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.

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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.

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 $\leq 2.5\times 10^{-37}$ 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 $\sim 3.5\times 10^{11}$/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.

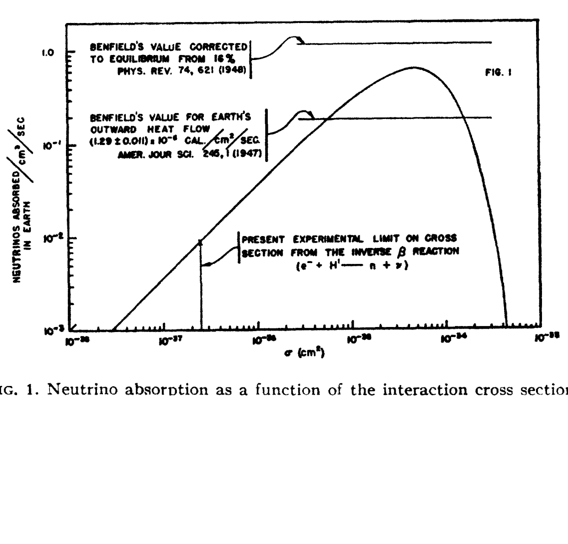

Fig. 1. Neutrino absorption as a function of the interaction cross section.

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[3] H. R. Crane, Rev. Mod. Phys. 20, 294 (1948).
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[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

TABLE I. Data connected with the beta-disintegration of Ho 166, Tm 170 and Lu 177.

Z	Element symbol	Half-life	Electron energy	Interpretation	Gamma calculated	Energy probable
67	Ho 166	27.7*H*	71.7 kev	*LI, II* (9.25 kev)	81.0 kev	
			72.6	*LIII* (8.35)	81.0	
			79.0	*M* (2.22)	81.2	
			80.6	*N* (0.45)	81.0	81.0 kev
69	Tm 170	120 *D*	22.9	*K* (61.4 kev)	84.3	
			73.9	*LI* (10.5)	84.4	
			74.3	*LII* (9.95)	84.3	
			75.3	*LIII* (8.94)	84.3	
			82.2	*M* (2.41)	84.6	
			83.8	*N* (0.50)	84.3	84.3
71	Lu 177	6.7*D*	47.6	*K* (65.4 kev)	113.0	
			102.5	*LI, II* (10.7)	113.2	
			103.6	*LIII* (9.6)	113.2	
			110.5	*M* (2.60)	113.1	
			112.4	*N* (0.54)	113.0	113.1
			143.2	*K* (65.4 kev)	208.6	
			197.5	*LI, II* (11.3)	208.8	208.6

the beta- and gamma-energies by absorption. The low energy gamma-ray in each element gave rise to electron lines attributable not only to the *K*, *M*, and *N* levels but also to the sub groups of the "*L*" level. Thus in thulium the single gamma-ray gives rise to six clearly resolved lines. Failure to recognize this complexity of structure for low energy gamma-rays has led to the assumption by the present authors of non-existent gamma-rays in certain other heavy elements.

Holmium. Previous studies[1] on holmium 166 report a half-life at values from 27.0 to 35 hours, with a beta-upper limit from 1.6 to 1.9 Mev and no gamma-rays. In this investigation the decay is followed through eight octaves and the half-life is found to be 27.7 hours. By absorption in aluminum (0.724 g/cm^2) the upper limit of the beta-spectrum appears to be 1.64 Mev. In addition to the low energy gamma-ray shown in Table I, absorption in lead indicates a high energy gamma at 0.92 Mev.

Thulium. Thulium 170 has been previously reported[1,2] to decay with a half-life between 105 and 127 days and a beta-upper limit of 0.98 to 1.1 Mev and a high energy gamma-ray of 0.83 Mev. An apparent half-life in the present investigation of 120 days must be confirmed by longer observation. The beta-absorption in aluminum (0.323 g/cm^2) indicates an upper energy limit of 0.9 Mev. No high energy gamma-ray appeared to be present, and the beautiful agreement in the energy of the converted gamma-ray by the many electron lines is shown in Table I.

Lutecium. The half-life of lutecium 177, previously reported[1,3] between 6.6 and 6.98 days, appears in this investigation to be 6.8 days. The beta-upper limit by absorption in aluminum (0.092 g/cm^2) is 0.46 Mev. The electron lines (see Fig. 1) with their

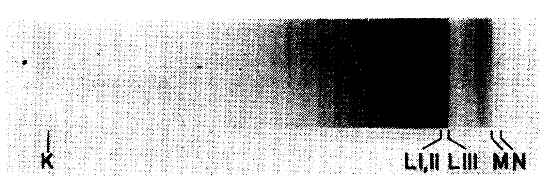

FIG. 1. Showing the electron lines associated with the 113.1 kev gamma-ray from hafnium 177, resulting from the beta-disintegration of lutecium 177.

unmistakable interpretation showing gamma-rays of energy 113.1 and 208.6 kev are presented in Table I.

This investigation was made possible by the joint support of the Atomic Energy Commission and the Office of Naval Research.

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Dynamic Probe Measurements in the Ionosphere

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EXPERIMENTAL volt-ampere characteristics obtained from a V-2 rocket in the lower part of the *E* layer on December 8, 1947, have been recently analyzed using a technique reported earlier.[1]

The experimental method involves applying a scanning voltage between two collectors on the rocket and transmitting the resulting volt-ampere characteristic to the ground. In this early experiment, the voltage was applied between a cylindrical ring on the nose and the rocket warhead. Utilizable data was obtained on the ascent from around 99 to 103.5 km. Characteristics for three different altitudes are shown plotted in Fig. 1.

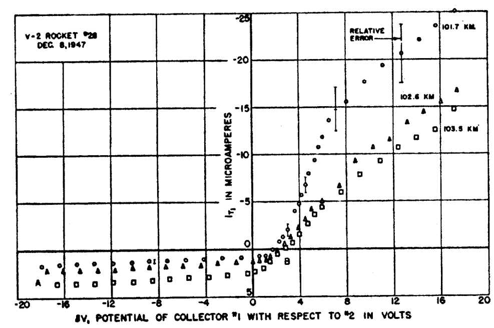

FIG. 1. Experimental volt-ampere characteristics for various altitudes.

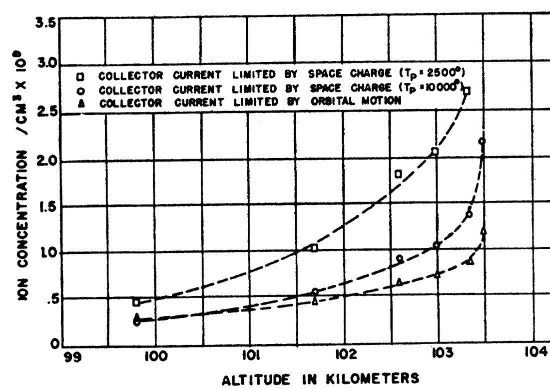

FIG. 2. Ion density *vs.* altitude.

The ion density is calculated from the region *AB* using a method which is based upon the linearity of the i_T^2 plot as a function of δV. The experimental data for this firing gives rise to fairly good straight lines. Dependent on the initial ion energy (which was not measured in this experiment), the ion density may be evaluated directly from the slopes of these lines. Figure 2 is a plot of the ion density as a function of altitude for a range of initial ion energies.

The lower curve is based upon initial ion energies high enough to establish orbital current limitation. This would be satisfied for energies greater than 3 volts. The other two curves are based upon ion energies small enough to establish more nearly a sheath area current limitation. All of the curves in Fig. 2 have been calculated considering edge effects, which are quite large in this experiment.

Indications of a very little ionization occurred around 70 km. However the sensitivity of the instrument did not permit any quantitative evaluation until an altitude of around 99 km was

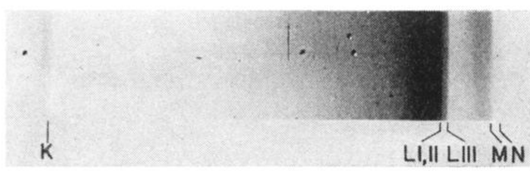

FIG. 1. Showing the electron lines associated with the 113.1 kev gamma-ray from hafnium 177, resulting from the beta-disintegration of lutecium 177.