electrode, and in other ways.[3] By proper biasing, a square-wave modulated spectrograph can be used to detect spectral lines and their Stark patterns with little distortion.

A second method of reducing distortion occurred to the writers shortly after the publication of Wilson's first note. This was to replace the flat central electrode in the absorption section by a small wire. In the case of a flat central electrode all the molecules in the wave guide are in a constant electric field at a given time, and hence the Stark pattern is well defined. When the fine wire is used as a central electrode the field is so highly divergent that at any given time very few of the molecules are subjected to the same field intensity, and hence there is no definite Stark pattern. This is indeed apparently the case when an ammonia line is examined by a simple method involving a single crystal; when a d.c. potential is applied to the central wire, the peak intensity of the ammonia decreases noticeably, but no Stark pattern is readily observable. We have done a number of experiments with absorption sections, using guide and central wires of different size with different modulating voltages. Preliminary results have been encouraging. This method of detection is extremely sensitive. In tests on methanol, as many lines have been observed as were reported by Dailey.[4] For high modulating voltage, lines begin to appear at pressures of the order of 1 mm of mercury and continue to increase in size as the pressure is decreased until electrical breakdown occurs at approximately 10^{-3} mm, thereby necessitating a decrease in modulating voltage. Receiver saturation occurs for many of the lines before breakdown. At still lower pressures the modulating voltage may be increased again. However, we have found the arrangement most useful as a tool for preliminary search and have achieved maximum sensitivity for relatively high pressures. Modulation frequencies of approximately 300 Kc have been used.

The lines observed are usually broader than those obtained when simpler methods of observation are used. This can be attributed in part to the fact that higher pressures are usually employed and in part to the fact that the residual Stark pattern, although much weaker than the main line, is still present and produces observable signals. The marked variation of line shape and intensity with pressure and modulating voltage is also disturbing. Observed intensities depend upon the nature of Stark effect for the transition involved as well as upon the true line intensity. One other source of difficulty encountered in the device is introduced by mechanical vibrations in the central wire which can produce a varying reflection pattern in the absorption section.

It is a pleasure to express our appreciation of helpful discussions with Professor E. Bright Wilson, who has done preliminary work on the development of a similar spectrograph.

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[1] R. H. Hughes and E. B. Wilson, Jr., Phys. Rev. **71**, 562 (1947).

[2] T. W. Dakin, W. E. Good, and D. K. Coles, Phys. Rev. **70**, 560 (1946).

[3] E. B. Wilson, Jr., paper presented at Symposium on Molecular Structure, The Ohio State University, June 1947.

[4] B. P. Dailey, S. Golden, and E. Bright Wilson, Jr., Phys. Rev. **72** (1947).

Piezoelectric Effect in Polycrystalline Barium Titanate

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WHILE investigating the rather large electrostrictive effect of a polycrystalline barium-titanate ceramic ($BaTiO_3$ sintered with a few parts per thousand of glass-forming oxides), we found that upon removal of the polarizing field there was a residual electromechanical effect of the linear (piezoelectric) kind.[1] The electromechanical coupling coefficient (a figure of merit for piezoelectric materials)[2] was found to exceed that of quartz by a factor of 4 or 5.

It was found that such polycrystalline aggregates of barium titanate may be rendered piezoelectric to a degree depending upon time of exposure to the electric field and on field intensity. After removal of the field the effect decreases with time, first rapidly for a few days, then more gradually, and appears to stabilize at a level which may be as high as 85 percent of the initial effect. Both magnitude and stability of the effect depend on field intensity and time of exposure. Highly piezoelectric pieces of good stability may be produced in a matter of minutes with field strengths of the order of 20,000 volts per centimeter, whereas several hours are required for similar results at lower field strengths. Measured while the field is applied, the effect increases rapidly (60 percent of final magnitude after two seconds at 20,000 volts per centimeter), but stability upon removal of field after such short exposure is very poor.

Excellent stability, on the other hand, is obtained by applying 20,000 volts per centimeter for one hour. Material thus treated, after showing an initial drop of about 15 percent, has remained piezoelectric for months without substantial change (see Fig. 1).

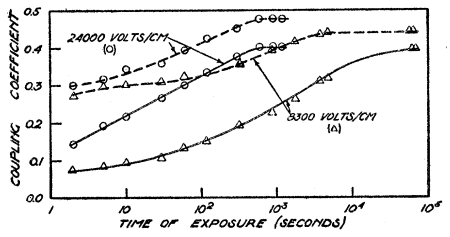

FIG. 1. Solid curves show magnitude of piezoelectric effect, measured one minute after exposure to field. Dotted curves show corresponding effect before removal of field.

Properly formed samples, held at 65 degrees C, drop more rapidly toward a stable value than they would at room temperature, but this stable value itself does not appear to be substantially lowered. Immersion in water does not seem to affect stability.

The piezoelectric axis coincides with the direction of the electric field used to polarize the material. Subsequent application of an alternating field in this direction produces alternate elongation and contraction of the material

in the direction of the field. Application of an alternating field in a direction perpendicular to that in which the polarizing field was applied sets up shear vibrations, the plane of shear embracing the directions of the polarizing and alternating fields. The converse phenomena are also observed.

The electromechanical coupling coefficient for shear is about 0.40; for the longitudinal effect it is near 0.35. These coefficients were obtained in two ways. First, the electrical output was observed with an alternating force of known magnitude at 800 cycles per second. Later, the electrical reactances of mechanically resonant slabs were measured in the radiofrequency range (about 500 kc per second).

Preliminary x-ray examination has shown no evidence of preferred orientation in the polarized material.

It is interesting to note that the material makes possible piezoelectric oscillators and transducers which cannot be formed from natural crystals. For example, a thin-walled cylinder is easily made in which the piezo axis is everywhere radial.

[1] Shepard Roberts, Phys. Rev. **71**, 890 (1947).
[2] W. P. Mason, *Electromechanical Transducers and Wave Filters* (D. Van Nostrand Company, Inc., New York, 1942), p. 204.

The Specific Primary Ionization of 1-Mev Electrons Relative to Sea Level Cosmic Radiation*

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THE average specific primary ionization of sea level cosmic radiation has been determined by Danforth and Ramsey,[1] Cosyns,[2] and Hazen.[3] Cosyns[2] has also determined the value of 1-Mev electrons and has pointed out that, considered relative to the cosmic-radiation results, it is incompatible with the theory of collision loss given by Bethe.[4]

In the course of the development of low efficiency self-quenching counters to be used in selective counter telescopes, an opportunity was afforded to repeat these measurements by a coincidence method. A quadruple coincidence train was employed as indicated in Fig. 1. An electron beam was provided by a specially prepared source consisting of a deposit of radium on a silver surface covered by a thin coating of palladium.

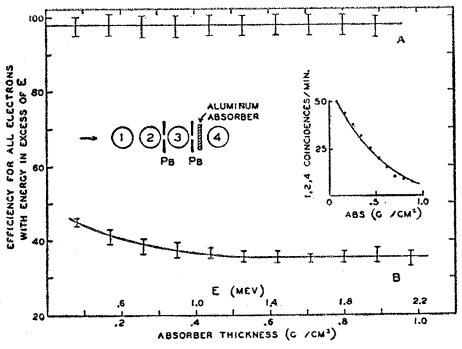

FIG. 1. The efficiency of the third counter *versus* absorber thickness. A schematic sketch of the apparatus and the electron-absorption curve is shown in inserts.

The ratio of coincidences 1, 2, 3, 4 to coincidences 1, 2, 4 was determined for various thicknesses of the aluminum absorber between the third and fourth counters, this ratio being a measure of the efficiency of the third counter. The path length through the counter was determined by a collimator as shown.

In order to insure the negligibility of parasitic effects such as accidental coincidences and scattering, the experiment was first carried through with four high efficiency (12-cm Hg argon-butane) counters in the system. Curve *A* indicates the results. The gamma-ray background was eliminated by a 3-in. lead shield between the source and the counter tray, the electron beam emerging through a $\frac{3}{16}$-in. hole. The insert in Fig. 1 shows the electron-absorption curve that was obtained.

The procedure was then carried through with a low pressure (3.5-cm Hg) helium-butane mixture in the third counter. This was the result of a search for a counter mixture which would operate at low pressures and retain adequate self-quenching properties. Curve *B* shows the results for the helium-butane mixture. The specific primary ionization, s, was computed from the efficiency by means of the relation,

$$\text{efficiency} = 1 - e^{-LsP/76}.$$

In order to achieve a value corresponding to about 1 Mev and make possible comparison with Cosyns' results, the computation was made for electron energies equal to and in excess of 0.9 Mev.

The telescope was then mounted vertically, the collimator and absorber removed, and the efficiency determined for the ionizing component of cosmic radiation. A value of 44.3 ± 3 percent was obtained. Exact calculation of the path length for this case, without the collimator, is extremely difficult. However, a rough computation indicates definite upper and lower limits. This makes possible the specification of an upper and lower limit for the specific ionization (see Table I).

TABLE I. Summary of results.

	Absorber	Specific primary ionization (N.T.P.) 1-Mev electrons s_e	Specific primary ionization (N.T.P.) cosmic rad. s_c	Ratio s_c/s_e
Danforth and Ramsey	Hydrogen		6.2	
Cosyns	Hydrogen	8.2 ± 0.2	6.0 ± 0.1	0.73 ± 0.02
Hazen	Helium-alcohol	7.3 ± 0.12	7.2 ± 0.12	0.99 ± 0.04
Author	Helium-butane	10.0 ± 0.4	17.0 ± 0.4 13.2 ± 0.4	1.70 ± 0.08* 1.32 ± 0.07**
Bethe theory	Hydrogen			1.3

* Upper limit.
** Lower limit.