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EQUIPMENT AND METHODS FOR AUTOMATIC TRACK ANALYSIS

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EQUIPMENT AND METHODS FOR AUTOMATIC TRACK ANALYSIS^{*†}

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A. INTRODUCTION

Some early ambitious attempts that undertook to develop automatic scanning equipment were probably premature. Even with the most modern electronics only limited functions appear to be performed with entire reliability; and the judgement, discrimination, and acuity of a human observer must also be utilized in track analysis.

What we now aim to accomplish by mechanisms is not to replace the observer but to aid him. This can be done by making his measurements more objective, by carrying out automatically calculations that are time-consuming and in which errors are frequent, by improving the data presentation and recording, by speeding the read-out of data, and by reducing tensions and complications that lead to fatigue and error.

In the University of California Radiation Laboratory we are fortunate to have a particularly competent technical organization. This greatly facilitates the development of new types of optical, electronic, or mechanical equipment. The physicist must, of course, correctly conceive the function to be performed and evaluate the errors and limitations set by instrument resolutions etc., so that he can prepare adequate specifications, but for the actual construction of a soundly conceived instrument, he can count on strong technical support.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

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In the past year the writer has initiated a comprehensive program of equipment development designed to give the maximum practical aid to the physicists and technicians who are carrying out track measurements. Some attention has also been given to developing systems of data handling using International Business Machine (IBM) equipment and Keysort cards. In addition, some of the steps to insure the accuracy of the emulsion data are taken long before the emulsion is studied under the microscope. For example, careful density measurements are made of each emulsion batch.

B. STACK ALIGNMENT

Of great importance to rapid and accurate stack measurements is the stack alignment. In order to improve the alignment,¹ it was decided to employ steep tracks passing from one pellicle to the next as the most precise means for matching adjacent surfaces to each other. A 1 mm grid is also printed on each pellicle.

The first step in the alignment is the milling of notches in the edge of the stack as shown in Fig. I. These notches are used for the location of the grid on the pellicle and in the preliminary steps of the final alignment adjustment. The grid is contact-printed on each pellicle by the use of the grid-printing machine shown in Fig. II. After the pellicles are mounted, steel strips are cemented to the glass by means of a device for location (Fig. III). A second steel strip is then bolted to the first with sufficient clearance in the holes to permit a fine adjustment of the position of one strip with respect to the other. The fine adjustment is carried out by the use of the two-microscope jig shown in Fig. IV. In this, the exit points of tracks emerging from the surface of a pellicle are matched to the entrance points of the same tracks in the bottom of the pellicle above it in the stack. The adjustment process is started with the first plate of the stack and carried through the entire stack. In this way each pellicle is matched to the one below it. Several hardened steel pins are fitted to the accurately reamed holes in the steel strips, and by this means the plates are located on the microscope stage in positions that are reproducible to 2 or 3 microns when four pins are used.

While this system locates the plate accurately on the stage, and any one track can be almost perfectly aligned, a fundamental difficulty with

emulsion limits the over-all alignment attainable by any system. When the relative positions of tracks in emulsion are examined critically, as with the two-microscope jig, the distortions causing track displacements are striking, especially in large pellicles. Stretching and other distortions of hundreds of microns have been witnessed. I regard the problem of mounting without distortion to be one of the most important problems to be solved before we can further improve the accuracy of emulsion measurements.

The distortions that occur in fixing and drying are sometimes also important. When distortion effects are severe, the alignment is no better with my method than with the grid alone. However, locating the plate by means of the pins has some advantages because one avoids the necessity of examining the grid to determine the plate position.

C. COORDINATE READ-OUT

A fundamental instrument for track analysis is one that will automatically measure in a rectangular frame the three coordinates of points in an emulsion stack. To be useful, the accuracy must approach one micron. When many points are measured, the sequence of the measurements should not be lost, and allowance must be made for varying shrinkage factors from plate to plate. The instrument should permit the effortless recording along with the coordinate data of other essential but secondary information.

Such an instrument is shown in Fig. V. One of the factors influencing the design was the existence of IBM data-processing equipment at the Radiation Laboratory. To enable this equipment to be used directly, the data were recorded on IBM cards.

The comparatively recent development of devices that ascertain and express electrically the angular position of a shaft has resulted in a means whereby measurements on instruments using screw movements can be obtained with precision and ease. These devices are known as analog-to-digital converters ("digitizers") in which shaft position is transformed into a discrete combination of on-off switches by means of a coded-disk and wiper-arm assembly.

The system described here consists of a microscope with analog-to-digital converters affixed to the three mechanical axes thereof.² These converters, in association with the proper electronic equipment, enable

the x, y, and z coordinates of any point in the "working" volume of the microscope to be punched into IBM data-processing cards. The cards subsequently provide input information for the IBM 650 data-processing machine, yielding solutions to any problems dependent upon these coordinates. Our foremost consideration has been to design a system suitable for accurate range measurements in stacks of nuclear-track emulsion, but the system is flexible enough to handle many other problems. A program has been written to compute ranges from these measurements (SIGH - A range computing program for the IBM-650 data-processing machine).

The particular microscope in use is one constructed to our specifications. It has a large stage and is capable of scanning an area of 100 cm^2 . Throat dimensions are such that one can easily scan to the center of a pellicle 2 ft square. The two digitizers attached to the x and y screws yield 1000 counts per revolution for 100 revolutions. With the millimeter-per-revolution pitch screws on these movements, the least distance measurable is one micron anywhere in an interval of 10 cm. The z-axis is equipped with a thousand-count-per-revolution unit. Using a 10-to-1 reduction between the disk and the z-movement, one can measure vertical distances of one micron anywhere in an interval of 1 mm (one revolution per 100 μ). All of the above units are Giannani Encoders. The microscope is shown in Fig. VI.

The output of the digitizers is in binary form and must be converted to decimal form before card punching occurs. This conversion is accomplished by a translator. The three disks are read sequentially into the translator whose output is fed into a card punch via a punch-control chassis.

Because the punched cards form the raw data, it was felt desirable to punch indicative information into each card to identify it. Thus, in addition to the three coordinates, information of the following nature appears on each card: (1) the event number, (2) the prong number, (3) the pellicle number, (4) the microscope number, (5) a card number (which is entered automatically). The entry of this information into the cards is accomplished by an indicative information control panel, shown in Fig. VII, and a punched card is shown in Fig. VIII.

In any system of this sort, a provision for correcting errors in measurement is essential. The program, SIGH, with which this system is to be used, identifies an 11-punch in Column 20 of the card as an error indication. The card bearing this punch also carries the corrected information. Upon sensing such a punch, the machine cancels the preceding calculation and performs it again using the corrected information. The correction must be made before the next measurement is taken, but may be repeated any number of times. Entry of the error punch is accomplished from the indicative-information control panel.

The read-out time per card, including that for the indicative information, is, four seconds (automatic duplication speed).

Provision has been made for expanding the system to include a greater number of microscopes. The intermediate electronics has been designed to handle four microscopes without modification, using one translator, one punch-control chassis, and one card punch. Each new microscope added to the system will need only the three digitizers, the indicative-information control panel and a disk-switching chassis for information entry.

When several microscopes and only one card punch are used, arrangements have to be made to prevent the simultaneous entry of data from different microscopes. These provisions are incorporated in the microscope switching chassis. If the card punch is in operation, interlocking circuits are activated so that no data can be entered from other microscopes. In Fig. IX the flow of information through the instrument is diagrammed. Other digitized devices may use the same card punch as it is not modified.

The bulk of the electronic circuitry is greatly reduced by the use of transistors and circuits printed on plastic cards. The cards plug in, so one may be substituted for another in a few seconds. Such a circuit is shown in Fig. X.

D. GRAIN-DENSITY MEASUREMENT

In order to improve the estimate of particle velocity, it is necessary to obtain the maximum amount of information from a given segment of track, and to make such readings more objective. For this purpose we have built another piece of equipment³ which borrows heavily from a device described by Baroni and Castagnoli.⁴

A constant-speed reversible electric motor drives the x movement of the microscope stage through gears at 40 and 200 μ /min. To aid in alignment of tracks with the x movement, a rotator with vacuum hold-down for the plate is mounted on the condenser frame, permitting a 60° rotation of the plate about the optic axis. Vacuum hold-downs on the stage also are provided so that the plate may be fixed to it without risk of disturbing the alignment.

The tabulator is a transistorized modification of the circuit used by Baroni and Castagnoli.⁴ On one traversal of the track, it tabulates the total number of gaps, the number of gaps greater than a preset length, and the integrated gap length with the operation of one push button. The tabulator is turned on by a foot switch simultaneously with an electric clock, which indicates the total time, or length of track scanned. The push button is depressed as the beginning of a gap crosses a line on the reticle and released at the end of a gap. This switch operates a second clock which integrates gap length, a counter which totals gaps, and, through a variable RC circuit, the long-gap counter. Figure XI shows the instrument. In Figs. XII and XIII are shown results obtained by using it.

E. MULTIPLE-SCATTERING MEASUREMENT

Another operation that lends itself to automation is the measurement of multiple scattering. In the Radiation Laboratory a device for this purpose has been constructed for Dr. G. Goldhaber⁵ and being operated. It has the following features:

(a) After each measurement the emulsion is advanced by a coded motor. The motor can be set either to various values of constant cell length, or it can be set for a varying cell length in accordance with any desired constant-sagitta cell scheme.

(b) A cross hair in the eyepiece is set on the track to be measured. This cross hair is controlled hydraulically from a screw attached to the microscope body (not the microscope head). The rotation of the screw is transmitted to a Giannini disk digitizer which allows the automatic recording of each setting.

(c) The Giannini disk translator is fed to a Frieden automatic adding machine. The adding machine

(1) prints out each reading,

(2) takes the first differences of the readings (these first differences are stored in a memory circuit),

(3) derives the second differences from the first differences.

As an end result, then the second differences are printed out automatically while the operator proceeds to the next measurement.

This microscope has been in operation for nearly one year and has proved satisfactory in multiple-scattering measurements. Noise measurements have not detected any additional noise introduced by the use of this instrument. Typical noise levels have been $\sim 0.14 \mu$. The instrument is illustrated in Figs. XIV and XV.

F. DATA RECORDING

We have been faced for some time with the constantly growing problem of recording and cataloging the data obtained from scanning emulsions. In the course of a few years we have filled dozens of notebooks with data referring to the location and analysis of many thousands of events. The task of extracting desired information from this bulk of data has involved repeatedly searching through thousands of pages of records.

In order to make our data more readily available, we have adopted a system based on "edge-punched" cards.⁶ As a good example of their use, I shall describe their application in the study of negative K mesons and the products of their interactions and decays. We have selected $8 \times 10\frac{1}{2}$ inch McBee Keysort cards (see Fig. XVI). The large size was chosen so that in addition to the general classifications coded into the edge of the cards there would be a reasonable amount of space available on the face and back of the card to write in data resulting from analysis of the particular event represented by the card in question. This, of course, aids in keeping all

data resulting from a particular event together and permanently available. Data can be added to a card at any time further analysis is carried out. A conscious effort was made to order the categories in sequences of decreasing generality. We have coded onto the edges of the cards only those categories which describe the event physically. In particular, the identification number of the event, the scanner's identification, the stack in which the event is located, and the pellicle number within the stack have not been included in the punched categories but are only indicated as "write-in" data on the face of the cards.

The holes across the top of the card describe a variety of possible occurrences, as follows: The first 6 holes are quite general. Three of these must always be punched. If a K^- meson comes to rest and interacts the card is punched " K^- " "rest" "interact". The next group of holes describes various products that may result from a K^- interaction or decay; a "minimum" track, a Σ particle, etc. (Note that along the top of the card there is no provision for stating such information as the charge of a hyperon. Such data will usually not be known without further analysis. In general, the holes at the top edge list only such data as the scanner can determine by merely examining the event without further analysis.) The next group of punches describes scattering of the K^- particle, and the remaining punches through ">6" enable us to state the number of "prongs" resulting from an interaction and in addition to state whether a "blob," "recoil," or electron are associated with the interaction. "Collinear" and "coplanar" are self-explanatory. The "area scan" punch is used if this method of scanning was used. We have several times both "area-scanned" pellicles and also followed tracks in from the edge; there is a possibility of duplication of data here. The "duplication" punch is used if such a duplication is detected.

The right edge of the card is reserved for Σ hyperons. Note that if " Σ " is punched along the top edge, the card may be selected at any later date for further analysis of the Σ . The results of analyzing the Σ follow the same pattern as the punches at the top of the card. The charge of the Σ , when determined, is entered in the first two holes. The next two punches state whether the Σ came to rest or interacted or decayed in flight (regardless of what the Σ does it must be either at rest or in flight). If the Σ decays the next group of punches state the decay

mode—either into a proton (p) or a minimum track (min). Because of the possibility of leptonic decay modes, we do not state that the min is necessarily a pion. The following group of holes, down to " Σ interact", describes the minimum track resulting from the Σ decay in an obvious way. The identification " π^+ π^- " or "other" can be made only after the min track is analyzed, and the presence of one of the punches indicates that the min has been analyzed.

The hole " Σ interact" and those following it describe the Σ interaction in a manner analogous to the description of the K^- interaction along the top edge of the card.

Along the left edge of the card we describe the analysis of any min track which may come from the meson. If along the top of the card " K^- " and "interact" are punched, then these punches describe the minimum from a "K star". On the other hand, if " K^- " and "decay" are punched at the top, these punches describe the decay product.

Further down the left edge is a group of holes describing the hyperfragment, if such results from the K^- interaction.

There remain several punches that function independently. At the far right of the top row there is an "!" punch, which we reserve for extremely rare or interesting events that we may wish to select from the card file by a single needling operation.

Below the Σ punches on the right there is a single punch which is used when it has been determined that the K^- in question does not give rise to a visible "strange" particle. Other holes at the top are punched when a hyperfragment or charged hyperon is produced. With these holes punched, it is easy to select the events which are still potential sources of strange particles.

Although they are designed for negative K mesons, we have been able to use the cards to record data collected during searches for Λ -hyperons. The scanner finding a typical "V event" punches "other" and " Λ " in the top edge of the card. (This does not, of course, guarantee that the event is really a Λ , but only that it is possibly a Λ .) Later, the two prongs of the V event are followed. If one is a proton and the other a pion, " π " in punched at the top. The events punched "other," " Λ ," and " π ," are now

analyzed by a physicist, and if the event is really a Λ , "decay" is punched at the top. We thus catalog possible Λ particles in several states of analysis by a simple coding.

The "write-in" data includes the following:

- (1) The location of the event in the pellicle and the "stack" number with a diagram of the event drawn by the scanner.
- (2) The location of any interesting related events, such as the termination of prongs from a K^- star. (Typically one might picture the location of a K^- star, the termination of a Σ that results from the K^- star, and the termination of the decay product of the Σ .)
- (3) Any data taken on the event not included in the punches. In particular, we list measured ranges, energies, and angles.
- (4) Initials of the physicist "verifying" the event. (It is general practice with us to have each event examined at the time it is discovered by a physicist.)

A single K^- interaction may give rise to both a minimum track and a decaying Σ hyperon. In such a case we need space to write the ranges, energies, and angles of (1) the minimum from the K^- meson, (2) the hyperon, and (3) the Σ decay product. By utilizing the back of the card, we have been able to list all data on such events on the card itself.

In addition to all of the foregoing, we identify all cards from a particular emulsion stack by painting the top edge with an identifying colored ink. This is not necessary, as the stack number appears on the face of the card, but enables one to select all cards from a particular stack at a glance.

On the bottom edge of the card we punch the date (month and year) on which the event was originally found.

Once the meaning of the punches is understood, operation is quite simple. For example, if one desires all K^- stars at rest that produce a Σ hyperon, a minimum track, and no other prongs, one would needle out successively the following holes:

" K^- ", "rest," " Σ ", "min", "2".

After the first selection one has discarded everything but K^- events; after the second, everything but K^- events at rest; after the third, everything but K^- at rest producing Σ (it is not necessary to select "interact"

as a Σ cannot result from K^- decay); after the fourth, everything but K^- stars at rest producing a Σ and a min; and finally everything but the two-prong stars among these. One now has a reasonable number of events and a particular one may be found by searching through this group if desired.

In practice, when searching for "rare" events, such as collinear K^- interactions, it is necessary only to stack the cards in a well-aligned pile and then visually investigate the punched edge. The comparatively rare "collinear" punch is easily detected and these cards may be withdrawn immediately.

REFERENCES

1. Walter H. Barkas, "An Alignment System for Emulsion Stacks," UCRL-8304 Abstract, May 1958.
2. C. J. Mason and W. H. Barkas, "A Microscope with Automatic Coordinate Readout Adapted for Calculating Particle Ranges," UCRL-8306 Abstract, May 1958.
3. N. A. Nickols and W. H. Barkas, "Equipment for Simultaneous Automatic Tabulation of Several Measures of Particle Ionization in Emulsion," UCRL-8305 Abstract, May 1958.
4. G. Baroni and C. Castagnoli, *Nuovo cimento* 12, Suppl., 364 (1954).
5. Gerson Goldhaber, "A Multiple-Scattering Microscope with Automatic Advance and Second-Difference Calculation," University of California Radiation Laboratory unpublished work.
6. Reynolds, Dyer, Mason, Nickols, Smith, Heckman, and Barkas, "Keysort Card System for Emulsion-Data Recording", UCRL-8307 Abstract, May 1958.

FIGURE LEGENDS

- Fig. I. Machining emulsion stack. The charged particles enter the stack normal to the area that is milled flat. With a sharp high-speed end-mill, grooves are cut for the aligning operations as described in the text. Note the double boards with the short spacer between them used for clamping the pellicles. This device provides a more uniform clamping pressure than does a single board.
- Fig. II. Grid printing machine. The pellicle is first laid on the negative film of the grid below the metal plate. The pellicle is held to the plate by vacuum or friction. By means of adjusting screws, it is translated in the horizontal plane until a point of the notch is in a standard position; then it is rotated around this point until the milled edge is brought up to a fixed line. The adjustment is carried out by employing two microscopes with red-light illumination. The grid is printed by the use of a point source of white light placed 1 meter below the pellicle.
- Fig. III. Strip-cementing jig. By the use of the notches milled in the edge of the pellicle for positioning, a steel strip is cemented to the plate as a step in the alignment procedure. This positioning is not critical and we do not attempt to obtain accuracy of better than a few hundred microns.
- Fig. IV. Stack-aligning jig. The plate with one steel strip cemented to it is moved into the identical position occupied by the adjacent plate. Two microscopes are used for observing the tracks. The plate is then clamped in this position by vacuum hold-downs while a second steel strip pinned to the metal bar in front is bolted to it.
- Fig. V. The microscope coordinate read-out system. The four units making up the complete machine are shown. (The card punch is in the background.) The operator sits at the microscope which is equipped with digital converters^{ers} of the rotary motion of shafts varying the x, y, and z coordinates.

- Fig. VI. Microscope with three digitized coordinate motions. A plate from an aligned stack is pinned to the stage. Any portion of this 9 by 12-inch plate is easily scanned.
- Fig. VII. Indicative-information panel. The items of information registered on this panel as well as the coordinates of a point are punched into each IBM card.
- Fig. VIII. An IBM card punched with typical information.
- Fig. IX. Information flow-chart for coordinate read-out system.
- Fig. X. Typical printed-circuit transistor unit used throughout coordinate read-out system.
- Fig. XI. Grain-density analysing apparatus.
- Fig. XII. Preliminary data showing the percentage transparency of elementary-particle tracks in a G.5 emulsion stack as a function of the particle velocity.
- Fig. XIII. Preliminary data showing integrated blob count as a function of projected residual range for tracks of varying steepness.
- Fig. XIV. General view of multiple-scattering microscope and auxiliary equipment.
- Fig. XV. Details of the multiple-scattering microscope.
- Fig. XVI. (Left) Front face of a card of a partially analysed K^- -capture event. (Right) Back face of card.

ZN-2027

Fig. 1

ZN-2028

Fig. II

ZN-2032

Fig. III

ZN-2026

Fig. IV

ZN-2029

Fig. V

ZN-2030

Fig. VI

ZN-2031

Fig. VII

ZN-2039

Fig. VIII

MU-16069

Fig. IX

ZN-2036

Fig. X

ZN-2033

Fig. XI

ZN-2037

Fig. XII

ZN-2038

Fig. XIII

ZN-2034

Fig. XIV

ZN-2035

Fig. XV

Observer HY TERM: NUS: PARTICLES 23-120-9

PICK UP: PLATE 122 SCATTER: PLATE

PLATE 120

034
17+3
11

CHECKED: PCG

COMMENTS: Z^- star yields hypo-frag.

PRONG# 1

Observer PCG

PLATE 125

CHECKED

3 prong $Z^- \rightarrow 2$ prong hypo-frag.

PRONG#

Observer

PLATE

CHECKED

PRONG#

Observer

PLATE

CHECKED

Mo Year

7 4 2 1 5P 7 4 2 1 5P '50 '60 '70

RANGE (g) .740 (corr) meas

Op at K (corr)

Op at end (corr)

Δ at K

Δ at end

T

E

pc

τ at K

τ at end

τ to end 24.0×10^{-12}

PRONG	RANGE	Op	Z^A	T	Θ	Tan δ
1	873 μ		H ⁺	13.0 MEV		
2	42 μ		HF	2		
3	4 μ		?	?		

Total = 23 Mev

Hyp-FRAG DATA:

	RANGE	Tan δ	Θ	$r\beta$	I	Ident.	T	pc
F						$^A\text{He (sure)}$		
1	22.481 $\pm$.281	+ .7784 $\pm$.0284	309.4 $\pm$ 5			proton	82.78	402.72
2	20.587 $\pm$.257	- .7643 $\pm$.0283	121.9 $\pm$ 5			"	78.71	392.29

1 and 2 are not colinear. Are definitely protons

Only $\text{He}^4 \rightarrow p+p+m.n$ tenable with $8E \leq 4.72 \pm .88$

space angle = 174°

Fig. XVI

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