tivity of the magnetic susceptibility for changes of the chemical composition is well known. Taking this into account, measurements were undertaken with the aim of widening the range of weighing for the determination of the number of vacant lattice sites in some titanates which had been slightly reduced for conversion to semiconductors. The three magnesium titanates were made by reaction in solid state and shaped into rods of about 2 mm diameter and 15 mm length. For conductivity measurements, platinum contacts were sintered on the ends. All rods were presintered in oxygen in a platinum furnace at 1450°C. This temperature was never exceeded in either the reduction treatment or the measurements. The rods were reduced in a wolfram furnace in hydrogen at different temperatures from 850°C upward.

The electrical conductivity was measured with an ohmmeter in helium or in toluene, depending on the temperature. The plotting showed the usual straight lines in a $1/T_{abs}$ *vs* log$R$ system. Nothing peculiar was found in these plottings.

The magnetic measurements were made at room temperature with a modified Curie-Chéveneau balance. The calibration was established using nickel chloride solutions with known concentrations. In the plotting of paramagnetic susceptibility *vs* percentage of removed oxygen, the values for two titanates, $MgTiO_3$ and Mg_2TiO_4, increased smoothly with a decrease of the oxygen. However, the third compound, $MgTi_2O_5$, showed a remarkable peak between 0.15 percent and 0.25 percent; as yet it has not been possible to determine the exact value of the peak with the equipment available. The samples with about 0.2 percent were so strongly magnetic that they were remarkably attracted by an ordinary toy magnet.

In order to determine the nature of this phenomenon, the dependence on magnetic field strength was determined. There was no apparent influence using the laboratory electromagnet, which could be varied from zero to about 2000 gauss field strength. This behavior is typical for paramagnetism and eliminates the possibility of a ferromagnetic effect, which was assumed at first because of the size of the observed forces.

Investigations (including other heavy metal titanates) of the dependence on temperature are in progress for a wider range of temperatures.

* Based in part on work done under contract with the USAF.
† A complete paper on this subject will be submitted by H. Katz to the Department of Electrical Engineering of the University of Illinois in partial fulfillment of the requirements for the Ph.D. degree.

Secondary Electron Spectrum of Pr^{142}†

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(Received April 21, 1952)

IN a previous publication concerning the radiations of Pr^{142}, the authors[1] reported the presence of one gamma-ray, having an energy of 1.57_6 Mev, and two beta-groups, with maximum energies of 2.15_4 Mev and 0.63_6 Mev. Other investigators[2] have reported a number of low energy gamma-rays for Pr^{142}. In the original work of the present authors[1] a search was made for low energy gamma-rays, but none was found. If these gamma-rays existed, however, they would have been observed as photoelectric lines superposed on a broad distribution of electrons which was ascribed to secondary electrons produced by bremsstrahlung.

Dr. Alburger[3] of Brookhaven National Laboratory has suggested that the broad distribution of electrons ascribed to secondary electrons produced by bremsstrahlung, as reported in our original paper,[1] might be due to beta-rays that have passed through part of the Lucite holder and then scattered from another part of the source holder. On repeating the experiment with $Sr^{90}-Y^{90}$ it was found that a substantial fraction, but not all, of the electron distribution attributed to bremsstrahlung was, in fact, due to scattered beta-particles, as suggested.

It seemed worthwhile, therefore, to re-examine the secondary electron spectrum of Pr^{142} in order to make a search for low energy gamma-rays under more favorable circumstances and also to determine the existence or nonexistence of an appreciable number of secondary electrons produced by bremsstrahlung. A sample of spectrographically pure (contaminants of Nd, La, and Ce less than 0.1 percent) Pr_6O_{11} made available through the courtesy of Dr. F. H. Spedding and Mr. T. A. Butler of this laboratory was

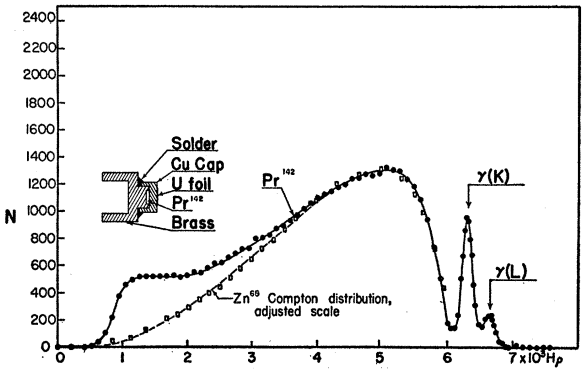

FIG. 1. The solid line, given by the circles, is the secondary electron spectrum of Pr^{142} as obtained with the arrangement shown in the insert. The broken line, given by squares, was obtained from the Compton distribution produced by the Zn^{65} gamma-ray (1.12 Mev) normalized to the Compton distribution from Pr^{142}. N is the number of counts per minute.

irradiated in the Argonne pile and then examined with a thin-lens spectrometer[4] modified to incorporate ring focusing.[5]

The irradiated praseodymium was placed in a brass holder and covered with a copper cap, of surface density 2.92 g/cm², on which was fastened a uranium foil of surface density 42 mg/cm². The secondary electron spectrum obtained with this source is shown by the solid line in Fig. 1. The insert in Fig. 1 shows a

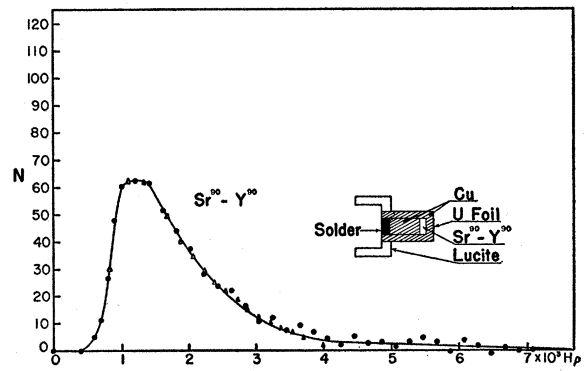

FIG. 2. The curve given by the solid circles is the secondary electron spectrum from the copper capsule and uranium foil, as produced by bremsstrahlung arising in the copper capsule due to the absorption the of beta-particles from Sr^{90}-Y^{90}. The arrangement of source, copper capsule, and uranium foil is shown in the insert. N is the number of counts per minute for this distribution. The triangles were obtained by subtracting the two curves shown in Fig. 1 and multiplying by an appropriate normalizing factor.

scale drawing of the arrangement of the Pr^{142}, brass holder, copper cap, and uranium foil. Spectra were obtained with and without the solder ring on the shoulder of the brass holder and no change in the shape of the spectrum was observed. Only one gamma-ray was observed, having an energy of 1.57_6 Mev as reported previously.[1]

Since no low energy gamma-rays were observed and the material surrounding the source was sufficient to absorb completely electrons with an energy greater than 5 Mev, it was concluded that the broad distribution of electrons observed at the low energy

end of the spectrum, in addition to the expected Compton distribution, is due to secondary electrons that are produced in the copper cap and uranium foil by the bremsstrahlung arising in the copper cap as a result of the absorption of the beta-particles.

As a check of the foregoing interpretation for the broad distribution of electrons at the low energy end of the spectrum shown in Fig. 1, a source of $Sr^{90}-Y^{90}$ was placed in a copper capsule to which was fastened the same uranium foil as that used with the Pr^{142} source. This copper capsule had the same diameter as the copper cap used with the praseodymium source. The $Sr^{90}-Y^{90}$ source, which is gamma-free and emits beta-particles with a maximum energy[6] (2.23 Mev) close to that for Pr^{142}, was found to give a secondary electron spectrum as shown by the circles and solid line in Fig. 2. The insert in Fig. 2 shows a scale drawing of the arrangement of source, copper capsule, and uranium foil. The end of the capsule on which the uranium foil was fastened had a surface density of 2.43 g/cm² while the sides of the capsule had a surface density of 2.12 g/cm². This was sufficient to absorb completely electrons with an energy of about 4 Mev.

The broken line shown in Fig. 1 was obtained from the Compton distribution produced by the Zn^{65} gamma-ray (1.12 Mev).[7] This was obtained under conditions similar to those for the Compton distribution for Pr^{142}. The scale of the Zn^{65} curve has been adjusted to match the Pr^{142} Compton distribution at the maximum ordinate and at the Compton high energy "edge." The triangles shown in Fig. 2 were obtained by substracting the two curves shown in Fig. 1 and normalizing the ordinates. It may be seen that the two secondary electron distributions produced by bremmstrahlung are in good agreement. It appears, then, that the broad distribution of electrons at the low energy end of the Pr^{142} spectrum shown in Fig. 1 is due to bremsstrahlung.

The secondary electron spectrum of Pr^{142}, shown in Fig. 1, is therefore regarded as a composite of the photoelectrons and Compton electrons arising from a single gamma-ray, plus the electrons produced by bremsstrahlung. This conclusion, accordingly, in no way alters the final results and conclusions regarding the radiations from Pr^{142} nor the decay scheme reported in the previous publication.[1]

The authors wish to express their appreciation to Messrs. Earl W. McMurry and James T. Jones, Jr. for their assistance in obtaining part of the data.

† Contribution No. 183 from the Institute for Atomic Research and Department of Physics, Iowa State College, Ames, Iowa. Work was performed in the Ames Laboratory of the AEC.

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The Nature of Cosmic-Ray Bursts Underground*

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(Received April 28, 1952)

In a previous publication,[1] size-frequency relations of cosmic-ray bursts observed underground were reported. The apparatus used was a duralumin ionization chamber of wall 1.2 cm thick, filled with argon to a pressure of 88 atmospheres at 20°. It was at least 2 to 4 meters from the wall of a tunnel under 30 meters of clay. It had a collecting volume of about 1.2 liters, and recorded bursts predominantly of sizes 10^6–10^7 ion-pairs, corresponding to about 15–150 minimum-ionizing particles. The integral size-frequency distributions [given originally in Fig. 4(c) of the previous publication] are reproduced in Fig. 1 with added indications of standard deviations. The ordinate gives the observed integral rate of bursts (except curve Pb, which has been adjusted as explained below) in number per hour. The abscissa gives the estimated energy of bursts assuming that they were produced by μ-mesons through the usual processes of knock-on, bremsstrahlung, and pair-production. The scale of the abscissa does not apply to curve *S*, which gives the theoretically estimated contribution of nuclear stars (presumably produced by μ-mesons) inside the chamber, based on observations by George and Evans.[2] Curve *C* indicates the actually observed number of bursts with the chamber unshielded (corrected for the contribution of stars as given by curve *S*), and hence probably produced from the clay of the wall of the tunnel. The energy of the bursts is estimated from the shower development and the geometry. Curve Pb indicates the bursts observed with lead plates of size 20×20 cm² and of average thickness 13 cm placed above the chamber (the correction for stars being negligible in this case). The interception efficiency (with respect to burst size) was estimated to have increased by a factor of 5, and the frequency by a factor of 30 in comparison with the observations for bursts produced from clay. This adjustment seems justified by comparing our results with those obtained recently by Driggers[3] at sea level. The dashed curve *D* represents his results directly. The agreement is satisfactory within experimental uncertainties.

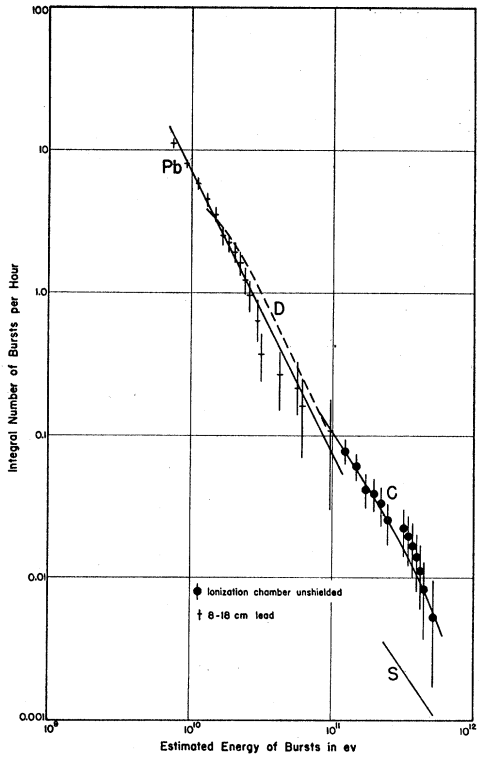

FIG. 1. Integral size—frequency relations of bursts.

The curves Pb and *C* should be compared with the well-known underground intensity *vs* depth relation actually observed.[2] The slope of curve *C* agrees well with the slope of the intensity *vs* depth curve at depth greater than about 200 m water equivalent. Hence if we assume that the conclusion is valid that the efficiency of burst production under similar geometrical conditions remained the same at ground level as underground, our experimental results show that either (a) fewer μ-mesons of energy higher than about 10^{11} ev or/and (b) more μ-mesons of energies in the range 10^{10}–10^{11} ev exist under 60 m water equivalent than at ground level.

Explanation based on alternative (a) has been given independently by Greisen[4] and by Hayakawa[5] in 1948. Due to the relativistic increase of the lifetime of the high-energy π-mesons,