A Study of the Production and Absorption of Mesotrons in the Substratosphere

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(Received October 28, 1940)

In a coincidence-counter experiment carried out in an airplane at altitudes up to 9.3 km (22.9 cm Hg) an attempt was made to observe the production of mesotrons in an 8-cm lead block by some non-ionizing radiation other than photons. From our results it would seem that the number of mesotrons so created is not greater than about five percent of the total number of mesotrons at this altitude. The experiment was also designed to give the absorption of mesotrons in lead of 19-cm and 27-cm thickness as a function of the altitude. From these data and from those obtained previously for 10 cm of lead we have constructed an energy spectrum of the mesotrons at an altitude of 6.7 km. At this altitude about 33 percent of all the mesotrons have energies below 5.2×10^{8} ev while at sea level a very small fraction of the mesotrons have energies in this range. This is in accord with the finding of many slow mesotrons in the cloud-chamber experiments of Herzog and Bostick at these altitudes.

PREVIOUS experiments[1] indicate that mesotrons can be produced in high altitudes by a non-ionizing radiation. To identify, if possible, this non-ionizing radiation we have carried out some experiments in an airplane in which, for the producing layer, a larger thickness of lead was used than previously. Furthermore, a lead block of 6-cm thickness was placed above the whole counter apparatus to eliminate photons as possible agents producing mesotrons.

The arrangement of the apparatus is shown in Fig. 1. The Geiger-Mueller counters 1 and 5 were 5.1 cm in diameter and had an effective length of 40 cm. The counters 2, 3 and 4 were 2.5 cm in diameter and had an effective length of 20 cm. The counter tubes were filled with a mixture of argon and petroleum ether, and were of the self-quenching type. The efficiency of each individual tube was very close to 1.

Counters 1, 2, 3 and 4 constituted one fourfold coincidence set and counters 2, 3, 4 and 5 constituted another. The solid angle of the top fourfold counter set was just covered by the bottom counter and likewise the solid angle of the bottom fourfold set was just covered by the top counter. The whole solid angle was filled with lead.

Each of the two coincidence circuits had a resolving power of 3×10^{-5} second which was directly determined with a cathode-ray oscilloscope.

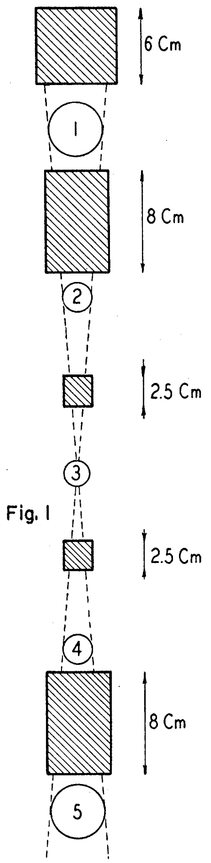
In the first flight a circuit was used similar to that described by Schein, Jesse and Wollan[1] except that the resistances in the grid and the plate circuit of the first stage of amplification were reduced to 10^{5} ohms. In the second flight a modified multivibrator circuit was used.[2] The coincidence counts of the two fourfold sets were separately recorded on a rotating film in the same way as by Schein, Jesse and Wollan.[1]

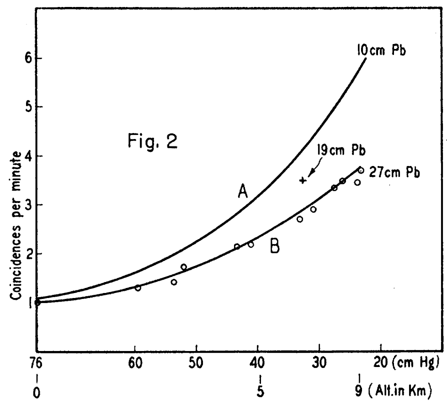
On account of the high resolving power of the coincidence circuits (3×10^{-5} second) the number of fourfold accidentals was negligible even at 9.3 km (highest altitude reached). Because of the rapid increase of the soft component of cosmic rays with altitude, the single counting rate of the individual Geiger-Mueller tube becomes very great. This will result in a decreased efficiency in recording coincidences unless the time constant of the tubes is sufficiently short. The time constant of each counter tube was determined with the cathode-ray oscilloscope and found to be 2×10^{-5} sec. which is sufficiently short that no change in efficiency greater than one percent could be expected.

The apparatus was arranged to record: (a) the number of penetrating ionizing particles which pass through all five counters; (b) those which pass through the top fourfold set and do not pass through counter 5 because they are either stopped or are scattered out in the bottom 8 cm of lead; (c) those cases in which an ionizing particle passes through the lower four counters 2, 3, 4

[1] M. Schein and V. C. Wilson, Rev. Mod. Phys. **11**, 292 (1939); M. Schein, W. P. Jesse and E. O. Wollan, Phys. Rev. **57**, 874 (1940).

[2] A description of this circuit will be published in a paper of G. Groetzinger in the Rev. Sci. Inst.





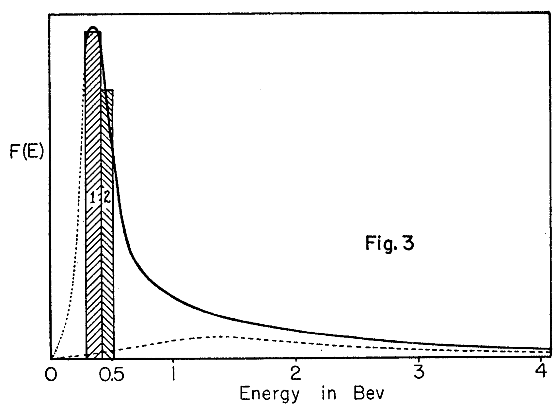


FIG. 1. Arrangement of counters.
FIG. 2. Mesotron intensity as a function of altitude for two different lead thicknesses.
FIG. 3. Energy spectrum of mesotrons. Solid curve at about 6.7 km altitude, dashed curve at sea level.

and 5 without being accompanied by an ionizing particle through the upper counter.

Except for the effect of scattering of mesotrons by the upper 8-cm lead block into the bottom set without hitting the top counter, (c) gives a measure of the production of mesotrons in the upper 8-cm lead block by a non-ionizing radiation.

The 6-cm lead block was placed above the upper counter tube to eliminate photons as possible agents in producing excess mesotrons in the upper 8-cm lead block. The probability is small that a photon after passing through 6 cm of lead would emerge without being accompanied by an electron which would set off the top counter and hence have the same effect as an ionizing particle. Therefore any non-ionizing radiation which does not cause a discharge of counter 1 (not accompanied by electrons) and produces mesotrons in the upper 8-cm lead block must be of a more penetrating type such as neutrons, neutrettos, or neutrinos.

Two flights were made. The first on December 17, 1939, the second on April 30, 1940. In the first flight the minimum pressure reached was 25.7 cm of mercury (8.2 km); in the second, 22.9 cm of mercury (9.3 km). The pressure was recorded with the same type of barometer as used by Jesse[3] in the balloon experiments.

THE PRODUCTION OF MESOTRONS

To determine whether or not there was a measurable production of mesotrons in the upper 8-cm lead block we compared the number of fourfold coincidences in the top and bottom counter set. Using the data from the second flight on December 17, in the altitude range between 5.2 km and 7.4 km[4] we obtained the following

[3] W. P. Jesse, Phys. Rev. **58**, 281 (1940).

[4] Because of the failure of the top counter tube we have data for both fourfold sets only up to 7.4 km and above the altitude we have complete data only for the lower fourfold set.

results. The number of fourfold coincidences in the *upper* counter set not accompanied by a simultaneous coincidence in the lower set was found to be *22±3* percent of the cases in which a simultaneous coincidence occurred in both sets (fivefold coincidence). The number of fourfold coincidences in the *lower* set not accompanied by a fivefold was found to be *9.7±3 percent.* This excess of *12 percent* in the upper set must then have been due to the stopping of mesotrons which had insufficient energy to traverse the lower 8-cm lead block.

At sea level we found that *8.1±2 percent* of the number of fourfold coincidences in the bottom set were unaccompanied by fivefold coincidences and within experimental error the same value was found for the top fourfold coincidence set. This shows that the excess in the bottom set is within statistical accuracy the same at sea level as at altitudes between 5.2 and 7.4 km.

The 8-cm lead block between counter 1 and 2, which constituted our producing layer, is four times as large as that used in the experiments of Schein, Jesse and Wollan,[1] in which mesotrons produced by a non-ionizing radiation (of any type) constituted about 15 percent of the vertical mesotron intensity at 7.5 km altitude. Since in the present experiment no effect of this type larger than about five percent was observed, the evidence is in favor of photons as the main agent responsible for the observed production of mesotrons.

Even if neutrons are capable of producing mesotrons, their energy would have to be greater than 2.9×10^8 ev (the minimum energy which would enable a mesotron to penetrate the 13 cm of lead in our lower fourfold counter set). According to Bethe, Korff and Placzek,[5] the large number of neutrons observed at high altitudes by Korff[6] can be accounted for if they are produced with an initial energy of about 30×10^6 ev, which would rule them out as a mesotron-producing agent.

An independent test for the presence of neutrons of high energy was made in the flight on April 30, by placing a block of paraffin of 35-cm thickness above the apparatus. If neutrons of high energy were present in any abundance one would expect that protons would be ejected with sufficient energy to penetrate our counter train and thus give rise to an increase in the counting rate of the coincidence sets. If the cross section for the scattering of neutrons by protons (3×10^{-23} cm^2)[7] which is known up to about 5×10^6 ev energy is taken to be approximately valid for high energy neutrons it can be shown that in this thickness of paraffin the probability of ejecting a proton by a neutron is practically unity. Since we observed with the paraffin no change in the coincidence counting rate within the experimental error of *4 percent* we can conclude that high energy neutrons are not present in altitudes up to 9.3 km to the extent of more than about *4 percent* of our observed mesotron intensity.

Intensity of mesotrons

In Fig. 2 are shown curves for the variation of the intensity of mesotrons as a function of the pressure down to 23.0 cm Hg. Curve B represents the data from the two airplane flights for the lower fourfold coincidence set. One can see from Fig. 1 that there were 13 cm of lead between the counters and 14 cm above the counters which gives a total lead thickness of 27 cm. For comparison of the intensity for different thicknesses of lead we have made use of the recent unpublished balloon measurements of Schein, Jesse and Wollan for 10 cm of lead between the counter tubes. These data are plotted as curve A.

Because curves A and B are obtained with two different sets of apparatus it was necessary to make a comparison of the counting rate of both sets at sea level. Nielsen and Morgan and others[8] have made absorption measurements of mesotrons in different thicknesses of lead at sea level. Since in these experiments the lead was placed between the counters, it may be objected that a small part of the effect is due to scattering of mesotrons. However, this would constitute a second-order effect so far as we are here concerned. Making a small correction for scattering we have taken 5 percent as a difference of the

[5] H. A. Bethe, S. A. Korff and G. Placzek, Phys. Rev. **57**, 573 (1940).
[6] S. A. Korff, Rev. Mod. Phys. **11**, 211 (1939).
[7] H. A. Bethe, Rev. Mod. Phys. **9**, 69 (1937).
[8] W. M. Nielsen and K. Z. Morgan, Phys. Rev. **54**, 245 (1938); P. Auger, L. Leprince-Ringuet and P. Ehrenfest, Jr., J. de phys. et rad. **7**, 58 (1936); B. Rossi, *La Radiation Cosmique* (Hermann, Paris, 1930).

number of mesotrons passing through 10 cm and those passing through 27 cm of lead at sea level.

The large difference in the ordinates of curves A and B in higher altitudes as shown in Fig. 2 can be affected only slightly by scattering of the mesotrons since 14 cm out of the 17 cm of lead (which represents the difference in the thicknesses for the two cases) was placed above the counters. Hence this difference must be ascribed to mesotrons which are stopped in the additional 17 cm of lead.

If we take this loss as entirely due to ionization, which must be very nearly the case for mesotrons, we can get some idea of the energy distribution of the mesotrons at these altitudes. Taking the ionization loss as 1.4×10^7 ev per cm of lead[9] and adding twice the rest mass of the mesotron (7.5×10^7) in units of ev we obtain 2.9×10^8 ev as the energy which a mesotron must have to traverse 10 cm of lead and 5.2×10^8 ev to traverse 27 cm of lead. The difference between the ordinates of the two curves represent those mesotrons which have energies between these two values. We see that for the maximum altitude reached (9.3 km) about $\frac{1}{3}$ of the measured number of mesotrons have energies in this interval.

When the data for the counting rate in the upper fourfold coincidence set are considered in comparison with that for the lower fourfold set we obtain a measure of the number of those mesotrons which can traverse the upper 19 cm of lead but are not able to traverse the total of 27 cm and thus be recorded in the lower set. This represents the number of those mesotrons which have energies lying between 4.2×10^8 ev and 5.2×10^8 ev. We have not represented these data in the form of a curve since the total number of counts which we obtained with the upper set was considerably less than that with the lower set. Taking all the data between 5.2 and 7.4 km we obtain a point for the number of mesotrons stopped in the lower 8 cm of lead at an average altitude of about 6.7 km which is represented by a cross in Fig. 2.

The high energy part of the mesotron spectrum, i.e., mesotrons of energies greater than about 5×10^9 ev will be practically the same at 6.7 km altitude as at sea level, since the change in energy by ionization and decay for these energies is very small between these altitudes. At sea level the number of mesotrons above 5×10^9 ev represents about 10 percent of the total mesotron intensity.[10] Since at 6.7 km the total mesotron intensity is increased by a factor of 4 over the sea level value, the mesotrons with energies above 5×10^9 ev at this altitude now represent only 2.5 percent of those present.

In Fig. 3 we have represented by the two blocks the number of mesotrons $F(E)dE$ in the above-mentioned energy intervals. The area under block 1 represents 18 percent and that under block 2 represents 12 percent of the total number of mesotrons with energies greater than 2.9×10^8 ev (energy required to traverse 10 cm of lead). Making use of the fact that 2.5 percent of the mesotrons have energies above 5×10^9 ev we have represented the energy spectrum as a solid line, the area under which is 97.5 percent in the energy interval of 2.9×10^8 ev to 5×10^9 ev. The low energy part of the spectrum, i.e., below 2.9×10^8 ev has been indicated by the dotted line as containing an area of about 10 percent of the total. This estimate has been taken from the cloud-chamber data of Herzog.[11]

For comparison with the mesotron spectrum at sea level we have included as the dashed curve the data of previous investigations.[12] This dashed curve has been drawn to have an area of 25 percent of that of the solid curve corresponding to the ratio of 4 : 1 in the mesotron intensities at 6.7 km altitude (curve A, Fig. 2) and sea level. Without any claim for accuracy concerning the shape of the energy spectrum of the mesotrons at 6.7 km altitude it is nevertheless obvious that the maximum of the spectrum is shifted to a much lower energy than that at sea level and also that many of these slow mesotrons are absorbed before reaching sea level. From Fig. 6 of the paper of Schein, Jesse and Wollan[1] we see that the absorption coefficient of mesotrons remains almost constant above an altitude of 6 km. Hence, it is to be expected that the mesotron spectrum in the low energy range between

[9] J.G. Wilson, Proc. Roy. Soc. **A172**, 517 (1939).

[10] D. J. Hughes, Phys. Rev. **57**, 592 (1940).

[11] G. Herzog, Phys. Rev. **57**, 337 (1940).

[12] P. M. S. Blackett, Proc. Roy. Soc. **A159, 1** (1936); H. Jones, Rev. Mod. Phys. **11**, 235 (1939).

2.9×10^8 ev and 2×10^9 ev is not much different from that shown in Fig. 3 even at much higher altitudes.

To investigate the influence of lateral showers on the results obtained in the present experiments, in the flight on December 17, 1939 the middle counter tube No. 3 was moved out of the line of the remaining counters. Registering for half an hour the lateral showers, the counting rate at an altitude above 5.2 km was found to be 3 percent of that with all the counters in line. This indicates that in our arrangement the lateral showers do not give any appreciable contribution to the observed fourfold coincidences and, therefore, our results are not influenced by them.

The authors wish to express their appreciation to Professor A. H. Compton for his interest in and his support of this investigation.

DECEMBER 15, 1940 PHYSICAL REVIEW VOLUME 58

Neutron Studies of Order in Fe-Ni Alloys*

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(Received October 24, 1940)

Neutron transmission measurements are used to study order in Fe–Ni alloys. The difference in neutron transmission between fully annealed and quenched alloys when plotted against the nickel content displays a broad peak around Ni_3Fe and falls to vanishingly small values near 35 atomic percent Ni and pure Ni. The higher the degree of order the greater the neutron transmission. The substitution of 2.3 atomic percent Mo or 4.1 atomic percent Cr for Fe in the annealed 78 atomic percent Fe–Ni alloy caused a decrease in the neutron transmission, relative to the annealed 78 atomic percent Fe–Ni alloy, of 15.6 and 21.2 percent, respectively. The cold working of an annealed binary 75 atomic percent Ni alloy, a treatment known to produce disorder, gave rise to a decrease of 20.6 percent in neutron transmission. These results demonstrate that neutron techniques serve as a useful tool to study order in Fe–Ni alloys, and suggest that they can be extended to study other solid state phenomena.

The previous work of Whitaker and Beyer[1,2] has shown that slow neutron interaction may be modified by the physical state of the material which the neutrons traverse. The dependence of neutron interaction on physical parameters of the system affords a possibility of investigating solid state phenomena. If only one parameter in a system be varied, changes in the neutron interaction may be correlated with the parameter in question. In the research reported here this approach was employed to investigate order in Fe–Ni alloys.

The measurements were made with neutrons diffusing from paraffin at room temperature. These neutrons have an energy distribution which corresponds to a de Broglie wave-length spectrum with the most probable wave-length in the region of 1.7 angstroms. The spacings of atoms in a crystal are of about this magnitude, so that interference phenomena should occur when these neutrons interact with matter in the solid state.

Although x-rays are very suitable for studying many aspects of the solid state there exist many problems where x-ray studies yield inconclusive results. This is the situation in the case of super-structures in alloys with the relative intensity of the super-structure lines depending on the difference in scattering powers of the constituent atoms.

In general, x-ray scattering is proportional to the number of electrons in the atoms (unless near

* Publication assisted by the Ernest Kempton Adams Fund for Physical Research of Columbia University.

[1] M. D. Whitaker and H. G. Beyer, Phys. Rev. **55**, 1101 (1939).

[2] H. G. Beyer and M. D. Whitaker, Phys. Rev. **57**, 976 (1940).