absorbed in air, between 3500 and 29,000 m, with a mean free path of $\sim$137 g$\cdot$cm^{-2}. We have found that the frequency of the stars with 4 or more prongs is 1450 cm$^{-3}\cdot d^{-1}$, in agreement with the figure $\sim$2000 cm$^{-3}\cdot d^{-1}$ obtained by Salant *et al.*[2] for the same kind of stars at 30,500 m.

The total number of stars we observed and their frequency per cubic centimeter, *versus* star size are given in columns 2 and 3 of Table I. In column 4 the star frequencies observed by Bernardini *et al.*[1] are given for comparison. The figures in column 5 are the absorption mean free paths λ in air, between 3500 and 29,000 m elevation, of the star primaries, deduced from the data in columns 3 and 4. Column 6 gives the ratios between the percent star frequencies at 29,000 and at 3500 m. Such percent frequencies have been calculated using the total number of stars with 3 or more prongs. Our data for percent star frequencies *versus* star size, as well as Bernardini's, are also plotted in Fig. 1.

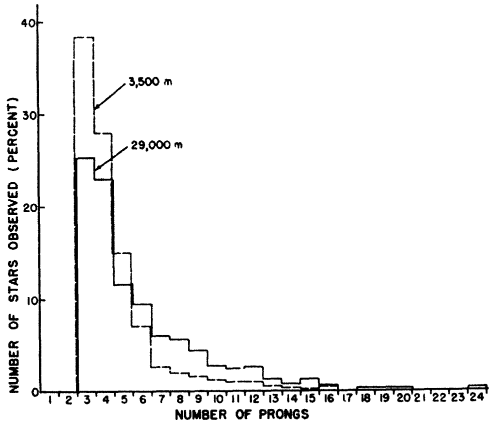

FIG. 1. Number of stars observed at 29,000 m *versus* star size.

Both the results in column 5 of Table I and the data given in Fig. 1 clearly show a decrease of λ when the star size increases; hence, an absorbability in air for the radiation capable of generating the largest stars greater than for the radiation that produces stars of small size.

This confirms the conclusions reached by Salant *et al.*,[2] comparing their data (at 30,500 m) with Wambacher's[3] (at 2300 m). We wish to point out, however, that both our and Salant's conclusions require the assumption that the data taken at the ground (Bernardini and Wambacher) are not influenced by the effect of the ground itself,[4] hence comparable with the data taken in the free atmosphere.

From Fig. 1, one can see that the percent frequencies of stars with less than 5 prongs are larger at 3500 m than at 29,000 m, while the percent frequencies of the stars with 5 or more prongs show the opposite behavior. Gardner and Peterson[5] have found that the percent frequency of the stars with 3 prongs, generated in the Berkeley cyclotron by deuterons with energies between 35 and 190 Mev, decreases when the energy increases; the percent frequencies of the stars with 4 or more prongs, instead, increases with increasing energy.

This leads us to think that the different size distribution of the stars observed at different altitudes can be explained by assuming that the star primaries have the same nature at both elevations, but greater energies at higher altitudes.

From the results in column 5 of Table I one might also deduce that the cross section for star production increases when the energy of the star primaries increases.

---

[1] Bernardini, Cortini, and Manfredini, Phys. Rev. **74**, 845 (1948).
[2] Salant, Hornbostel, and Dollmann, Phys. Rev. **74**, 694 (1948).
[3] H. Wambacher, Wien. Ber. **149**, 157 (1940).
[4] J. J. Lord and M. Schein, Phys. Rev. **75**, 1956 (1949).
[5] E. Gardner and V. Peterson, Phys. Rev. **75**, 364 (1949).

Meson Background in Penetrating Shower Experiments

GIUSEPPE COCCONI
Laboratory of Nuclear Studies, Cornell University, Ithaca, New York

August 15, 1949

DURING the past year experiments have been performed both at Ithaca (260 m) and at Echo Lake (3260 m) to study the interaction mean free path of the ionizing particles that generate penetrating showers.[1] The interpretation of the results of these experiments with the assumption that all the penetrating showers observed are due to the nucleonic component created rather serious difficulties.

In order to clarify the problem, during the past winter further experiments have been performed at Ithaca inside a tunnel, under a thickness of rocks equivalent to 2000 g$\cdot$cm^{-2} water (2 atmospheres).* The purpose of these experiments was to determine whether ionizing particles different from nucleons give an appreciable contribution to the showers recorded with our apparatus. At 2000 g$\cdot$cm^{-2} underground the nucleonic component should be reduced by a factor larger than 10^4, hence any "penetrating showers" observed at such a depth have to be related to the mesonic component, which there is reduced only by a factor 4.

The showers were firstly observed with the same apparatus used in the research of the past year (see Fig. 1). Coincidences $A+B+C+D$ revealed the showers in which at least two particles are present capable of penetrating more than two inches of lead. When only one of the 20 counters E was discharged (event $A+B+C+D+1E$), it was assumed that the showers originated in the lead P.

The rate of coincidences $A+B+C+D+1E$, as it resulted from 1638 hours of observation, was $0.114h^{-1}$, practically independent of the thickness of lead (0 and 8 in.) put in Σ.**

The facts that the rate observed under 2000 g$\cdot$cm^{-2} water equivalent is about $\frac{1}{9}$ of the rate observed in the same conditions outside the tunnel, and that the presence or absence of the lead in Σ does not affect it, lead us to think that the primaries of the showers we observed inside the tunnel are mostly mesons.

A further experiment has been performed in the same tunnel with the arrangement drawn in Fig. 2. The showers were again detected by coincidences $A+B+C+D$; counters E gave, here, information about the number of particles generated in the lead P, capable of penetrating the absorber Σ.

Coincidences $A+B+C+D+1E$, $A+B+C+D+2E$, $A+B+C+D+\geq 3E$ were recorded. Measurements have been taken with the absorber Σ equal to: (a) 2 in. Pb, (b) 2 in. Fe, (c) 5 in. Pb, (d) 6 in. Fe. Absorber (a) is practically equivalent to (b), and absorber (c) to (d), for particles losing their energy through ionization,

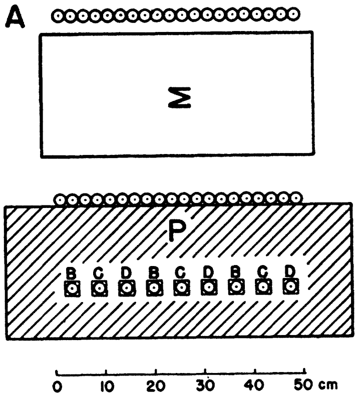

FIG. 1. Arrangement of the counters and of the absorbers in the experiments at Ithaca, at Echo Lake, and in the first set of measurements underground.

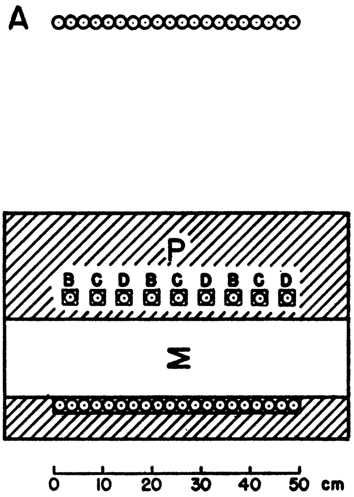

FIG. 2. Arrangement of the counters and of the absorbers in the second set of measurements underground.

while (a) and (c) are more effective than (b) and (d) in stopping electrons and photons.

In 2340 hours of observation the following results have been obtained:

$\Sigma=$	2 in. Pb	2 in. Fe	5 in. Pb	6 in. Fe
$A+B+C+D+\ 1E(h^{-1})$	0.086±.01	0.05 ±.01	0.10 ±.01	0.058±.008
$A+B+C+D+\geq 3E(h^{-1})$	0.041±.01	0.074±.015	0.011±.004	0.021±.005

Coincidences $A+B+C+D+1E$ are mostly due to mesons which have created in P a shower fully absorbed in Σ. The fact that these coincidences are more frequent when the absorber is lead shows that the particles created in the showers are more strongly absorbed in lead than in iron. The situation is reversed for coincidences $A+B+C+D+\geq 3E$, that represent instead the events in which at least two of the particles created in the showers are capable of crossing the absorber Σ.

Hence, both results agree in indicating that the particles created in the showers we observed underground are mostly electrons and photons, generated by mesons through knock-on and/or radiation processes. The same conclusion has been reached by Mr. D. Hudson, who in the same tunnel studied bursts produced in ion chambers.

On the basis of the information acquired in these experiments, some of the conclusions given in reference 1 must be modified. In fact, it is clear now that we overestimated in the previous paper the arguments which led us to disregard the contribution of showers created by mesons. Those arguments could only show that most, not all, of the showers recorded were due to nucleons. Actually a not negligible fraction of the showers we observed both at Ithaca and at Echo Lake were due, not to the nucleonic component, but to mesons.

The experiments underground allow us to make an estimate of this meson background. Though the total meson component is reduced in the tunnel by a factor 4, the energetic mesons that produce the showers we observed are likely reduced by a smaller factor, say between 2 and 3. This leads us to assume that the meson background in the showers detected at Ithaca is close to 0.3 h^{-1}, 30 percent of the total rate recorded with $\Sigma=0$. At Echo Lake only 3 to 5 percent of the rate registered in the same conditions can be accounted for by such a background. By subtracting the meson background, the absorption curves obtained both at Ithaca and at Echo Lake approach pure exponential shape, and indicate interaction mean free paths for the ionizing nucleonic component that produces penetrating showers practically equal to the ones deduced from the initial slopes of the uncorrected curves obtained at Echo Lake, i.e., 160 $g\cdot cm^{-2}$ in Pb, and 100 $g\cdot cm^{-2}$ in C. This correction eliminates the disturbing variation of the mean free paths with the thickness of the absorbers, which was so hard to understand. The absorption mean free path in air of the nucleonic component, after correction for meson background, is found to be $\sim$120 $g\cdot cm^{-2}$.

We wish finally to emphasize the importance of the evaluation of an eventual contribution due to mesons in all experiments on penetrating showers. Probably some of the discrepancies among the results of various authors are due to such a spurious effect.

---

[1] G. Cocconi, Phys. Rev. 75, 1074 (1949).

* We are grateful to the Gun Company, Ithaca, New York, for allowing the use of the tunnel and furnishing the power.

** The rate of the coincidences in which two or more of the counters E were discharged (events $A+B+C+D+\geq 2E$) was 30 percent of the rate $A+B+C+D+1E$.

Addendum: Heat Flow in Metals Below 1°K and a New Method for Magnetic Cooling

J. G. DAUNT AND C. V. HEER
Mendenhall Laboratory, Ohio State University, Columbus, Ohio
August 11, 1949

USING the results of experiments on the new method of magnetic cooling briefly described in a previous letter,[1] it is it is possible to calculate the effectiveness of the following heat pump for transferring heat from a low temperature bath B (see Fig. 1) maintained at temperatures below 1°K to a higher temperature bath A, say at 1°K. A and B are connected to a paramagnetic salt D via two superconducting wires, S_1 and S_2, having a high transition temperature (e.g., Ta, Pb, Cb). S_1 and S_2 are removed some distance from D but kept in good thermal contact with D through copper posts, C. During the magnetization of D by the field $N-S$, S_1 is converted to the normal state by a magnetic field, H_1 (see Fig. 1), and the heat of magnetization is conducted through S_1 to A. Meanwhile S_2 is superconductive and therefore presents a thermal barrier to the flow of heat to B. The field H_1 next to reduced to zero; D is demagnetized and a magnetic field H_2 is placed around S_2 sufficient to convert it into the normal state; thereby placing D and B in effective thermal contact. S_1, having previously become superconductive on the removal of the field around it maintains D and B well isolated from A. This process of operation can be repeated cyclically by alternately switching on and off the three magnetic fields in the correct order.

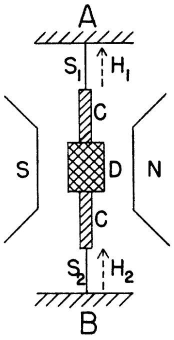

FIG. 1. Diagram of suggested heat pump.

In this manner it is estimated that, using 10 cc of salt, heat could be removed from B at 0.1°K at a rate of 10^5 ergs/cycle or more, using readily accessible magnetic fields and equipment, and that the repetition rate could be 1 cycle/min. or higher. By using therefore one or more such heat pumps, either in parallel or in series or both (as can be arranged to operate without increasing the number of magnetic fields required), a continuous cyclic