Resistivity of Evaporated Tellurium Films

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A TELLURIUM film was made on a substrate of a silica plate by vacuum evaporation, and its resistivity was measured at various temperatures. The thickness of film was varied from 200 to 5000A. When the substrate was kept at room temperature during evaporation, the film deposited showed high resistivity immediately after the evaporation, but the resistivity decreased with time and reached a finite value. By raising and lowering the temperature, $\log R-1/T$ curves were obtained, an example of which is shown in Fig. 1. As seen in this figure, the resistivity changed irreversibly when the temperature was raised above that in which the film had ever been placed, but reversibly at the temperature in which the film had been put or lower. It was found that the resistivity R in the reversible region could be expressed by the equation

$$\ln(R-r)=U/2kT+\text{const},$$

by inserting a suitable constant r, where U is the activation energy of a bulk specimen, 0.34 ev. By raising the temperature above that which the film had undergone, the value of r was found to increase and approach a finite value. These facts are indicated in the figure by the decrease of inclination and the increase of curvature in successive reversible courses. The value of r/R was nearly the same for a film with thickness larger than 1000A, but it was less for thinner films. Upon raising the temperature to about 180°C a sudden increase of resistivity set in, and upon lowering the temperature a decrease of r was observed. This feature was conspicuous for thinner films.

When the film was bombarded by electrons of about 10,000 ev after evaporation, the change of resistivity with temperature was entirely reversible, and the constant r showed the value given by the heat treatment. On the other hand, when the tellurium was deposited on a hot substrate about 200°C in temperature, the $\log R-1/T$ curve of the film was found to be in good accord with that of the bulk specimen, as is shown in Fig. 2. The measured activation energies in the intrinsic and extrinsic ranges were 0.34 and 0.040 ev, respectively.

It seems that the tellurium atoms, deposited on a cold substrate, might wander to make microcrystals but these crystals are buried by amorphous deposit. After evaporation, the crystals grow larger with time and reach an equilibrium at a given temperature. In this case, the resistance of the film is given by the sum of the resistance of microcrystals, the intrinsic semiconductor, and that of the amorphous deposit r which is large in value and has a small temperature coefficient. By heat treatment or electron bombardment, crystals grow larger and amorphous portions diminish; this will result in a decrease of resistance. By the migration of atoms, however, small empty spaces grow in the amorphous portions, which causes the increase of r.

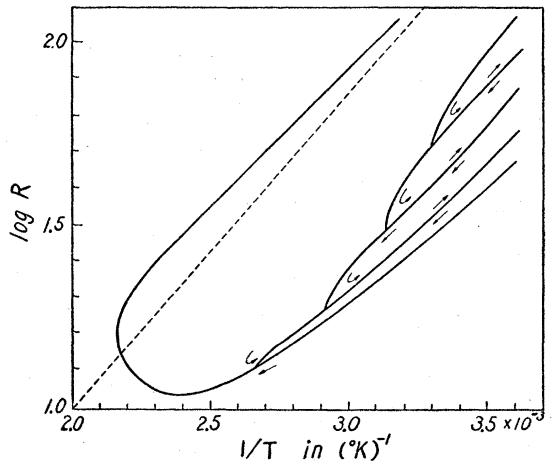

FIG. 1. Resistivity of tellurium film deposited on a cold substrate as a function of temperature. The dashed curve is the result obtained for a bulk specimen.

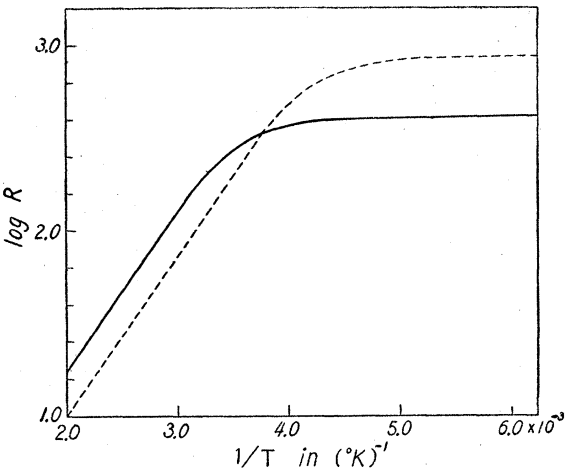

FIG. 2. Resistivity of tellurium film deposited on a hot substrate as a function of temperature. The dashed curve is the result obtained for a bulk specimen.

These phenomena were observed also by means of the electron microscope and electron diffraction. When the substrate is kept at a high temperature, the atoms deposited have sufficient energy to wander and to form crystals during the whole course of evaporation, and hence the largest part of the film is well crystallized. Thus evaporated films prepared by a suitable procedure are quite the same as bulk crystals from the point of view of electrical resistivity; and other experimental data obtained with them, as well as with bulk specimens, seem to be available for theories of semiconductors.

Production Cross Section and Energy Spectrum of the Neutral Mesons in Cosmic Rays*

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WE summarize here our results on the neutral mesons obtained at Echo Lake, Colorado, during the summer of 1951. The nuclear events in which the neutral mesons are created are produced in sodium iodide crystals mounted inside a cloud chamber, and are detected by 1*P*21 photomultipliers (Fig. 1). This method[1] keeps our bias in detection as low as that of the nuclear emulsions, yet gives higher efficiency in detecting the photons into which the π_0 decays.

The distribution of the nuclear events according to the number of the emitted shower particles (ionization ≤ 1.5 minimum[2]) is given in Table I, second row. In the third row the number of nuclear events with electromagnetic component is given.

1. *Energy distribution of the neutral mesons.* In most of the cases, the electromagnetic component associated with a nuclear event consisted of two cores diverging from the origin. We regarded the sum of the estimated energies of these two electromagnetic cores as the energy of the π_0 emitted.[3] The main uncertainty in these estimates comes from the fluctuation of the electronic cascade. The results are given in the histogram of Fig. 2.

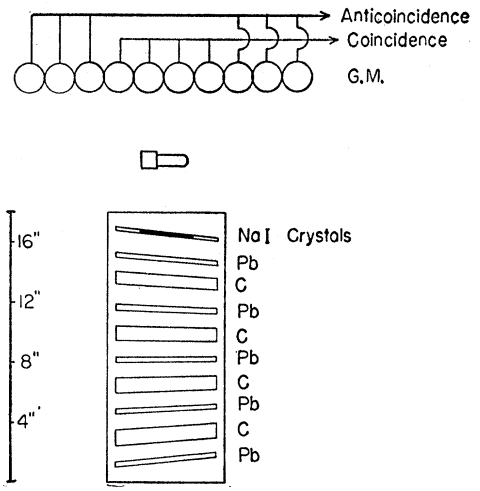

FIG. 1. Experimental disposition; coincidence and anticoincidence Geiger-Mueller counters were used to concentrate on proton-produced events and to cut down air showers.

We have also plotted the points reported by the Bristol Group[4] referring to the charged mesons. The average atomic weight of our crystals almost equals that of the nuclear emulsions. Comparison with the Bristol data[5] on the energy distribution of the π_0 in the air will be discussed in a later paper.

TABLE I. Distribution of nuclear events, N_s, according to the number of shower particles.

No. of shower particles, s:	1	2	3	4	≥ 5
No. of nuclear events, N_s, containing s shower particles:	216	92	45	23	19
No. of nuclear events, N_s, having electromagnetic component:	25	28	29	16	16

2. *Ratio of neutral to charged mesons.* We consider first the events with three or more shower particles. These events show 336 shower particles, and for them we estimate 74 neutral mesons, corresponding to about 22 percent of the shower particles. The shower particles mainly consist of protons and π-mesons, and the π-mesons are about 60 percent of the shower particles.[4]

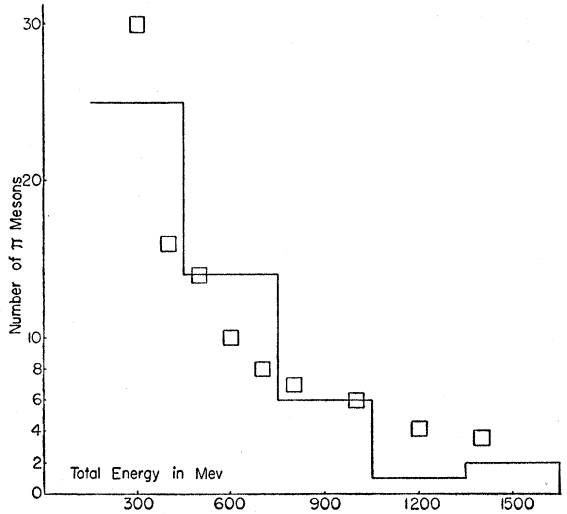

FIG. 2. Differential energy distribution of the π-mesons. Squares: $\pi_+ + \pi_-$; histogram: π_0.

TABLE II. Summary of data on neutral mesons.

Energy of the protons	σ production	Energy distribution	$\pi_0/(\pi_+ + \pi_-)$
0.345 Bev	$\sim 1/200\,\sigma_{geom}$[7]	...	...
0.8–2 Bev	$0.22 \pm 0.06\,\sigma_{geom}$	Compare Fig. 2	0.4 ± 0.1
>2 Bev	$0.7 \pm 0.15\,\sigma_{geom}$		0.37 ± 0.08

This value gives for the ratio of neutral to charged mesons, $R = \pi_0/(\pi_+ + \pi_-) = 0.37 \pm 0.08$, in agreement with the previous observations by Tinlot and Gregory[3] and the earlier results of the Bristol Group.[5]

On the other hand, if we make the corresponding estimate for the events with 1, 2, 3, or 4 shower particles, we find again a similar value, $R = 0.4 \pm 0.1$. This is not in agreement with the recent Bristol value[6] $R = 1 \pm 0.3$ for these events.

3. *Production cross section of the π_0.* We divide the events of Table I into two groups: (a) those with one or two shower particles, or with at least one neutral meson, and (b) those with three or more shower particles.

If we assume that the proton nucleus total cross section for one "nucleus" of sodium iodide is geometrical, σ_{geom}, then we can estimate the cross section $\sigma_{\pi 0}$ for π_0 production for events (a) and (b). For events (a) we find a value $\sigma_{\pi 0} = 0.22 \pm 0.06\sigma_{geom}$; for events (b) $\sigma_{\pi 0} = 0.7 \pm 0.15\sigma_{geom}$. Recent results[6] on the correlation between the primary proton energy and the size of the nuclear events indicate that events (a) are mostly produced by protons of energy $\sim 0.8-2$ Bev; (b) are by protons of energy ≥ 2 Bev.

In Table II, we summarize the pertinent data on the neutral mesons.

* Assisted by the joint program of the ONR and AEC.

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The Nuclear Gyromagnetic Ratio of V^{50} and Measurements on Rb^{85} and Cl^{35}*

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THE nuclear gyromagnetic ratio of vanadium 50 has been determined in a nuclear induction apparatus similar to that described by Proctor[1] and previously reported.[2] An electronically regulated electromagnet with a gap of $1\frac{3}{4}$ inches produced a field homogeneous to 0.1 gauss over the sample volume. Frequency measurements were made with a Signal Corps BC-221 frequency meter calibrated with harmonics from an external 100 kc, crystal-controlled oscillator, which in turn was compared with *WWV* at 10 Mc.

The sample consisted of 271 mg of electromagnetically enriched vanadium as $VOCl_3$, of which an estimated 25 mg was vanadium 50. This enriched sample was preptred from V_2O_5 and was sealed in a small spherical glass vial which was placed in a test tube and surrounded by a saturated solution of RbCl containing 15 percent D_2O. No magnetic catalyst was added.

The vanadium 50 resonance was first observed near 6 Mc at a field of 14,250 gauss. Frequency measurements were made at