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FORTRAN PROGRAMS FOR COMPUTING ANGULAR
DISTRIBUTIONS AND Q VALUES OF NUCLEAR REACTIONS

by

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ABSTRACT

Three Fortran programs, written for the IBM-704 computer, process the data from multichannel pulse-height analyzers in order to derive the Q values and differential cross sections of the groups observed. The standard deviations of the derived Q values and of the differential cross sections are also computed. With another program which has been written, the effects of impurities can be subtracted from pulse-height spectra observed when a target contains a mixture of nuclides. A fifth program computes the center-of-mass transformation quantities by means of the exact relativistic equations.

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FORTRAN PROGRAMS FOR COMPUTING ANGULAR DISTRIBUTIONS AND Q VALUES OF NUCLEAR REACTIONS

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I. INTRODUCTION

Nuclear reactions are often studied by observing one or more groups of particles at many angles. When many groups are seen and when data must be taken at many angles, weeks of tedious computation are necessary for the derivation of angular distributions. Most of this routine numerical analysis can be done by computer. Analysis by computer has several advantages: (1) the experimenter is freed from the most routine parts of the analysis, (2) more exact calculations become practical, (3) the analysis is done consistently by the same method, (4) a given mass of data is analyzed more quickly, and (5) the probability of error is reduced.

As programmed in Fortran for the IBM-704 computer, the computation is divided into three stages, the first of which is computation of the over-all constant of proportionality of the system (i.e., the range of particle energies at the detector per channel on the analyzer). This calibration computation uses the scattering from known levels, usually ones in C^{12} . The constant may be determined several times and the results averaged by the least-squares method.

The second stage is to use the known constant of proportionality and the kinematical relationships in order to derive accurate Q values. The Q value of each group is derived at the angles at which that group shows to best advantage and a least-squares average is taken of all the determinations. The least-squares error in the Q value is also computed.

In the third stage the angular distributions are computed. The computer is given the relevant information: mass numbers, charge numbers, Q values of groups to be analyzed, absorber thickness, constant of proportionality (keV/channel), number of channels to take in summing the peaks, target thickness, background, estimated error in background, etc. The computer then proceeds to sum each peak, subtract the estimated background, convert to a lab. cross section, convert to a c.m. cross section, and (for the elastic peak only) find the ratio to Rutherford scattering.

Sometimes the targets used contain a mixture of different nuclides, either because of the unavailability of pure (99% pure) separated isotopes or for chemical reasons. If a target containing a different proportion of the impurity is studied at the same time and if the compositions and weights of the targets involved are known, the effects of one or two impurities can be subtracted from the observed spectrum by use of the fourth program discussed below.

Finally, it is often desirable to tabulate the energy of the observed particle, the c.m. angle, and the solid-angle transformation factor. The fifth program uses the exact relativistic expressions to calculate these quantities as a function of laboratory angle. This program can also compute the effects of one or more absorbers upon the energy of the observed particle.

If an absorber is used, the corrections for energy lost in the absorber are made in terms of a Taylor expansion of the range-energy relation. These corrections are included in all of the programs.

The programs have been used successfully in several experiments.¹

¹ H. W. Broek, Phys. Rev. (to be published).

II. ENERGY CALIBRATION

For purposes of energy calibration, the position of a peak in the pulse-height spectrum is assumed to be a linear function of the energy that the particles deposit in the detector. (Zero pulse height need not correspond to zero energy.) The positions of two peaks from a reaction with accurately known Q values are given to the computer. The energies of the peaks are computed in the program. The gain of the system is simply the difference in energy (in MeV) of the groups divided by the difference in pulse height (in channels).

A. Calculation

First the computer uses the masses of the particles in the calibration reaction, the lab. angle, the beam energy, and the known Q values to find the energy (at the target) of the particles in the two observed peaks. If an absorber is used, the program will then compute the particle energy at the detector by use of a Taylor expansion of the range-energy relation. This expansion is discussed in Sec. VII.

The computer is given the positions of the centers of two of the peaks and the estimated uncertainty in the distance between peaks. The peak centers $\bar{L}$ may be estimated by eye; or they may be estimated in terms of the average position of the counts in the peak by use of the relation

$$\bar{L} = \left(\sum_L L N_L \right) / \sum_L N_L, \quad (1)$$

where L is a channel number, and N_L is the number of counts in channel L . Usually the two methods agree to better than 0.1 channel, provided the statistical accuracy is good. But whatever method is used, all the peak centers should be estimated by the same method.

Then the computer divides the difference in energy at the detector by the distance between peak centers to get the gain in MeV per channel. The estimated uncertainty in distance between peaks is used to get the uncertainty in the gain. No provision is made for taking other sources of error into account.

To improve the accuracy, the computation may be done for as many as 40 pairs of peaks. For this purpose, data may be taken at many different angles. An average is taken, and the average absolute value of deviation from the average is also taken. A least-squares average and least-squares standard deviation are also computed.

B. Experimental

The detector used in the experiments must be linear in energy. Examples of linear detectors are solid-state detectors, NaI and other inorganic scintillation crystals (except when used to detect heavy ions), proportional counters, and ionization chambers.

The most successful calibration reactions in these experiments have been elastic and inelastic scattering from C^{12} nuclei in a polyethylene target. This reaction gives four prominent peaks: the elastic peak and the three peaks at 4.433, 7.656, and 9.630 MeV excitation. Thus three determinations of gain can be made from one spectrum. Calibration data are taken several times during a day's experiment. The various determinations are compared to see if there is a variation with Q value (i.e., a nonlinearity) or with time (drift in the equipment).

C. Use of the Program

The program uses two card formats. The first type of card tells what nuclear reaction is being studied; the second gives

information needed for a particular determination of gain. (In this report it is assumed that the reader understands the use of format statements as described in the Fortran manual.² The formats for the various cards usually will not be given explicitly in the body of the text, but may be found in the appendices under the appropriate statement.) In the program "READ INPUT TAPE 7" is used instead of simply "READ" because data on cards are put on magnetic tape by the operators of the IBM-704 (in order to save computer time).³

The first type of card (Statement 10 in Appendix A) gives in order: the masses of the incident particle, target nucleus, and observed particle, the charge of the observed particle, and the energy of the incident particle.

The second type of card (Statement 40) gives the remaining information, eight numerical quantities of six digits each. A typical example is 182.35001445000.15000000-4.4330033420028.5000001. This set of numbers means the following. The center of peak A is at channel 182.35, the center of peak B is at channel 144.5, the uncertainty in the peak separation is 0.15 channels, the Q value of peak A is zero (elastic peak), the Q value of peak B is -4.433 MeV (first excited state), an absorber 33.42 mg/cm² thick was placed between target and detector, and the data were taken at a lab. angle of 28.5°. The final quantity is a branching instruction which tells the computer what to do after computing the gain. If this quantity is positive, the computer will take an average of all the values of gain, write the results on tape, and go back to reading the card of format one. When it is zero, the computer will read another card of format two and will re-determine the gain of the system.

² Reference Manual, 704 FORTRAN Programming System, International Business Machines Corporation (1961).

³ OOPS Manual, by T. C. Barts and M. K. Butler, Argonne National Laboratory, Technical Memorandum No. 37 (1962).

III. Q VALUES

If the calibration program has yielded an accurate value of gain (in MeV per channel) and if this gain is independent of channel number and of time, then accurate Q values can be derived for the reaction under study. The calculation assumes that one of the peaks (for example the elastic peak) of the reaction has an accurately known Q value.

A. Calculation

The computer takes the relevant information and computes the energy (at the detector) of the group with known Q value. This energy, the center of the peak with known Q value, the center of the other peak, and the calibration gain determine the energy (at the detector) of the other peak. Next the energy at the target and finally the Q value are calculated for this other peak. The total uncertainty in Q value is that due to uncertainty in gain added in quadrature to that due to uncertainty in separation of the two peaks. A least-squares average of the determinations of Q value is taken. The average absolute deviation from the average is given as well as the least-squares uncertainty.

B. Experiment

Data are generally taken at several angles because not every peak shows prominently at each angle. The Q value of a given group is calculated at those angles at which it is best seen. Data in the vicinity of possible contamination peaks are not used.

C. Use of the Program

This program uses two card formats, the first of which (Statement 10 in Appendix B) is identical to card format one of the

calibration program. Card format two (Statement 30 in Appendix B) contains nine six-digit numbers. An example of format two is

001884172.75000.25-1.3330011260000120022850043.5000001.

These

numbers are interpreted as: the peak with known Q value is at channel 188.4, the other peak is at channel 172.75, the peak separation is known to an accuracy of 0.25 channels, the known Q value is -1.333 MeV, the gain is 0.1126 ± 0.0012 MeV per channel, an absorber 22.85 mg/cm² thick was used, and the lab. angle was 43.5°. The final quantity tells the computer what to do after it finishes computing Q . If this branching quantity is zero, the computer will read another card of format two and will make another determination of the Q of the same peak. If it is one, the computer will average the determinations it has made and then read another card of format two (process another peak from the same reaction). If it is greater than one, the computer will average the determinations, read a card of format one, and then read a card of format two (and thus process a peak from another reaction).

IV. ANGULAR DISTRIBUTIONS

This stage computes the angular distributions. The computer is given the necessary data and control quantities and from them it decides which channels are in a given peak, adds these channels, subtracts either a computed background or a specified background, and multiplies by the appropriate numbers to get the differential cross section in mb/sr. The pulse-height spectra can be fed in on either magnetic tape or punched cards. The control quantities must be on punched cards. Spectra with 400 channels or less can be analyzed. Spectra with more channels could be analyzed if the dimension statements at the start of the program were changed. Similarly, up to 21 groups can be analyzed but more could be analyzed if the dimension statement were changed. The program has been used primarily for

elastic and inelastic scattering but certainly is adaptable to other reactions that lead to two final particles. The program can be used for reactions with gas targets as well as solid targets (but the numerical quantity in Statement 684 will be different for different geometrical arrangements in gas scattering).

A. Calculation

This section describes the calculation. The method of calculation is of course the same regardless of whether the spectra are fed into the computer from magnetic tape or from punched cards.

The first part of the programs (Statements 36-210 in Appendices C and D) deals with background subtraction and will be discussed later in this section. The parameters of interest are fed in on cards (Statements 211-452 in Appendix C). Then the computer is ready to sum the counts in the ground-state peak (Statements 454-530). (If the reaction under study does not excite the ground state, then some other group with known Q value may be substituted for the ground state for purposes of computation.) The computer has been fed the position L_0 of the ground-state peak and the number of channels ΔL to include in the summation. The region of summation has limits

$$L_0 \pm \frac{1}{2} \Delta L \quad (2)$$

which usually are nonintegral. The fractional channels at the ends of the region are prorated in accordance with the understanding that channel 152, for example, includes pulses from 151.5 to 152.5 units in height. Thus if the lower limit is 151.8, the computer adds 0.7 of the counts in channel 152. Similarly, if 157.8 were the upper limit, 0.3 of the counts in channel 158 would be added. The center of the elastic peak is re-evaluated by Eq. (1) to improve accuracy. Statements 550-676

govern computation of the nonrelativistic kinematical quantities: c.m. angle, solid-angle ratio for the c.m. transformation, lab. energy before absorber (from the known Q value), and lab. energy after absorber. Then in Statements 677-705 the cross section can be computed from the total number of counts, the geometrical quantities, and the target density (mg/cm^2). A specified number of background counts can also be subtracted before computing the cross section. The uncertainty in the cross section is computed from the statistical counting error and a specified uncertainty in the number of background counts. The two errors are added in quadrature. If the Q value of the ground-state group is zero (elastic scattering), a ratio to the Rutherford scattering cross section is computed.

If the number of excited-state groups to be analyzed is zero, the computer then goes to the next spectrum. If the number is positive, then for each group the computer will find the position of the peak (Statement 858) from the known energies of the ground-state and excited-state groups, the known gain ($\text{MeV}/\text{channel}$), and the known position of the ground-state peak. Then the number of channels to be used, ΔL , gives the limits of summation by Eq. (2), and the summation is performed by the methods used for the ground-state peak (Statements 859-950). The kinematic quantities for each peak are computed in Statements 740-856.

Next, background is subtracted by either of two methods. In the first and simpler method, the background (in counts per channel) and its uncertainty are estimated by eye. This method should be used for peak D in Fig. 1. However, the background under peak B is due to the tail of peak A; and the background under peak C is due to the tails of peaks A and B. It is assumed that the shape of the tail of peak A can be obtained by observing the reaction at an angle at which peaks B and C are negligible. This shape is fed into the computer which then removes this type of background by a numerical "peak shape" subtraction

Fig. 1. Typical observed spectrum. The dotted lines show the background levels under peaks B, C, and D.

of the type indicated graphically in Fig. 1. The computer is also given the estimated relative error (0.1 for example) to be expected in this method of estimating background. The error due to uncertainty in background is then added in quadrature to the statistical error of the peak (the square root of the total number of counts in the peak). The routine for subtracting background is found in Statements

960-1060. After the subtraction, the cross sections and their uncertainties are computed (Statements 1080-1090), the results are written on tape, and the analysis of the next spectrum begins.

B. Use of the Program with All Data on Cards

Card 1 tells the number of channels to be taken in summing the elastic peak and gives the peak center of the peak-shape spectrum (Statement 36 in Appendices C and D). Thus 000008107.30 in columns 1-12 means that 8 channels are used in summing the elastic peak and that the peak-shape spectrum has its center in channel 107.30. The peak-shape spectrum is the spectrum that is due to the ground-state group alone. This spectrum is put on cards 2-11 in the format 12F6.0 (Statement 38). This peak-shape spectrum is 120 channels long, a sufficient length for practical use.

Card 12 consists of four quantities (Statement 211). The first is a control quantity which is zero for a solid target and positive for a gas target. The second quantity is the number of channels in the spectrum. The third is a number by which the tail of the peak-shape spectrum

may be multiplied. Normally this quantity is set equal to unity. The fourth quantity is the number of particles in a unit of beam. If the unit of beam is $0.1 \mu\text{C}$ of doubly-charged alpha particles, this quantity would be 3.12×10^{11} . The card reads 0000010000960001.0000003.12E11 in columns 1-30 for a gas target, 96 channels per spectrum, normal peak-shape, and 3.12×10^{11} particles per unit of charge.

Card 13 (Statement 220) contains quantities relevant only to a solid target. An example is 0025.00.31750.7071 in columns 1-18, which means that the target was 25 cm from the detector aperture which was $1/8 \text{ in.} = 0.3175 \text{ cm}$ in diameter, and the sine of the angle between the target and the beam was 0.7071.

Card 14 (Statement 222) gives the masses of the incident particle, target nucleus, and observed particle, the charges of the observed particle and of the target nucleus, the beam energy (MeV), the Q of the ground-state group (MeV), the surface density (g/cm^2) of the target, and the number N of excited-state groups.

The 15th card (Statement 256) gives the number of channels to be used in summing each of the N peaks. The peaks are listed in order of increasing excitation energy. The number of channels must not be less than two for any peak; otherwise the summation routine will not work properly. These numbers may be nonintegral because the summation routine will take the appropriate fraction of the number of counts in a channel. If more than 12 groups are to be analyzed, a second card of this type is needed. If N is zero, the 15th and 16th cards must be omitted.

The 16th card (Statement 258) gives the Q values (in MeV) of the groups to be analyzed. The groups must be listed in the same order as on card 15.

Cards 17-19 give the quantities needed to analyze a particular spectrum. Cards of these three types must be written for each individual spectrum. Card 17 (Statement 360) gives the lab. angle of

observation (in degrees), the number of units of beam (number of integrator counts), the fraction of dead time, the position of the center of the elastic peak, the number of background counts per channel under the elastic peak, the uncertainty in this quantity (in counts per channel), the calibration gain (MeV/channel), the absorber thickness (mg/cm²), and an instruction. The instruction tells the computer what step in the program to go to after analyzing the spectrum it is about to get. If this instruction is 36, it will go back to the beginning and read another card 1 (Statement 36). If the instruction is 211, the computer will go back and read another card 12 (Statement 211). If the instruction is 222, the computer will go back to read card 14 (Statement 222). And if the instruction is 360, the computer will read another card 17 (Statement 360). This last alternative is the one most frequently used, since usually none of the quantities on the first 16 cards changes between runs.

Card 18 (Statement 370) gives the background (in counts per channel) under each of the excited-state peaks. If the background is set equal to zero, the peak-shape method will be used to compute the background.

Card 19 (Statement 374) gives the uncertainty in background (in counts per channel). However, if the peak-shape method of estimating background is chosen for a certain peak, then on card 19 the quantity corresponding to that peak will be taken to mean the ratio uncertainty/value for the estimated background.

After reading the nineteen cards, the computer proceeds to read the spectrum (Statement 407), analyze the spectrum, and write out the results on magnetic tape. Then it goes back to read the instruction specified by the instruction on card 17. More than one reaction can be analyzed with a single stack of cards by instructing the computer to go back to Statement 222 at the appropriate times.

C. Use of the Program with Spectra Read from Magnetic Tape

The comparison of various target nuclei is often facilitated by observing the same reaction from each target at a given lab. angle, and proceeding to a different angle after all the targets have been observed at the first angle. In this way all targets can be observed at exactly the same lab. angle and the same beam energy. But when this set of data is put on tape, the data from several reactions occur together on the same tape. A program like that of Sec. B would require that six cards (cards 14-19) be written for each run. However, in the program described below some of the variables on cards 14-16 are changed to subscripted variables, and only three cards need be written for each run (after the first run).

Cards 1-13 are the same as before (i.e., the same as in Appendix C). Card 14 (Statement 222 of Appendix D) specifies the masses of the beam particle and observed particle, the charge number of the observed particle, the beam energy (MeV), and the number of targets (10 or fewer) being analyzed.

For each target, a card of the following form must be written. These are cards 15A, 15B, 15C, etc., corresponding to Statement 224 of Appendix D. The card gives the mass and charge of the target atom, the Q value of the ground-state reaction, the surface density of the target (g/cm^2), and the number of excited-state groups to be analyzed.

For each target for which the number of excited-state groups is greater than zero, two more cards should be written. These give the number of channels to be used in summing each excited-state group and the Q value of each group. The two cards are read for the first target, then for the second target, etc. The formats are the same as in the previous program.

The next card is nearly the same as card 17 in the previous program. The first eight quantities are the same as before. The ninth quantity is the instruction that tells the computer what to do after it finishes analyzing the spectrum. If the instruction is 36, it will go to Statement 36 (read a card of type 1); if 211, it will go to Statement 211 (read a card of type 12); if 360 it will read another card of this type after the analysis. Usually the instruction is 360. If a minus sign is placed in front of the instruction, the computer will read the spectrum but will not analyze it and will then proceed as indicated by the magnitude of the instruction. The tenth quantity is the number of the target (in the order in which they are listed in the cards of type 15). The last quantity, NGOOF, provides a method for correcting errors (goofs) on the magnetic tape by means of instructions on cards. The next two cards give the background counts per channel and the uncertainty in background. The format and usage are the same as before. These two cards must be supplied even if the instruction is negative.

At this point the computer reads the spectrum from the magnetic tape. Then the cross sections are computed in the same fashion as in the previous program since Statements 434-1140 of the two programs are identical.

D. Use of Magnetic Tape

The pulse-height spectra are fed from the R.I.D.L. analyzer to a tally punch which punches the information on paper tape. The data are also typed out by an IBM electric typewriter which may be driven either by the analyzer or by a tape reader. Use of the tape reader frees the analyzer for accumulating more data while the relatively slow typeout is underway. A manual-entry circuit has been built so that an end-of-record mark and six identifying digits can be placed at the start of a run. To facilitate reading the tape by eye (if need be) and to facilitate

correcting any errors on the tape, channel numbers are included in the data. The beginning of a spectrum on paper tape would be coded as GGGGxec729004TS000S000000S001S000243S002S Here the G's are leader, the E, C, T, and S are used solely in controlling the type-writer, the X becomes an end-of-record on the magnetic tape, the 729 indicates the date (July 29), the 004 is the spectrum number, and the other numbers are 3-digit channel numbers alternating with 6-digit data. The letters are ignored when transferring the data to magnetic tape (except for X which causes an end of record). Records on the magnetic tape are 108 characters in length. Each record (after the first one) consists of twelve 6-digit pieces of data and twelve 3-digit channel numbers. An exception is the last record of each run, which is only partially filled with data.

Occasionally a character is lost or an extraneous character is inserted either during the punchout or during the conversion from paper tape to magnetic tape. At first, these difficulties were handled by correcting the paper tape if necessary and then converting to magnetic tape again. However, since this procedure was not satisfactory, provision was made for correcting the number of characters after the data have been read into the computer. The quantity NGOOF, mentioned above, is set equal to the number of errors to be corrected. A set of cards, one for each error, is placed after all the other cards for the corresponding run. Each of these cards contains the number of the channel in which an error occurred, the true number of counts in that channel, and a shift instruction. This shift instruction should be positive if a character was omitted, negative if an extraneous character was inserted, and zero if the routine is used merely to change the value of one point in the spectrum. The error-correcting routine comprises steps 423-433 of the program.

V. MIXED TARGETS

A. Calculation

Ideally one would like to bombard targets consisting of a single nuclide. But often for practical reasons it is impossible to do so. However, if one successively bombards N targets, each with a different major constituent and with no minor constituent that is not the major one in one of the other $N-1$ targets, then a subtraction procedure will yield the spectra that would have been observed had the N targets been monoisotopic. Such a subtraction procedure has been written for the case of $N = 3$. It has been used successfully in such experiments as one involving a Ta^{46} target containing several percent each of Ti^{47} and Ti^{48} . The program assumes that the isotopic and chemical composition of each target is known.

Suppose a target contains mostly material κ , and the ratio of the number of atoms of material λ to that of material κ is $A_{\kappa\lambda}$. Then N_{κ}' , the counting rate observed per atom/cm² of the principal component is given by

$$N_{\kappa}' = \sum_{\lambda} A_{\kappa\lambda} N_{\lambda}, \quad (3)$$

where N_{λ} is the counting rate that would have been observed from a monoisotopic target containing the same number of atoms per cm² of the λ component. Let B be the inverse of matrix A . Then

$$\sum_{\kappa} B_{\eta\kappa} A_{\kappa\lambda} = \delta_{\eta\lambda} \quad (4)$$

and the true counting rate is

$$N_{\lambda} = \sum_{\kappa} B_{\eta\kappa} N_{\kappa}'. \quad (5)$$

(All of the quantities N and N' must be referred to the same integrated beam current incident on the target, of course.) The matrix A is defined such that its diagonal elements are unity, i.e.,

$$A_{\lambda\lambda} = 1.0. \quad (6)$$

The program finds the inverse matrix B by the simple "brute force" method. When three related spectra (different targets, same reaction, same angle) are fed into the computer, they are unraveled by use of Eq. (5). All three spectra must have the same calibration constant (MeV/channel), but need not have the same intercept on the calibration plot. All three spectra should be taken with the same resolution width; otherwise residual peaks and dips may be produced by the subtraction. Furthermore, each spectrum must have a visible elastic peak or other reference peak. The program is written for the case in which the elastic peaks (due to the various components of each target) are unresolved. The various targets need not have the same thickness.

Possible systematic errors introduced by the subtraction program are not estimated. The errors in the output spectra are greater than the square root of the number of counts if an appreciable subtraction has been made.

B. Use of the Program

The first card (Statement 1 in Appendix E) contains the masses of the target atoms (M_1, M_2, M_3) in atomic mass units. The second card (Statement 2) contains the composition matrix C . The matrix element C_{12} is the atomic proportion of material 2 in the target whose principal component is material 1. The matrix elements are to be given in decimal form. The diagonal elements of the C matrix are not used in the program. Thus the sum

$$\sum_{\lambda} C_{\kappa\lambda} \quad (7)$$

need not be exactly unity.

The third card (Statement 3) gives the surface densities of the three targets in mg/cm² or in any other convenient units.

The fourth card (Statement 27) contains the calibration gain (MeV/channel), the number of channels to be taken in summing the elastic peak, and the number of channels per spectrum.

The fifth card (Statement 40) contains quantities needed for processing a particular spectrum. One card of this type must be written for each spectrum. Card five contains the run number, an instruction (explained below), the subscript designating the principal component in the target (1, 2, or 3, depending on how the first card was written), the number of integrator counts, the proportion of dead time, the position of the center of the elastic (or reference) peak in the spectrum (in channels), the lab. energy of the particles in this peak (in MeV), a branching quantity (described below), and the number of errors (if any) to be corrected on the tape. If the number of errors to be corrected is greater than zero, one card must be written for each error in the manner discussed in Sec. IV.D.

The first five digits of the instruction should be the same for each member of a set of three runs, and should serve to distinguish that set from all other runs. The final digit in the instruction is 1, 2, or 3 and gives the order in which the runs appear on the tape. Thus when the computer comes to a run whose instruction quantity is 000083, it will search for runs with instruction quantities 000081 and 000082 which should already be in storage. If the search is successful, the subtraction will be performed. If unsuccessful, the next run will be read into storage. If a run is not a member of a set of three for which such subtractions are appropriate, the instruction should be set equal to zero.

The branching quantity tells the computer where to go after processing the run. If the branching quantity is 1, it goes to Statement 1; if 27, to Statement 27; if 32, to Statement 32; and if greater than 32 it will print out the A matrix and other quantities of interest and then go to Statement 1.

VI. CENTER-OF-MASS TRANSFORMATION

A program was written to give the various kinematic quantities of interest in the center-of-mass transformation. The program computes the c.m. angle, the solid-angle transformation ratio, and the lab. energy of the observed particle. It also can compute the energy that the observed particle would have after passing through one or more absorbers. All calculations in this program use the relativistically correct expressions. The other programs discussed above use nonrelativistic expressions.

The computer is given the relevant quantities: mass of beam particles, mass of target nuclei, mass of observed particles, charge number of the observed particle, Q value of the reaction (MeV), lab. energy of beam particle (MeV), minimum lab. angle, increment in lab. angle, maximum lab. angle (all angles in degrees), and the number of absorbers.

The computation is first performed first at the minimum lab. angle; then the lab. angle is increased by the increment and the computation is repeated. The computer will keep on increasing the lab. angle by this constant increment and repeating the calculation until the maximum angle is reached. However certain reactions cannot be seen beyond a certain lab. angle. For these reactions, the computer will replace the given maximum lab. angle by the maximum lab. angle at which the reaction can be seen. This quantity will be printed on the output. If the lab. energy of the observed particle is a double-valued function of lab. angle, both values are computed.

If the number of absorbers stated on the first card is greater than zero, a second card must give the absorber thicknesses (in mg/cm² of Al equivalent).

VII. RANGE-ENERGY CURVE

A Taylor expansion of the range-energy relation was developed in order to facilitate the computations. The expansion is:

$$170 - R = \frac{A}{Z^2} [29.59 (10 - E) - 1.14 (10 - E)^2 - 0.0075 (10 - E)^3 - 0.00034 (10 - E)^4], \quad (8)$$

where R is the range in mg/cm², A is the mass number, Z is the charge number, and E is the energy per unit mass (MeV per nucleon). This formula is consistent to within 0.5% with the known range-energy relation⁴ (for Al absorber) from 2 to 20 MeV/nucleon. This formula was employed in all the programs, except that in the center-of-mass program, it was employed only below 16 MeV per nucleon. Above 16 MeV per nucleon, a second expansion was used, namely,

$$852.02528 - R = \frac{A}{Z^2} [60.54 (25 - E) - 0.965 (25 - E)^2 - 0.00284 (25 - E)^3]. \quad (9)$$

The two expressions give exactly the same value for R at 16 MeV per nucleon.

No explicit function E(R) was found. Instead the appropriate expression for R was inverted numerically by Newton's method.

⁴ R. M. Sternheimer, Phys. Rev. 115, 137 (1959).

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APPENDIX A PROGRAM FOR ENERGY CALIBRATION

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C      1369-PHY      HOWARD W BROEK      X-2349
C      CALCULATION OF DETECTOR GAIN IN MEV PER CHANNEL
      DIMENSION DEDL(40),DDEDL(40)
10     READ INPUT TAPE 7,1010,AM1,AM2,AM3,Z3,E1
1010   FORMAT(4F6.0,F6.1)
14     WRITE OUTPUT TAPE 6,1014
1014   FORMAT(94H1 CALCULATION OF DETECTOR GAIN IN MEV PER CHANNEL
X      1369-PHY      HOWARD BROEK      X-2349)
15     WRITE OUTPUT TAPE 6,1015,AM1,AM2,AM3,Z3,E1
1015   FORMAT(7H AM1 =F4.0,7H AM2 =F4.0,7H AM3 =F4.0,6H Z3 =F4.0,6H
X      E1 =F5.1)
19     N=0
20     W=E1*AM2/(AM1+AM2)
21     AM4=AM1+AM2-AM3
22     SUM=0.0
23     AOZ2=AM3/(Z3**2)
25     WRITE OUTPUT TAPE 6,1025
1025   FORMAT(91H PEAK A      PEAK B      DELTAPEAKS      QA      QB      ABS
X      XORBER THETALAB      DEDL DELTADEDL)
40     READ INPUT TAPE 7,1040,PHA,PHB,DELPH,QA,QB,
X      XABSORB,THL,NBR
1040   FORMAT(3F6.1,2F6.3,F6.2,F6.0,I6)
44     N=N+1
48     Q=QA
49     J=0
50     THETAR=0.017453292*THL
60     SINE2=(SINF(THETAR))**2
70     ROOTA=(COSF(THETAR)*SQRTF(AM1*AM3*E1)+
X      XSQRTF((AM1*AM3*E1)*(1.0-SINE2)+(AM3+AM4)*
X      (AM4*Q+(AM4-AM1)*E1)))/(AM3+AM4)
C      FIND ENERGY AT DETECTOR (ED) IN TERMS OF ENERGY AT TARGET (ET)
90     EPTA=10.0-(ROOTA**2)/AM3
100    IF (ABSORB) 110,110,145
110    EPDA=EPTA
120    GO TO 156
145    XTA=AOZ2*(29.59*EPTA
X      X-1.14*EPTA**2-0.0075*EPTA**3
X      X-0.00034*EPTA**4)
146    XDA=XTA+ABSORB
147    K=0
148    EPDA=XDA/29.59
149    DXDE=AOZ2*(29.59-2.28*EPDA
X      X-0.0225*EPDA**2-0.00136*EPDA**3)
150    K=K+1
151    X1DA=AOZ2*(29.59*EPDA
X      X-1.14*EPDA**2-0.0075*EPDA**3
X      X-0.00034*EPDA**4)
152    EPDA=EPDA+(XDA-X1DA)/DXDE
153    IF (K-10)154,154,156
154    XERR=ABSF(XDA-X1DA)
155    IF (XERR-0.01)156,156,149
156    IF (J) 160,160,200
160    EDA=(10.0-EPDA)*AM3
157    J=1
170    Q=QB
180    GO TO 70
200    EDB=(10.0-EPDA)*AM3
210    DEDL(N)=ABSF((EDA-EDB)/(PHA-PHB))
211    SUM=SUM+DEDL(N)
215    DDEDL(N)=DEDL(N)*DELPH/ABSF(PHA-PHB)
220    WRITE OUTPUT TAPE 6,1220,PHA,PHB,DELPH,
X      XQA,QB,ABSORB,THL,DEDL(N),DDEDL(N)

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1220 FORMAT(F8.2,F9.2,F12.2,2F10.3,F12.2,F10.1,2F10.6)
225 IF (NBR) 40,40,235
C AVERAGE THE RESULTS
235 AN=N
250 AVER=SUM/AN
260 DIFF=0.0
270 DO 290 I=1,N
280 DIFF=DIFF+ABSF(DEDL(I)-AVER)
290 CONTINUE
300 ERR=DIFF/AN
305 PERC=100.0*ERR/AVER
310 WRITE OUTPUT TAPE 6,1310,AVER,ERR,PERC
1310 FORMAT(16H AVERAGE DEDL =F10.6/16H          +OR- F10.6,9H      0
XR F8.4,9H PERCENT)
311 YLL=0.0
312 DLL=0.0
313 DO 315 I=1,N
314 DLL=DLL+1.0/(DDEDL(I)**2)
315 YLL=YLL+DEDL(I)/(DDEDL(I)**2)
316 AVLSQ=YLL/DLL
317 ERLSQ=1.0/SQRTF(DLL)
318 PCLSQ=100.0*ERLSQ/AVLSQ
319 WRITE OUTPUT TAPE 6,1319,AVLSQ,ERLSQ,PCLSQ
1319 FORMAT(16H LEAST SQ AV =F10.6/16H          +OR- F10.6,9H      0
XR F8.4,9H PERCENT)
320 GO TO 10

```

APPENDIX B PROGRAM FOR THE DERIVATION OF Q VALUES

```

C 1370-PHY HOWARD W BROEK X-2349
C CALCULATION OF Q-VALUES FROM PEAK POSITIONS
DIMENSION QB(40)
10 READ INPUT TAPE 7,1010,AM1,AM2,AM3,Z3,E1
1010 FORMAT(4F6.0,F6.1)
14 WRITE OUTPUT TAPE 6,1014
1014 FORMAT(90H1 CALCULATION OF Q-VALUES FROM PEAK POSITIONS          1
X370-PHY HOWARD BROEK X-2349)
15 WRITE OUTPUT TAPE 6,1015,AM1,AM2,AM3,Z3,E1
1015 FORMAT(7H AM1 =F4.0,7H AM2 =F4.0,7H AM3 =F4.0,6H Z3 =F4.0,6H
XE1 =F5.1)
16 AM4=AM1+AM2-AM3
17 AOZ2=AM3/(Z3**2)
18 WRITE OUTPUT TAPE 6,1018
1018 FORMAT(106H PEAK A PEAK B DELTAPEAKS QA DEDL DELTAD
XEDL ABSORBER THL NSTRC QB DELTAQB1)
22 SUM=0.0
23 SUMD=0.0
24 I=0
25 J=0
30 READ INPUT TAPE 7,1030,PHA,PHB,DELPH,QA,DEDL,DDEDL,
XABSORB,THL,NSTRC
1030 FORMAT(3F6.1,F6.3,2F6.4,F6.2,F6.0,16)
50 THETAR=0.017453292*THL
60 SINE2=(SINF(THETAR))**2
70 ROOTA=(COSF(THETAR)*SQRTF(AM1*AM3*E1)+
XSQRTF((AM1*AM3*E1)*(1.0-SINE2)+(AM3+AM4)*
X(AM4*QA+(AM4-AM1)*E1)))/(AM3+AM4)
90 EPTA=10.0-(ROOTA**2)/AM3
100 IF (ABSORB)130,110,145

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110 EPDA=EPTA
120 GO TO 256
130 STOP
145 XTA=AOZ2*(29.59*EPTA
      X-1.14*EPTA**2-0.0075*EPTA**3
      X-0.00034*EPTA**4)
146 XDA=XTA+ABSORB*(1.0-2.0*FLOATF(J))
247 K=0
248 EPDA=XDA/29.59
249 DXDE=AOZ2*(29.59-2.28*EPDA
      X-0.0225*EPDA**2-0.00136*EPDA**3)
250 K=K+1
251 X1DA=AOZ2*(29.59*EPDA
      X-1.14*EPDA**2-0.0075*EPDA**3
      X-0.00034*EPDA**4)
252 EPDA=EPDA+(XDA-X1DA)/DXDE
253 IF (K-10)254,254,256
254 XERR=ABSF(XDA-X1DA)
255 IF (XERR-0.01)256,256,249
256 IF (J)130,257,340
257 EPTA=EPDA+(PHA-PHB)*DEDL/AM3
258 J=1
270 GO TO 100
340 ETB=(10.0-EPDA)*AM3
370 DEE=(AM3+AM4)*(SQRTF(ETB))-(COSF
      X(THETAR))*SQRTF(AM1*AM3*E1)
380 PHEI=(DEE**2-AM1*AM3*E1*((COSF
      X(THETAR))**2))/(AM3+AM4)
389 I=I+1
390 QB(I)=(PHEI+(AM1-AM4)*E1)/AM4
392 DELQB=QB(I)*SQRTF((DELPH/(PHA-PHB))**2
      X+(DDEDL/DEDL)**2)
394 SUM=SUM+QB(I)/(DELQB**2)
396 SUMD=SUMD+1.0/(DELQB**2)
400 WRITE OUTPUT TAPE 6,1400,PHA,PHB,DELPH,QA,DEDL,
      XDDEDL,ABSORB,THL,NSTRC,QB(I),DELQB
1400 FORMAT(F8.2,F9.2,F12.2,F8.3,F10.6,F11.6,F11.2,F7.1,I9,F11.3,F10.3)
401 IF (NSTRC)130,25,410
410 AI=I
420 QAV=SUM/SUMD
421 ERSUM=0.0
430 DO 450 L=1,I
450 ERSUM=ERSUM+ABSF(QB(L)-QAV)
460 DELQAV=ERSUM/AI
470 DEV=1.0/(SQRTF(SUMD))
480 WRITE OUTPUT TAPE 6,1480,QAV,DELQAV
1480 FORMAT(12H QAVERAGE =F8.3,12H      +OR- F8.3)
485 WRITE OUTPUT TAPE 6,1480,QAV,DEV
490 IF (NSTRC-1)130,18,10

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APPENDIX C PROGRAM FOR THE DERIVATION OF CROSS SECTIONS (CARD INPUT)

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C      1350-PHY      HOWARD W BROEK      X-2349
C      ANGULAR DISTRIBUTIONS OF GROUPS FROM NUCLEAR REACTIONS
C      SPECTRA READ FROM CARDS
      DIMENSION COUNTS(400),PEAKSH(120),TRUCO(20),
      XQ(20),GRCEN(20),BKD(20),DELBKD(20),ASUM(20)
36 READ INPUT TAPE 7,2036,AJ,PKSHCN

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2036 FORMAT(F6.0,F6.2)
38 READ INPUT TAPE 7,2038,(PEAKSH(I),I=1,120)
2038 FORMAT(12F6.0)
C SUM THE PEAK-SHAPE DATA
40 BJ=PKSHCN-AJ/2.0
60 JD=XINTF(BJ+0.5)
70 DJ=JD
80 PEKSM=PEAKSH(JD)*(DJ+0.5-BJ)
85 SUMLC=PEKSM*(BJ+DJ+0.5)/2.0
90 IF (DJ+1.5-AJ-BJ)100,140,140
95 STOP
100 JD=JD+1
110 DJ=JD
120 PEKSM=PEKSM+PEAKSH(JD)
122 SUMLC=SUMLC+PEAKSH(JD)*DJ
125 GO TO 90
140 PEKSM=PEKSM+PEAKSH(JD+1)*(AJ+BJ-DJ-0.5)
142 SUMLC=SUMLC+PEAKSH(JD+1)*(AJ+BJ-DJ-0.5)
X*(AJ+BJ+DJ+0.5)/2.0
144 PKSHCN=SUMLC/PEKSM
145 WRITE OUTPUT TAPE 6,2145
2145 FORMAT(112H1 ANGULAR DISTRIBUTIONS OF GROUPS FROM NUCLEAR REACTION
1S CARD VERSION HOWARD W BROEK X-2349 1350-PHY)
190 WRITE OUTPUT TAPE 6,2190
2190 FORMAT(21H PEAK-SHAPE SPECTRUM)
200 WRITE OUTPUT TAPE 6,2200,(PEAKSH(I),I=1,120)
2200 FORMAT(10F9.0)
210 WRITE OUTPUT TAPE 6,2210,PEKSM
2210 FORMAT(9H PEKSM=F9.0)
C READ REACTION DATA
211 READ INPUT TAPE 7,2211,GAS,L,CORR,BEAM
2211 FORMAT(F6.0,I6,F6.2,IPE12.5)
218 IF (GAS)95,220,222
220 READ INPUT TAPE 7,2220,DIST,DIAM,SNITAN
2220 FORMAT(F6.0,F6.4,F6.6)
222 READ INPUT TAPE 7,2222,AM1,AM2,AM3,Z3,Z4,E1,QUZER,DENS,N
2222 FORMAT(5F6.0,F6.1,F6.3,F6.6,I6)
226 AM4=AM1+AM2-AM3
230 W=E1*AM2/(AM1+AM2)
234 BETA=1.2954*((Z3*Z4*(1.0+AM1/AM2)/E1)**2)
238 AOZ2=AM3/(Z3**2)
254 IF (N) 360,360,256
256 READ INPUT TAPE 7,2038,(ASUM(I),I=1,N)
258 READ INPUT TAPE 7,2258,(Q(I),I=1,N)
2258 FORMAT(12F6.3)
360 READ INPUT TAPE 7,2360,THL,ENTCO,CLOSS,ELCNTR,ELBKD,
XRRBKD,DEDL,ABSORB,NSTRC
2360 FORMAT(F6.1,F6.0,2F6.2,2F6.0,F6.5,F6.2,I6)
366 IF (N) 95,382,370
C ENTER BACKGROUND DATA
370 READ INPUT TAPE 7,2038,(BKD(I),I=1,N)
374 READ INPUT TAPE 7,2038,(DELBKD(I),I=1,N)
382 ALPHA=SQRTF((AM1*AM3)/(AM2*AM4)
X*(W/(QUZER+W)))
407 READ INPUT TAPE 7,2038,(COUNTS(I),I=1,L)
434 IF (NSTRC)1140,438,438
438 WRITE OUTPUT TAPE 6,2145
439 WRITE OUTPUT TAPE 6,2439,AM1,AM2,AM3,Z3,Z4,E1,
XQUZER,DENS,DEDL,AJ,GAS,L,N,PKSHCN,CORR,BEAM

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2439 FORMAT(7H AM1 =F4.0,6H AM2 =F5.0,6H AM3 =F4.0,6H Z3 =F3.0,5H Z4
X=F4.0,6H E1 =F5.1,10H QUZER =F7.3,19H TARGET DENSITY =F9.6/8H
X DEDL =F7.4,7H AJ =F3.0,7H GAS =F3.0,5H L =14,5H N =13,10H
XPKSHCN =F6.2,8H CORR =F5.2,8H BEAM =1PE12.3)
440 IF (GAS)95,441,442
441 WRITE OUTPUT TAPE 6,2441,DIST,DIAM,SNTGAN
2441 FORMAT(8H DIST =F6.1,8H DIAM =F6.4,10H SNTGAN =F9.6)
442 WRITE OUTPUT TAPE 6,2442,THL,ENTCO,CLOSS,ABSORB
2442 FORMAT(12H THETALAB =F6.2,17H INTEGRATOR =F6.0,15H LOSSRA
XTE =F5.3,14H ABSORBER =F6.2)
443 IF (N)95,450,444
444 WRITE OUTPUT TAPE 6,2444
2444 FORMAT(56H NUMBER OF CHANNELS TO BE SUMMED IN EXCITED-STATE PEAKS
X)
445 WRITE OUTPUT TAPE 6,2445,(ASUM(I),I=1,N)
2445 FORMAT(12F9.1)
447 WRITE OUTPUT TAPE 6,2447
2447 FORMAT(33H Q-VALUES OF EXCITED-STATE PEAKS)
448 WRITE OUTPUT TAPE 6,2448,(Q(I),I=1,N)
2448 FORMAT(12F9.3)
450 WRITE OUTPUT TAPE 6,2450
2450 FORMAT(25H SPECTRUM TO BE ANALYZED)
452 WRITE OUTPUT TAPE 6,2200,(COUNTS(I),I=1,L)
C SUM THE GROUND-STATE PEAK
454 BJ=ELCNTR-AJ/2.0
456 JD=XINTF(BJ+0.5)
458 DJ=JD
460 ELASCO=COUNTS(JD)*(DJ+0.5-BJ)
465 SMLC=ELASCO*(BJ+DJ+0.5)/2.0
470 IF (DJ+1.5-AJ-BJ)480,520,520
480 JD=JD+1
490 DJ=JD
500 ELASCO=ELASCO+COUNTS(JD)
505 SMLC=SMLC+COUNTS(JD)*DJ
510 GO TO 470
520 ELASCO=ELASCO+COUNTS(JD+1)*(AJ+BJ-DJ-0.5)
522 SMLC=SMLC+COUNTS(JD+1)*(AJ+BJ-DJ-0.5)
X*(AJ+BJ+DJ+0.5)/2.0
524 ELCNTR=SMLC/ELASCO
528 ELASCO=ELASCO-ELBKD*AJ
529 BJ=ELCNTR-AJ/2.0
530 EJ=AJ+BJ
C CM TRANSFORMATION FOR THE GROUND-STATE PEAK
550 THETAR=0.017453292*THL
560 SINE2=(SINF(THETAR))**2
570 ANGLER=THETAR+ASINF(ALPHA*SINF(THETAR))
580 ANGLE=57.295779*ANGLER
640 RATIO=(SINF(THETAR)/SINF(ANGLER))**3
X*(1.0+ALPHA*COSF(ANGLER))
650 ROOTEL=(COSF(THETAR)*SQRTF(AM1*AM3*E1)+
XSQRTF((AM1*AM3*E1)*(1.0-SINE2)+(AM3+AM4)*
X(AM4*QUZER+(AM4-AM1)*E1)))/(AM3+AM4)
660 E3EL=ROOTEL**2
C ABSORBER CORRECTION FOR THE GROUND-STATE PEAK
661 IF(ABSORB)662,662,664
662 EDL=E3EL
663 GO TO 677
664 EPTL=10.0-E3EL/AM3
665 XTL=A0Z2*(29.59*EPTL-1.14*EPTL**2
X-0.0075*EPTL**3-0.00034*EPTL**4)

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666 XDL=XTL+ABSORB
667 K=0
668 EPDL=XDL/29.59
669 DXDE=A0Z2*(29.59-2.28*EPDL-0.0225
X*EPDL**2-0.00136*EPDL**3)
670 K=K+1
671 XIDL=A0Z2*(29.59*EPDL-1.14*EPDL**2
X-0.0075*EPDL**3-0.00034*EPDL**4)
672 EPDL=EPDL+(XDL-XIDL)/DXDE
673 IF (K-10)674,674,676
674 XERR=ABSF(XDL-XIDL)
675 IF (XERR-0.01)676,676,669
676 EDL=(10.0-EPDL)*AM3
677 IF (GAS)95,686,678
678 READ INPUT TAPE 7,2678,TEMP,COMP,ATPMOL,PRESS
2678 FORMAT(F6.2,F6.5,F6.0,F6.2)
679 WRITE OUTPUT TAPE 6,2679,TEMP,COMP,ATPMOL,PRESS
2679 FORMAT(15H TEMPERATURE =F6.2,26H DEG C COMPRESSIBILITY =F6.5,23
XH ATOMS PER MOLECULE =F2.0,14H PRESSURE =F6.2,6H MM HG)
684 ABS=4.7907E12*(TEMP+273.16)*COMP*(SINF(THETAR))
X/(ATPMOL*PRESS*BEAM)
685 GO TO 688
686 ABS=2114.0*((DIST/DIAM)**2)*
XAM4*SNTGAN/(DENS*BEAM)
C CROSS SECTION FOR THE GROUND STATE
688 SIG=ELASCO*RATIO*(ABS/ENTCO)/(1.0-CLOSS)
690 ARX=ELASCO+ELBKD*AJ+((RRBKD*AJ)**2)
691 DELSIG=SIG*(SQRTF(ARX))/ELASCO
692 IF(QUZER)700,693,700
693 RFAC=((SINF(ANGLE*0.017453292*0.5))**4)/BETA
694 RUTH=SIG*RFAC
696 DLRU=DELSIG*RFAC
698 WRITE OUTPUT TAPE 6,2698,RUTH,DLRU
2698 FORMAT(23H RATIO TO RUTHERFORD =F9.6/
X23H +OR- F9.6)
700 WRITE OUTPUT TAPE 6,2700
2700 FORMAT(117H Q-VALUE THETACM SIGMA DELSIGMA FIRST LAS
XT RATIO E3TARGET E3DETECTOR NETCOUNTS BKDCOUNTS PEAKCENTER)
705 WRITE OUTPUT TAPE 6,2705,QUZER,ANGLE,SIG,DELSIG,
XBJ,EJ,RATIO,E3EL,E
XDL,ELASCO,ELBKD,RRBKD,ELCNTR
2705 FORMAT(F9.3,F10.2,F12.6,F11.6,2F7.2,F7.4,F10.3,F11.3,F11.0,F7.0,F7
X.2,F8.2)
708 IF (N)1140,1140,730
730 DO 1130 I=1,N
C CM TRANSFORMATION FOR EXCITED STATES
740 ALPHA=SQRTF((AM1*AM3)/(AM2*AM4)
X*(W/(Q(I)+W)))
750 ANGLER=THETAR+ASINF(ALPHA*SINF(THETAR))
760 ANGLE=57.295779*ANGLER
820 RATIO=(SINF(THETAR)/SINF(ANGLER))**3
X*(1.0+ALPHA*COSF(ANGLER))
830 ROOTIN=(COSF(THETAR)*SQRTF(AM1*AM3*E1)+
XSQRTF((AM1*AM3*E1)*(1.0-SINE2)+(AM3+AM4)*
X(AM4*Q(I)+(AM4-AM1)*E1)))/(AM3+AM4)
840 E3IN=ROOTIN**2
C ABSORBER CORRECTION FOR EXCITED STATES
841 IF(ABSORB)842,842,844
842 EDN=E3IN
843 GO TO 858

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844 EPTN=10.0-E3IN/AM3
845 XTN=AOZ2*(29.59*EPTN-1.14*EPTN**2
      X-0.0075*EPTN**3-0.00034*EPTN**4)
846 XDN=XTN+ABSORB
847 K=0
848 EPDN=XDN/29.59
849 DXDE=AOZ2*(29.59-2.28*EPDN-0.0225
      X*EPDN**2-0.00136*EPDN**3)
850 K=K+1
851 X1DN=AOZ2*(29.59*EPDN-1.14*EPDN**2
      X-0.0075*EPDN**3-0.00034*EPDN**4)
852 EPDN=EPDN+(XDN-X1DN)/DXDE
853 IF (K-10)854,854,856
854 XERR=ABSF(XDN-X1DN)
855 IF (XERR-0.01)856,856,849
856 EDN=(10.0-EPDN)*AM3
C    SUM THE EXCITED-STATE PEAK
858 GRcen(I)=ELCNTR+(EDN-EDL)/DEDL
859 AZ=ASUM(I)
860 BJ=GRcen(I)-AZ/2.0
870 JD=XINTF(BJ+0.5)
880 DJ=JD
890 ANELCO=COUNTS(JD)*(DJ+0.5-BJ)
900 IF (DJ+1.5-AZ-BJ)941,945,945
940 STOP
941 JD=JD+1
942 DJ=JD
943 ANELCO=ANELCO+COUNTS(JD)
944 GO TO 900
945 ANELCO=ANELCO+COUNTS(JD+1)*(AZ+BJ-DJ-0.5)
950 EJ=AZ+BJ
960 IF(BKD(I))940,973,971
971 DELTCO=SQRTF(ANELCO+(DELBKD(I)*AZ)**2)
972 GO TO 1060
C    CALCULATE BKD DUE TO GROUND-STATE PEAK
973 PKPOS=PKSHCN-ELCNTR+GRcen(I)
980 JH=XFIXF(PKPOS)
981 PKLOW=JH
984 DEL=PKPOS-PKLOW
990 BKD(I)=CORR*((1.0-DEL)*PEAKSH(JH)+
      XDEL*PEAKSH(JH+1))*ELASCO/PEKSM
991 M=I-1
992 IF(M)940,1055,1000
C    CALCULATE BKD DUE TO HIGHER PEAKS
1000 DO 1050 K=1,M
1010 PKPOS=PKSHCN-GRcen(K)+GRcen(I)
1020 JH=XFIXF(PKPOS)
1030 PKLOW=JH
1040 DEL=PKPOS-PKLOW
1050 BKD(I)=BKD(I)+CORR*((1.0-DEL)*PEAKSH(JH)+
      XDEL*PEAKSH(JH+1))*TRUCO(K)/PEKSM
1055 DELTCO=SQRTF(ANELCO+(DELBKD(I)*BKD(I)*AZ)**2)
1060 TRUCO(I)=ANELCO-BKD(I)*AZ
C    COMPUTE CROSS SECTIONS FOR HIGHER PEAK
1080 SIG=TRUCO(I)*RATIO*(ABS/ENTCO)
      X/(1.0-CLOSS)
1090 DELSIG=DELTCO*RATIO*(ABS/ENTCO)
      X/(1.0-CLOSS)
1130 WRITE OUTPUT TAPE 6,2705,Q(I),ANGLE,SIG,DELSIG,BJ,
      XEJ,RATIO,E3IN,EDN,TRUCO(I),BKD(I),DELBKD(I),GRcen(I)

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1140 NY=XABSF(NSTRC)
1150 IF (NY-211)36,211,1160
1160 IF (NY-222)222,222,360

```

APPENDIX D PROGRAM FOR THE DERIVATION OF CROSS SECTIONS (TAPE INPUT)

```

C      1413-PHY      HOWARD W BROEK      X-2349
C      ANGULAR DISTRIBUTIONS OF GROUPS FROM NUCLEAR REACTIONS
C      SPECTRA READ FROM MAGNETIC TAPE
      DIMENSION COUNTS(400),PEAKSH(120),TRUCO(20),CHN(400),
      XQ(20),GRCEN(20),BKD(20),DELBKD(20),ASUM(20)
      DIMENSION QM(20,10),ASMM(20,10),
      XAM2L(10),Z4L(10),QUZL(10),DNLL(10),NLL(10)
36     READ INPUT TAPE 7,2036,AJ,PKSHCN
2036    FORMAT(F6.0,F6.2)
38     READ INPUT TAPE 7,2038,(PEAKSH(I),I=1,120)
2038    FORMAT(12F6.0)
C      SUM THE PEAK-SHAPE DATA
40     BJ=PKSHCN-AJ/2.0
60     JD=XINTF(BJ+0.5)
70     DJ=JD
80     PEKSM=PEAKSH(JD)*(DJ+0.5-BJ)
85     SUMLC=PEKSM*(BJ+DJ+0.5)/2.0
90     IF (DJ+1.5-AJ-BJ)100,140,140
95     STOP
100    JD=JD+1
110    DJ=JD
120    PEKSM=PEKSM+PEAKSH(JD)
122    SUMLC=SUMLC+PEAKSH(JD)*DJ
125    GO TO 90
140    PEKSM=PEKSM+PEAKSH(JD+1)*(AJ+BJ-DJ-0.5)
142    SUMLC=SUMLC+PEAKSH(JD+1)*(AJ+BJ-DJ-0.5)
      X*(AJ+BJ+DJ+0.5)/2.0
144    PKSHCN=SUMLC/PEKSM
145    WRITE OUTPUT TAPE 6,2145
2145   FORMAT(111H1 ANGULAR DISTRIBUTIONS OF GROUPS FROM NUCLEAR REACTION
      XS - TAPE VERSION      1413-PHY      HOWARD W BROEK      X-2349)
190    WRITE OUTPUT TAPE 6,2190
2190   FORMAT(21H PEAK-SHAPE SPECTRUM)
200    WRITE OUTPUT TAPE 6,2200,(PEAKSH(I),I=1,120)
2200   FORMAT(10F9.0)
210    WRITE OUTPUT TAPE 6,2210,PEKSM
2210   FORMAT(9H PEKSM =F9.0)
C      READ REACTION DATA
211    READ INPUT TAPE 7,2211,GAS,L,CORR,BEAM
2211   FORMAT(F6.0,I6,F6.2,1PE12.5)
212    AL=L
216    LHI=L-1
218    IF (GAS)95,220,222
220    READ INPUT TAPE 7,2220,DIST,DIAM,SNTGAN
2220   FORMAT(F6.0,F6.4,F6.6)
222    READ INPUT TAPE 7,2222,AM1,AM3,Z3,E1,NTAR
2222   FORMAT(3F6.0,F6.1,I6)
224    READ INPUT TAPE 7,2224,(AM2L(I),Z4L(I),QUZL(I),
      XDNLL(I),NLL(I),I=1,NTAR)
2224   FORMAT (2F6.0,F6.3,F6.6,I6)

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250 DO 260 I=1,NTAR
252 NLM=NLL(I)
254 IF (NLM)260,260,256
256 READ INPUT TAPE 7,2038,(ASMM(JK,I),JK=1,NLM)
258 READ INPUT TAPE 7,2258,(QM(JK,I),JK=1,NLM)
2258 FORMAT(12F6.3)
260 CONTINUE
C READ SPECTRUM
360 READ INPUT TAPE 7,2360,THL,ENTCO,CLOSS,ELCNTR,ELBKD,
XRRBKD,DEDL,ABSORB,NSTRC,ITAR,NGOOF
2360 FORMAT(2F6.0,2F6.2,2F6.0,F6.5,F6.2,3I6)
361 AM2=AM2L(ITAR)
362 Z4=Z4L(ITAR)
363 QUZER=QUZL(ITAR)
364 DENS=DNLL(ITAR)
365 N=NLL(ITAR)
366 IF (N) 95,380,367
367 DO 369 I=1,N
368 ASUM(I)=ASMM(I,ITAR)
369 Q(I)=QM(I,ITAR)
C ENTER BACKGROUND DATA
370 READ INPUT TAPE 7,2038,(BKD(I),I=1,N)
374 READ INPUT TAPE 7,2038,(DELBKD(I),I=1,N)
380 AM4=AM1+AM2-AM3
381 W=E1*AM2/(AM1+AM2)
382 ALPHA=SQRTF((AM1*AM3)/(AM2*AM4)
X*(W/(QUZER+W)))
383 BETA=1.2954*((Z3*Z4*(1.0+AM1/AM2)
X/E1)*2)
384 A0Z2=AM3/(Z3*2)

407 READ INPUT TAPE 9,2407,C7,CPR,C9,(CHN(I),COUNTS(I),I=1,10),CHN(11)
407 FORMAT(12(F6.0,F3.0))
408 IF (CHN(1)-301.0)409,409,405
409 CMFN=MODF(CPR,AL)
411 IF (CMFN)405,422,405
422 READ INPUT TAPE 9,2407,COUNTS(11),(CHN(I),COUNTS(I),I=12,LM1)
423 IF (NGOOF)95,434,424
424 DO 433 I=1,NGOOF
425 READ INPUT TAPE 7,2425,NCHG,GCOU,GSFT
2425 FORMAT(16,2F6.0)
426 COUNTS(NCHG)=GCOU
4426 NCHG=NCHG+1
427 IF (GSFT)431,433,428
428 DO 429 JP=NCHG,LM1
4428 CHN(JP)=INTF(CHN(JP)/10.0)+MODF(COUNTS(JP-1),10.0)*100.0
429 COUNTS(JP)=INTF(COUNTS(JP)/10.0)
X+MODF(CHN(JP),10.0)*1.0E5
430 GO TO 433
431 DO 432 JP=NCHG,LM1
4431 CHN(JP)=INTF(COUNTS(JP)/1.0E5)+10.0*MODF(CHN(JP),100.0)
432 COUNTS(JP)=INTF(CHN(JP+1)/100.0)+10.0*MODF(COUNTS(JP),1.0E5)
433 CONTINUE
434 IF (NSTRC)1140,438,438
438 WRITE OUTPUT TAPE 6,2145
439 WRITE OUTPUT TAPE 6,2439,AM1,AM2,AM3,Z3,Z4,E1,
XQUZER,DENS,DEDL,AJ,GAS,L,N,PKSHCN,CORR,BEAM

```

Replace statements 4428 and 429 by the four statements:

```

3428 GUR=CHN(JP)
4428 CHN(JP)=INTF(GUR/10.0)+MODF(FOP,10.0)*100.0
5428 FOP=COUNTS(JP)
429 COUNTS(JP)=INTF(FOP/10.0)+MODF(GUR,10.0)*1.0E5

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2439 FORMAT(7H AM1 =F4.0,6H AM2 =F5.0,6H AM3 =F4.0,6H Z3 =F3.0,5H Z4
X=F4.0,6H E1 =F5.1,10H QUZER =F7.3,19H TARGET DENSITY =F9.6/8H
X DEDL =F7.4,7H AJ =F3.0,7H GAS =F3.0,5H L =I4,5H N =I3,10H
XPKSHCN =F6.2,8H CORR =F5.2,8H BEAM =IPE12.3)
440 IF (GAS)95,441,442
441 WRITE OUTPUT TAPE 6,2441,DIST,DIAM,SNTGAN
2441 FORMAT(8H DIST =F6.1,8H DIAM =F6.4,10H SNTGAN =F9.6)
442 WRITE OUTPUT TAPE 6,2442,THL,ENTCO,CLOSS,ABSORB
2442 FORMAT(12H THETALAB =F6.2,17H INTEGRATOR =F6.0,15H LOSSRA
XTE =F5.3,14H ABSORBER =F6.2)
443 IF (N)95,450,444
444 WRITE OUTPUT TAPE 6,2444
2444 FORMAT(56H NUMBER OF CHANNELS TO BE SUMMED IN EXCITED-STATE PEAKS
X)
445 WRITE OUTPUT TAPE 6,2445,(ASUM(I),I=1,N)
2445 FORMAT(12F9.1)
447 WRITE OUTPUT TAPE 6,2447
2447 FORMAT(33H Q-VALUES OF EXCITED-STATE PEAKS)
448 WRITE OUTPUT TAPE 6,2448,(Q(I),I=1,N)
2448 FORMAT(12F9.3)
450 WRITE OUTPUT TAPE 6,2450
2450 FORMAT(25H SPECTRUM TO BE ANALYZED)
452 WRITE OUTPUT TAPE 6,2200,(COUNTS(I),I=1,LM1)
C SUM THE GROUND-STATE PEAK
454 BJ=ELCNTR-AJ/2.0
456 JD=XINTF(BJ+0.5)
458 DJ=JD
460 ELASCO=COUNTS(JD)*(DJ+0.5-BJ)
465 SMLC=ELASCO*(BJ+DJ+0.5)/2.0
470 IF (DJ+1.5-AJ-BJ)480,520,520
480 JD=JD+1
490 DJ=JD
500 ELASCO=ELASCO+COUNTS(JD)
505 SMLC=SMLC+COUNTS(JD)*DJ
510 GO TO 470
520 ELASCO=ELASCO+COUNTS(JD+1)*(AJ+BJ-DJ-0.5)
522 SMLC=SMLC+COUNTS(JD+1)*(AJ+BJ-DJ-0.5)
X*(AJ+BJ+DJ+0.5)/2.0
524 ELCNTR=SMLC/ELASCO
528 ELASCO=ELASCO-ELBKD*AJ
529 BJ=ELCNTR-AJ/2.0
530 EJ=AJ+BJ
C CM TRANSFORMATION FOR THE GROUND-STATE PEAK
550 THETAR=0.017453292*THL
560 SINE2=(SINF(THETAR))**2
570 ANGLER=THETAR+ASINF(ALPHA*SINF(THETAR))
580 ANGLE=57.295779*ANGLER
640 RATIO=(SINF(THETAR)/SINF(ANGLER))**3
X*(1.0+ALPHA*COSF(ANGLER))
650 ROOTEL=(COSF(THETAR)*SQRTF(AM1*AM3*E1)+
XSQRTF((AM1*AM3*E1)*(1.0-SINE2)+(AM3+AM4)*
X(AM4*QUZER+(AM4-AM1)*E1)))/(AM3+AM4)
660 E3EL=ROOTEL**2
C ABSORBER CORRECTION FOR THE GROUND-STATE PEAK
661 IF(ABSORB)662,662,664
662 EDL=E3EL
663 GO TO 677
664 EPTL=10.0-E3EL/AM3
665 XTL=AOZ2*(29.59*EPTL-1.14*EPTL**2
X-0.0075*EPTL**3-0.00034*EPTL**4)
666 XDL=XTL+ABSORB
667 K=0

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668 EPDL=XDL/29.59
669 DXDE=AOZ2*(29.59-2.28*EPDL-0.0225
X*EPDL**2-0.00136*EPDL**3)
670 K=K+1
671 XIDL=AOZ2*(29.59*EPDL-1.14*EPDL**2
X-0.0075*EPDL**3-0.00034*EPDL**4)
672 EPDL=EPDL+(XDL-XIDL)/DXDE
673 IF (K-10)674,674,676
674 XERR=ABSF(XDL-XIDL)
675 IF (XERR-0.01)676,676,669
676 EDL=(10.0-EPDL)*AM3
677 IF (GAS)95,686,678
678 READ INPUT TAPE 7,2678,TEMP,COMP,ATPMOL,PRESS
2678 FORMAT(F6.2,F6.5,F6.0,F6.2)
679 WRITE OUTPUT TAPE 6,2679,TEMP,COMP,ATPMOL,PRESS
2679 FORMAT(15H TEMPERATURE =F6.2,26H DEG C COMPRESSIBILITY =F6.5,23
XH ATOMS PER MOLECULE =F2.0,14H PRESSURE =F6.2,6H MM HG)
684 ABS=4.7907E12*(TEMP+273.16)*COMP*(SINF(THETAR))
X/(ATPMOL*PRESS*BEAM)
685 GO TO 688
686 ABS=2114.0*((DIST/DIAM)**2)*
XAM4*SNTGAN/(DENS*BEAM)
C CROSS SECTION FOR THE GROUND STATE
688 SIG=ELASCO*RATIO*(ABS/ENTCO)/(1.0-CLOSS)
690 ARX=ELASCO+ELBKD*AJ+((RRBKD*AJ)**2)
691 DELSIG=SIG*(SQRTF(ARX))/ELASCO
692 IF(QUZER)700,693,700
693 RFAC=((SINF(ANGLE*0.017453292*0.5))**4)/BETA
694 RUTH=SIG*RFAC
696 DLRU=DELSIG*RFAC
698 WRITE OUTPUT TAPE 6,2698,RUTH,DLRU
2698 FORMAT(23H RATIO TO RUTHERFORD =F9.6/
X23H +OR- F9.6)
700 WRITE OUTPUT TAPE 6,2700
2700 FORMAT(117H Q-VALUE THETACM SIGMA DELSIGMA FIRST LAS
XT RATIO E3TARGET E3DETECTOR NETCOUNTS BKDCOUNTS PEAKCENTER)
705 WRITE OUTPUT TAPE 6,2705,QUZER,ANGLE,SIG,DELSIG,
XBJ,EJ,RATIO,E3EL,E
XDL,ELASCO,ELBKD,RRBKD,ELCNTR
2705 FORMAT(F9.3,F10.2,F12.6,F11.6,2F7.2,F7.4,F10.3,F11.3,F11.0,F7.0,F7
X.2,F8.2)
708 IF (N)1140,1140,730
730 DO 1130 I=1,N
C CM TRANSFORMATION FOR EXCITED STATES
740 ALPHA=SQRTF((AM1*AM3)/(AM2*AM4)
X*(W/(Q(I)+W)))
750 ANGLER=THETAR+ASINF(ALPHA*SINF(THETAR))
760 ANGLE=57.295779*ANGLER
820 RATIO=(SINF(THETAR)/SINF(ANGLER))**3
X*(1.0+ALPHA*COSF(ANGLER))
830 ROOTIN=(COSF(THETAR)*SQRTF(AM1*AM3*E1)+
XSQRTF((AM1*AM3*E1)*(1.0-SINE2)+(AM3+AM4)*
X(AM4*Q(I)+(AM4-AM1)*E1)))/(AM3+AM4)
840 E3IN=ROOTIN**2
C ABSORBER CORRECTION FOR EXCITED STATES
841 IF(ABSORB)842,842,844
842 EDN=E3IN
843 GO TO 858
844 EPTN=10.0-E3IN/AM3
845 XTN=AOZ2*(29.59*EPTN-1.14*EPTN**2
X-0.0075*EPTN**3-0.00034*EPTN**4)

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846 XDN=XTN+ABSORB
847 K=0
848 EPDN=XDN/29.59
849 DXDE=AOZ2*(29.59-2.28*EPDN-0.0225
      X*EPDN**2-0.00136*EPDN**3)
850 K=K+1
851 X1DN=AOZ2*(29.59*EPDN-1.14*EPDN**2
      X-0.0075*EPDN**3-0.00034*EPDN**4)
852 EPDN=EPDN+(XDN-X1DN)/DXDE
853 IF (K-10)854,854,856
854 XERR=ABS(XDN-X1DN)
855 IF (XERR-0.01)856,856,849
856 EDN=(10.0-EPDN)*AM3
C SUM THE EXCITED-STATE PEAK
858 GRNEN(I)=ELCNTR+(EDN-EDL)/DEDL
859 AZ=ASUM(I)
860 BJ=GRNEN(I)-AZ/2.0
870 JD=XINTF(BJ+0.5)
880 DJ=JD
890 ANELCO=COUNTS(JD)*(DJ+0.5-BJ)
900 IF (DJ+1.5-AZ-BJ)941,945,945
940 STOP
941 JD=JD+1
942 DJ=JD
943 ANELCO=ANELCO+COUNTS(JD)
944 GO TO 900
945 ANELCO=ANELCO+COUNTS(JD+1)*(AZ+BJ-DJ-0.5)
950 EJ=AZ+BJ
960 IF(BKD(I))940,973,971
971 DELTCO=SQRTF(ANELCO+(DELBKD(I)*AZ)**2)
972 GO TO 1060
C CALCULATE BKD DUE TO GROUND-STATE PEAK
973 PKPOS=PKSHCN-ELCNTR+GRNEN(I)
980 JH=XFIXF(PKPOS)
981 PKLOW=JH
984 DEL=PKPOS-PKLOW
990 BKD(I)=CORR*((1.0-DEL)*PEAKSH(JH)+
      XDEL*PEAKSH(JH+1))*ELASCO/PEKSM
991 M=I-1
992 IF(M)940,1055,1000
C CALCULATE BKD DUE TO HIGHER PEAKS
1000 DO 1050 K=1,M
1010 PKPOS=PKSHCN-GRNEN(K)+GRNEN(I)
1020 JH=XFIXF(PKPOS)
1030 PKLOW=JH
1040 DEL=PKPOS-PKLOW
1050 BKD(I)=BKD(I)+CORR*((1.0-DEL)*PEAKSH(JH)+
      XDEL*PEAKSH(JH+1))*TRUCO(K)/PEKSM
1055 DELTCO=SQRTF(ANELCO+(DELBKD(I)*BKD(I)*AZ)**2)
1060 TRUCO(I)=ANELCO-BKD(I)*AZ
C COMPUTE CROSS SECTIONS FOR HIGHER PEAK
1080 SIG=TRUCO(I)*RATIO*(ABS/ENTCO)
      X/(1.0-CLOSS)
1090 DELSIG=DELTCO*RATIO*(ABS/ENTCO)
      X/(1.0-CLOSS)
1130 WRITE OUTPUT TAPE 6,2705,Q(I),ANGLE,SIG,DELSIG,BJ,

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      XEJ,RATIO,E3IN,EDN,TRUCO(I),BKD(I),DELBKD(I),GRcen(I)
1140 NY=XABSF(NSTRC)
1150 IF (NY-211)36,211,360

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APPENDIX E PROGRAM FOR UNRAVELING SPECTRA FROM MIXED TARGETS

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C      1427-PHY      HOWARD W BROEK      X-2349
C      UNRAVELLING OF SPECTRA FROM MIXED TARGETS
C      SPECTRA READ FROM MAGNETIC TAPE
C      3-DIGIT CHANNEL NUMBERS FOLLOWED BY 6-DIGIT DATA
      DIMENSION NRUN(25),NSTRC(25),MAT(25),
      XAM2(3),COUNTS(25,199),NBR(25),
      XENTCO(25),CLOSS(25),EDL(25),ELCNTR(25),
      XELASCO(25),NCH(199),DEN(3),DIFSP(199),
      XIPR(3),FACT(25),CHN(199)
1      READ INPUT TAPE 7,2001,(AM2(M),M=1,3)
2001  FORMAT(3F6.0)
2      READ INPUT TAPE 7,2002,C11,C12,C13,C21,C22,C23,C31,C32,C33
2002  FORMAT(9F6.4)
3      READ INPUT TAPE 7,2003,(DEN(M),M=1,3)
2003  FORMAT(3F6.3)
C      NORMALIZE THE C MATRIX
4      A11=1.0
5      A12=C12/(1.0-C12-C13)
6      A13=C13/(1.0-C12-C13)
7      A21=C21/(1.0-C21-C23)
8      A22=1.0
9      A23=C23/(1.0-C21-C23)
10     A31=C31/(1.0-C31-C32)
11     A32=C32/(1.0-C31-C32)
12     A33=1.0
C      INVERT THE MATRIX A
15     DET=A11*(A22*A33-A32*A23)
      X+A12*(A23*A31-A33*A21)
      X+A13*(A21*A32-A31*A22)
16     B11=(A22*A33-A32*A23)/DET
17     B12=(A13*A32-A12*A33)/DET
18     B13=(A12*A23-A13*A22)/DET
19     B21=(A23*A31-A21*A33)/DET
20     B22=(A11*A33-A13*A31)/DET
21     B23=(A13*A21-A11*A23)/DET
22     B31=(A21*A32-A22*A31)/DET
23     B32=(A12*A31-A11*A32)/DET
24     B33=(A11*A22-A21*A12)/DET
C      DECIDE WHERE TO STORE NEXT RUN
25     WRITE OUTPUT TAPE 6,2025
2025  FORMAT(83H1 1427-PHY      UNRAVELLING OF SPECTRA FROM MIXED TARGETS
      X      HOWARD W BROEK      X-2349)
27     READ INPUT TAPE 7,2027,DEDL,AJ,L
2027  FORMAT(F6.5,F6.0,I6)
28     AL=L
31     LM1=L-1
32     I=0
33     I=I+1
34     IF (I-25)37,37,35
35     I=25
36     GO TO 40

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37 IF (NSTRC(I))52,40,33
C   READ NEXT RUN
40 READ INPUT TAPE 7,2040,NRUN(I),NSTRC(I),MAT(I),ENTCO(I),
   XCLOSS(I),ELCNTR(I),EDL(I),NBR(I),NGOOF
2040 FORMAT(3I6,F6.0,3F6.2,2I6)

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2044 FORMAT(12(F6.0,I3))
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49 READ INPUT TAPE 9,2044,COUNTS(I,11),(NCH(LA),COUNTS(I,LA),LA=12,
   XLM1)
51 IF (NSTRC(I))52,40,62
52 STOP
62 DO 64 LA=1,LM1
64 CHN(LA)=NCH(LA)
C   CORRECT TAPE IF NECESSARY
66 IF (NGOOF)52,100,67
67 DO 87 I=1,NGOOF
68 READ INPUT TAPE 7,2068,NCHG,GCOU,GSFT
2068 FORMAT(I6,2F6.0)
69 COUNTS(I,NCHG)=GCOU
70 NCH(NCHG)=NCH(NCHG-1)+1
72 CHN(NCHG)=NCH(NCHG)
77 NCHG=NCHG+1
78 IF (GSFT)83,87,79
79 DO 81 JP=NCHG,LM1
80 CHN(JP)=INTF(CHN(JP)/10.0)
   X+MODF(COUNTS(I,JP-1),10.0)*100.0
3080 NCH(JP)=CHN(JP)
81 COUNTS(I,JP)=INTF(COUNTS(I,JP)/10.0)
   X+MODF(CHN(JP),10.0)*1.0E5
82 GO TO 87
83 DO 85 JP=NCHG,LM1
84 CHN(JP)=INTF(COUNTS(I,JP)/1.0E5)
   X+10.0*MODF(CHN(JP),100.0)
3084 NCH(JP)=CHN(JP)
85 COUNTS(I,JP)=INTF(CHN(JP+1)/100.0)+10.0*
   XMODF(COUNTS(I,JP),1.0E5)
87 CONTINUE
C   FIND TOTAL COUNTS AND CENTER OF ELASTIC PEAK
100 BJ=ELCNTR(I)-AJ/2.0
110 JD=XINTF(BJ+0.5)
120 DJ=JD
130 ELASCO(I)=COUNTS(I,JD)*(DJ+0.5-BJ)
135 SUMLC=ELASCO(I)*(BJ+DJ+0.5)/2.0
140 IF (DJ+1.5-AJ-BJ)150,180,180
150 JD=JD+1
160 DJ=JD
170 ELASCO(I)=ELASCO(I)+COUNTS(I,JD)
175 SUMLC=SUMLC+COUNTS(I,JD)*DJ
178 GO TO 140
180 ELASCO(I)=ELASCO(I)+COUNTS(I,JD+1)*(AJ+BJ-DJ-0.5)
185 SUMLC=SUMLC+COUNTS(I,JD+1)*(AJ+BJ-DJ-0.5)
   X*(AJ+BJ+DJ+0.5)/2.0
190 ELCNTR(I)=SUMLC/ELASCO(I)

```

Replace statements 80, 3080, and 81 by the five statements:

```

3079 GUR=CHN(JP)
   80 CHN(JP)=INTF(GUR/10.0)+MODF(FOP,10.0)*100.0
3080 FOP=COUNTS(I,JP)
4080 NCH(JP)=CHN(JP)
   81 COUNTS(I,JP)=INTF(FOP/10.0)+MODF(GUR,10.0)*1.0E5

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C     TEST FOR SUBTRACTIBILITY
200 NST=NSTRC(I)
205 NSUB=XMODF(NST,10)
210 IF (NSUB-3)212,220,52
212 NMM=NBR(I)
214 IF (NMM-28)1,32,1798
C     FIND THE TWO OTHER RUNS OF THE SET
220 UNST=NSTRC(I)
230 NUM=XINTF(UNST/10.0)
240 NSP=NUM*10+1
250 NSR=NSP+1
258 I1=0
259 I2=0
260 DO 350 J=1,25
270 NSTJ=NSTRC(J)
280 IF (NSTJ-NSP)300,290,300
290 I1=J
300 IF (NSTJ-NSR)350,340,350
340 I2=J
350 CONTINUE
C     PREPARE FOR NEXT READ INSTRUCTION
351 NSTRC(I)=0
352 NSTRC(I1)=0
353 NSTRC(I2)=0
356 IF (I1*I2*(I1-I2))358,32,358
C     INVERT THE MAT FUNCTION
358 MATR=MAT(I)
360 IPR(MATR)=I
365 M1=MAT(I1)
370 IPR(M1)=I1
375 M2=MAT(I2)
380 IPR(M2)=I2
385 IM1=IPR(1)
390 IM2=IPR(2)
395 IM3=IPR(3)
C     NORMALIZE THE 3 RUNS TO SAME DENSITY OF TARGET ATOMS
400 FACT(IM1)=(A11*AM2(1)+A12*AM2(2)+A13*AM2(3))
X/(ENTCO(IM1)*(1.0-CLOSS(IM1))*DEN(1))
402 FACT(IM2)=(A21*AM2(1)+A22*AM2(2)+A23*AM2(3))
X/(ENTCO(IM2)*(1.0-CLOSS(IM2))*DEN(2))
404 FACT(IM3)=(A31*AM2(1)+A32*AM2(2)+A33*AM2(3))
X/(ENTCO(IM3)*(1.0-CLOSS(IM3))*DEN(3))
406 ELASCO(IM1)=ELASCO(IM1)*FACT(IM1)
408 ELASCO(IM2)=ELASCO(IM2)*FACT(IM2)
410 ELASCO(IM3)=ELASCO(IM3)*FACT(IM3)
412 DO 417 LA=1,LM1
414 COUNTS(IM1,LA)=COUNTS(IM1,LA)*FACT(IM1)
416 COUNTS(IM2,LA)=COUNTS(IM2,LA)*FACT(IM2)
417 COUNTS(IM3,LA)=COUNTS(IM3,LA)*FACT(IM3)
C     FIND THE TRUE COUNTS IN THE ELASTIC PEAKS
418 TRC1=B11*ELASCO(IM1)+B12*ELASCO(IM2)+B13*ELASCO(IM3)
419 TRC2=B21*ELASCO(IM1)+B22*ELASCO(IM2)+B23*ELASCO(IM3)
420 TRC3=B31*ELASCO(IM1)+B32*ELASCO(IM2)+B33*ELASCO(IM3)
C     AVERAGE ENERGY OF EACH ELASTIC PEAK
430 EAV1=(A11*EDL(IM1)*TRC1+A12*EDL(IM2)*TRC2+A13*EDL(IM3)*TRC3)
X/ELASCO(IM1)
440 EAV2=(A21*EDL(IM1)*TRC1+A22*EDL(IM2)*TRC2+A23*EDL(IM3)*TRC3)
X/ELASCO(IM2)
450 EAV3=(A31*EDL(IM1)*TRC1+A32*EDL(IM2)*TRC2+A33*EDL(IM3)*TRC3)
X/ELASCO(IM3)

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C      PULSE-HEIGHT INTERCEPTS
460  PIN1=ELCNTR(IM1)-EAV1/DEDL
470  PIN2=ELCNTR(IM2)-EAV2/DEDL
480  PIN3=ELCNTR(IM3)-EAV3/DEDL
C      MATRIX ELEMENTS FOR M1
482  D11=B11
484  D12=B12
486  D13=B13
C      DIFFERENCES IN INTERCEPTS
490  DPI2=PIN2-PIN1
495  DPI3=PIN3-PIN1
C      FIND FIRST MEANINGFUL CHANNEL IN DIFSP
500  DPMN=MIN1F(DPI2,DPI3)
510  IF (DPMN)520,540,540
520  KD=1-XINTF(DPMN)
530  GO TO 550
540  KD=0
C      FIND LAST MEANINGFUL CHANNEL IN DIFSP
550  DPMX=MAX1F(DPI2,DPI3)
560  IF (DPMX)590,590,570
570  KE=1+XINTF(DPMX)
580  GO TO 595
590  KE=0
C      FIND CORRESPONDING CHANNELS
595  LB=LM1-KE-KD
600  KF2=XINTF(DPI2)
610  KF3=XINTF(DPI3)
620  IF (DPI2)630,650,650
630  KG2=+KF2-1
631  DEL2=FLOATF(KF2)-DPI2
640  GO TO 660
650  KG2=KF2
651  DEL2=1.0-DPI2+FLOATF(KF2)
660  IF (DPI3)670,690,690
670  KG3=KF3-1
671  DEL3=FLOATF(KF3)-DPI3
680  GO TO 700
690  KG3=KF3
691  DEL3=1.0-DPI3+FLOATF(KF3)
700  DO 742 K=1,LB
710  KA=K+KD
720  KB=KA+KG2
730  KC=KA+KG3
C      TAKE THE DIFFERENCE
740  DIFSP(KA)=COUNTS(IM1,KA)*D11
      X+COUNTS(IM2,KB)*D12*DEL2
      X+COUNTS(IM2,KB+1)*D12*(1.0-DEL2)
      X+COUNTS(IM3,KC)*D13*DEL3
      X+COUNTS(IM3,KC+1)*D13*(1.0-DEL3)
C      SET MEANINGLESS CHANNELS EQUAL TO 888
742  DIFSP(KA)=DIFSP(KA)/FACT(IM1)
750  IF (KD)770,770,760
760  DO 762 KA=1,KD
762  DIFSP(KA)=888.0
770  IF (LM1-LB-KD)790,790,771
771  LBB=LB+KD+1
772  DO 774 KA=LBB,LM1
774  DIFSP(KA)=888.0
790  WRITE OUTPUT TAPE 6,2790,(NCH(LE),DIFSP(LE),LE=1,LM1)
      X,I,ENTCO(IM1),MAT(IM1),ELCNTR(IM1),NRUN(IM1)

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2790 FORMAT(12(I3,F7.0))
C PERMUTE SUBSCRIPTS AND FIND 2 OTHER DIFSP
820 IF (NSUB-3)870,840,52
840 D11=B22
850 D12=B23
860 D13=B21
870 IM4=IM1
880 IM1=IM2
890 IM2=IM3
900 IM3=IM4
910 PIN4=PIN1
920 PIN1=PIN2
930 PIN2=PIN3
940 PIN3=PIN4
950 NSUB=NSUB-1
960 IF (NSUB-1)1010,970,490
970 D11=B33
980 D12=B31
990 D13=B32
1000 GO TO 490
1010 NMN=NBK(IM1)
1020 IF (NMN-27)11,27,1030
1030 IF (NMN-32)32,32,1798
C WRITE HEADINGS, COMPOSITION MATRIX, AND INVERSE MATRIX
1798 WRITE OUTPUT TAPE 6,2025
1802 WRITE OUTPUT TAPE 6,2802
2802 FORMAT(20H COMPOSITION MATRIX)
1803 WRITE OUTPUT TAPE 6,2803,A11,A12,A13,A21,A22,A23,A31,A32,A33
2803 FORMAT(F20.4,F10.4,F10.4)
1805 WRITE OUTPUT TAPE 6,2805
2805 FORMAT(16H INVERSE MATRIX)
1808 WRITE OUTPUT TAPE 6,2803,B11,B12,B13,B21,B22,B23,B31,B32,B33
1822 WRITE OUTPUT TAPE 6,2822,(AM2(M),M=1,3)
2822 FORMAT(21H TARGET MASSES F9.6,F9.6,F9.6)
1824 WRITE OUTPUT TAPE 6,2824,(DEN(M),M=1,3)
2824 FORMAT(21H TARGET DENSITIES F9.6,F9.6,F9.6)
1826 WRITE OUTPUT TAPE 6,2826,DEDL,AJ,L
2826 FORMAT(8H DEDL =F9.6,6H AJ =F5.1,5H L =15)
1828 GO TO 1

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APPENDIX F PROGRAM FOR THE CENTER-OF-MASS TRANSFORMATION

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C PHY-1529 REVISED CM TRANSFORMATION
  DIMENSION ABSORB(10),E3D(10)
  8 CSQ=931.16
 10 READ INPUT TAPE 7,2010,AM1,AM2,AM3,Z3,Q,E1,
  XTHETA3,DELTA,CUTOFF,NBSRB
2010 FORMAT(4F6.0,F6.3,F6.1,3F6.0,I6)
 12 IF (NBSRB)20,20,15
 15 READ INPUT TAPE 7,2015,(ABSORB(I),I=1,NBSRB)
2015 FORMAT(12(F6.2))
 20 WRITE OUTPUT TAPE 6,2020
2020 FORMAT(39H1 PHY-1529 REVISED CM TRANSFORMATION)
 25 AM4=AM1+AM2-AM3
 30 WRITE OUTPUT TAPE 6,2030,AM1,AM2,AM3,AM4,Z3,
  XQ,E1
2030 FORMAT(6H M1 =F4.0,6H M2 =F4.0,6H M3 =F4.0,6H M4 =F4.0,6H Z3
  X=F4.0/5H Q =F7.3,6H E1 =F6.3)
 35 WRITE OUTPUT TAPE 6,2035,(ABSORB(I),I=1,10)

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2035 FORMAT(38H LAB ANGLE CM ANGLE RATIO E3 DX=010(F8.2))
45 AOZ2=AM3/(Z3**2)
54 ETA=E1+AM4*CSQ
56 HUNT=AM3*CSQ+ETA+Q
58 RTDEE=Q**2+2.0*ETA*Q+2.0*
  X(AM4-AM1)*CSQ*E1
C TEST FOR DOUBLE BRANCH
61 DUBLR=RTDEE**2+4.0*RTDEE*HUNT*AM3*CSQ
62 IF (DUBLR)63,69,70
63 C2MXTH=-DUBLR/(4.0*((AM3*CSQ)**2)
  X*(E1**2+2.0*E1*AM1*CSQ))
64 SMXTH=SQRTF(1.0-C2MXTH)
65 CUTOFF=57.295779*ASINF(SMXTH)
66 GO TO 70
69 CUTOFF=90.0
70 BRNCH=1.0
75 THETA=THETA3
80 THETAR=0.017453292*THETA
90 SINE2=(SINF(THETAR))**2
C LAB ENERGY BEFORE ABSORBER
162 ZETA=4.0*E1*(E1+2.0*AM1*CSQ)
  X*(1.0-SINE2)
170 BEEMIN=4.0*RTDEE*HUNT+2.0*AM3*CSQ*ZETA
172 AX2=8.0*HUNT**2-2.0*ZETA
174 RAD=4.0*ZETA*((AM3*CSQ)**2*ZETA+DUBLR)
180 E3T=(BEEMIN+BRNCH*SQRTF(RAD))/AX2
C FIND CM ANGLE
210 VEER=E3T/(AM3*CSQ)
220 VLAB=(SQRTF(2.0*VEER+VEER**2))/(1.0+VEER)
230 VR1=E1/(AM1*CSQ)
240 VIL=(SQRTF(2.0*VR1+VR1**2))/(1.0+VR1)
242 PL=VIL*(AM1*CSQ+E1)
244 EZER=(AM1+AM2)*CSQ
246 VTRN=PL/(EZER*SQRTF(1.0+(PL/EZER)**2))
248 VELR=VTRN/VLAB
250 SNRAT=SQRTF(1.0-2.0*VELR*COSF(THETAR)+VELR**2)
254 SANGLE=SINF(THETAR)/SNRAT
260 VLX=VLAB*COSF(THETAR)-VTRN
270 IF (VLX)300,280,280
280 ANGLE=57.295779*ASINF(SANGLE)
290 GO TO 310
300 ANGLE=180.0-57.295779*ASINF(SANGLE)
C SOLID ANGLE RATIO
310 CSCM=COSF(0.017453292*ANGLE)
320 RATIO=((SNRAT**2)*ABSF(SNRAT+VELR*CSCM))
  X/SQRTF(1.0-VTRN**2)
C ENERGY LOST IN ABSORBER
561 IF (NBSRB)710,710,562
562 EPT=10.0-E3T/AM3
563 IF (EPT+6.0)570,565,565
565 XT=AOZ2*(29.59*EPT-1.14*EPT**2
  X-0.0075*EPT**3-0.00034*EPT**4)
566 GO TO 580
570 EPT=EPT+15.0
572 XT=AOZ2*(60.54*EPT-0.965*EPT**2
  X-0.00284*EPT**3-682.02528)
580 DO 677 I=1,NBSRB
586 XD=XT+ABSORB(I)
590 IF (XD-171.0)622,610,610
610 E3D(I)=0.0

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620 GO TO 677
622 K=0
624 IF (XD+217.4)626,668,668
626 XD=XD+682.02528
628 EPD=XD/60.54
630 DXDE=AOZ2*(60.54-1.83*EPD-0.00852*EPD**2)
632 K=K+1
634 X1D=AOZ2*(60.54*EPD-0.965*EPD**2
      X-0.00284*EPD**3)
636 EPD=EPD+(XD-X1D)/DXDE
638 IF (K-10)640,640,676
640 XERR=ABSF(XD-X1D)
642 IF (XERR-0.5)644,644,630
644 E3D(I)=(25.0-EPD)*AM3
646 GO TO 677
668 EPD=XD/29.59
669 DXDE=AOZ2*(29.59-2.28*EPD-0.0225
      X*EPD**2-0.00136*EPD**3)
670 K=K+1
671 X1D=AOZ2*(29.59*EPD-1.14*EPD**2
      X-0.0075*EPD**3-0.00034*EPD**4)
672 EPD=EPD+(XD-X1D)/DXDE
673 IF (K-10)674,674,676
674 XERR=ABSF(XD-X1D)
675 IF (XERR-0.05)676,676,669
676 E3D(I)=(10.0-EPD)*AM3
677 CONTINUE
710 WRITE OUTPUT TAPE 6,2710,THETA,ANGLE,
      XRATIO,E3T,(E3D(I),I=1,NBSRB)
2710 FORMAT(F11.2,F10.3,F8.4,F9.4,10(F8.4))
720 THETA=THETA+DELTA
722 IF (THETA-90.0)730,730,724
724 BRNCH=-1.0
730 IF (THETA-CUTOFF)80,80,740
740 IF (BRNCH)10,10,750
750 IF (DUBLR)760,10,10
760 BRNCH=-1.0
770 WRITE OUTPUT TAPE 6,2770,CUTOFF
2770 FORMAT(16H MAX THETALAR =F7.3)
780 GO TO 75

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