Cosmic Ray Events Observed in Nuclear Emulsions Exposed at 100,000 Feet[1]

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The atmosphere of the earth is constantly bombarded by extremely high energy particles from outer space, many with energies of the order of tens of billions of electron volts and some with much greater energies. These are the so-called primary cosmic rays. It is believed that they are composed of protons, alpha particles, and heavier stripped nuclei, the protons being predominant.

The effects of the radiations may be detected at sea level, but the intensity of the secondary particles rapidly increases with altitude so it is desirable to have some means available whereby these effects may be detected and recorded at high altitudes.

At present, two devices are commonly employed to accomplish this. One is the Wilson cloud chamber; the other is the nuclear emulsion. We shall be concerned here only with the nuclear emulsion technique.

Nuclear emulsions are precisely what the name implies; they are suspensions of light-sensitive silver salts, usually silver bromide, in a gelatin-like substance. This emulsion is usually mounted on a glass plate for the sake of rigidity.

It has long been known that a charged particle passing through a photographic emulsion causes the grains along the track to become developable. Thus, it becomes possible to obtain a record of nuclear phenomena merely by exposing a nuclear emulsion to high-energy particles.

As was previously mentioned, this may most efficiently be accomplished at altitudes which are of the order of one hundred thousand feet. This optimum value of altitude occurs because at higher altitudes the air is so thin that very few interactions occur between the primaries and nuclei in the air resulting in decreasingly small secondary radiation at altitudes higher than the optimum value. Conversely, as the altitude decreases from the optimum value the air becomes so dense that both the secondary and primary radiations are rapidly absorbed. Our nuclear emulsions have been exposed at approximately one-hundred thousand feet by means of free-flight balloons.

After the plates have been exposed they are developed and then observed, or scanned, under a microscope. In scanning, it must be remembered that the emulsion is a three-dimensional affair, whereas one ordinarily thinks of a thin film as being two-dimensional, for all practical purposes.

When an interesting track is discovered in the process of scanning, it is naturally desirable to make a photograph of it for the sake of recording the event and also due to the fact that area measurements may more conviently and accurately be made upon the photograph of the track than directly through use of the microscope.

The principal difficulty in making a photomicrograph occurs because practically all tracks encountered dip in the emulsion, i. e. the tracks are inclined with respect to the horizontal plane of the microscope. It is thus impossible to focus upon the entire length of track within view. Only short elements may be focused upon, the length of the elements being dependent upon the degree of dip. It is then necessary to make a picture of each succeeding element of track which may be focused upon in order to obtain all of the track in focus.

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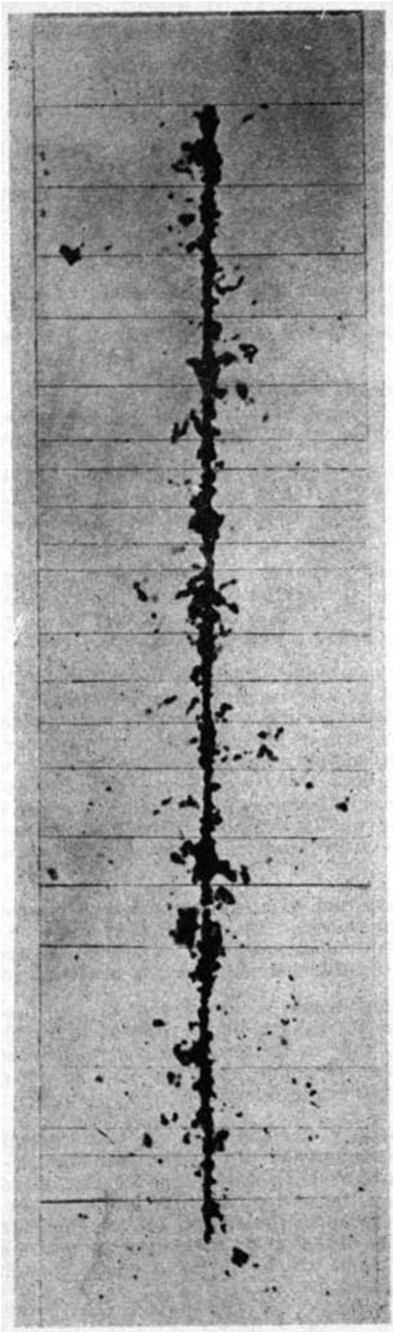

PLATE I. *Track of an energetic stripped heavy nucleus showing numerous delta-ray tracks.*

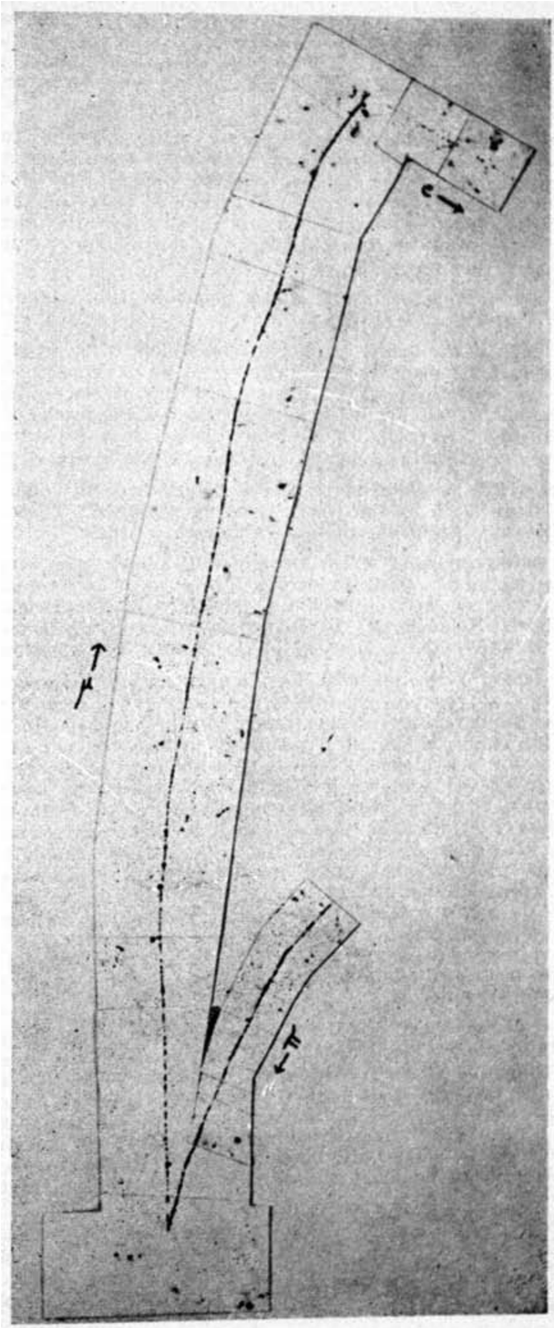

PLATE II. A pion (π) comes to rest, emits a muon (μ) which in turn comes to rest and emits an electron (e).

In practice, the Leitz Ortholux microscope and a standard Leica 35 mm camera prove to be quite satisfactory in the making of these photomicrographs. The lens of the camera may be replaced by an adapter which is constructed such that, when it is inserted in the ocular tube of the microscope, the image is in focus in the film plane of the camera.

As was previously outlined, negatives are made of each succeeding element of the track in focus and prints are then made from these negatives. The parts of each print in focus are then selected and the part of the print not in focus cut off and thrown away. The desired parts of the several prints are then fitted together to make what is called a mosaic which gives a picture of the entire track in focus. If it is so desired, prints and slides of the mosaic may then be made.

We have several representative slides made in this manner which contain certain interesting features.

This plate depicts the track of a particle which is believed to be a stripped nucleus and, as such, is also believed to be a primary cosmic-ray particle. Note the abundance of delta-rays and the extremely heavy appearance of the track. These are both characteristics of the tracks of stripped nuclei. The delta-rays are tracks of electrons ejected from molecules in the emulsion due to the excitation energy supplied by the stripped nucleus.

The charge of this particle has not been determined, although methods exist whereby an estimate of the charge may be obtained. These methods depend upon the counting of the delta-rays along the track.

This plate shows an event which is quite well known; the event shown is the pi-meson, mu-meson, positron decay. The event was first discovered and analyzed by C. F. Powell of Bristol in 1947, for which accomplishment he was awarded the Nobel Prize. In analyzing the event he discovered the positive pi-meson which has a mass of approximately 272 electron masses.

Notice the track of the pi-meson has increasing grain density and increasing scattering as one proceeds along the track toward the first decay process. This is an indication of the energy loss of the particle as it proceeds through the emulsion. In the first decay process the pi-meson decays into a mu-meson and a neutrino. There is no explicit experimental evidence for the existence of the neutrino here, however, it must be postulated in order to conserve momentum. Note the sudden change in grain density at the point of decay; evidently a new charged particle, the mu-meson, has been formed in the decay process since the grain density suddenly becomes less. The mu-meson has a mass of approximately 210 electron masses. Notice the increasing grain density and increasing scattering of the track of the mu-meson; this is again evidence of the energy loss. At the end of the track of the mu-meson another decay process occurs with the resulting production of a positron. Notice that the track of the positron is much lighter than the tracks of either of the two mesons which is an indication of the much smaller mass of the positron.

It has been verified experimentally that the energy of the mu-meson in this event is characteristic, i. e. 4.1 MeV. When one finds an event like this in an emulsion it is very convenient because it makes possible the calibration of the emulsion as to range energy relationships. The average range of the mu-meson produced in this reaction is 590 microns in the Ilford G-5 emulsion. The range energy relationship will vary somewhat for individual plates of the same type, however, so that the occurrence of this event on a plate being scanned makes possible an internal range-energy calibration.

This event also gives a cross check on the spin of the pi-meson. From beta-ray theory, the spin of the neutrino is one-half and the spin of the mu-meson is also one-half. Then the spin of the pi-meson must be either 0 or 1. Independent experimental evidence indicates that the spin of the pi-meson is actually 0.

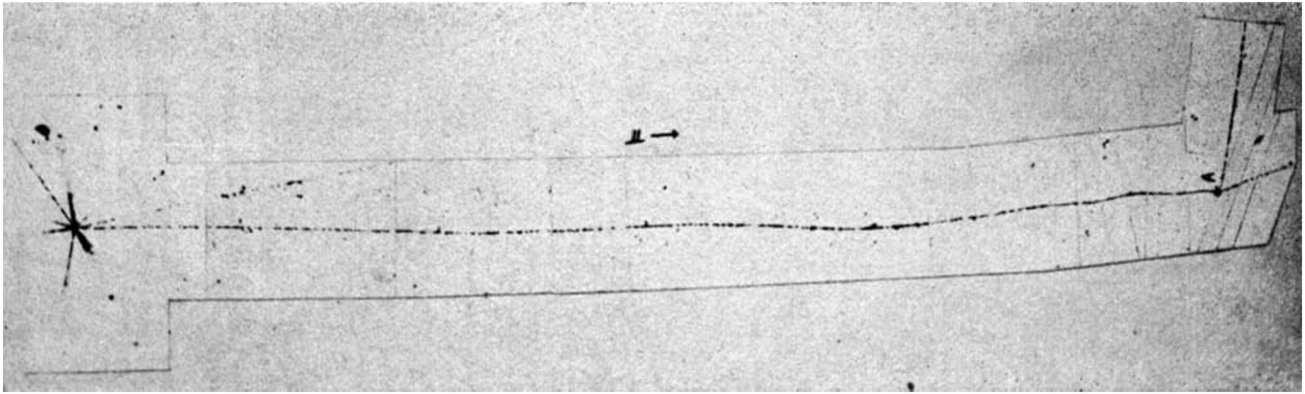

PLATE III. A heavy nucleus is shattered by an energetic cosmic ray. One of the particles emitted by the heavy nucleus is a negative pion which comes to rest and is absorbed by a second nucleus resulting in its disintegration.

This plate shows two nuclear disruptions, or "stars" as they are commonly known. A negative pi-meson is emitted from the evidently more energetic star and is in turn absorbed by a second nucleus with the resulting less energetic second star. This is also a quite well-known event.

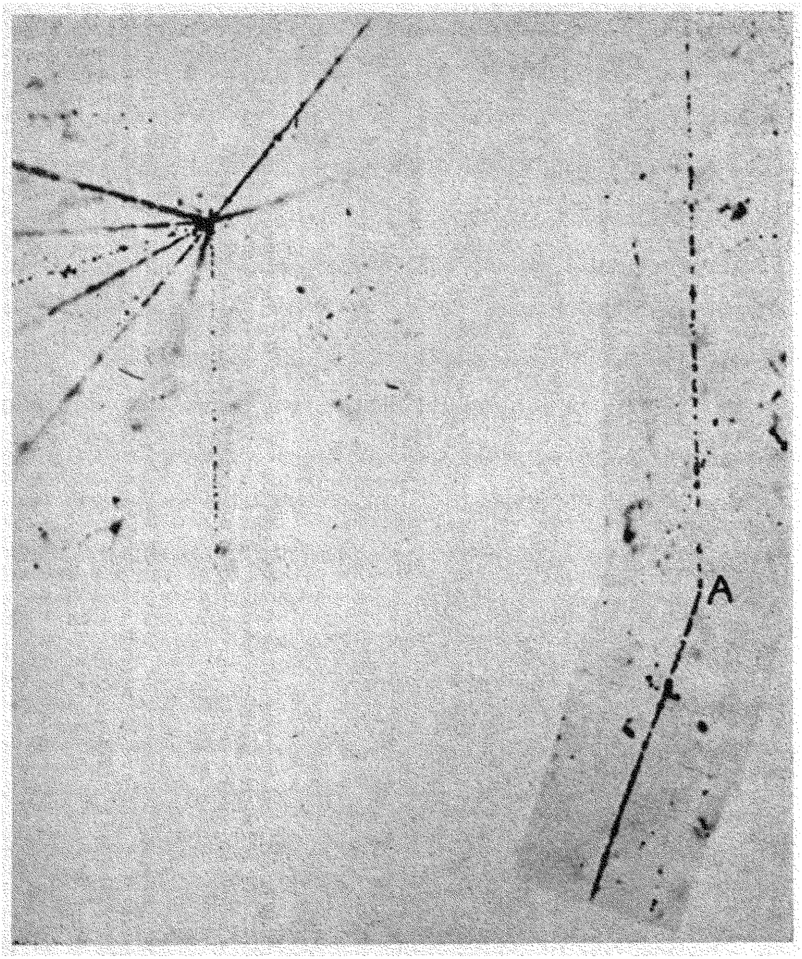

PLATE IV. A cosmic ray "star" like that shown in Plate III. The curious change in the nature of the track at point A is as yet unexplained.

This plate shows a light track which originates in a star. The track is approximately 4000 microns in length and preliminary scattering measurements indicate that the mass of the particle is approximately 1100 electron masses.

Notice the sudden large angle scattering and the sudden change in grain density. Notice also that the track is not noticeably scattered after the one large angle scattering. This is evidently not a decay process like the one illustrated in Plate II. If a lighter particle were produced in the decay process its energy, as indicated by the large grain density, would be so small that it should be appreciably scattered. This is evidently not the case since the approximately 180 microns of track between the large angle scattering and the point where the particle passes out the bottom of the emulsion is quite straight. An event of this type is then what one looks for in scanning a nuclear emulsion. Further analysis in the case of this event has not yet been carried out due to the fact that most of the time of the Norman group has recently been spent in the analysis of another, perhaps more interesting event. Anomalous events of this kind are the things which keep cosmic ray workers searching for new particles and new types of nuclear interactions.