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Automatic Analysis of Charged Particle Spectra

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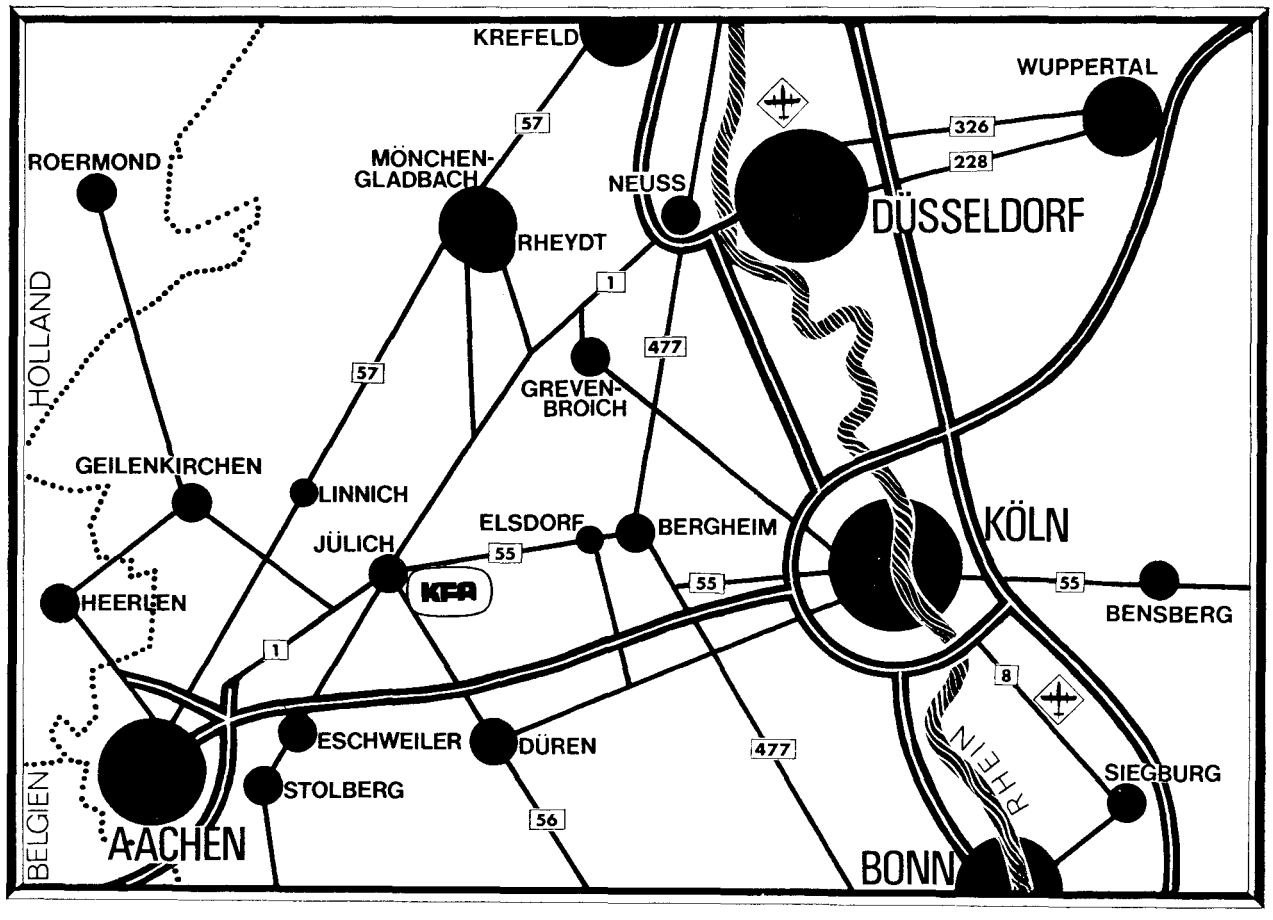

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Z. Seres and A. Kiss

AUTOMATIC ANALYSIS OF CHARGED PARTICLE SPECTRA

Z. Seres[+] and A. Kiss

Abstract:

A computer program system is developed for off-line automatic analysis of a series of charged particle spectra measured by solid-state detectors and collected on magnetic tapes. The procedure results in complete angular distributions for the excited levels of the final nucleus up to about 15 MeV.

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1. Introduction

The present paper reports on a computer program system developed for automatic off-line analysis of charged particle angular distribution measurements of two-body reactions, A(b,c)D. The amplitude spectra considered contain well-defined peaks of about the same width sitting on a smooth background. The series of spectra are unfolded in a reasonable and consistent way and are combined into complete cross section angular distributions with little effort by the user. The system is general enough to adapt to other similar problems and for further developments.

The data acquisition system in its actual form fits the requirements of the experimental set-up and research program (e.g. Ref. 1)) at the Jülich isochronous cyclotron JULIC. The charged particle spectra, which are produced in the mentioned type of nuclear reactions by light particles with incident energies of several times 10 MeV (e.g. 45 - 90 MeV for deuterons), are measured by detector telescopes operating in the ΔE-E mode using Si surface - barrier dE detectors and Ge(Li) diodes of side entry type. The spectra are stored on magnetic tapes. From the research point of view the interesting range of the excitation energy of the residual nucleus is up to 15 MeV. The computer codes are written for a PDP 15/30 computer and require 24 K core memory. The data handling system and the computer facilities are reported elsewhere[2].

2. Description of the system

The block scheme of the program system is shown in Fig. 1. The full analysis of the series of amplitude spectra is done in two main steps. First the individual spectra are unfolded (program ADAMT). In the second

step energy calibration and kinematic analysis are performed for the peaks found in the spectrum evaluation. This part of the analysis results in calculated cross section angular distributions for those selected peaks which are seen systematically in the spectra and show the required kinematic behaviour (program KEPLER). The program TAYLOR is used to edit tables of cross section stored on DEC-tape. It permits modification, normalization and unification of results of different experimental runs. The program MURILO makes kinematic plots on request; these serve for orientation in the spectra during the course of the experiments. Finally, the program system is completed with further codes for error scanning on magnetic tapes and file saving on DEC-tapes.

2.1. Sepctrum unfolding

The spectra considered are assumed to consist of several peaks superimposed on a smooth quadratic background. The peak forms are approximated by an analytic function after Routti et al.[3] a Gaussian distribution with a low energy exponential tail. According to some additional analysis, an energy dependence of the peak form for peaks lying in the higher quarter of the spectra was not observed and so was neglected. On the other hand, the peak-form parameters for an individual spectrum were determined from the spectrum itself because of possible kinematic and radiation damage effects.

The structure of the spectra is learned using correlation technics[4]. The peak positions and their approximative relative intensities are determined from the cross correlation function of a Gaussian searching function and the measured spectrum. This method is assumed to give the true peak positions except for two small corrections. These corrections take the asymmetry of the peaks and background effects into account.

The intensity values obtained from the cross correlation function are used for peak selection and for orientation in the spectrum. The most intense peak is assumed to be isolated and most appropriate for the determination of the peak-form parameters. Fitting is done by the Newton Raphson method.

The channel numbers limiting the evaluated part of a spectrum are matched to the most intensive peak and the given maximum excitation energy. If the parameters for energy calibration are given, the program calculates the required limits. Whenever there is a peak in the neighbourhood of the limit, the evaluation region is reasonably corrected.

After determination of the peak positions, the peakform parameters, and the fit interval, decomposition of the spectrum is reduced to a linear problem. The amplitudes of the peaks and the background parameters are fitted by the method of least squares.

The input information for the ADAMT program is organised into three blocks indicated as "Particles" (basic nuclear constants) "Lexicon" (actual reaction constants and experimental parameters) and "Task" (information for the individual spectra and actual program control) in Fig. 1. The program can be controlled from teletype or by the mentioned "Task" in batch mode. Certain phases of spectrum unfolding can be displayed at request. The fit limits can be changed interactively and the calculation can be aborted at several points. The results are collected on a DEC-tape file: the experimental parameter values, the results of the form parameter and overall fits with their χ^2-s, the fit limits, the parameters of the energy calibration, and some remarks. In order to have a fast check of the fits, the measured and fitted spectra can be plotted (on a CALCOMP plotter or on the filmplotter by the

IBM 370-165 computer using the data channel between the PDP-15/30 and IBM 360-67 computers and the auxiliary code ADAPD.

Fig. 2 shows typical results of the spectrum unfolding.

2.2. Cross section calculation and energy calibration

The program KEPLER calculates the cross sections from the peak area values and the experimental parameters stored in the result file of the program ADAMT. Using relativistic kinematic relations, the program performs an energy calibration giving the excitation energy of the residual nucleus for every peak. The energy calibration can be made using two identified peaks of a spectrum or calculating the kinematic shift of an identified peak in two spectra measured at two different angles. The number of the peaks corresponding to the E, E+dE excitation energy interval can be plotted in a histogram. Further, an energy map is readily constructed by plotting the excitation energies of all the peaks found in a series of spectra vs. laboratory angle. The energy map clearly shows which levels of the residual nucleus were excited, and gives information on impurities in the target. Fig. 3 shows a typical histogram and energy map for the $^{27}Al(d,d')^{27}Al$ reaction at 60.6 MeV incident energy. Finally, the program selects the peaks having excitation energies in a given interval and plots their cross sections vs. the C.M. angle.

3. Discussion

The data analysing system has been used effectively in the angular distribution experiments of the (d,d'), (d,^{3}He) and (d,^{6}Li) reactions on light target nuclei at 45 - 90 MeV incident energies.

In spite of the fact that the spectrum unfolding procedure uses approximations, the spectrum evaluation worked well. Only in about one percent of all cases was the spectrum evaluation found to be unsatisfactory. The reason for the failure was due to the following:

- There was no isolated peak in the spectrum suitable for peak-form parameter determination. Such spectra could be unfolded using peak-form parameters of other spectra.
- The background could not be approximated well by a quadratic function. In such cases the fit interval had to be shortened.
- The analytic function of the peak-form was not correct for all peaks in the spectra. This was the case for spectra which contained unresolved peaks.

The generally-used width of the searching function is 2/3 of the approximate FWHM of the peaks[4]. The program resolves two peaks of the same intensity if they are separated by a distance equal to their FWHM. Using a narrower searching function, the resolution of two peaks is better but spurious peaks can appear in the flat part of the spectrum. The spurious peaks can be discriminated against by using a higher statistical threshold factor.

The authors are grateful to Professor C. Mayer-Böricke for continuous encouragement and to Dr. B. Mertens for helpful discussions.

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Figure captions

Fig. 1 Block diagram of the data acquisition program system.

Fig. 2 Typical plots of measured spectra and the fits. The unfolding of the spectra was usually checked by similar plots.

Fig. 3 Energy map and histogram of the excited peaks for an experimental run of the $^{27}Al(d,d')^{27}Al$ reaction at 60.6 MeV incident energy.

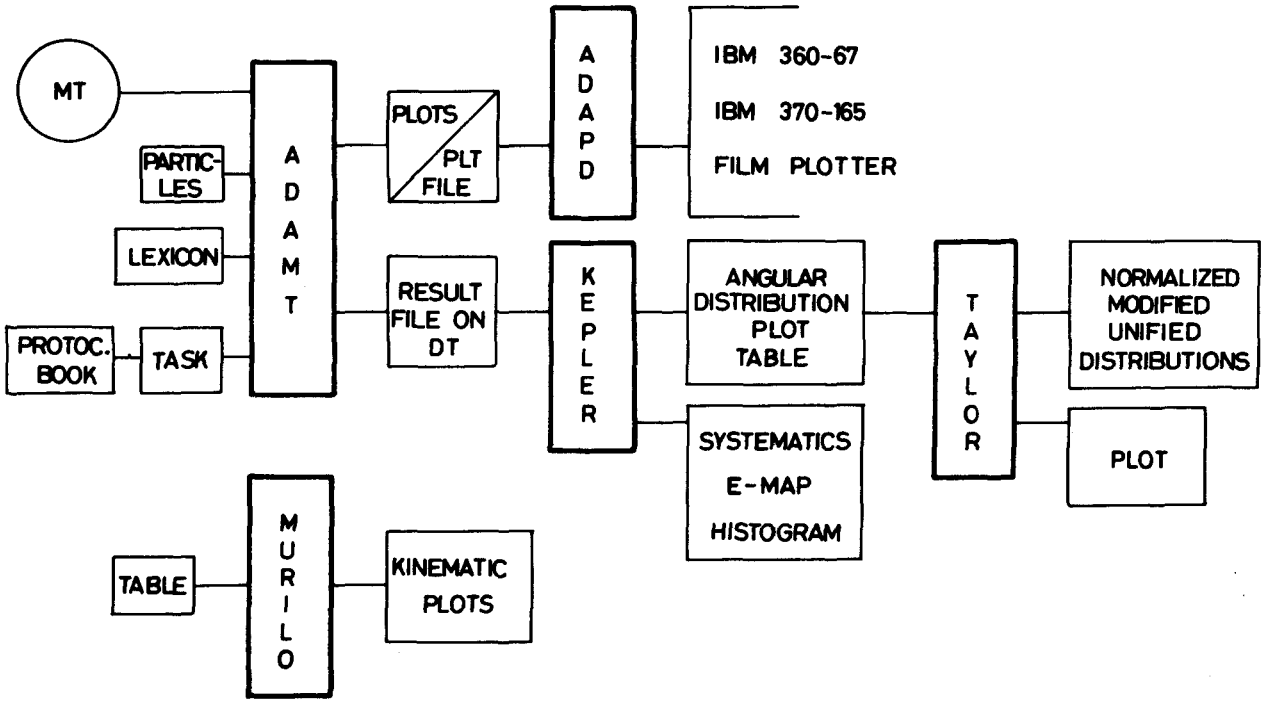
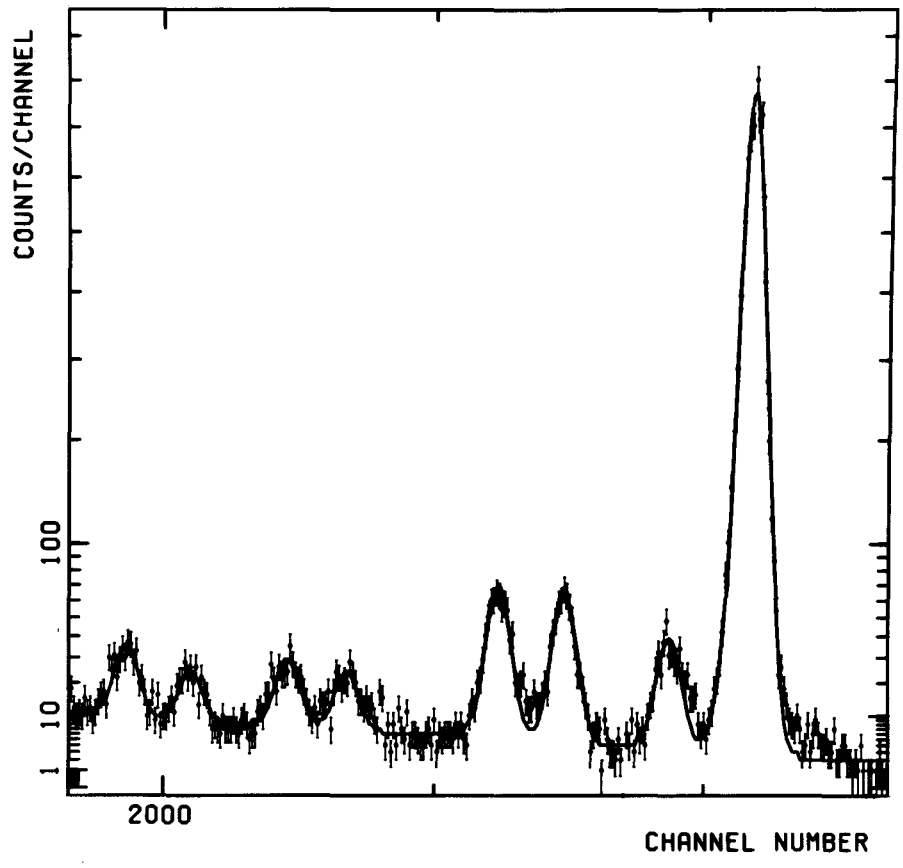

MT
PARTIC-LES
LEXICON
PROTOC. BOOK
TASK
ADAMT
PLOTS / PLT FILE
RESULT FILE ON DT
ADAPD
IBM 360-67
IBM 370-165
FILM PLOTTER
KEPLER
ANGULAR DISTRIBUTION PLOT TABLE
SYSTEMATICS E-MAP HISTOGRAM
TAYLOR
NORMALIZED MODIFIED UNIFIED DISTRIBUTIONS
PLOT
TABLE
MURILO
KINEMATIC PLOTS

Fig. 1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10
1
2000
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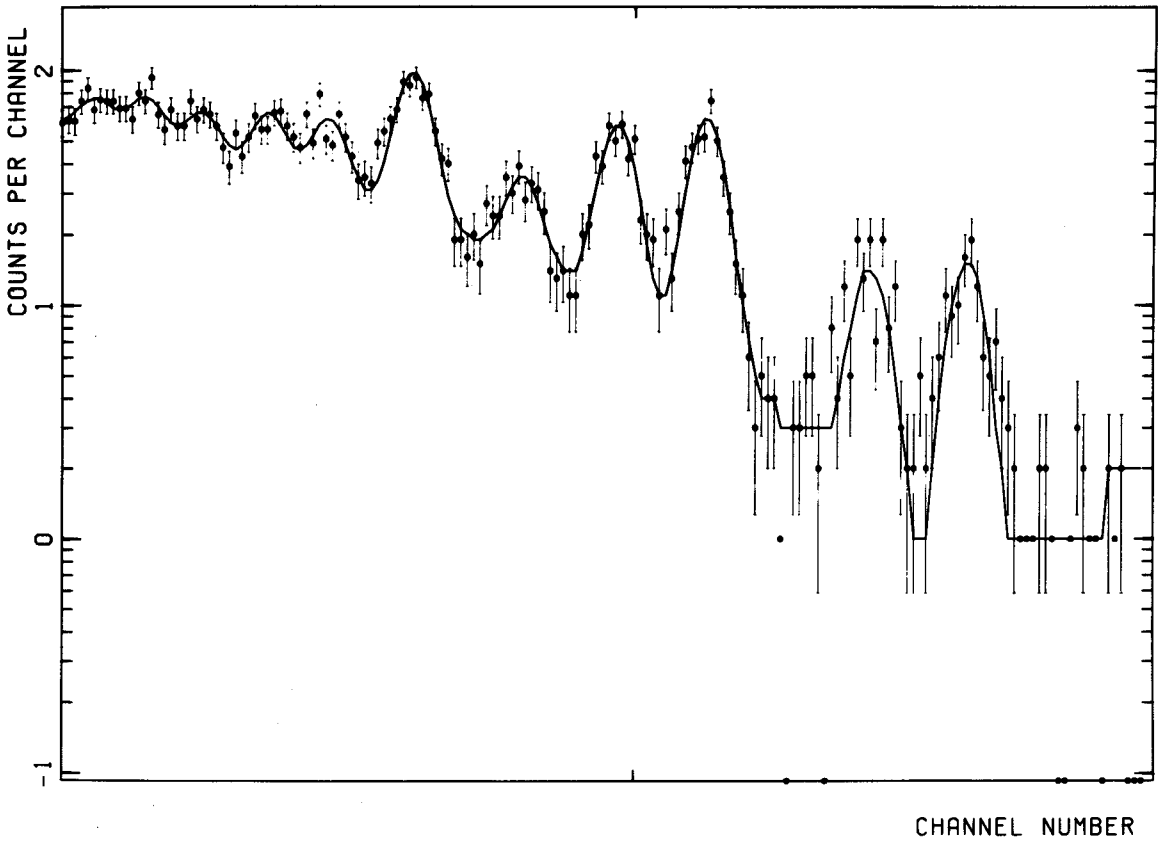
LAB.ANGLE: 50.0 BOMBARDING ENERGY: 77.3 MT: KRK31 NTAG: 58

Fig. 2a


COUNTS PER CHANNEL
2
1
0
-1
CHANNEL NUMBER
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LAB.ANGLE: 37.5 BOMBARDING ENERGY: 80.0 MT: 6LI10 NTAG: 34

Fig. 2b

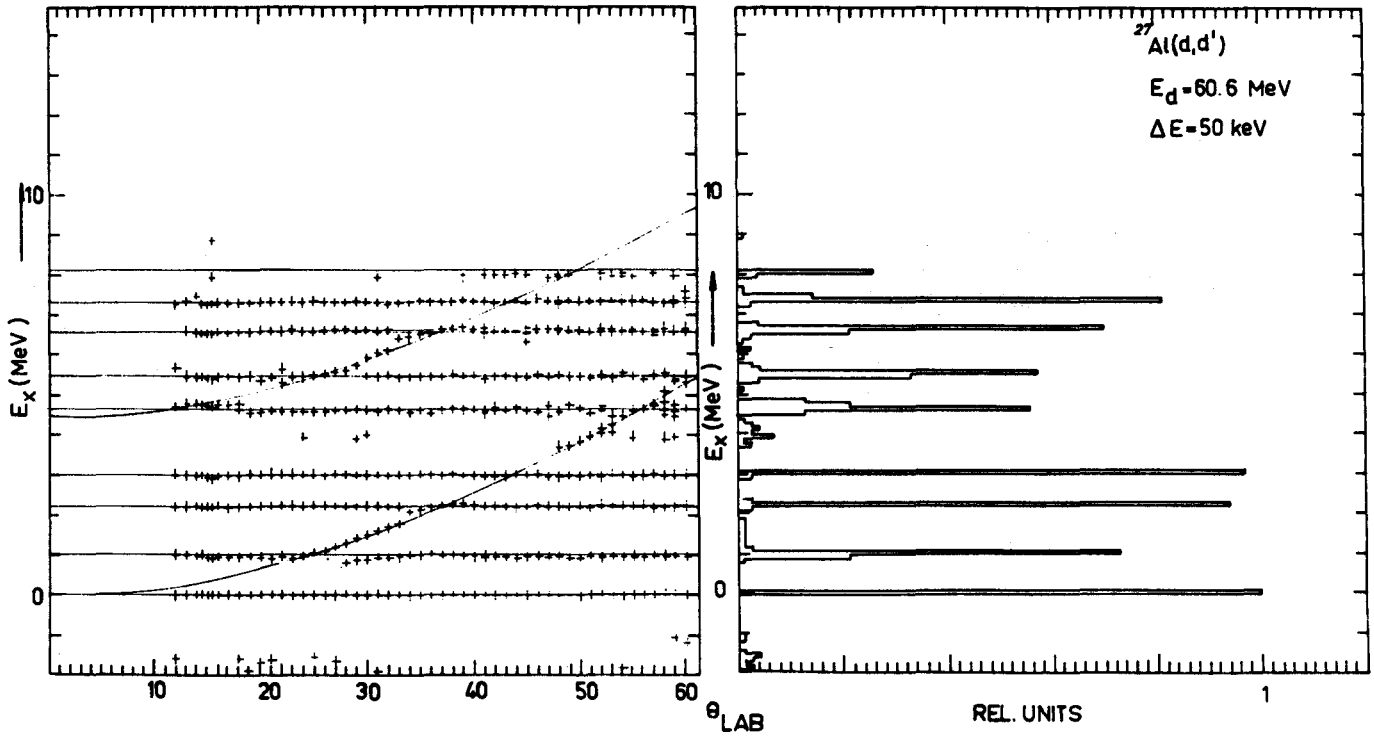
10
0
E_x (MeV)
10
20
30
40
50
60
θ_{LAB}
^{27}Al(d,d')
E_d=60.6 MeV
ΔE=50 keV
REL. UNITS
1

Fig. 3