taken from Lisowski

Figure 2-3 Energy spread of the 0^{o} neutron beam produced by the $^{2}H(d,n)$ reaction in the deuterium gas cell. E_n is the neutron energy for 0^{o} neutrons produced at the center of the gas cell. ΔE_n is the difference in energy between the 0^{o} neutrons produced at the front and back of the gas cell. The pressure in the gas cell was 5 atm below E_n = 9.1 MeV and 6 atm above E_n = 9.1 MeV.


$^2H(d,n)^3He$
2.5 cm Gas cell
5 or 6 atm
5.6 μm havar foil
ΔE_n (MeV)
$E_n(0^\circ)$ (MeV)
0.0
0.2
0.4
0.6
0.8
1.0
6
8
10
12
14
16
18

(1973). Cross sections for the $^{2}H(d,n)$ reaction were taken from Drosg (1978).

2.3 Target

The target consisted of 32.4 grams of 96.4% isotopically pure ^{13}C in the form of a fine powder. The target was pressed into a lucite cylinder with interior dimensions of 3.8 cm height and 3.8 cm diameter. An identical empty lucite cylinder was used for performing target out measurements. The target was suspended by wires in air at a distance of 8.9 cm from the center of the target to the center of the deuterium gas cell.

2.4 Detectors

The γ-ray detection system consisted of two 25 cm by 25 cm cylindrical NaI scintillators. Each NaI detector was surrounded, except in the rear, by a 10 cm thick NE110 plastic anti-coincidence shield (Suffert et al., 1968). The shields in turn were surrounded by 10 cm of lead and 20 cm of paraffin doped with (50% by weight) lithium carbonate. The right detector had a 0.15 cm cadmium sheet between the lead and paraffin. The left detector had a 0.6 cm boron plastic sheet between the lead and paraffin. In both cases, the purpose of the additional shielding was to attenuate thermal neutrons produced in the paraffin or in the room. Each detector was collimated by a tapered lead collimator so that the rear face of the NaI detector was fully illuminated at the

standard distance of 106 cm from the center of the target to the back face of the NaI detector. Each NaI detector was shielded from neutrons produced by the gas cell using 38 kg tungsten shadow bars. Figure 2-4 shows the gas cell, target, and detector geometry.

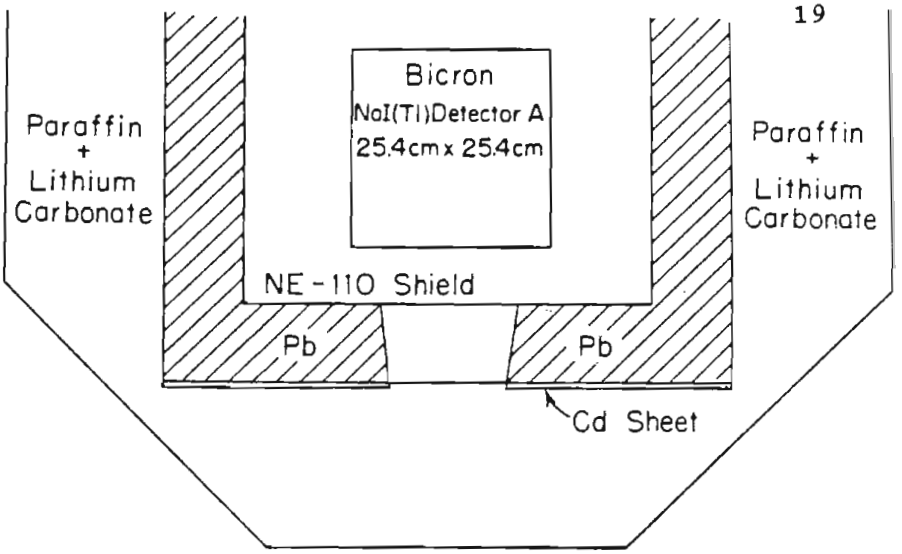
Some of the data was taken at a target to detector distance of 145 cm. This geometry allowed much better shielding of the detector at forward angles from neutrons produced by the gas cell, and allowed the detector to move to more extreme angles without colliding with the beam line. A collimator correctly tapered for this distance was used for the fore-aft asymmetry data. The larger target to detector distance reduced the count rate by a factor of approximately 2.5 and so was used only when use of the standard distance was not possible.

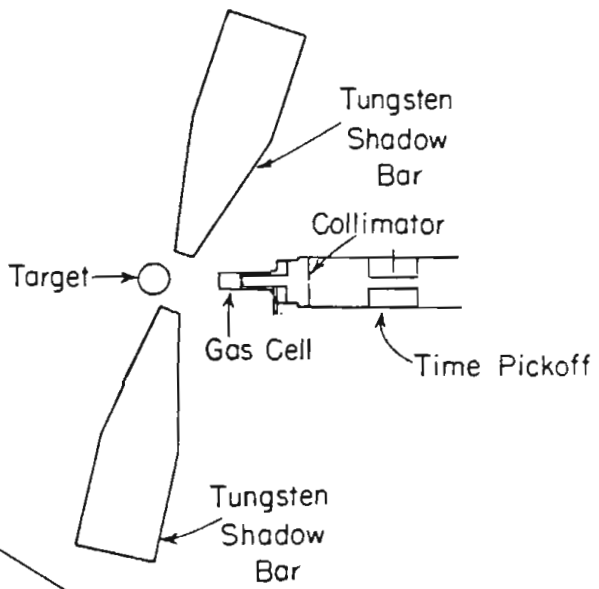
An NE213 scintillator located at 0^{o} at a distance of 260 cm from the target was used to monitor the neutron beam. Pulse shape discrimination was used to separate the neutrons from the γ rays. A time-of-flight spectrum was produced which clearly showed the neutrons from the $^{2}H(d,n)$ reaction as well as the slower neutrons produced from deuteron breakup.

2.5 Electronics

A simplified block diagram of the electronics is presented in Figure 2-5. Each NaI detector was viewed by six gain matched RCA 8575 photo tubes. The separate outputs were summed and amplified and clipped to 350 nsec by a partially terminated coax cable clipping line. The

Figure 2-4 Gas cell, target, and γ-ray detector geometry.


Bicron
NaI(Tl)Detector A
25.4cm x 25.4cm
Paraffin
+
Lithium
Carbonate
Paraffin
+
Lithium
Carbonate
NE-110 Shield
Pb
Pb
Cd Sheet


Tungsten
Shadow
Bar
Collimator
Target
Gas Cell
Time Pickoff
Tungsten
Shadow
Bar

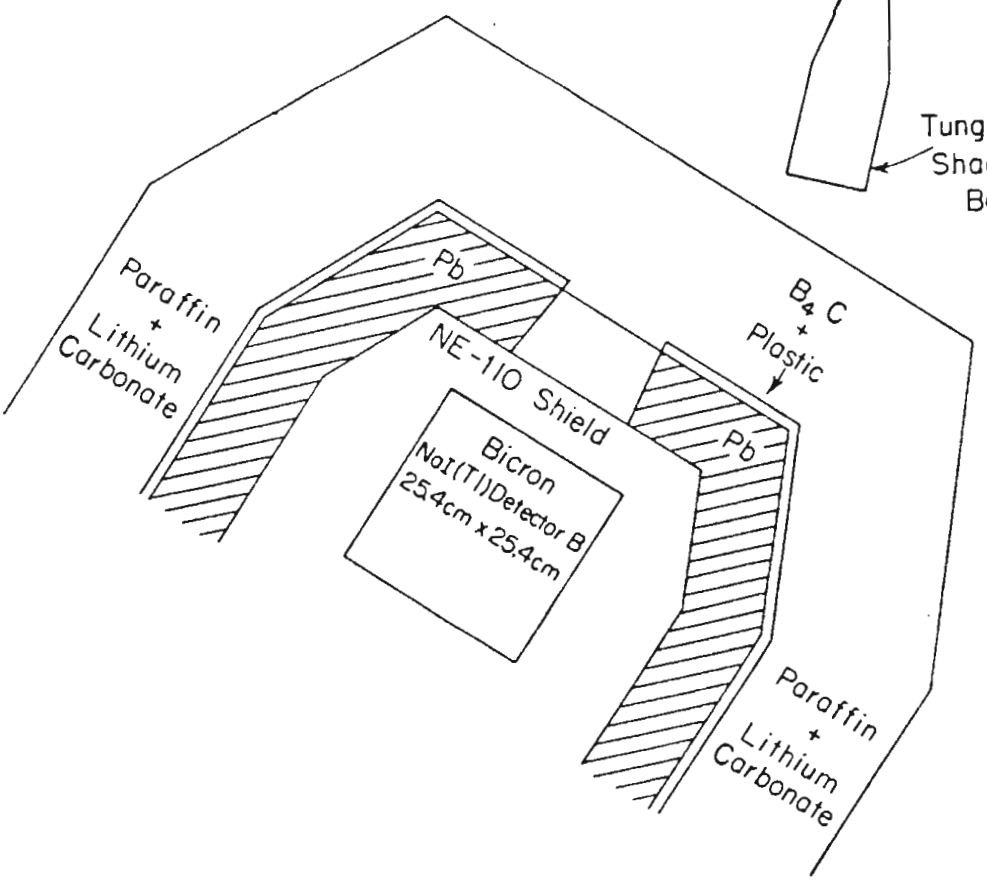
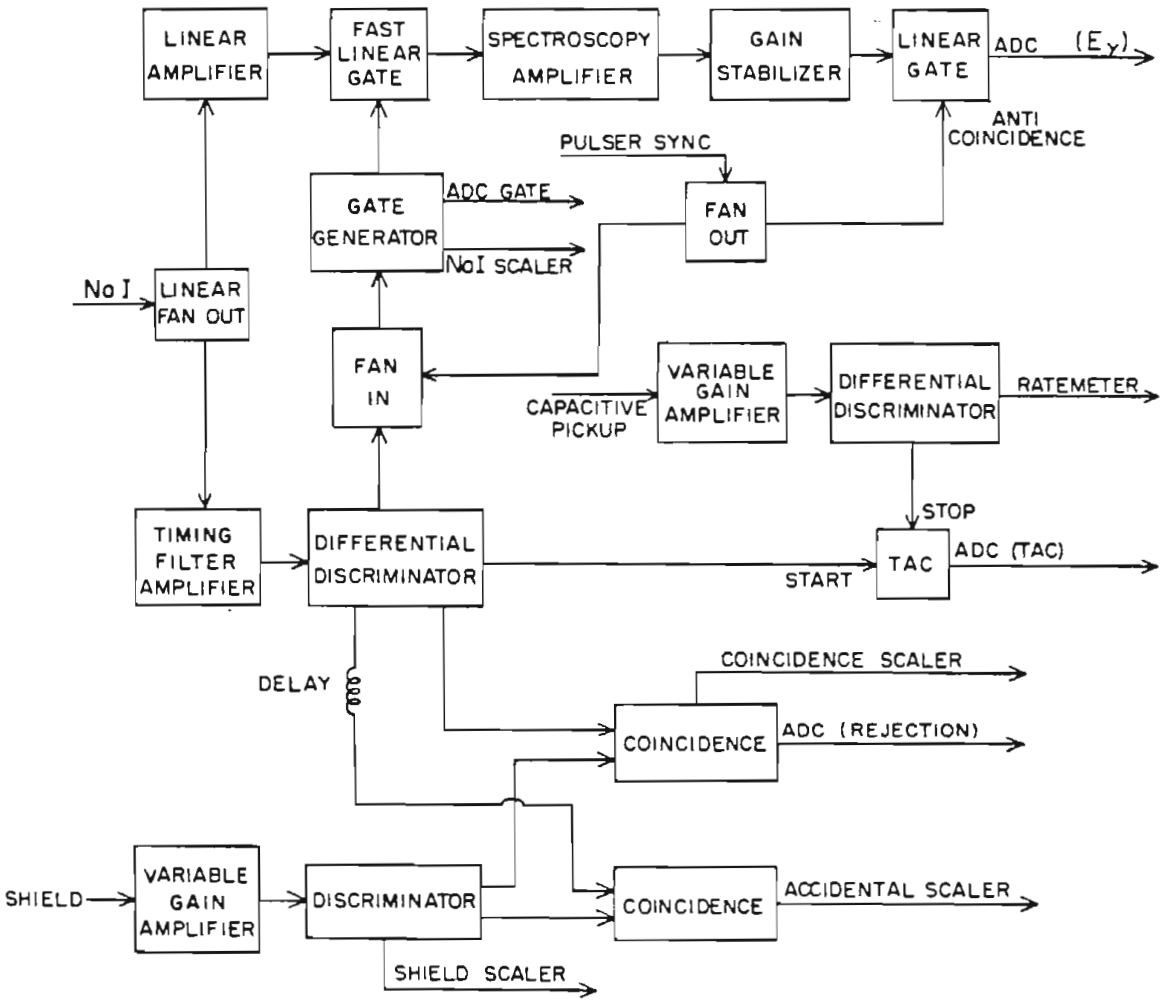

Paraffin
+
Lithium
Carbonate
Pb
NE-110 Shield
Bicron
NaI(Tl)Detector B
25.4cm x 25.4cm
B_4C
+
Plastic
Pb
Paraffin
+
Lithium
Carbonate

Figure 2-5 Block diagram of the γ-ray detection electronics for each of the NaI detectors.


LINEAR AMPLIFIER
FAST LINEAR GATE
SPECTROSCOPY AMPLIFIER
GAIN STABILIZER
LINEAR GATE
ADC (Ey)
ANTI COINCIDENCE
PULSER SYNC
GATE GENERATOR
ADC GATE
NoI SCALER
FAN OUT
NoI
LINEAR FAN OUT
FAN IN
CAPACITIVE PICKUP
VARIABLE GAIN AMPLIFIER
DIFFERENTIAL DISCRIMINATOR
RATEMETER
STOP
TIMING FILTER AMPLIFIER
DIFFERENTIAL DISCRIMINATOR
START
TAC
ADC (TAC)
DELAY
COINCIDENCE SCALER
COINCIDENCE
ADC (REJECTION)
SHIELD
VARIABLE GAIN AMPLIFIER
DISCRIMINATOR
COINCIDENCE
ACCIDENTAL SCALER
SHIELD SCALER

signal was then sent to a 400 nsec fast linear gate, used to reduce the effects of pileup, and to a TD101 differential discriminator. The discriminator output opened the fast linear gate and was sent to two coincidence circuits. The NaI pulses were checked for coincidence with a pulse from the plastic shield. Coincident events were routed into different spectra in the computer. The peak resulting from the $^{13}C(n,\gamma_0)^{14}C$ reaction would have been completely obscured in the spectra without the used of this active shielding. The resolving time of the coincidence system was typically 60 nsec when measured using cosmic rays. An estimate of the number of accidental coincidences between the NaI detector and the shield was provided by comparing the NaI pulses to shield pulses that were delayed by about 330 nsec. Any coincidences with the delayed shield signal must be random events. Most of the data presented in this thesis were taken in the "low rejection" mode where accidental coincidence rates are typically less than 1%. In the "high rejection" mode the beam currents occasionally were reduced in order to keep the accidental coincidence rate below 10%. Selection of rejection modes is accomplished by varying the gain on the shield. Operating in low rejection mode reduces the resolution of the detector system but increases the efficiency. Overall efficiency for the detection of the full energy of γ rays entering the acceptance angle of the detector system was 27 $\pm$ 2 % in the low rejection mode (Weller and Roberson, 1981).

A Canberra 2050 hybrid analogue-digital gain stabilizer was used for data obtained during the latter stages of this work. A light

emitting diode inside the metal can surrounding the NaI detector was pulsed at 1 kHz to generate a signal equivalent to a 7-MeV γ ray in the detector. The gain stabilizer was adjusted to keep the 7-MeV pulse at a fixed voltage in the NaI linear energy signal. A synchronization signal from the electronics driving the LED was used to block the pulser signal from entering the analogue-to-digital converter (ADC) and causing pileup or dead time.

In addition to being sent to the coincidence circuitry, the signal from the NaI discriminator was sent to the start input of a time-to-amplitude converter (TAC). Stop signals were provided by the time pick-off signal from the beam. The output from the TAC was sent to an ADC and stored in the computer. Gamma-ray and neutron events could be clearly separated in the TAC spectrum. Software windows were set in the TAC spectrum and separate spectra were generated for events below, in, and above the γ-ray peak.

2.6 Data Acquisition

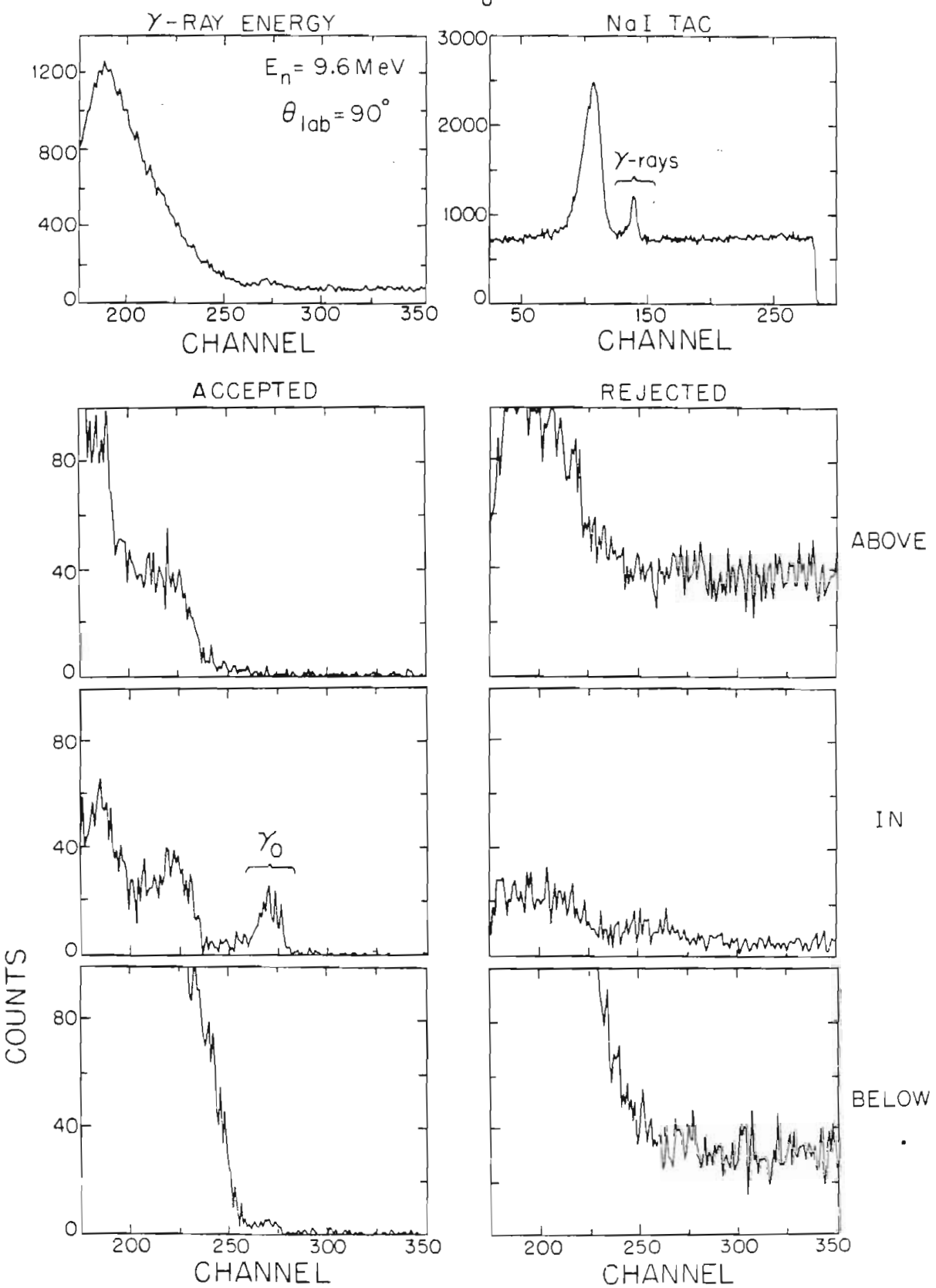
Three linear signals and four scaler signals were sent to the computer for each of the NaI detector systems. The three linear signals were the NaI energy, the beam burst to NaI detection time, and the shield rejection signal. The rejection signal was not a true linear signal but was the output of a gate and delay generator where the presence of a signal indicated a coincident event. The signals were fed to a LeCroy 2259A 12 input ADC. The scaler signals were NaI counts,

shield counts, coincidence counts, and accidental coincidence counts. Dead times for the ADC were determined by comparing the numbers of stored linear signals to the number of NaI scaler counts. Dead times were typically less than 1%. Scalers were also used to count pulses from the beam current integrator, from the beam time pick-off, and clock time.

Data taken during the early part of this work were acquired using the DDP-224 system discussed in Jensen (1981). Later data were taken using the new VAX 11/780 computer manufactured by Digital Equipment Corporation. The ADC's and scalers were resident in a CAMAC crate. The crate was interfaced to the computer system using a BiRa MBD-11 microprogrammed branch driver (Roberson and Edwards, 1981). The software used for data acquisition was the XSYS system developed at TUNL (Gould et al., 1981). Spectra were displayed on a Tektronix 4010 graphics terminal.

Thirteen spectra were accumulated for each NaI detector. The raw γ-ray energy spectrum was accumulated along with the six spectra generated by the time and coincidence rejection criteria. The raw TAC spectrum was accumulated along with three NaI energy gated TAC spectra. The seven γ-ray spectra plus the TAC spectrum are shown in Figure 2-6 for a typical data point. An additional spectrum for each NaI detector was the two valued rejection spectrum where the peak at channel 0 corresponded to accepted events and the other peak corresponded to rejected events. Since measurement of most of the data points required several hours of beam time in order to obtain an acceptable number of

Figure 2-6 Typical $^{13}C(n,\gamma_0)^{14}C$ spectra. From upper left they are: accepted in window, rejected in window, accepted below window, rejected below window, accepted above window, rejected above window, all NaI events, NaI TAC.


$^{13}C(n,\gamma_0)^{14}C$
γ-RAY ENERGY
E_n= 9.6 MeV
θ_{lab}=90°
NaI TAC
γ-rays
CHANNEL
CHANNEL
ACCEPTED
REJECTED
ABOVE
IN
BELOW
γ_0
COUNTS
CHANNEL
CHANNEL

counts, the spectra were periodically dumped and cleared in order to monitor the quality of the data. The thirteenth spectrum for each detector showed the accumulation of the in-the-window, accepted γ-ray spectrum for all of the partial measurements. In addition a spectrum was accumulated for the 0^{o} neutron monitor. During polarized beam measurement spin up and spin down spectra were both resident in memory. A total of 54 spectra were used for each polarized data point.

Scalers and other numeric data were displayed on a VT100 terminal using a software package developed by the author. Using the character graphics capabilities of the VT100 terminal, four large "scaler" boxes, thirty-two small "scaler" boxes and two large "message" boxes were drawn on the screen. Each scaler box contained room for an eight character header and an eight character value. Every two seconds the hardware scalers were read and the values written to the screen. In addition, quantities such as detector count rates, detector dead times, coincidence resolving times, accidental coincidence rates, elapsed time of current data point and time to completion of current data point were calculated and displayed. In the case of analyzing power measurements, the data peaks were summed and the current value and error of the analyzing power (defined below) was dynamically displayed on the screen. The message boxes were used to display up to ten lines of 32 character messages for communication between individuals running the experiment. A representation of the box display is shown in Figure 2-7.

Offline analysis of the spectra was performed using XSYS and the program MULFIT (King, 1980). Using standard XSYS commands, target-out

Figure 2-7 A representation of the XSYS box display after a typical run.

ACC1 CR	ACC2 CR	PRESET	BCI
1.2 %	0.4 %	0	350000

NAI1	SHLD1	COIN1	ACC1	REM TIME	LIVETIME	TIME	RUN NUM
80174	622407	67968	902	0:00:00	1:41:34	60949	1559

NAI2	SHLD2	COIN2	ACC2			MONITOR	DTC OMON
71964	463932	65626	358			1015425	1.013778

NaI1 CR	SHLD1 CR	TACC1 CR	DTC DET1	RSLV TM1	T RSLV 1	EVACTR 1	INI PRES
14	101	1.33	1.012247	93	110	79204	350000

NaI2 CR	SHLD2 CR	TACC2 CR	DTC DET2	RSLV TM2	T RSLV 2	EVACTR 2	PICKOFFS
12	76	0.55	1.021926	71	65	70420	242491

Do QR in slit mode before DU.

Fill trap at 9 AM and 9 PM

Total Ay = -0.064 +/- 0.054
O+:288. N+:255. O-:262. N-:268.

backgrounds were normalized and subtracted from the target-in spectra. The spectra were then fit to the standard line shape (Turner, 1978) of the response function of the NaI detector using MULFIT. The number of counts in the peaks was then normalized to beam current integration, dead times, accidental coincidence rates and, for some of the data, to the 0^{o} neutron monitor.

3 Analyzing Power and Fore-Aft Asymmetry Measurements

3.1 Peak Stripping and Summing

Ninety-degree analyzing powers (see below) were measured with the two NaI detectors at 17 energies from E_n = 7.75 MeV to E_n = 15 MeV. Fore-aft asymmetries (see below) were measured at 7 energies from E_n = 10.2 MeV to E_n = 17 MeV. The response of the NaI detector to monoenergetic γ rays is a broadened peak that can be parameterized by a width, height, and centroid. Each spectrum was input into the MULFIT program which searched the width, height, and centroid of the standard γ-ray line shape to determine the best fit to the data. The widths produced by the program for the peaks did not exhibit the proper smooth increase with increasing γ-ray energy due to statistical fluctuations in the data. The widths for the peaks were fit to a straight line as a function of γ-ray energy using the method of least squares. The data were then refit by varying only the height and centroid. Due to the fluctuations in the data and to questions about the accuracy of the line shape used by MULFIT it was determined that more reliable values for the areas under the peaks could be obtained by summing the data directly rather than integrating the curve produced by the fitting procedure. The spectra were summed from 1 width below the centroid of the peak to 1.1 widths above the centroid. Fractional channels were summed at the edges of the summing region where indicated by width and centroid. The purpose of the fitting program then was to find widths for the peaks individually so that a smoothly varying width function could be

calculated, and to find the centroid of each peak so that a precise summing region could be determined.

Target-out background spectra were taken for each data point using the empty lucite shell for about 1/3 of the integrated beam current used in the target-in measurements. The target-out background spectra were summed using the same summing region for each spectrum as was used in the corresponding target-in measurement. The sums were then normalized to beam current integration, accidental coincidence rate, and electronic dead time. Since each individual background sum had only a small number of counts, the values for the sums varied from one point to the next due to statistical fluctuations but, at a given γ-ray angle, were essentially constant overall as a function of neutron energy. To obtain more reliable values for the background counts, the sums at each γ-ray angle were fit to a straight line as a function of neutron energy using the method of least squares. The fitted sums were then subtracted from the target-in sums to get the net yield for each point. The yield was then converted to the center of mass. The background ranged from 5% of the total counts where the $^{13}C(n,\gamma_0)^{14}C$ yield was high to 25% where the yield was low.

3.2 Analyzing power

Analyzing power is defined as

$$A_y = \frac{1}{P_n} \frac{N_+ - N_-}{N_+ + N_-} \qquad 3\text{-}1$$

where N_+ is the number of counts for neutron spin up, N_- is the number of counts for neutron spin down, and P_n is the polarization of the incident neutron beam. Many experimental uncertainties can be cancelled out by doing analyzing power measurements using two detectors at the same angle on opposite sides of the beam line and flipping the spin of the beam periodically. While one detector is measuring spin up the other is simultaneously measuring spin down. Errors in beam current integration and detector efficiency are canceled out. For a two detector simultaneous measurement, A_y can be expressed by

3-2 $$r = \left\langle \frac{L_+ R_-}{L_- R_+} \right\rangle^{\frac{1}{2}}$$

$$A_y = \frac{1}{P_n} \frac{r - 1}{r + 1}$$

where L represents the left detector and R represents the right detector. Following the Madison convention, for a spin "up" beam the left detector is measuring spin "up" while the right detector is measuring spin "down". The ratio r above is therefore the "true" spin up counts over the "true" spin down counts. The experimental results are shown in Figure 3-1. The data were combined, via a weighted average, with the 90° analyzing powers determined from the angular distribution measurements of chapter 4. The combined data are presented in Figure 3-2 and in Table A-1.

3.3 Fore-aft Asymmetry

Evaluation of the fore-aft asymmetry data is very similar to the

Figure 3-1 Direct two detector measurement of the 90^{o} analyzing power of the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction.

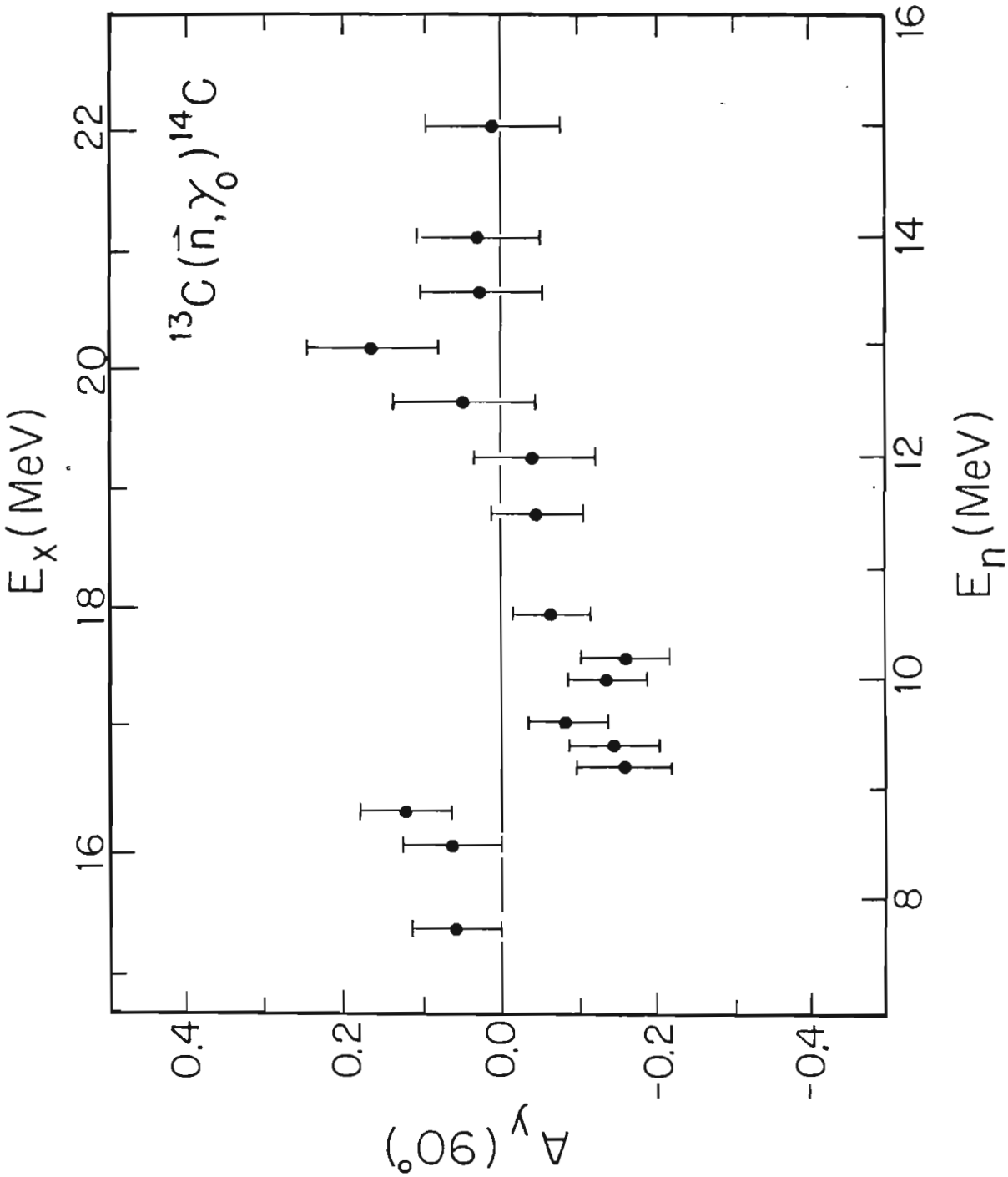
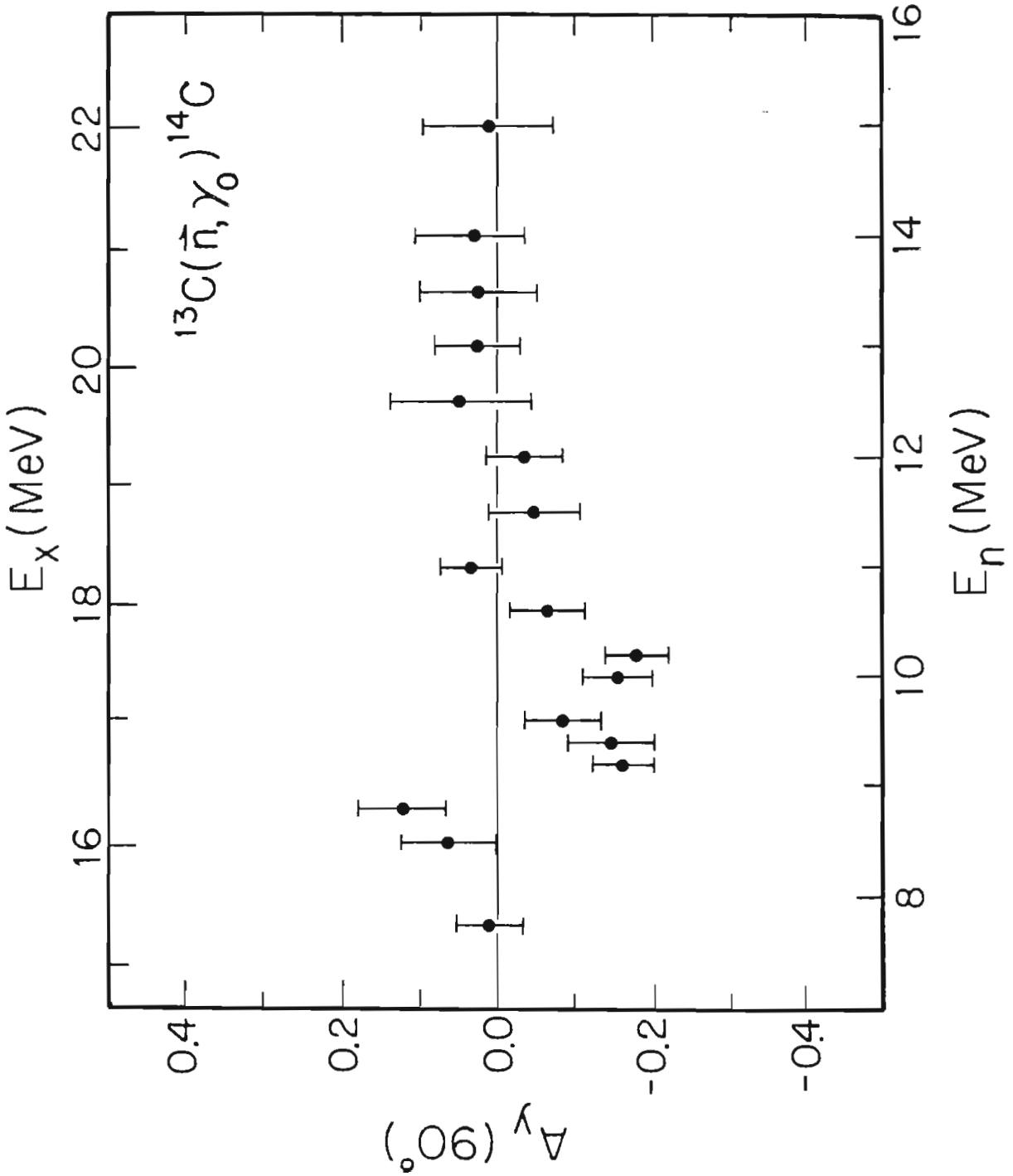

$^{13}C(\vec{n},\gamma_0)^{14}C$
$A_y(90°)$
E_x (MeV)
E_n (MeV)
0.4
0.2
0.0
-0.2
-0.4
16
18
20
22
8
10
12
14
16

Figure 3-2 The 90^{o} analyzing power of the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction determined by combining the direct measurements with the angular distributions.


$^{13}C(\vec{n},\gamma_0)^{14}C$
A_y (90°)
E_x (MeV)
E_n (MeV)
0.4
0.2
0.0
-0.2
-0.4
16
18
20
22
8
10
12
14
16

evaluation of the analyzing power data discussed above. The fore-aft asymmetry is defined by

$$3\text{-}3 \qquad a_s = \frac{N_{55} - N_{125}}{N_{55} + N_{125}}$$

where N_{55} is the number of counts observed with the γ-ray detector at 55° and N_{125} is the number of counts at 125°. Fore-aft asymmetry is more precisely defined at the zero's of Legendre polynomial P_2 (54.7° and 125.3°) in the center of mass. This distinction can be neglected experimentally because of the 10° angular acceptance of the NaI detectors. In a manner analogous to the two detector measurement of analyzing power, we can cancel certain experimental errors in the fore-aft asymmetry measurement by placing one detector at 55° while the other is at 125° and then swapping positions and repeating the measurement. The fore-aft asymmetry can then be expressed as

$$3\text{-}4 \qquad r = \left\langle \frac{L_{55}\ R_{55}}{L_{125}\ R_{125}} \right\rangle^{\frac{1}{2}},$$

$$a_s = \frac{r - 1}{r + 1}.$$

The experimental results are shown in Figure 3-3. The data were combined, via a weighted average, with the fore-aft asymmetries determined from the angular distribution measurements. The combined data are presented in Figure 3-4 and in Table A-2.

3.4 Cross Section

The cross section at the various energies measured in the above

Figure 3-3 Direct two detector measurement of the fore-aft asymmetry of the $^{13}C(n,\gamma_0)^{14}C$ reaction.

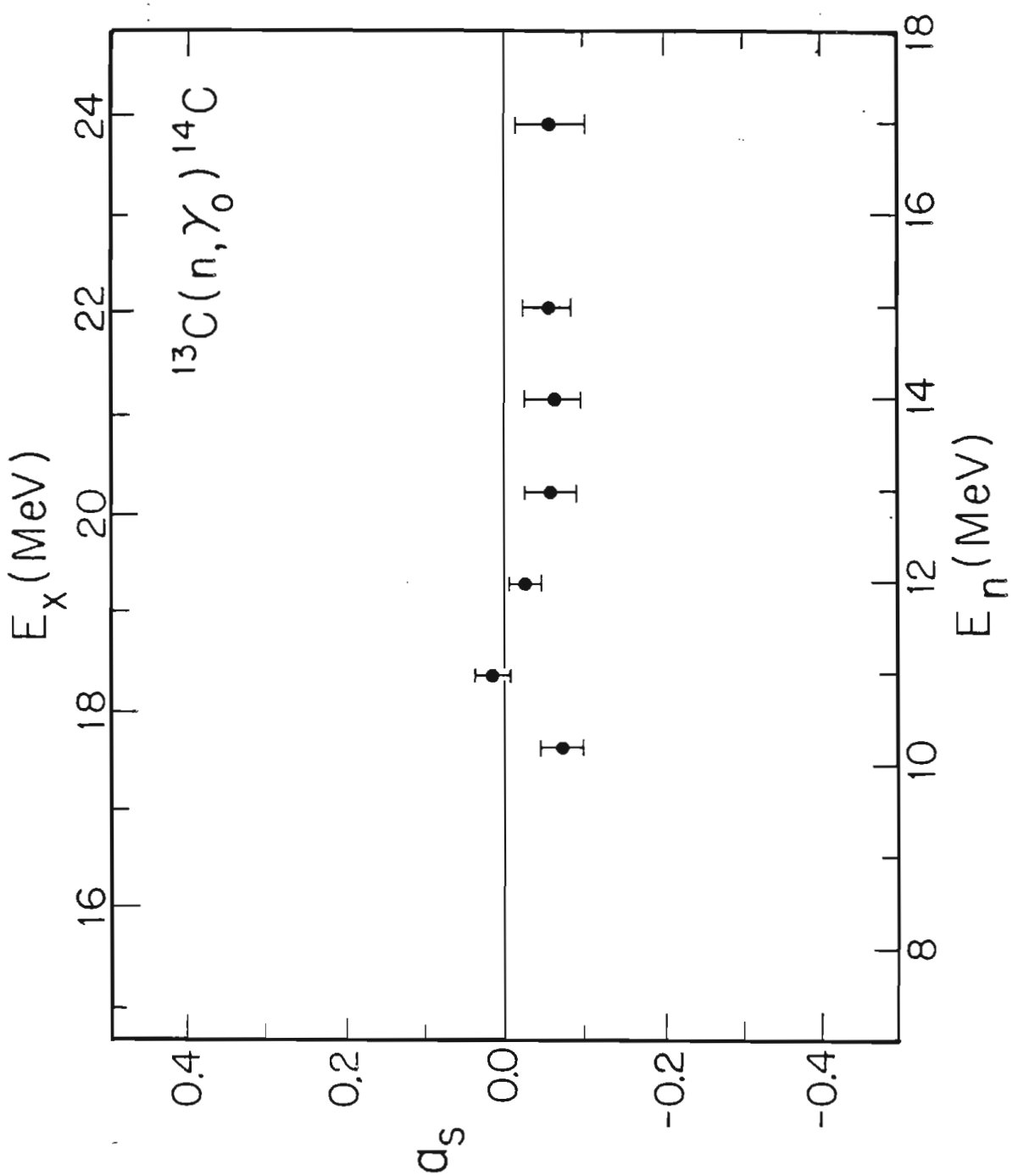
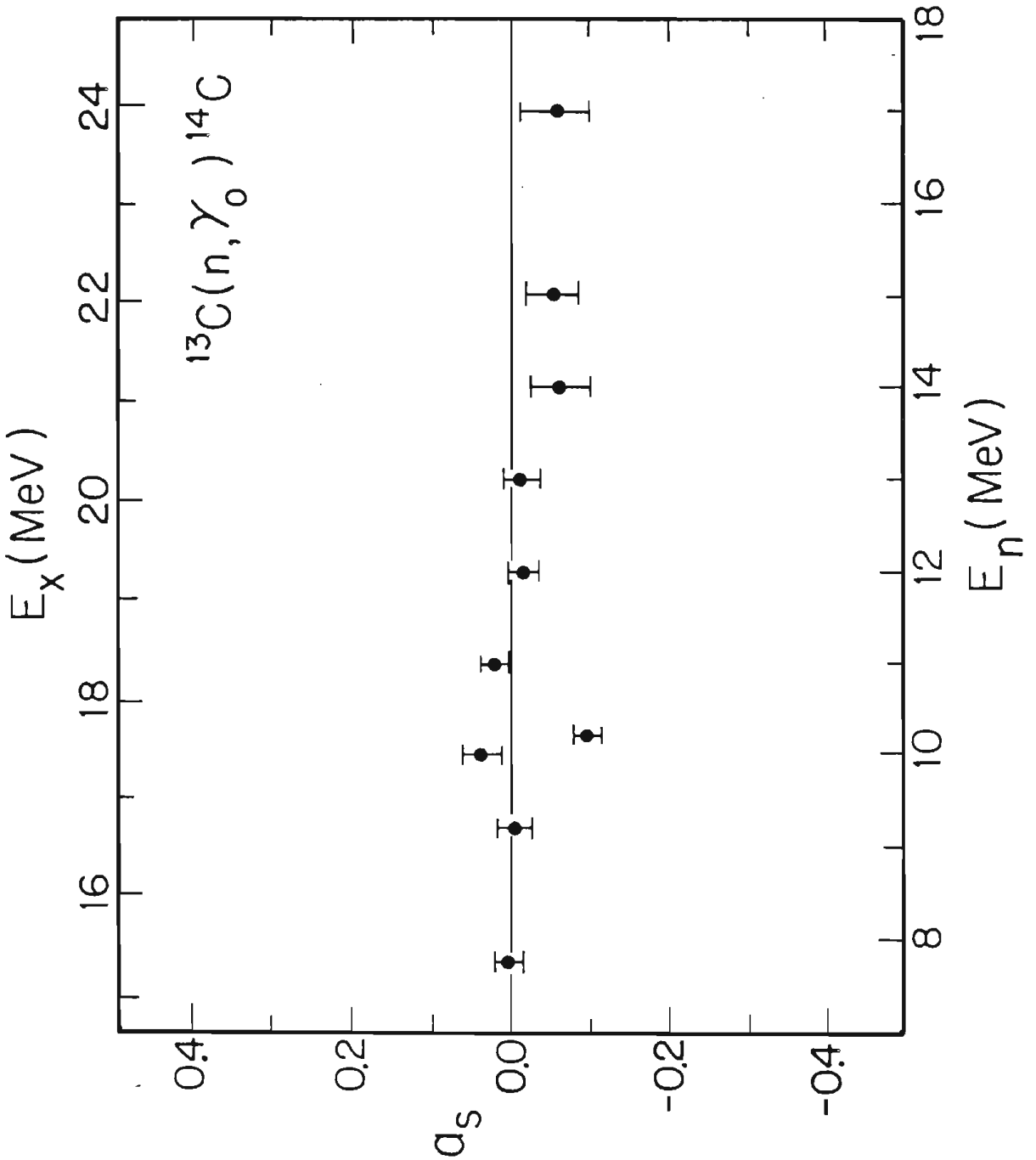

$^{13}C(n,\gamma_0)^{14}C$
E_x (MeV)
E_n (MeV)
a_s
16
18
20
22
24
8
10
12
14
16
18
0.4
0.2
0.0
-0.2
-0.4

Figure 3-4 The fore-aft asymmetry of the $^{13}C(n,\gamma_0)^{14}C$ reaction determined by combining the direct measurements with the angular distributions.


$^{13}C(n,\gamma_0)^{14}C$
E_x (MeV)
E_n (MeV)
a_s
16
18
20
22
24
8
10
12
14
16
18
0.4
0.2
0.0
-0.2
-0.4

data can be calculated and compared with the 90^{o} yield curve of Jensen (1981). The spin up and spin down yields from the 90^{o} analyzing power measurements can be combined to form an unpolarized yield by using

$$3\text{-}5 \qquad N_{un} = \frac{P_{-}N_{+} + P_{+}N_{-}}{P_{+} + P_{-}}$$

where P_{+} is the polarization of the spin-up beam and P_{-} is the polarization of the spin-down beam. The unpolarized yield was corrected for the energy dependence of the $^{2}H(\vec{d},\vec{n})$ reaction, efficiency of the detectors, and finite geometry corrections (Jensen, 1981). Jensen's yield curve was taken at a deuterium gas cell pressure of 2 atm while the analyzing power data was taken at 5 or 6 atm. Jensen's data was converted to an equivalent yield curve for the higher gas cell pressure by performing a convolution integral for the difference in neutron energy spreads resulting from the difference in cell pressures.

The fore-aft asymmetry data was measured at 55^{o} and 125^{o} and therefore required conversion to equivalent 90^{o} data. Including only Legendre polynomials of order up to 3, the conversion factor may be calculated by applying

$$3\text{-}6 \qquad \frac{\sigma(55^{o}) + \sigma(125^{o})}{2} = A_{0}\left[\, 1 - 0.0065\ a_{2} \,\right] \simeq A_{0}$$

and

$$\sigma(90^{o}) = A_{0}\left[\, 1 - 0.5\ a_{2} \,\right].$$

A value for a_{2} is required to complete the calculation. The conversion factor could be easily be calculated for neutron energies below E_{n} = 14 Mev since the angular distributions of cross section had been

measured. The two-level doorway state calculations of chapter 7 were used to provide an estimate of a_2 for 14, 15, and 17 MeV. The converted data was then corrected and normalized as described above.

An overall normalization factor between the two cross section data sets was determined by calculating the normalization factor for each overlapping point in the data sets separately and then performing a weighted average of the individual normalization factors. The new data were then combined with Jensen's data by a weighted average to give the final yield curve. Figure 3-5 shows the cross section from the two data sets separately while Figure 3-6 shows the combined cross section. The combined cross section is given in tabular form in Table A-3.

In order to calculate the total photoneutron cross section, σ_{γ,n_0}, we must first calculate the total radiative capture cross section, σ_{n,γ_0}, and then apply detail balance. The total capture cross section can be written (see §4-2) as

$$\sigma_{n,\gamma} = 4\pi A_0 \quad . \tag{3-7}$$

A value for A_0 is known at each energy where the angular distribution of cross section or the fore-aft asymmetry was measured. For other energies, the $\sigma(90^\circ)/A_0$ ratio must be estimated. The two-level doorway state calculations (see §7-3) did a good job of fitting the measured a_2 coefficients. The calculation represented by the dashed curve in Figure 7-4 was used to provide the $\sigma(90^\circ)/A_0$ ratio for the entire energy range of the 90° cross section measurements. The total neutron capture cross section is shown in Figure 3-7 and Table A-4.

Figure 3-5 90^{o} cross section of the $^{13}C(n,\gamma_0)^{14}C$ reaction. The circles are the data of Jensen. The X's are the data of this work.

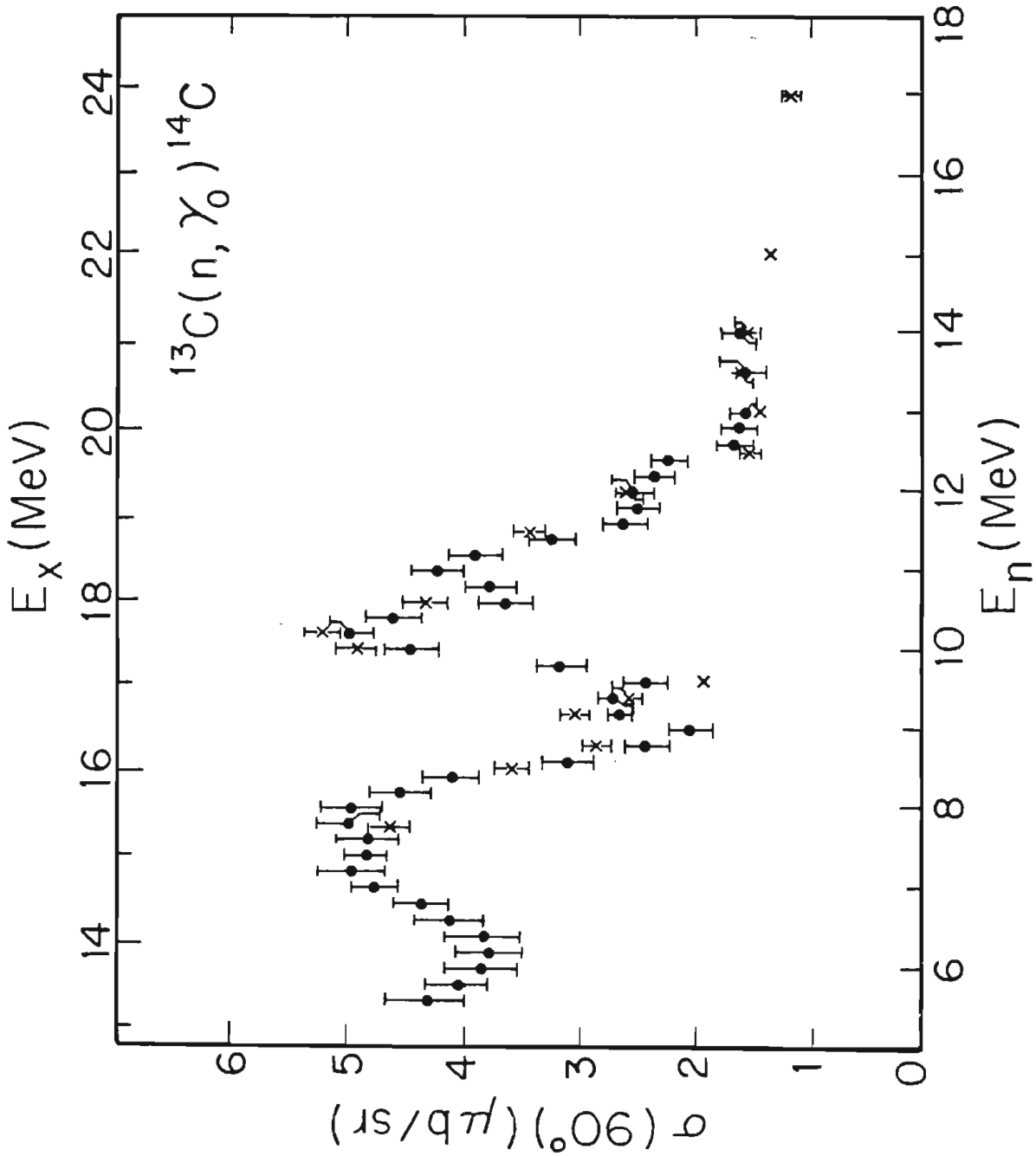

$^{13}C(n,\gamma_0)^{14}C$
E_x (MeV)
E_n (MeV)
σ (90°) (μb/sr)
14
16
18
20
22
24
6
8
10
12
14
16
18
0
1
2
3
4
5
6

Figure 3-6 90^{o} cross section of the $^{13}C(n,\gamma_0)^{14}C$ reaction. The points represent the weighted average of the two data sets presented in Figure 3-5. The curve is the result of the direct-semidirect model calculations of chapter 7.

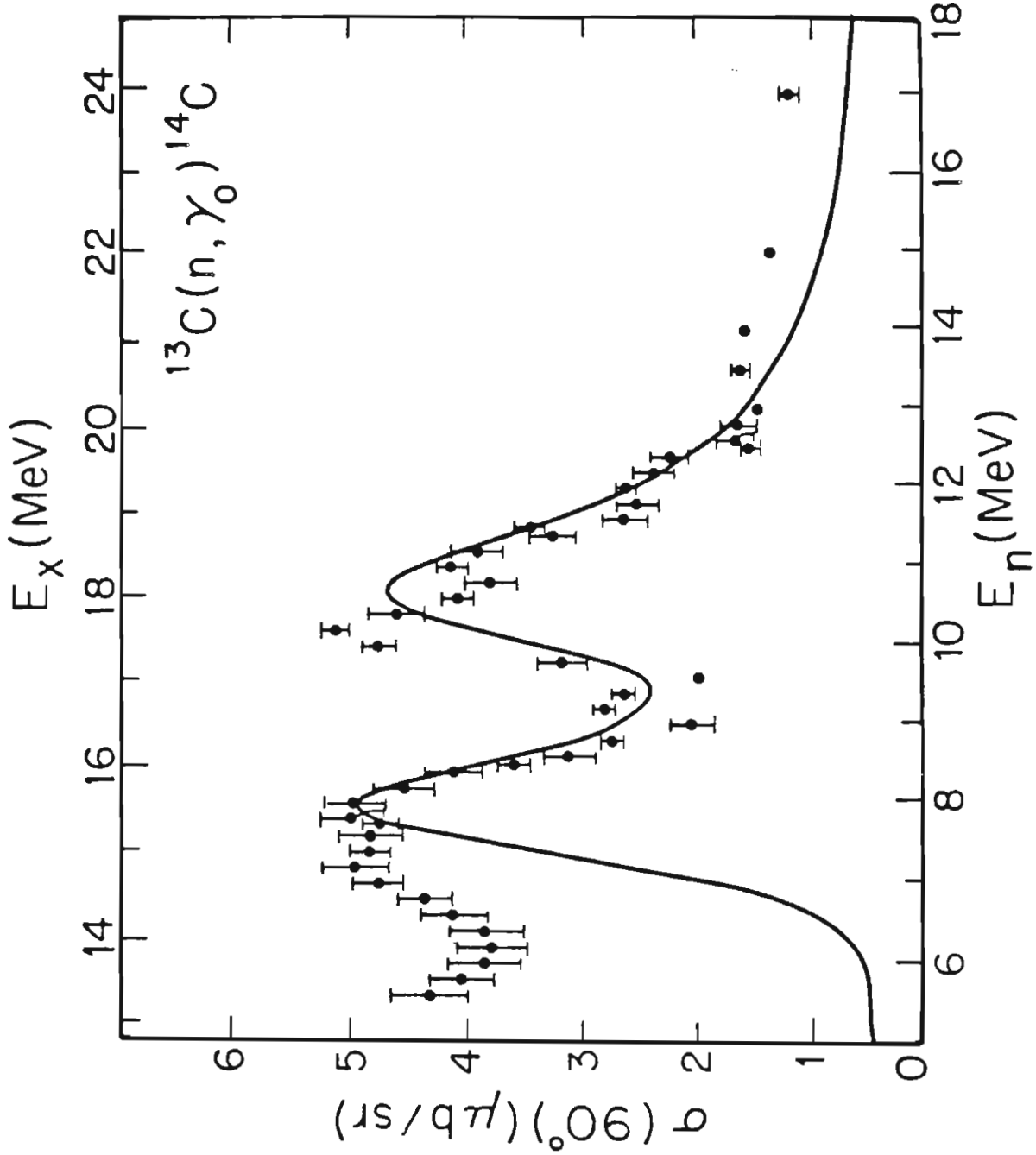
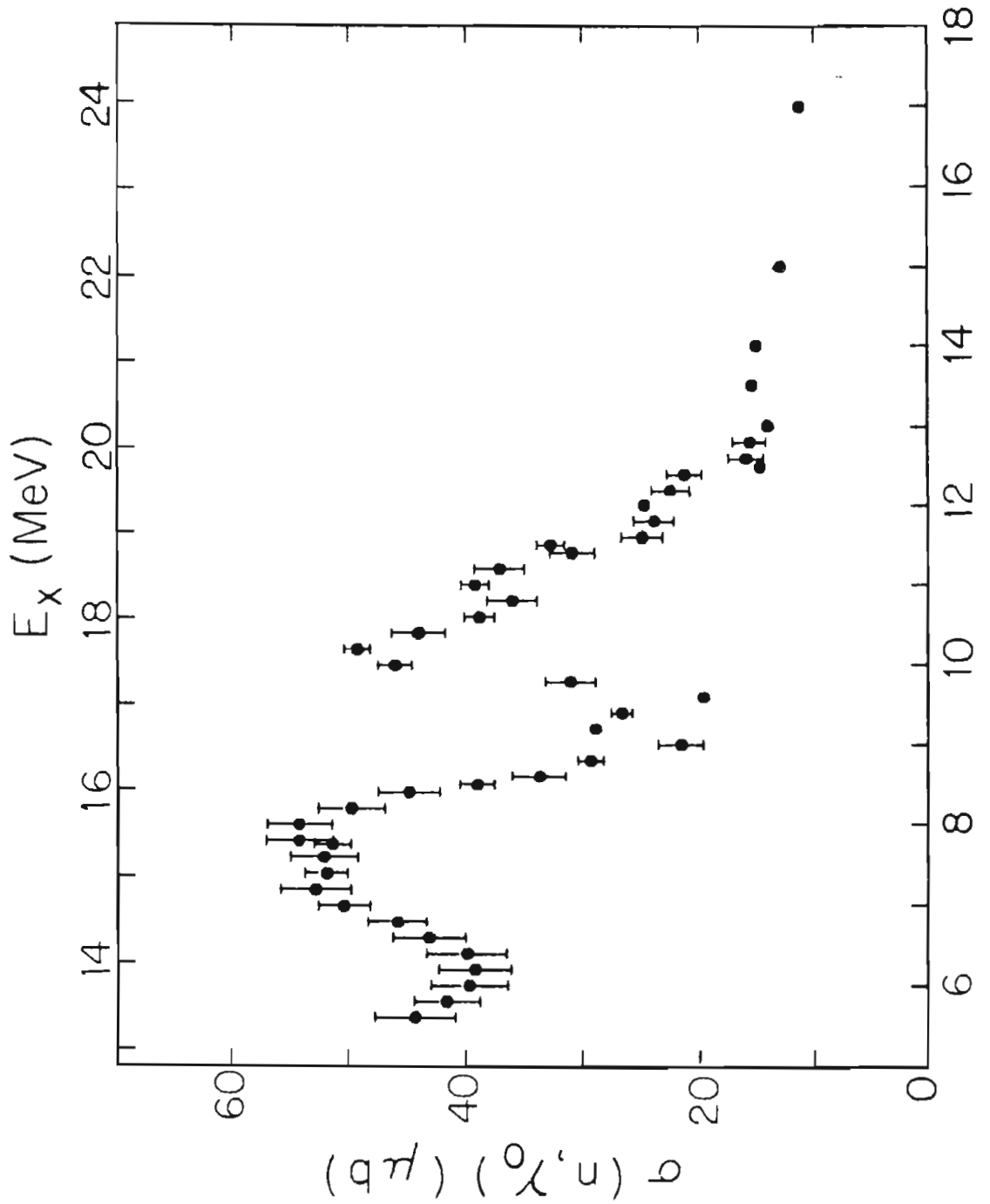

$^{13}C(n,\gamma_0)^{14}C$
E_x (MeV)
E_n (MeV)
σ (90°) (μb/sr)
14
16
18
20
22
24
6
8
10
12
14
16
18
0
1
2
3
4
5
6

Figure 3-7 Total cross section of the $^{13}C(n,\gamma_0)^{14}C$ reaction.

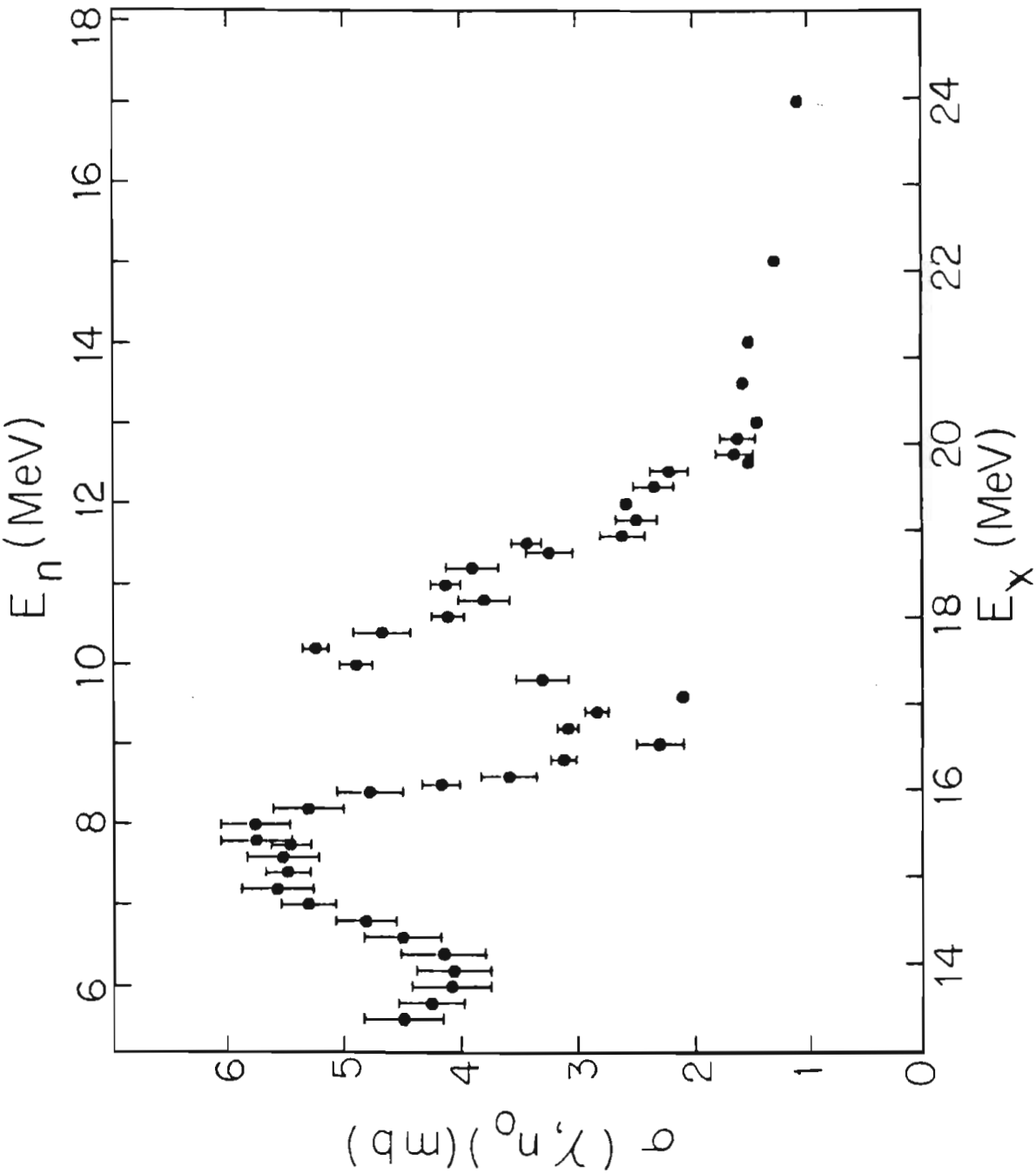

E_x (MeV)
14
16
18
20
22
24
E_n (MeV)
6
8
10
12
14
16
18
$\sigma(n,\gamma_0)$ (μb)
0
20
40
60

The detail balance relation between radiative capture and photonuclear emission is given by

$$3\text{-}8 \qquad \sigma_{\gamma,n_0} = 2 \frac{2J_A + 1}{2J_{A+1} + 1} \frac{A}{A+1} \frac{E_x - Q}{E_x^2} M c^2 \sigma_{n,\gamma_0}$$

where J_A and J_{A+1} are the spins of the neutron target and resultant nucleus, Q is the Q-value of the capture reaction, and $M c^2$ is the energy equivalent of the rest mass of the neutron. The detail balance cross section is presented in Figure 3-8 and Table A-5.

Figure 3-8 Total cross section of the $^{14}C(\gamma,n_0)^{13}C$ reaction obtained through detail balance.


σ (γ, n₀) (mb)
E_n (MeV)
E_x (MeV)
0
1
2
3
4
5
6
6
8
10
12
14
16
18
14
16
18
20
22
24

4 Angular Distributions

4.1 Peak Stripping and Summing

Angular distributions of cross section were measured at neutron energies of 7.75, 12 and 13 MeV. A partial angular distribution of analyzing power was measured at E_n = 13 MeV. Previously unreported angular distributions of cross section at 10 and 11 MeV and analyzing power at E_n = 10 MeV were analyzed. Jensen's angular distributions of cross section and analyzing power at 7.75, 9.2, 10.2, 11, and 12 MeV were reexamined and the data at 11 and 12 MeV were completely reanalyzed.

The spectra were fit in the same manner as described in §3-1. The peaks were fit using MULFIT, the fitted peak widths were averaged for each angular distribution, and the spectra were refitted with the fixed peak widths. The spectra were then summed from 1 width below the peak to 1.1 widths above the peak. Target-out background measurements were performed for the new data sets and were analyzed as described above. Backgrounds for the older data sets were estimated by examining the number of counts per channel appearing in the spectra in the region just above the peak for all of the data sets. For data sets having target-out measurements, the target-out counts per channel in the region under the peak were about 1.5 times the counts per channel above the peak in the target-in spectra. The counts per channel above the peak were multiplied by 1.5 and summed for the proper number of channels to

give background estimates for the old data sets. The net yields were then normalized to beam current integration, accidental coincidence rate, and electronic dead time. The yields were then corrected for multiple scattering and finite geometry effects using the Monte Carlo code SPINFIX (Jensen, 1981). The data are presented in tabular form in Table B-1.

4.2 Angular Distributions of Cross Section

The angular distributions of cross section can be expanded in terms of Legendre polynomials

$$4\text{-}1 \qquad \sigma(\theta) = \sum_{k=0}^{k_{max}} A_k P_k(\cos\theta)$$

where the A_k are the fitting coefficients and the P_k are the Legendre polynomials. In order to emphasize the shape of the angular distributions, the data were normalized and expanded via weighted least squares in terms of the Legendre polynomial coefficients $a_k = A_k / A_0$ giving

$$4\text{-}2 \qquad \frac{\sigma(\theta)}{A_0} = \sum_{k=0}^{k_{max}} a_k P_k(\cos\theta) \ .$$

The presence of quadrupole radiation would indicate that terms up to $k = 4$ should appear in the expansion. However, the data were of sufficient quality to justify only terms up to $k = 3$.

More than one measurement of the angular distribution was performed at each energy. Since the individual measurements at some

energy all describe the same physical distribution they should all be described by the same values for a_1, a_2, and a_3 and differ only in the value for A_0. The separate measurements were fit to A_0 while a_1 through a_3 were fixed according to some initial guess. The data were normalized according to the values of A_0 and the combined data were fitted to give new values for a_1 through a_3. These values were used to generate new A_0's and the procedure was iterated until the values converged. This method of normalization was particularly useful for normalizing data taken at extreme angles with the detector in the "pulled-back" position to data taken at the standard position since the extreme angle data, by itself, did not constitute a sufficiently complete angular distribution to allow expansion into Legendre polynomials. Figure 4-1 shows the angular distributions of cross section along with the Legendre polynomial fits. The coefficients for the fits are presented in Table B-2.

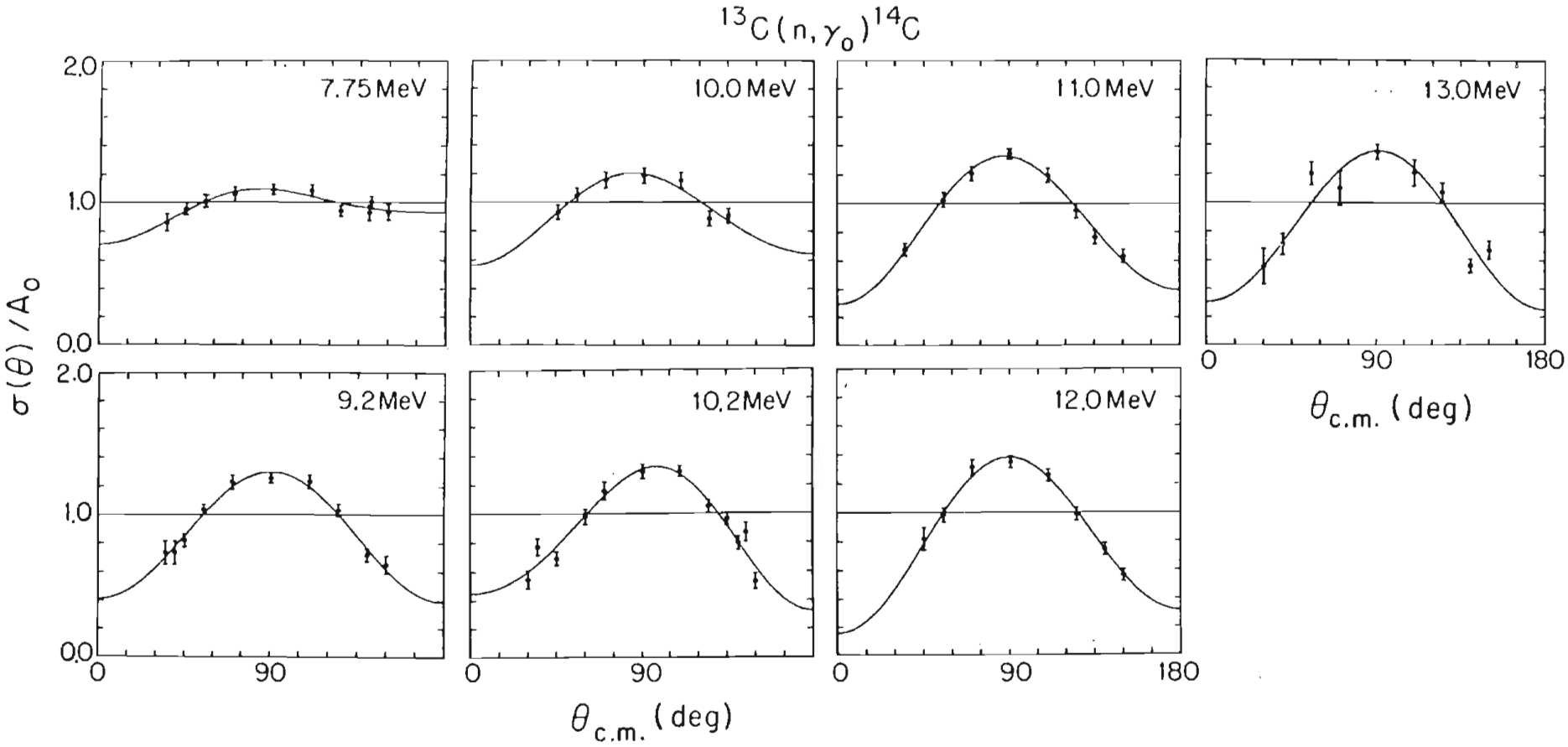
4.3 Angular Distribution of Analyzing Power

The angular distributions of the cross section-analyzing power product were expanded according to

$$\frac{A_y(\theta)\ \sigma(\theta)}{A_0} = \sum_{k=1}^{k_{max}} b_k P_k^1(\cos\theta) \qquad 4\text{-}3$$

where the b_k are the fitting coefficients and the P_k^1 are the associated Legendre polynomials of the first kind. The expansions were performed up to k = 3. The measurements of the angular distributions of analyzing power were performed before the second NaI detector was available and so

Figure 4-1 Angular distributions of cross section for the $^{13}C(n,\gamma_0)^{14}C$ reaction at various energies. The curves are Legendre polynomial expansions through $k = 3$.


$^{13}C(n,\gamma_0)^{14}C$
7.75MeV
10.0MeV
11.0MeV
13.0MeV
9.2MeV
10.2MeV
12.0MeV
$\sigma(\theta)/A_0$
$\theta_{c.m.}$ (deg)
2.0
1.0
0.0
0
90
180

the formula of Equation 3-1 was used to form the analyzing power. The analyzing power was then multiplied by the cross section determined from both the polarized and unpolarized measurements to form the cross section-analyzing power product. The cross sections determined from the data taken with the polarized beam at 10, 11, and 12 MeV were inconsistent with the cross sections determined from the unpolarized data and the fore-aft asymmetry measurements at the same energies and were inconsistent with any reasonable theoretical interpretation. This behavior is partially explained by the fact that the beam produced by the polarized ion source is less intense and has poorer pulsing characteristics than the beam produced by the direct extraction source. The cross section information from the polarized beam at these three energies was not included in the final results.

4.4 Constrained Fits

The angular distributions of cross section give a value for the fore-aft asymmetry according to

$$a_s = 0.5773\, a_1 - 0.3849\, a_3 \,, \tag{4-4}$$

which is derived by expanding Equation 3-3 in terms of the Legendre polynomials up to order 3. The error of the asymmetry is given by

$$\Delta a_s = 0.3333\, \sigma_{a_1}^{\,2} + 0.1481\, \sigma_{a_3}^{\,2} - 0.2222\, \sigma_{a_1 a_3}^{\,2} \tag{4-5}$$

where $\sigma_{a_1 a_3}^{\,2}$ is the correlated error of a_1 and a_3. The angular distributions of cross section-analyzing power product give a value for

the 90° analyzing power according to

$$4\text{-}6 \qquad A_y = \frac{\sigma(90^{\circ})}{A_0} \left[b_1 - 1.5\, b_3 \right],$$

with error

$$4\text{-}7 \qquad \Delta A_y = \frac{\sigma(90^{\circ})}{A_0} \left[\sigma_{b_1}^{\,2} + 2.25\, \sigma_{b_3}^{\,2} - 3.0\, \sigma_{b_1 b_3}^{\,2} \right].$$

The values of a_s and A_y calculated from the angular distributions using the above equations are presented in Table B-2. They were combined by a weighted average with the direct measurements of the asymmetry and analyzing power to give the final results presented in Table B-3.

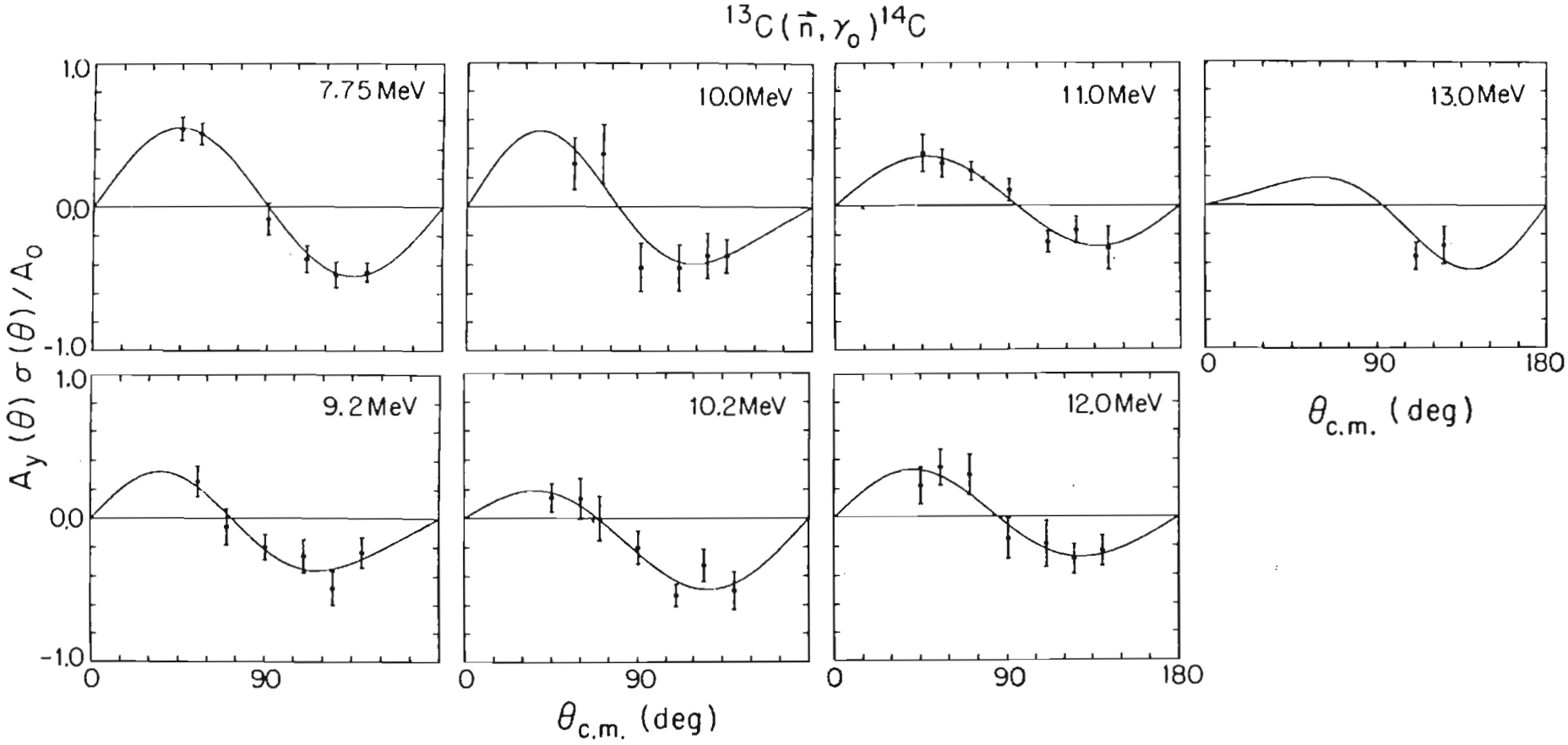
A problem now arises. The Legendre coefficients a_k are inconsistent, in the sense that Equation 4-4 is no longer obeyed, with the final fore-aft asymmetries reported in Table B-3 due to the additional fore-aft asymmetry data. Likewise, the Legendre coefficients b_k are inconsistent with the final 90° analyzing power data. In order to have a consistent data set, the values for the Legendre coefficients must be refined to account for the existence of the additional data. The fore-aft asymmetry data cannot simply be merged into the angular distributions of cross section since they do not represent a sufficiently complete angular distribution. Furthermore, the asymmetry measurements were performed using two detectors and the asymmetry was calculated according to Equation 3-4. The 90° analyzing power data could be combined with the angular distributions, but the problem with the two detector formalism still exists.

The solution was to fit the angular distributions subject to the additional constraint that the fitted coefficients generate the proper value for the asymmetry or analyzing power. In other words, the angular distributions of cross section were expanded in terms of Legendre polynomials with coefficients a_k, such that when the a_k coefficients were inserted into Equation 4-4, the desired value for the fore-aft asymmetry resulted. The constraint was required to be satisfied exactly since the value for the fore-aft asymmetry was determined using all of the available data with proper consideration being given to the various errors involved. The error of the fore-aft asymmetry was allowed to contribute to the errors on the a_k coefficients. The b_k coefficients were redetermined in the same manner. The new Legendre coefficients are presented in Table B-3. The change in the values for the Legendre coefficients was small enough that no obvious qualitative difference resulted in the appearance of the fits. The derivation of the constrained fitting procedure is presented in the next chapter and is valid for any linear least squares fitting.

The constrained fitting procedure allowed use to be made of the analyzing power measured at E_n = 13 MeV at 110^o and 125^o. The measurement of the full angular distribution of analyzing power could not be completed due to a failure of the polarized ion source. Examination of Figure 7-1 shows that the direct-semidirect model calculations of the angular distributions of analyzing power indicate the value of b_2 is constant and b_3 is zero for neutron energies near 13 MeV. The data in the same energy region show similar

characteristics. The two point distribution was fit to b_1 with b_2 fixed at 0.20 ± 0.04 and b_3 fixed at 0.01 ± 0.03. The value for b_1 then determined an effective value for the 90° analyzing power which could be averaged with the directly measured value. The final results were obtained by fixing $b_2 = 0.20 \pm 0.04$ and fitting b_1 and b_3 to the 110° and 125° data subject to the 90° analyzing power constraint. The coefficients for the unconstrained and constrained fits are presented in Table B-2 and Table B-3, respectively. Figure 4-2 shows the angular distributions of analyzing power along with the constrained Legendre polynomial fits.

Figure 4-2 Angular distributions of analyzing power-cross section product for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction at various energies. The curves are associated Legendre polynomial expansions through k = 3.


$^{13}C(\vec{n},\gamma_0)^{14}C$
7.75 MeV
10.0MeV
11.0MeV
13.0MeV
9.2MeV
10.2MeV
12.0MeV
1.0
0.0
-1.0
0
90
180
$A_y(\theta)\,\sigma(\theta)/A_0$
$\theta_{c.m.}$ (deg)

5 Constrained Linear Least Squares

5.1 Introduction

Let $y(x)$ be any function linear in its coefficients a_k. Then $y(x)$ can be written as

$$5\text{-}1 \qquad y(x) = \sum_{k=0}^{n} a_k P_k(x) \ ,$$

where a_k is a number and $P_k(x)$ is any function. The symbols a_k and $P_k(x)$ are customarily used to represent the Legendre coefficients and polynomials but the discussion that follows is valid for any collection of functions and is not restricted to Legendre polynomials. Let us impose a collection of constraint equations of the form

$$5\text{-}2 \qquad \sum_{k=0}^{n} \lambda_{kc} a_k = \tilde{\lambda}_c \ , \qquad c=1,n$$

where λ_{kc} and $\tilde{\lambda}_c$ are numbers, possibly zero, and the expression $c=1,n$ means that c takes on all integral values from 1 to n. We can solve a constraint equation for some a_i in terms of the other coefficients appearing in the same constraint equation as

$$5\text{-}3 \qquad a_i = \frac{1}{\lambda_{ic}} \left[\tilde{\lambda}_c - \sum_{k \neq i} \lambda_{kc} a_k \right] .$$

We can use the above equation to reexpress $y(x)$ in terms of some subset of the original a_k coefficients. We can then perform the least squares fitting to determine the values for the subset of the coefficients and substitute into Equation 5-3 to determine the remaining coefficients.

5.2 Reexpression of the function to be fit

The selection of which subset of the coefficients to fit and which to calculate from the constraint equations is complicated by the existence of multiple constraint equations, any of which may refer to any of the a_k coefficients. We can simplify the system of constraint equations by considering them to be a system of n+1 equations in the n+1 unknowns a_k

5-4
$$\begin{aligned}
\lambda_{00}a_0 + \lambda_{10}a_1 + \ldots + \lambda_{n0}a_n &= \tilde{\lambda}_0 \\
\lambda_{01}a_0 + \lambda_{11}a_1 + \ldots + \lambda_{n1}a_n &= \tilde{\lambda}_1 \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
\lambda_{0n}a_0 + \lambda_{1n}a_1 + \ldots + \lambda_{nn}a_n &= \tilde{\lambda}_n .
\end{aligned}$$

We can then use the method of Gaussian elimination with full pivoting (Kreyszig, 1972) to reduce the the system to the form

5-5
$$\begin{aligned}
b_0 + u_{10}b_1 + u_{20}b_2 + \ldots + u_{n0}b_n &= \tilde{u}_0 \\
b_1 + u_{21}b_2 + \ldots + u_{n1}b_n &= \tilde{u}_1 \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
b_r + \ldots + u_{nr}b_n &= \tilde{u}_r \\
0 &= \tilde{u}_{r+1} \\
&\ldots\ldots \\
0 &= \tilde{u}_n
\end{aligned}$$

where the a_k coefficients must be written as b_k coefficients since the column pivoting may rearrange the columns of the matrix. For later use,

we will define the set of functions $G_k(x)$ to represent the same rearrangement of the $P_k(x)$ functions of Equation 5-1. That is, we now express $y(x)$ as

$$5\text{-}6 \qquad y(x) = \sum_{k=0}^{n} b_k G_k(x)$$

where the set of functions $G_k(x)$ is the same set of functions as $P_k(x)$ except that the indices have been rearranged as a result of the Gaussian elimination, and the b_k coefficients multiply the $G_k(x)$ functions in the same way that the a_k coefficients multiply the $P_k(x)$ functions. We can assume the system of Equation 5-4 has more than one solution or least squares fitting would not be necessary. This implies $0 \leq r < n$ and $\tilde{u}_i = 0$, for $r < i \leq n$. We can now solve Equation 5-5 for each b_i, $0 \leq i \leq r$ in terms of only b_j, $r+1 \leq j \leq n$, and do the least squares fitting to determine the b_j coefficients. The solution to Equation 5-5 will be of the form

$$5\text{-}7 \qquad \begin{aligned} b_0 + v_{r+1,0} b_{r+1} + \ldots + v_{n0} b_n &= \tilde{v}_0 \\ b_1 + v_{r+1,1} b_{r+1} + \ldots + v_{n1} b_n &= \tilde{v}_1 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots & \\ b_r + v_{r+1,r} b_{r+1} + \ldots + v_{nr} b_n &= \tilde{v}_r \,. \end{aligned}$$

The r^{th} equation here is identical to the r^{th} equation in Equation 5-5 and is trivially solved giving

$$5\text{-}8 \qquad b_r = \tilde{u}_r - \sum_{k=r+1}^{n} u_{kr} b_k = \tilde{v}_r - \sum_{k=r+1}^{n} v_{kr} b_k \,,$$

where

$$5\text{-}9 \qquad v_{rk} = u_{rk} \quad \text{and} \quad \tilde{v}_r = \tilde{u}_r \qquad\qquad k=r+1,n \,.$$

The solution for b_i, $0 \leq i < r$ can be derived by

5-10 $$b_i = \tilde{u}_i - \sum_{j=i+1}^{r} u_{ji} b_j - \sum_{k=r+1}^{n} u_{ki} b_k ,$$

$$= \tilde{u}_i - \sum_{j=i+1}^{r} u_{ji} \left[\tilde{v}_j - \sum_{k=r+1}^{n} v_{kj} b_k \right] - \sum_{k=r+1}^{n} u_{ki} b_k ,$$

$$= \tilde{u}_i - \sum_{j=i+1}^{r} u_{ji} \tilde{v}_j - \sum_{k=r+1}^{n} \left[u_{ki} - \sum_{j=i+1}^{r} u_{ji} v_{kj} \right] b_k .$$

This, when compared with Equation 5-7, gives the recursion relation between the u's and v's

5-11 $$\tilde{v}_i = \tilde{u}_i - \sum_{j=i+1}^{r} u_{ji} \tilde{v}_j , \qquad i=0,r-1$$

$$v_{ki} = u_{ki} - \sum_{j=i+1}^{r} u_{ji} v_{kj} . \qquad \begin{matrix} i=0,r-1 \\ k=r+1,n \end{matrix}$$

Equation 5-9 and Equation 5-11 together allow all of the $\tilde{v}_i$'s and v_{ki}'s to be calculated.

We can now write y(x) as a function of only a subset of the original set of a_k coefficients (now represented as b_k)

5-12 $$y(x) = \sum_{k=r+1}^{n} b_k G_k(x) + \sum_{k=0}^{r} b_k G_k(x) ,$$

$$= \sum_{k=r+1}^{n} b_k G_k(x) + \sum_{k=0}^{r} \left\langle \tilde{v}_k - \sum_{j=r+1}^{n} v_{jk} b_j \right\rangle G_k(x) ,$$

$$= \sum_{k=r+1}^{n} b_k G_k(x) + \sum_{k=0}^{r} \tilde{v}_k G_k(x) - \sum_{j=r+1}^{n} b_j \left\langle \sum_{k=0}^{r} v_{jk} G_k(x) \right\rangle .$$

The above expression can be simplified by defining

5-13 $$F_k(x) \equiv G_k(x) - \sum_{\ell=0}^{r} v_{k\ell} G_\ell(x) .$$

Finally we can write

5-14 $$y(x) = \sum_{k=r+1}^{n} b_k F_k(x) + \sum_{k=0}^{r} \tilde{v}_k G_k(x) .$$

5.3 Determination of fitting coefficients

We will now follow the method of Bevington (1969) to determine the fitting coefficients. The data set to be fitted consists of a set of N measurements y_i with error σ_i at the points x_i. We define the function χ^2 as a measure of the goodness of fit by

5-15 $$\chi^2 \equiv \sum_{i=1}^{N} \frac{1}{\sigma_i} \left[y_i - y(x_i) \right]^2 .$$

We can now minimize χ^2 by taking its derivative with respect to each of the fitting coefficients b_k and setting each derivative to zero.

5-16 $$\frac{\partial \chi^2}{\partial b_k} = \frac{\partial}{\partial b_k} \sum_{i=1}^{N} \frac{1}{\sigma_i} \left[y_i - \sum_{\ell=r+1}^{n} b_\ell F_\ell(x_i) - \sum_{\ell=0}^{r} \tilde{v}_\ell G_\ell(x_i) \right]^2 = 0 . \qquad k=r+1,n$$

The derivative can be evaluated and the expression rearranged to give

5-17 $$\sum_{i=1}^{N} \frac{F_k(x_i)}{\sigma_i^2} \left[y_i - \sum_{\ell=0}^{r} \tilde{v}_\ell G_\ell(x_i) \right] = \sum_{\ell=r+1}^{n} b_\ell \sum_{i=1}^{N} \frac{F_k(x_i) F_\ell(x_i)}{\sigma_i^2} . \qquad k=r+1,n$$

The above equation can be reexpressed as a matrix equation by defining

5-18 $$\beta_k \equiv \sum_{i=1}^{N} \frac{F_k(x_i)}{\sigma_i^2} \left[y_i - \sum_{\ell=0}^{r} \tilde{v}_\ell G_\ell(x_i) \right] , \qquad k=r+1,n$$

$$\alpha_{\ell k} \equiv \sum_{i=1}^{N} \frac{F_k(x_i) F_\ell(x_i)}{\sigma_i^2} . \qquad k=r+1,n$$

Equation 5-17 becomes

5-19 $$\beta_k = \sum_{\ell=r+1}^{n} \alpha_{\ell k} b_\ell \qquad \text{or} \qquad \vec{\beta} = \overleftrightarrow{\alpha}\, \vec{b} .$$

We can invert the curvature matrix $\overleftrightarrow{\alpha}$ to produce an inverse matrix $\overleftrightarrow{\varepsilon}$, customarily referred to as the error matrix. Note that the indices for these matrices run from r+1 to n. Then

5-20 $$\vec{b} = \vec{\beta}\, \overleftrightarrow{\varepsilon} .$$

The expressions for the b_k coefficients become

5-21 $$b_k = \sum_{\ell=r+1}^{n} \varepsilon_{k\ell} \left\{ \sum_{i=1}^{N} \frac{F_\ell(x_i)}{\sigma_i^2} \left[y_i - \sum_{j=0}^{r} \tilde{v}_j G_j(x_i) \right] \right\} , \qquad k=r+1,n$$

$$b_k = \tilde{v}_k - \sum_{\ell=r+1}^{n} v_{\ell k} b_\ell . \qquad k=0,r$$

The b_k coefficients can then be rearranged to produce the a_k coefficients originally desired.

5.4 Error on fitted coefficients

We need to calculate the error on the b_k coefficients due to the error on the data points. We can also allow a somewhat restrictive error condition on the constraint equations. Namely let

5-22 $$\sum_{k=0}^{n} \lambda_{kc} a_k = \tilde{\lambda}_c \pm \Delta\tilde{\lambda}_c \qquad c = 1,n$$

be the constraint equations and assume that the errors on the $\tilde{\lambda}_c$'s are uncorrelated. Note that the λ_{kc}'s have no error associated with them. After the Gaussian elimination of §5-2, the system of constraint equations is reduced to Equation 5-7 so that $\Delta\tilde{\lambda}_c \rightarrow \Delta\tilde{v}_c$.

The error, or variance, on a b_k coefficient is the root sum square of the errors on the quantities used to determine the coefficient times the effect that quantity has on the value of the coefficient. That is, for the b_k coefficients determined from the χ^2-fit,

5-23 $$\sigma_{b_k}^2 = \sum_{d=1}^{N} \sigma_d^2 \left[\frac{\partial b_k}{\partial y_d}\right]^2 + \sum_{m=0}^{r} \Delta\tilde{v}_m^2 \left[\frac{\partial b_k}{\partial \tilde{v}_m}\right]^2 . \qquad k=r+1,n$$

Taking the partial derivatives,

5-24 $$\frac{\partial b_k}{\partial y_d} = \sum_{\ell=r+1}^{n} \varepsilon_{k\ell} \frac{F_\ell(x_d)}{\sigma_d^2} , \qquad k=r+1,n$$

$$\frac{\partial b_k}{\partial \tilde{v}_m} = \sum_{\ell=r+1}^{n} \varepsilon_{k\ell} \left[\left\langle \sum_{d=1}^{N} \frac{F_\ell(x_d)}{\sigma_d^2} (-G_m(x_d)) \right\rangle \right] \equiv \sum_{\ell=r+1}^{n} \varepsilon_{k\ell} \mu_{\ell m} \qquad k=r+1,n$$

where we have defined $\mu_{\ell m}$ as the term in the braces in order to simplify the expressions that follow. Instead of evaluating the variance, $\sigma_{b_k}^2$, we will want evaluate the covariance, $\sigma_{b_k b_\ell}^2$, so that we will determine the correlated errors of the coefficients.

5-25 $$\sigma_{b_k b_\ell}^2 = \sum_{d=1}^{N} \sigma_d^2 \frac{\partial b_k}{\partial y_d} \frac{\partial b_\ell}{\partial y_d} + \sum_{m=0}^{r} \Delta\tilde{v}_m^2 \frac{\partial b_k}{\partial \tilde{v}_m} \frac{\partial b_\ell}{\partial \tilde{v}_m} , \qquad k,\ell=r+1,n$$

$$= \sum_{d=1}^{N} \sigma_d^2 \left\langle \left[\sum_{i=r+1}^{n} \varepsilon_{ki} \frac{F_i(x_d)}{\sigma_d^2} \right] \right\rangle \left\langle \left[\sum_{j=r+1}^{n} \varepsilon_{\ell j} \frac{F_j(x_d)}{\sigma_d^2} \right] \right\rangle$$

$$+ \sum_{m=0}^{r} \Delta\tilde{v}_m^2 \left\langle \left[\sum_{i=r+1}^{n} \varepsilon_{ki} \mu_{im} \right] \right\rangle \left\langle \left[\sum_{j=r+1}^{n} \varepsilon_{\ell j} \mu_{jm} \right] \right\rangle ,$$

$$= \sum_{i=r+1}^{n} \sum_{j=r+1}^{n} \varepsilon_{ki} \varepsilon_{\ell j} \left\langle \left[\sum_{d=1}^{N} \frac{F_i(x_d) F_j(x_d)}{\sigma_d^2} \right] \right\rangle$$

$$+ \sum_{i=r+1}^{n} \sum_{j=r+1}^{n} \varepsilon_{ki} \varepsilon_{\ell j} \left\langle \left[\sum_{m=0}^{r} \Delta\tilde{v}_m^2 \mu_{im} \mu_{jm} \right] \right\rangle ,$$

$$= \sum_{i=r+1}^{n} \sum_{j=r+1}^{n} \varepsilon_{ki} \varepsilon_{\ell j} \alpha_{ij}$$

$$+ \sum_{i=r+1}^{n} \sum_{j=r+1}^{n} \varepsilon_{ki} \varepsilon_{\ell j} \left\langle \left[\sum_{m=0}^{r} \Delta\tilde{v}_m^2 \mu_{im} \mu_{jm} \right] \right\rangle ,$$

5-26 $$\sigma_{b_k b_\ell}^2 = \varepsilon_{k\ell} + \sum_{i=r+1}^{n} \sum_{j=r+1}^{n} \varepsilon_{ki} \varepsilon_{\ell j} \left\langle \left[\sum_{m=0}^{r} \Delta\tilde{v}_m^2 \mu_{im} \mu_{jm} \right] \right\rangle . \quad k, \ell = r+1, n$$

We thus have the usual result for unconstrained fits, $\varepsilon_{k\ell}$, plus a term due to the error on the $\tilde{v}_m$. We will define the quantity on the right hand side of the above equation to be the total error matrix, $\tilde{\varepsilon}_{k\ell}$, that is

5-27 $$\tilde{\varepsilon}_{k\ell} \equiv \varepsilon_{k\ell} + \sum_{i=r+1}^{n} \sum_{j=r+1}^{n} \varepsilon_{ki} \varepsilon_{\ell j} \left\langle \left[\sum_{m=0}^{r} \Delta\tilde{v}_m^2 \mu_{im} \mu_{jm} \right] \right\rangle . \quad k, \ell = r+1, n$$

5.5 Error on all coefficients

The error on any function $H(a_0, a_1, \ldots, a_n)$ of the fitting coefficients, for example, the fore-aft asymmetry in Equation 4-4, is given by

$$5\text{-}28 \qquad \sigma_H^2 = \sum_{i=0}^{n} \sum_{j=0}^{n} \sigma_{a_i a_j}^2 \frac{\partial H}{\partial a_i} \frac{\partial H}{\partial a_j} \ .$$

What we have calculated so far (Equation 5-26) is only the covariance between some of the coefficients, namely $b_{r+1}, \ldots, b_n$. In order to find the error on H we must first reexpress H as a function $H'(b_{r+1}, \ldots, b_n)$ and apply the formula

$$5\text{-}29 \qquad \sigma_{H'}^2 = \sum_{i=r+1}^{n} \sum_{j=r+1}^{n} \sigma_{b_i b_j}^2 \frac{\partial H'}{\partial b_i} \frac{\partial H'}{\partial b_j} \ .$$

It clearly will be more convenient to evaluate the covariance between all of the coefficients; both those that were fitted and those that were determined from the constraint equations. The covariances can then be relabeled to give $\sigma_{a_i a_j}^2$ and Equation 5-28 can be used directly. Recall from Equation 5-21 we have

$$5\text{-}30 \qquad b_k = \tilde{v}_k - \sum_{i=r+1}^{n} v_{ik} b_i \ . \qquad k=0,r$$

Taking derivatives,

$$5\text{-}31 \qquad \frac{\partial b_k}{\partial y_d} = - \sum_{i=r+1}^{n} v_{ik} \frac{\partial b_i}{\partial y_d} \ , \qquad k=0,r$$

$$\frac{\partial b_k}{\partial \tilde{v}_m} = \delta_{mk} - \sum_{i=r+1}^{n} v_{ik} \frac{\partial b_i}{\partial \tilde{v}_m} \qquad k=0,r$$

where δ_{mk} is zero if $m \neq k$ and is 1 if $m=k$. Then for $k, \ell \leq r$ we can write

5-32
$$\sigma_{b_k b_\ell}^2 = \sum_{d=1}^{N} \sigma_d^2 \frac{\partial b_k}{\partial y_d} \frac{\partial b_\ell}{\partial y_d} + \sum_{m=0}^{r} \Delta\tilde{v}_m^2 \frac{\partial b_k}{\partial \tilde{v}_m} \frac{\partial b_\ell}{\partial \tilde{v}_m} , \qquad k, \ell = 0, r$$

$$= \sum_{i=r+1}^{n} \sum_{j=r+1}^{n} v_{ik} v_{j\ell} \left\langle \sum_{d=1}^{N} \sigma_d^2 \frac{\partial b_i}{\partial y_d} \frac{\partial b_j}{\partial y_d} \right\rangle$$

$$+ \sum_{m=0}^{r} \Delta\tilde{v}_m^2 \delta_{mk} \delta_{m\ell}$$

$$- \sum_{m=0}^{r} \Delta\tilde{v}_m^2 \delta_{mk} \left\langle \sum_{j=r+1}^{n} v_{j\ell} \frac{\partial b_i}{\partial \tilde{v}_m} \right\rangle$$

$$- \sum_{m=0}^{r} \Delta\tilde{v}_m^2 \delta_{m\ell} \left\langle \sum_{i=r+1}^{n} v_{ik} \frac{\partial b_i}{\partial \tilde{v}_m} \right\rangle$$

$$+ \sum_{i=r+1}^{n} \sum_{j=r+1}^{n} v_{ik} v_{j\ell} \left\langle \sum_{m=0}^{r} \Delta\tilde{v}_m^2 \frac{\partial b_i}{\partial \tilde{v}_m} \frac{\partial b_j}{\partial \tilde{v}_m} \right\rangle ,$$

5-33
$$\sigma_{b_k b_\ell}^2 = \sum_{i=r+1}^{n} \sum_{j=r+1}^{n} v_{ik} v_{j\ell} \tilde{\varepsilon}_{ij} + \Delta\tilde{v}_k^2 \delta_{k\ell}$$

$$- \Delta\tilde{v}_k^2 \sum_{j=r+1}^{n} \sum_{i=r+1}^{n} v_{j\ell} \varepsilon_{ji} \mu_{ik} - \Delta\tilde{v}_\ell^2 \sum_{i=r+1}^{n} \sum_{j=r+1}^{n} v_{ik} \varepsilon_{ij} \mu_{j\ell} \cdot$$

$$k, \ell = 0, r$$

We now calculate $\sigma_{b_k b_\ell}^2$ for $k=0,r$ and $\ell=r+1,n$, and by symmetry, for $k=r+1,n$ and $\ell=0,r$.

5-34
$$\sigma_{b_k b_\ell}^2 = \sum_{d=1}^{N} \sigma_d^2 \frac{\partial b_\ell}{\partial y_d} \left[- \sum_{i=r+1}^{n} v_{ik} \frac{\partial b_i}{\partial y_d} \right]$$

$$+ \sum_{m=0}^{r} \Delta\tilde{v}_m \frac{\partial b_\ell}{\partial \tilde{v}_m} \left[\delta_{mk} - \sum_{i=r+1}^{n} v_{ik} \frac{\partial b_i}{\partial y_d} \right] \qquad \begin{matrix} k=0,r \\ \ell=r+1,n \end{matrix},$$

$$= - \sum_{i=r+1}^{n} v_{ik} \left[\sum_{d=1}^{N} \sigma_d^2 \frac{\partial b_\ell}{\partial y_d} \frac{\partial b_i}{\partial y_d} \right] + \sum_{m=0}^{r} \Delta\tilde{v}_m^2 \delta_{mk} \frac{\partial b_\ell}{\partial \tilde{v}_m}$$

$$- \sum_{i=r+1}^{n} v_{ik} \left[\sum_{m=0}^{r} \Delta\tilde{v}_m^2 \frac{\partial b_\ell}{\partial \tilde{v}_m} \frac{\partial b_i}{\partial y_d} \right],$$

5-35
$$\sigma_{b_k b_\ell}^2 = - \sum_{i=r+1}^{n} v_{ik} \tilde{\varepsilon}_{i\ell} + \Delta\tilde{v}_k^2 \sum_{j=r+1}^{n} \varepsilon_{\ell j} \mu_{jk} . \qquad \begin{matrix} k=0,r \\ \ell=r+1,n \end{matrix}$$

6 Transition Matrix Analysis

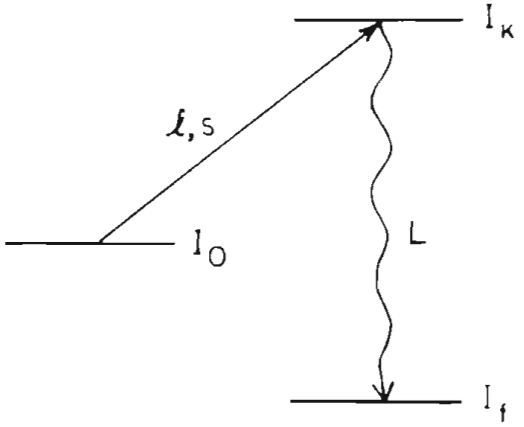
6.1 Introduction

Non-zero odd terms in the Legendre polynomial expansions of the angular distributions of cross section and analyzing power indicate the presence of non-E1 radiation. The Legendre coefficients do not, however, indicate the magnitude of the non-E1 radiation. We can reexpress the Legendre coefficients in terms of the transition matrix elements described by Seyler and Weller (1979). The transition matrix elements will be written in the j-j coupling scheme (Hayward, 1970). The incident particle with spin $\vec{s}$ and orbital angular momentum $\vec{\ell}$ is captured by a nucleus with spin $\vec{I}_0$. The angular momenta $\vec{\ell}$ and $\vec{s}$ couple to form $\vec{j}$ and then $\vec{j}$ and $\vec{I}_0$ couple to form the spin of the excited state, $\vec{I}_k$. The excited state decays to the final state, with spin $\vec{I}_f$, by the emission of a γ ray of multipolarity L. The angular momenta must obey the triangle selection rule

$$6\text{-}1 \qquad | I_k - I_f | \leq L \leq I_k + I_f \ .$$

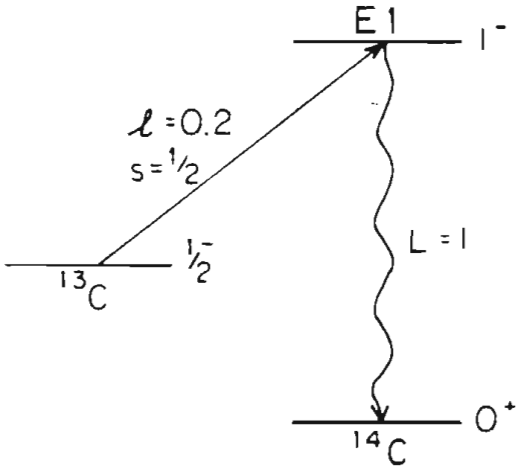
A schematic diagram of the allowed E1, E2, and M1 transition matrix elements for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction is shown in Figure 6-1. The transition matrix elements associated with a given multipolarity γ ray can be denoted by the the incident neutron's orbital and total angular momenta. Each matrix element is complex and can be written as a real amplitude and phase. Equations 6-2, 6-3, and 6-4 in the following sections give the relationships between the Legendre coefficients and

Figure 6-1 Schematic representation of radiative capture in the j-j coupling scheme and the E1, E2, and M1 transition j-j coupling schemes for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction.



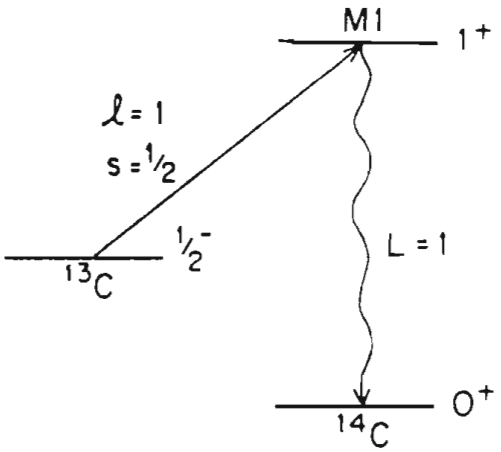
$\vec{\ell} + \vec{s} = \vec{j}$

$\vec{j} + \vec{I}_0 = \vec{I}_K$



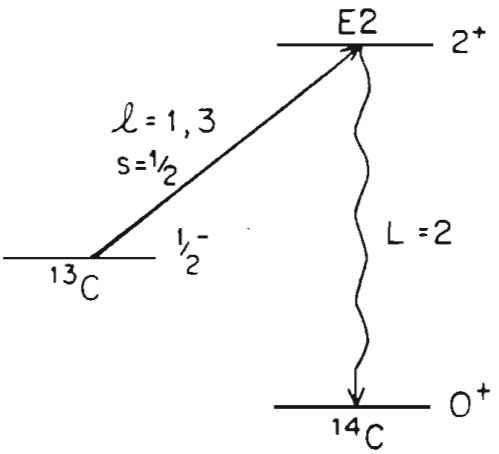
$\ell = 0, j = 1/2$: $s_{1/2}$

$\ell = 2, j = 3/2$: $d_{3/2}$



$\ell = 1, j = 1/2$: $p_{1/2}$

$\ell = 1, j = 3/2$: $p_{3/2}$



$\ell = 1, j = 3/2$: $p_{3/2}$

$\ell = 3, j = 5/2$: $f_{5/2}$

the transition matrix elements.

Two methods can be used to determine the transition matrix elements. The data can first be fit with Legendre polynomials, yielding the Legendre coefficients, and then the matrix elements can be calculated from the coefficients using the systems of equations given below. Problems can arise when the Legendre coefficients describe an unphysical distribution, for example, one where the cross section is negative at extreme angles. In addition, to fully describe the error in the original angular distribution it would be necessary to use the entire error matrix produced by the Legendre polynomial fitting procedure and not just the error on each of the coefficients separately. These problems can be avoided by fitting the transition matrix elements directly to the data using non-linear least squares. An initial guess for the values of the matrix elements is made, then Legendre coefficients are calculated from the matrix elements and used to generate an angular distribution which is compared to the observed distribution. The matrix elements are varied to produce the best fit, using chi-squared criteria, between the observed and calculated distributions. The errors in the transition matrix elements obtained with this procedure are directly related to the errors in the data.

As was discussed in chapter 4, the Legendre coefficients determined from the fits to the angular distributions were constrained to be consistent with the independent measurements of fore-aft asymmetry and 90° analyzing power. Unfortunately, there is no easy way to include these constraints when fitting the matrix elements directly to the data.

Therefore for the non-E1 analysis reported in the following sections, the values for the amplitudes and phases were taken from the fits to the coefficients while the errors on the amplitudes and phases were taken from the fits to the data. In all cases, except 13 MeV, the difference in the values for the matrix elements generated by the two methods was less than 1/2 of the corresponding error bar. It was essential to fit the matrix elements for the 13 MeV data to the constrained coefficients because the angular distribution of analyzing power at that energy contained only two data points.

6.2 E1 Analysis

For E1 radiation resulting from the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction, there are two complex valued transition matrix elements, $s_{1/2} \exp[\, i\, \varphi_{s_{1/2}}\,]$ and $d_{3/2} \exp[\, i\, \varphi_{d_{3/2}}\,]$. The two amplitudes and their relative phase, $\varphi_{d_{3/2}} - \varphi_{s_{1/2}}$, can be determined from the angular distribution of cross section and analyzing power by

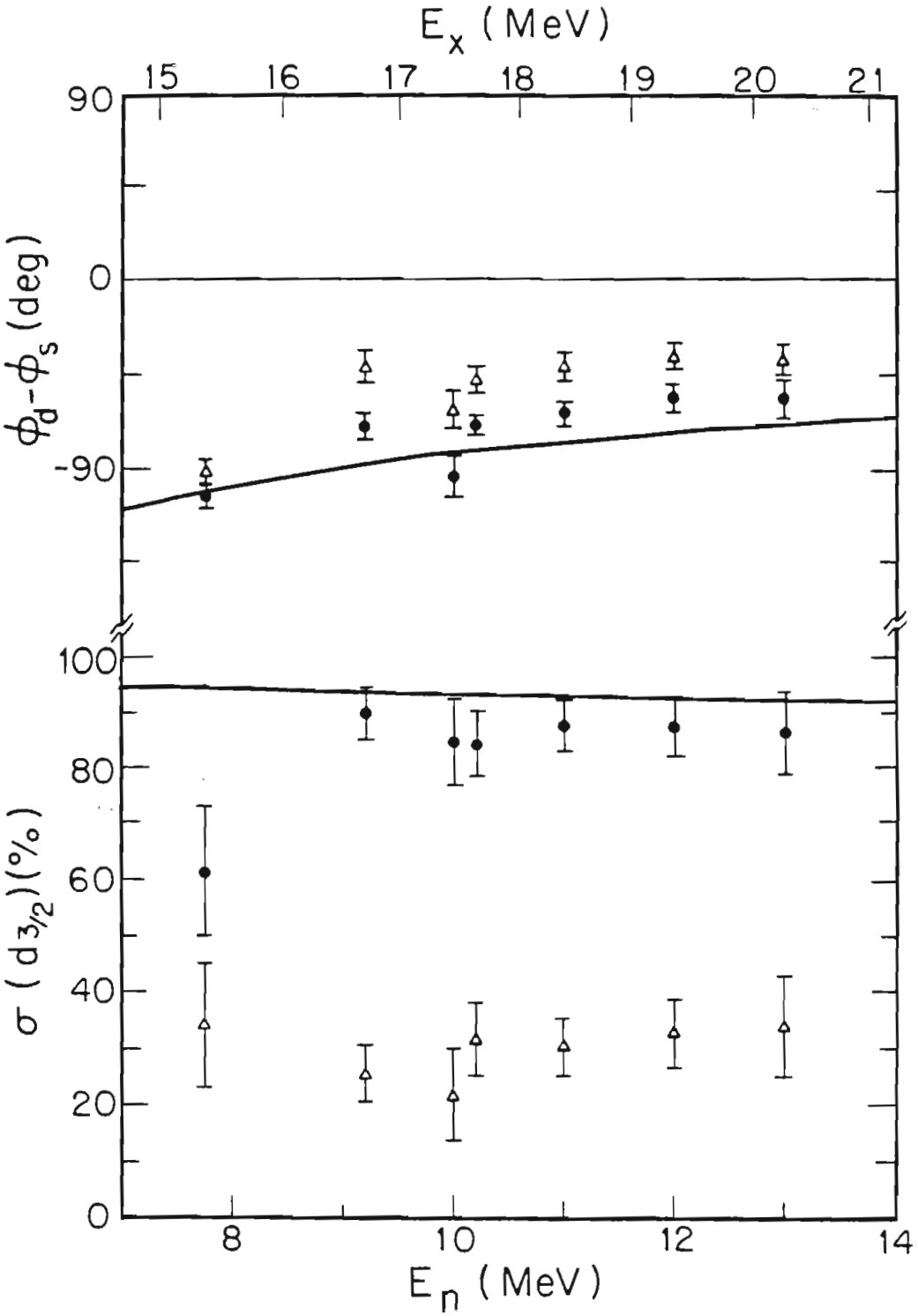
$$6\text{-}2 \qquad a_0 = s_{1/2}^2 + 2\, d_{3/2}^2$$

$$a_2 = -2\, s_{1/2}\, d_{3/2} \cos[\, \varphi_{d_{3/2}} - \varphi_{s_{1/2}}\,] - d_{3/2}^2$$

$$b_2 = -\, s_{1/2}\, d_{3/2} \sin[\, \varphi_{d_{3/2}} - \varphi_{s_{1/2}}\,] .$$

The quadratic nature of the above equations results in two solutions. One solution has a dominant $s_{1/2}$ matrix element and the other has a dominant $d_{3/2}$ matrix element. The two solutions are presented in Table C-1 and Figure 6-2. The curves in Figure 6-2 are the result of

Figure 6-2 E1 solutions for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. The quadratic nature of the E1 equations resulted in two solutions for each energy. The $d_{3/2}$ cross section and relative phase are plotted for the two solutions. The solid lines are the result of a direct-semidirect model calculation and indicate the physical solution.


E_x (MeV)
15
16
17
18
19
20
21
90
0
-90
100
80
60
40
20
0
φ_d-φ_s (deg)
σ (d3/2)(%)
8
10
12
14
E_n (MeV)

the direct-semidirect model calculation presented in the next chapter. The calculation clearly indicates that the dominant $d_{3/2}$ solution is the physical one. The remainder of the transition matrix analysis will be performed using only the dominant $d_{3/2}$ solution.

6.3 E1-E2 Analysis

The maximum order of the Legendre expansion needed to describe radiation of multipolarity L_{max} is $2 * L_{max}$. Quadrupole radiation can therefore give rise to non-zero values for Legendre coefficients up to a_4 and b_4. For this reaction, E2 radiation is due to two transition matrix elements, $p_{3/2} \exp[\, i \varphi_{p_{3/2}} \,]$ and $f_{5/2} \exp[\, i \varphi_{f_{5/2}} \,]$. The resulting angular distribution equations are given by

$$
\begin{aligned}
6\text{-}3 \qquad a_0 &= s_{1/2}^2 + 2\, d_{3/2}^2 + 2\, p_{3/2}^2 + 3\, f_{5/2}^2 \\
a_1 &= 3.464\; s_{1/2}\, p_{3/2} \cos[\, \varphi_{p_{3/2}} - \varphi_{s_{1/2}} \,] \\
&\quad + 0.6928\; d_{3/2}\, p_{3/2} \cos[\, \varphi_{p_{3/2}} - \varphi_{d_{3/2}} \,] \\
&\quad + 6.235\; d_{3/2}\, f_{5/2} \cos[\, \varphi_{f_{5/2}} - \varphi_{d_{3/2}} \,] \\
a_2 &= -\, d_{3/2}^2 + p_{3/2}^2 + 1.714\, f_{5/2}^2 \\
&\quad - 2\; s_{1/2}\, d_{3/2} \cos[\, \varphi_{d_{3/2}} - \varphi_{s_{1/2}} \,] \\
&\quad + 0.8571\; p_{3/2}\, f_{5/2} \cos[\, \varphi_{f_{5/2}} - \varphi_{p_{3/2}} \,]
\end{aligned}
$$

$$a_3 = -3.464\, s_{1/2}\, f_{5/2} \cos[\varphi_{f_{5/2}} - \varphi_{s_{1/2}}]$$
$$- 4.157\, d_{3/2}\, p_{3/2} \cos[\varphi_{p_{3/2}} - \varphi_{d_{3/2}}]$$
$$- 2.771\, d_{3/2}\, f_{5/2} \cos[\varphi_{f_{5/2}} - \varphi_{d_{3/2}}]$$

$$a_4 = -1.714\, f_{5/2}^2$$
$$- 6.857\, p_{3/2}\, f_{5/2} \cos[\varphi_{f_{5/2}} - \varphi_{p_{3/2}}]$$

$$b_1 = -1.732\, s_{1/2}\, p_{3/2} \sin[\varphi_{p_{3/2}} - \varphi_{s_{1/2}}]$$
$$- 1.386\, d_{3/2}\, p_{3/2} \sin[\varphi_{p_{3/2}} - \varphi_{d_{3/2}}]$$
$$+ 3.118\, d_{3/2}\, f_{5/2} \sin[\varphi_{f_{5/2}} - \varphi_{d_{3/2}}]$$

$$b_2 = - s_{1/2}\, d_{3/2} \sin[\varphi_{d_{3/2}} - \varphi_{s_{1/2}}]$$
$$+ 0.7143\, p_{3/2}\, f_{5/2} \sin[\varphi_{f_{5/2}} - \varphi_{p_{3/2}}]$$

$$b_3 = -1.155\, s_{1/2}\, f_{5/2} \sin[\varphi_{f_{5/2}} - \varphi_{s_{1/2}}]$$
$$+ 1.386\, d_{3/2}\, p_{3/2} \sin[\varphi_{p_{3/2}} - \varphi_{d_{3/2}}]$$
$$- 0.2309\, d_{3/2}\, f_{5/2} \sin[\varphi_{f_{5/2}} - \varphi_{d_{3/2}}]$$

$$b_4 = -1.714\, p_{3/2}\, f_{5/2} \sin[\varphi_{f_{5/2}} - \varphi_{p_{3/2}}] .$$

The above system of equations represents 9 equations in 7 unknowns; 4 amplitudes and 3 relative phases. However, the experimental data were not of sufficient quantity and statistical accuracy to allow extraction of a_4 and b_4. This means we now have 7 equations in 7 unknowns. A solution can still be found but will not result in a value for

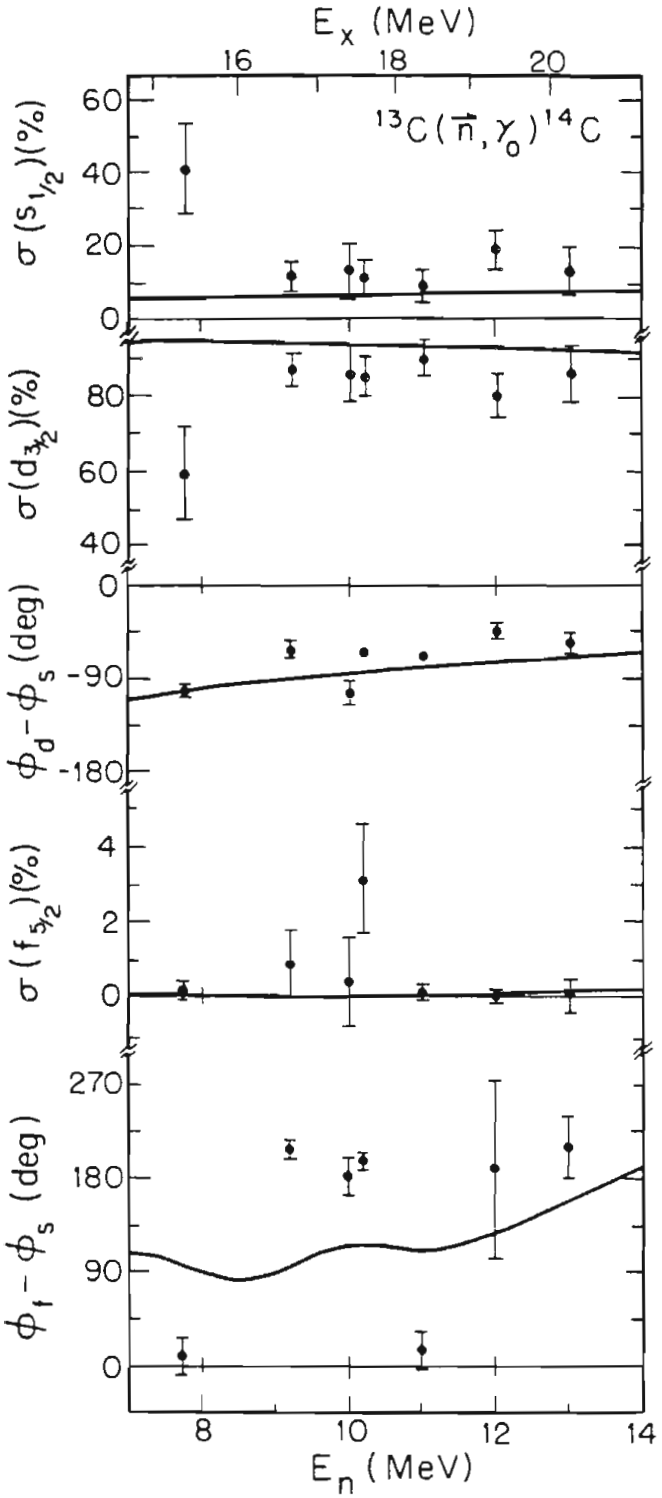
chi-square. It is desirable to drop one of the E2 matrix elements from the analysis so that we have 7 equations in 5 unknowns and can determine a chi-square. The DSD calculations, discussed in the next chapter, were used as a guide and indicated that the $p_{3/2}$ matrix element will be smaller than the $f_{5/2}$ element by at least a factor of 10 in the energy region being considered. The $p_{3/2}$ matrix element was set to zero and the analysis was performed using the $f_{5/2}$ element only.

The results are presented in Table C-2 and Figure 6-3. The $f_{5/2}$ amplitude is small and consistent with zero at 4 of the energies measured. The apparent E2 strength seen between 9.2 MeV and 10.2 MeV will be seen in the next chapter to be more likely due to M1 radiation than E2 radiation. The $f_{5/2}$ relative phases were not well determined from the analysis due to the small values for the $f_{5/2}$ amplitudes. The solid lines in Figure 6-3 are the result of an E1-E2 direct-semidirect model calculation using an E2 resonance whose parameters are typical for E2 resonances in this mass region (see Table D-1).

6.4 E1-E2-M1 Analysis

Structure in the a_1 and b_1 coefficients without corresponding structure in the a_3 and b_3 coefficients can arise from the presence of M1 radiation. For M1 radiation there exists two possible transition matrix elements, $p_{1/2} \exp[\, i\, \phi_{p_{1/2}}\,]$ and $p'_{3/2} \exp[\, i\, \phi_{p'_{3/2}}\,]$. The $p_{1/2}$ matrix element describes the transition between two wave functions which differ only in their principle quantum number. Since the M1 operator

Figure 6-3 E1-E2 solutions for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. Two E1 amplitudes, the $f_{5/2}$ E2 amplitude and two relative phases were fit. The solid lines are the result of a direct-semidirect model calculation.


E_x (MeV)
16
18
20
13C(n⃗, γ0)14C
σ(s1/2)(%)
60
40
20
0
σ(d3/2)(%)
80
60
40
0
φd − φs (deg)
-90
-180
σ(f5/2)(%)
4
2
0
φf − φs (deg)
270
180
90
0
8
10
12
14
En (MeV)

has no radial dependence, this matrix element is identically zero. The $f_{5/2}$ E2 matrix element will also be included in the analysis but the $p_{3/2}$ E2 element will not be used, as in the case of the E2 analysis. The angular distribution equations are

6-4
$$a_0 = s_{1/2}^2 + 2\, d_{3/2}^2 + 2\, p_{3/2}'^2 + 3\, f_{5/2}^2$$

$$a_1 = 2\, s_{1/2}\, p_{3/2}' \cos[\varphi_{p_{3/2}'} - \varphi_{s_{1/2}}] - 2\, d_{3/2}\, p_{3/2}' \cos[\varphi_{p_{3/2}'} - \varphi_{d_{3/2}}] + 6.235\, d_{3/2}\, f_{5/2} \cos[\varphi_{f_{5/2}} - \varphi_{d_{3/2}}]$$

$$a_2 = -\, d_{3/2}^2 - p_{3/2}'^2 + 1.714\, f_{5/2}^2 - 2\, s_{1/2}\, d_{3/2} \cos[\varphi_{d_{3/2}} - \varphi_{s_{1/2}}] - 3.464\, p_{3/2}'\, f_{5/2} \cos[\varphi_{p_{3/2}'} - \varphi_{f_{5/2}}]$$

$$a_3 = -\, 3.464\, s_{1/2}\, f_{5/2} \cos[\varphi_{f_{5/2}} - \varphi_{s_{1/2}}] - 2.771\, d_{3/2}\, f_{5/2} \cos[\varphi_{f_{5/2}} - \varphi_{d_{3/2}}]$$

$$a_4 = -\, 1.714\, f_{5/2}^2$$

$$b_1 = -\, s_{1/2}\, p_{3/2}' \sin[\varphi_{p_{3/2}'} - \varphi_{s_{1/2}}] + 4\, d_{3/2}\, p_{3/2}' \sin[\varphi_{p_{3/2}'} - \varphi_{d_{3/2}}] + 3.118\, d_{3/2}\, f_{5/2} \sin[\varphi_{f_{5/2}} - \varphi_{d_{3/2}}]$$

$$b_2 = - s_{1/2}\, d_{3/2} \sin[\varphi_{d_{3/2}} - \varphi_{s_{1/2}}]$$

$$+ 2.887\, p'_{3/2}\, f_{5/2} \sin[\varphi_{p'_{3/2}} - \varphi_{f_{5/2}}]$$

$$b_3 = - 1.155\, s_{1/2}\, f_{5/2} \sin[\varphi_{f_{5/2}} - \varphi_{s_{1/2}}]$$

$$- 0.2309\, d_{3/2}\, f_{5/2} \sin[\varphi_{f_{5/2}} - \varphi_{d_{3/2}}]$$

$$b_4 = 0 \quad .$$

The chi-square as a function of M1 and E2 cross section was calculated for each of the seven angular distributions. The value of $\sigma(p'_{3/2})$ was varied in 24 steps of varying size between 0% and 20% of the total cross section. The value of $\sigma(f_{5/2})$ was varied in 24 steps of varying size between 0% and 10% of the total. The two E1 amplitudes and the three relative phases were searched by the fitting code to produce the minimum chi-square at each of the 576 points of E2 and M1 cross section. Figure 6-4 and Figure 6-5 show, as examples, contour plots of reduced chi-square for the 10.2 and 12 MeV angular distributions. The contour interval is 0.25 chi-square in each plot. The 10.2 MeV plot shows a broad valley of low chi-square in the region of one percent E2 and from one to over twenty percent M1 cross section. The surface rises quickly for E2 cross sections above two percent. The 12 MeV plot shows a valley of from zero to two percent E2 and zero to six percent M1 and another with less than one percent E2 and zero to over twenty percent M1 cross section. The 12 MeV chi-square surface is clearly very shallow and serves mainly to indicate that the E2 cross section is less than five percent of the total.

Figure 6-4 Contours of reduced chi-square as a function of M1 and E2 cross section for the E_n = 10.2 MeV polarized angular distribution. The two E1 amplitudes and the three relative phases were searched to yield the minimum chi-square while the M1 and E2 cross section were held constant.

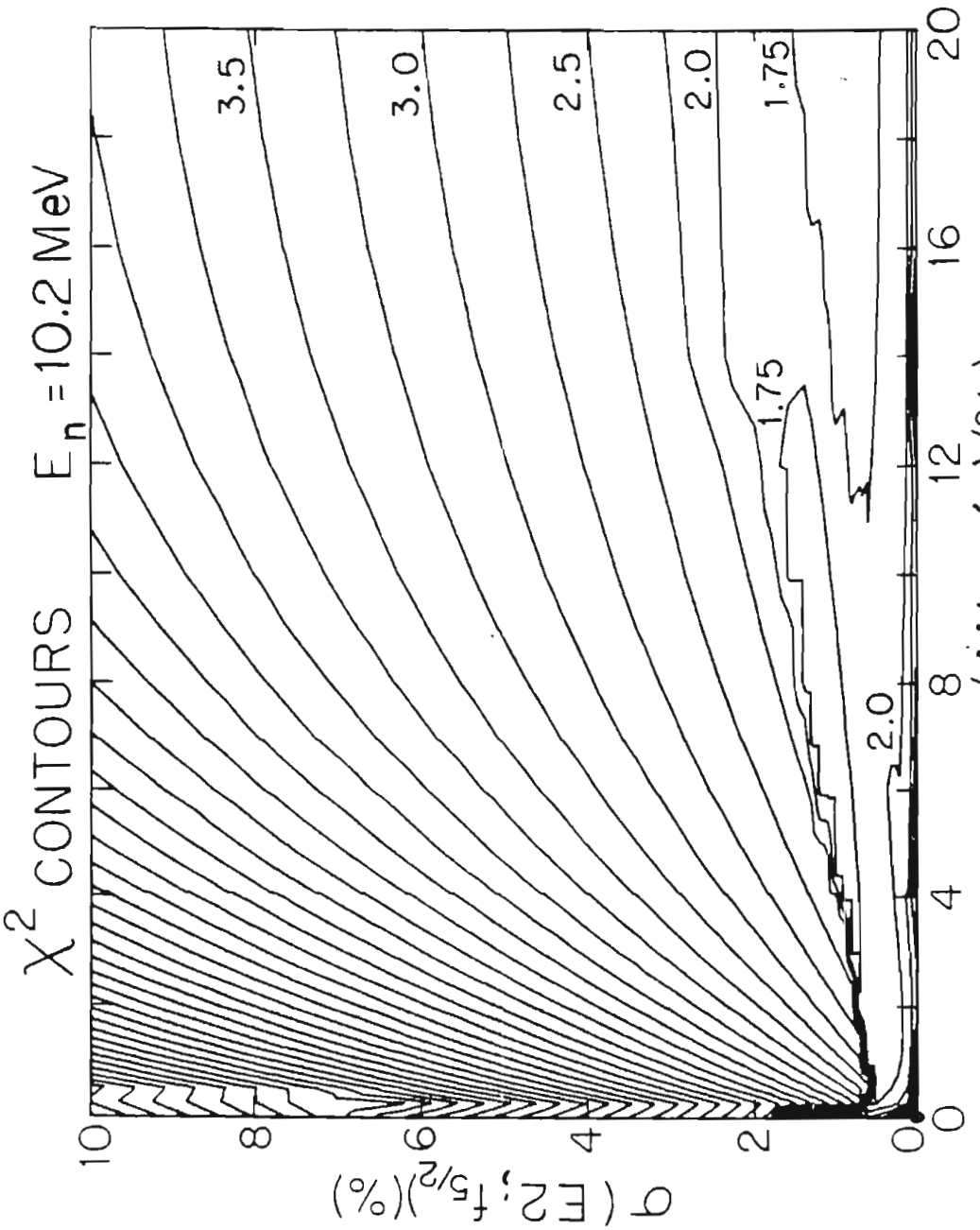
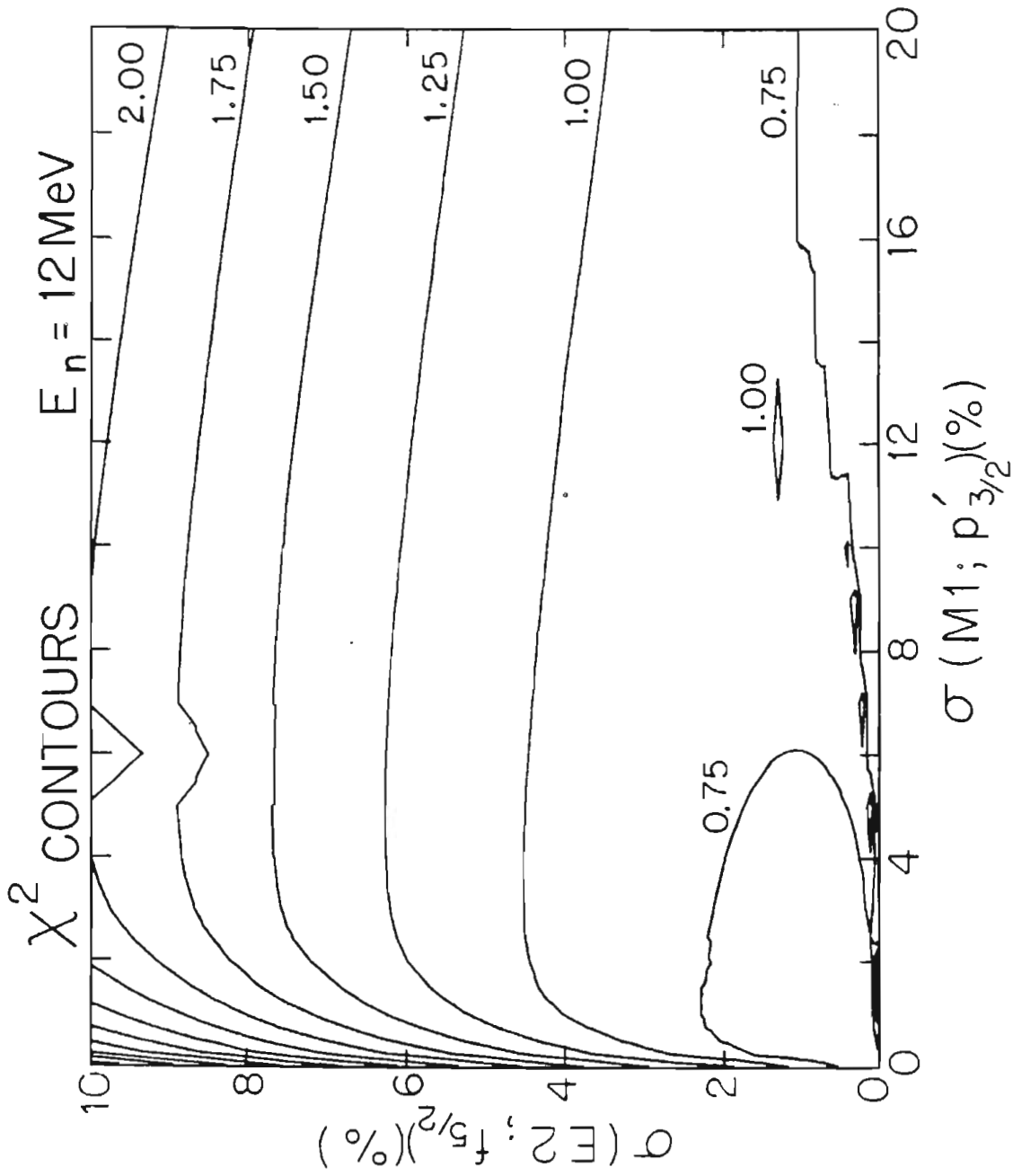

χ^2 CONTOURS
E_n = 10.2 MeV
3.5
3.0
2.5
2.0
1.75
1.75
2.0
$q\,(E2;f_{5/2})(\%)$
$\sigma\,(M1;p'_{3/2})(\%)$
0
2
4
6
8
10
0
4
8
12
16
20

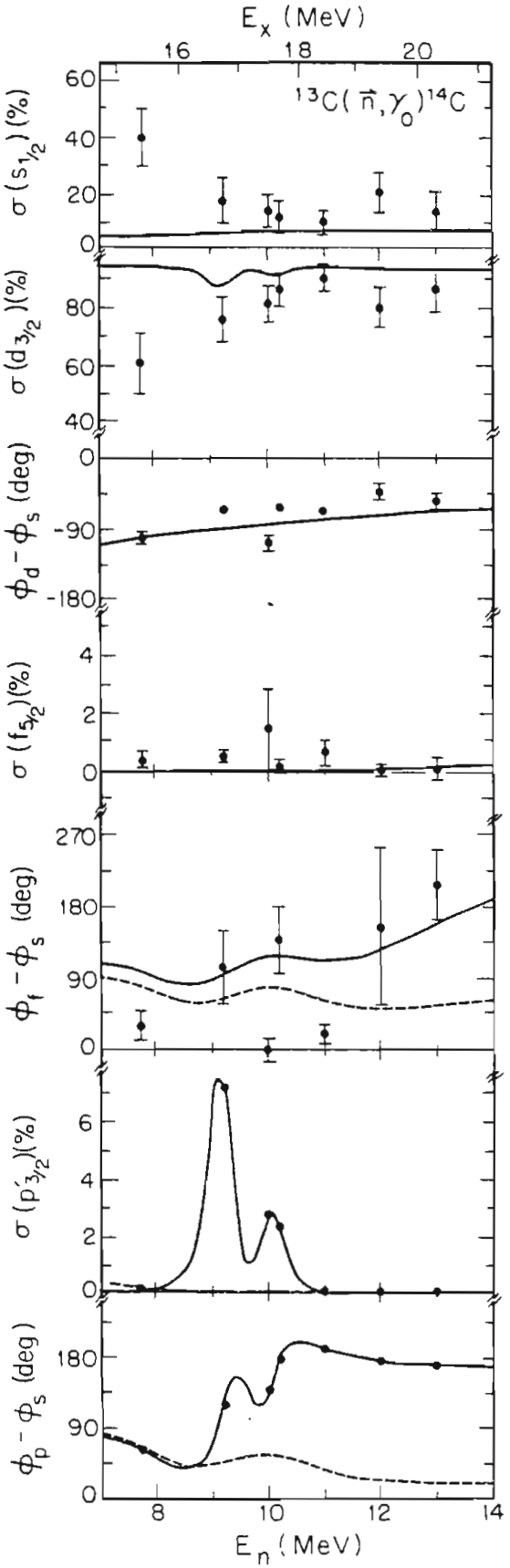
Figure 6-5 Same as Figure 6-4 for E_n = 12 MeV.


χ^2 CONTOURS
E_n = 12 MeV
2.00
1.75
1.50
1.25
1.00
0.75
1.00
0.75
$q\,(E2\,;\,f_{5/2})(\%)$
$\sigma\,(M1\,;\,p'_{3/2})(\%)$
0
2
4
6
8
10
0
4
8
12
16
20

The behavior of the chi-square surfaces show that it will not be possible to extract a unique value for the M1 cross section from the data since the data are consistent with almost any value for the M1 cross section. The DSD calculations of the next chapter were therefore used to calculate the $p'_{3/2}$ transition matrix element, and thus the M1 cross section, as a function of energy. At each energy, the complex M1 transition matrix element was fixed at the calculated value and the E2 and E1 matrix elements were determined by the fitting code. The results are presented in Table C-3 and Figure 6-6.

The large E2 amplitude seen at E_n = 10.2 MeV in the calculation of the previous section is now essentially zero. The E2 cross section is less than one percent at all energies except 10.0 MeV where the value has a large error bar. The $f_{5/2}$ relative phases are still not well determined from the data. The solid lines in Figure 6-6 are the result of an E1-E2 direct-semidirect model calculation using an E2 resonance whose parameters are typical for E2 resonances in this mass region (see Table D-1). The dashed lines on the same plots result from inclusion of direct E2 only. The solid lines for the $\sigma(p'_{3/2})$ and $(\varphi_{p'_{3/2}} - \varphi_{s_{1/2}})$ plots are the result of the DSD calculation and are the values used in the fitting procedure. The dashed lines represent the $p'_{3/2}$ matrix element resulting from direct M1 only. In conclusion, the data are consistent with zero to twenty percent M1 and with one or two percent E2.

Figure 6-6 E1-E2-M1 solutions for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. Two E1 amplitudes, the $f_{5/2}$ E2 amplitude and the two relative phases were fit. The $p'_{3/2}$ M1 complex matrix element was held constant to the value determined at each energy by the direct-semidirect model calculation of Chapter 7 including two M1 resonances. The solid lines are the result of the DSD calculation; the dashed lines are the result of a DSD calculation including only direct E2 and M1.


E_x (MeV)
16
18
20
13C(n, γ0)14C
σ (s1/2) (%)
σ (d3/2) (%)
φd - φs (deg)
σ (f5/2) (%)
φf - φs (deg)
σ (p'3/2) (%)
φp - φs (deg)
E_n (MeV)

7 Comparison to Theory

7.1 Sum Rules

The sum rules are a measure of the photonuclear absorptive strength (Hayward, 1970). For E1 absorption, the classical dipole sum rule is given by

$$7\text{-}1 \qquad \int \sigma_\gamma(E1)\, dE_\gamma = 60 \frac{N Z}{A} \text{ mb·MeV} .$$

For ^{14}C, the dipole absorptive strength is 206 mb·MeV. For isoscalar E2 radiation, the strength is given by the isoscalar energy weighted sum rule (Gell-Mann and Telegdi, 1953)

$$7\text{-}2 \qquad \int \frac{\sigma_\gamma(E2)}{E_\gamma^2} = \frac{\pi^2}{137} \frac{A}{12} \frac{\langle r_0^2 \rangle}{938} \text{ fm}^2/\text{MeV} .$$

Using the value $\langle r_0^2 \rangle = 6.66$ fm^2 for the nuclear radius determined from electron scattering (deJager et al., 1974), the E2 absorptive strength for ^{14}C is $5.97\ 10^{-4}$ fm^2/MeV = 5.97 μb/MeV. The fraction of the sum rule strengths measured in the (γ,n_0) channel was calculated by separating the detail balance (γ,n_0) total cross section of Table A-5 into an E1 and an E2 component according to the results of the transition matrix analysis of Table C-3 and integrating using a weighted histogram rule. The E1 integral yielded a result of 29.1 ± 0.2 mb·MeV and therefore the (γ,n_0) channel exhausted 14.1 ± 0.1 % of the classical dipole sum. The E2 integral gave a result of 0.17 ± 0.03 μb/MeV exhausting 2.8 ± 0.6 % of the isoscalar E2 energy weighted sum.

7.2 Direct-Semidirect Model

The direct-semidirect model code HIKARI (Kitazawa, 1980) was used to fit the $^{13}C(\vec{n},\gamma_0)^{14}C$ experimental data. The continuum wave functions for the unbound neutron were calculated with the optical model using the parameter set of Watson et al. (1969). This set uses an energy dependent real well potential and an imaginary surface potential. The spin orbit potential strength and the radius and diffuseness parameters are not functions of energy. The bound state wave functions were calculated using a Wood-Saxon well whose depth was modified until the binding energy of the neutron was correct. The radius and diffuseness parameters and the spin orbit well depth were the same as the Watson real well potential parameters. The spectroscopic factor was taken from Cohen and Kurath (1967). The recoil effective charges were calculated using Equation 1-1. The parameters used in the DSD model calculations are presented in Table D-1.

Two E1 resonances were included in the calculation of the 90^{o} cross section, and the positions, widths, and strengths of these resonances were varied to produce the best fit to the data. The fine structure is, of course, not reproduced by the calculation. The deviation of the fit from the data at lower energies is assumed to be due to compound nuclear effects not included in the DSD model.

In order to fit the odd terms in the Legendre expansions of cross sections and analyzing power, an isoscalar E2 resonance was included in

the calculation using parameters typical for E2 resonances in this mass region (Weller and Roberson, 1980). Included in the DSD calculation was a convolution integral to account for the energy spread of the incident neutron beam (see Figure 2-3). The results of the calculation of the angular distributions are shown in Figure 7-1 while the 90° cross section calculation is shown in Figure 3-6. The E2 cross section was small enough compared to the E1 cross section that the E2 resonance had no effect on the appearance of the cross section curve in Figure 3-6 or the a_2 and b_2 curves in Figure 7-1. The calculation is in general agreement with the data for the odd Legendre coefficients except for b_1 in the region of 17 MeV excitation energy. The structure seen below E_x = 18 MeV in the calculated curves is the result of direct M1 and E2 capture. In the region above E_x = 18 MeV where the effect of the E2 resonance becomes more significant, we see a disagreement between the calculation and the fore-aft asymmetry and 90° analyzing power data. The transition matrix elements resulting from the calculation can be compared with the transition matrix analysis of the preceeding chapter (see Figure 6-3 and Figure 6-6). The data show little evidence for the existence of E2 radiation in the (γ,n_0) channel.

The structure seen in b_1 and $A_y(90^{\circ})$ can arise from the presence of M1 radiation. The results of a DSD calculation including two narrow M1 resonances at E_x = 16.7 and 17.5 MeV are presented in Figure 7-2 and Figure 7-3. The widths used for both resonances in the calculation were 200 keV. The calculated curves also have the approximately 300 keV energy spread of the incident neutron beam folded into them. The

Figure 7-1 Legendre expansion coefficients, fore-aft asymmetry, and 90° analyzing power for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. The solid lines are the result of a direct-semidirect calculation including an isoscalar E2 resonance whose parameters are typical for this mass region.

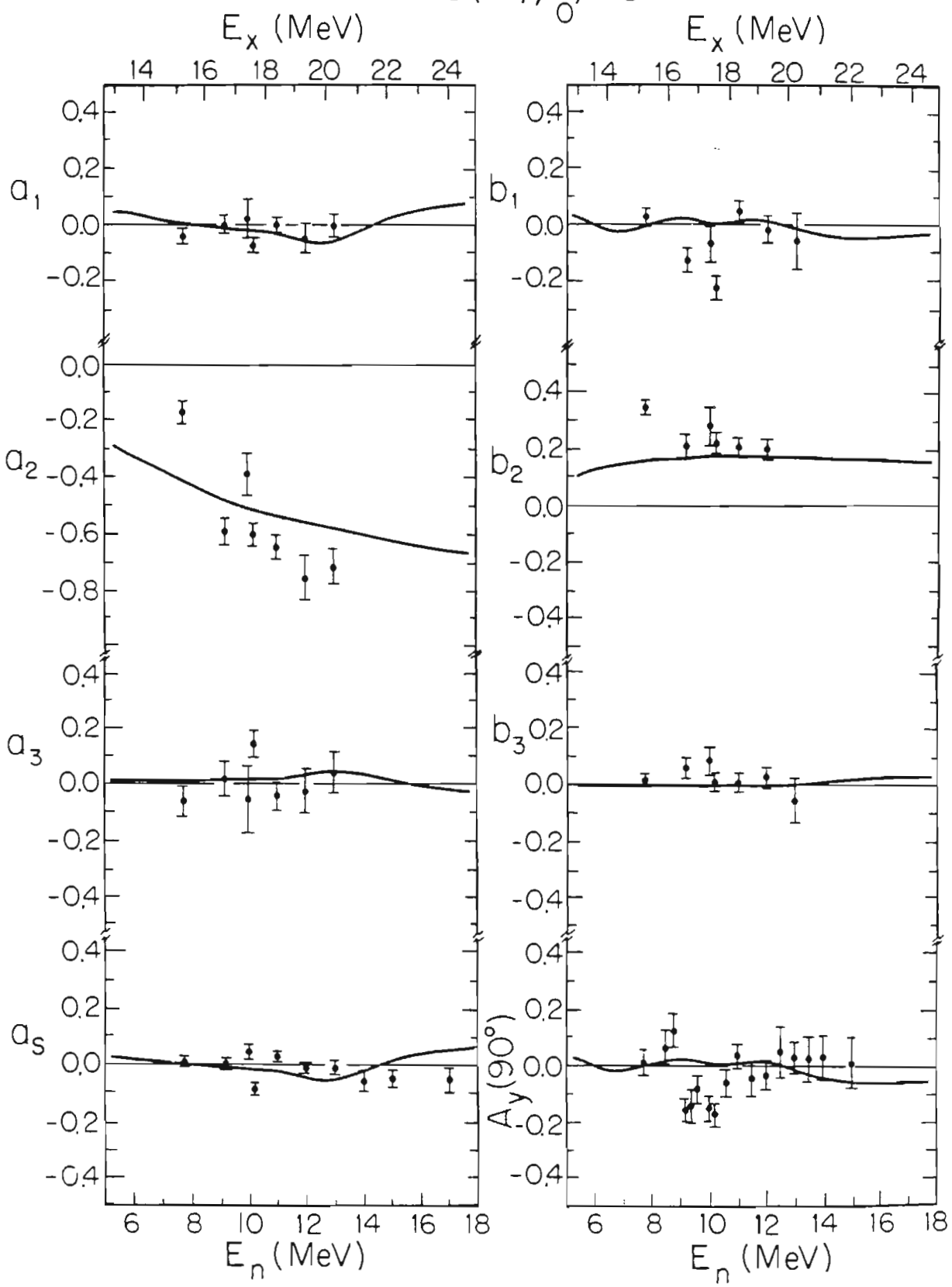

$^{13}C(n,\gamma_0)^{14}C$
E_x (MeV)
14 16 18 20 22 24
a_1
a_2
a_3
a_s
b_1
b_2
b_3
$A_y(90°)$
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
6 8 10 12 14 16 18
E_n (MeV)

Figure 7-2 Legendre expansion coefficients, fore-aft asymmetry, and 90° analyzing power for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. The solid lines are the result of a direct-semidirect calculation including two isovector M1 resonances whose parameters were optimized to fit the $A_y(90^{\circ})$ data.

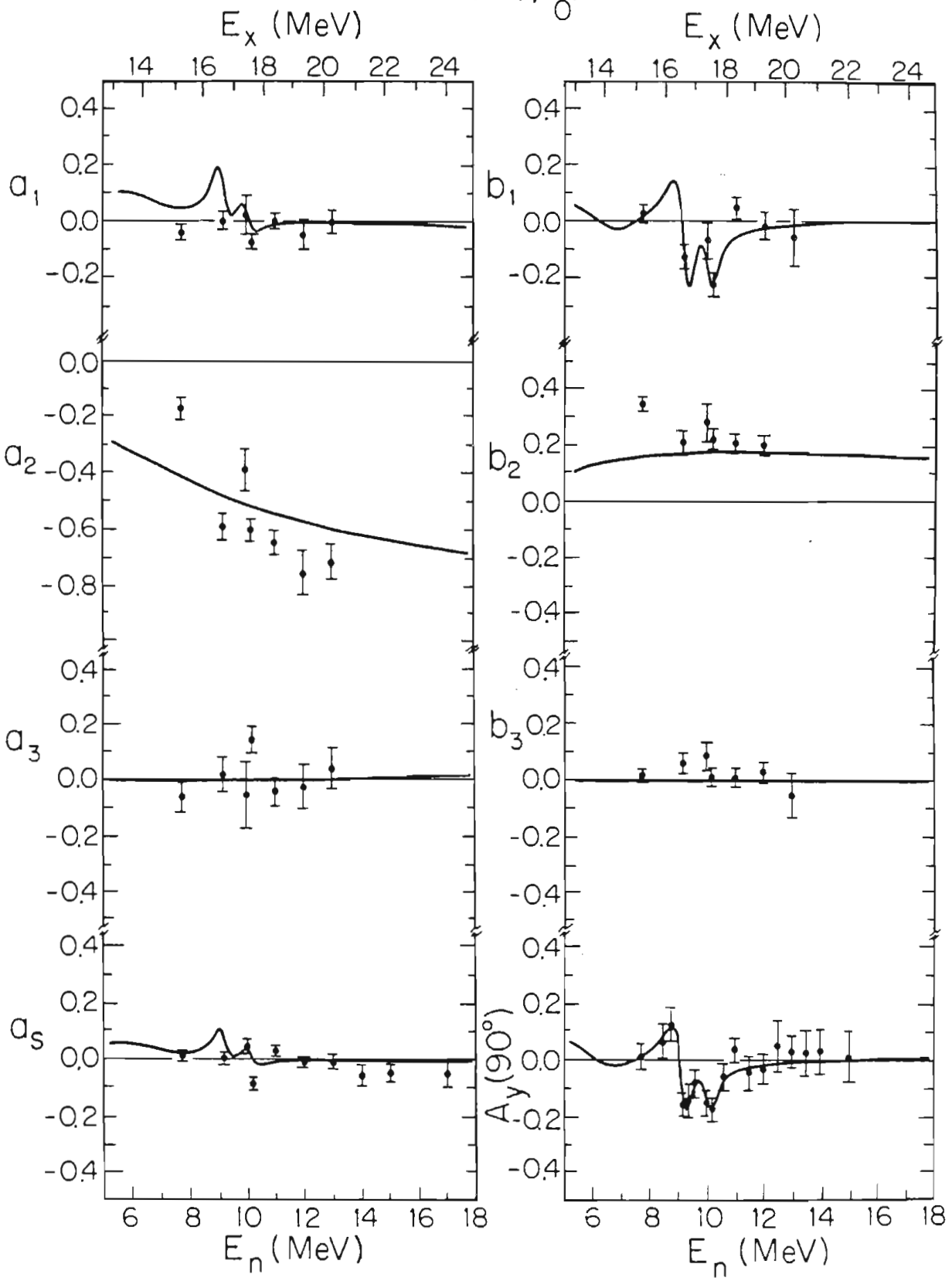
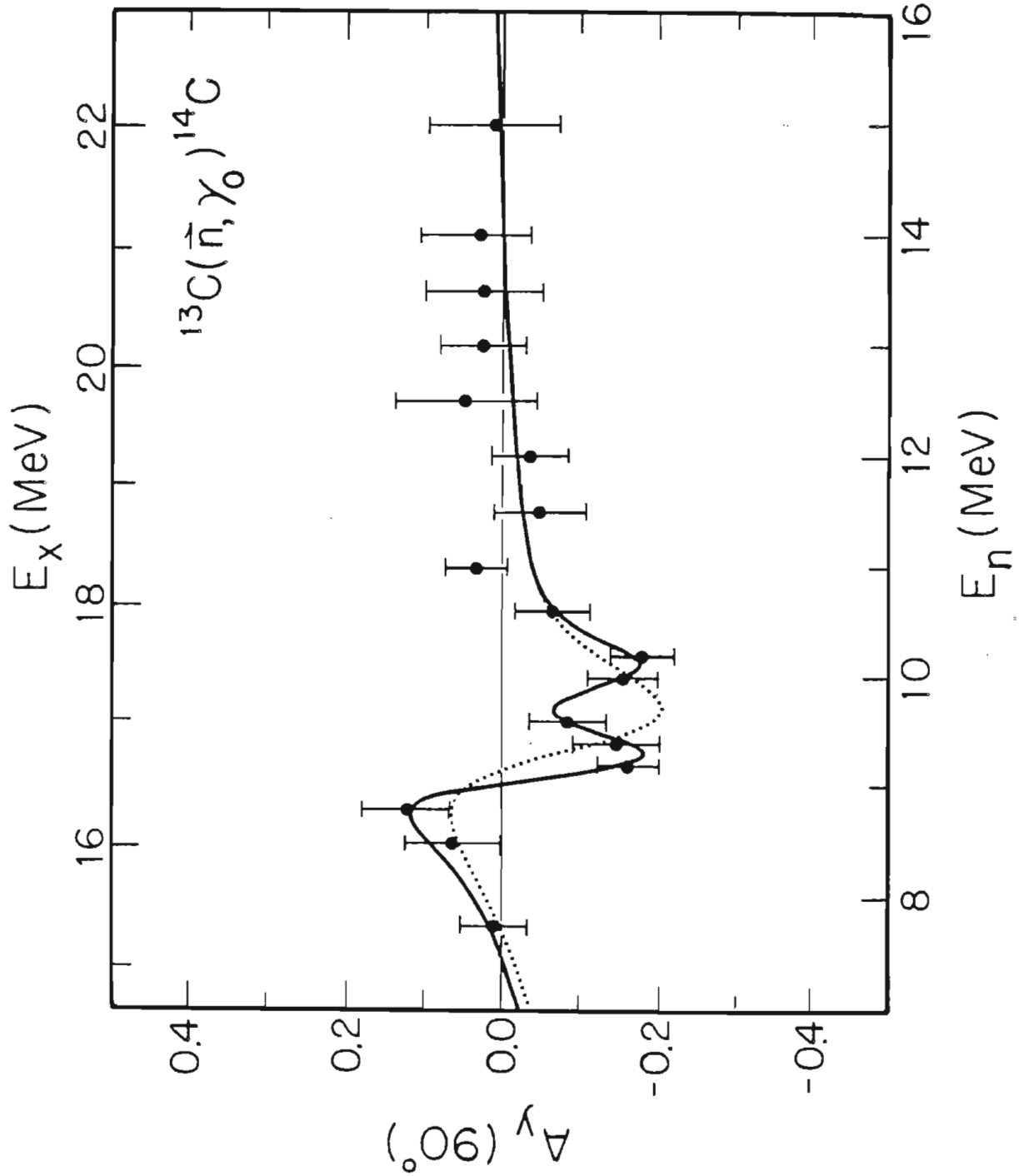

$^{13}C(n,\gamma_0)^{14}C$
E_x (MeV)
14 16 18 20 22 24
a_1
a_2
a_3
a_S
b_1
b_2
b_3
$A_y(90°)$
0.4 0.2 0.0 -0.2 -0.4 -0.6 -0.8
6 8 10 12 14 16 18
E_n (MeV)

Figure 7-3 The $A_y(90^\circ)$ data for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. The solid line is the result of a direct-semidirect calculation including two isovector M1 resonances. The dotted line is the result of a DSD calculation including only one isovector M1 resonance.


$^{13}C(\vec{n},\gamma_0)^{14}C$
E_x (MeV)
E_n (MeV)
A_y (90°)
16
18
20
22
8
10
12
14
0.4
0.2
0.0
-0.2
-04

resonance parameters were optimized to fit the $A_y(90^o)$ data, and the agreement between the $A_y(90^o)$ data and the calculation is excellent throughout the energy region measured. The qualitative features of the fore-aft asymmetry data are also reproduced. As in the case of the E2 calculation, the M1 cross section was small enough that no effect was seen in the 90^o cross section or the a_2 and b_2 coefficients. The M1 strengths determined from the fits were 0.24 μ_0^2 for the 16.7 MeV resonance and 0.17 μ_0^2 for the 17.5 MeV resonance.

Similar M1 resonances have been seen by Snover *et al.* (1979) in $^{15}N(p,\gamma_0)^{16}O$ at 16.22, 17.14, and 18.8 MeV excitation energy with widths of 18, 36, and ~250 keV, respectively. The total M1 strength in ^{16}O was ~0.24 μ_0^2, which is similar in magnitude to the value of ~0.41 μ_0^2 seen in ^{14}C in this work. The values of B(M1) reported here for ^{14}C should be considered as only approximate values since the M1 states may have large single particle components and thus are not strictly described by the DSD model. The dotted curve in Figure 7-3 represents a DSD calculation including only one M1 resonance at E_x = 17.0 MeV with a width of 800 keV and a strength B(M1) = 0.50 μ_0^2. The calculation does not describe the data nearly as well as the calculation involving 2 M1 resonances.

The large energy spread of the incident neutron beam limits the number of points of 90^o analyzing power that can be measured. Conclusive results await the availability of a higher flux polarized deuteron beam allowing a lower pressure in the deuterium gas cell and therefore a smaller neutron energy spread.

7.3 Two-Level Doorway State Calculations

The DSD calculations do not reproduce the structure seen in a_2 and b_2 at E_n = 7.75 MeV. Another approach is to perform a two-level doorway state calculation (Calarco et al., 1977) to obtain the transition matrix elements as a function of energy, and from them calculate the Legendre coefficients A_0, a_2, and b_2. For a given neutron channel ℓ,j, the transition matrix element $T_{\ell,j}$ can be written as

$$T_{\ell,j} = \frac{\left[\left\langle g_A^{\ell,j} g_A^{\gamma}\left[E-E_A+i\frac{\Gamma_A}{2}\right] + g_A^{\ell,j} g_B^{\gamma} V_{AB}\right\rangle\right] e^{i\varphi_A^{\ell}}}{\left[E-E_A+i\frac{\Gamma_A}{2}\right]\left[E-E_B+i\frac{\Gamma_B}{2}\right]-|V|^2} + \frac{\left[\left\langle g_B^{\ell,j} g_B^{\gamma}\left[E-E_B+i\frac{\Gamma_B}{2}\right] + g_B^{\ell,j} g_A^{\gamma} V_{BA}\right\rangle\right] e^{i\varphi_B^{\ell}}}{\left[E-E_A+i\frac{\Gamma_A}{2}\right]\left[E-E_B+i\frac{\Gamma_B}{2}\right]-|V|^2} \qquad 7\text{-}3$$

where $g^{\ell,j}$ and g^{γ} are the square roots of the particle and γ decay widths, and φ^{ℓ} is the phase, of partial wave ℓ, and where V is the interaction strength between the levels A and B. The energies and widths for the two E1 resonances were taken from the DSD calculations of the preceeding section (see Table D-1). The values for $g^{\ell,j}$ and φ^{ℓ} were taken from the $s_{1/2}$ and $d_{3/2}$ amplitudes and phases extracted from the data at the energies corresponding to the peaks of the two E1 resonances (see Table C-1). The γ decay widths, g^{γ}, and the interaction strength, V, were varied to produce the best fit to the data. Also included in the calculation was a noninterfering constant background of 0.89 μb. The results of the calculations are presented as the solid line in

Figure 7-4 The 90^{o} cross section, a_2 and b_2 Legendre coefficients, and $s_{1/2}$ and $d_{3/2}$ transition matrix elements for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. The solid lines are the result of a two-level doorway state calculation using parameters taken from the DSD calculations and the transition matrix element analysis. The dashed lines are the result of a two-level doorway state calculation where the transition matrix element parameters were varied to produce the best fit to the data. The dotted lines are the result of a direct-semidirect model calculation.

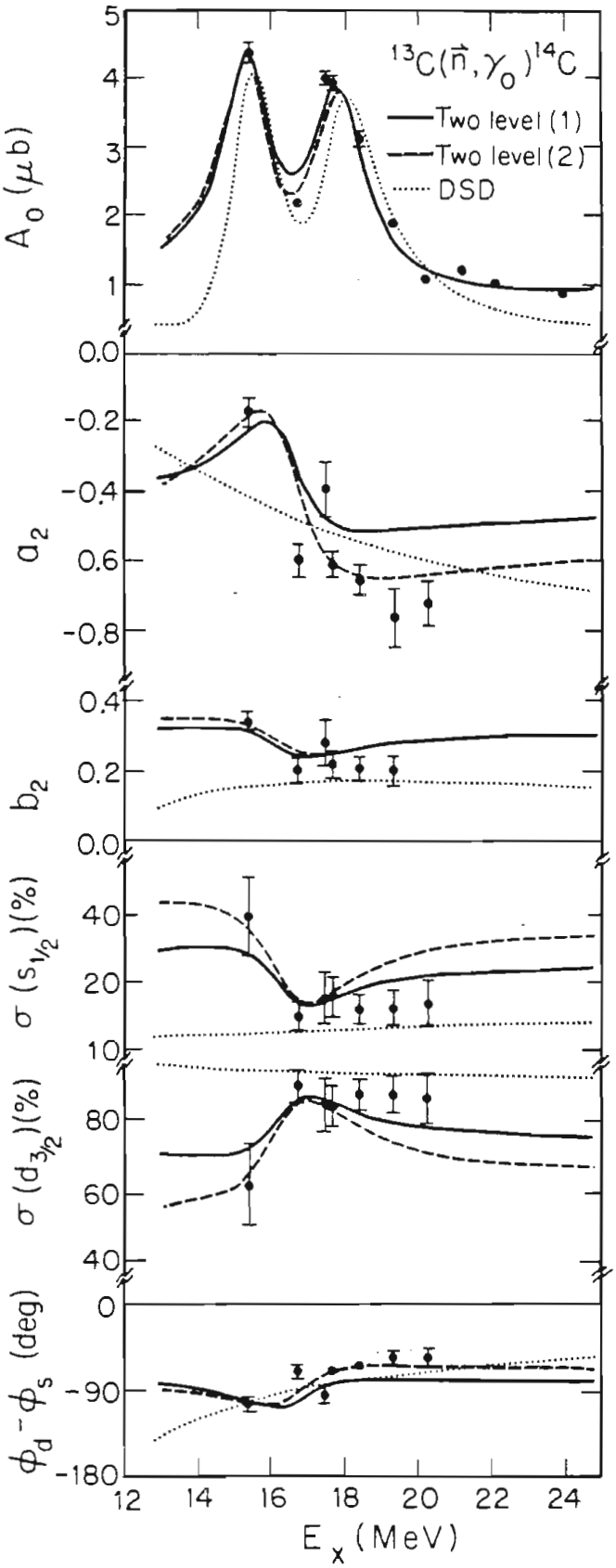

$^{13}C(\vec{n},\gamma_0)^{14}C$
Two level (1)
Two level (2)
DSD
A_0 (μb)
a_2
b_2
$\sigma(s_{1/2})$(%)
$\sigma(d_{3/2})$(%)
$\phi_d - \phi_s$ (deg)
E_x (MeV)

Figure 7-4 while the dotted line in the same figure represents the result of the DSD calculations of the preceeding section. The energy dependence of the data is well reproduced by the calculation. The angular distribution at E_n = 10.0 MeV suffered from large backgrounds at extreme angles so that the value for a_2 at 10.0 MeV should lie along side the values at neighboring energies. If the intrinsic values for the $s_{1/2}$ to $d_{3/2}$ ratio and phase of the two resonances are adjusted so that the two-level calculation gives the observed values at the peaks of the two resonances then the calculation gives better quantitative agreement for a_2 and b_2 throughout the energy region measured, as seen by the dashed line in Figure 7-4. The two-level calculation indicates that the parameterization of the giant dipole resonance as the two resonances used in the DSD calculations is a reasonable one.

If the interaction strength between two nearby levels of the same spin and parity is not zero then the cross section between the two resonances can have two minima and one maximum which is not itself a resonance (Lane and Thomas, 1958). This effect could be used to explain the small peak observed in the 90° cross section minimum at E_n = 9.2 MeV. The effect arises due to the interference of the two resonances with all other resonances on both sides. The lack of information about other possible resonances in this energy region makes calculations of the effect difficult. A calculation using a coherent background with a constant amplitude and phase did produce a small cross section bump between the two resonances but did not result in an acceptable overall fit to the data. The best fits to the data occurred

when the interaction strength V between the two resonances was set to zero.

7.4 Summary

The giant dipole resonance in ^{14}C was found to be split into two components at excitation energies of 15.45 and 17.85 MeV and with widths of 1.5 and 1.75 MeV, respectively. Two-level doorway state calculations agree well with the measured a_2 and b_2 coefficients and indicate that it is resonable to parameterize the giant dipole resonance as two different levels of the same spin and parity. After detail balance conversion to photoneutron cross section, the integrated E1 yield exhausted 14 % of the classical dipole sum rule in the (γ,n_0) channel in the region of 13.4 to 24 MeV excitation energy. A model independent E1 transition matrix analysis of the data yielded two solutions, one where the $d_{3/2}$ matrix element accounted for about 85 % of the E1 cross section, the other where the $d_{3/2}$ element accounted for about 30 % of the E1 cross section. Direct-semidirect model calculations indicate the dominant $d_{3/2}$ solution to be the physical one.

The E1-E2-M1 transition matrix element analysis showed that the E2 strength was less than 2 % of the total cross section and that the M1 strength could not be determined by examination of a single angular distribution. The observed E2 strength exhausts 2.8 ± 0.6 % of the isoscalar E2 energy weighted sum rule. The data show little evidence for collective E2 strength in the (γ,n_0) channel.

Structure in the 90^{o} analyzing power and in the Legendre coefficient b_1 near 9.2 and 10.2 MeV neutron energy suggests the existence of narrow M1 resonances at these energies. A direct-semidirect model calculation was in good overall agreement with all of the experimental data when it included two M1 resonances at excitation energies 16.7 and 17.5 MeV, with strengths 0.24 and 0.17 μ_0^2, and widths less than the 300 keV energy spread of the neutron beam.

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A Excitation Functions

Table A-1 The 90^{o} analyzing power of the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. The uncertainties represent one standard deviation of the statistical error.

E_n (MeV)	90^{o} analyzing power
7.75	0.009 ± 0.045
8.50	0.062 ± 0.062
8.80	0.120 ± 0.057
9.20	-0.161 ± 0.040
9.40	-0.146 ± 0.057
9.60	-0.085 ± 0.049
10.00	-0.154 ± 0.044
10.20	-0.178 ± 0.040
10.60	-0.065 ± 0.048
11.00	0.033 ± 0.041
11.50	-0.047 ± 0.059
12.00	-0.036 ± 0.051
12.50	0.046 ± 0.091
13.00	0.025 ± 0.056
13.50	0.023 ± 0.078
14.00	0.027 ± 0.078
15.00	0.008 ± 0.086

Table A-2 The fore-aft asymmetry of the $^{13}C(n,\gamma_0)^{14}C$ reaction. The uncertainties represent one standard deviation of the statistical error.

E_n (MeV)	Fore-aft asymmetry
7.75	0.003 ± 0.017
9.20	−0.006 ± 0.020
10.00	0.036 ± 0.024
10.20	−0.095 ± 0.017
11.00	0.020 ± 0.016
12.00	−0.017 ± 0.016
13.00	−0.015 ± 0.024
14.00	−0.063 ± 0.036
15.00	−0.055 ± 0.033
17.00	−0.059 ± 0.044

Table A-3 The 90^{o} cross section of the $^{13}C(n,\gamma_0)^{14}C$ reaction. The uncertainties represent one standard deviation of the statistical error.

E_n (MeV)	$\sigma(90^{o})$ (μb/sr)	E_n (MeV)	$\sigma(90^{o})$ (μb/sr)	E_n (MeV)	$\sigma(90^{o})$ (μb/sr)
5.60	4.33 ± 0.33	8.50	3.59 ± 0.14	11.50	3.44 ± 0.13
5.80	4.05 ± 0.27	8.60	3.11 ± 0.21	11.60	2.62 ± 0.19
6.00	3.85 ± 0.32	8.80	2.74 ± 0.10	11.80	2.51 ± 0.18
6.20	3.79 ± 0.30	9.00	2.06 ± 0.18	12.00	2.60 ± 0.07
6.40	3.84 ± 0.33	9.20	2.81 ± 0.08	12.20	2.37 ± 0.17
6.60	4.13 ± 0.30	9.40	2.64 ± 0.09	12.40	2.24 ± 0.16
6.80	4.37 ± 0.24	9.60	1.99 ± 0.06	12.50	1.55 ± 0.08
7.00	4.77 ± 0.21	9.80	3.17 ± 0.21	12.60	1.68 ± 0.16
7.20	4.96 ± 0.28	10.00	4.75 ± 0.14	12.80	1.65 ± 0.15
7.40	4.84 ± 0.17	10.20	5.12 ± 0.11	13.00	1.48 ± 0.05
7.60	4.83 ± 0.27	10.40	4.60 ± 0.24	13.50	1.62 ± 0.07
7.75	4.74 ± 0.15	10.60	4.07 ± 0.14	14.00	1.58 ± 0.05
7.80	4.99 ± 0.27	10.80	3.78 ± 0.22	15.00	1.36 ± 0.06
8.00	4.96 ± 0.26	11.00	4.12 ± 0.13	17.00	1.18 ± 0.08
8.20	4.55 ± 0.26	11.20	3.90 ± 0.22		
8.40	4.11 ± 0.24	11.40	3.25 ± 0.20		

Table A-4 The total cross section of the $^{13}C(n,\gamma_0)^{14}C$ reaction. The uncertainties represent one standard deviation of the statistical error.

E_n (MeV)	σ_{n,γ_0} (μb)	E_n (MeV)	σ_{n,γ_0} (μb)	E_n (MeV)	σ_{n,γ_0} (μb)
5.60	44.3 ± 3.4	8.50	39.0 ± 1.5	11.50	32.7 ± 1.2
5.80	41.6 ± 2.8	8.60	33.7 ± 2.3	11.60	24.9 ± 1.8
6.00	39.7 ± 3.3	8.80	29.3 ± 1.1	11.80	23.9 ± 1.7
6.20	39.2 ± 3.1	9.00	21.6 ± 1.9	12.00	24.7 ± 0.7
6.40	39.9 ± 3.4	9.20	28.9 ± 0.8	12.20	22.5 ± 1.6
6.60	43.1 ± 3.1	9.40	26.6 ± 0.9	12.40	21.3 ± 1.5
6.80	45.8 ± 2.5	9.60	19.7 ± 0.6	12.50	14.8 ± 0.8
7.00	50.3 ± 2.2	9.80	31.0 ± 2.1	12.60	16.0 ± 1.5
7.20	52.7 ± 3.0	10.00	46.0 ± 1.4	12.80	15.7 ± 1.4
7.40	51.8 ± 1.8	10.20	49.2 ± 1.1	13.00	14.1 ± 0.5
7.60	52.0 ± 2.9	10.40	44.0 ± 2.3	13.50	15.5 ± 0.7
7.75	51.3 ± 1.6	10.60	38.8 ± 1.3	14.00	15.1 ± 0.5
7.80	54.1 ± 2.9	10.80	36.0 ± 2.1	15.00	13.0 ± 0.6
8.00	54.1 ± 2.8	11.00	39.2 ± 1.2	17.00	11.3 ± 0.8
8.20	49.7 ± 2.8	11.20	37.1 ± 2.1		
8.40	44.8 ± 2.6	11.40	30.9 ± 1.9		

Table A-5 The total cross section of the $^{14}C(\gamma,n_0)^{13}C$ reaction from detail balance. The uncertainties represent one standard deviation of the statistical error.

E_n (MeV)	σ_{γ,n_0} (mb)	E_n (MeV)	σ_{γ,n_0} (mb)	E_n (MeV)	σ_{γ,n_0} (mb)
13.38	4.49 ± 0.34	16.07	4.17 ± 0.16	18.86	3.43 ± 0.13
13.56	4.25 ± 0.28	16.16	3.59 ± 0.24	18.95	2.61 ± 0.19
13.75	4.08 ± 0.34	16.35	3.12 ± 0.11	19.13	2.49 ± 0.18
13.93	4.06 ± 0.32	16.53	2.30 ± 0.20	19.32	2.58 ± 0.07
14.12	4.15 ± 0.36	16.72	3.08 ± 0.09	19.51	2.34 ± 0.17
14.31	4.50 ± 0.33	16.91	2.83 ± 0.10	19.69	2.21 ± 0.16
14.49	4.81 ± 0.26	17.09	2.10 ± 0.06	19.78	1.53 ± 0.08
14.68	5.30 ± 0.23	17.28	3.30 ± 0.22	19.88	1.65 ± 0.16
14.86	5.57 ± 0.31	17.46	4.89 ± 0.14	20.06	1.62 ± 0.15
15.05	5.48 ± 0.19	17.65	5.23 ± 0.11	20.25	1.45 ± 0.05
15.23	5.52 ± 0.31	17.83	4.67 ± 0.24	20.71	1.58 ± 0.07
15.37	5.45 ± 0.17	18.02	4.11 ± 0.14	21.18	1.53 ± 0.05
15.42	5.75 ± 0.31	18.21	3.80 ± 0.22	22.11	1.30 ± 0.06
15.61	5.76 ± 0.30	18.39	4.13 ± 0.13	23.96	1.09 ± 0.07
15.79	5.30 ± 0.30	18.58	3.90 ± 0.22		
15.98	4.78 ± 0.28	18.76	3.24 ± 0.20		

B Angular Distributions

Table B-1 Observed cross section and analyzing power angular distributions for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction at neutron energies of 7.75, 9.2, 10.0, 10.2, 11, 12, and 13 MeV. The uncertainties represent one standard deviation of the statistical error.

E_n	θ	$\sigma(\theta)/A_0$	$A_y(\theta)$	$A_y(\theta)\sigma(\theta)/A_0$
7.75	35	0.861 ± 0.061		
	45	0.956 ± 0.042	0.564 ± 0.080	0.539 ± 0.080
	55	1.004 ± 0.025	0.500 ± 0.073	0.502 ± 0.075
	70	1.055 ± 0.051		
	90	1.090 ± 0.034	−0.075 ± 0.100	−0.082 ± 0.109
	110	1.083 ± 0.039	−0.329 ± 0.083	−0.357 ± 0.091
	125	0.942 ± 0.038	−0.493 ± 0.091	−0.464 ± 0.088
	140	0.928 ± 0.052		
	141	1.005 ± 0.038	−0.445 ± 0.063	−0.447 ± 0.066
	150	0.933 ± 0.054		

Table B-1 Continued.

E_n	θ	$\sigma(\theta)/A_0$	$A_y(\theta)$	$A_y(\theta)\sigma(\theta)/A_0$
9.2	35	0.735 ± 0.081		
	40	0.737 ± 0.081		
	45	0.820 ± 0.045		
	55	1.035 ± 0.038	0.248 ± 0.101	0.257 ± 0.105
	70	1.227 ± 0.049	-0.046 ± 0.102	-0.056 ± 0.125
	90	1.257 ± 0.034	-0.157 ± 0.069	-0.197 ± 0.087
	110	1.233 ± 0.046	-0.210 ± 0.092	-0.259 ± 0.115
	125	1.032 ± 0.042	-0.465 ± 0.113	-0.480 ± 0.117
	140	0.722 ± 0.043	-0.327 ± 0.139	-0.236 ± 0.103
	150	0.655 ± 0.061		
10.0	45	0.932 ± 0.049		
	55	1.051 ± 0.049	0.283 ± 0.168	0.297 ± 0.177
	70	1.155 ± 0.054	0.315 ± 0.174	0.364 ± 0.202
	90	1.186 ± 0.055	-0.351 ± 0.138	-0.417 ± 0.165
	110	1.154 ± 0.055	-0.363 ± 0.137	-0.419 ± 0.159
	125	0.888 ± 0.051	-0.377 ± 0.173	-0.335 ± 0.155
	135	0.909 ± 0.051	-0.371 ± 0.122	-0.338 ± 0.113

Table B-1 Continued.

E_n	θ	$\sigma(\theta)/A_0$	$A_y(\theta)$	$A_y(\theta)\sigma(\theta)/A_0$
10.2	30	0.549 ± 0.062		
	35	0.772 ± 0.058		
	45	0.691 ± 0.045	0.206 ± 0.136	0.143 ± 0.097
	60	0.979 ± 0.053	0.139 ± 0.093	0.136 ± 0.140
	70	1.157 ± 0.062	0.000 ± 0.090	0.000 ± 0.153
	90	1.290 ± 0.049	−0.154 ± 0.086	−0.199 ± 0.112
	110	1.291 ± 0.037	−0.410 ± 0.060	−0.530 ± 0.078
	125	1.051 ± 0.045	−0.306 ± 0.105	−0.322 ± 0.111
	135	0.964 ± 0.042		
	141	0.797 ± 0.048	−0.622 ± 0.094	−0.496 ± 0.131
	145	0.871 ± 0.065		
	150	0.533 ± 0.054		
11.	35	0.680 ± 0.044		
	45		0.416 ± 0.075	0.362 ± 0.128
	55	1.027 ± 0.052	0.285 ± 0.091	0.292 ± 0.095
	70	1.209 ± 0.049	0.197 ± 0.053	0.238 ± 0.065
	90	1.347 ± 0.033	0.079 ± 0.057	0.106 ± 0.076
	110	1.197 ± 0.049	−0.208 ± 0.060	−0.250 ± 0.072
	125	0.952 ± 0.053	−0.176 ± 0.095	−0.167 ± 0.091
	135	0.767 ± 0.048		

Table B-1 Continued.

E_n	θ	$\sigma(\theta)/A_0$	$A_y(\theta)$	$A_y(\theta)\sigma(\theta)/A_0$
11.	Continued.			
	142		-0.411 ± 0.099	-0.294 ± 0.148
	150	0.635 ± 0.044		
12.	45	0.821 ± 0.079	0.266 ± 0.152	0.218 ± 0.127
	55	0.986 ± 0.049	0.348 ± 0.124	0.343 ± 0.123
	70	1.314 ± 0.053	0.222 ± 0.105	0.292 ± 0.138
	90	1.350 ± 0.040	-0.111 ± 0.101	-0.149 ± 0.137
	110	1.259 ± 0.041	-0.148 ± 0.126	-0.186 ± 0.159
	125	0.989 ± 0.045	-0.295 ± 0.101	-0.292 ± 0.101
	140	0.747 ± 0.042	-0.313 ± 0.138	-0.233 ± 0.104
	150	0.566 ± 0.042		
13.	30	0.559 ± 0.123		
	40	0.713 ± 0.074		
	55	1.204 ± 0.080		
	70	1.103 ± 0.121		
	90	1.354 ± 0.050		
	110	1.213 ± 0.090	-0.287 ± 0.073	-0.348 ± 0.093
	125	1.080 ± 0.062	-0.253 ± 0.118	-0.274 ± 0.129
	140	0.566 ± 0.048		
	150	0.675 ± 0.062		

Table B--2 Unconstrained cross section and analyzing power angular distribution coefficients for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction, with $k_{max} = 3$. Also shown are the fore-aft asymmetry and the 90° analyzing power determined from the Legendre coefficients. The uncertainties represent one standard deviation of the statistical error.

E_n (MeV)	Legendre Coefficients		χ^2_n
7.75	a_1	-0.041 ± 0.027	0.90
	a_2	-0.179 ± 0.041	
	a_3	-0.069 ± 0.054	
	b_1	-0.012 ± 0.048	0.02
	b_2	0.340 ± 0.025	
	b_3	0.031 ± 0.028	
	a_s	0.003 ± 0.017	
	$A_y(90^{\circ})$	-0.062 ± 0.071	

Table B-2 Continued.

E_n (MeV)		Legendre Coefficients	χ^2_n
9.2	a_1	-0.001 ± 0.031	1.04
	a_2	-0.598 ± 0.045	
	a_3	0.012 ± 0.062	
	b_1	-0.127 ± 0.051	0.93
	b_2	0.203 ± 0.042	
	b_3	0.052 ± 0.039	
	a_s	-0.006 ± 0.020	
	$A_y(90^\circ)$	-0.163 ± 0.055	
10.0	a_1	0.020 ± 0.069	1.35
	a_2	-0.396 ± 0.075	
	a_3	-0.062 ± 0.117	
	b_1	-0.103 ± 0.082	0.97
	b_2	0.284 ± 0.065	
	b_3	0.113 ± 0.063	
	a_s	0.036 ± 0.024	
	$A_y(90^\circ)$	-0.234 ± 0.102	

Table B-2 Continued.

E_n (MeV)	Legendre Coefficients		χ^2_n
10.2	a_1	-0.082 ± 0.024	2.40
	a_2	-0.610 ± 0.038	
	a_3	0.167 ± 0.052	
	b_1	-0.233 ± 0.049	1.10
	b_2	0.217 ± 0.036	
	b_3	0.013 ± 0.036	
	a_s	-0.112 ± 0.022	
	$A_y(90^\circ)$	-0.198 ± 0.057	
11.	a_1	0.003 ± 0.029	0.72
	a_2	-0.654 ± 0.042	
	a_3	-0.058 ± 0.057	
	b_1	0.047 ± 0.038	0.85
	b_2	0.206 ± 0.030	
	b_3	-0.002 ± 0.033	
	a_s	0.024 ± 0.024	
	$A_y(90^\circ)$	0.033 ± 0.041	

Table B-2 Continued.

E_n (MeV)	Legendre Coefficients		χ^2_n
12.	a_1	-0.039 ± 0.055	0.62
	a_2	-0.756 ± 0.082	
	a_3	-0.043 ± 0.079	
	b_1	-0.007 ± 0.060	0.61
	b_2	0.198 ± 0.037	
	b_3	0.018 ± 0.040	
	a_s	-0.006 ± 0.024	
	$A_y(90^o)$	-0.030 ± 0.070	
13.	a_1	0.025 ± 0.041	4.38
	a_2	-0.723 ± 0.061	
	a_3	-0.089 ± 0.091	
	b_1	-0.107 ± 0.097	0.71
	b_2^*	0.200 ± 0.040	
	b_3^*	0.010 ± 0.025	
	a_s	0.048 ± 0.038	
	$A_y(90^o)$	-0.090 ± 0.076	

* fixed - see text.

Table B-3 Constrained cross section and analyzing power angular distribution coefficients for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction, with $k_{max} = 3$. Also shown are the fore-aft asymmetry and the 90° analyzing power determined from the Legendre coefficients. The uncertainties represent one standard deviation of the statistical error. The method of constraint is discussed in §4-3.

E_n (MeV)	Legendre Coefficients		χ^2_n
7.75	a_1	-0.041 ± 0.027	0.90
	a_2	-0.179 ± 0.041	
	a_3	-0.069 ± 0.054	
	b_1	0.025 ± 0.035	0.21
	b_2	0.340 ± 0.025	
	b_3	0.010 ± 0.021	
	a_s	0.003 ± 0.017	
	$A_y(90^{\circ})$	0.009 ± 0.045	

Table B-3 Continued.

E_n (MeV)		Legendre Coefficients	χ^2_n
9.2	a_1	-0.001 ± 0.031	1.04
	a_2	-0.598 ± 0.045	
	a_3	0.012 ± 0.062	
	b_1	-0.128 ± 0.047	0.70
	b_2	0.203 ± 0.042	
	b_3	0.054 ± 0.034	
	a_s	-0.006 ± 0.020	
	$A_y(90^\circ)$	-0.161 ± 0.040	
10.0	a_1	0.020 ± 0.069	1.35
	a_2	-0.396 ± 0.075	
	a_3	-0.062 ± 0.117	
	b_1	-0.066 ± 0.067	0.85
	b_2	0.278 ± 0.065	
	b_3	0.079 ± 0.047	
	a_s	0.036 ± 0.024	
	$A_y(90^\circ)$	-0.154 ± 0.044	

Table B-3 Continued.

E_n (MeV)		Legendre Coefficients	χ_n^2
10.2	a_1	-0.074 ± 0.023	2.19
	a_2	-0.611 ± 0.038	
	a_3	0.135 ± 0.046	
	b_1	-0.224 ± 0.042	0.89
	b_2	0.218 ± 0.036	
	b_3	0.006 ± 0.030	
	a_s	-0.095 ± 0.017	
	$A_y(90^\circ)$	-0.178 ± 0.040	
11.	a_1	0.001 ± 0.027	0.58
	a_2	-0.654 ± 0.042	
	a_3	-0.051 ± 0.047	
	b_1	0.047 ± 0.038	0.85
	b_2	0.206 ± 0.030	
	b_3	0.002 ± 0.033	
	a_s	0.020 ± 0.016	
	$A_y(90^\circ)$	0.038 ± 0.040	

Table B-3 Continued.

E_n (MeV)	Legendre Coefficients		χ_n^2
12.	a_1	-0.050 ± 0.053	0.54
	a_2	-0.763 ± 0.081	
	a_3	-0.031 ± 0.077	
	b_1	-0.015 ± 0.050	0.49
	b_2	0.199 ± 0.037	
	b_3	0.023 ± 0.033	
	a_s	-0.017 ± 0.016	
	$A_y(90^\circ)$	-0.036 ± 0.051	
13.	a_1	-0.005 ± 0.039	4.11
	a_2	-0.722 ± 0.062	
	a_3	0.032 ± 0.073	
	b_1	-0.055 ± 0.095	2.62
	b_2	0.200 ± 0.040	
	b_3	-0.059 ± 0.076	
	a_s	-0.015 ± 0.024	
	$A_y(90^\circ)$	0.025 ± 0.056	

C Transition Matrix Element Analysis

Table C-1 E1 solutions for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. The quadratic nature of the E1 equations resulted in two solutions for each energy. The cross sections are defined as:

$\sigma(s_{1/2}) = |s_{1/2}|^2$

$\sigma(d_{3/2}) = 2\,|d_{3/2}|^2$.

E_n (MeV)	$\sigma(s_{1/2})$ (%)	$\sigma(d_{3/2})$ (%)	$\varphi_d - \varphi_s$ (deg)
7.75	38.8 ± 11.4	61.2 ± 11.6	-103 ± 6
	65.7 ± 11.4	34.3 ± 11.2	-92 ± 6
9.20	10.1 ± 4.4	89.9 ± 4.8	-69 ± 6
	74.3 ± 5.5	25.7 ± 5.1	-40 ± 7
10.00	15.5 ± 7.4	84.5 ± 7.8	-93 ± 10
	78.0 ± 8.6	22.0 ± 8.1	-61 ± 9
10.20	15.8 ± 5.7	84.2 ± 6.0	-69 ± 4
	68.3 ± 6.4	31.7 ± 6.3	-47 ± 6
11.00	12.4 ± 4.1	87.6 ± 4.6	-63 ± 5
	69.8 ± 5.5	30.2 ± 5.0	-40 ± 5
12.00	12.6 ± 4.9	87.4 ± 5.4	-55 ± 6
	67.0 ± 6.3	33.0 ± 5.9	-35 ± 6
13.00	14.7 ± 7.2	85.3 ± 8.1	-53 ± 10
	66.0 ± 9.7	34.0 ± 8.9	-37 ± 7

Table C-2 E1-E2 solutions for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. Two E1 amplitudes, the $f_{5/2}$ E2 amplitude and two relative phases were fit. The cross sections are defined as:

$\sigma(s_{1/2}) = |s_{1/2}|^2$

$\sigma(d_{3/2}) = 2\,|d_{3/2}|^2$

$\sigma(f_{5/2}) = 3\,|f_{5/2}|^2$.

E_n (MeV)	$\sigma(s_{1/2})$ (%)	$\sigma(d_{3/2})$ (%)	$\phi_d - \phi_s$ (deg)	$\sigma(f_{5/2})$ (%)	$\phi_f - \phi_s$ (deg)	χ^2_n
7.75	40.48 ±11.90	59.37 ±12.22	−102 ± 6	0.15 ±0.22	10 ±17	0.7
9.20	12.06 ± 4.03	87.04 ± 4.42	−62 ± 7	0.90 ±0.86	208 ± 8	0.9
10.00	13.55 ± 7.38	86.06 ± 7.49	−104 ±11	0.39 ±1.19	183 ±17	1.3
10.20	11.69 ± 4.77	85.15 ± 5.26	−63 ± 5	3.17 ±1.45	197 ± 7	1.7
11.00	9.73 ± 4.14	90.11 ± 4.69	−67 ± 5	0.15 ±0.22	16 ±18	0.7
12.00	19.74 ± 5.23	80.20 ± 5.92	−43 ± 7	0.06 ±0.03	190 ±86	0.6
13.00	13.74 ± 6.61	86.13 ± 7.53	−55 ±10	0.14 ±0.54	211 ±29	3.9

Table C-3 E1-E2-M1 solutions for the $^{13}C(\vec{n},\gamma_0)^{14}C$ reaction. Two E1 amplitudes, the $f_{5/2}$ E2 amplitude and two relative phases were fit. The $p'_{3/2}$ M1 complex matrix element was held constant to the value determined at each energy by the direct-semidirect model calculation of Chapter 7. The cross sections are defined as:

$\sigma(s_{1/2}) = |s_{1/2}|^2$

$\sigma(d_{3/2}) = 2\,|d_{3/2}|^2$

$\sigma(f_{5/2}) = 3\,|f_{5/2}|^2$

$\sigma(p'_{3/2}) = 2\,|p'_{3/2}|^2$.

E_n (MeV)	$\sigma(s_{1/2})$ (%)	$\sigma(d_{3/2})$ (%)	$\varphi_d-\varphi_s$ (deg)	$\sigma(f_{5/2})$ (%)	$\varphi_f-\varphi_s$ (deg)	$\sigma(p'_{3/2})$ (%)	$\varphi_p-\varphi_s$ (deg)	χ^2_n
7.75	39.43±10.13	60.08±10.48	-102± 6	0.30±0.33	30±18	0.19	63	0.8
9.20	16.90± 8.00	75.44± 8.00	-66± 5	0.45±0.17	103±46	7.21	121	1.2
10.00	13.60± 5.72	81.00± 6.38	-107±10	1.46±1.39	-1±15	2.78	139	1.2
10.20	11.60± 5.56	85.94± 5.92	-63± 5	0.13±0.24	138±42	2.33	179	2.1
11.00	9.48± 4.23	89.81± 4.79	-66± 5	0.62±0.43	19±11	0.10	192	0.7
12.00	20.03± 7.00	79.91± 7.00	-43±10	0.03±0.21	154±99	0.03	177	0.6
13.00	13.72± 6.61	86.20± 7.52	-55±10	0.07±0.38	208±44	0.02	172	3.9

D Comparison to Theory

Table D-1 Direct-Semidirect Model Parameters used to fit the $^{13}C(\vec{n},\gamma_0)^{14}C$ data.

Continuum Wave Function:

Real Well:

$$V = 60.0 + 27\,\frac{N-Z}{A} - 0.3\,E_{c.m.}\ \text{MeV}$$

$$r = 1.14\ \text{fm}$$

$$a = 0.57\ \text{fm}$$

Imaginary Surface:

$$W_s = W_s(E) + 10\,\frac{N-Z}{A}\ \text{MeV}$$

$$W_s(E) = \begin{cases} 0.64\,E_{c.m.}; & E_{c.m.} \leq 13.8\ \text{MeV} \\ 9.60 - 0.06\,E_{c.m.}; & E_{c.m.} > 13.8\ \text{MeV} \end{cases}$$

$$r = 1.14\ \text{fm}$$

$$a = 0.50\ \text{fm}$$

Spin Orbit:

$$V_{so} = 5.5\ \text{MeV}$$

$$r = 1.14\ \text{fm}$$

$$a = 0.57\ \text{fm}$$

Coulomb Radius:

$$r_c = 1.14\ \text{fm}$$

Table D-1 Continued.

Bound State Wave Function:

$V = 53.1$ MeV at $E_n = 11.0$ MeV

$E_B = -8.1766$ MeV

$r = 1.14$ fm

$a = 0.57$ fm

$V_{so} = 5.5$ MeV

$C^2S = 1.7336$ (Spectroscopic Factor)

Effective Charges:

$$\varepsilon_1 = \frac{-Z_t}{1 + A_t} = -0.429$$

$$\varepsilon_2 = \frac{Z_t}{(1 + A_t)^2} = 0.0306$$

Semidirect Form Factors:

Electric Dipole:

Isovector Volume Coupling Form Factor:

$V = 68$ MeV

$r = 1.14$ fm

$a = 0.57$ fm

Resonance:

Position:	15.45	MeV	17.85	MeV
Width:	1.50	MeV	1.75	MeV
Strength:	0.26	Sum Rule	0.25	Sum Rule

Table D-1 Continued.

Semidirect Form Factors (continued):

Electric Quadrupole:

Isoscalar Surface Coupling Form Factor:

V = 53 MeV

r = 1.14 fm

a = 0.57 fm

Resonance:

Position: 20.0 MeV

Width: 4.0 MeV

Strength: 0.4 Sum Rule

Magnetic Dipole:

Isovector Volume Coupling Form Factor:

V = 40 MeV

r = 1.14 fm

a = 0.57 fm

Resonance:

Position:	16.70	MeV	17.50	MeV
Width:	0.20	MeV	0.20	MeV
Strength:	0.24	μ_0^2	0.17	μ_0^2

E Polarized Ion Source Microprocessor

The following pages have been extracted from the instruction manual for the polarized ion source. They contain the operating instructions for the microprocessor based interlock and control system. Primary responsibility for the design, construction, and installation of the system rested with the author of this thesis.

OVERVIEW

The Polarized Ion Source Microprocessor is a Vector Graphics brand Z-80 based computer running with the CP/M operating system. CP/M is used to edit, compile, and load the SENSE program from disk and begin its execution. Once put into operation, the SENSE program monitors the condition of the source by interrogating various sensors located on the high and low voltage frames, and turns devices on or off if dangerous conditions arise or if previous fault conditions have become cleared. SENSE provides the user with information about the status of the source and about operations that it has performed. SENSE also provides an extensive set of commands with which the user may request information and alter the condition of the source. The user may enter commands at the microprocessor console itself or at any VAX terminal by using the XSYS program XPIS. Output information is displayed on the microprocessor console and on standard TV monitors connected to the video output of the console. No information is displayed on the user's VAX terminal when running the XPIS program (except under certain error conditions during spin flip or quench commands) but SENSE does communicate with the XPIS program itself to indicate normal completion or error completion.

STARTUP PROCEDURE

To run the SENSE program perform the following operations:

1 - Insert the floppy disk containing the program into the slot in the right hand disk drive and load it by pushing the plastic lever to the right. Orient the the disk with the label toward the front and on the left.
2 - Push the RESET button on the front of the computer.
3 - Type B in response to the MON> prompt. This (B)oots the CP/M operating system.
4 - Type SENSE<CR> in response to the A> prompt. This loads and begins execution of the SENSE program.
5 - After the SENSE program has been loaded (about 10 seconds), unload the disk by pushing the lever to the right and letting it spring back to the left. Leave the floppy disk in the slot. It is bad for the disk to leave it in the loaded position for extended periods of time.
6 - Type SET mm/dd hh:mm:ss to set the real time clock.
7 - Check the sense panels and relay boxes on the high and low voltage frames to be sure the source is in a safe condition. When the light next to the power switch on either relay box is on, it means the microprocessor has control of the devices attached to that box. The switch can be used to disable microprocessor control.

COMMANDS

The following is an alphabetical list of the commands understood by the SENSE program. The last (or only) keyword appearing on a command line may be abbreviated to as little as 3 letters. Separate all subcommands from the main commands by a space.

IGNORE

The IGNORE command tells the microprocessor to ignore the condition of the physical sense lines. The microprocessor will not respond to changes in the ignored sense lines and will use the status information contained in the sense line status table to determine what actions to perform.

Subcommand:

ALL - Ignore all of the sense lines.
HIGH - Ignore the high voltage sense lines.
LOW - Ignore the low voltage sense lines.

INITIALIZE

The INITIALIZE command clears the sense line status table, the wait table, and the control line status table. In addition, all devices are turned "on".

MONITOR

The MONITOR command causes SENSE to return to the CP/M monitor.

QUENCH and UNQUENCH

Quenching of the polarized source beam is controlled by a standard control line (named QUN) and may be altered using any of the control line commands listed below. The QUENCH and UNQUENCH commands provide a more convenient notation for the operation. In addition, a message is sent to the VAX after the command has been performed indicating success or failure of the operation. Any VAX program using this command should wait for the beam to stabilize before proceeding.

SET

The SET command sets the real time clock. The "/" and ":" need not be typed, but each numerical field must be separated by one character.

Subcommand:

mm/dd hh:mm:ss - The current time.

SPIN

The spin direction on the polarized source is controlled by a standard control line (named SPN) and may be altered using any of

the control line commands listed below. The SPIN command is provided to allow the spin to be "flipped" as well as being set to UP or DOWN. In addition, a message is sent to the VAX after the SPIN command has been performed indicating success or failure of the operation. Any VAX program using this command should wait for the beam to stabilize before proceeding.

Subcommand:

- UP - Set spin direction to up.
- DOWN - Set spin direction to down.
- FLIP - Flip spin direction.
- STATUS - Report spin direction.

SST

The SST command causes the status off all sense lines included in the short status list to be output.

STATUS

The STATUS command causes the microprocessor to output the status of the requested sense and/or control lines. A header is typed to label the various pieces of information.

Subcommand:

- SENSE - All allocated sense lines.
- CONTROL - All allocated control lines.
- HSENSE - All allocated high voltage sense lines.
- LSENSE - All allocated low voltage sense lines.
- HCONTROL - All allocated high voltage control lines.
- LCONTROL - All allocated low voltage control lines.
- ALL - All sense lines and control lines including spares.

TEST

The TEST command alters or reports the status of the sense/control line testing mechanism.

Subcommand:

- ON - Turn testing on.
- OFF - Turn testing off.
- STATUS - Report whether testing is on or off.

TIME

The TIME command causes the real time clock to be printed, including the month and day.

SENSE LINE COMMANDS

The following subcommands are used to alter or report information in the sense line status table. See below for a discussion of this table. These subcommands are entered by typing the 3 letter abbreviation for the sense line followed by the subcommand. The

list of currently defined sense lines and their abbreviations is output by the STATUS ALL command.

Subcommand:

- FAULT - Set the line status to always fault.
- GOOD - Set the line status to always good.
- OPEN - Set the line status to always open.
- CLOSED - Set the line status to always closed.
- ON - Set the line status to always on.
- OFF - Set the line status to always off.
- STATUS - Report the sense line status.
- NORMAL - Restore the sense line to normal operation (no override).
- SST - Enter the sense line into the short status list.
- NOSST - Remove the sense line from the short status list.
- RESET - Perform a manual reset for the sense line.

CONTROL LINE COMMANDS

The following subcommands are used to alter or report information in the control line status table or to alter the state of a control line. See below for a discussion of the control line status table. These subcommands are entered by typing the 3 letter abbreviation for the control line followed by the subcommand. The list of currently defined control lines and their abbreviations is output by the STATUS ALL command.

Subcommand:

- FAULT - Set the line status to fault.
- GOOD - Set the line status to good.
- OPEN - Set the line status to open.
- CLOSED - Set the line status to closed.
- ON - Set the line status to on.
- OFF - Set the line status to off.
- UP - Set the line status to up.
- DOWN - Set the line status to down.
- STATUS - Report the control line status.
- NORMAL - Restore the control line to normal operation (no override).
- (ALWAYS) - Insert this subcommand between the control line abbreviation and one of the subcommands listed above (except STATUS and NORMAL). This causes the control line to be manually overridden and always have the indicated status.

The following commands exist in the SENSE program but do not function because the necessary hardware has not been installed.

ALARM

The ALARM command performs a simple alarm clock function. When the set time has arrived, the terminal will start beeping. A carriage return typed on the terminal will stop the beeping.

Subcommand:

SET hh:mm - Set the time.
TIME - Print the alarm time if it has been set, else print a message.
OFF - Turn alarm off.

BEEP

The BEEP command alters or reports the status of the message beep mechanism. Certain important unsolicited messages appearing on the terminal will be accompanied by "bells" being sent to the terminal until the operator types a carriage return to acknowledge reading the message.

Subcommand:

ON - Turn message beeping on.
OFF - Turn message beeping off.
STATUS - Report status of message beeping.

DVM

The DVM command is used to read the voltage present on one of the channels of the digital volt meter oh the high voltage frame.

Subcommand:

xx - a channel number in the range 0 to 31.

OVERVIEW OF THE SENSE SOFTWARE

The philosophy of the SENSE software is similar to that of the XSYSTEM. There is a collection of more or less independent subroutines operating on a common data base. The microprocessor is a single user machine running only one program organized into separate subroutines while the XSYSTEM is a multiuser machine running separate programs simultaneously. The main program of SENSE is an endless loop that checks for the completion of an input command from the user and calls subroutines periodically to monitor sense line inputs.

SEQUENCES

The sense and control line action sequences are the heart of the SENSE program. All of the logic needed to decide the actions that are necessary in response to external conditions is contained in the sequences. The program is very general and does not need to be changed in order to make large changes in the way the microprocessor responds to events occurring on the source.

The sequences are contained in the assembly language common block SEQUEN. The sequences are not really in assembly language, rather the assembler provides a convenient notation for encoding the sequences. The EQU assembler directive is used to equate the 3 letter abbreviation for a sense or control line with its number (1-40). The DB (define byte) assembler directive is used to place the sequences of sense or control line numbers into memory.

Each sense line has two sequences, a "fault" sequence and a "good" sequence. The fault sequence contains a list of the control lines, in order, to be turned "off" if a fault occurs on the sense line. If a control line is to be turned "on" during a fault condition then the control line symbol is entered as a negative number. Turning a valve "off" means to close the valve, "on" means to open the valve. The adjective to be used in describing the operations of a control line is determined by its entry in the BCTEXT table. The operations to be performed when a sense line returns to the good condition are not necessarily the inverse of the operations performed during the execution of the fault sequence, therefore a separate "good" sequence is provided for each line. The good sequence contains a list of the devices to be turned on, with negative numbers indicating turn the device off. The sequences are of variable length and are terminated by the SQEND command. If two lines are to use the same sequence then the sequence for the second line can be defined with the EQU directive. A line with no sequence can be EQU'd to NONE. An example of a simple set of sequences is:

```
FP3F:     DB      -AUD,FV4,DP5,GV5,SQEND
FP3G:     DB      -AUD,FV4,SQEND
FP4F      EQU     FP3F
FP4G      EQU     FP4F
FP5F      EQU     NONE
FP5G      EQU     NONE
```

Additional capabilities are provided for the sequences by the sequence commands SQCOR,SQRPT,SQMAN, and WAIT#. SQMAN is used to suspend execution of a sequence until the user issues a reset command at the terminal. When the reset command is given, execution of the sequence continues with the sequence elements following SQMAN. The WAIT# command (for # between 1 and 6) provides a means of delaying execution of a sequence. The sequence element following the WAIT# command is the duration of the waiting time in minutes. A negative number for the time indicates seconds. Up to 6 wait operations (WAIT1 through WAIT6) may be encoded in a sequence. During the waiting time, the status of the sense line is not examined. If at the end of the wait the status of the sense line is unchanged, execution of the sequence continues with the sequence elements after the wait command. If the status of the sense line changes during the wait, then the sequence is reexecuted from the beginning in the opposite sense. That is, if the WAIT# command is used in a fault sequence, devices that were turned off by the execution of the sequence up to the point of the WAIT# command are turned back on. WAIT# commands occurring before the one that was just executed are ignored during the reexecution of the sequence.

One might imagine conditions under which a sense line would repeatedly change status during a waiting period. For example, close a valve and the vacuum gets good, reopen the valve and the vacuum gets bad again. Inserting a SQRPT command into a sequence immediately after a WAIT# command sets a limit on the number of times a sequence may be reexecuted. The maximum number of executions is inserted after the SQRPT command itself. Each time the status of a sense line changes during a wait period, the corresponding entry in the array SREP is incremented. If the maximum count is reached, the logical status of the line is set to fault and the line is no longer monitored. SREP is cleared any time the status does not change during the wait period or by the RESET or NORMAL subcommands of the sense line commands. For example the sequence:

```
FP1G:     DB      -AUD,WAIT1,-15,FV1,WAIT2,3,SQRPT,5,DP1,DP2,SQEND
```

means that if sense line FP1 returns to "good" after having been "fault", then turn off control line AUD, wait 15 seconds, turn on line FV1 and wait 3 minutes. If at the end of three minutes FP1 still indicates "good", then turn on DP1 and DP2 and clear the element of the array SREP corresponding to sense line FP1. If, on the other hand, FP1 now indicates "fault", then turn AUD on and FV1 off and increment the element of SREP. If the element of SREP now is equal to 5, then set the status of sense line FP1 to permanently "fault".

The SQCOR command allows the status of sense lines to be correlated

with one another in order to determine the proper response. The command is entered into a sequence by entering the command SQCOR, the number of sense lines to be examined, the names of the sense lines to examine, then the sequence elements (control lines and commands) to be executed if the correlation condition is met. The sense lines named in the command must all be "fault" in order to have a correlation, unless a sense line name appears as a negative number in which case the line must be "good". If the condition is not met, then the sequence elements which follow the SQCOR command are not executed until another SQCOR command is found or the end of the sequence is reached. The SQCOR's are therefore not nested, but are checked sequentially. Zero may be used for the number of sense lines if it is desired to have an unconditionally executed action list occur after a conditional one. Care should be used in coding WAIT statements into the action list of a SEQCOR command. It is possible, in principle, for the sense lines named in the correlation list to change during the waiting time and therefore remove the correlation. The SENSE program has no way to know if that has occurred and so the assumption is made that the other lines do not change, that is, the status at the time the sequence is being reexecuted is assumed to be the same as when the sequence was initially executed. This assumption is almost always valid for the current operating setup and in any case would not cause dangerous conditions to arise because of the constant monitoring of all sense lines. In the following simple example assume D3T and D4T are sense lines and DP3,DP4, and FRV are control lines:

```
D3TF:     DB     DP3,SQCOR,1,D4T,FRV,SQEND
D3TG:     DB     DP3,SQEND
D4TF:     DB     DP4,SQCOR,1,D3T,FRV,SQEND
D4TG:     DB     DP4,SQCOR,1,D3T,FRV,SQEND
```

If D3T or D4T indicates a fault then the corresponding DP line is turned off, but if both sense lines indicate a fault then FRV is also turned off. If D4T returns to the good condition after D3T then FRV will be turned back on, but if D4T returns to good first then FRV will not be turned back on. The use of asymmetric correlation conditions illustrated by the "good" sequences above allows time ordering of events on the source to be considered when deciding the proper response. By combining multiple SQCOR and WAIT# commands, almost any function relating sense lines to control lines can be implemented.

Control line sequences list the sense lines that should be examined before turning a device on or off. Sense lines appearing in the "on" sequence must all be "good" (unless entered as a negative number, in which case it must be fault) before the device will be turned "on". Likewise, the "off" sequence lists sense lines that must be "fault". The control sequences are checked any time a control line is to be altered, whether in response to an event on the source or to an input command. If the operator desires to override the checking, the ALWAYS option of the control line command must be used.

DESCRIPTION OF THE PROGRAM

When the program begins execution, the main program SENSE performs various startup procedures - enables the real time clock interrupt, passes variable addresses to assembly language subroutines, clears all sense line tables to indicate no faults, and initializes variables. It then enters an endless loop that checks for the completion of an input command and then branches to one of two subroutines, SSENSE or INPUT. If no command has been entered then SSENSE is called. This subroutine examines all of the sense lines in numerical order, determines if any have changed state and if so performs the assigned fault or good sequence. If an input command has been typed (signified by IDONE nonzero) then the subroutine INPUT is called. INPUT decodes and executes the input command, calling most of the other subroutines in the process.

The Vector Graphics contains an internal 55.5 Hz clock which causes an interrupt to assembly language subroutine CLKINT 55 times a second. CLKINT maintains an internal counter which counts up to 55 and then generates a call to the calendar and clock subroutine INTER. Thus, roughly once per second the time is updated. The time is written onto the microprocessor console in the lower right corner through a series of POKES into the memory mapped display. To maintain chronological accuracy, 24 seconds are added to the clock every hour to compensate for the half-Hertz clock error. INTER also performs a test on one sense/control line pair by enabling a hardware connection between the control line output and the sense line input, blipping the control line status, and verifying that the sense line has also blipped. The test is done rapidly enough so that the control relays do not actually change state during the test. Thus, one sense/control pair is tested every second. In this manner all sense and control lines are tested every 40 seconds.

Keyboard entries are interpreted via this same clock interrupt structure. After incrementing its internal 55Hz counter, CLKINT checks the status of the flashwriter input port to see if a character has been typed within the last clock interrupt cycle. If so, it picks up the character and puts it into the array ILINE (whose address was previously passed by the call to ENABLE). If the character was a carriage return, IDONE is set as a flag to the main program that a completed command line has been input. Besides checking the flashwriter keyboard, CLKINT checks for any input on serial port C (which is connected to a dedicated VAX terminal port) and strings these characters into ILINE along with the flashwriter input. Thus either device can input a command line. Note that as the keyboard and serial port C are checked only 55 times a second, data must be input slower than this (about 30 chars per second seems to work well). It does not matter what the VAX baud rate is; but the VAX must slow down its data output to less than 30 chars per second or data will be lost.

The SSENSE subroutine performs a DO loop which picks up the current status of each sense line via a call to PSSTAT and compares it with the status read during the last cycle saved in BSSTAT. If BSSTAT is good but the line is now fault, a subloop is entered which examines the sense line several times in succession (currently six times) for noise immunity. This is necessary since a tank or frame spark can glitch the sense lines momentarily. If the sense line shows a hard fault, the fault sequence for the sense line is activated by calling EXSEQ. If the examination of a sense line shows it to have become good, EXSEQ is called to execute the SGOOD sequence. SSENSE also checks each line to see if a wait operation just has been completed for the line, and whether the status changed or not during the wait.

The sense line status table, BSSTAT, contains six fields. The first bit indicates the status of the line the last time it was examined. The second bit indicates whether or not the physical status of the sense line should be examined. If the second bit is set, the hardware line will be ignored and the first bit in the status table will be used to determine the condition of the sense line. The third bit indicates whether or not a reset command has been issued for the sense line. The bit is cleared when the reset has been performed. The fourth bit indicates the condition of the sense/control test loop for the sense/control line pair. The fifth bit indicates whether or not the sense line is to be included in the short status list. The short status list exists to allow lines that are judged likely to change status to be easily examined by the operator. The last three bits in BSSTAT are used to process wait operations. If all three bits are zero then no wait operation is related to this line. If all three bits are one then a wait operation is currently in progress. Otherwise the last three bits represent the number of a WAIT# command that has just been completed. The control line status table, BCSTAT, contains only one field. The last bit indicates whether or not the line is under manual control. Lines under manual control will not be altered in response to a status change on the source or to a type in command. They can only be changed by using the ALWAYS subcommand of the control line commands or by returning the line to NORMAL operation.

Wait operations needed during the execution of a sense line sequence are performed by the WAIT subroutine. It is not practical for the program to actually halt during the wait time because it would then be unable to respond to other commands or failures. Therefore the WAIT subroutine simply enters the wait time and the sense line number into the global arrays WTIME and WLINE. WTIME is then decremented by the real time interrupt routine INTER until it reaches zero. When this occurs the sense line status table is altered by the interrupt routine to indicate that the wait has been completed. SSENSE will note the change in the sense line status table on its next loop through the sense lines.

SUBROUTINE DESCRIPTIONS

CLKINT

Assembly language interrupt handler for the real time clock interrupts. CLKINT calls INTER to perform the required actions.

DCADJ

```
DOUBLE PRECISION FUNCTION DCADJ(II,ONOFF,NORREV)
Return proper adjective to describe the state of a control line.
Input:
   II     = Number of the sense line
   ONOFF  = ON  -> Return the "on" adjective
          = OFF -> Return the "off" adjective
   NORREV < 0 -> Return the opposite adjective
          > 0 -> Return the normal adjective
Output:
   The value of the function will be an 8 character string containing
   the proper adjective.
```

DSADJ

```
DOUBLE PRECISION FUNCTION DSADJ(II,FAGO,NORREV)
Return proper adjective to describe the state of a sense line.
Input:
   II     = Number of the sense line
   FAGO   = FAULT -> Return the "fault" adjective
          = GOOD  -> Return the "good" adjective
   NORREV < 0 -> Return the opposite adjective
          > 0 -> Return the normal adjective
Output:
   The value of the function will be an 8 character string  containing
   the proper adjective.
```

DVM

```
SUBROUTINE DVM(NUM)
Read high voltage frame dvm.
Input:
   NUM   = Channel number (1-32)
```

ENABLE

```
SUBROUTINE ENABLE(ARRAY,FLAG)
Input:
   ARRAY = LOGICAL*1 input buffer for type in commands
   FLAG  = LOGICAL*1 flag to use to signal completion of input
```

EXCSEQ

```
     SUBROUTINE EXCSEQ(II,ONOFF,ALWAYS,WASOK)
     Execute a control inhibit sequence.
  Input:
     II     = # of control line whose inhibit sequence is to be executed
            < 0 -> Perform opposite operation to that specified by ONOFF
     ONOFF  = ON  -> Turn device "on"
            = OFF -> Turn device "off"
     ALWAYS =  0 -> Execute sequence, turn device on or off if allowed
            <> 0 -> Ignore sequence and turn device on or off
  Output:
     WASOK  = Device was successfully turned on or off
  Local:
     ITEM   = Item in control inhibit sequence
     ISEQ   = pointer to sequence
```

EXSEQ

```
     SUBROUTINE EXSEQ(II,FAGO,ONOFF,BWAIT)
     Execute a sense line action sequence.
  Input:
     II     = Number of sense line whose sequence is to be executed
     FAGO   = FAULT -> Execute the "fault" sequence
            = GOOD  -> Execute the "good" sequence
     ONOFF  = ON    -> Turn appropriate devices "on"
            = OFF   -> Turn appropriate devices "off"
     BWAIT  > 0 -> (-BWAIT) is the code for the wait command that has
                   finished where the status changed during the wait
                   period
            = 0 -> No wait operation has been involved for this sense
                   line
            < 0 -> BWAIT is the code for the wait command that has
                   finished where the status did not change during the
                   wait period
  Local:
     BITEM  = Item from the control sequence being executed
     ISEQ   = Pointer to an item in the control sequence
     TIME   = Length of wait time
     DUNIT  = Units of wait time (minutes or seconds)
     NCORR  = Number of sense lines to correlate status
```

INPUT

```
     SUBROUTINE INPUT
     Decode and execute terminal input commands.
```

INTER

```
     SUBROUTINE INTER
     Process real time clock interrupt.
```

PCSTAT

```
     LOGICAL FUNCTION PCSTAT(I)
     Assembler language subroutine to read the value of a control line.
  Input:
     II = Number of the control line to read
```

PSSTAT

```
     LOGICAL FUNCTION PSSTAT(I)
     Assembler language subroutine to read the value of a sense line.
  Input:
     II = Number of the sense line to read
```

SEQUEN

Assembly language block data common block. Holds the sense and control sequence definitions and the index pointers into the sequence table.

SENSE

PROGRAM SENSE
Main program. Variables are initialized, then an infinite loop calling SSENSE and INPUT is entered.

SETCNT

```
     SUBROUTINE SETCNT(II,ONOFF)
     Assembler language subroutine to set a control line.
  Input:
     II    = Control line number
     ONOFF = LOGICAL*1 value to assign to control line
```

SSENSE

```
     SUBROUTINE SSENSE
     Check sense lines and respond to changes.
  Local:
     BWAIT   = Flag for handling waits, passed to EXSEQ.
         > 0 -> (-BWAIT) is the code for the wait command that has
                finished where the status changed during the wait
                period
         = 0 -> No wait operation has been involved for this sense
                line
         < 0 -> BWAIT is the code for the wait command that has
                finished where the status did not change during the
                wait period
     NUSTAT  = New status of sense line
```

TABLES

Fortran block data common block. Contains the name, abbreviation, and adjective descriptors of the sense and control lines.

TSSTAT

```
     SUBROUTINE TCSTAT(II)
     Type the status of one sense line.
  Input:
     II = Number of the control line whose status is to be typed
```

TCSTAT

```
     SUBROUTINE TSSTAT(II)
     Type the status of one sense line.
  Input:
     II = Number of the sense line whose status is to be typed
```

WAISUB

```
     SUBROUTINE WAISUB(TIME,DUNIT,LINE,BMASK)
     Set up a wait operation using the real time clock.
  Input:
     TIME   = Length of wait time
     DUNIT  = Units of wait time
     LINE   = Location to alter to signal completion
     BMASK  = Mask to use to signal completion
```

COMMON DATA BASE

Global Arrays

Sense line tables
QSABBR = R*4 Three character abbreviated name of sense line.
QSNAME = R*4 2D(6) Twenty four character full name of sense line.
BSSTAT = L*1 Status of sense line.
SREP   = I*2 Number of repeats executed.
BSTEXT = L*1 Define which adjective describes sense line status.
SFAULT = I*2 Location of start of fault sequence in SEQUEN.
SGOOD = I*2 Location of start of good sequence in SEQUEN.

Control line tables
QCABBR = R*4 Three character abbreviated name of control line.
QCNAME = R*4 2D(6) Twenty four character full name of control line.
BCSTAT = L*1 Status of control line.
BCTEXT = L*1 Define which adjective describes control line status.
CON   = I*2 Location of start of on sequence in SEQUEN.
COFF   = I*2 Location of start of off sequence in SEQUEN.

```
SEQUEN = L*1 Array containing all of the sequences.

WTIME  = I*2 Remaining wait time is seconds.
WLINE  = I*2 Sense line number for which the wait is being performed.
BWMASK = L*1 Byte to use to signal completion of the wait.

ILINE  = L*1 Text of the input command.
```

Global Variables

```
DOTEST = L*1 Flag to enable testing of sense/control loops.
ITEST  = I*2 Number of next sense/control loop to test.
BTESTF = L*1 Number of sense/control loop that has just changed status.
IDONE  = L*1 Flag to indicate an input line is completed.
ALERT  = L*1 Flag to enable message beeping.
MBEEP  = L*1 Flag to indicate message beeper is beeping.
ALARM  = L*1 Flag to enable alarm beeping.
ABEEP  = L*1 Flag to indicate alarm beeper is beeping.
```

Global Constants

```
NLINES = Number of sense/control lines wired.
NSTLOW = Start of low voltage channels.

Bit masks for sense line status
FAULTM = 10000000 -> Sense line is fault.
IGNORM = 01000000 -> Sense line is being ignored.
MANM   = 00100000 -> A manual reset has been given for this sense line.
TESTM  = 00010000 -> This sense/control pair tests faulty.
SSTM   = 00001000 -> Sense line is included in short status.
WAITM  = 00000111 -> A wait is being performed on this sense line.

Bit mask for control line status
CMANM  = 00000001 -> Control line is under manual control.

Bit masks for BSTEXT, BCTEXT tables
FAGOVM = 00000001 -> Fault/good are valid adjectives for this line.
OPCLVM = 00000010 -> Open/closed are valid adjectives for this line.
ONOFVM = 00000100 -> On/off are valid adjectives for this line.
UPDNVM = 00001000 -> Up/down are valid adjectives for this line.
```

MODIFYING THE SOFTWARE

Modifications to the program itself will be relatively rare since most of the desired changes can be accomplished by modifying the sequences and tables. Each subroutine exists as a separate file on the disk. It is only necessary to edit and recompile the subroutines being changed. A command file, SL.SUB, exists to link subroutines and block data together. Files can be edited using the SCOPE editor. SCOPE is a full screen editor with several nice features made possible by the memory mapped display. The CP/M operating system is similar in many ways to VAX/VMS and should be easy for a VAX user to learn. There is a loose leaf notebook near the microprocessor containing manuals for all of the system software.

To define a new sense line or control line in the system only the files TABLES.FOR and SEQUEN.MAC need to be altered. The table entries for the spare line that is being redefined to an active line should be changed to the appropriate values for the new function of the line.

F SENSE Program Listing

The following pages contain the source listing for the SENSE program run on the polarized ion source microprocessor. The program is written in Microsoft FORTRAN and assembly language for the Vector Graphics brand Z80 computer running the CP/M operating system.

```
      PROGRAM SENSE
C Polarized Ion Source Microprocessor Operating System
C Written by Michael Wright
C Triangle Universities Nuclear Lab
C Duke University, Duke Station, Durham, NC 27701
C
C
C Sense/control tables
C QSABBR = Abbreviated name of sense line
C QSNAME = Full name of sense line
C BSSTAT = Status of sense line
C SREP   = Number of repeats executed
C BSTEXT = Define which adjective describes sense line status
C SFAULT = Location of start of fault sequence
C SGOOD  = Location of start of good sequence
C QCABBR = Abbreviated name of control line
C QCNAME = Full name of control line
C BCSTAT = Status of control line
C BCTEXT = Define which adjective describes control line status
C CON    = Location of start of on sequence
C COFF   = Location of start of off sequence
C SEQUEN = Array containing all of the sequences
C
C Wait tables
C WTIME  = Length of wait time in seconds
C WLINE  = Number of the sense line that is being waited on
C BWMASK = Byte to .AND. into BSSTAT(WLINE) to signal completion of the wait
C
C Bit masks for status bytes
C FAULTM = 10000000 -> Sense line is fault
C IGNORM = 01000000 -> Sense line is being ignored
C MANM   = 00100000 -> A manual reset has been given for this sense line
C TESTM  = 00010000 -> This sense/control pair tests faulty
C SBTM   = 00001000 -> Sense line is included in short status
C WAITM  = 00000111 -> A wait is being performed on this sense line
C CMANM  = 00000001 -> Control line is under manual control
C FAQOVM = 00000001 -> Fault/good are valid adjectives for this line
C OPCLVM = 00000010 -> Open/closed are valid adjectives for this line
C ONOFVM = 00000100 -> On/off are valid adjectives for this line
C UPDNVM = 00001000 -> Up/down are valid adjectives for this line
C
C Number of physical sense/control lines
C NLINES = Number of sense/control lines wired
C NSTLOW = Start of low voltage channels
C NSHIGH = Number of high voltage sense lines used
C NCHIGH = Number of high voltage control lines used
C NSLOW  = Number of low voltage sense lines used
C NCLOW  = Number of low voltage control lines used
C
C Keywords to make program more readable
C FAULT  = 1
C GOOD   = 2
C ON     = 3
C OFF    = 4
C YES    = 5
C NO     = 6
C
      IMPLICIT  INTEGER*2(A,C,E-P,R-Z),REAL*4(D),REAL*8(D),BYTE(B)
      DIMENSION QSNAME(6,40),QSABBR(40),BSTEXT(40),BSBTAT(40),SREP(40)
      DIMENSION QCNAME(6,40),QCABBR(40),BCTEXT(40),BCSTAT(40)
      LOGICAL*1 IDONE,ALERT,MBEEP,ALARM,ABEEP,DOTEST
      BYTE      FAULTM,IGNORM,WAITM,MANM,TESTM,SBTM,CMANM,
     1          FAQOVM,OPCLVM,ONOFVM,UPDNVM
      BYTE      ILINE(80)
      DIMENSION WTIME(25),WLINE(25),BWMASK(25)
C
      COMMON /SENTAB/ QSNAME,QSABBR,BSTEXT,BSSTAT,SREP
      COMMON /CONTAB/ QCNAME,QCABBR,BCTEXT,BCSTAT
      COMMON /MASKS/  FAULTM,IGNORM,WAITM,MANM,TESTM,SBTM,CMANM,
     1                FAQOVM,OPCLVM,ONOFVM,UPDNVM
      COMMON /NUMBER/ NLINES,NSTLOW,NSHIGH,NCHIGH,NSLOW,NCLOW
      COMMON /TIME/   MONTH,IDAY,HOUR,MIN,SEC,ALAHR,ALAMIN
      COMMON /WAIT/   WTIME,WLINE,BWMASK,WAISIZ,DMIN,DSEC
      COMMON /FLAGS/  ALERT,MBEEP,ALARM,ABEEP,DOTEST,ITEST,BTESTF
      COMMON /KEYS/   FAULT,GOOD,ON,OFF,YES,NO
      COMMON /INPUTC/ IDONE,ILINE
C
      DATA FAULTM/-128/,IGNORM/64/,MANM/32/,TESTM/16/,SBTM/8/,WAITM/7/,
     1     CMANM/1/,FAQOVM/1/,OPCLVM/2/,ONOFVM/4/,UPDNVM/8/
      DATA WAISIZ/25/,DMIN/'MINUTES '/,DSEC/'SECONDS '/
      DATA FAULT/1/,GOOD/2/,ON/3/,OFF/4/,YES/5/,NO/6/
      DATA BREV/20/
C
C Main Program
C
C Cold start
      WRITE(1,1000)
 1000 FORMAT(' SENSE  --  Version 3.4  --  October 6,1982')
C
C     Init wait table
      DO 30 I=1,WAISIZ
   30  WTIME(I)=0
      DO 35 I=1,NLINES
       BCSTAT(I) = 0
       SREP(I) = 0
   35  BSSTAT(I) = 0
C
C     Init flags
      ALERT = .TRUE.
      ABEEP = .FALSE.
      MBEEP = .FALSE.
      ALARM = .FALSE.
      DOTEST = .TRUE.
      ITEST = 2
      BTESTF = 0
C
C     Init real time clock
      MONTH = 0
      IDAY = 0
      HOUR = 0
      MIN = 0
      SEC = 0
C
   40 IDONE = 0
      WRITE(1,4000)MONTH,IDAY,HOUR,MIN,SEC
 4000 FORMAT(' ',I2,'/',I2,'  ',I2,2(':',I2))
      CALL ENABLE(ILINE,IDONE)
C
C     Check sense lines
   60 CALL SSENSE
C
C     If a test loop has changed status, print a message
      IF(BTESTF.GT.0)WRITE(1,5000)QSABBR(BTESTF),QCABBR(BTESTF)
 5000 FORMAT('+',A3,'/',A3,' TEST LOOP IS NOW GOOD'/)
      IF(BTESTF.LT.0)WRITE(1,6000)QSABBR(-1*BTESTF),QCABBR(-1*BTESTF),
```

```
     1 $REV,BREV
 6000 FORMAT('+',A3,'/',A3,' TEST LOOP IB NOW ',A1,'FAULT',A1/)
      BTESTF = 0
C
C     If input line is ready then execute it
      IF (IDONE.EQ.0) GOTO 60
       IDONE=0
       CALL INPUT
       CALL POKE(2'F757','<')
       CALL POKE(2'F758','-')
       CALL POKE(2'F759','>')
       GOTO 60
      END
      SUBROUTINE INPUT
C
C INPUT.  Subroutine to decode and execute terminal input commands
C
C The keyboard is interrupt driven and is always active.  Input may be
C typed at any time.  An interrupt routine sets the logical variable IDONE
C to true to signal the completion of an input line and puts the text of
C the line into the 80 byte array ILINE.  Subroutine INPUT is then called
C by the main program to decode and process the input.
C
C The commands themselves are described elsewhere.
C
      IMPLICIT   INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(B)
      DIMENSION QSNAME(6,40),QSABBR(40),BSTEXT(40),BSSTAT(40),BREP(40)
      DIMENSION QCNAME(6,40),QCABBR(40),BCTEXT(40),BCSTAT(40)
      DIMENSION WTIME(25),WLINE(25),BWMASK(25)
      LOGICAL*1 IDONE,ALERT,MBEEP,ALARM,ABEEP,DOTEST
      BYTE      FAULTM,IGNORM,WAITM,MANM,TESTM,BSTM,CMANM,
     1          FAQOVM,OPCLVM,ONOFVM,UPDNVM
      BYTE      ILINE(80),ONCR(4),UPCR(4),BLANK,CR
C
      COMMON /SENTAB/ QSNAME,QSABBR,BSTEXT,BSSTAT,BREP
      COMMON /CONTAB/ QCNAME,QCABBR,BCTEXT,BCSTAT
      COMMON /MASKB/  FAULTM,IGNORM,WAITM,MANM,TESTM,BSTM,CMANM,
     1                FAQOVM,OPCLVM,ONOFVM,UPDNVM
      COMMON /NUMBER/ NLINES,NSTLOW,NSHIGH,NCHIGH,NSLOW,NCLOW
      COMMON /TIME/   MONTH,IDAY,HOUR,MIN,SEC,ALAHR,ALAMIN
      COMMON /WAIT/   WTIME,WLINE,BWMASK,WAIS1Z,DMIN,DSEC
      COMMON /FLAGS/  ALERT,MBEEP,ALARM,ABEEP,DOTEST,ITEST,BTESTF
      COMMON /KEYS/   FAULT,QOOD,ON,OFF,YES,NO
      COMMON /INPUTC/ IDONE,ILINE
C
      EQUIVALENCE (QCOMAN,ILINE(1)),(QACTIN,ILINE(5)),
     1(QSUBCO,ILINE(9)),(QALMSB,ILINE(12)),(QALMSB,ILINE(7))
      EQUIVALENCE (QONCR,ONCR(1)),(QUPCR,UPCR(1))
C
C     Define 3 letter codes and abbreviations
      DATA QMON/'MON '/,QINI/'INI '/,QBTA/'BTA '/,QDVM/'DVM '/,
     1QTIM/'TIM '/,QSET/'SET '/,QIGN/'IGN '/,QALL/'ALL '/,QHIQ/'HIQ '/,
     1QLOW/'LOW '/,QBEE/'BEE '/,QXON/' ON '/,QXOF/' OF '/,QALA/'ALA '/,
     1QOFF/'OFF '/,QSST/'SST '/,QSEN/'SEN '/,QHSE/'HSE '/,QLSE/'LSE '/,
     1QCON/'CON '/,QHCO/'HCO '/,QLCO/'LCO '/,QFAU/'FAU '/,QGOO/'GOO '/,
     1QOPE/'OPE '/,QCLO/'CLO '/,QONx/'ON  '/,QRES/'RES '/,QNOR/'NOR '/,
     1QNOS/'NOS '/,QALW/'ALW '/,QTES/'TES '/,QXST/' ST '/,QFLI/'FLI '/,
     1QSPI/'SPI '/,QQUE/'QUE '/,QXUP/' UP '/,QXDO/' DO '/,QUPX/'UP  '/,
     1QDOW/'DOW '/,QXFL/' FL '/,QUNQ/'UNQ '/,QSPN/'SPN '/,QQUN/'QUN '/,
     1QSPAR/'SPAR'/
      DATA ONCR/'O','N',13,' '/,UPCR/'U','P',13,' '/
      DATA DALW/' ALWAYS '/,DNOALW/'        '/,BLANK/' '/,CR/13/
      DATA DDOWN/'DOWN    '/
C
      ILINE(4) = BLANK
C
C     Monitor command
C
      IF (QCOMAN.EQ.QMON) BTOP
C
C     Initialize command
C
      IF (QCOMAN.EQ.QINI) GOTO 180
C
C     Status command
C
      IF (QCOMAN.EQ.QSTA) GOTO 200
C
C     Dvm command
C
      IF (QCOMAN.NE.QDVM) GOTO 10
C      VAX version of decode statement
C      DECODE(6,1100,ILINE)CHANEL
C      MICROSOFT version of decode statement
       DECODE(ILINE,1100)CHANEL
 1100  FORMAT(4X,I2)
       CALL DVM(CHANEL)
       RETURN
C
C     Print real time clock command
C
   10 IF (QCOMAN.NE.QTIM) GOTO 20
       WRITE(1,1200)MONTH,IDAY,HOUR,MIN,SEC
 1200  FORMAT('+',I2,'/',I2,' ',I2,2(':',I2)/)
       RETURN
C
C     Set real time clock command
C
   20 IF (QCOMAN.NE.QSET) GOTO 30
C      VAX version of decode statement
C      DECODE(18,1300,ILINE)MONTH,IDAY,HOUR,MIN,SEC
C      MICROSOFT version of decode statement
       DECODE(ILINE,1300)MONTH,IDAY,HOUR,MIN,SEC
 1300  FORMAT(3X,5(1X,I2))
       WRITE(1,1350)MONTH,IDAY,HOUR,MIN,SEC
 1350  FORMAT('+','TIME SET TO ',I2,'/',I2,' ',I2,2(':',I2)/)
C      In principle this is an error message:  write(1,1400)
 1400  FORMAT('+Proper format is:  SET 00/00 00:00:00'/)
       RETURN
C
C     Ignore sense lines (including spares) command
C
   30 IF (QCOMAN.NE.QIGN) GOTO 80
       ILINE(1) = BLANK
       IF (QSUBCO.NE.QALL.AND.QSUBCO.NE.QHIQ) GOTO 50
        III = NSTLOW-1
        DO 40 II=1,III
   40    BSSTAT(II) = BSSTAT(II).OR.IGNORM
        WRITE(1,1410)
 1410  FORMAT('+HIGH VOLTAGE SENSE LINES IGNORED'/)
   50  IF (QSUBCO.NE.QALL.AND.QSUBCO.NE.QLOW) RETURN
        DO 60 II=NSTLOW,NLINES
   60    BSSTAT(II) = BSSTAT(II).OR.IGNORM
        WRITE(1,1420)
 1420  FORMAT('+LOW VOLTAGE SENSE LINES IGNORED'/)
       RETURN
```

```
C
C     Turn message beep flag on or off command
C
   80 IF (QCOMAN.NE.QBEE) GOTO 100
       ILINE(8) = BLANK
       IF (QACTIN.NE.QXON) GOTO 90
        ALERT =  TRUE
        WRITE(1,1430)
 1430   FORMAT('+MESSAGE BEEP ON')
        RETURN
   90  IF (QACTIN.NE.QXOF) GOTO 310
        ALERT =  FALSE
        MDEEP = .FALSE.
        WRITE(1,1440)
 1440   FORMAT('+MESSAGE BEEP OFF')
        RETURN
C
C     Alarm command
C
  100 IF (QCOMAN.NE.QALA) GOTO 122
       ILINE(10) = BLANK
       IF (QALMSB.NE.QOFF) GOTO 110
C       Turn alarm off
        ALARM = .FALSE.
        ADEEP =  FALSE.
        WRITE(1,1550)
        RETURN
  110  IF (QALMSB.NE.QTIM) GOTO 120
C       Print alarm time
        IF (ALARM) WRITE(1,1500)ALAHR,ALAMIN
 1500   FORMAT('+ALARM TIME IS ',I2,':',I2/)
        IF ( NOT ALARM) WRITE(1,1550)
 1550   FORMAT('+ALARM IS NOW OFF')
        RETURN
  120  IF (QALMSB.NE.QSET) GOTO 310
C       Set alarm time
C       VAX version of decode statement
C       DECODE(15,1600,ILINE)ALAHR,ALAMIN
C       MICROSOFT version of decode statement
        DECODE(ILINE,1600)ALAHR,ALAMIN
 1600   FORMAT(10X,I2,1X,I2)
        ALARM = .TRUE.
        WRITE(1,1610)ALAHR,ALAMIN
 1610   FORMAT('+ALARM SET TO ',I2,':',I2/)
        RETURN
C
C     Turn test flag on or off command
C
  122 IF (QCOMAN.NE.QTES) GOTO 130
       ILINE(8) = BLANK
       IF (QACTIN.NE.QXON) GOTO 126
        DOTEST = .TRUE.
        WRITE(1,1633)
        RETURN
  126  IF (QACTIN.NE.QXOF) GOTO 127
        DOTEST =  FALSE.
        WRITE(1,1666)
        RETURN
  127  IF (QACTIN.NE.QXST) GOTO 310
        IF (DOTEST) WRITE(1,1633)
 1633   FORMAT('+TEST IS NOW ON')
        IF ( NOT DOTEST) WRITE(1,1666)
 1666   FORMAT('+TEST IS NOW OFF')
        RETURN
C
C     Short status command
C
  130 IF (QCOMAN.NE.QSST) GOTO 550
      WRITE(1,2000)
2000  FORMAT(' ABBR         NAME                LINE   STATUS IGNORE',
     1' WAITING TEST REPEATS')
       DO 140 II=1,NLINES
        IF ((BSSTAT(II).AND.SBTM).EQ.SBTM) CALL TBSTAT(II)
  140  CONTINUE
       RETURN
C
C     Spin command
C
  550 IF (QCOMAN.NE.QSPI) GOTO 600
       ILINE(9) = BLANK
       DO 553 II=1,NLINES
        IF (QCABBR(II).EQ.QSPN) GOTO 556
  553  CONTINUE
       GOTO 590
  556  IF (QACTIN.EQ.QXUP) GOTO 560
       IF (QACTIN.EQ.QXDO) GOTO 570
       IF (QACTIN.NE.QXFL) GOTO 580
        IF (PCSTAT(II)) GOTO 570
C         Set spin direction to up
  560    CALL EXCSEQ(II,ON,0,WASOK)
         IF (WASOK.NE.YES) GOTO 590
          WRITE(1,22000)(QCNAME(I,II),I=1,6)
22000     FORMAT('+',6A4,'UP')
          WRITE(7,25000)
          RETURN
C         Set spin direction to down
  570    CALL EXCSEQ(II,OFF,0,WASOK)
         IF (WASOK.NE.YES) GOTO 590
          WRITE(1,23000)(QCNAME(I,II),I=1,6)
23000     FORMAT('+',6A4,'DOWN')
          WRITE(7,25000)
          RETURN
  580  IF (QACTIN.NE.QXBT) GOTO 310
       CALL TCSTAT(II)
       WRITE(7,25000)
       RETURN
C      Send "error" code back to the VAX
  590  WRITE(7,24000)
24000  FORMAT('N')
25000  FORMAT('Y')
       RETURN
C
C      Perform quench and unquench commands
C
  600 IF (QCOMAN.NE.QQUE.AND.QCOMAN.NE.QUNQ) GOTO 150
       DO 610 II=1,NLINES
        IF (QCABBR(II).EQ.QQUN) GOTO 620
  610  CONTINUE
       GOTO 590
  620  IF (QCOMAN.NE.QQUE) GOTO 630
        CALL EXCSEQ(II,ON,0,WASOK)
        IF(WASOK.NE.YES) GOTO 590
         WRITE(1,26000)(QCNAME(I,II),I=1,6)
26000    FORMAT('+',6A4,'ON')
         WRITE(7,25000)
         RETURN
```

```
  630   CALL EXCSEQ(II,OFF,0,WASOK)
        IF(WASOK.NE.YES) GOTO 590
        WRITE(1,27000)(QCNAME(I,II),I=1,6)
27000   FORMAT('+',6A4,'OFF')
        WRITE(7,25000)
        RETURN
C
C     Insert future commands here
C
C     Look for sense line command
  150 ILINE(8) = BLANK
      DO 160 II=1,NLINES
       IF (QCOMAN.EQ.QSABBR(II)) GOTO 320
  160 CONTINUE
C
C     Look for control line command
      ILINE(15) = BLANK
      DO 170 II=1,NLINES
       IF (QCOMAN.EQ.QCABBR(II)) GOTO 450
  170 CONTINUE
C
C     Invalid command or empty line
      ABEEP =  FALSE
      MBEEP =  FALSE
      IF (ILINE(1).EQ.CR) RETURN
      WRITE(1,3000)
3000  FORMAT('+',53X,'Invalid command')
      RETURN
C
C     Initialize entire system
C
  180 DO 190 I=1,NLINES
C      Init sense status
       BSSTAT(I) = 0
       SREP(I) = 0
C      Init control line status
       CALL SETCNT(I,,TRUE.)
       BCSTAT(I) = 0
  190 CONTINUE
      DO 195 I=1,WAITZ
  195  WTIME(I) = 0
      WRITE(1,3500)
 3500 FORMAT('+SYSTEM INITIALIZED'/)
      RETURN
C
C     Type system status on control terminal
C
  200 ILINE(11) = BLANK
      IF (QSUBCO.NE.QBEN.AND.QBUBCO.NE.QHSE) GOTO 220
       WRITE(1,2000)
C
C      Do high voltage sense lines
       III=NSTLOW-1
       DO 210 II=1,III
       IF (QSNAME(1,II).EQ.QSPAR) GOTO 210
       CALL TSSTAT(II)
  210  CONTINUE
  220 IF (QSUBCO.EQ.QHSE) RETURN
      IF (QSUBCO.EQ.QLSE) WRITE(1,2000)
      IF (QSUBCO.NE.QBEN.AND.QBUBCO.NE.QLSE) GOTO 240
C
C      Do low voltage sense lines
       DO 230 II=NSTLOW,NLINES
       IF (QSNAME(1,II).EQ.QSPAR) GOTO 230
       CALL TSSTAT(II)
  230  CONTINUE
       RETURN
  240 IF (QSUBCO.NE.QCON.AND.QSUBCO.NE.QHCO) GOTO 260
C
C      Do high voltage control lines
       III=NSTLOW-1
       DO 250 II=1,III
       IF (QCNAME(1,II).EQ.QSPAR) GOTO 250
       CALL TCSTAT(II)
  250  CONTINUE
  260 IF (QSUBCO.EQ.QHCO) RETURN
      IF (QSUBCO.NE.QCON.AND.QSUBCO.NE.QLCO) GOTO 280
C
C      Do low voltage control lines
       DO 270 II=NSTLOW,NLINES
       IF (QCNAME(1,II).EQ.QSPAR) GOTO 270
       CALL TCSTAT(II)
  270  CONTINUE
       RETURN
C
C     Do status of all lines including spares
  280 IF (QSUBCO.NE.QALL) GOTO 310
      WRITE(1,2000)
C      All sense lines
       DO 290 II=1,NLINES
  290   CALL TSSTAT(II)
C      All control lines
       DO 300 II=1,NLINES
  300   CALL TCSTAT(II)
       RETURN
C
C     Invalid subcomand
  310 WRITE(1,4000)
4000  FORMAT('+',53X,'Invalid subcomand')
      RETURN
C
C     Perform sense line actions
C
C     Type out status
  320 IF (QACTIN.NE.QSTA) GOTO 340
       WRITE(1,2000)
       CALL TSSTAT(II)
       RETURN
C
C     Do other sense line actions
C     Make line fault
  340 IF (QACTIN.NE.QFAU) GOTO 350
       IF ((BSTEXT(II).AND.FAQOVM).EQ.0) GOTO 440
       WRITE(1,5000)(QSNAME(I,II),I=1,6)
5000   FORMAT('+',6A4,' FAULT'/)
       BSSTAT(II) = FAULTM.OR.IQNORM
       CALL EXSEQ(II,FAULT,OFF,0)
       RETURN
C
C     Make line good
  350 IF (QACTIN.NE.QGOO) GOTO 360
       IF ((BSTEXT(II).AND.FAQOVM).EQ.0) GOTO 440
       WRITE(1,6000)(QSNAME(I,II),I=1,6)
6000   FORMAT('+',6A4,' GOOD'/)
       BSSTAT(II) = IQNORM
       CALL EXSEQ(II,GOOD,ON,0)
```

```
      RETURN
C
C     Make line open
  360 IF (QACTIN.NE.QOPE) GOTO 370
      IF ((BSTEXT(II).AND.OPCLVM).EQ.0) GOTO 440
      WRITE(1,7000)(QSNAME(I,II),I=1,6)
 7000 FORMAT('+',6A4,' OPEN'/)
      BSSTAT(II) = FAULTM.OR.IGNORM
      CALL EXSEQ(II,FAULT,OFF,0)
      RETURN
C
C     Make line closed
  370 IF (QACTIN.NE.QCLO) GOTO 380
      IF ((BSTEXT(II).AND.OPCLVM).EQ.0) GOTO 440
      WRITE(1,8000)(QSNAME(I,II),I=1,6)
 8000 FORMAT('+',6A4,' CLOSED'/)
      BSSTAT(II) = IGNORM
      CALL EXSEQ(II,QOOD,ON,0)
      RETURN
C
C     Make line on
  380 IF (QACTIN.NE.QONX.AND.QACTIN.NE.QONCR) GOTO 390
      IF ((BSTEXT(II).AND.ONOFVM).EQ.0) GOTO 440
      WRITE(1,9000)(QSNAME(I,II),I=1,6)
 9000 FORMAT('+',6A4,' ON'/)
      BSSTAT(II) = FAULTM.OR.IGNORM
      CALL EXSEQ(II,FAULT,OFF,0)
      RETURN
C
C     Make line off
  390 IF (QACTIN.NE.QOFF) GOTO 400
      IF ((BSTEXT(II).AND.ONOFVM).EQ.0) GOTO 440
      WRITE(1,10000)(QSNAME(I,II),I=1,6)
10000 FORMAT('+',6A4,' OFF'/)
      BSSTAT(II) = IGNORM
      CALL EXSEQ(II,QOOD,ON,0)
      RETURN
C
C     Reset sense line
  400 IF (QACTIN.NE.QRES) GOTO 410
      BSSTAT(II) = BSSTAT(II).OR.MANM
      BSSTAT(II) = BSSTAT(II).AND.( NOT.FAULTM)
      SREP(II) = 0
      WRITE(1,11000)(QSNAME(I,II),I=1,6)
11000 FORMAT('+',6A4,' MANUAL RESET'/)
      CALL EXSEQ(II,QOOD,ON,0)
      RETURN
C
C     Stop manual override of status
  410 IF (QACTIN.NE.QNOR) GOTO 420
      BSSTAT(II) = BSSTAT(II).AND.( NOT.IGNORM)
      SREP(II) = 0
      WRITE(1,12000)(QSNAME(I,II),I=1,6)
12000 FORMAT('+',6A4,' NORMAL'/)
      RETURN
C
C     Include line in short status list
  420 IF (QACTIN.NE.Q66T) GOTO 430
      BSSTAT(II) = BSSTAT(II).OR.BSTM
      WRITE(1,13000)(QSNAME(I,II),I=1,6)
13000 FORMAT(' ',6A4,' INSERTED INTO SHORT STATUS LIST'/)
      RETURN
C
C     Remove line from short status list
  430 IF (QACTIN.NE.QNOS) GOTO 440
      BSSTAT(II) = BSSTAT(II).AND.(.NOT.SBTM)
      WRITE(1,14000)(QSNAME(I,II),I=1,6)
14000 FORMAT(' ',6A4,' REMOVED FROM SHORT STATUS LIST'/)
      RETURN
C
C     Insert future sense line actions here
C
C     Invalid sense line action
  440 WRITE(1,15000)
15000 FORMAT('+',53X,'Invalid sense line action')
      RETURN
C
C     Perform control line actions
C
  450 IF (QACTIN.NE.QSTA) GOTO 470
C      Type out status
      CALL TCSTAT(II)
      RETURN
C
C     Put line under manual control also
  470 IF (QACTIN.NE.QALW) GOTO 480
      QACTIN = QALWSB
      DALWAY = DALW
      ALSTAT = CMANM
      GOTO 490
  480 DALWAY = DNOALW
      ALSTAT = 0
C
C     Make line on
  490 IF (QACTIN.NE.QONX.AND.QACTIN.NE.QONCR) GOTO 500
      IF ((BCTEXT(II).AND.ONOFVM).EQ.0) GOTO 540
      CALL EXCSEQ(II,ON,ALSTAT,WASOK)
      IF (WASOK.NE.YES) RETURN
       BCSTAT(II) = BCSTAT(II).OR.ALSTAT
       WRITE(1,16000)(QCNAME(I,II),I=1,6),DALWAY
16000  FORMAT('+',6A4,'      ON',A8/)
       RETURN
C
C     Make line off
  500 IF (QACTIN.NE.QOFF) GOTO 510
      IF ((BCTEXT(II).AND.ONOFVM).EQ.0) GOTO 540
      CALL EXCSEQ(II,OFF,ALSTAT,WASOK)
      IF (WASOK.NE.YES) RETURN
       BCSTAT(II) = BCSTAT(II).OR.ALSTAT
       WRITE(1,17000)(QCNAME(I,II),I=1,6),DALWAY
17000  FORMAT('+',6A4,'     OFF',A8/)
       RETURN
C
C     Make line open
  510 IF (QACTIN.NE.QOPE) GOTO 520
      IF ((BCTEXT(II).AND.OPCLVM).EQ.0) GOTO 540
      CALL EXCSEQ(II,ON,ALSTAT,WASOK)
      IF (WASOK.NE.YES) RETURN
       BCSTAT(II) = BCSTAT(II).OR.ALSTAT
       WRITE(1,18000)(QCNAME(I,II),I=1,6),DALWAY
18000  FORMAT('+',6A4,'    OPEN',A8/)
       RETURN
C
C     Make line closed
  520 IF (QACTIN.NE.QCLO) GOTO 523
      IF ((BCTEXT(II).AND.OPCLVM).EQ.0) GOTO 540
```

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      CALL EXCSEQ(II,OFF,ALSTAT,WASOK)
      IF (WASOK.NE.YES) RETURN
       BCSTAT(II) = BCSTAT(II).OR.ALBTAT
       WRITE(1,19000)(QCNAME(I,II),I=1,6),DALWAY
19000  FORMAT('+',6A4,' CLOSED',A8/)
       RETURN
C
C     Make line up
  523 IF (QACTIN.NE.QUPI.AND.QACTIN.NE.QUPCR) GOTO 526
       IF ((BCTEXT(II).AND.UPDNVM).EQ.0) GOTO 540
       CALL EXCSEQ(II,ON,ALSTAT,WASOK)
       IF (WASOK.NE.YES) RETURN
        BCSTAT(II) = BCSTAT(II).OR.ALBTAT
        WRITE(1,19300)(QCNAME(I,II),I=1,6),DALWAY
19300   FORMAT('+',6A4,'      UP',A8/)
        RETURN
C
C     Make line down
  526 IF (QACTIN.NE.QDOW) GOTO 530
       IF ((BCTEXT(II).AND.UPDNVM).EQ.0) GOTO 540
       CALL EXCSEQ(II,OFF,ALSTAT,WASOK)
       IF (WASOK.NE.YES) RETURN
        BCSTAT(II) = BCSTAT(II).OR.ALBTAT
        WRITE(1,19600)(QCNAME(I,II),I=1,6),DALWAY
19600   FORMAT('+',6A4,'    DOWN',A8/)
        RETURN
C
C     Remove line from manual control
  530 IF (QACTIN.NE.QNOR) GOTO 540
       BCSTAT(II) = BCSTAT(II).AND.(.NOT.CMANM)
       WRITE(1,20000)(QCNAME(I,II),I=1,6)
20000  FORMAT('+',6A4,' NORMAL')
       RETURN
C
C     Insert future control line actions here
C
C     Invalid control line action
  540 WRITE(1,21000)
21000 FORMAT('+',53X,'Invalid control line action')
      RETURN
      END
      SUBROUTINE SBSENSE
C
C SBSENSE.  subroutine to perform sense/control function
C
C Local:
C BWAIT   - Flag for handling waits, passed to iseq
C     > 0 -> (-BWAIT) is the code for the wait command that has finished
C            where the status changed during the wait period
C     = 0 -> No wait operation has been involved for this sense line
C     < 0 -> BWAIT is the code for the wait command that has finished
C            where the status did not change during the wait period
C NUSTAT  - New status of sense line
C
      IMPLICIT  INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(B)
      DIMENSION QSNAME(6,40),QSABBR(40),BSTEXT(40),BSSTAT(40),SREP(40)
      DIMENSION QCNAME(6,40),QCABBR(40),BCTEXT(40),BCSTAT(40)
      LOGICAL*1 ALERT,MBEEP,ALARM,ABEEP,DOTEST
      BYTE      FAULTM,IGNORM,WAITM,MANM,TESTM,SSTM,CMANM,
     1          FAQOVM,OPCLVM,ONOFVM,UPDNVM,NUSTAT
      LOGICAL*1 PSSTAT,PCSTAT
C
      COMMON /SENTAB/ QSNAME,QSABBR,BSTEXT,BSSTAT,SREP
      COMMON /CONTAB/ QCNAME,QCABBR,BCTEXT,BCSTAT
      COMMON /MASKS/  FAULTM,IGNORM,WAITM,MANM,TESTM,SSTM,CMANM,
     1                FAQOVM,OPCLVM,ONOFVM,UPDNVM
      COMMON /NUMBER/ NLINES,NSTLOW,NSHIGH,NCHIGH,NSLOW,NCLOW
      COMMON /FLAGS/  ALERT,MBEEP,ALARM,ABEEP,DOTEST,ITEST,BTESTF
      COMMON /KEYS/   FAULT,GOOD,ON,OFF,YES,NO
C
      DATA   BREV/20/
C
      DO 60 II=1,NLINES
C
C     Set repeat count for noise immunity
      IREPT=6
C
C       See if we are performing a wait on this line
    1  BWAIT = BSSTAT(II).AND.WAITM
       IF (BWAIT.EQ.WAITM) GOTO 60
C
C        Set BWAIT = iiii lrrr  where rrr is the wait number
         IF (BWAIT.NE.0) BWAIT = BWAIT.OR.(.NOT.WAITM)
C        Set NUSTAT to be the new status as determined by bsstat(II) or by
C        psstat(II) depending on the IGNORE bit in bsstat(II).
         NUSTAT = BSSTAT(II).AND.FAULTM
         IF (((BSSTAT(II).AND.IGNORM)).NE.0) GOTO 5
          NUSTAT = FAULTM
          IF (PSSTAT(II)) NUSTAT = NUSTAT.XOR.FAULTM
C         If bstext(II)<0 then reverse the value of NUSTAT
          IF (BSTEXT(II).LT.0) NUSTAT = NUSTAT.XOR.FAULTM
C        See if status has changed since last examination
    5    IF (NUSTAT.EQ.((BSSTAT(II).AND.FAULTM))) GOTO 40
C
C        Examine IREPT times for noise immunity
C        Loop takes an estimated 200 microseconds
         IREPT=IREPT-1
         IF (IREPT.GT.0) GOTO 1
C
C         New status is different from old status
C         Set "fault" bit of bsstat to "fault" bit of nustat
          BSSTAT(II) = BSSTAT(II).AND.(.NOT.FAULTM)
          BSSTAT(II) = BSSTAT(II).OR.NUSTAT
C
          IF (NUSTAT.EQ.0) GOTO 20
C
C          Sense line is now fault
           IF (BWAIT.NE.0) GOTO 10
C           No wait operation is involved
            DADJ = DSADJ(II,FAULT,1)
            WRITE(1,1000)(QSNAME(I,II),I=1,6),BREV,DADJ,BREV
 1000       FORMAT('+',6A4,A1,A8,A1/)
            CALL EXSEQ(II,FAULT,OFF,BWAIT,WASOK)
            IF (ALERT) MBEEP = .TRUE.
            GOTO 60
C
C           Has just finished waiting
   10       DADJ = DSADJ(II,FAULT,1)
            WRITE(1,2000)(QSNAME(I,II),I=1,6),BREV,DADJ,BREV
 2000       FORMAT('+',6A4,' NOW',A1,A8,A1/)
            BWAIT = -BWAIT
            CALL EXSEQ(II,GOOD,OFF,BWAIT,WASOK)
            GOTO 60
C
C          Sense line is now good
   20       IF (BWAIT.NE.0) GOTO 30
```

```
C           No wait operation is involved
            DADJ = DSADJ(II, QOOD, 1)
            WRITE(1,1500)(QSNAME(I,II), I=1,6), DADJ
 1500       FORMAT('+',6A4,A8/)
            CALL EXSEQ(II,QOOD,ON,BWAIT,WASOK)
            GOTO 60
C
C           Has just finished waiting
   30       DADJ = DSADJ(II,QOOD,1)
            WRITE(1,2500)(QSNAME(I,II),I=1,6),DADJ
 2500       FORMAT('+',6A4,' NOW',A8/)
            BWAIT = -BWAIT
            CALL EXSEQ(II,FAULT,ON,BWAIT,WASOK)
            GOTO 60
C
C         Sense line status is unchanged
   40     IF (BWAIT.EQ.0) GOTO 60
C
C          Has just finished waiting
           IF (NUSTAT.EQ.0) GOTO 50
C
C           Sense line is still fault
            DADJ = DSADJ(II,FAULT,1)
            WRITE(1,3000)(QSNAME(I,II),I=1,6),BREV,DADJ,BREV
3000        FORMAT('+',6A4,' STILL',A1,A8,A1/)
            CALL EXSEQ(II,FAULT,OFF,BWAIT,WASOK)
            GOTO 60
C
C           Sense line is still good
   50       DADJ = DSADJ(II,QOOD,1)
            WRITE(1,3500)(QSNAME(I,II),I=1,6),DADJ
3500        FORMAT('+',6A4,' STILL',A8/)
            CALL EXSEQ(II,QOOD,ON,BWAIT,WASOK)
   60 CONTINUE
      RETURN
      END
      SUBROUTINE EXSEQ(II,FAQD,AONOFF,BAWAIT)
C
C EXSEQ. subroutine to execute a sense/control sequence
C
C Input.
C II      = Number of sense line whose sequence is to be executed
C FAQD    = FAULT -> Execute the "fault" sequence
C         = GOOD  -> Execute the "good" sequence
C ONOFF   = ON    -> Turn appropriate devices "on"
C         = OFF   -> Turn appropriate devices "off"
C BWAIT   > 0 -> (-BWAIT) is the code for the wait command that has finished
C                where the status changed during the wait period
C         = 0 -> No wait operation has been involved for this sense line
C         < 0 -> BWAIT is the code for the wait command that has finished
C                where the status did not change during the wait period
C
C Local
C BITEM   = Item from the control sequence being executed
C IBEQ    = Pointer to an item in the control sequence
C TIME    = Length of wait time
C DUNIT   = Units of wait time (minutes or seconds)
C NCORR   = Number of sense lines to correlate status
C ISEQ2   = Pointer to the item following the end of a correlation list
C
      IMPLICIT  INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(B)
      DIMENSION QSNAME(6,40),QSABBR(40),BSTEXT(40),BSSTAT(40),BREP(40)
      DIMENSION QCNAME(6,40),QCABBR(40),BCTEXT(40),BCSTAT(40)
      DIMENSION SFAULT(40),BQOOD(40),CON(40),COFF(40)
      DIMENSION WTIME(25),WLINE(25),BWMASK(25)
      BYTE      SEQUEN(2000)
      BYTE      FAULTM,IGNORM,WAITM,MANM,TESTM,BBTM,CMANM,
     1          FAQOVM,OPCLVM,ONOFVM,UPDNVM
      BYTE      SEQEND,SEQMAN,SEQRPT,SEQCOR,WAIT1,WAIT6
C
      COMMON /SENTAB/ QSNAME,QSABBR,BSTEXT,BSSTAT,BREP
      COMMON /CONTAB/ QCNAME,QCABBR,BCTEXT,BCSTAT
      COMMON /SEQPTR/ SFAULT,BQOOD,CON,COFF
      COMMON /SEQCOM/ SEQUEN
      COMMON /SEQCMD/ SEQEND,SEQMAN,SEQRPT,SEQCOR,WAIT1,WAIT6
      COMMON /MASKS/  FAULTM,IGNORM,WAITM,MANM,TESTM,BBTM,CMANM,
     1                FAQOVM,OPCLVM,ONOFVM,UPDNVM
      COMMON /NUMBER/ NLINES,NSTLOW,NSHIGH,NCHIGH,NBLOW,NCLOW
      COMMON /KEYS/   FAULT,GOOD,ON,OFF,YES,NO
      COMMON /WAIT/   WTIME,WLINE,BWMASK,WAIBIZ,DMIN,DSEC
C
      DATA    BREV/20/
C
      ISEQ = BQOOD(II)
      IF (FAQD.EQ.FAULT) ISEQ = SFAULT(II)
    5 ONOFF = AONOFF
      BWAIT = BAWAIT
C
   10 BITEM = SEQUEN(ISEQ)
      ITEM = BITEM
      AITEM = IABS(ITEM)
      ISEQ = ISEQ+1
      IF (ITEM.GT.NLINES) GOTO 30
       IF (BWAIT.LT.0) GOTO 10
C
C       We are not skipping to a wait command, change control line
        IF (BCBTAT(AITEM).NE.CMANM) GOTO 20
C        Line is under manual control
         WRITE(1,1000)(QCNAME(I,AITEM),I=1,6),BREV,BREV
 1000    FORMAT('+',6A4,' ',A1,'IS UNDER MANUAL CONTROL',A1/)
         GOTO 10
C
C        Turn line on or off
   20    CALL EXCSEQ(ITEM,ONOFF,0,WASOK)
         IF (WASOK.NE.YES) GOTO 10
C         Line is not blocked
          DADJ = DCADJ(AITEM,ONOFF,ITEM)
          WRITE(1,2000)(QCNAME(I,AITEM),I=1,6),DADJ
 2000     FORMAT('+',6A4,A8/)
          GOTO 10
C
C     Process end of sequence command
   30 IF (BITEM.NE.SEQEND) GOTO 40
C      Clear MANUAL ( and IGNORM )
C      IF ((BSSTAT(II).AND.MANM).EQ.MANM) BSSTAT(II) = BSSTAT(II) .AND.
C     1  (.NOT.MANM) .AND. (.NOT.IGNORM)
       BSSTAT(II) = BSSTAT(II) .AND. (.NOT.MANM)
       RETURN
C
C     Process manual command
   40 IF (BITEM.NE.SEQMAN) GOTO 60
       IF ((BSSTAT(II).AND.MANM).NE.MANM) GOTO 50
C       Have manual reset
        GOTO 10
C       Need manual reset
   50   WRITE(1,3000)BREV,BREV
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 3000   FORMAT('+',A1,'REQUIRES MANUAL RESET',A1/)
        RETURN
C
C     Process wait command
   60 IF (BITEM.LT.WAIT1.OR.BITEM.GT.WAIT6) GOTO 110
       BITEM = BITEM.OR.(.NOT.WAITM)
       IF (BWAIT.NE.0) GOTO 80
C       Execute a wait
        TIME = SEQUEN(ISEQ)
        ISEQ = ISEQ+1
        DUNIT = DMIN
        IF (TIME.GT.0) GOTO 70
C        Time is in seconds
         TIME = -TIME
         DUNIT = DSEC
   70   WRITE(1,4000)TIME,DUNIT
 4000   FORMAT('+WAIT',I3,' ',A8/)
        BSSTAT(II) = BSSTAT(II).OR.WAITM
        CALL WAISUB(TIME,DUNIT,II,BITEM)
        RETURN
C
C      Executed wait command found, status changed during wait
C      Stop processing sequence
   80  IF (BITEM.NE.-BWAIT) GOTO 90
        BSSTAT(II) = BSSTAT(II).AND.(.NOT.(WAITM.OR.MANM))
        ISEQ = ISEQ+1
        BITEM = SEQUEN(ISEQ)
        ISEQ = ISEQ+1
        IF (BITEM.NE.SEQRPT) RETURN
C
C        Process a repeat command
         ITEM = SEQUEN(ISEQ)
         ISEQ = ISEQ+1
C        Increment repeat count
         SREP(II) = SREP(II)+1
         IF (SREP(II).NE.ITEM+1) RETURN
C         Allowable number of repeats exceeded
          SREP(II) = SREP(II)+1
          BSSTAT(II) = FAULTM.OR.IONORM
          WRITE(1,3000)(QSNAME(I,II),I=1,6),BREV,BREV
 3000     FORMAT('+',6A4,' ',A1,'MAXIMUM REPEAT COUNT EXCEEDED',/,
     1     ' REQUIRES MANUAL RESET',A1/)
c         Reexecute sequence from start
          ONOFF = OFF
          BWAIT = 0
          ISEQ = SFAULT(II)
          GOTO 5
C
C      Executed wait command found, status did not change during wait
C      Stop skipping, resume normal processing.
   90  IF (BITEM.NE.BWAIT) GOTO 100
        BWAIT = 0
        BSSTAT(II) = BSSTAT(II).AND.(.NOT.WAITM)
C
C      Continue skipping to find executed wait command.
  100  ISEQ = ISEQ+1
       BITEM = SEQUEN(ISEQ)
       IF (BITEM.EQ.SEQEND) GOTO 30
       IF (BITEM.NE.SEQRPT) GOTO 10
C       Reset repeat counter if line is not being ignored
        IF ((BSSTAT(II).AND.IONORM).EQ.0) SREP(II) = 0
        ISEQ = ISEQ+2
        GOTO 10
C
C     Process correlate command
  110 IF (BITEM.NE.SEQCOR) GOTO 10
  120  NCORR = SEQUEN(ISEQ)
       ISEQ = ISEQ+1
       ISEQ2 = ISEQ+NCORR
       IF (BWAIT.LT.0) GOTO 200
C      Examine correlated sense lines
       IF (NCORR.EQ.0) GOTO 10
       DO 130 I=1,NCORR
        ITEM = SEQUEN(ISEQ)
        ISEQ = ISEQ+1
        IF (ITEM.LT.0) GOTO 125
         IF ((BSSTAT(ITEM).AND.FAULTM).NE.FAULTM) GOTO 150
         GOTO 130
  125    IF ((BSSTAT(-1*ITEM).AND.FAULTM).EQ.FAULTM) GOTO 150
  130  CONTINUE
C      Have correlation, continue processing control sequence
       GOTO 10
C
C      No correlation, if no wait, flush rest of this correlate command
  150  ISEQ = ISEQ2
       IF (BWAIT.GT.0) GOTO 180
  160  BITEM = SEQUEN(ISEQ)
       ISEQ = ISEQ+1
       IF (BITEM.EQ.SEQEND) RETURN
       IF (BITEM.EQ.SEQCOR) GOTO 120
       GOTO 160
C
C      No correlation, look for changed wait, if so then pretend correlation
  180  BITEM = SEQUEN(ISEQ)
       ISEQ = ISEQ+1
       IF (BITEM.EQ.SEQCOR) GOTO 120
       IF (BITEM.GE.WAIT1.AND.BITEM.LE.WAIT6)
     1  BITEM = BITEM.OR.(.NOT.WAITM)
       IF (BITEM.EQ.-BWAIT) GOTO 190
       GOTO 180
  190  ISEQ = ISEQ2
       GOTO 10
C
C      Skip test of correlation, continue skipping for an unchanged wait
  200  ISEQ = ISEQ2
       GOTO 10
      END
      SUBROUTINE EXCSEQ(II,ONOFF,ALWAYS,WASOK)
C
C EXCSEQ:  subroutine to execute a control inhibit sequence
C
C Input:
C II      = Number of control line whose inhibit sequence is to be executed.
C         < 0 -> Perform opposite operation to that specified by ONOFF
C ONOFF   = ON  -> Turn device "on"
C         = OFF -> Turn device "off"
C ALWAYS =  0 -> Execute sequence then turn device on or off if allowed
C         <> 0 -> Ignore sequence and turn device on or off
C
C Output.
C WASOK   = Device was successfully turned on or off
C
C Local:
C ITEM    = Item in control inhibit sequence
C ISEQ    = pointer to sequence
C
```

```
      IMPLICIT  INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(B)
      DIMENSION QSNAME(6,40),QSABBR(40),BBTEXT(40),BBSTAT(40),BREP(40)
      DIMENSION QCNAME(6,40),QCABBR(40),BCTEXT(40),BCBTAT(40)
      DIMENSION SFAULT(40),BQOOD(40),CON(40),COFF(40)
      BYTE      SEQUEN(2000)
      BYTE      BEQEND,SEQMAN,BEQRPT,BEQCOR,WAIT1,WAIT6
      BYTE      FAULTM,IGNORM,WAITM,MANM,TESTM,BBTM,CMANM,
     1          FAQOVM,OPCLVM,ONOFVM,UPDNVM
C
      COMMON /BENTAB/ QSNAME,QSABBR,BBTEXT,BBBTAT,BREP
      COMMON /CONTAB/ QCNAME,QCABBR,BCTEXT,BCBTAT
      COMMON /SEQPTR/ SFAULT,BQOOD,CON,COFF
      COMMON /SEQCOM/ SEQUEN
      COMMON /SEQCMD/ BEQEND,SEQMAN,BEQRPT,BEQCOR,WAIT1,WAIT6
      COMMON /MASKB/  FAULTM,IGNORM,WAITM,MANM,TESTM,BBTM,CMANM,
     1                FAQOVM,OPCLVM,ONOFVM,UPDNVM
      COMMON /KEYS/   FAULT,QOOD,ON,OFF,YES,NO
      COMMON /NUMBER/ NLINEB,NSTLOW,NSHIGH,NCHIGH,NSLOW,NCLOW
C
      II = AII
      ONOFF = AONOFF
      IF (II.GE.0) GOTO 20
C      Do inverse operation
       II = -II
       IF (ONOFF.EQ.ON) GOTO 10
       ONOFF = ON
       GOTO 20
   10  ONOFF = OFF
C
   20 WASOK = YES
      IF (BCTEXT(II).GE.0) GOTO 40
C      Do inverse operation
       IF (ONOFF.EQ.ON) GOTO 30
       ONOFF = ON
       GOTO 40
   30  ONOFF = OFF
C
   40 IF (ALWAYS.EQ.0) GOTO 60
C      Ignore sequences
       IF (ONOFF.EQ.ON) GOTO 50
       CALL SETCNT(II,.FALSE.)
       RETURN
   50  CALL SETCNT(II,.TRUE.)
       RETURN
C
C     Turn line on
   60 IF (ONOFF.EQ.OFF) GOTO 90
       ISEQ = CON(II)
   70  ITEM = SEQUEN(ISEQ)
       ISEQ = ISEQ+1
C      Examine inhibit sequence
       IF (IABS(ITEM).GE.NLINEB) GOTO 80
        IF (ITEM.LT.0) GOTO 72
         IF ((BSSTAT(ITEM).AND.FAULTM).NE.FAULTM) GOTO 70
         GOTO 73
   72    IF ((BSSTAT(-I*ITEM).AND.FAULTM).EQ.FAULTM) GOTO 70
   73    WRITE(1,1000)(QCNAME(I,II),I=1,6),(QSNAME(I,ITEM),I=1,6)
 1000    FORMAT('+',6A4,' BLOCKED BY ',6A4/)
         WASOK = NO
         GOTO 70
C      Line not inhibited
   80  IF (WASOK.EQ.YES) CALL SETCNT(II,.TRUE.)
       RETURN
C
C      Turn line off
   90  ISEQ = COFF(II)
  100  ITEM = SEQUEN(ISEQ)
       ISEQ = ISEQ+1
C      Examine inhibit sequence
       IF (IABS(ITEM).GE.NLINEB) GOTO 110
        IF (ITEM.LT.0) GOTO 102
         IF ((BSSTAT(ITEM).AND.FAULTM).EQ.FAULTM) GOTO 100
         GOTO 103
  102    IF ((BSSTAT(-I*ITEM).AND.FAULTM).NE.FAULTM) GOTO 100
  103    WRITE(1,1000)(QCNAME(I,II),I=1,6),(QSNAME(I,ITEM),I=1,6)
         WASOK = NO
         GOTO 100
C      Line not inhibited
  110  IF (WASOK.EQ.YES) CALL SETCNT(II,.FALSE.)
       RETURN
      END
      SUBROUTINE INTER
C
C INTER:  Subroutine to process once each second interupt
C
C  This subroutine is entered once each second as a result of the real time
C clock interupt.  The following operations are performed:
C 1 - The real time clock is updated.
C 2 - The remaining time for all wait operations is decremented.
C 3 - A "BELL" is sent to the terminal if necessary.
C 4 - One sense/control loop is tested.
C
      IMPLICIT  INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(B)
      DIMENSION QSNAME(6,40),QSABBR(40),BBTEXT(40),BBBTAT(40),BREP(40)
      DIMENSION QCNAME(6,40),QCABBR(40),BCTEXT(40),BCBTAT(40)
      BYTE      FAULTM,IGNORM,WAITM,MANM,TESTM,BBTM,CMANM,
     1          FAQOVM,OPCLVM,ONOFVM,UPDNVM
      DIMENSION WTIME(25),WLINE(25),BWMASK(25),AMONTH(12)
      DIMENSION BEEP(8),BBEEP(8)
      LOGICAL*1 ALERT,MBEEP,ALARM,ABEEP,DOTEST
      LOGICAL*1 PSSTAT,PCBTAT
      LOGICAL*1 NEWS,OLDS,OLDC
C
      COMMON /SENTAB/ QSNAME,QSABBR,BBTEXT,BBBTAT,BREP
      COMMON /CONTAB/ QCNAME,QCABBR,BCTEXT,BCBTAT
      COMMON /MASKS/  FAULTM,IGNORM,WAITM,MANM,TESTM,BBTM,CMANM,
     1                FAQOVM,OPCLVM,ONOFVM,UPDNVM
      COMMON /NUMBER/ NLINES,NSTLOW,NSHIGH,NCHIGH,NSLOW,NCLOW
      COMMON /TIME/   MONTH,IDAY,HOUR,MIN,SEC,ALAHR,ALAMIN
      COMMON /FLAGS/  ALERT,MBEEP,ALARM,ABEEP,DOTEST,ITEST,BTESTF
      COMMON /WAIT/   WTIME,WLINE,BWMASK,WAIBIZ,DMIN,DSEC
C
      DATA BEEP/7,7,7,7,7,27,91,65/,BBEEP/7,0,0,0,7,27,91,65/
      DATA AMONTH/31,28,31,30,31,30,31,31,30,31,30,31/
C
C     Increment real time clock
C
      SEC = SEC+1
      IF (SEC.NE.60) GOTO 5
       SEC = 0
       MIN = MIN+1
       IF (MIN.NE.60) GOTO 5
        MIN = 0
        HOUR = HOUR+1
C        Patch to keep correct time
        SEC=22
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        IF (HOUR.NE.24) GOTO 5
         HOUR = 0
         IDAY = IDAY+1
         IF (IDAY.LE.AMONTH(MONTH)) GOTO 5
          IDAY = 1
          MONTH = MONTH+1
          IF (MONTH.EQ.13) MONTH = 1
C
C     Print clock time
C
   5  CALL POKE(Z'F778',HOUR/10+Z'30')
      CALL POKE(Z'F779',HOUR-10*(HOUR/10)+Z'30')
      CALL POKE(Z'F77A',Z'3A')
      CALL POKE(Z'F77B',MIN/10+Z'30')
      CALL POKE(Z'F77C',MIN-10*(MIN/10)+Z'30')
      CALL POKE(Z'F77D',Z'3A')
      CALL POKE(Z'F77E',SEC/10+Z'30')
      CALL POKE(Z'F77F',SEC-10*(SEC/10)+Z'30')
C
C     Decrement wait times
C
      DO 20 I=1,MAIBIZ
       IF (WTIME(I).NE.1) GOTO 10
C       Wait is completed, signal the main program
        WTIME(I) = 0
        LINE = WLINE(I)
        BSSTAT(LINE) = BSSTAT(LINE).AND.BWMASK(I)
  10   IF (WTIME(I).GT.1) WTIME(I) = WTIME(I)-1
  20  CONTINUE
C
C     Check alarm time
C
      IF ( NOT.(ALARM.AND.(ALAMIN.EQ.MIN).AND.(ALAHR.EQ.HOUR))) GOTO 25
       ABEEP = .TRUE.
       ALARM = .FALSE.
C     Sound the alarm if needed
C  25 IF (ABEEP) WRITE(2,1000)BEEP
   25 CONTINUE
 1000 FORMAT(' ',BA1)
C
C     Sound the message beep
C     IF (MBEEP) WRITE(2,1000)BBEEP
C
C     Test one sense/control line
      IF ( NOT.DOTEST.OR.(BTESTF.NE.0)) GOTO 90
C     The test cannot be done if the sense line is already .false.
   27 IF (PSSTAT(ITEST).EQ.0) GOTO 80
       OLDC = PCSTAT(ITEST)
       TLINE = 1
C      Set for 7.5 msec delay
       IDELAY = 300
       IF (ITEST.LT.NSTLOW) GOTO 29
       TLINE = NSTLOW
       IDELAY = 1
   29  CALL SETCNT(TLINE,.FALSE.)
C      Wait for slow optical circuits
       DO 30 J=1,IDELAY
   30  CONTINUE
       OLDS = PSSTAT(ITEST)
       CALL SETCNT(ITEST,.NOT.OLDC)
C      Wait for slow optical circuits
       DO 50 J=1,IDELAY
   50  CONTINUE
       NEWS = PSSTAT(ITEST)
C      Restore lines
       CALL SETCNT(ITEST,OLDC)
       CALL SETCNT(TLINE,.TRUE.)
C      Dont return until line has settled
       DO 55 J=1,IDELAY
   55 CONTINUE
C
       IF (NEWS.EQ.OLDS) GOTO 70
C
C       Test loop is good
        IF ((BSSTAT(ITEST).AND.TESTM).NE.TESTM) GOTO 80
C        Has changed since last looked at
         BSSTAT(ITEST) = BSSTAT(ITEST).AND.(.NOT.TESTM)
         BTESTF = ITEST
         GOTO 80
C
C       Test loop is fault
   70   IF ((BSSTAT(ITEST).AND.TESTM).NE.0) GOTO 80
C        Has changed since last looked at
         BSSTAT(ITEST) = BSSTAT(ITEST).OR.TESTM
         IF (ALERT) MBEEP = .TRUE.
         BTESTF = -ITEST
C
C     Increment test line counter
   80  ITEST=ITEST+1
C      Skip low voltage test line
       IF (ITEST.EQ.NSTLOW) GOTO 80
       IF (ITEST.GT.NLINES) ITEST=2
C
C     Reenable one hertz interrupt
C  90 CALL ENINTR
   90 CONTINUE
      END
      SUBROUTINE TCSTAT(II)
C
C TCSTAT:  Type the status of one sense line
C
C Input.
C II = Number of the control line whose status is to be typed
C
      IMPLICIT  INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(B)
      DIMENSION QCNAME(6,40),QCABBR(40),BCTEXT(40),BCSTAT(40)
      BYTE      FAULTM,IQNORM,WAITM,MANM,TESTM,BSTM,CMANM,
     1          FAQOVM,OPCLVM,ONOFVM,UPDNVM
      LOGICAL*1 PCSTAT,PSSTAT
C
      COMMON /CONTAB/ QCNAME,QCABBR,BCTEXT,BCSTAT
      COMMON /MASKS/  FAULTM,IQNORM,WAITM,MANM,TESTM,BSTM,CMANM,
     1                FAQOVM,OPCLVM,ONOFVM,UPDNVM
      COMMON /KEYS/   FAULT,GOOD,ON,OFF,YES,NO
C
      DATA    BREV/20/,BNUL/0/
C
C     Read physical status and reverse if BCTEXT<0
      IF (PCSTAT(II).AND.(BCTEXT(II).GT.0)) GOTO 10
      IF ((PCSTAT(II).EQ.0).AND.(BCTEXT(II).LT.0)) GOTO 10
       DSTAT = DCADJ(II,OFF,1)
       GOTO 20
   10  DSTAT = DCADJ(II,ON,1)
C
C     Set reverse video flag if line is different from normal
   20 BPST = BNUL
```

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      IF((PCSTAT(II).EQ.0).AND.((BCTEXT(II).AND.UPDNVM).EQ.0))BPST=BREV
C
C     Write status line
      IF ((BCSTAT(II).AND.CMANM).EQ.CMANM) GOTO 30
       WRITE(1,1000)QCABBR(II),(QCNAME(I,II),I=1,6),BPST,DSTAT,BPST
1000   FORMAT('+',A3,2X,6A4,A1,A8,A1/)
       RETURN
   30  WRITE(1,2000)QCABBR(II),(QCNAME(I,II),I=1,6),BPST,DSTAT,BPST,
     1  BREV,BREV
2000   FORMAT('+',A3,2X,6A4,A1,A8,A1,' ',A1,'UNDER MANUAL CONTROL',A1/)
       RETURN
      END
      SUBROUTINE TSSTAT(II)
C
C TSSTAT: Type the status of one sense line
C
C Input:
C II = Number of the sense line whose status is to be typed
C
      IMPLICIT  INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(B)
      DIMENSION QSNAME(6,40),QSABBR(40),BSTEXT(40),BSSTAT(40),BREP(40)
      BYTE      FAULTM,IQNORM,WAITM,MANM,TESTM,BSTM,CMANM,
     1          FAQOVM,OPCLVM,ONOFVM,UPDNVM
      LOGICAL*1 PSSTAT,PCSTAT
C
      COMMON /SENTAB/ QSNAME,QSABBR,BSTEXT,BSSTAT,BREP
      COMMON /MASKS/  FAULTM,IQNORM,WAITM,MANM,TESTM,BSTM,CMANM,
     1                FAQOVM,OPCLVM,ONOFVM,UPDNVM
      COMMON /NUMBER/ NLINES,NSTLOW,NSHIGH,NCHIGH,NSLOW,NCLOW
      COMMON /KEYB/   FAULT,QOOD,ON,OFF,YES,NO
C
      DATA QNO/'NO  '/,QYES/'YES '/
      DATA DFAULT/'FAULT   '/,DQOOD/'QOOD    '/
      DATA BREV/20/,BNUL/0/
C
      IF (PSSTAT(II).AND.BSTEXT(II).QT.0) GOTO 10
      IF ((PSSTAT(II).EQ.0).AND.BSTEXT(II).LT.0) GOTO 10
       DLINE = DSADJ(II,FAULT,1)
       BLNR = BREV
       IF ((BSTEXT(II).AND.UPDNVM).NE.0) BLNR = BNUL
       GOTO 20
   10  DLINE = DSADJ(II,QOOD,1)
       BLNR = BNUL
   20 IF ((BSSTAT(II).AND.FAULTM).NE.FAULTM) GOTO 30
       DSTAT = DSADJ(II,FAULT,1)
       BSTR = BREV
       IF ((BSTEXT(II).AND.UPDNVM).NE.0) BSTR = BNUL
       GOTO 40
   30  DSTAT = DSADJ(II,QOOD,1)
       BSTR = BNUL
   40 IF ((BSSTAT(II).AND.IQNORM).EQ.IQNORM) GOTO 50
       QIGN = QNO
       BIGR = BNUL
       GOTO 60
   50  QIGN = QYES
       BIGR = BREV
   60 IF ((BSSTAT(II).AND.WAITM).EQ.WAITM) GOTO 70
       QWAIT = QNO
       GOTO 80
   70  QWAIT = QYES
   80 IF ((BSSTAT(II).AND.TESTM).EQ.TESTM) GOTO 90
       DTEST = DQOOD
       BTST = BNUL
       GOTO 100
   90  DTEST = DFAULT
       BTST = BREV
  100 WRITE (1,1000)QSABBR(II),(QSNAME(I,II),I=1,6),BLNR,DLINE,BLNR,
     1 BSTR,DSTAT,BSTR,BIGR,QIGN,BIGR,QWAIT,BTST,DTEST,BTST,BREP(II)
1000  FORMAT('+',A3,2X,6A4,A1,A8,2A1,A7,A1,2X,A1,A3,A1,4X,A3,
     1 3X,A1,A5,' ',A1,I3/)
      RETURN
      END
      SUBROUTINE WAISUB(TIME,DUNIT,LINE,BMASK)
C
C WAIT: subroutine to execute a wait using the real time clock
C
C Input:
C TIME   = Length of wait time
C DUNIT  = Units of wait time
C LINE   = Location to alter to signal completion
C BMASK  = Mask to use to signal completion
C
      IMPLICIT  INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(B)
      DIMENSION WTIME(25),WLINE(25),BWMASK(25)
      DIMENSION QSNAME(6,40),QSABBR(40),BSTEXT(40),BSSTAT(40),BREP(40)
C
      COMMON /SENTAB/ QSNAME,QSABBR,BSTEXT,BSSTAT,BREP
      COMMON /WAIT/   WTIME,WLINE,BWMASK,WAIBIZ,DMIN,DSEC
C
C     Look for free slot in table
      DO 10 I=1,WAIBIZ
       IF (WTIME(I).NE.0) GOTO 10
C      Enter wait operation into table
       IF (DUNIT.EQ.DMIN) TIME = TIME*60
       WTIME(I) = TIME
       WLINE(I) = LINE
       BWMASK(I) = BMASK
       RETURN
10    CONTINUE
C     Table is full
      WRITE(1,1000)
 1000 FORMAT(' Wait table is full, no wait performed.')
      BSSTAT(LINE) = BSSTAT(LINE).AND.BMASK
      RETURN
      END
      DOUBLE PRECISION FUNCTION DCADJ(II,ONOFF,NORREV)
C
C DCADJ: Return proper adjective to describe the state of a control line
C
C INPUT:
C II      = Number of the sense line
C ONOFF   = ON  -> Return the "on" adjective
C         = OFF -> Return the "off" adjective
C NORREV < 0 -> Return the opposite adjective
C        > 0 -> Return the normal adjective
C
C OUTPUT:
C The value of the function will be an 8 character string containing the
C proper adjective
C
      IMPLICIT INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(B)
      DIMENSION QCNAME(6,40),QCABBR(40),BCTEXT(40),BCSTAT(40)
      BYTE      FAULTM,IQNORM,WAITM,MANM,TESTM,BSTM,CMANM,
     1          FAQOVM,OPCLVM,ONOFVM,UPDNVM
C
      COMMON /CONTAB/ QCNAME,QCABBR,BCTEXT,BCSTAT
```

```
      COMMON /MASKB/   FAULTM, IQNORM, WAITM, MANM, TESTM, BBTM, CMANM,
     1                 FAQOVM, OPCLVM, ONOFVM, UPDNVM
      COMMON /KEYS/    FAULT, QOOD, ON, OFF, YES, NO
C
      DATA DOPEN/' OPEN    '/,DCLOSE/' CLOSED '/
      DATA DON/' ON      '/,DOFF/' OFF     '/
      DATA DUP/' UP      '/,DDOWN/' DOWN    '/
C
C     Decide which type of adjective to return
      IF (NORREV.GT.0 AND.ONOFF EQ OFF) GOTO 10
      IF (NORREV.LT.0.AND.ONOFF.EQ.ON) GOTO 10
C
C     Assign adjective
      IF ((BCTEXT(II).AND.ONOFVM).NE.0) DCADJ = DON
      IF ((BCTEXT(II).AND.OPCLVM).NE.0) DCADJ = DOPEN
      IF ((BCTEXT(II).AND.UPDNVM).NE.0) DCADJ = DUP
      RETURN
   10 IF ((BCTEXT(II).AND.ONOFVM).NE.0) DCADJ = DOFF
      IF ((BCTEXT(II).AND.OPCLVM).NE.0) DCADJ = DCLOSE
      IF ((BCTEXT(II).AND.UPDNVM).NE.0) DCADJ = DDOWN
      RETURN
      END
      DOUBLE PRECISION FUNCTION DBADJ(II,FAQO,NORREV)
C
C DBADJ: Return proper adjective to describe the state of a sense line
C
C Input:
C II     = Number of the sense line
C FAQO   = FAULT -> Return the "fault" adjective
C        = QOOD  -> Return the "good" adjective
C NORREV < 0 -> Return the opposite adjective
C        > 0 -> Return the normal adjective
C
C Output:
C The value of the function will be an 8 character string containing the
C proper adjective.
C
      IMPLICIT INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(8)
      DIMENSION QSNAME(6,40),QSABBR(40),BSTEXT(40),BSBTAT(40),BREP(40)
      BYTE       FAULTM, IQNORM, WAITM, MANM, TESTM, BBTM, CMANM,
     1           FAQOVM, OPCLVM, ONOFVM, UPDNVM
C
      COMMON /BENTAB/ QSNAME, QSABBR, BSTEXT, BSBTAT, BREP
      COMMON /MASKB/   FAULTM, IQNORM, WAITM, MANM, TESTM, BBTM, CMANM,
     1                 FAQOVM, OPCLVM, ONOFVM, UPDNVM
      COMMON /KEYB/    FAULT, QOOD, ON, OFF, YES, NO
C
      DATA DFAULT/' FAULT   '/,DQOOD/' QOOD    '/
      DATA DOPEN/' OPEN    '/,DCLOSE/' CLOSED '/
      DATA DON/' ON      '/,DOFF/' OFF     '/
      DATA DUP/' UP      '/,DDOWN/' DOWN    '/
C
C     Decide which type of adjective to return
      IF (NORREV.GT.0 AND.FAQO.EQ.QOOD) GOTO 10
      IF (NORREV.LT.0.AND.FAQO.EQ.FAULT) GOTO 10
C
C     Assign adjective
      IF ((BSTEXT(II).AND.FAQOVM).NE.0) DSADJ = DFAULT
      IF ((BSTEXT(II).AND.OPCLVM).NE.0) DSADJ = DOPEN
      IF ((BSTEXT(II).AND.ONOFVM).NE.0) DSADJ = DON
      IF ((BSTEXT(II).AND.UPDNVM).NE.0) DSADJ = DUP
      RETURN
   10 IF ((BSTEXT(II).AND.FAQOVM).NE.0) DSADJ = DQOOD
      IF ((BSTEXT(II).AND.OPCLVM).NE.0) DBADJ = DCLOSE
      IF ((BSTEXT(II).AND.ONOFVM).NE.0) DBADJ = DOFF
      IF ((BSTEXT(II).AND.UPDNVM).NE.0) DBADJ = DDOWN
      RETURN
      END
      SUBROUTINE DVM(NUM)
C
C DVM: Subroutine to read dvm
C
C NUM   = Channel number
C
      IMPLICIT INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(8)
      WRITE(1,1000)NUM
 1000 FORMAT(' DVM function not enabled for line ',I2)
      RETURN
      END
C
C TABLES: Block data
C
      BLOCK DATA TABLES
      IMPLICIT INTEGER*2(A,C,E-P,R-Z),REAL*4(Q),REAL*8(D),BYTE(8)
      DIMENSION QSNAME(6,40),QSABBR(40),BSTEXT(40),BSBTAT(40),BREP(40)
      DIMENSION QCNAME(6,40),QCABBR(40),BCTEXT(40),BCBTAT(40)
      COMMON /BENTAB/QSNAME,QSABBR,BSTEXT,BSBTAT,BREP
      COMMON /CONTAB/QCNAME,QCABBR,BCTEXT,BCBTAT
      COMMON /NUMBER/NLINES,NSTLOW,NSHIGH,NCHIGH,NSLOW,NCLOW
      DATA   NLINES/40/,NSTLOW/25/,NSHIGH/24/,NCHIGH/19/,
     1       NSLOW/14/,NCLOW/11/
C
C INITIALIZE SENSE/CONTROL TABLES
C
      DATA QSNAME/
     1 'HIGH',' VOL','TAGE',' STA','TUS ',' ',
     1 'FORE','PUMP',' 1 P','RESS','URE ',' ',
     1 'FORE','PUMP',' 2 P','RESS','URE ',' ',
     1 'DUOP','LASM','ATRO','N BO','X VA','CUUM',
     1 'CESI','UM B','OX V','ACUU','M   ',' ',
     1 'COIL',' BOX',' VAC','UUM ',' ',' ',
     1 'DIFF','USIO','N PU','MP 1',' THE','RMAL',
     1 'DIFF','USIO','N PU','MP 2',' THE','RMAL',
     1 'DIFF','USIO','N PU','MP 3',' THE','RMAL',
     1 'DIFF','USIO','N PU','MP 4',' THE','RMAL',
     1 'PROB','E WA','TER ',' ',' ',' ',
     1 'ANOD','E WA','TER ',' ',' ',' ',
     1 'ARC ','RESI','STOR',' MAT','ER  ',' ',
     1 'SPAR','E BE','NSE ','A   ',' ',' ',
     1 'SOUR','CE M','AGNE','T WA','TER ',' ',
     1 'SPAR','E BE','NSE ','C   ',' ',' ',
     1 'SPAR','E BE','NSE ','D   ',' ',' ',
     1 'SPAR','E BE','NSE ','E   ',' ',' ',
     1 'SPAR','E BE','NSE ','F   ',' ',' ',
     1 'SPAR','E BE','NSE ','G   ',' ',' ',
     1 'SPAR','E BE','NSE ','H   ',' ',' ',
     1 'STAN','DBY ','MODE',' ',' ',' ',
     1 'SPAR','E BE','NSE ','J   ',' ',' ',
     1 'OPER','ATIN','G MO','DE  ',' ',' ',
     1 'LOW ','VOLT','AGE ','STAT','US  ',' ',
     1 'FORE','PUMP',' 3 P','RESS','URE ',' ',
     1 'DIFF','USIO','N PU','MP 5',' THE','RMAL',
     1 'MIRR','OR B','OX V','ACUU','M   ',' ',
     1 'CHIL','LER ','FAIL','URE ',' ',' ',
     1 'OIL ','PRES','SURE',' ',' ',' ',
     1 'OIL ','TEMP','ERAT','URE ',' ',' ',
```

```
     1 'WATE','R PR','ESSU','RE  ','    ','    ',
     1 'WATE','R TE','MPER','ATUR','E   ','    ',
     1 '50 D','EGRE','E WA','TER ','PRES','SURE',
     1 '50 D','EGRE','E WA','TER ','TEMP','    ',
     1 '80 D','EGRE','E WA','TER ','PRES','SURE',
     1 '80 D','EGRE','E WA','TER ','TEMP','    ',
     1 'SAFE','TY I','NTER','LOCK','    ','    ',
     1 'SPAR','E SE','NSE ','L   ','    ','    ',
     1 'SPAR','E SE','NSE ','M   ','    ','    '/
C
      DATA QSABBR/
     1 'HVS ','FP1 ','FP2 ','DBV ','C9V ','C8V ','D1T ','D2T ',
     1 'D3T ','D4T ','PRW ','ANW ','ARW ','BSA ','BMW ','BSC ',
     1 'SSD ','SSE ','SSF ','SSG ','SSH ','SBY ','SSJ ','OPR ',
     1 'LVS ','FP3 ','D5T ','MBV ','CHL ','DLP ','OLT ','WAP ',
     1 'WAT ','P50 ','T50 ','P80 ','T80 ','BIL ','BSL ','BSM '/
C
C
C     -128=80hex, -127=81hex, -126=82hex, etc
      DATA BSTEXT/
     1 -127,01,01,01,01,01,01,01,
     1 01,01,01,01,01,02,01,02,
     1 02,02,02,02,02,-124,02,-124,
     1 -127,01,01,01,01,01,01,01,
     1 01,01,01,01,01,01,02,02/
C
      DATA QCNAME/
     1 'HIGH',' VOL','TAGE',' TEB','T   ','    ',
     1 'DIFF','USIO','N PU','MP 1','    ','    ',
     1 'DIFF','USIO','N PU','MP 2','    ','    ',
     1 'DIFF','USIO','N PU','MP 3','    ','    ',
     1 'DIFF','USIO','N PU','MP 4','    ','    ',
     1 'FREQ','N CO','MPRE','SSOR','    ','    ',
     1 'SPAR','E CO','NTRO','L A ','    ','    ',
     1 'ARC ','CURR','ENT ','    ','    ','    ',
     1 'FORE','LINE',' VAL','VE 1','    ','    ',
     1 'FORE','LINE',' VAL','VE 2','    ','    ',
     1 'FORE','LINE',' VAL','VE 3','    ','    ',
     1 'COIL',' CUR','RENT','B   ','    ','    ',
     1 'GATE',' VAL','VE 1','    ','    ','    ',
     1 'GATE',' VAL','VE 2','    ','    ','    ',
     1 'GATE',' VAL','VE 3','    ','    ','    ',
     1 'GATE',' VAL','VE 4','    ','    ','    ',
     1 'SPAR','E CO','NTRO','L B ','    ','    ',
     1 'SPIN',' DIR','ECTI','ON  ','    ','    ',
     1 'QUEN','CH  ','    ','    ','    ','    ',
     1 'SPAR','E CO','NTRO','L E ','    ','    ',
     1 'SPAR','E CO','NTRO','L F ','    ','    ',
     1 'SPAR','E CO','NTRO','L G ','    ','    ',
     1 'SPAR','E CO','NTRO','L H ','    ','    ',
     1 'SPAR','E CO','NTRO','L I ','    ','    ',
     1 'LOW ','VOLT','AGE ','TEST','    ','    ',
     1 'WATE','R CI','RCUL','ATIO','N PU','MP  ',
     1 'OIL ','CIRC','ULAT','ION ','PUMP','    ',
     1 'DIFF','USIO','N PU','MP 5','    ','    ',
     1 'SPAR','E CO','NTRO','L J ','    ','    ',
     1 'FORE','LINE',' VAL','VE 4','    ','    ',
     1 'AUDI','O AL','ARM ','    ','    ','    ',
     1 'FRAM','E VO','LTAG','E   ','    ','    ',
     1 'SPIN',' ROT','ATIO','N SO','LENI','OD  ',
     1 'CITY',' WAT','ER L','INE ','    ','    ',
     1 'GATE',' VAL','VE 5','    ','    ','    ',
     1 'SPAR','E CO','NTRO','L K ','    ','    ',
     1 'SPAR','E CO','NTRO','L L ','    ','    ',
     1 'SPAR','E CO','NTRO','L M ','    ','    ',
     1 'SPAR','E CO','NTRO','L N ','    ','    ',
     1 'SPAR','E CO','NTRO','L O ','    ','    '/
C
      DATA QCABBR/
     1 'HVT ','DP1 ','DP2 ','DP3 ','DP4 ','FRC ','BCA ','ARC ',
     1 'FV1 ','FV2 ','FV3 ','CCB ','QV1 ','QV2 ','QV3 ','QV4 ',
     1 'BCB ','SPN ','QUN ','BCE ','BCF ','BCG ','BCH ','BCI ',
     1 'LVT ','WCP ','DCP ','DP5 ','BCJ ','FV4 ','AUD ','FRV ',
     1 'BRS ','CWL ','QV5 ','BCK ','BCL ','BCM ','BCN ','BCO '/
C
C
      DATA BCTEXT/
     1 -124,04,04,04,04,04,04,04,
     1 02,02,02,04,02,02,02,02,
     1 02,08,04,04,04,04,04,04,
     1 -124,04,04,04,04,02,-124,04,
     1 04,02,02,04,04,04,04,04/
      END
```

```
;
; CLOCK INTERRUPT HANDLING
;
        EXT     INTER   ;ONCE EACH SECOND CLOCK UPDATE ROUTINE
;
CLKINT: PUSH    PSW     ;SAVE PSW
        LDA     CKBT    ;PICK UP 55HZ COUNTER
        DCR     A       ;DECREMENT
        STA     CKBT    ;UPDATE
        JNZ     CKOUT   ;BRANCH IF NON-ZERO
        MVI     A,55    ;ELSE RESET TO 55
        STA     CKBT
        PUSH    B       ;PUSH EVERYTHING
        PUSH    D
        PUSH    H
        CALL    INTER   ;AND GO DO CLOCK SUBROUTINE
        POP     H       ;THEN POP BACK
        POP     D
        POP     B
CKOUT:  IN      9       ;CLEAR CLOCK INTERRUPT
        IN      7       ;CHECK REMOTE KEYBOARD INPUT
        ANI     2
        JZ      CKOT5   ;IF NO INPUT
        IN      6       ;ELSE PICK IT UP
        ANI     7FH     ;STRIP EIGHTH BIT
        JMP     CKOT6
CKOT5:  IN      0       ;CHECK FLASHWRITER INPUT
        ANI     40H
        JZ      CKOT1   ;EXIT IF NO INPUT
        IN      1       ;ELSE PICK IT UP
        ANI     0F0H    ;CHECK NUMERIC
        XRI     030H
        JZ      CKOT7   ;PASS NUMBERS THROUGH
        IN      1       ;LOAD IT AGAIN
        ANI     0DFH    ;MAKE LOWER CASE UPPER
        JNZ     CKOT6   ;SPECIAL PATCH FOR ZAPPED ENCODER
        MVI     A,20H   ;MAKE NULLS SPACES
        JMP     CKOT6
CKOT7:  IN      1       ;LOAD NUMBER BACK
CKOT6:  PUSH    H       ;SAVE HL
        PUSH    D       ;AND DE
        LHLD    LINEP   ;LOAD SCREEN POINTER
        XCHG
        STAX    D       ;ECHO CHAR TO FLASHWRITER
        INX     D
        XCHG
        SHLD    LINEP   ;AND INCREMENT SCREEN POINTER
        LHLD    PINDX   ;LOAD INDEX POINTER
        XCHG
        STAX    D       ;STORE CHAR
        XRI     08H     ;CHECK FOR BACKSPACE
        JNZ     CKOT3   ;IF NOT
        MVI     A,20H   ;ELSE LOAD BLANK
        LHLD    LINEP   ;GET LINE POINTER BACK
        XCHG
        DCX     D       ;BACK UP TO PREV CHAR (THIS IS REALLY MESSY)
        STAX    D       ;ERASE GARBAGE RUBOUT CHAR
        DCX     D       ;BACK UP POINTER
        STAX    D       ;AND ERASE OFFENDING CHAR
        XCHG
        SHLD    LINEP   ;UPDATE LINE POINTER
        LHLD    PINDX   ;GET INDEX POINTER BACK
        XCHG
        DCX     D       ;MOVE BACK ONE CHAR
        JMP     CKOT4   ;FANCY UPDATE HERE
CKOT3:  LDAX    D       ;PICK UP CHAR AGAIN
        INX     D
CKOT4:  XCHG
        SHLD    PINDX   ;INCREMENT INDEX (OR INDEED DECREMENT)
        XRI     0DH     ;CHECK FOR CR
        JNZ     CKOT2   ;EXIT IF NOT
        MVI     A,20H   ;ELSE LOAD BLANK
        LHLD    LINEP   ;PICK UP LINE POINTER
        XCHG
        DCX     D       ;BACK UP POINTER
        STAX    D       ;AND ERASE GARBAGE CHAR
        MVI     A,1H    ;SET FLAG TO SIGNAL LINE READY
        LHLD    P2AD    ;PICK UP FLAG ADDRESS
        XCHG
        STAX    D       ;STORE A ONE THERE
        LHLD    P1AD
        SHLD    PINDX   ;RESET INDEX TO START OF BUFFER
        LHLD    LASTL
        SHLD    LINEP   ;RESET SCREEN POINTER TO START OF LINE
CKOT2:  POP     D       ;RESTORE DE
        POP     H       ;AND HL
CKOT1:  EI              ;ENABLE INTERRUPTS
        POP     PSW     ;RESTORE PSW
        RET             ;AND EXIT
CKBT:   DB      55      ;55HZ COUNTER
LASTL:  DW      0F75AH  ;ADDRESS OF LAST SCREEN LINE
LINEP:  DW      0F75AH  ;CURRENT SCREEN POINTER
;
;   INTERRUPT ENABLE ROUTINE
;   CALL ENABLI(ARRAY,FLAG)
;    WHERE ARRAY (LOGICAL*1) BECOMES INPUT BUFFER
;          FLAG  (LOGICAL*1) BECOMES NON-ZERO ON CR TO SIGNAL BUF READY
ENTRY   ENABLE
ENABLE: SHLD    P1AD    ;SAVE P1 ADDRESS (ARRAY)
        SHLD    PINDX   ;SET INDEX POINTER
        XCHG
        SHLD    P2AD    ;SAVE P2 ADDRESS (FLAG)
        LHLD    CTAD    ;LOAD CLOCK INT TRANSFER ADDRESS
        SHLD    39H     ;STORE IT
        MVI     A,0FFH  ;ENABLE CROMEMCO OUTPUT LINES
        OUT     26H
        IN      6       ;CLEAR INITIAL CHARACTER
        IN      7       ;CLEAR INITIAL CHARACTER
        IN      0       ;CLEAR INITIAL CHARACTER
        IN      1       ;CLEAR INITIAL CHARACTER
        EI              ;ENABLE CLOCK INTERRUPTS
        RET
CTAD:   DW      CLKINT  ;INTERRUPT TRANSFER ADDRESS
P1AD:   DW      0
P2AD:   DW      0
PINDX:  DW      0
        END
;
; I/O SUBROUTINES FOR CROMENCO BOARD SENSE AND CONTROL LINES
;
;  READS INPUT SENSE LINES
;  FUNCTION PSSTAT(I)
;    WHERE I IS (INTEGER*1) SENSE LINE NUMBER
ENTRY   PSSTAT
PSSTAT: XCHG            ;PUT FIRST PARAM ADDR IN DE
```

```
        LDAX    D       ;LOAD PARAM VALUE
        CALL    DBRM    ;GENERATE PORT AND BIT
        ADI     30H     ;ADD OFFSET ADDRESS TO PORT
        STA     PSB1+1  ;PLANT PORT
PSB1:   IN      0       ;READ PORT
        ANA     B       ;MASK OUT BIT
        ANA     A       ;CHECK IF ZERO
        JZ      PSB2    ;YES
        MVI     A,0FFH  ;ELSE SET ALL ONES
PSB2:   MOV     C,A     ;SAVE IN C
        LDA     CLAS    ;PICK UP PORT #
        CPI     2
        JP      PSB3    ;JUMP IF Q.E. 2
        MOV     A,C
        XRI     0FFH    ;ELSE COMPLEMENT RESULT
        MOV     C,A
PSB3:   MOV     A,C     ;RESULT IN A FOR LOGICAL FUNCTION RETURN
        MOV     H,A     ;PUT INTO (HL) FOR INTEGER FUNCTION RETURN
        MOV     L,A
        RET             ;EXIT
;
;  READS CONTROL LINE STATUS
;  FUNCTION PCSTAT(I)
;     WHERE I IS (INTEGER*1) CONTROL LINE NUMBER
ENTRY   PCSTAT
PCSTAT: XCHG            ;PUT PARAM ADDR IN DE
        LDAX    D       ;LOAD PARAM VALUE
        CALL    DBRM    ;GENERATE PORT AND BIT
        ADI     20H     ;ADD OFFSET ADDRESS TO PORT
        STA     PCB1+1  ;PLANT
PCB1:   IN      0       ;READ PORT
        ANA     B       ;MASK OUT BIT
        ANA     A       ;TEST ZERO RESULT
        JZ      PCB2    ;IF ZERO
        MVI     A,0FFH  ;ELSE SET ALL ONES
PCB2:   MOV     C,A     ;SAVE IN C
        LDA     CLAS    ;PICK UP PORT #
        CPI     3       ;CHECK LT 3
        JM      PCB3    ;YES, EXIT WITH RESULT
        MOV     A,C
        XRI     0FFH    ;COMPLEMENT RESULT IF GT 3
        MOV     C,A
PCB3:   MOV     A,C     ;RESULT IN A
        MOV     H,A     ;AND (HL)
        MOV     L,A
        RET
;
;  SET CONTROL LINE
;  CALL SETCNT(I,L)
;     WHERE I IS (INTEGER*1) CONTROL LINE NUMBER
;           L IS (LOGICAL*1) VALUE TO SET PORT TO
ENTRY   SETCNT
SETCNT: XCHG            ;PARAM ADDR IN DE
        LDAX    D       ;LOAD BYTE INTO A
        CALL    DBRM    ;GENERATE PORT AND BIT
        ADI     20H     ;GENERATE PORT ADDRESS
        STA     CLIN+1  ;PLANT
        STA     CLOUT+1 ;TWICE
        XCHG            ;SECOND PARAM
CLIN:   IN      0       ;PICK UP THE WORD
        MOV     C,A     ;SAVE IT
        LDAX    D       ;PICK UP SECOND ARG
        ANA     A       ;SET Z BIT
        JNZ     PASB
        LDA     CLAS    ;PORT NUMBER TO A
        CPI     3       ;IF LESS THAN 3,
        JM      CLON    ;GO ON
        JMP     PASB2   ;ELSE COMPLEMENT LOGIC STATE
CLON:   MOV     A,B     ;ZERO THE BIT IF ARG 2 ZERO
        XRI     0FFH
        ANA     C
        JMP     CLOUT
PASB:   LDA     CLAS    ;PORT NUMBER TO A
        CPI     3       ;IF LESS THAN 3,
        JM      PASB2   ;GO ON
        JMP     CLON    ;ELSE COMPLEMENT LOGIC STATE
PASB2:  MOV     A,C     ;SET THE BIT IF ARG 2 NONZERO
        ORA     B       ;SET THE BIT
CLOUT:  OUT     0       ;OUTPUT IT
        RET             ;AND EXIT
CLAS:   DB      0
;
;  SUBROUTINE TO GENERATE PORT AND BIT #
;  ENTERS WITH LINE NUMBER IN A
;  RETURNS WITH PORT # IN A AND CORRECT BIT SET IN B
;
DBRM:   DCR     A       ;COUNT FROM 1 NOT 0
        MVI     B,7H    ;LOAD MASK
        MOV     C,A
        ANA     B       ;BIT # TO B
        MOV     B,A
        MOV     A,C
        RAR             ;DIVIDE BY 8
        RAR
        RAR
        ANI     1FH     ;PORT # TO A
        MOV     C,A
        CPI     3       ;CHECK IF GT 2
        JM      DBRP    ;NO, JUMP
        INR     C       ;ELSE SPACE OVER GAP
DBRP:   MVI     A,1H    ;PUT 1 IN A
        INR     B       ;OFFSET BIT COUNT BY 1
DBLP:   DCR     B       ;DEC B
        JZ      DBOT    ;RETURN IF ZERO
        RLC             ;SHIFT A LEFT
        JMP     DBLP    ;LOOP UNTIL DONE
DBOT:   MOV     B,A     ;BIT INTO B
        MOV     A,C     ;PORT TO A
        STA     CLAS    ;SAVE PORT #
        RET
        END
;
; SEQUEN: Action sequence definitions
;
        TITLE   SEQUEN  PIB MICRO ACTION SEQUENCES
        COMMON  /SEQCMD/
;DEFINE SENSE AND CONTROL LINE NAMES
HVS   EQU 1
FP1   EQU 2
FP2   EQU 3
DBV   EQU 4
CSV   EQU 5
CBV   EQU 6
D1T   EQU 7
D2T   EQU 8
D3T   EQU 9
```

```
D4T     EQU 10
PRW     EQU 11
ANW     EQU 12
ARW     EQU 13
SMW     EQU 15
SBY     EQU 22
OPR     EQU 24
LVS     EQU 25
FP3     EQU 26
D3T     EQU 27
MBV     EQU 28
CHL     EQU 29
OLP     EQU 30
OLT     EQU 31
WAP     EQU 32
WAT     EQU 33
P30     EQU 34
T30     EQU 35
PB0     EQU 36
TB0     EQU 37
BIL     EQU 38
;
HVT     EQU 1
DP1     EQU 2
DP2     EQU 3
DP3     EQU 4
DP4     EQU 5
FRC     EQU 6
SCA     EQU 7
ARC     EQU 8
FV1     EQU 9
FV2     EQU 10
FV3     EQU 11
CCB     EQU 12
QV1     EQU 13
QV2     EQU 14
QV3     EQU 15
QV4     EQU 16
SPN     EQU 18
GUN     EQU 19
LVT     EQU 25
WCP     EQU 26
OCP     EQU 27
OP3     EQU 28
FV4     EQU 30
AUD     EQU 31
FRV     EQU 32
SRS     EQU 33
CHL     EQU 34
QV5     EQU 35
;
WAIT1   EQU     010000018
WAIT2   EQU     010000108
WAIT3   EQU     010000118
WAIT4   EQU     010001008
WAIT5   EQU     010001018
WAIT6   EQU     010001108
SQMAN   EQU     010010008
SQRPT   EQU     010100008
SQCOR   EQU     010110008
SQEND   EQU     011110008
;
;       MAKE ACTUAL COMMON BLOCK
;       DB      SQEND,SQMAN,SQRPT,SQCOR,WAIT1,WAIT6
;
; DEFINE ACTION SEQUENCES
;
; SBY AND OPR ARE SENSE LINES THAT INDICATE THE USAGE STATUS OF THE PIB
;   SBY .EQ. ON IMPLIES TURNON PROCEDURE IS IN PROGRESS - COMPUTER
;               IGNORES MANY VACUUM FAULTS AND GLOWB RESPONSES.
;   OPR .EQ. ON IMPLIES AN EXPERIMENT IS RUNNING.  DELAYS ARE INSERTED
;               BEFORE PERFORMING ACTIONS THAT WILL LOSE THE BEAM.
;               (OPR.EQ ON MEANS ALSO SBY.EQ ON)
;
        COMMON  /SEQCOM/
SEQSTR  EQU  HVSF
;
;DEFINE SENSE LINE SEQUENCES
;
HVSF:   DB      -AUD,SQEND
HVSQ    EQU     HVSF
FP1F:   DB      SQCOR,2,SBY,-OPR,FV1,FV2,WAIT1,3,-AUD,WAIT2,1,ARC
        DB      QV1,QV2,DP1,DP2
        DB      SQCOR,1,OPR,-AUD,WAIT3,-5,FV1,FV2,ARC,QV1,QV2,DP1,DP2
        DB      SQCOR,1,-SBY,-AUD,FV1,FV2,QV1,QV2,DP1,DP2
        DB      SQEND
FP1Q:   DB      -AUD
        DB      SQCOR,2,SBY,-OPR,FV1,FV2
        DB      SQCOR,1,OPR,FV1,FV2,WAIT1,5,SQRPT,5,QV1,QV2,DP1,DP2
        DB      SQEND
FP2F:   DB      -AUD,FRV,DP3,DP4,FV3,SQEND
FP2Q:   DB      -AUD,FV3,WAIT1,1,SQRPT,5,DP3,DP4,SQEND
DBVF:   DB      WAIT1,-5,-AUD,WAIT2,-15,DP2,DP1,SQEND
DBVQ    DB      -AUD,DP1,DP2,SQEND
CSVF:   DB      -AUD,SQEND
CSVQ:   DB      -AUD,SQEND
CBVF:   DB      WAIT1,-5,-AUD,WAIT2,-15,DP3,DP4
        DB      WAIT3,1,QV3,QV4,FRV,SQEND
CBVQ:   DB      -AUD,DP3,DP4,QV3,QV4,SQEND
D1TF:   DB      DP1,SQEND
D1TQ    EQU     D1TF
D2TF:   DB      DP2,SQEND
D2TQ    EQU     D2TF
D3TF:   DB      DP3,SQCOR,1,D4T,FRV,SQEND
D3TQ:   DB      DP3,SQEND
D4TF:   DB      DP4,SQCOR,1,D3T,FRV,SQEND
D4TQ:   DB      DP4,SQEND
PRWF:   DB      -AUD,WAIT1,-15,ARC,SQEND
PRWQ:   DB      -AUD,ARC,SQEND
ANWF    EQU     PRWF
ANWQ    EQU     PRWQ
ARWF    EQU     PRWF
ARWQ    EQU     PRWQ
SMWF    EQU     PRWF
SMWQ    EQU     PRWQ
SBYF    EQU     NONE
SBYQ    EQU     NONE
OPRF    EQU     NONE
OPRQ    EQU     NONE
LVSF    EQU     HVSF
LVSQ    EQU     HVSQ
FP3F    DB      -AUD,FV4,DP5,QV5,FRV,SQEND
FP3Q:   DB      -AUD,FV4,WAIT1,5,SQRPT,5,QV5,WAIT2,5,DP5,SQEND
D5TF:   DB      DP5,WAIT1,2,-AUD,WAIT2,1,FRV,SQEND
D5TQ:   DB      -AUD,DP5,SQEND
MBVF    DB      WAIT1,-5,-AUD,WAIT2,-15,DP5
```

```
        DB      WAIT3,2,QV5,FRV,SQEND
MBVQ:   DB      -AUD,DP5,QV5,SQEND
CHLF:   DB      -AUD,WAIT1,30,CC6,SR5,ARC,DP1,DP2,DP3,DP4,FRC
        DB      WAIT2,20,WCP,OCP,SQEND
CHLQ:   DB      -AUD,SQMAN,WCP,OCP,WAIT1,-15,DP1,DP2
        DB      DP3,DP4,FRC,ARC,SR5,CC8,BQEND
DLPF:   DB      -AUD,WAIT1,-10,OCP,SR5,CC8,SQEND
DLPQ:   DB      -AUD,SQMAN,OCP,SR8,CC8,WAIT1,-10,BQEND
DLTF:   DB      -AUD,WAIT1,1,SR8,CC9,WAIT2,20,OCP,BQEND
DLTQ    EQU     DLPQ
WAPF:   DB      -AUD,WAIT1,-10,ARC,DP1,DP2,DP3,DP4,FRC,WCP,BQEND
WAPQ:   DB      -AUD,SQMAN,WCP,FRC,DP4,DP3,DP2,DP1,ARC,WAIT1,-10,SQEND
WATF:   DB      -AUD,WAIT1,1,DP2,DP3,DP4,WAIT2,10,DP1,FRC,ARC,BQEND
WATQ:   DB      -AUD,FRC
        DB      SQCOR,1,-BBY,WAIT1,5
        DB      SQCOR,0,DP1,DP2,DP3,DP4,ARC,BQEND
P50F:   DB      -AUD,WAIT1,10,CC8,SR5,ARC,DP1,DP2,DP3,DP4,FRC
        DB      WAIT2,20,WCP,OCP,SQEND
P50Q    EQU     CHLQ
T50F:   DB      -AUD,WAIT1,20,CC8,SR8,ARC,DP1,DP2,DP3,DP4,FRC,WAIT2,20
        DB      WCP,OCP,BQEND
T50Q    EQU     CHLQ
PB0F:   DB      -AUD,DP5,WAIT1,1,FRV,BQEND
PB0Q:   DB      -AUD,DP5,BQEND
TB0F:   EQU     PB0F
TB0Q    EQU     PB0Q
SILF:   DB      FRV,BQEND
SILQ    EQU     SILF
SSSF:   DB      WAIT1,-2,SQRPT,5,BQEND
SSSQ    EQU     NONE
;
;DEFINE CONTROL LINE INHIBIT SEQUENCES
;
NONE    DB      SQEND
HVTON   EQU     NONE
HVTOF   EQU     NONE
DP1ON:  DB      D1T,FP1,WAT,WAP,BQEND
DP1OF   EQU     NONE
DP2ON:  DB      D2T,FP1,WAT,WAP,BQEND
DP2OF   EQU     NONE
DP3ON:  DB      D3T,FP2,WAT,WAP,BQEND
DP3OF   EQU     NONE
DP4ON:  DB      D4T,FP2,WAT,WAP,BQEND
DP4OF   EQU     NONE
FRCON:  DB      WAT,WAP,BQEND
FRCOF   EQU     NONE
ARCON:  DB      PRW,ANW,ARW,BQEND
ARCOF   EQU     NONE
FV1ON:  DB      FP1,BQEND
FV1OF   EQU     NONE
FV2ON   EQU     FV1ON
FV2OF   EQU     NONE
FV3ON   EQU     FP2,BQEND
FV3OF   EQU     NONE
CCSON   DB      DLT,DLP,BQEND
CCSOF   EQU     NONE
QV1ON   EQU     FV1ON
QV1OF   EQU     NONE
QV2ON   EQU     FV1ON
QV2OF   EQU     NONE
QV3ON:  DB      FP2,BQEND
QV3OF   EQU     NONE
QV4ON   EQU     QV3ON
QV4OF   EQU     NONE
SPNON   EQU     NONE
SPNOF   EQU     NONE
QUNON   EQU     NONE
QUNOF   EQU     NONE
LVTON   EQU     NONE
LVTOF   EQU     NONE
WCPON   EQU     NONE
WCPOF   EQU     NONE
OCPON   EQU     NONE
OCPOF   EQU     NONE
DP5ON:  DB      D5T,FP3,PB0,TB0,BQEND
DP5OF   EQU     NONE
FV4ON:  DB      FP3,BQEND
FV4OF   EQU     NONE
AUDON   EQU     NONE
AUDOF   EQU     NONE
FRVON:  DB      SIL,BQEND
FRVOF   EQU     NONE
SRSON   EQU     CCSON
SRSOF   EQU     NONE
CHLON   EQU     NONE
CHLOF   EQU     NONE
QV5ON   EQU     FV4ON
QV5OF   EQU     NONE
SCSON   EQU     NONE
SC5OF   EQU     NONE
;
; Initialize sequence pointers
;
        COMMON  /SEQPTR/
;
;
;DEFAULT POINTERS
        DW      MVSF-SEQSTR+1
        DW      FP1F-SEQSTR+1
        DW      FP2F-SEQSTR+1
        DW      DBVF-SEQSTR+1
        DW      CSVF-SEQSTR+1
        DW      CBVF-SEQSTR+1
        DW      D1TF-SEQSTR+1
        DW      D2TF-SEQSTR+1
        DW      D3TF-SEQSTR+1
        DW      D4TF-SEQSTR+1
        DW      PRWF-SEQSTR+1
        DW      ANWF-SEQSTR+1
        DW      ARWF-SEQSTR+1
        DW      SSSF-SEQSTR+1
        DW      SMWF-SEQSTR+1
        DW      SSSF-SEQSTR+1
        DW      SSSF-SEQSTR+1
        DW      SSSF-SEQSTR+1
        DW      SSSF-SEQSTR+1
        DW      SSSF-SEQSTR+1
        DW      SSSF-SEQSTR+1
        DW      SBYF-SEQSTR+1
        DW      SSSF-SEQSTR+1
        DW      OPRF-SEQSTR+1
        DW      LVSF-SEQSTR+1
        DW      FP3F-SEQSTR+1
        DW      D5TF-SEQSTR+1
        DW      MBVF-SEQSTR+1
        DW      CHLF-SEQSTR+1
```

```
        DW      OLPF-SEQSTR+1
        DW      OLTF-SEQSTR+1
        DW      WAPF-SEQSTR+1
        DW      WATF-SEQBTR+1
        DW      P3OF-SEQ9TR+1
        DW      T3OF-SEQSTR+1
        DW      P8OF-SEQSTR+1
        DW      T8OF-SEQSTR+1
        DW      S1LF-SEQSTR+1
        DW      SSSF-SEQSTR+1
        DW      S8SF-SEQ6TR+1

;8000D POINTERS
        DW      HVSQ-SEQ9TR+1
        DW      FP1Q-SEQ9TR+1
        DW      FP2Q-SEQ6TR+1
        DW      DBVQ-SEQSTR+1
        DW      CSVQ-SEQ8TR+1
        DW      CBVQ-SEQ8TR+1
        DW      D1TQ-SEQ6TR+1
        DW      D2TQ-SEQ8TR+1
        DW      D3TQ-SEQ9TR+1
        DW      D4TQ-SEQ8TR+1
        DW      PRWQ-SEQ9TR+1
        DW      ANWQ-SEQ6TR+1
        DW      ARWQ-SEQ8TR+1
        DW      6SSQ-SEQ8TR+1
        DW      6MWQ-SEQ8TR+1
        DW      SSSG-SEQ6TR+1
        DW      SSBQ-SEQ8TR+1
        DW      SSSQ-SEQ8TR+1
        DW      SSSG-SEQ8TR+1
        DW      6SSQ-SEQ8TR+1
        DW      SSSQ-SEQ8TR+1
        DW      SBYQ-SEQ8TR+1
        DW      SSSQ-SEQ8TR+1
        DW      OPRQ-SEQ8TR+1
        DW      LVSQ-SEQ9TR+1
        DW      FP3Q-SEQ8TR+1
        DW      D5TQ-SEQ8TR+1
        DW      MBVQ-SEQ8TR+1
        DW      CHLQ-SEQ8TR+1
        DW      OLPQ-SEQ8TR+1
        DW      OLTQ-SEQ9TR+1
        DW      WAPQ-SEQ8TR+1
        DW      WATQ-SEQ8TR+1
        DW      P5OG-SEQ8TR+1
        DW      T5OQ-SEQ8TR+1
        DW      P8OG-SEQ8TR+1
        DW      T8OQ-SEQ8TR+1
        DW      S1LQ-SEQ8TR+1
        DW      6SSQ-SEQ9TR+1
        DW      6SSQ-SEQBTR+1

;CON POINTERS
        DW      HVTON-SEQ8TR+1
        DW      DP1ON-SEQ8TR+1
        DW      DP2ON-SEQ8TR+1
        DW      DP3ON-SEQ8TR+1
        DW      DP4ON-SEQ9TR+1
        DW      FRCON-SEQ8TR+1
        DW      SCSON-SEQ8TR+1
        DW      ARCON-SEQ8TR+1
        DW      FV1ON-SEQBTR+1
        DW      FV2ON-SEQ8TR+1
        DW      FV3ON-SEQ8TR+1
        DW      CCSON-SEQ8TR+1
        DW      QV1ON-SEQ8TR+1
        DW      QV2ON-SEQ8TR+1
        DW      QV3ON-SEQ9TR+1
        DW      QV4ON-SEQ8TR+1
        DW      BCBON-SEQ8TR+1
        DW      SPNON-SEQ8TR+1
        DW      QUNON-SEQ8TR+1
        DW      SCSON-SEQ9TR+1
        DW      SCSON-SEQBTR+1
        DW      SCSON-SEQ8TR+1
        DW      SCSON-SEQ8TR+1
        DW      SCSON-SEQ6TR+1
        DW      LVTON-SEQ8TR+1
        DW      WCPON-SEQ8TR+1
        DW      OCPON-SEQ8TR+1
        DW      DP5ON-SEQ8TR+1
        DW      SCSON-SEQ8TR+1
        DW      FV4ON-SEQ9TR+1
        DW      AUDON-SEQ8TR+1
        DW      FRVON-SEQBTR+1
        DW      SASON-SEQ8TR+1
        DW      CWLON-SEQ8TR+1
        DW      QV5ON-SEQ8TR+1
        DW      SCBON-SEQ8TR+1
        DW      SCSON-SEQ8TR+1
        DW      BCSON-SEQBTR+1
        DW      SCSON-SEQ8TR+1
        DW      BCSON-SEQ8TR+1

;COFF POINTERS
        DW      HVTOF-SEQBTR+1
        DW      DP1OF-SEQ8TR+1
        DW      DP2OF-SEQ8TR+1
        DW      DP3OF-SEQ8TR+1
        DW      DP4OF-SEQ8TR+1
        DW      FRCOF-SEQ8TR+1
        DW      SCSOF-SEQ8TR+1
        DW      ARCOF-SEQ6TR+1
        DW      FV1OF-SEQ8TR+1
        DW      FV2OF-SEQ8TR+1
        DW      FV3OF-SEQ8TR+1
        DW      CCSOF-SEQ8TR+1
        DW      QV1OF-SEQ8TR+1
        DW      QV2OF-SEQ8TR+1
        DW      QV3OF-SEQ6TR+1
        DW      QV4OF-SEQ8TR+1
        DW      SCSOF-SEQ8TR+1
        DW      BPNOF-SEQ8TR+1
        DW      QUNOF-SEQ8TR+1
        DW      SCSOF-SEQ8TR+1
        DW      SCSOF-SEQ8TR+1
        DW      SCSOF-SEQ8TR+1
        DW      SCSOF-SEQ6TR+1
        DW      SCSOF-SEQ8TR+1
        DW      LVTOF-SEQ8TR+1
        DW      WCPOF-SEQ8TR+1
        DW      OCPOF-SEQ8TR+1
        DW      DP5OF-SEQ8TR+1
        DW      SCSOF-SEQ8TR+1
```

```
        DW      FV4OF-SEQSTR+1
        DW      AUDOF-SEQSTR+1
        DW      FRVOF-SEQSTR+1
        DW      SRSOF-SEQSTR+1
        DW      CWLOF-SEQSTR+1
        DW      CV5OF-SEQSTR+1
        DW      SC5OF-SEQSTR+1
        DW      SC5OF-SEQSTR+1
        DW      SC5OF-SEQSTR+1
        DW      SC9OF-SEQSTR+1
        DW      SC5OF-SEQSTR+1

        END
```

BIOGRAPHY

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