those of the other beam particles, unless the beam radius is almost as small as the Budker equilibrium radius.

This effect may be minimized if the neutral atom density is small enough so that the neutralization time is at least a tenth as long as the time necessary to reach equilibrium in the radiation stage. In such a case the results of Sec. VIII D, should still represent the approximate behavior of the beam after the neutralization fraction has become large.

Although this possibility of electron capture makes an accurate calculation of the beam behavior difficult, the effect may be useful in the production of an intense beam. In fact, appreciable electron capture may be necessary to compensate for losses. (The single-scattering loss mechanism discussed in the present work and in references 1 and 3 very likely leads to an underestimate of the rate of electron loss.)

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$LiH_3(SeO_3)_2$: New Room-Temperature Ferroelectric*

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$LiH_3(SeO_3)_2$ crystallizes in the monoclinic system and exhibits useful ferroelectric properties in the entire temperature range −196°C to 90°C. The spontaneous polarization and coercive field at room temperature are 15.0 μcoulombs/cm² and 1400 v/cm, respectively. X-ray examination reveals that the crystals belong to the space group *Pn*, with cell dimensions $a=6.25_8$A, $b=7.88_6$A, $c=5.43_3$A, $\beta=105.2°$, and two formula units per unit cell. The polar direction is perpendicular to the (001) plane. No Curie temperature could be observed. $NaH_3(SeO_3)_2$ is not isomorphous, but is ferroelectric below −79°C.

INTRODUCTION

A SURVEY of various recently-discovered ferroelectrics reveals the importance of the near-planar configuration of the glycine molecule, and of the tetrahedral ions $(NH_4)^+$ and $(SO_4)^{--}$, in ferroelectric transitions. Now we have found that hydrogen-bonded crystals containing pyramidal ions like $(SeO_3)^{--}$ also exhibit interesting phase transitions. For example, optical examination reveals that $KHSeO_3$ exhibits a beautiful transition at −39°C; however, no dielectric anomaly could be detected at this temperature. $NaH_3(SeO_3)_2$, which crystallizes in the monoclinic system and undergoes a transition at −79°C, exhibits useful ferroelectric properties from this temperature down to liquid nitrogen temperature. Detailed measurements on this crystal will be reported elsewhere. $LiH_3(SeO_3)_2$, on the other hand, is ferroelectric at room temperature and possesses many features of practical importance. The results of x-ray crystallographic, dielectric, and thermal measurements of this crystal are reported here.

PREPARATION AND PROPERTIES OF $LiH_3(SeO_3)_2$

$LiH_3(SeO_3)_2$, also described as $LiHSeO_3 \cdot H_2SeO_3$, can easily be crystallized from aqueous solution of lithium hydroxide or lithium carbonate in selenious acid in stoichiometric proportions: one mole equivalent of LiOH to two moles of H_2SeO_3. The crystals obtained are fairly stable at room temperature and do not require protective coating. X-ray measurements using single-crystal Weissenberg photographs with Cu*Kα* radiation reveal that the crystal belongs to the monoclinic system, with space group *Pn* and with the cell dimensions $a=6.25_8$A, $b=7.88_6$A, $c=5.43_3$A, and $\beta=105.2°$. There are two formula units per unit cell. The crystal possesses an imperfect cleavage plane perpendicular to the *b* axis. A detailed crystal structure analysis is in progress in this laboratory; this will be followed by a neutron analysis at Brookhaven National Laboratory.

The ferroelectric direction is perpendicular to the (001) plane and is close to the $[40\bar{1}]$ direction, thus again demonstrating that in monoclinic ferroelectric crystals the polar direction can lie along any general direction perpendicular to the *b* axis, or along **b**.

Figure 1 represents the temperature variation of the small-field dielectric constant, measured at a frequency of 10 kc/sec and with a field of 5 v/cm applied along the polar direction. The dielectric constant, which has a value of 30 at room temperature, rises very rapidly above 80°C, with a corresponding increase in dielectric loss due possibly to increasing ionic conductivity. To determine whether this rise in dielectric constant might be due to a phase transition at higher temperature,

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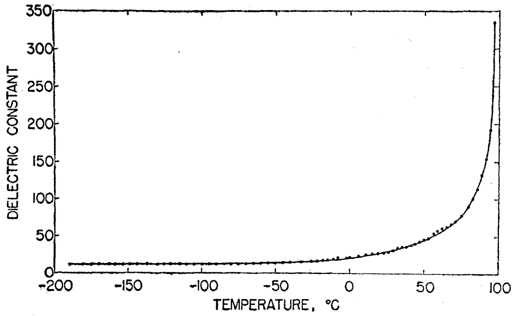

FIG. 1. $LiH_3(SeO_3)_2$. Dielectric constant measured along the polar direction, as a function of temperature.

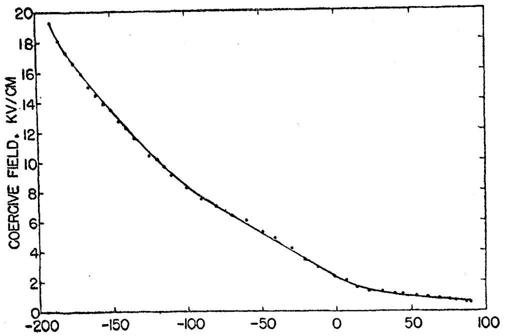

FIG. 2. $LiH_3(SeO_3)_2$. Coercive field *vs* temperature.

measurements were carried up to the melting point of the crystal at 110°C; but no dielectric anomaly could be detected. This result was substantiated by specific heat measurements over the temperature range −175°C to 110°C. No transition could be observed below the melting point.

The dielectric constants ϵ_a and ϵ_b, with the electric field applied parallel to the *a* and *b* axes, respectively, have values 29 and 13 at room temperature, and their variations with temperatures are quite similar to Fig. 1.

Examination in a hysteresis bridge reveals that one can obtain good, well-saturated, square hysteresis loops in $LiH_3(SeO_3)_2$ over the entire temperature range from −196°C to 90°C. The spontaneous polarization is by far the largest yet observed for a water-soluble ferroelectric; it has a constant value of 15 microcoulomb/cm^2 in the temperature range mentioned above. This is about three times the magnitude of the spontaneous polarization of the ferroelectric dihydrogen phosphates, and compares favorably with the value of 26 μcoul/cm^2 as found in $BaTiO_3$ single crystals. The coercive field has a value of 1400 v/cm for an applied field of 5 kv/cm at room temperature, and its variation with temperature is represented in Fig. 2.

No measurement of switching-time characteristics has yet been carried out on this crystal; but the high spontaneous polarization suggests that the switching will be fast.

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