cm$^{-1}$, $B \sim 0$ in the crystal used here. There remains the remote possibility that the Pu$^{239}$ in the crystal, resulting from the decay of Np$^{239}$, exists as Pu (IV) and might be observed with, fortuitously, the $g$ factor of NpO$_2^{+2}$. An experiment to rule out this possibility will be attempted.

A crystal containing 0.3 $\mu$g Np$^{239}$ and 100 $\mu$g Np$^{237}$ was also prepared. This showed only the Np$^{237}$ lines (both allowed and forbidden), but the Np$^{239}$ lines were too weak to be seen.

A separate experiment in which we attempted to dynamically polarize Np$^{239}$ nuclei by saturating the forbidden paramagnetic resonance transitions as suggested by Jeffries[6] was also performed. No $\gamma$-ray anisotropy was observed ($\epsilon < 0.05\%$), which is consistent with $I(\mathrm{Np}^{239}) = \frac{1}{2}$.

Using the value $A(\mathrm{Np}^{237})$ of Bleaney *et al.*[4] and our value $A(\mathrm{Np}^{239})$ quoted above yields the ratio of the nuclear $g$ factors:

$$|g(\mathrm{Np}^{237})|/|g(\mathrm{Np}^{239})| = A(\mathrm{Np}^{237})/A(\mathrm{Np}^{239}) = 3.287 \pm 0.04.$$

Neglecting hyperfine structure anomalies, this gives for the magnetic moment ratio

$$|\mu(\mathrm{Np}^{237})|/|\mu(\mathrm{Np}^{239})| = 16.45 \pm 0.17.$$

Taking the value $|\mu(\mathrm{Np}^{237})| = 6 \pm 2.5$ nm of Bleaney *et al.*,[4] we find $|\mu(\mathrm{Np}^{239})| \cong 0.3$ nm.

We wish to thank Professor B. B. Cunningham for his helpful discussions and advice.

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[1] J. G. Conway and R. D. McLaughlin, Phys. Rev. **96**, 541 (1954).

[2] Hollander, Smith, and Mihelich, Phys. Rev. **102**, 704 (1956); Smith, Gibson, and Hollander, Phys. Rev. **105**, 151 (1957); J. M. Hollander, Phys. Rev. **105**, 1518 (1957); Newton, Rose, and Milsted, Phil. Mag. (to be published); I. Perlman and F. Asaro, *Annual Review of Nuclear Science* (Annual Reviews, Inc., Stanford, 1954), Vol. 4, p. 157.

[3] See, e.g., B. Bleaney and K. W. H. Stevens, Repts. Progr. in Phys. **16**, 108 (1953); K. D. Bowers and J. Owen, Repts. Progr. in Phys. **18**, 305 (1955).

[4] Bleaney, Lewellyn, Pryce, and Hall, Phil. Mag. **45**, 991, 992 (1954).

[5] Dobrowolski, Jones, and Jeffries, Phys. Rev. **101**, 1001 (1956).

[6] C. D. Jeffries, Phys. Rev. **106**, 164 (1957).

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# Electrical Properties of BaTiO$_3$† Containing Samarium

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THE properties of BaTiO$_3$ have been shown to be sensitive to impurities.[1,2] Work in this laboratory has revealed that BaTiO$_3$ containing samarium has very unusual electrical characteristics associated with its crystallographic transitions (Fig. 1). In the tetragonal region (0−120°C) the resistivity is almost independent of temperature, but at constant temperature it decreases with increasing applied voltage (noted also in other temperature regions). This voltage dependence is too large to be explained by non-ohmic contact effects. As the temperature increases above the Curie point transition (about 120°C), the resistivity rises rapidly through several orders of magnitude until about 250°C (not shown in the figure) when the resistivity then decreases with increasing temperature. The resistivity in all temperature regions varies widely with a small change in the percentage of samarium.

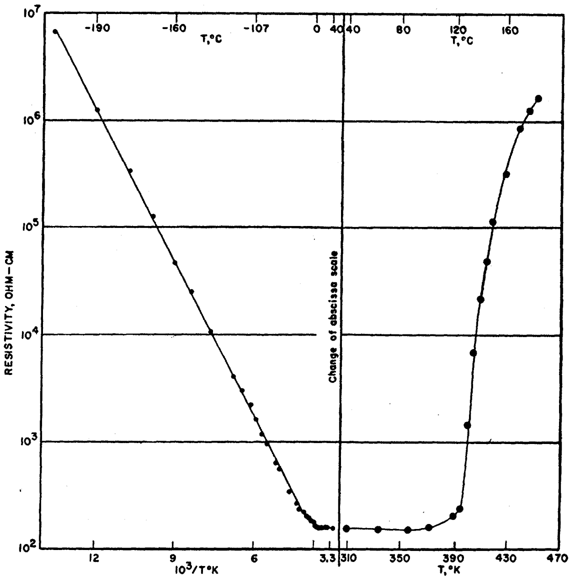

FIG. 1. Resistivity *vs* temperature for BaTiO$_3$+0.1 mole % Sm$_2$O$_3$. Note the change of abscissa scale from $10^3/T$ (°K)$^{-1}$ in the left-hand portion to $T$°K in the right-hand portion.

Below the 0°C transition the material displays characteristics of a semiconductor with a small thermal activation energy (0.1 ev). The −80°C transition produces a very small jump in the curve (unnoticeable in Fig. 1) but results in no apparent change in properties. Thermal hysteresis is observed around the various transitions.

At room temperature the material gives large front to back resistance ratios, when tested with a phosphor bronze point contact using dc voltage. Alternating current, however, experiences little or no rectification.

Optical measurements indicate that samarium introduces one or possibly two absorption bands between 0.9 and 1.5 ev below the optical absorption edge (3.1 at room temperature).

The only electrodes employed so far have been silver paint, indium-gallium, and evaporated silver (soldered with indium). The latter two are by far the best, though not entirely ohmic. Aging effects at room temperature, in the form of an increase of resistance with time, are ascribed to contacts. Temperature cycling above 250°C with ac voltage applied helps to stabilize the resistance. Quenching through the Curie point has not apparent effect on this aging process.[2] When relatively high voltages are applied, the current becomes independent of the voltage and the material acts as a current (or voltage) regulator. This effect is due to the Joule heating developed in the material which raises the temperature above the Curie point. Under these conditions there have been no aging effects noted over a period of several weeks.

A rigorous explanation for the observed effects is not available at the present time. The percentage of samarium is high enough to lead one to suspect impurity-band electrical conduction. The crystallographic changes at the $BaTiO_3$ transitions would be expected to modify the band structure and thus the conductivity. It is possible that the conductivity is due to overlap of the wave functions of the inner-shell ($4f$) electrons in the samarium.

The material used so far has consisted of 100% stoichiometric,[3] spectrographically pure $BaTiO_3$ with from 0.025 to 0.2 mole percent $Sm_2O_3$ introduced as the nitrate. The samples were pressed and then fired on platinum for 20 to 30 hours at 1350°C. This long firing has been found necessary to diffuse the impurity throughout the specimen.[4]

Future work will involve studies of other ferroelectrics and antiferroelectrics, with additions of various $4f$- and $5f$-type rare earths. Because of the tetragonal nature of $BaTiO_3$ there exists the possibility of obtaining controllable anisotropic conductivity. Tentative measurements have indicated a very high thermoelectric power and this will be further investigated.

The author wishes to acknowledge valuable discussions with Dr. Alan Franklin.

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[1] See for instance, J. P. Remeika, J. Am. Chem. Soc. **76**, 940 (1954); A. Nishioka, J. Phys. Soc. Japan **11**, 180 (1956); K. Oshima *et al.*, J. Chem. Phys. **24**, 903 (1956). After the manuscript was submitted the author's attention was called to the following note: H. A. Sauer and S. S. Flaschen, Ceramic Industry **66**, 95 (1956).

[2] J. Meisinger, Z. angew. Phys. **8**, 422 (1956).

[3] W. S. Clabaugh *et al.*, J. Research Natl. Bur. Standards **56**, 289 (1956).

[4] Samples were kindly prepared by Harold Johnson.

# Prediction of Delayed-Neutron Precursors*

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RECENT studies on the delayed neutrons from six fissionable nuclides[1] have revealed large variations in both relative and total delayed-neutron yields among the various fissionable nuclides. In order to explain individual group yield values—these being the product of relative group yield and total absolute yield—one must hypothesize particular precursor nuclides which are responsible for a given delayed-neutron group. In an attempt to select the most probable precursors, a comprehensive survey has been made of all possible delayed-neutron contributors—more than 100 nuclides under the light and heavy peaks of the fission mass distribution curve. No preselection was made on the basis of nuclide mass or charge, odd-even characteristics, etc. Individual precursor yields for the six fissionable nuclides have been calculated from the appropriate mass- and charge-distributions, including shell effects.[2] Comparison of precursor yields thus calculated with measured delayed-neutron yields for the various nuclides then gives neutron-to-$\beta$ branching ratios which may be related to theoretical branching ratios.[3–5] This treatment provides criteria for selecting the most probable precursors associated with a given delayed-neutron group. The predictions resulting from preliminary calculations are summarized in Table I. Refined calculations, now in progress, of theoretical $P_n$ values are expected to narrow further the choice of possible precursors for each delayed-neutron group.

TABLE I. Predicted delayed-neutron precursors.

| Group index | Delayed-neutron period ($U^{235}$) | Predicted precursor nuclides[a] |
|---|---|---|
| 1 | 54.5 sec | $Br^{87}$ |
| 2 | 21.8 | $I^{137}$, ($Br^{88}$, $Se^{86}$) |
| 3 | 6.0 | $I^{138}$, $Br^{90}$, $Br^{89}$, ($Cs^{144}$) |
| 4 | 2.2 | $I^{139}$, $Br^{91}$, $Kr^{93}$, $Xe^{141}$, ($Xe^{142}$) |
| 5 | 0.50 | $I^{140}$, $Kr^{95}$, $Br^{92}$, $Cs^{145}$ |
| 6 | 0.18 | ··· |

[a] All predictions are tentative. The nuclide which appears to be the "most probable" main precursor is listed first; possible minor contributors are enclosed in parentheses.

$Br^{87}$ and $I^{137}$ in Table I are, of course, the well-known 55-sec and 22-sec delayed neutron precursors chemically identified by Sugarman.[6,7] The third-group precursor has previously been attributed to an isotope of bromine with mass number in the range 89–91,[6] although present calculations would indicate $I^{138}$ as the most probable third-group main precursor. Certain other nuclides previously proposed as delayed-neutron emitters (e.g., $Sb^{135}$ proposed for the fourth group, and $Sb^{137}$ or $As^{85}$ proposed for the fifth group[2,4] are not supported by the selection criteria and are therefore excluded from Table I. No satisfactory prediction is available, as yet, for the sixth delayed-neutron group. Reported yield measurements on $Be^7$ and $Be^{10}$ formation in $U^{235}$ fission[2] provide a basis for rejecting the hypothesis[8] that the sixth delayed-neutron group follows $Li^9$ $\beta$-decay, the $Li^9$ being formed as a light fragment in ternary fission. Similarly, the possibility of short-period neutron contributions from photoneutron production (via high-energy fission gammas from the irradiated sample) may be ruled out on the basis of simple yield considerations. The sixth-group precursor is thus