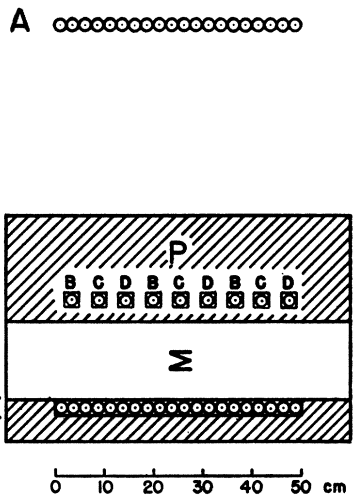

FIG. 2. Arrangement of the counters and of the absorbers in the second set of measurements underground.

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
$A+B+C+D+\ 1E(h^{-1})$	$0.086\pm.01$	$0.05\ \pm.01$	$0.10\ \pm.01$	$0.058\pm.008$
$A+B+C+D+\geq 3E(h^{-1})$	$0.041\pm.01$	$0.074\pm.015$	$0.011\pm.004$	$0.021\pm.005$

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

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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.

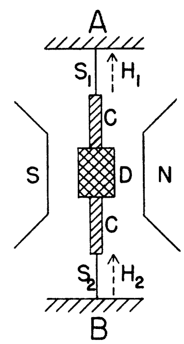

FIG. 1. Diagram of suggested heat pump.

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 method of maintaining constant temperature baths well below 1°K is available which may prove of value for low temperature research. Moreover such an arrangement used as a two or three stage magnetic cooling system should enable the lowest temperatures to be attained without the use of intense magnetic fields.

We wish to thank The Research Corporation for their support and the Office of Naval Research for their assistance in later stages of the work by a contract with the Ohio State University Research Foundation. We also wish to thank Dr. K. W. Taconis and Professor J. de Boer for valuable discussions.

[1] J. G. Daunt and C. V. Heer, Phys. Rev. 76, 854 (1949).

The Neutrinos from the Sun and the Source of the Earth's Heat

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August 16, 1949

SINCE Bethe's classic paper on the carbon-nitrogen cycle as the source of stellar energy,[1] it has been conjectured that the sun may produce a considerable neutrino flux even at distances as far as the earth. Bethe estimated that the neutrinos in the N^{13} and O^{15} disintegrations carry off as much as 7 percent of the total energy production. Whether these neutrinos get outside the sun depends on their interaction cross section.

From the average result of neutrino interaction or closely related experiments,[2] the limit of $\leq 10^{-31}$ cm² can be made for the neutrino cross section. Crane[3] has estimated that the region 10^{-34} to 10^{-35} cm² is also eliminated; for if it were not, both the sun's surface temperature gradient and the heating of the earth would be excessive, far from known equilibrium conditions. However, Benfield[4] has since pointed out that the geophysical argument is far from secure, due to the present non-equilibrium conditions in the earth's surface gradient. In view of this, the question of the role of the sun's neutrinos in the heating of the earth seems open to further experimental work.

Although neutrino interaction experiments are difficult because of the limited sources available, there are reactions which are equivalent, which involve the same coupling constant and give the same theoretical cross section within an order of magnitude.[5,6]

The following inverse β-reaction:

$$e^- + H^1 \rightarrow n + \nu,$$

has been tried using a small van de Graaff generator. The 1.0-Mev electron beam from the generator passed out through a 2 mil (13.6 mg/cm²) Al window and was stopped in paraffin. The neutrons that might be produced ($E_n \sim 300$ ev) were moderated in the same paraffin geometry and counted in a B^{10} lined and $B^{10}F_3$ filled proportional counter. A fast preamplifier and amplifier were used in conjunction with the usual scale of 64. During the taking of data all pulses were monitored in an oscilloscope, so that neutron pulses could be distinguished from electrical pick-up or bremsstrahlung pile-up. When the generator was turned on for the first time, the bremsstrahlung pile-up was high enough to jam the mechanical recorder. By placing Pb shielding between the paraffin and counter, by removing all high Z substances from near the beam path, and finally by speeding up the preamplifier and amplifier, it was possible to run at 20μ-amp. and still keep the bremsstrahlung below the amplifier clipping level. The counter geometry efficiency was estimated to be 5×10^{-3} at 300 ev. This value was extrapolated from two known sources at higher energies, γ (Sb, Be)n at 25 kev, and γ (Ra, Be)n at $\sim$1 Mev.[7] The number of atoms of H^1 effective in the inverse β-reaction 3×10^{22} was estimated from the thickness of paraffin to slow the 1.0-Mev electrons down to 0.29 Mev, the threshold for the reaction.

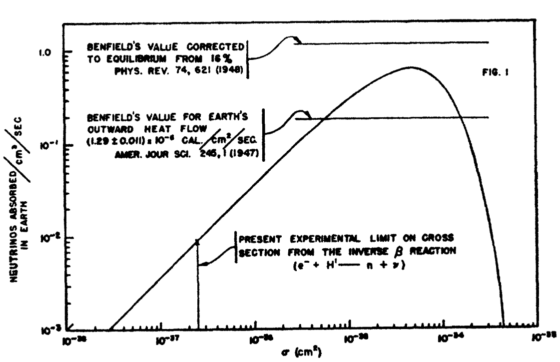

FIG. 1. Neutrino absorption as a function of the interaction cross section.

At the maximum beam current used, 20μ-amp. there was no observable effect beyond statistics. The estimated error of 0.28 counts/min. when used with the other data gives a cross-section limit of $\leq 2.5\times10^{-37}$ cm².

In Fig. 1 is shown the neutrino absorption/cm³/sec. in the earth as a function of the interaction cross section. The solid curve was calculated assuming a point source model[1] for the sun's neutrinos; exponential absorption in the sun, and homogeneous absorption in the earth. The two horizontal lines represent the observed level for the earth's heat losses in equivalent neutrino absorptions. Assuming the equivalence of the observed cross section to that for neutrinos, it follows from Fig. 1 that at most 4 percent (and probably only 1 percent) of the observed earth's heat losses could be attributed to the absorption of the sun's neutrinos. If the further assumption is made that other neutrino interactions such as inelastic scattering are negligible, then the present result eliminates the sun's neutrinos as a significant source of the earth's heat. It should be mentioned that Crane's results[3] for the neutrino heating effect seem to be larger than the present one by a factor of 10. The particular solar model and constants used can influence the results radically. With the observed limit on the cross section, already most of the neutrinos escape the sun, giving a flux at the earth of $\sim 3.5\times10^{11}$/cm²/sec.

The ultimate cross section that can be detected by the present method is considerably smaller than 2.5×10^{-37} cm². By using a more efficient detector with lower background, and also higher beam currents it should be possible to reach 10^{-38} to 10^{-39}.

The author wishes to thank M. Burgy for many stimulating discussions, from the inception of the experiment to its completion. Also, many thanks to L. Johnson and T. Brill's group for the flawless performance of counter and circuits. The van de Graaff generator was used under the guidance of S. Rocklin.

[1] H. A. Bethe, Phys. Rev. 55, 434 (1939).
[2] E. O. Wollan, Phys. Rev. 72, 445 (1947); H. R. Crane, Phys. Rev. 55, 501 (1939); R. L. Burling and F. N. D. Kurie, Phys. Rev. 74, 109 (1948).
[3] H. R. Crane, Rev. Mod. Phys. 20, 294 (1948).
[4] A. E. Benfield, Phys. Rev. 74, 621 (1948).
[5] H. A. Bethe and R. F. Bacher, Rev. Mod. Phys. 8, 196 (1936).
[6] H. Primakoff, Phys. Rev. 74, 110 (1948).
[7] The photo-neutron source calibration was kindly done for us by A. Wattenberg and his group.

Radioactivity in Holmium 166, Thulium 170, and Lutecium 177

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SPECIMENS of holmium, thulium, and lutecium of high purity, prepared by Dr. G. E. Boyd, were made available by the AEC and were irradiated in the Oak Ridge pile. Conversion electron lines in each of the elements were recorded photographically. Observations were also made of the half-lives and