These lines are Stark-broadened[11] and show a density (of order 10^{21} cm^{-3}) which is about twice as high as when the Ne-$K\alpha$ line is absent. It seems that energy carried inwards by fast particles (mainly ions) effectively enhances the heat conduction which was found[11] to otherwise to be inhibited. This effect should be favorable for compression, in contrast to preheating.

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Tricritical Point in KH_2PO_4†

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A pressure-induced tricritical point is indicated for KH_2PO_4 near 2 kbar pressure. This estimate is based on analysis of our static dielectric data for pressures up to 3 kbar.

Tricritical points in an experimentally accessible three-dimensional space of the pressure, temperature, and electric field are possible in ferroelectrics. Peercy[2] found a tricritical point in SbSI near 235 K and 1.40 kbar. A proposal[3] for a tricritical point in KH_2PO_4 (KDP) at high pressure was based on the fact that the critical field E_{cr} for KD_2PO_4 (DKDP) is 7100 V/cm,[4] and only about 200 V/cm in KDP. The transition temperature T_c decreases from 223 K in DKDP to 123 K in KDP, and applying pressure to KDP reduces T_c until it approaches 0 K at 17 kbar,[5] so one could expect that the tricritical pressure p_t required to reduce E_{cr} to zero would be much less than 17 kbar. A portion of the proposed phase diagram in pressure–temperature–electric-field space appears in Fig. 1.

To determine this phase diagram experimentally, we first measured E_{cr} at $p = 0$ and obtained 232 ± 70 V/cm,[6] in fair agreement with most of the other reported values. From electrocaloric experiments, Strukov *et al.*[7] calculated $E_{cr} = 124$ V/cm. Reese[8] found no latent heat for fields above 300 V/cm. From polarization measured as a function of temperature and bias field, Sidnenko and Gladkii[9] found a critical field of 370 V/cm. From quasi-static tracing of hysteresis loops, Okada and Sugié[10] obtained 160 V/cm for E_{cr}. Birefringence measurements of Vallade[11] lead to a critical field value of 254 V/cm. In contrast to these low values, Kobayashi, Uesu, and Enomoto[12] found $E_{cr} = 8500$ V/cm from x-ray dilatometric studies. Eberhard and Horn[13] derived 6500 V/cm from thermal hysteresis of the ac dielectric susceptibility, but our reanalysis of their data taking other sources of hysteresis into account is consistent with a critical field near 300 V/cm.[14]

We report here our measurements of static dielectric behavior of a second KH_2PO_4 crystal at pressures of 0, 1, and 3 kbar; and using these results, we employ Landau theory[15] to estimate the tricritical pressure p_t.

The $1 \times 1 \times 0.2$ cm^3 crystal was prepared by Cleveland Crystals, Inc. with chrome-gold electrodes evaporated onto the large faces which are perpendicular to the ferroelectric c axis. No guard-ring configuration was used. The sample was suspended inside the pressure vessel which is enclosed by a double-walled cryostat immersed

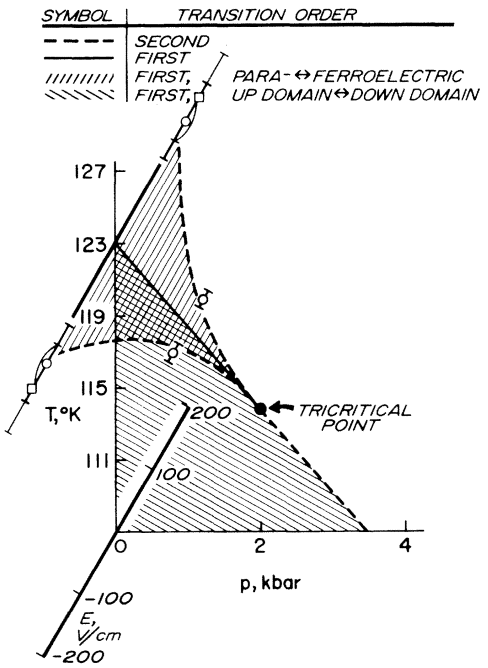

FIG. 1. Portion of proposed phase diagram for KH_2PO_4, showing our critical field results. The diagram is based on $T_c(p)$ as measured by Samara (Ref. 5), $p_t = 2.0$ kbar, $E_{cr} = 180$ V/cm for $p = 0$, and $E_{cr} \propto (p_t - p)^{5/2}$ for $p \leq p_t$ as predicted by Eq. (1) if $B \propto (p - p_t)$. Squares and circles indicate E_{cr} results for crystal 1 (Ref. 6) and crystal 2, respectively.

in liquid nitrogen. The temperature of the pressure vessel can be held constant within ± 2 mK. The pressure medium was helium, which is a fluid above its critical point under our experimental conditions. The pressure is determined with an accuracy of ± 0.4 bar as measured by a thermostated Harwood manganin cell.

The equilibrium polarization P was determined from electrometer measurements of the voltage across an 8-μF polystyrene capacitor in series with the crystal, for various combinations of p, T, and E. We display and analyze these data as curves of constant polarization, or "isopols." In the isopol picture, a first-order transition is identified by $E = 0$ intercepts which rise above T_0 for small P and fall below T_0 for large P, as shown in Figs. 2 and 3 for pressures of 0 and 1 kbar, respectively. At 3 kbar the transition appears to be second order because the extrapolated isopols shown in Fig. 4 do not cross but their $E = 0$ intercepts fall below T_0 quite rapidly with increasing P.

The behavior of our crystal as displayed in these isopol plots is well described by the Landau

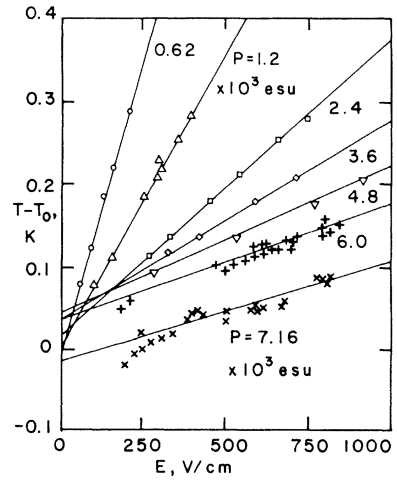

FIG. 2. Constant polarization (isopol) plots for KH_2PO_4 at zero pressure. Straight lines here and in Figs. 3 and 4 are plots of Eq. (1) for the polarization indicated, using coefficients given in Table I.

equation of state[15]

$$E = A_0(T - T_0)P + BP^3 + CP^5, \quad (1)$$

which obtains from differentiating the free energy expanded as a Taylor polynomial in P. In the Landau picture the transition is first order for B negative, second order for B positive, and zero at a tricritical point. We determine A_0 in Eq. (1) from $A_0 = (\partial E/\partial T)_P/P$ for individual isopols. To find T_0, the $E = 0$ intercepts of the low-P isopols are extrapolated to $P = 0$. We find B and C from a plot of $[-A_0(T - T_0)/P^2]_{E=0}$ versus P^2, in which B is the intercept and C is the slope. From these

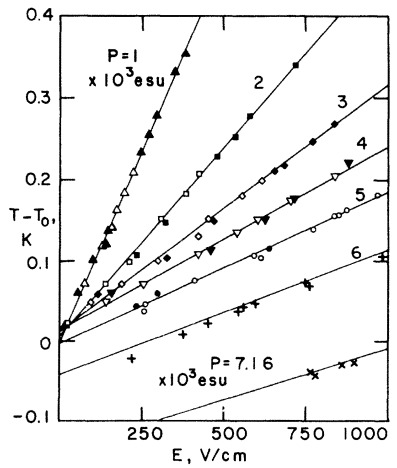

FIG. 3. Isopol plots for KH_2PO_4 at 1 kbar. Solid symbols represent data obtained before T_0 made an apparent 37 mk upward jump; open symbols, + and × indicate data obtained subsequent to this jump.

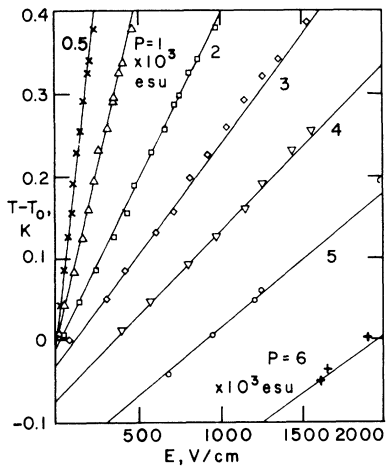

FIG. 4. Isopol plots for KH_2PO_4 at 3 kbar.

results for A_0, B, and C we calculate E_{cr} and T_{cr} from Eq. (2) below. The results are shown in Table I. A linear interpolation yields $B = 0$ at 2.0 ± 0.3 kbar, which leads us to conclude that a tricritical point occurs at this pressure. Possible sample-dependence and pressure-medium-dependence (helium may diffuse into the crystal) of the tricritical pressure have not yet been investigated.

The coordinates of the critical point of the first-order transition line in the temperature-electric field plane, as obtained from Eq. (1) are

$$T_{cr} = T_0 + 9B^2/20A_0C,$$
$$E_{cr} = [2(-B/5)^5/(C/3)^3]^{1/2}. \quad (2)$$

For an isopol plot, this critical point is identified as the $E \neq 0$ apex of a distorted triangle formed by the caustic of intersecting isopols, because the intersection of extrapolated isopols occurs in regions where the free energy has local minima and first-order transitions occur where these minima are equal. Such critical points can be seen in Figs. 2 and 3.

We now discuss briefly the predictions of certain theories of KDP regarding the tricritical point. The Slater-Takagi-Senko model for KDP includes the possibility of a tricritical point,[3] because Silsbee, Uehling, and Schmidt[16] showed that the transition order predicted by this model depends on the relative magnitudes of three parameters, the Slater energy ϵ_0, the Takagi energy ϵ_1, and the long-range interaction parameter β. Blinc and Svetina[17] showed that while the analysis of Ref. 16 gives good agreement with experiment for DKDP, introduction of a proton intrabond tunneling parameter Γ helps to explain phenomena in KDP. A calculation of the pressure dependences of these four parameters and the corresponding effect of hydrostatic pressure on the order of the transition will appear elsewhere.[18]

In conclusion, a Landau-type analysis of our dielectric data indicates that KH_2PO_4 has a tricritical point near 2-kbar pressure. These studies are being continued and will be described elsewhere in detail.

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TABLE I. Landau coefficients and transition parameters for KH_2PO_4 at three pressures. The apparent slight deviations of the Landau parameters from linear pressure dependence cannot be considered significant without additional data.

Pressure (kbar)	$A_0 \times 10^3$ (cgs-esu)	$B \times 10^{11}$ (cgs-esu)	$C \times 10^{19}$ (cgs-esu)	E_{cr} (V/cm)	$T_{cr} - T_c$ (^{0}K)	ΔP (T_c) (μC/cm^2)
0.0016	3.93 ± 0.07	-1.48 ± 0.05	3.1 ± 0.2	186 ± 60	0.053 ± 0.010	1.99 ± 0.15
1.000	3.64 ± 0.08	-0.89 ± 0.05	3.6 ± 0.2	43 ± 13	0.018 ± 0.005	1.43 ± 0.10
3.000	4.04 ± 0.10	$+0.90 \pm 0.05$	6.1 ± 0.2		(not applicable)	

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Neutron Scattering Study of Elementary Excitations in Liquid Helium-3†

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The neutron inelastic scattering function of liquid helium-3 at 0.015 K has been measured for wave vectors in the range $0.8\ \text{Å}^{-1} \leq q \leq 2.2\ \text{Å}^{-1}$. For $q < 1.4\ \text{Å}^{-1}$, the scattering function contains two peaks. The peak at lower energy is due to spin-fluctuation scattering in the particle-hole region while the peak at higher energy is identified to be the zero sound mode. By comparing the measured structure factor with the x-ray structure factor, the spin-dependent scattering cross section and the corresponding structure factor are determined.

The importance of neutron inelastic scattering results for liquid ^{3}He has long been recognized,[1,2] but the large neutron absorption cross section of the ^{3}He nucleus has discouraged experimental efforts in the past. However, recent development of high flux reactors and experimental techniques has made such measurements feasible; and a series of experiments at ILL in Grenoble has been reported by Scherm *et al.*,[3] and Stirling and coworkers.[4,5] The lowest temperature of the Grenoble measurement was 0.63 K and, in all cases, the spectra consisted of a broad peak with no discernible structure. In particular, no structure consistent with a well defined zero-sound mode was observed. In the present Letter we report measurements of the neutron inelastic scattering function for liquid ^{3}He at 0.015 ± 0.005 K and for wave vectors in the range $0.8\ \text{Å}^{-1} \leq q \leq 2.2\ \text{Å}^{-1}$.

The measurements were made at the CP-5 reactor at the Argonne National Laboratory.[6] This is a rather modest flux reactor; to overcome the experimental difficulties associated with the large absorption in the sample, the statistical chopper time-of-flight technique was used.[7] In order to utilize fully the advantage of the statistical modulation technique, great care was taken to suppress scattering of the modulated beam other than by ^{3}He. In order to avoid systematic errors, it is also very important that an accurate correction for the extraneous scattering by applied. The sample arrangement which was used in the present study was designed with these criteria in mind and will be described in detail elsewhere. The sample was cooled in a ^{3}He-^{4}He dilution refrigerator[8]; and the sample temperature was monitored by two carbon resistors attached to the sample container.

Time-of-flight spectra were measured in fifteen separate groups of detectors at scattering angles between 30.4° and 106.7°; the incident neutron energy was 4.82 meV. Data were collected for 10 days with liquid ^{3}He in the container and for an equal length of time with the container empty. The scattering observed with the container empty was subtracted from the scattering observed with liquid ^{3}He in the container after normalization to equal incident flux as measured by a beam monitor. Examples of the resulting time-of-flight spectra are shown in Fig. 1. Standard correction procedures were used to transform the time-of-flight spectra to the scattering function at constant angle.[9] Three points are worth mentioning with regard to these procedures: (i) The data were put on an absolute scale by normalization to the elastic scattering from a vanadium foil in a geometry closely reproducing the geometry of the ^{3}He surface; (ii) the correction for absorption in the sample was made along the lines recently discussed by Sears[10]; and (iii) no correction for instrumental resolution has been applied to the data; the energy resolution is ≈ 0.3 meV and the wave-vector resolution is less than $0.1\ \text{Å}^{-1}$ over the range of the measurement.

It is clearly more advantageous to represent the scattering function at a constant value of q rather than at a constant angle of scattering. Standard interpolation procedures[9] were employed to obtain the scattering function values of q in the