ON THE CONSTRUCTION OF LARGE NUCLEAR EMULSION BLOCK DETECTORS

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I. Introduction

All emulsion block detectors whose construction has been reported so far have the shape of flat slabs whose thickness is by a factor of about six, smaller than one or both lateral dimensions. Such a shape is usually advantageous in the study of artificially produced nuclear phenomena where the radiation incident on the detector has a strongly preferred spatial direction. On the other hand, when exposed to cosmic radiation at high altitudes, which usually shows little directional preference, the "best" shape depends strongly on the type of phenomena to be investigated. In general a flat detector is suitable for studying the incident radiation, but the spherical or cubical detector is much more advantageous when studying secondary particles, irrespective of whether the latter are stable or unstable, neutral or charged. Roughly:—

The number of incident particles recorded is larger in a flat detector than a cubical one of equal volume.

The number of nuclear interactions per unit volume produced by the incident radiation is nearly independent of the detector shape as long as the detector is not large compared to a nuclear mean free path.

It follows that in a cubical detector the average potential path length of primaries is larger, often appreciably larger, than in flat detectors. This will also be true for low energy secondaries ejected isotropically from stars and for tertiary particles emitted from unstable particles

which have been brought to rest. If the incident radiation is isotropically distributed over the upper hemisphere it will also apply to fast secondaries which preserve more or less the direction of the primaries.

Thus, for a given primary star population the cubical detector will in general contain a larger fraction of secondary and tertiary particles which come to rest, a larger fraction of decays in flight and also a larger fraction of nuclear interactions produced by secondary particles. This last feature may be of great importance in the study of K-mesons and Hyperons if, as some experimental data now suggest, π-meson produced stars are richer in K-mesons and Hyperons than nucleon produced stars.*

For this reason we decided last Fall to begin the construction of an emulsion block detector whose thickness is comparable with its other dimensions.

In deciding the over-all dimension of the detector one has to make a compromise between what is desirable and what is practical. Since part of our objective was to get precise information on the mass and decay schemes of various K-mesons and Hyperons it would have been best to have a detector with a stopping power of at least 100 grams/cm.^{2}, *i.e.*, linear dimension of 25 cms. This is needed because at present exact information on the energy and the nature of charged decay products from unstable particles is only obtainable if their range can be measured.

* It can easily be shown that for an isotropic flux, the average potential track length of primaries in a rectangular block is independent of its orientation and equals $\frac{4V}{S}$, where V and S are its volume and surface area respectively. For secondaries, if they also have angular isotropy, the mean potential length, is half as large: $<L> = \frac{2V}{S}$.

In the table below we have given the mean length $<L>$ of the trajectories of secondary and tertiary particles as well as the approximate ratio (R) of stars produced by primary and by secondary particles in our Blocks, and in those of various European Laboratories (Sardinia flights, 1953). In order to calculate R we have assumed an average of 3 fast secondaries, with interaction length of 27 cms. per primary star.

Block	No. of Emulsion Sheets	Lateral Dimensions cm.	$<L>$ cm.	R
Bombay No. 1 ..	24	10×15	1·15	7·75
Bombay No. 2 ..	125	15×15	3·75	2:4
Bombay No. 3 ..	200	15×15	4·60	1·95
Sardinia ..	40	15×15	1·80	5·0

An elementary calculation, however, reveals that cubical shapes and linear dimensions of the order of 25 cms. when combined will give an emulsion block which will not only present a very heavy load compared to customary balloon borne equipment, but will also be so expensive that the risk seems justified only after one can be confident that all technical problems involved in the construction of such emulsion block detectors have been successfully solved. We have, therefore, decided to reduce the lateral dimensions rather than compromise too much on the shape, and have exposed two stacks of square emulsion sheets 15×15 cm., $600\,\mu$ thick. One stack consisted of 200 emulsion sheets and had, therefore, a thickness of 12 cms., the other one contained 125 emulsion sheets corresponding to 7·5 cms. thickness.

II. Technical Problems Connected with the Construction of Large Emulsion Block Detectors

In an earlier paper[1] a description was given of the technique used in constructing and aligning our first emulsion block detector consisting of 24 sheets of emulsion. We now consider only those technical problems which were not satisfactorily solved previously and those which arise because of the increased size of the detector. These are of two types.

One set of difficulties, by no means negligible, is connected simply with the larger number of plates to be handled. Apart from the more than normal precaution to be taken in order to recover such valuable equipment after the balloon flight, it is necessary to organize the processing, cutting and aligning in such a way that it can be done in a reasonable number of man-hours. Furthermore, since for many problems the usefulness of the emulsion block detector is greatly reduced if a single emulsion sheet is spoiled, destroyed or lost, it becomes necessary to instal automatic safety devices for the processing operation.

The second set of difficulties is connected with the fact that a large stack is only fully useful if the tracing of particles is possible even when their tracks have minimum ionisation and, therefore, no longer stand out against the unavoidable background of electron tracks. This implies that the mounted sheets must be so well aligned that when successive slides are placed into the microscope stage holder, one looks at corresponding points of the adjacent emulsion surfaces with an error which should not exceed about $20\,\mu$. It is of course true that minimum tracks can be traced even though the alignment error is of the order of 100–$200\,\mu$, but in that case elaborate

[1] D. Lal, Yash Pal and B. Peters, *Proc. Ind. Acad. Sci.*, 1953, **38**, 277.

plots of other tracks in the region are necessary, and the time required to trace a minimum ionisation track through 50 or 100 plates becomes prohibitive.

Reference (1) describes an aligning procedure in which the microscope slides were placed on plastic frames and adjusted under the microscope into their proper relative positions; the tracks of heavy primaries were used for establishing corresponding points on adjacent surfaces. The accuracy achieved was limited by:

(*a*) Emulsion distortion. The two adjacent plates may have been brought back exactly to the relative position they occupied before exposure. Nevertheless, subsequent distortion could move a point on the air surface away from its proper position, and thus when exchanging plates in the slide holder, the continuation of a given track may not be found where it was expected.

(*b*) In our first block detector there were gaps between adjacent emulsion sheets during exposure which varied between 100–150 μ. These were due to the tissue papers which were placed between emulsions in order to prevent sticking, and also to the lack of compression between the sheets in the block. Compression was then intentionally kept small so as to avoid damaging or blackening the emulsion surfaces.

(*c*) The alignment of each microscope slide required about 20 minutes. Any five minutes saved by improving the procedure would constitute a saving of nearly 200 man-hours on large detectors.

III. A New Reference System for Plate Alignment

In order to overcome the difficulties listed above we placed between the emulsions a network of nylon threads of 18 μ diameter, which were made α-particle active. These threads produced lines on the emulsion surface along which α-particles were emitted and the line's center could be easily determined with an accuracy of 5 μ. α-particles penetrate deep enough under the surface to prevent their being rubbed off, and yet not so deep as to interfere with scanning and measurements. Since the markings are identical on contiguous surfaces of adjacent emulsions, the exact mis-alignment in any region of the plate due to distortion or other causes can be measured quickly and accurately.

The nylon fibres themselves proved adequate for keeping the emulsion sheets separated and preventing their sticking together. Thus, paper sheets between emulsions could be eliminated. It was possible to exert strong

pressure by means of screws on the assembled emulsion sheets before exposure. The gaps between emulsion sheets were now small and found to vary only between 25 and 35 μ.

Finally instead of heavy primary tracks the grid lines imprinted on adjacent emulsion surfaces were used for the purpose of plate alignment and with the help of the double microscope set up, described below, the time necessary for alignment could be reduced by a factor of four. The details of the procedure were as follows:

(*a*) *Preparation of the Polonium Solution*

It is essential to prepare a sample of Polonium free from β-activity since otherwise the emulsions will be fogged.* Polonium was extracted chemically from 10 old radon needles and the extract was found to contain about 30 microcuries. The purity was tested by counters as well as nuclear emulsions. The Polonium was then brought into solution of 15 litres by adding water.

(*b*) *Preparation of the Nylon Grids*

The nylon fibres used were so fine that they can only be seen with good illumination, against a dark background. In order to place them between emulsion sheets in a darkroom it is necessary to mount them in such a way that they can be handled without difficulty. For this reason we constructed grids.

The nylon fibres were obtained from strands of nylon rope and were found to have a uniform diameter of 18 μ. They were stuck with fast drying glue, on thick cardboard window frames, the inside dimensions of which were $9'' \times 9''$. The grid spacing was 1 cm. throughout. The cardboard edges were then immersed in liquid hot paraffin wax, taking care that the wax did not touch the inside 6″ square of the grid. 600 such grids were produced.

The frames were now soaked in the Polonium solution for a period of six hours and dried in air. They were then transferred to smaller cardboard frames with inside dimensions of $6\frac{1}{4}'' \times 6\frac{1}{4}''$. The cardboard had a thickness of only 500 μ. After transferring the grid to the new frame, using again fast drying cement, the contaminated outer frame was cut off with a sharp blade. The grids were then ready for use.

(*c*) *Assembly of the Emulsion Block*

To keep the emulsions of the stack in position and to have them roughly aligned during the entire exposure, we built a special frame consisting of a

* We are indebted to Dr. H. D. Sharma for preparing the solution.

wooden base plate into which five brass rods were fixed. Two of the rods were made eccentric and permitted the emulsions to be brought in flush with the two edges defined by the remaining rods. The frames covering the grids were punched at appropriate places on their inner edges to fit snugly outside the rods. Each emulsion was alternated with a grid and the entire assembly was pressed down firmly with a second wooden board passing through the five rods. The stacks were flown with the sheets in a vertical position.

(*d*) *Processing*

Mounting and processing procedures did not differ from those previously described. One observation may, however, be of some interest to other laboratories. We found that the probability of getting bubbles during development depends to a large extent on the quality of the treated glass plates used for mounting. A sheet of emulsion cut in two, and mounted with identical procedures, one on a freshly prepared glass sheet and one on a glass sheet which had been exposed to the atmosphere for some time, yielded two plates of which one was free from bubbles and the other very heavily effected. Thus, by using fairly fresh glass plates and storing them in a refrigerator we reduced in our large blocks, the number of bubbles to the tolerable value of about one per 75 sq. cm.

It may also be worth mentioning that in an attempt to reduce distortion we kept the plates in a well levelled tank and did not touch them from the beginning of the soaking stage until they were removed completely dried from the concentrated alcohol bath. We found the distortions in these emulsions reasonable (~ 30 Covans in the larger and ~ 80 Covans in the smaller of the two blocks).

(*e*) *Experimental Details of Alignment*

Two microscopes were placed close to each other. One was a travelling microscope and the other an ordinary stationary microscope with a moveable stage. Two different points on the plate could be viewed simultaneously. The microscope slides are pasted onto plastic frames in the same manner as described previously. For pasting we used a thin celluloid solution in 80% acetone and 20% amyl acetate. This solution takes about one minute to dry which is adequate for making accurate adjustments. The plate is moved until the cross of two Polonium lines appear in the center of the "stationary microscope" field. The travelling microscope is then adjusted until another Polonium line appears in the center of its field. The next plate is then glued on its frame in such a position that the identical configuration appears in the two microscopes when viewing corresponding surfaces.

The accuracy obtained by this procedure is about 5μ. An additional $\sim 5\mu$ error arises from the elastic deformation of the plastic frame when placed in the stage holder. The resulting 5–10μ accuracy applies only to those points which were used for plate alignment. Other points on the plate will be displaced with respect to each other because of distortion and possible stretching of sheets at the time when they were rolled on to glass plates. We find that except near the processed edge or near a bubble, the average error is between 20 and 30μ, and, with very few exceptions, it is less than 50μ for all points on the plate.

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