tions of these investigators do not yield direct evidence on the nature of the recorded particles (they could have been protons as well as mesotrons) it can be asserted that in our experiments mesotrons were observed. Our experiments also bring to light an essential singularity—the predominance of secondary slow particles with exceedingly small ranges.

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[1] G. Herzog, Phys. Rev. 57, 337 (1940); M. Schein, E. O. Wollan, G. Groetzinger, Phys. Rev. 58, 1027 (1940); G. Herzog, Phys. Rev. 59, 117 (1941); G. Herzog and W. H. Bostick, Phys. Rev. 59, 122 (1941).
[2] B. Rossi and H. Regener, Phys. Rev. 58, 837 (1940).
[3] V. Veksler and B. Isajev, Comptes rendus Acad. Sci. USSR 17, 189 (1937); V. Veksler and N. Dobrotin, Comptes rendus Acad. Sci. USSR 19, 479 (1938).
[4] The probability of such electrons having been recorded by our counters is exceedingly small.
[5] The cathodes of the counters were made of brass nets; the walls of the boxes which enclosed the counters were 0.09 g/cm² thick.
[6] V. Veksler, K. Alekseeva and N. Reynov, Comptes rendus Acad. Sci. USSR 21, 122 (1938); V. Veksler and N. Dobrotin, Bull. Acad. Sci. USSR, Série Physique 4, 260 (1940).
[7] These observations also pointed to the existence of heavily ionizing particles with essentially longer ranges of the order of a few grams per cm², i.e., apparently slow secondary protons.
[8] V. Veksler and N. Dobrotin, Comptes rendus Acad. Sci. USSR 25, 103 (1939).

Time Lags in Geiger-Müller Counter Discharges

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Some time ago we reported[1] the existence of delayed counts in Geiger-Müller counters in which the appearance of a potential on the counter wire did not take place until several microseconds after the formation of the primary ions responsible for the discharge. We suggested that the cause of this long time lag was the capture of the electrons of the primary ion pairs, forming negative molecular ions which moved relatively slowly into the region of the counter wire. In this region of high field strengths, the molecular ions were broken up and the electrons released were multiplied by the ordinary processes of ionization by collision. These long-time lags are not to be confused with the shorter ones which represent the periods necessary for the building up of the space charge around the counter wire.

Some new experiments have been performed to establish the correctness of this explanation, and to measure the capture probabilities. A counter 18 mm in diameter and 120 mm long, with an oxidized copper cathode, was used. Ultraviolet light could strike the interior of the cathode by passing through a quartz window and a small hole in the cathode, and eject photoelectrons. The light was produced by a spark which caused, at the same time, an electrical pulse. The difference in time between the occurrence of this pulse and the beginning of the change of potential of the counter wire was measured by a vacuum-tube circuit of the type previously described.[1]

If n is the average number of photoelectrons produced by a spark, then the fraction f of the number of sparks which cause a counter discharge is $f=1-e^{-n}$. If α is the probability that an electron be captured in such a manner as to produce a time lag greater than a given amount τ, then the probability p that the spark will give rise to a delayed counter discharge is

$$P=\sum_{m=1}^{\infty}\alpha^m\frac{e^{-n}n^m}{m!}=(e^{\alpha n}-1)e^{-n},$$

since all of the electrons must be captured if the count is to be delayed. Hence, by measuring p and f, n and α may be determined. If the proposed explanation for the delayed counts is correct, then the values α calculated in this way should be independent of n for a given pressure and composition of the gas in the counter. Thus, measuring α provides a sensitive test of the correctness of the picture.

Table I. *Values of the probability α that an electron will be captured so as to produce a time lag greater than τ.*

Electrons per Spark, n	0.22	0.41	0.64	Mean
τ, microseconds				
1.4	0.40	0.42	0.39	0.40
2.3	0.19	0.17	0.18	0.18
3.7	0.08	0.10	0.08	0.08

An example of the results of such a test is shown in Table I. The counter was filled with a mixture of argon with six percent oxygen at a pressure of 104.5 mm of mercury. For a given time lag the values of α are the same within the accuracy of the observations.

Other observations show that α increases with increasing pressure. From the knowledge of the time of travel of the negative molecular ions, we can estimate the capture cross section of an electron by an oxygen molecule to be of the order of 10^{-18} cm². This is in agreement with the results of Rose and Ramsey,[2] and other more direct determinations.

If the primary ions are produced within the gas of the counter, as when gamma-rays or cosmic rays are being counted, then both n and α increase with the pressure of the counter gas. Hence, as the pressure is increased, the probability of a delayed count p first increases, reaches a maximum value, and then decreases again.

[1] C. G. Montgomery, W. E. Ramsey, D. B. Cowie and D. D. Montgomery, Phys. Rev. 56, 635 (1939).
[2] M. E. Rose and W. E. Ramsey, Phy. Rev. 59, 616 (1941).

Superconducting Films as Radiometric Receivers

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Three years ago a series of experiments was undertaken to investigate the usefulness of superconducting films as resistance thermometers in the measurement of small quantities of energy[1] and in particular as receivers in radiometers. The latter application has since been suggested independently by A. Goetz.[2] Because of the interest in the optical properties of superconducting surfaces and the possibilities of this new radiometric method in the infrared, we are presenting a few preliminary results at this time.

Lead films were prepared[3] by evaporating the metal on clean glass in a high vacuum giving a bright metallic mirror-like surface. The glass was in the form of a ribbon 1.5 cm long, 1 mm wide and 25μ thick, fused to a glass plate at the ends in such a way that the ribbon bowed up slightly in the middle. Contacts were made by means of platinum wires sealed into the glass at the ends of the ribbon. This "receiver" was placed on a thin copper base-plate suspended on quartz fibers attached to a small heavy-walled copper vessel in which the liquid helium was made by the Simon expansion method. Our most sensitive film had a transition zone roughly 0.02° wide in which the resistance varied from 100 ohms (normal) to 10^{-3} ohm (superconducting). The estimated thickness of the film was 10 mμ. Other films studied varied in thickness up to 500 mμ and had correspondingly lower resistances. By means of a small electrical heating coil attached to the base-plate, the temperature of the film was maintained in the middle of the "steep" portion of the transition during the radiation measurement. Judging from the observed fluctuation in resistance of the lead film, the temperature was maintained effectively constant to within 10^{-6} degree.

The source of radiation was a blackened copper disk, electrically heated and with thermocouple attached. It was suspended about 5 cm above the receiver, with shutter and diaphragms in between so that measured amounts of energy could be transmitted.

The potential drop across the film was measured with a potentiometer circuit, the galvanometer beam having a deflection of 1 cm per μv. Radiation was flashed on the receiver from the radiator at a series of temperatures from 15°K to 150°K. The receiver was at a temperature of about 7°K and the shutter at 14°K.

The largest ratio of potential drop to input of radiant energy was obtained with the unblackened 10 mμ film. This receiver (glass+lead) had a heat capacity of about one erg deg.$^{-1}$. A beam of radiant energy, 6 erg sec.$^{-1}$, produced a galvanometer deflection corresponding to about 6 millivolts in less than 1 sec. This is equivalent to a sensitivity of 10^{-4} erg sec.$^{-1}$ per mm deflection. Blackening the lead surface with a thin layer of cobalt oxide produced no appreciable increase in sensitivity.

Because of temperature fluctuations in the receiver, this sensitivity of 10^{-4} erg sec.$^{-1}$ per mm deflection was too high to permit accurate measurements. The highest precision obtained was in an experiment with the radiator at 35°K. A beam of 2×10^{-4} erg sec.$^{-1}$ gave a deflection of 7 mm. The probable error corresponded to 1.5 mm, giving a precision of measurement of 4×10^{-3} erg sec.$^{-1}$.

It appears that the ratio of potential drop to radiant energy input is several orders of magnitude higher than in the other methods for measuring radiation in the infra-red region, and that the possibilities for sensitivity and precision are correspondingly high. It is probable that, with superconducting receivers of higher resistance, more sensitive galvanometer systems, and better temperature control, the precision can be improved considerably beyond the results reported here.

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[1] D. H. Andrews, Am. Phil. Soc. Year Book (1938), p. 132.
[2] A. Goetz, Phys. Rev. **55**, 1270 (1939).
[3] W. F. Brucksch, Jr., W. T. Ziegler, E. R. Blanchard and D. H. Andrews, Phys. Rev. **59**, 688 (1941).

Production of Radioactive Hydrogen by Neutron Bombardment of Boron and Nitrogen

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Saturated water solutions containing an excess of boric acid crystals, or of ammonium nitrate crystals, were bombarded for several thousand microampere hours by fast neutrons produced by the $Be^9(d, n)B^{10}$ reaction, with 16.5-Mev deuterons. In all cases the water surrounding the crystals, when placed as water vapor in a Geiger-Müller counter, showed an activity of approximately 10^4 counts per mole per second. Control samples of distilled water had less than five percent as much activity.

The following reactions are energetically possible, with 20 Mev as the upper limit of the neutrons used:

$$_5B^{10}+{}_0n^1\rightarrow[_5B^{11}]^*\rightarrow{}_4Be^8+{}_1H^3+Q_1 \quad (1)$$
$$_4Be^8\rightarrow 2_2He^4$$
$$_5B^{11}+{}_0n^1\rightarrow[_5B^{12}]^*\rightarrow{}_4Be^9+{}_1H^3+Q_2 \quad (2)$$
$$_7N^{14}+{}_0n^1\rightarrow[_7N^{15}]^*\rightarrow{}_6C^{12}+{}_1H^3+Q_3 \quad (3)$$
$$_7N^{14}+{}_0n^1\rightarrow[_7N^{15}]^*\rightarrow 3_2He^4+{}_1H^3+Q_5 \quad (3a)$$
$$_7N^{15}+{}_0n^1\rightarrow[_7N^{16}]^*\rightarrow{}_6C^{13}+{}_1H^3+Q_4 \quad (4)$$

where $Q_1=+0.2$ Mev; $Q_2=-9.6$ Mev; $Q_3=-4.3$ Mev; $Q_4=-10.1$ Mev; $Q_5=-11.5$ Mev.

Reaction (1) might be expected, since the compound nucleus formed has already been observed to yield radioactive hydrogen.[1]

Since only 0.38 percent of the bombarded nitrogen was N^{15}, it is not likely that reaction (4) was primarily responsible for the observed activity.

The total neutron output of the 60-inch cyclotron has been recently measured by Dr. Emilio Segrè and Mr. Hubert Yockey. Using their unpublished and preliminary result of one neutron per 200 deuterons, and 31 years as the half-life,[2] one may obtain a rough value for the reaction cross sections. Assuming that (1) and (2) are involved for boron, and (3) and (3a) are involved for the nitrogen, one obtains for both elements approximately 10^{-26} cm^2 as the fast neutron cross section for the production of hydrogen three. It is estimated that these values for both cross sections may be in error by a factor of five.

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[1] R. D. O'Neal and M. Goldhaber, Phys. Rev. **57**, 1086 (1940).
[2] R. D. O'Neal and M. Goldhaber, Phys. Rev. **58**, 574 (1940).