Discovery of Pi and Mu Mesons and Brazil-Japan Collaboration on Cosmic-Rays[1]

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It is my great honor to be invited at the Annual Meeting of Sociedade Brasileira de Pesquisadores Nikkeis, and to be given an opportunity to talk on the research of cosmic-rays. As was mentioned by the speech of the President, Professor Yashiro Yamamoto, this year is the fifty years since the discovery of pi and mu mesons by Professor Cesar Lattes. His discovery is very important to Japanese physics, giving the decisive evidence for Yukawa meson theory and Sakata two meson model. So, there started close friendship between physics communities of the two countries, particularly for those on particle physics and cosmic-rays. From this basis, we are working in collaboration on cosmic-ray study with experiment at the mountain laboratory at Bolivian Andes, the historic place of the pi and mu meson discovery. Professor Lattes is the comandante of our cosmic-ray collaboration running since 1962.

Discovery of pi and mu mesons

Let me first show the historic events of pi and mu meson, which were observed by the photo-graphic plates of nuclear emulsion exposed at Pic du Midi in France (Fig. 1). The transparency shows mosaic of the microscopic picture of the meson tracks registered in the photographic plates. Here, you can recognize that a slow cosmic ray meson comes from outside and stops in the middle of photographic emulsion layer, and, from the stopping point, a new meson of low energy appears. In the historic paper of Lattes, Muirhead, Occhialini and Powell published in Nature, 1947, they call it the double meson event, and they reported the two examples of this type.

They thought of a possibility that a negative meson comes to stop in emulsion and is absorbed by a nucleus, and, after some nuclear transformation, a meson receives some amount of energy and goes out of the nucleus. At the same time, they did not forget a possibility of a heavy meson coming to rest in emulsion and decays into a light meson under the two meson hypothesis. Of course, it was not possible to draw a definite conclusion from observation of two examples.

They knew immediately that what they observed in their photographic plates would have decisive significance on the particle physics. Lattes convinced Powell and Occhialini, to make an immediate exposure of the photographic plates to cosmic-rays at higher altitude. He knew that the exposure is possible at Chacaltaya meteorological observatory in Bolivia, at altitude of 5200 m, near city of LaPaz. He went alone there with the photographic plates, and made the exposure with help of Ismael Escobar, who was running mini-observatory there. After the exposure of a month, Lattes made test processing at house of Escobar in LaPaz, and he saw a good example of the double meson event under his microscope. Now the expedition was successful.

[1] Conferência apresentada à 5ª Reunião da Sociedade Brasileira de Pesquisadores Nikkeis, Águas de Lindóia, SP, 8 a 10 de agosto de 1997, na sessão dedicada a comemorar os 50 anos da descoberta do méson-π, na qual o Prof. Cesar Lattes foi homenageado com uma placa alusiva ao evento.

After his coming back to Bristol with exposed photographic plates, the processing was made and the scanning of meson events was carried out by a whole of Bristol group. In this way, they obtained dozens of the double meson events. What is remarkable is that range of the second meson, from its start to the end, is always constant, about 600 microns in the photographic emulsion, showing the second meson is emitted always with the same amount of kinetic energy. It shows clearly the two-body decay of a heavier meson (pi-meson or pion) into a lighter meson (mu-meson or muon) and an undetected neutral particle (neutrino).

At the same time, they found events of a stopped meson of other types. In the figure, you see an example of stopping meson making nuclear disintegration. It is a negative pi-meson stopped and absorbed by a nucleus giving its rest energy into the nucleus and making its disintegration.

Nuclear emulsion technique

It is known that the photographic plates are a good detector of radiation, as you remind the old discovery of Uranium-radioactivity by Becquerel by use of the photographic plates. Tracks of individual alpha-particles from radio-activity were first observed by Kinoshita, a Japanese studying in Rutherford Laboratory, in 1910s. A large improvement of the photographic emulsion, suitable for observing tracks of a particle, was made by the effort of Waller in Illford Co., just after the World War II. He succeeded to increase the content of silver bromide crystal in emulsion nearly by one order of magnitude. Here, you can see the difference in comparison of tracks of alpha-particles from radioactivity. New photographic plates with improved emulsion record a particle with much thicker track (Fig. 2). The photographic emulsion, particularly made for the purpose, is called as the nuclear emulsion, and the plate with such emulsion is named as the nuclear emulsion plate.

The nuclear emulsion plates could register a slow proton with a clear track, and it was used as a proton detector for study of nuclear reactions. It was the original intention for the improved emulsion.

Young school of São Paulo University at Bristol

Occhialini was the first to join Powell in Bristol, when Powell was setting up a laboratory for study of nuclear reactions with the improving nuclear emulsion technics. Then, Occhialini immediately realized that this new emulsion technics opened a large possibility for cosmic-ray studies as well. He suggested Powell to invite Cesar Lattes, and later Ugo Camerini, to Bristol from São Paulo as a key member of the new group with new emulsion technique.

You know Occhialini was together with Gleb Wataghin at Universidade de São Paulo, working on cosmic-ray showers with a cloud chamber. Wataghin laboratory of Universidade de São Paulo was the first nuclear physics laboratory in Brazil, and many leaders in theoretical and experimental modern physics in Brazil were old boys from this laboratory. Occhialini had to leave the laboratory during the wartime, because of his Italian passport. Lattes was working there on slow mesons with his cloud chamber. He sent to Occhialini a picture of cosmic-rays taken by the cloud chamber to show him the progress. Then, Occhialini replied to Lattes with a microscopic picture of tracks of particles in the new nuclear emulsion plate at Bristol.

Lattes noticed the excellent quality of tracks registered in the nuclear emulsion plates, and he decided immediately to join Bristol group and asked Occhialini to send the invitation.

I can find in Occhialini writing, how he wanted young and active Brazilians joining his venture into cosmic-ray study with the new technique, and how they worked in Bristol bringing their young energy and new culture into the traditional and academic atmosphere of English university.

So, Lattes came to Bristol in the beginning of 1946. First, he worked on nuclear reactions with the new plates, and he extended his study to neutron detection with Boron-loaded nuclear emulsion plates. The Boron-loaded plates of his idea worked very well for neutron detection, and, at the same time, he found it is stronger against the fading of latent images than the unloaded ordinary plates.

Immediately after, Lattes and Occhialini decided to make an exposure of the emulsion plates at a high mountain, that is Pic du Midi in France, trying to observe cosmic-ray particles. Occhilanini is a mountain-climber, and he supported his life as a mountain-guide at Itatiaia during wartime. So, it was not difficult for him to go there with nuclear emulsion plates of ordinary type and of Boron-loaded type.

After processing the exposed plates at Bristol laboratory, they found under the microscope, that the Boron-loaded emulsion plates registered many more tracks than the normal emulsion plates, showing that the Boron plates are really strong against fading. In a large number of events of cosmic-rays recorded in the Boron plates, they saw rich varieties of cosmic-ray phenomena, which were never seen before. Above all, there was this two-meson event. Now, the study of cosmic-ray mesons with Boron plates was put with highest priority.

Now you see that a young school of São Paulo, being planted in Bristol with the new nuclear emulsion technique, opened their flower of two meson discovery.

Powell, the head of laboratory, knew that this venturing into the field of cosmic-ray study was possible and successful only with participation of young school of São Paulo University. He then became enthusiastic for international collaboration and cultural exchange. His laboratory had been since then full of young physicists from all over the world. I worked there from 1953 to 55, and I benefited well the international atmosphere of Bristol laboratory.

Meson theory from Japan

Let me talk a significance of the two meson discovery, that is, how the long-lasting puzzles of meson theory were solved by the discovery and how it opened a new stage of particle physics.

Yukawa original intention of his theory of meson, published in 1935, is really ambitious. By introducing a new particle, with mass intermediate between an electron and a proton, he wanted to solve the two fundamental problems of nuclear physics. One is the nuclear forces, which bind protons and neutrons together into a nucleus. He assumed that the nuclear force was due to exchange of a virtual meson between a proton and a neutron, The other is beta-decay, a radioactive nucleus decaying with emission of an electron and a neutrino. He proposed that this is decay of a meson, virtually emitted from a nucleus, going into an electron and a neutrino. The newly proposed particle was called as U-particle in his first paper, but later the name was settled down to meson showing its intermediate mass.

It is an important question to me why this idea came out with a young unknown physicist in Japan, but not with the experienced authorities at the center of physics, that is, in Europe. Please remind you that the situation of Japan in 1930s was miserable and nothing good for the basic research. Though there were already some pioneer works on modern physics, Japanese academic community was weak and sick. The universities were under threat of the thought-police and the dominating militarism.

Naturally, his new theory was met by cool reaction from national as well as international communities. It was fortunate for him, because he had good collaborators around him. Among them, I might mention Shoichi Sakata and Mituo Taketani. Through their collaboration, they were able to formulate his meson idea into a form of quantum field theory of mesons, and start to make the theoretical calculations and the quantitative comparison with experimental information. There was already the quantum theory of electrons and of electro-magnetic field, but it was not known how to generalize the scheme to cover possible cases of a new particle with intermediate mass.

A part of answer to the previous question can be found in Taketani methodology, the three-stage theory, which he formulated from his study on history of sciences. The work was almost at the same time with Yukawa idea of meson. In European physics communities, it was generally believed that the science develops through two stages, the phenomenological stage and the essentialistic stage. It means that the former is with empirical formulas and the latter with the complete theory. Taketani pointed out that there is an important intermediate stage, called the substantialistic stage. It concerns to find out which is the key substance of the phenomena in question. He got his idea from the fact that the discovery of a neutron was the key to understand the phenomena of atomic nuclei. He was firmly convinced that the Yukawa idea is just this substantialistic theory that is needed to arrive at the essentialistic theory of sub-nuclear world.

Mesons in cosmic-rays

The cosmic-rays, which was discovered already in 1912, were beginning to be understood only in 1930s with new detector technics of counter-controlled cloud chamber under strong magnetic field. The positron was discovered by Anderson in 1932 giving an evidence for Dirac theory of an electron. Then, there was the discovery of electron-positron pair production by Blackett and Occhialini.

The cosmic-rays were known, phenomenologically, to be composed of the two components, The soft component, which is absorbed by lead plate of a few cm thick, was found mainly electrons, positrons and gamma-rays. While, there was the hard component that can easily penetrate through lead plates of 10 cm or more. In 1936, Anderson and Neddermeyer obtained an evidence for existence of a new particle with intermediate mass, i.e., a meson. Since then, a large part of the hard component was known to be mesons.

The discovery of a meson in cosmic-rays was certainly encouraging to Yukawa and his collaborators in Japan. At the same time, it turned attention of physics communities in Europe and America to the study of the new particle, meson. Through intensive studies on the meson problem, both from the side of theory and of cosmic-ray experiments, the meson theory of Yukawa was found with full of difficulties. The meson problem was full of puzzles. It was the general situation around 1939-40, when the break of Second World War destroyed international exchange of scientific information.

From the theoretical study, the meson theory was found with inherent difficulties, though many of which were common to the case of electrons and of electro-magnetic field. The comparison with cosmic-ray experiment was more serious. Yukawa theory of mesons could not give even qualitative agreement with the experimental results on cosmic-ray mesons. Even Yukawa himself was becoming skeptical to his theory, thinking that the frame of field theory might be not suitable for this original idea and he looked for a new theory beyond the quantum theory. It was Shoichi Sakata, who is confident in the original meson idea, and tried to find a solution under the hypothesis of two mesons. He told me that he wanted to solve the problem with the substantialistic term of Taketani methodology. Sakata, Tanikawa and Inoue published, in 1942, their result of analysis with the two meson theory. This work was not informed to outside of Japan, and it was made public over all the world only in 1947. What Lattes found with the nuclear emulsion plates was just identical to the case studied by Sakata and Inoue.

New picture with two mesons.

Let me summarize the understanding of mesons after discovery of two mesons, pi and mu. The pi-meson, or pion, is a particle which Yukawa introduced to understand the nuclear forces. Protons and neutrons bind together to make a nucleus, because they exchange pi-mesons, Therefore, a pi-meson has a strong interaction with a nucleus, and it is one of what we call hadrons. A pi-meson decays, with short life-time, into a mu-meson and an undetectable neutral particle (mu-neutrino). Therefore, we can find pi-mesons in cosmic-rays only just after its creation by nuclear collision of cosmic-rays. A positive pi-meson, when it comes to stop, will make decay into a positive mu-meson. A negative pi-meson, after its stopping, will be absorbed by a nucleus and make the nuclear disintegration (Fig. 3) .

Mu-meson is cosmic-ray meson which Anderson and Neddermeyer found in their cloud chamber. Though a mu-meson has mass a little less than that of a pi-meson, they are very much different. Mu-meson has only weak interaction with a nucleus, several order of magnitude smaller than that of pi-mesons. So, a mu-meson is nothing to do with nuclear forces, and, in a way, it is similar to an electron. It is one of what we call leptons, and may be better to call a heavy electron rather than a meson. A mu-meson decays into an electron with continuous energy spectrum, so the decay is associated with emission of more than two undetectable neutral particles (electron-neutrino and mu-neutrino). Since life-time of a mu-meson is much larger than that of a pi-meson, it occupies the major part of the hard component of cosmic-rays.

Discovery of artificial production of mesons

Lattes left Bristol at the end of 1947 and went to Radiation Laboratory at Berkeley, California, trying to find the artificial production of mesons. There was 184-inch cyclotron, the biggest in the world, which is producing a beam of alpha-particles with 380 MeV. Since an alpha-particle is made of two protons and two neutrons, the beam is equivalent to a beam of protons with one quarter of the energy, 95MeV. This energy is not enough to create a pi-mesons in its collision with a proton at rest in the target. Lattes knew that protons and neutrons in a nucleus are moving just like molecules in gas. He can estimate the motion of protons and neutrons in a nucleus and he knows the best estimated mass value of a pi-meson. He concludes that the artificial production of a pi-meson is possible with this alpha-particle beam, if you take into account of the motion of a proton and a neutron inside a nucleus.

He collaborated with Gardner there to find positive and negative pi-mesons artificially produced by irradiation of alpha-particle beam on the target. His knowledge on the nuclear emulsion technics and his estimated value is essential in the design of experiment. They arranged the produced pi-mesons to be deflected by the magnetic field and to stop in the nuclear emulsion plates after passing through the absorbing material layer. The pi-mesons were found exactly at the place he anticipated.

In the next year, 1949, just before leaving Berkeley, he found artificial pi-mesons produced by high energy gamma-ray from 300 MeV electron synchrotron there.

This work at Berkeley was enough to open doors of accelerators to meson physics. It is the beginning of particle physics with large accelerators, which we call high energy physics. The physics communities became enthusiastic for construction of large accelerators for study of pi-mesons, and then for studies on variety of new particles.

If he had not gone to Berkeley, of course, the accelerator experiment of mesons would be certainly delayed, and I do not know who would be the pioneer of high energy physics neither how would be the fate of large accelerators. Instead, he would benefit further improved nuclear emulsion plates with high sensitivity to detect an electron track. There is a microscopic picture of the improved nuclear emulsion plates which record chain decay of a pi-meson to a mu-meson, and then to an electron (Fig. 4).

Japan, Brazil and Nikkei colonies

Yukawa received Nobel Prize in 1949, after his idea was fully confirmed by the two meson discovery. It was a big national event for Japan after the defeat.

There was movement among Nikkei colonies to invite Yukawa to São Paulo at his occasion. They collected the donation from Japanese immigrants for the fund to invite Yukawa here, but unfortunately visit of Yukawa was not realized because of his health condition. Instead, they decided to use the fund to contribute to the theoretical physics group in Japan, encouraging their research activity, and the money was sent through Mainichi Press. In the old document, we find that the donated sum was as large as a few million yen at that time, very large amount for the physics research under miserable economical situation in Japan. I can find name of Shigueo Watanabe as a member of the committee of this movement.

At the receiving side in Japan, Professors Tomonaga and Taketani were responsible since Yukawa was in USA. The donated money was used for scientific publication of internal circular on the particle physics and for discussion meeting for preparing Japanese work to be presented at the international conference on theoretical physics held in 1953 at Kyoto. This Kyoto conference was the first international conference on science after the defeat. Those were not all. Theoretical physics professors thought that they should encourage experimental work on meson physics, more specifically, the study on cosmic rays with the nuclear emulsion technics. They were impressed by much by the two meson discovery, and they wanted, someday, nuclear emulsion work in Japan with fruitful results. They gave a part of Brazilian Nikkei fund to young experimentalists on cosmic rays. I am one of those who received the support, and I was able to buy binocular attachment to my monocular microscope. With this microscope, I saw the two meson decay event in the nuclear emulsion plates made by Fuji Film and Sakura Film.

Taketani came to São Paulo by invitation of Instituto de Fisica Teórica at Pamplona. This year, 1958, happened to be the anniversary of 50 years of Japanese immigration. Yukawa visited São Paulo at this occasion, and both professors expressed their deep gratitude to Nikkei members for their fund to help the particle physics research sent a several years ago. They went together to a small village called Mizuho, where the movement started to help Japanese physics.

A close friendship between Japanese and Brazilian physicists started at this occasion. Since then, there is a continuous exchange of researchers between the two countries, and the number increases year after year.

Collaboration experiment on cosmic-rays at Mt. Chacaltaya

Our cosmic ray collaboration work is based on such history. After coming back home from study at Bristol with the nuclear emulsion technics, I attended a workshop held at Yukawa Institute (Institute of Fundamental Physics) in Kyoto in 1956 trying to draw a future plan of cosmic-ray experiment on Inter-University basis. We came to a new idea of detector, which is a multi-layered sandwich of lead plates and nuclear emulsion plates to catch high energy electron showers, and we named the new device as the emulsion chamber. With this idea of emulsion chamber, a group of young boys planned a balloon experiment for observation of production of pi-mesons in high energy cosmic ray nuclear collisions. The experiment was made immediately with good success.

Seeing the emulsion chamber works well, we planned to increase the size and to work at higher energy region. The balloon was not suitable for the purpose, and we started the mountain experiment at Norikura observatory at altitude of 2800 m. We found the idea working well, but the mountain laboratory was to low to get enough number of observed events. So, we were looking for possibility to make the experiment at famous Chacaltaya observatory, the place of two meson discovery. Yukawa was kind to us to introduce our intention to Lattes, asking the experiment at Chacaltaya to be the collaboration of Japanese group and Brazilian group. I remember well that we were very glad to receive a positive answer.

Lattes visited Japan in 1961 to attend the international cosmic ray conference at Kyoto, and at that occasion we got together to make the plan for collaboration experiment. In those days, there were no way to make international collaboration experiment in our Japanese system, so we have to ask most of the necessary expenditure abroad to be on Lattes side. He was very generous and he promised us to prepare every necessary material at Chacaltaya, and offered traveling and staying expenses. He told us to bring Japanese emulsion plates and X-ray films prepared for

Norikura exposure, then the experiment could start immediately. Following his advice, Yokoi and myself went, in 1962, to his laboratory at São Paulo University together with photographic material, and we started the emulsion chamber experiment at Chacaltaya.

Since then, we obtained a number of experimental results. What we found on meson production in high energy cosmic ray nuclear collisions was later confirmed by the large accelerator experiment at CERN. Besides, we encountered with a new phenomenon that we named Centauro. It is an arrival bundle of high energy hadrons, which can not be expected from the present knowledge from the accelerator experiments. It could be that, among cosmic ray particles arriving at earth from space, there are particles not known yet in the laboratory experiment. We will wait another occasion in future to talk on more details of the cosmic ray collaboration experiment.

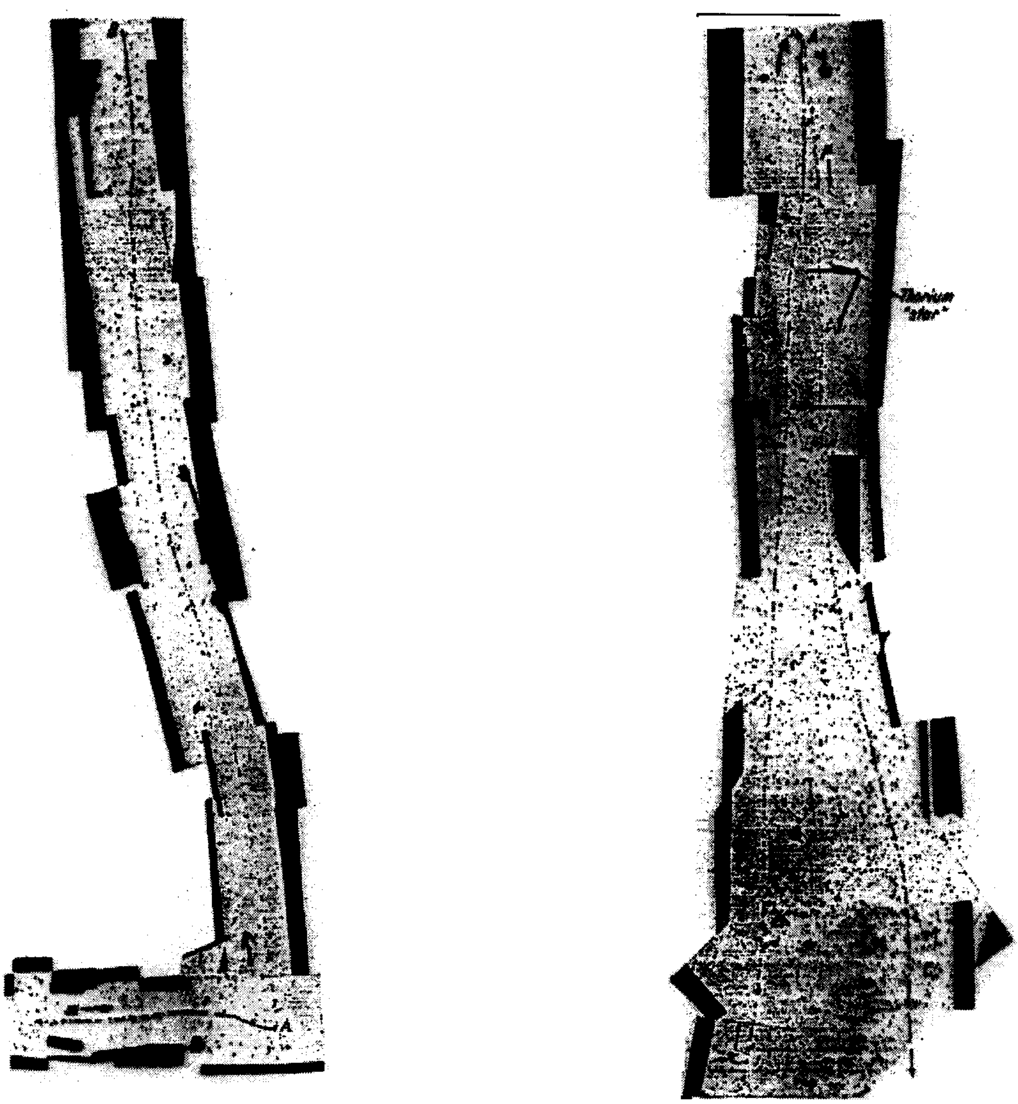

Figure 1: The first double-meson events found in nuclear emulsion plates. Lattes, Muirhead, Occhialini and Powel; Nature, 159 (1947), 694. It is a mosaic of the microscopic picture of particle track registered in nuclear emulsion layer of a photographic plate. Left is the first, and is the second event they found.

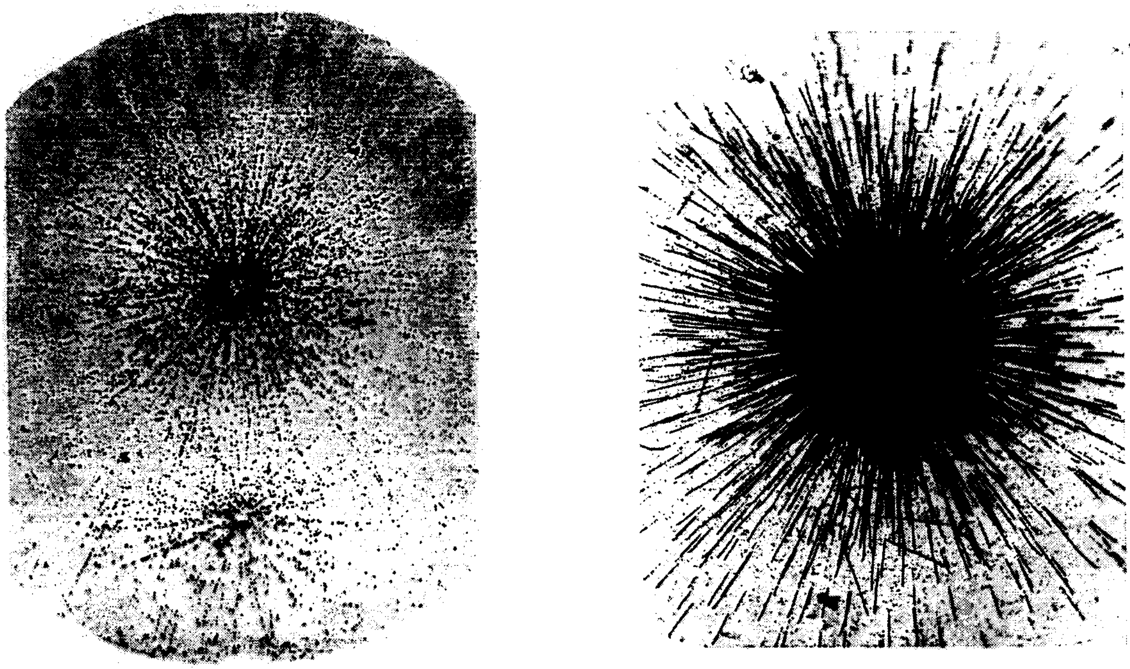

Figure 2:Microscopic picture of tracks of alpha-particles which come out from a radio-activity source placed at the center.
Left: Tracks in an ordinary photographic plate by Kinoshita and Ikeuti (1915).
Right: Tracks in a nuclear emulsion plate, Ilford B, by Occhialini and Powell(1947).

Figure 3: Microscopic picture of a meson event of another type. It is the first event, discovered by Perkins in 1947, which shows a negative meson coming to stop in the emulsion layer and making the nuclear desintegration with emission of three charged partcicles.

Figure 4: The pi-mu meson decay events in the improved nuclear emulsion plate, Ilford G5. The nuclear emulsion is sensitive to all charged particles including electrons. One can recognize that a pi-meson decays into a mu-meson and then decays into an electron.