C/325
7-23-63

ORNL-3405
UC-34 - Physics
TID-4500 (20th ed., Rev.)

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PROCESSING OF MULTICHANNEL-ANALYZER NUCLEAR
REACTION SPECTRA WITH THE NEWDAC PROGRAM

J. B. Ball

OAK RIDGE NATIONAL LABORATORY

operated by

UNION CARBIDE CORPORATION

for the

U.S. ATOMIC ENERGY COMMISSION

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Contract No. W-7405-eng-26

ELECTRONUCLEAR DIVISION

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DATE ISSUED

JUL 16 1963

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J. B. Ball

ABSTRACT

A FORTRAN program is presented for processing pulse-height data for particles emitted from a nuclear reaction. The program corrects the particle energy for any absorber preceding the detector and computes the differential center-of-mass cross section as a function of the reaction Q value and the excitation energy of the final nucleus. At the discretion of the user, the energies can be computed either relativistically or nonrelativistically. The program is written as a series of subroutines to facilitate possible expansion of the program and to allow easy accommodation of different data input routines. The output of the program is printed in tabular form and, at the discretion of the user, punched on cards for off-line plotting or for input to other programs.

INTRODUCTION

Much of the information obtained from studies of nuclear reactions is collected in the form of pulse-height data from an energy-sensitive detector. The NEWDAC program was written to transform this pulse-height data into an energy spectrum that allows extraction of precise nuclear information. The purpose of the NEWDAC program is much like that of the CONDAC program.¹ The NEWDAC program reflects the experience of several years of use of CONDAC as well as advances in both multichannel-analyzer and particle-detector technology since the writing of CONDAC.

The current practice of recording the energy spectra of several different particles simultaneously by selectively resetting the multichannel-analyzer address scaler results in a block of data with subsections referring to different reactions. NEWDAC is designed to process the entire block of data, with a single set of lead cards preceding the entire data array. In addition, the NEWDAC program contains the option of computing its own Mev/channel and the option of performing all of the energy and Q -value computations relativistically.

The NEWDAC program was written from the viewpoint of the experimentalist interested in direct interactions and nuclear-level determination. The program does not provide for the statistical-model analysis features found in CONDAC. Also, unlike CONDAC, the NEWDAC program assumes a linear detector response for all particles.

¹C. D. Goodman and B. D. Williams, *Nuclear Data Processing on an IBM-704 Computer with the CONDAC Program*, ORNL-2925 (1960).

DESCRIPTION OF THE NEWDAC PROGRAM

An operational block diagram of the program is shown in Fig. 1, which illustrates the sequencing of operations and employment of the subroutines. Optional bypasses in the sequencing of the main program are indicated by the dashed lines.

The value of Mev/channel may either be read as input or computed by the program. If the position of the elastic peak is provided as input, the program will compute its own Mev/channel by calculating the energy of the scattered particle at the detector with the aid of the EVALUE function and the SDEDX subroutine. Alternately, the program can compute its own Mev/channel from any specified channel of a reaction-product spectrum for which the Q value is known.

The counts-per-channel data are processed in the following fashion: Each analyzer channel is treated as extending from half the distance to the next lower channel to half the distance to the next higher channel. Thus, channel 1 would be treated as extending from the channel boundaries 0.5 to 1.5. Each channel boundary is multiplied by the value of Mev/channel to obtain its detector energy value. The detector energy of each boundary is then corrected back through the absorber preceding the counter by use of the SDEDX subroutine to obtain the true laboratory energy. The laboratory energy of the channel is taken as the arithmetic mean of the two boundary laboratory energies, and the energy span of the channel is the difference between the two laboratory boundary energies. The KINTWO subroutine supplies the center-of-mass scattering angle from the given scattering conditions and the factor to transform the laboratory cross section into the center-of-mass frame of reference. (The KINTWO calculations are nonrelativistic.) The differential center-of-mass cross section is then computed by multiplying the number of counts in a given channel by the cross-section transformation factor appropriate for the channel laboratory energy and then dividing this by the product of the channel energy span and an input monitor factor.

The reaction Q value corresponding to each channel is obtained from the true laboratory energy of the channel by the QVALUE function. The excitation energy corresponding to each channel is obtained by subtracting the reaction Q value from the ground-state Q value, Q_0 . Q_0 is taken either from an input value or is computed from the input masses.

INPUT INFORMATION AND PROGRAM OPTIONS

The input information for the NEWDAC program is supplied by a series of lead cards preceding the data to be analyzed. There are, in order, a title card, an initial-state card, as many final-state cards as there are cases to be processed from the same data, and a control card to signal the end of input information.

The Title Card. — This card may contain any desired information to identify the data being processed. The first 66 columns of this card will be reproduced at the top of each printed output sheet.

The Initial-State Card. — This card contains information common to all of the cases to be processed from the same block of input data. The card is divided into ten 8-column fields, and the first nine fields are used for input. The decimal point is assumed to be at the right edge of each field unless it is specifically entered. The input required on the initial-state card is summarized in Table 1.

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Fig. 1. Operational Block Diagram of the NEWDAC Program. Dotted lines indicate optional bypasses.

Table 1. Summary of Data on Initial-State Input Card

Fields are eight columns each

Field	Entry	Units
1	Mass of the incident particle, M1	amu
2	Charge number of the incident particle, Z1	
3	Mass of the target nucleus, M2	amu
4	Laboratory energy of the incident particle	Mev
5	Laboratory scattering angle	degrees
6	Absorber thickness	mg/cm ²
7	Monitor factor	
8	(Elastic channel or -Mev/channel) ^a	
9	Base-line offset	

^aOptional entries.

Either precise or integral masses may be used. If the program is to compute its own Q_0 , the precise masses must be entered. The program is written for masses on the basis $C^{12} = 12.0000$. The thickness of the absorber preceding the detector is treated as mg/cm² of aluminum equivalent. The counts per channel are divided by the monitor factor. If the monitor factor is chosen to yield a laboratory cross section in millibarns/steradian, for example, when divided into laboratory counts, the output of the program will be in units of millibarns/Mev·steradian in the center-of-mass system. If Mev/channel is to be computed from the position of the elastic channel, the true channel number of the elastic peak position should be entered in field 8. If Mev/channel is known from a previous calibration, this may be entered in field 8 as a negative number. If neither the elastic peak position nor Mev/channel is known and it is desired to compute Mev/channel from a known state in a reaction, this field is left blank. The base-line offset is the true channel number of analyzer channel zero.²

The Final-State Card. — This card contains information pertinent to the specific reaction to be processed and is also divided into ten 8-column fields, the first nine being used for input. As many of these cards are inserted as there are cases to be processed from the same block of data. The input required on the final-state cards is summarized in Table 2.

The program uses the value of Q_0 to compute the excitation energy of the final nucleus. If the precise masses are entered, the program will use these to determine Q_0 . If the precise mass of the residual nucleus is not readily available, but the Q value for exciting the ground state is available, field 3 should be left blank and the value of Q_0 entered in field 8.

²Reference will be made to two types of channel numbers: the analyzer channel number and the true channel number. The analyzer channel number is the actual channel as numbered in the multichannel array. The true channel number is that which would normally be used in making a plot of pulse-height data and is the number on the scale where channel zero corresponds to zero pulse height. As an example, suppose that deuterons are being collected in channels 100 to 199 of a 400-channel analyzer and the ADC (Analog-to-Digital Converter) of the analyzer is offset +20 channels. A deuteron peak falling in analyzer channel 176 would be in true channel 96.

Table 2. Summary of Data on Final-State Input Card

Field	Entry	Units
1	Mass of the observed particle, $M3$	amu
2	Charge number of the observed particle, $Z3$	
3	(Mass of the residual nucleus, $M4$) ^a	amu
4	Base analyzer channel for observed particle	
5	Start channel (>0)	
6	Stop channel	
7	(Channel of known final state) ^a	
8	(Q value for known final state) ^a	Mev
9	(Suppress output on cards) ^a	

^aOptional entries.

Field 4 contains the number of the analyzer channel at which the spectrum begins for the particular particle type. In the example given in the preceding footnote, the base channel for the deuterons would be 100. The start and stop channels are true channel numbers representing the range of points to be processed. The start channel must be greater than zero.

If it is desired to have the program compute Mev/channel from a known state in the reaction data, the true channel number of this state is entered in field 7. The Q value for exciting this state should be entered in field 8. If the selected state is the ground state, and if the precise masses have been written in fields 1 and 3, no entry is needed in field 8.³

Any nonzero number in field 9 will cause omission of the writing of the punched-card data on the auxiliary output tape.

The Control Card. — After the last final-state card, a card containing a zero in the first 8-column field (a negative number or blank field is also acceptable) must be inserted. This transfers control to the DATAIN subroutine. An example of input data, written on a standard IBM key-punch sheet, is shown in Fig. 2.

OUTPUT FROM THE PROGRAM

A typical output sheet from NEWDAC is shown in Fig. 3. The first line of the heading contains the information in the first 66 columns of the title card, a case number, and the name of the observed particle. The case number is a three-digit identification, taken from the DATAIN subroutine, preceded by the mass number of the observed particle. In the example of Fig. 3, the data identification was the number 206.

³The program will always use the Q_0 determined from precise masses for computing excitation energy. If integer masses are used, the entry in field 8 will be taken as Q_0 , providing that field 3 is left blank. If the integer mass of the residual nucleus is entered in field 3, the value of Q_0 will be taken as zero.

650 DATA SHEET

REQUEST 1588 JOB TITLE NEWDAC WRITTEN BY J. BALL DATE 12/12/62

1-8	9-16	17-24	25-32	33-40	41-48	49-56	57-64	65-72	73-80
TITLE CARD (UP TO 66 CHARACTERS)									
M1	Z1	M2	ELAB	ANGLE	ABS	MON	(EL CH) (MEV/CH)	OFFSET	
M3	Z3	(M4)	BASE CH	START CH	STOP CH	(FS CH)	(FS Q)	(CARDS)	
M3	Z3	etc.							
0.0									
(the data deck is inserted at this point)									
<u>EXAMPLE:</u>									
TARGET IS ZIRCONIUM-92									
5-JUN-62									
1.00783	1.0	91.9046	22.3	40.0	60.0	388.5	114.6	20.0	
1.00783	1.0	91.9046	0.0	50.0	120.0				
2.0141	1.0	90.9053	100.0	40.0	90.0				
3.01605	1.0	89.9043	200.0	40.0	85.0				
0.0									
(data deck)									

Fig. 2 Input Format for the NEWDAC Lead Cards. For an explanation of the symbols see Tables 1 and 2. In the example case above, the program is to process spectra for three different observed particles: protons, deuterons, and tritons. The first page of the output for the deuteron spectra is shown in Fig. 3.

TARGET IS ZIRCONIUM-92

5-JUN-62

CASE#2206

OBSERVED PARTICLES ARE DEUTERONS

ENERGY#22.30		ABSORBER# 60.0		EL CHAN#114.6		MEV/CHAN#0.1838		K FACTOR# 388.50		ANGLE# 40.0	
Z1#1	Z3#1	M1#1.00783	M2# 91.9046	M3#2.01420	M4# 90.9053	Q0# -6.59					
CHANNEL	CTS/CHAN	ELAB	LOG CTS/CH	Q	N(E)	Q0 - Q	LOG N(E)	CCM ANG	E DEFECT		
40.C	45.	11.08	3.807	-11.106	8.278E-C1	4.521	-0.189	40.81	-0.000		
41.0	61.	11.21	4.111	-10.970	1.112E 00	4.384	0.107	40.81	-0.000		
42.C	91.	11.35	4.511	-10.832	1.646E 00	4.246	0.498	40.80	-0.000		
43.C	118.	11.49	4.771	-10.693	2.119E 00	4.107	0.751	40.80	-0.000		
44.C	143.	11.63	4.963	-10.553	2.546E 00	3.967	0.934	40.79	-0.000		
45.0	129.	11.77	4.860	-10.412	2.280E 00	3.826	0.824	40.79	-0.000		
46.C	134.	11.91	4.898	-10.269	2.352E 00	3.684	0.855	40.79	-0.000		
47.C	121.	12.05	4.796	-10.126	2.109E 00	3.540	0.746	40.78	-0.000		
48.0	140.	12.20	4.942	-9.982	2.424E 00	3.396	0.886	40.78	-0.000		
49.C	223.	12.34	5.407	-9.836	3.841E 00	3.251	1.346	40.77	-0.000		
50.C	202.	12.49	5.308	-9.690	3.456E 00	3.104	1.240	40.77	-0.000		
51.C	95.	12.63	4.554	-9.543	1.616E 00	2.957	0.480	40.76	-0.000		
52.C	41.	12.78	3.714	-9.395	6.935E-C1	2.809	-0.366	40.76	-0.000		
53.C	52.	12.93	3.951	-9.246	8.749E-C1	2.660	-0.134	40.75	-0.000		
54.C	68.	13.08	4.220	-9.097	1.138E 00	2.511	0.129	40.75	-0.000		
55.0	60.	13.23	4.094	-8.946	9.994E-01	2.360	-0.001	40.74	-0.000		
56.C	34.	13.38	3.526	-8.795	5.640E-C1	2.209	-0.573	40.74	-0.000		
57.C	10.	13.53	2.303	-8.643	1.650E-C1	2.057	-1.802	40.74	-0.000		
58.0	7.	13.68	1.946	-8.490	1.150E-01	1.904	-2.163	40.73	-0.000		
59.C	8.	13.83	2.079	-8.337	1.309E-C1	1.751	-2.034	40.73	-0.000		
60.C	12.	13.98	2.485	-8.183	1.955E-C1	1.597	-1.632	40.72	-0.000		
61.C	18.	14.14	2.890	-8.028	2.921E-01	1.442	-1.231	40.72	-0.000		
62.0	8.	14.29	2.079	-7.873	1.293E-01	1.287	-2.046	40.72	-0.000		
63.C	4.	14.45	1.386	-7.717	6.442E-C2	1.131	-2.742	40.71	-0.000		

Fig. 3. Typical Output Sheet from NEWDAC.

If the channel of the elastic peak is not entered on the initial-state input card, the heading will print ELCHAN = -0. The item labeled K FACTOR is the input monitor factor. The symbols M_1 , M_2 , M_3 , and M_4 are, respectively, the masses of the incident particle, the target nucleus, the observed particle, and the residual nucleus. If M_4 is not included in the input, it is taken as $M_4 = M_1 + M_2 - M_3$. If the number of channels to be analyzed exceeds one page of output, succeeding pages are headed by the first line and column heads only.

The first column of output information is the true channel number. The second column is the number of counts in this channel as read from the input data. The third column is the corresponding laboratory energy for the observed particle, which has a pulse height falling in this channel, before traversing any absorber preceding the energy detector. The fourth column is the natural logarithm of the second column. The fifth column is the Q in Mev, of the reaction defined as the change in kinetic energy between the initial and final systems. The sixth column, $N(E)$, is the differential cross section in the center-of-mass frame of reference. The units of $N(E)$ are $[(\text{units on monitor factor}) (\text{Mev})]^{-1}$. The seventh column is the excitation energy in Mev, of the final nucleus. The eighth column is the natural logarithm of the sixth column. The ninth column is the center-of-mass scattering angle for the reaction at the given energies.

The last output column is for checking purposes. The KINTWO subroutine returns a value of the observed particle energy appropriate to the Q value of column 5. This energy is computed nonrelativistically. The entry in the E DEFECT column is the difference between this energy and the entry in column 3; the units are Mev. If the nonrelativistic forms of the EVALUE and QVALUE functions are used, the entry in the E DEFECT column should be zero. If the relativistic forms of the EVALUE and QVALUE functions are used, this column serves as an indication of the error that would have been introduced by using the nonrelativistic forms. Since the cross section and angle transformations are performed nonrelativistically, a large value of E DEFECT should serve as a warning to examine the accuracy required for these two items. Only very special cases should experience any problem in this regard.

The items punched on cards and their position on the card are given in Table 3. Each case on punched cards is preceded by a lead card with a 9-punch extending from columns 1 to 72 and a case number, identical to the printed output, punched in columns 77 to 80.

NOTES ON THE USE OF THE PROGRAM

The FORTRAN listing for the NEWDAC main program is given in the following section. The subroutines required by the main program are shown in Fig. 4. If it is desired to process the energy spectra relativistically, the relativistic forms of the EVALUE and QVALUE functions should be used in the program deck. If it is desired to process the energy spectra nonrelativistically, the nonrelativistic EVALUE and QVALUE functions should be used in the program deck. The only distinction between relativistic and nonrelativistic processing is in the form of the functions placed in the program deck.

Table 3. Placement of Output Data on Punched Cards

Entry ^a	Columns	Decimal Point
CHANNEL	1-6	4
ELAB	7-16	13
COM ANG	17-24	22
LOG N(E)	25-34	30
$Q_0 - Q$	43-52	48
Q	53-62	58
LOG CTS/CH	63-72	68
CASE	77-80	

^aEntry titles correspond to the printed output shown in Fig. 3.

Fig. 4. Subroutines and Functions Required by the NEWDAC Program. Either relativistic or nonrelativistic EVALUE and QVALUE functions may be used.

The DATAIN Subroutine. — The data-input subroutine may be rewritten to accommodate any type of input format. As an example, the FORTRAN listing for processing a data deck for an analyzer which punches cards directly is shown in the following section (see "The DATAIN Subroutine"). Each card of the data deck contains the decimal content of ten channels in the first ten 6-column fields; the decimal analyzer channel number of the tenth field is punched in columns 65 to 67, and an identifying deck number is punched in columns 73 to 75. The subroutine examines each card for proper deck number, and the data are placed in the memory array ordered by channel number. A minus number in the first six columns of a control card following the data deck causes the subroutine to return control to the main program. The data array and the deck identification are transmitted to the main program through the argument list of the subroutine.

The SDEDX Subroutine. — This subroutine uses a form of the dE/dx expression similar to that used by Aron, Hoffman, and Williams:⁴

$$\frac{-dE}{dx} = (3.071 \times 10^{-4}) \frac{z^2 Z}{\beta^2 A} \left[\ln \left(\frac{1.022 \times 10^6}{1 - \beta^2} \right) \frac{\beta^2}{I} - \beta^2 \right],$$

where z is the charge of the particle, Z is the atomic number of the stopping material, A is the atomic weight of the stopping material, I is the mean excitation potential of the stopping material in ev, and $\beta = v/c$ for the charged particle. The value of dE/dx has the units Mev/mg·cm⁻². This equation does not contain the shell correction terms for low energies or the density factor for very high energies. In addition, this approximate form of the equation is not well behaved at a very low energy, and at a value of $E/m \cong 77$ kev the value of dE/dx changes sign. Under certain conditions this improper behavior may be encountered for the first few channels of a spectrum. In this case the SDEDX subroutine returns a negative particle energy to the main program, which is written to bypass any channels resulting in the return of a negative energy.

The subroutine computes the energy of a particle after traversing an absorber by performing a numerical integration. The absorber is divided into a number of increments. At each increment the program uses the initial particle energy to calculate a value of dE/dx and estimate the particle energy after the absorber increment. The estimated energy is then used to obtain the average energy of the particle in traversing the increment. The dE/dx corresponding to this average energy is then used to compute the final particle energy after the absorber increment. This final energy is then used as the initial energy for the next increment. The entire process is repeated for each increment of the absorber.

In the NEWDAC program the number of absorber increments for the numerical integration is chosen by the relation

$$N = [2tz/(E + 7)] + 1,$$

where t is the total absorber thickness in mg/cm², z is the charge of the particle, and E is the energy of the particle.

The SDEDX subroutine also stores in arrays the value of the energy, the value of dE/dx , and the total absorber traversed at each step of the integration. This array information is not used by the NEWDAC program. The FORTRAN listing is given in the next section.

The KINTWO Subroutine. — This subroutine is a shortened form of the KINEMATICS II program.⁵ The subroutine returns the laboratory energy of the scattered particle, the center-of-mass angle of the scattering, and the factor for transforming the laboratory cross section to center-of-mass cross section, all computed nonrelativistically. The FORTRAN listing is given in the next section.

The NAMER Subroutine. — This subroutine identifies the observed particle by its mass and charge. The Hollerith literal name of the particle is entered in the memory through the argument of a function. In this case the XABSF function has been used and the name treated in fixed-point format. Use of this func-

⁴W. A. Aron, B. G. Hoffman, and F. C. Williams, AECU-663, UCRL-121 (1949).

⁵J. B. Ball, *KINEMATICS II: A Nonrelativistic Kinematics FORTRAN Program to Aid Analysis of Nuclear Reaction Angular Distribution Data*, ORNL-3251 (1962).

tion requires restoring the sign bit when the first character is stored as octal 40 or larger, for example, any alphabetic character beyond I. The FORTRAN listing for this subroutine is given in the next section. The + sign in the function arguments is required by the FORTRAN compiler.

The QVALUE Function. — The FORTRAN listing for the nonrelativistic Q equation is also given in the next section. The standard form of the nonrelativistic expression is used:

$$Q = [E_3(M_3 + M_4) - E_1(M_4 - M_1) - 2 \cos \theta (M_1 M_3 E_1 E_3)^{1/2}] / M_4 ,$$

where the subscripts 1, 3, and 4 refer to the incident particle, the observed particle, and the residual nucleus respectively. The FORTRAN listing for the relativistic Q equation is given in the next section. The equation used is^{6,7}

$$Q = E_3 - E_1 + G_4 \left(\left\{ 1 + (G_3/G_4)^2 (E_3/G_3) (2 + E_3/G_3) + (G_1/G_4)^2 (E_1/G_1) (2 + E_1/G_1) - (2G_1 G_3/G_4^2) [(E_1 E_3/G_1 G_3) (2 + E_3/G_3) (2 + E_1/G_1)]^{1/2} \cos \theta \right\}^{1/2} - 1 \right) ,$$

where G_1 , G_3 , and G_4 are the rest masses, in Mev, of the incident particle, the observed particle, and the residual nucleus respectively.

The EVALUE Function. — The nonrelativistic form of the energy equation is taken from the KINTWO subroutine. It can be expressed in analytic form as

$$\begin{aligned} E_3 &= [B \cos \theta \pm (A - B^2 \sin^2 \theta)^{1/2}]^2 , \\ A &= M_4 \{ E_1 [1 - M_1/(M_3 + M_4)] + Q \} / (M_3 + M_4) , \\ B &= (M_3 M_1 E_1)^{1/2} / (M_3 + M_4) . \end{aligned}$$

The FORTRAN listing is given in the next section; the EVALUE function uses the positive root. The form of the energy-value equation used for the relativistic EVALUE function is^{8,9}

$$\begin{aligned} E_3 &= \left\{ 4G_3 D - AB \pm 2 \cos \theta [E_1(E_1 + 2G_1)(B^2 - 2G_3 AB + 4G_3^2 D)]^{1/2} \right\} / (A^2 - 4D) , \\ A &= 2(G_3 + G_4 + E_1 + Q) , \\ B &= 2E_1(G_1 - G_4 - Q) - Q(2G_4 + Q) , \\ D &= E_1(E_1 + 2G_1) \cos^2 \theta . \end{aligned}$$

The symbol G stands for the rest mass of the indicated particle, as in the relativistic QVALUE function. The FORTRAN listing for the relativistic EVALUE function is given in the next section. As in the non-relativistic case, the positive root is used by the function.

The normal floating-point arithmetic in the IBM 709/7090 retains eight significant figures. This presents a possible complication in the relativistic EVALUE and QVALUE functions, where the reaction

⁶P. Morrison, *Experimental Nuclear Physics* (ed. by E. Segré), p 12, Wiley, New York, 1953.

⁷1960 *Nuclear Data Tables*, Pt 3, (ed. by J. B. Marion), p 161, National Academy of Sciences—National Research Council, 1960.

⁸A. S. Langsdorf, Jr., J. E. Monahan, and W. A. Reardon, *A Tabulation of Neutron Energies from Monoenergetic Protons on Lithium*, ANL-5219 (1954).

⁹*Loc. cit.*, 1960 *Nuclear Data Tables*. In this reference the 2 in front of the $\cos \theta$ term has been accidentally omitted.

energies are additive to quantities of the same order of magnitude as the rest mass of the system. Depending upon the mass of the reacting system, errors of the order of 1 to 10 kev may be introduced. If greater accuracy is desired, these functions may be reprogrammed with "double-precision" arithmetic.

ACKNOWLEDGMENT

The author would like to acknowledge several helpful discussions with C. D. Goodman, who also supplied the original form of the DATAIN subroutine used in the text.

FORTRAN LISTINGS

The NEWDAC Main Program

```

C      NEW DATA ANALYSIS CODE          J. B. BALL          JUNE 21, 1962
      DIMENSION CHAN(400),CTS(400),CTSLOG(400),ELAB(400),Q(400),EX(400),
1     REDATA(400),REDLOG(400),DEFECT(400),ANGCOM(400),DATA(600).
2     W3(9),Z3(9),W4(9),BASE(9),START(9),FINISH(9),GSCHAN(9),QGS(9),
3     CNO(9),IWORD(2),TITLE(11),DY4(200),DY5(200),DY6(200)
11    READ INPUT TAPE 10,41,TITLE,W1,Z1,W2,EI,ANGLE,ABS,FMON,ELCHAN,
1     OFFSET
      I#1
12    READ INPUT TAPE 10,42,W3(I),Z3(I),W4(I),BASE(I),START(I),FINISH(I)
1     ,GSCHAN(I),QGS(I),CNO(I)
      IF(W3(I))11,14,13
13    I#I+1
      GO TO 12
14    CALL DATAIN(DATA,DECK)
      L9#XABSF(+6H999999)
C      ABSORBER IS ASSUMED TO BE ALUMINUM
      ALZ#13.0
      ALA#27.0
      ALI#166.4
      IF(ELCHAN)20,20,21
20    EPERCH#-ELCHAN
      ELCHAN#-0.0
      GO TO 22
C      DETERMINATION OF MEV/CHANNEL FROM ELASTIC SCATTERING CHANNEL
21    QEL#0.0
      ESCAT#EVALUE(W1,W1,W2,EI,QEL,ANGLE)
      NABS#2.0*ABS*Z1/(ESCAT+7.0)+1.0
CALL SDOEX(Z1,W1,ESCAT,ALZ,ALA,ALI,ABS,NABS,DY3,DY4,DY5,DY6,EF)
      EPERCH#EF/ELCHAN
22    ABS3#-ABS
C      BEGINNING OF CALCULATIONS FOR SELECTED OBSERVED PARTICLE
      DO 38 J#1,I
      IF(W3(J))11,11,23
23    MTEST#W3(J)+0.002
      IF(W4(J))24,24,25
24    W4(J)#W1+W2-W3(J)
      QD#QGS(J)
      GO TO 253
C      THE VALUE OF QD IS CALCULATED FOR MASSES ON THE BASIS C-12#12.0000
25    QD#(W1+W2-W3(J)-W4(J))*931.44
      IF(QGS(J))253,252,253
252    QGS(J)#QD
253    IF(GSCHAN(J))255,255,254
C      DETERMINATION OF MEV/CHANNEL FROM REACTION Q VALUE
254    ESCAT#EVALUE(W1,W3(J),W4(J),EI,QGS(J),ANGLE)
      NABS#2.0*ABS*Z3(J)/(ESCAT+7.0)+1.0
      CALL SDOEX(Z3(J),W3(J),ESCAT,ALZ,ALA,ALI,ABS,NABS,DY3,DY4,DY5,
1     DY6,EF)
      EPERCH#EF/GSCHAN(J)
255    IF(EPERCH)2551,2551,2552
2551   WRITE OUTPUT TAPE 9,50,TITLE,MTEST,DECK
      GO TO 38
2552   LCOUNT#0
      L#FINISH(J)-OFFSET+BASE(J)
256    K#START(J)-OFFSET+BASE(J)
      EUPPER#(START(J)-0.5)*EPERCH

```



```

NABS#2.0*ABS*Z3(J)/(EUPPER+7.0)+1.0
CALL SDEOX(Z3(J),W3(J),EUPPER,ALZ,ALA,ALI,ABS3,NABS,DY3,DY4,DY5,
1 DY6,EPLUS)
IF(EPLUS)257,257,258
257 START(J)#START(J)+1.0
GO TO 256
258 DO 28 M#K,L
LCOUNT#LCOUNT+1
FLTGM#M
CHAN(LCOUNT)#FLTGM+OFFSET-BASE(J)
CTS(LCOUNT)#DATA(M)
EMINUS#EPLUS
EUPPER#(CHAN(LCOUNT)+0.5)*EPERCH
NABS#2.0*ABS*Z3(J)/(EUPPER+7.0)+1.0
CALL SDEOX(Z3(J),W3(J),EUPPER,ALZ,ALA,ALI,ABS3,NABS,DY3,DY4,DY5,
1 DY6,EPLUS)
ELAB(LCOUNT)#0.5*(EPLUS+EMINUS)
Q(LCOUNT)#QVALUE(W1,W3(J),W4(J),EI,ELAB(LCOUNT),ANGLE)
EX(LCOUNT)#QD-Q(LCOUNT)
CALL KINTWO(W1,W2,W3(J),W4(J),EI,Q(LCOUNT),ANGLE,ECHECK,
1 ANGCOS(LCOUNT),XTRANS)
REDATA(LCOUNT)#DATA(M)*XTRANS/(FMON*(EPLUS-EMINUS))
IF(REDATA(LCOUNT))26,26,27
26 CTSLOG(LCOUNT)#-9.999
REDLOG(LCOUNT)#-9.999
GO TO 28
27 CTSLOG(LCOUNT)#LOGF(CTS(LCOUNT))
REDLOG(LCOUNT)#LOGF(REDATA(LCOUNT))
28 DEFECT(LCOUNT)#ECHECK-ELAB(LCOUNT)
IF(CNO(J))282,281,282
C OUTPUT FOR CARDS ON AUXOUT TAPE
281 WRITE OUTPUT TAPE 6,43,L9,L9,L9,L9,L9,L9,L9,L9,L9,L9,MTEST,
1 DECK
WRITE OUTPUT TAPE 6,44,(CHAN(NCARD),ELAB(NCARD),ANGCOS(NCARD),
1 REDLOG(NCARD),EX(NCARD),Q(NCARD),CTSLOG(NCARD),MTEST,DECK,
2 NCARD#1,LCOUNT)
C SELECTION OF PARTICLE NAME FOR TITLE LINE OF OUTPUT HEADINGS
282 IZ#Z3(J)
CALL Namer(MTEST,IZ,IWORD)
C OUTPUT ROUTINE FOR MULTIPLE PAGES WITH EXTENDED FIRST PAGE HEADING
C AND A TOTAL NUMBER OF LINES EQUAL TO LCOUNT
30 IF(LCOUNT-24)31,31,32
31 LSTOP#LCOUNT
ASSIGN 38 TO LTRANS
GO TO 33
32 LSTOP#24
ASSIGN 34 TO LTRANS
33 WRITE OUTPUT TAPE 9,45,TITLE,MTEST,DECK,IWORD
WRITE OUTPUT TAPE 9,46,EI,ABS,ELCHAN,EPERCH,FMON,ANGLE,Z1,Z3(J),
1 W1,W2,W3(J),W4(J),QD
WRITE OUTPUT TAPE 9,47,(CHAN(LINE),CTS(LINE),ELAB(LINE),
1 CTSLOG(LINE),Q(LINE),REDATA(LINE),EX(LINE),REDLOG(LINE),
2 ANGCOS(LINE),DEFECT(LINE),LINE#1,LSTOP)
GO TO LTRANS,(34,38)
34 LSTART#LSTOP+1
IF(LCOUNT-LSTART-25)35,35,36
35 LSTOP#LCOUNT
ASSIGN 38 TO LTRANS
GO TO 37
36 LSTOP#LSTOP+26
37 WRITE OUTPUT TAPE 9,45,TITLE,MTEST,DECK,IWORD

```

```

WRITE OUTPUT TAPE 9,47,(CHAN(LINE),CTS(LINE),ELAB(LINE),
1 CTSLOG(LINE),Q(LINE),REDATA(LINE),EX(LINE),REDLOG(LINE),
2 ANGCOM(LINE),DEFECT(LINE),LINE#LSTART,LSTOP)
GO TO LTRANS,(34,38)
38 CONTINUE
GO TO 11
41 FORMAT(11A6/9F8.0)
42 FORMAT(9F8.0)
43 FORMAT(12A6,4X11,A3)
44 FORMAT(F6.2,F10.3,F8.2,F10.4,8XF10.4,F10.4,F10.4,4X11,A3)
45 FORMAT(11H1,11A6,4X5HCASE#11,A3,5X23HOBSERVED PARTICLES ARE ,2A6)
46 FORMAT(1H0,2X7HENERGY#F6.2,6X9HABSORBER#F5.1,6X8HEL CHAN#F5.1,
1 6X9HMEV/CHAN#F6.4,6X9HK FACTOR#F7.2,6X6HANGLE#F5.1/1H0,
2 2X3HZ1#-1PF1.1,4X3HZ3#F1.1,6X3HMI#OPF7.5,6X3HM2#F8.4,6X3HM3#F7.5,
3 6X3HM4#F8.4,6X3HQ0#F6.2)
47 FORMAT(1H0/9H CHANNEL,5X8HCTS/CHAN,5X4HELAB,4X10HLOG CTS/CH,
1 7X1HQ,11X4HN(E),7X6HQ0 - Q,5X8HLOG N(E),4X7HCOM ANG,5X8HE DEFECT/
2 (1H0,F7.1,5XF7.0,4XF7.2,3XF8.3,4XF9.3,4X1PE10.3,3XOPF9.3,3XF8.3,
3 4XF8.2,4XF8.3))
50 FORMAT(11H1,11A6,4X5HCASE#11,A3/1H0/1H0,74H **INPUT DATA RESULTED 1
1 N NEGATIVE OR ZERO VALUE OF MEV/CHAN FOR THIS CASE/1H0,3X67HCHECK
2 DATA FOR MISTAKE IN ABSORBER OR IDENTIFICATION OF KNOWN LEVEL/
3 1H0/1H ,30H **THIS CASE HAS BEEN BYPASSED)
END

```

—The-DATAIN-Subroutine—

```

SUBROUTINE DATAIN(DATA,IDENT)
DIMENSION DATA(600),TSTORE(10)
DO 1 I#1,600
1 DATA(I)#0.0
READ INPUT TAPE 10,11,TSTORE,K,IDENT
NCARD#1
NPASS#1
7 DO 2 I#1,10
J#K-10+1
IF(J)2,2,3
3 IF(600-J)2,8,8
8 DATA(J)#TSTORE(I)
2 CONTINUE
9 READ INPUT TAPE 10,11,TSTORE,K,ID
NCARD#NCARD +1
IF(TSTORE(1))4,5,5
4 RETURN
5 IF(ID-IDENT)6,7,6
6 IF(NPASS-1)21,21,22
21 WRITE OUTPUT TAPE 9,13
NPASS#NPASS+1
22 WRITE OUTPUT TAPE 9,12,ID,NCARD
GO TO 9
11 FORMAT(10F6.0,4X13,5XA3)
12 FORMAT(17H0IDENTIFICATION, A3,9H, ON THE 12,40HTH CARD DOES NOT AG
1 REE WITH DECK NUMBER./28H THIS CARD HAS BEEN IGNORED.)
13 FORMAT(63HIAN ERROR HAS BEEN DETECTED IN THE INPUT DATA FOR THE NE
1 XT CASE/1H0)
END

```

The SDEX Subroutine

```

C      SUBROUTINE FOR COMPUTING ENERGY LOSS OF CHARGED PARTICLES IN
C      TRAVERSING AN ABSORBER          J. B. BALL          21-FEB-1962
      SUBROUTINE SDEX(PZ,PM,EINIT,ABSZ,ABSA,ABSI,ABSTH,N,NLIM,E,DEX,
      RTABS,EFINAL)
      DIMENSION E(200),DEX(200),RTABS(200)
      FLTGN#N
      DABSTH#ABSTH/FLTGN
      ARG1#(3.071E-4)*(PZ**2)*ABSZ/ABSA
      ARG2#(1.022E6)/ABSI
      EPART#EINIT
      DO 103 I#1,N
      E(I)#EPART
      SQBETA#1.0-(931.1/((E(I)/PM)+931.1))**2
      DEX(I)#(ARG1/SQBETA)*(LOGF(ARG2*SQBETA/(1.0-SQBETA)))-SQBETA)
      FLTGI#I
      RTABS(I)#(FLTGI-1.0)*DABSTH
      NLIM#I
      IF(ABSTH)100,104,100
100    EF1#EPART-DEX(I)*DABSTH
      IF(EF1)101,101,102
101    EPART#EF1
      GO TO 104
102    EA#(EPART+EF1)/2.0
      SQBETA#1.0-(931.1/((EA/PM)+931.1))**2
      ADEX#(ARG1/SQBETA)*(LOGF(ARG2*SQBETA/(1.0-SQBETA)))-SQBETA)
      EPART#EPART-ADEX*DABSTH
      IF(EPART)104,104,103
103    CONTINUE
104    EFINAL#EPART
      RETURN
      END

```

The KINTWO Subroutine

```

C      SUBROUTINE FOR CALCULATING NON-RELATIVISTIC KINEMATICS          15880105
C      J. B. BALL          3-MAY-1962          15880106
      SUBROUTINE KINTWO(W1,W2,W3,W4,ELAB1,Q,ANGLAB,ELAB3,ANGCOM,XTRANS) 15880108
      EICOM#(W2/(W1+W2))*ELAB1          15880110
      EFCOM#EICOM+Q          15880112
      E1#(W2/(W1+W2))*EICOM          15880114
      E3#(W4/(W3+W4))*EFCOM          15880116
      V3#SQRTF(2.0*E3/W3)          15880118
      VCM#SQRTF((2.0*W1/((W1+W2)**2))*ELAB1)          15880120
      PSI#ANGLAB/57.29578          15880122
      TEST#(V3**2)-(VCM**2)*(SINF(PSI)**2)          15880124
      IF(TEST)101,102,102          15880202
101    ANGCOM#-0.0          15880204
      ELAB3#-0.0          15880206
      XTRANS#-0.0          15880208
      RETURN          15880210
102    VV3#VCM*COSF(PSI)+SQRTF(TEST)          15880212
      ARG#SINF(PSI)/(COSF(PSI)-VCM/VV3)          15880214
      IFDIVIDECHECK103,104          15880216
103    THETA#1.570797          15880218
      GOTO106          15880220
104    THETA#ATANF(ARG)          15880222
      IF(THETA)105,106,106          15880224
105    THETA#THETA+3.1415927          15880302
106    ELAB3#W3*(VV3**2)/2.0          15880304
      ANGCOM#THETA*57.29578          15880306
      XTRANS#V3*SQRTF(TEST)/(VV3**2)          15880308
      RETURN          15880310
      END          15880312

```

The NAMER Subroutine

```

C      SUBROUTINE TO PROVIDE HOLLERITH NAMES FOR PARTICLES AS A FUNCTION
C      OF THEIR CHARGE AND MASS                                J.B. BALL      26-JUNE-1962
      SUBROUTINE NAMER(IM,IZ,IWORD)
      DIMENSION IWORD(2)
      IF(IZ-1)104,101,104
101    IF(IM-1)102,110,102
102    IF(IM-2)103,111,103
103    IF(IM-3)119,112,119
104    IF(IZ-2)119,105,119
105    IF(IM-4)106,113,106
106    IF(IM-3)119,114,119
110    IWORD(1)=-XABSF(+6HPROTON)
      IWORD(2)=-XABSF(+6HS      )
      GO TO 120
111    IWORD(1)=-XABSF(+6HDEJTER)
      IWORD(2)=-XABSF(+6HONS      )
      GO TO 120
112    IWORD(1)=-XABSF(+6HTRITON)
      IWORD(2)=-XAB3F(+6HS      )
      GO TO 120
113    IWORD(1)=-XABSF(+6HALPHAS)
      IWORD(2)=-XABSF(+6H      )
      GO TO 120
114    IWORD(1)=-XABSF(+6HHELIUM)
      IWORD(2)=-XABSF(+6H-3      )
      GO TO 120
119    IWORD(1)=-XABSF(+6HNOT NA)
      IWORD(2)=-XABSF(+6HMED      )
120    RETURN
      END

```

The Nonrelativistic QVALUE Function

```

C      NON-RELATIVISTIC FORM OF THE Q EQUATION
      FUNCTION QVALUE(W1,W3,W4,E1,E3,ANGLAB)
      THETA#ANGLAB/57.29578
      QVALUE#(E3*(W3+W4)-E1*(W4-W1)
1    -2.0*SQRTF(W1*W3*E1*E3)*COSF(THETA))/W4
      RETURN
      END

```

The Relativistic QVALUE Function

```

C      RELATIVISTIC FORM OF THE Q EQUATION                                J B BALL      7/2/62
      FUNCTION QVALUE(W1,W3,W4,E1,E3,ANGLAB)
      THETA#ANGLAB/57.29578
      G1#W1*931.44
      G3#W3*931.44
      G4#W4*931.44
      R1#E1/G1
      R3#E3/G3
      QVALUE#E3-E1+G4*(SQRTF(1.0+(((W3/W4)**2)*R3*(2.0+R3))+(((W1/W4)**2
1    )*R1*(2.0+R1)))-(2.0*(W1*W3/(W4**2))*SQRTF(R1*R3*(2.0+R3)*(2.0+R1))
2    *COSF(THETA)))-1.0)
      RETURN
      END

```

The Nonrelativistic EVALUE Function

```

C  NON-RELATIVISTIC FORM OF THE ENERGY EQUATION
    FUNCTION EVALUE(W1,W3,W4,E1,Q,ANGLAB)
    THETA#ANGLAB/57.29578
    EICOM#E1*(W3+W4-W1)/(W3+W4)
    V3SQ#2.0*W4*(EICOM+Q)/(W3*(W3+W4))
    VVCM#SQRTF(2.0*W1*E1)/(W3+W4)
    EVALUE#0.5*W3*((VVCM*COSF(THETA)+SQRTF(V3SQ-
I  ((VVCM*SINF(THETA))**2)))**2)
    RETURN
    END

```

The Relativistic EVALUE Function

```

C  RELATIVISTIC FORM OF THE ENERGY EQUATION      J B BALL      7/2/62
    FUNCTION EVALUE(W1,W3,W4,E1,Q,ANGLAB)
    THETA#ANGLAB/57.29578
    G1#W1*931.44
    G3#W3*931.44
    G4#W4*931.44
    A#2.0*(G3+G4+E1+Q)
    B#2.0*E1*(G1-G4-Q)-Q*(2.0*G4+Q)
    D#E1*(E1+2.0*G1)*(COSF(THETA)**2)
    EVALUE#(4.0*G3*D-A*B+2.0*COSF(THETA)*SQRTF(E1*(E1+2.0*G1))*((B**2)-
I  2.0*G3*A*B+4.0*(G3**2)*D)))/((A**2)-4.0*D)
    RETURN
    END

```

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