more than the statement of the contents of equation. However, he gets success by manipulating solution even though he has not obtained this mathematically but experimentally and because he knows this is so, that is so, by joining these together he can get something else which is so. As a matter of fact, even according to mathematical physics, Kepler's law, for example, you can manipulate Kepler's law and the different law to get other conclusion without, even though it has not been able to trace them from the fundamental law, inverse squares. So perhaps in the last analysis the happy combination of ingenuity of the inventor and regular discipline of the pure scientist will in the end prevail most efficiently to the advancement with battle which we have with terrible complexity we find in this great subject.

Now I will shut talking my nonsense and will call upon the first speaker, Prof. Rossi who will address on the subject of this problem.

III-8-3. Lecture on Future Prospect

B. Rossi

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Mr. Chairman, ladies and gentlemen. If we look back to the history of cosmic-ray research, we see that, from the outset, the interest of cosmic-ray physicists has ranged all the way from the smallest objects known to man to the largest—from the atom and the sub-atomic particles at one extreme to the galaxies and the whole universe at the other.

Now, between the atom and universe lies the whole of our physical world. And yet, until recently, cosmic-ray physics had managed somehow to conserve its individual identity, distinct from all other branches of physics. There were problems that belonged unequivocally and exclusively to cosmic-ray physics. Foremost among them were the problems of discovering the nature of primary cosmic rays, and the problem of explaining the genetic relationship between the various components of the secondary radiation found in the atmosphere. Also there was a time when the whole field of meson physics was the exclusive domain of cosmic-ray physicists; and there was a time, a few years later, when the study of the strange particles belonged exclusively to cosmic-ray physicists.

Now, however, we are faced with an entirely different situation. Most of the problems to which the cosmic-ray physicists applied themselves in the past have been solved. Other problems, of course, have arisen and they are even more stimulating and more exciting than the old problems, but here cosmic-ray physicists can no longer work in the condition of relative isolation in which they used to work in the past. Now the cosmic-ray physicists must work hand in hand with geophysicists, with astrophysicists, with plasma physicists, with physicists specialized in high-energy accelerators, and so on. Indeed, many of us find it necessary to stretch the meaning of cosmic-ray physics in order that we may continue to call ourselves cosmic-ray physicists.

In the years to come, it seems that cosmic-ray physicists will find their most important problems in two fields: the field of high-energy interactions, and the field which, for lack of a better name, I would like to call the physics of space. By this I mean the study of the space between planets of our solar system; the space between stars of our Galaxy; the space between the galaxies of our universe.

Prof. Powell will discuss the implications of cosmic-ray studies in the field of high-energy interactions. I would like just to touch upon some of the problems which cosmic-ray physicists will meet in the field of space physics. The two fields—physics of space and high-energy interactions—have a certain area of overlap and the most important item found in this area is the study of air showers. Moreover, there are important areas of overlap between the physics of space and the physics of the objects found in space: planets, stars, galaxies, and so on. For example the magnetosphere may be properly regarded as a region of transition between the earth and space outside of earth. Similarly the stellar atmosphere may be regarded as a region of transition between the stars and surrounding space and so does the study of the envelope of supernovae. And the galaxies perhaps merge with intergalactic space through the halos.

During the course of this Conference, we have learned a great many exceedingly interesting results pertaining to the physics of space. As usualy these results have opened many more problems than they have settled, and I would like to touch upon some of these unsettled problems. Let me make clear once more, however, that most of these problems do not belong to the cosmic-ray physicists alone, but are shared by a much wider groups of scientists. Let me start with the interplanetary space, including the boundary regions of the solar atmosphere and the earth's magnetosphere. The general picture of the situation prevailing in this region, which has developed during the last decade, is well known to all of you. You know that ionized plasma flows out of the sun, perhaps continuously, certainly at times of enhanced solar activity. This plasma moves through interplanetary space carrying with it the magnetic lines of force. Upon arriving on the magnetosphere, it produces all sorts of geophysical effects.

We have learned during this Conference that plasma probes and magnetometers aboard space ships have now provided direct evidence for the existence of this plasma and have measured its approximate density, its approximate velocity and the intensity of magnetic field associated with it. Even though the results are of a preliminary character, they have revealed some unexpected features. For example, there is some evidence that the plasma may be divided into sharply separated regions of entirely different structure. It will be certainly a most exciting task for the next several years to follow up these preliminary observations with more precise and extensive measurements. The detailed picture of the magnetohydrodynamic conditions of interplanetary space that will emerge from these observations, will be of great value for understanding what goes on in the solar atmosphere, and what happens when the interplanetary plasma strikes the magnetosphere. It will also furnish the necessary experimental basis for the development of the theory of a plasma in which collisions are negligible and wall effects inexistent.

But other less direct methods for the study of the interplanetary plasma will continue to play an important role. As Prof. Biermann has pointed out, the comets are natural plasma probes. The observation at their tails, which gave the first indication for the existence of a "solar wind", may be expected to furnish further essential information on the plasma flow in the distant regions of space that our satellites or space may not be able to reach in next few years.

The interplanetary plasma is intimately related with the interplanetary magnetic field. This field affects both the cosmic radiation that enters the solar system from the outside, and the high-energy particles that are often emitted by the sun at the time of solar flares.

To many of us, it has been a source of great wonder to learn how much detailed information of the structure of the interplanetary magnetic field can be obtained by an intelligent analysis of the data on solar particles; data relating to the location on the solar disk of the flare where the particles originate, relating to the transit time of the particles to the earth, relating to their directions at arrival, relating to their storage time in our surrounding space, and so on. Similarly, it now appears that the modulation effects of the interplanetary field on extra-solar cosmic rays will soon be understood in some detail. There is no question that the continued observation of solar particles and the continued study of the modulation effects will give further results of vital importance in the years to come. Indeed, there are certain features of the interplanetary field which can be studied more effectively by means of these indirect methods of investigation than by direct measurements with space ships. For example, the question as to whether there are magnetic field lines connecting the sun to the earth can be answered more readily by studying the propagation of solar-flare particles than by making detailed measurements of the magnetic field in interplanetary space.

Coming closer to the earth, we find magnetosphere. The problems relating to the magnetosphere are so many and of such bewildering complexity that here I hardly dare to touch upon them.

Clearly, the study of the radiation belt will continue to hold a central position. Even though there is reason to believe that the high-energy protons observed in the inner belt arise from the decay of neutrons from the cosmic-ray albedo, the origin of the remaining particles, and particularly of those found in the outer belt is still an open question. During this Conference we have learned about various pieces of evidence pointing to a local acceleration of particles by hydromagnetic disturbances produced in the magnetosphere by the impact of the plasma flow from interplanetary space. I am sure that this question will be the subject of many experimental and theoretical investigations in the years to come.

Among the many other problems, let me mention just one, that of the ring current, whose initiation or whose changes are held responsible for the main phase of the magnetic storms. Two experimental methods of attack are possible here. One is based on measurements of the magnetic field carried out with satellites or space ships, at distances of several earth radii, where these currents are supposed to be located. Only preliminary results are available from experiments of this kind. During the Moscow Conference two years ago and again during this Conference we heard reports indicating the existence of certain anomalies in the earth's magnetic field; such as may be produced by a ring current centered at a few earth radii. It is quite clear that more accurate measurements and more frequent observations will be required to solve this problem. The other method is based on the direct observation of the charged particles whose motion is responsible for the current. To my knowledge no attempt has been done as yet along this line. The development of the suitable instrumentation and the execution of the appropriate measurements will be one of the important tasks of space exploration in the years to come. Let me now turn from interplanetary space to the space beyond: the space between the stars of our Galaxy and the space between the galaxies.

Galactic space, like interplanetary space, is supposed to contain moving ionized plasma and magnetic fields. Possibly intergalactic space, too, contains a plasma much more diluted than that found in the Galaxy. Most likely, magnetic field are also present in that region.

In all likelihood, cosmic ray particles arise from localized sources such as solar flares and supernovae. They then diffuse through the galactic space, being temporarily trapped within this space by the galactic magnetic field, until they eventually escape into intergalactic space. Occasionally, particles from intergalactic space may enter our own Galaxy. How much of the energy of cosmic-ray particles observed on the earth is given to the particles at the source, and how much is gained by the particles in their subsequent wandering through space, is still an open question. In any case, it is quite clear that the study of cosmic rays is potentially capable of providing information both on the conditions prevailing in the localized regions of space where cosmic-ray particles originate, as well as on the whole of the galactic and extragalactic space through which the particles have travelled on their way from the source to the earth.

Among the new results reported at this Conference, two of the most stimulating were the discovery of electrons and the probable discovery of photons in the primary cosmic-ray flux. There is no doubt that these preliminary observations represent just the beginning of an active field of research destined to yield important results in the years to come.

Concerning first the electrons, I hardly need to remind you that the presence of high-energy electrons in outer space had been inferred from the radio emission of Galaxy, which is ascribed to synchrotron radiation of electrons spiraling along field lines. The discovery of electrons in the primary radiation now confirmed this view. It is quite clear that a better knowledge about their intensity and their energy spectrum will make it possible to interpret the radioastronomical data more precisely and to use these data for a detailed study of the galactic magnetic field. There is still a question about the origin of the electrons. It is possible that they arise from high-energy nuclear collisions, giving rise to charged π-mesons which then undergo $\pi \rightarrow \mu \rightarrow e$ decay. It is also possible that electrons might be accelerated by the same hydromagnetic disturbances which are responsible for the acceleration of protons and heavy nuclei in the primary cosmic radiation. It will be an important task of cosmic-ray physicists to distinguish between these two hypotheses. A possible method of achieving this goal has been discussed during our Conference. It is based upon the fact that if the electrons arise from high-energy nuclear interactions, they should be about half positive and half negative. If on the other hand the electrons arise from a direct acceleration process, then they will be practically all negative.

Turning next to the photons, their peculiar interest arises mainly from the fact, unlike charged particles, photons travel along lines straight. Thus the flux observed in a given direction is proportional to the integrated source strength along the line of sight. The photons that were discussed at this Conference have energies greater than about 100 Mev. Practically, these arise only from the decay of π°-mesons ($\pi^{\circ} \rightarrow 2\gamma$); and π°-mesons arise only from high-energy interactions or from annihilation processes of matter and antimatter. Thus the γ-ray flux incident upon the atmosphere carries information concerning high-energy interactions and annihilation processes in outer space. Several possible point sources of γ-ray have been discussed, both galactic (e.g. the Crab nebula) and extragalactic. Moreover, in addition to the point sources, there should be a background of γ-rays, due to nuclear collisions of cosmic-ray particles with interstellar matter in our Galaxy. This should be concentrated along the galactic plane, perhaps with a maximum in the direction of the center.

The main difficulty of γ-ray observations lies in the very large γ-ray background produced by the cosmic-ray particles in the atmosphere. There are two possible methods to solve this difficulty. The first method is based on the use of satellites. The second method is based on the observation of air showers. I shall come back to air-shower experiments later. Here I would like to say a few words about the results obtained by satellite observations. Preliminary results of such observations, which have been reported at this meeting, seem to indicate the presence of a γ-ray flux consistent with that predicted from the nuclear collisions of cosmic-ray particles with interstellar matter. On the other hand, the flux is certainly much smaller than that predicted by the steady-state cosmology, under the assumption of a continuous creation of matter and antimatter. We all look forward with great interest to the much more precise informations that will come from the continuation and extension of these preliminary experiments.

The mass spectrum of the primary radiation is another subject that was discussed extensively at this Conference. We learned that the techniques have been developed to such a high degree of perfection that one can now begin to investigate in detail the isotopic composition of cosmic-rays. This investigation is of great importance because the isotopic composition reflects the conditions prevailing at the place where cosmic-rays are created as well as the conditions prevailing in the regions of space through which cosmic-rays travel. Thus the results will provide data of vital importance on the origin of cosmic rays as well as on the amount of time they spend in various regions at space.

Let me come finally to the subject of extensive air showers, which, as I mentioned before, holds a central position in cosmic ray physics because it belongs both to the physics of space and to the physics of high-energy interactions. Here I shall confine my remarks to the first aspect. The importance of the study of extensive air shower arises from the fact that the observation of extensive air showers is the only method that enables us to detect and study cosmic-ray particles of the highest energies (above 10^{15} ev). We have heard a great deal about extensive air showers during this Conference. Here again the experimental methods have reached a high degree of sophistication and refinement, and it is now possible to draw from the experimental results much more definite and precise conclusions than could be done a few years ago. I shall just mention two points that are of interest with regard to the problem of the physics of space. The first point concerns the highest observed energy of cosmic-ray particles. We have learned during this Conference, that the largest extensive air showers that have been detected required primary particles with energies beyond 10^{19} ev and perhaps approaching 10^{20} ev. A particle cannot possibly be accelerated to this enormous energy in the envelope of a supernova. Also it seems that our whole Galaxy, including the halo, is not large enough for this purpose. Thus it begins to appear likely that part of the observed cosmic radiation is of metagalactic origin. This conclusion is still of a preliminary nature and points to the need of further experiments designed to extend the study of the energy spectrum to still higher energy.

The second point concerns the nature of the particles responsible for extensive air showers. At our Conference, different groups discussed various methods which may be capable of distinguishing between extensive air showers produced by protons, by heavy nuclei and by photons. Some of these methods have already been tried out in a preliminary way, with encouraging results. This is a problem on which undoubtedly a great deal of work will be done in future years. The results to be achieved by its solution are of very great interest. I already pointed out the importance of γ-ray astronomy and mentioned the possibility that one may approach the study of extraterrestrial γ-ray by investigating the air showers produced by them. The separation of protons and heavier nuclei among the high-energy particles responsible for extensive air showers is also a problem with important implications concerning the mechanism of production and the place of origin of cosmic rays. For example, for a given total energy, highly charged nuclei can be contained in the Galaxy much more easily than protons. Thus it is very important to know whether the largest observed showers are induced by protons or by heavier nuclei.

Finally, I would like to mention briefly some most stimulating, although very preliminary, results obtained by various groups represented at this Conference, which seem to indicate an anisotropy in the directions of arrival of certain selected groups of air shower primaries. This is another question which undoubtedly will be studied very intensively in the near future. I am afraid I have already talked too much, and I would like to stop. However, I cannot pass over the opportunity I have to join my voice to that of Prof. Swann in expressing the gratitude that all of us feel toward our Japanese colleagues for their warm hospitality and their extreme kindness; and also in expressing our admiration for the absolutely outstanding scientific contribution that Japanese scientists are making to the progress of cosmic-ray physics.

This is fifth international conference on cosmic rays that I have attended. Again it has been a most stimulating and most rewarding experience. We all go back with new knowledge and new ideas for future work. We all go back with the heart-warming feeling of having renewed and strengthened our ties at friendship with our colleagues from all nations of the world.