Generation of DD – Reactions in a Ferroelectric KD2PO4 Single Crystal During Transition Through Curie Point (T_c = 220 K)

A.G. Lipson[1,3], A.S. Roussetski[2], E.I. Saunin[3], G.H. Miley[1]

[1]University of Illinois at Urbana-Champaign, Department of Nuclear, Plasma and Radiological Engineering Urbana IL, 61801 USA

[2] Lebedev Physics Institute, The Russian Academy of Sciences, Moscow, 117285 Russia

[3] Institute of Physical Chemistry, The Russian Academy of Sciences, Moscow, 117915 Russia

Neutron emission from ferroelectric crystals during transition through Curie point

- B. Naranjo et al (Nature, **434**, 1115-1117, (2005) presented a desktop neutron generator based on deuteron beam ionized and accelerated up to 100 keV by electric field arising from the spontaneous polarization of pyroelectric LiTaO3 crystal at a low pressure deuterium gas adsorption.

Fracto-emission

- The fracto-fusion caused by a weak neutron emission has been observed during the fracture of deuterated dielectric crystals (i.e. induced polarization), where cracks serve as tiny accelerators (B.V. Deryaguin, et al, Nature **341**, 492 (1989).

Neutron emission in deuterated ferroelectrics KD_2PO_4 (DKDP) during passing through Curie point

- The reason of search for neutron emission in deuterated ferroelectrics was a strongest electric field in the lattice ($E \sim 10^{10}$ V/m) that arises in the course of spontaneous polarization during heating or cooling of KD_2PO_4 (DKDP) single crystal through the Curie point T_c =222 K.

  A.G. Lipson, et al, JETP, **76**(6), 1070-1076 (1993).

Experimental

- Transitions through Curie point Tc =220 K by heating-cooling cycle using LN2 cryostate. Control of transition with Thermally stimulated depolarization (TSD).
- Neutron measurements with BF3 – 7 counter proportional neutron detector.
- Tritium measurements with liquid scintillator technique with dissolving of DKDP crystals in H2O.
- Recently done: 3.0 MeV proton measurement with CR-39 (open and filtered with Al foils) attached to DKDP plates cycled through Curie point.

Neutron Emission: Amplitude Spectra

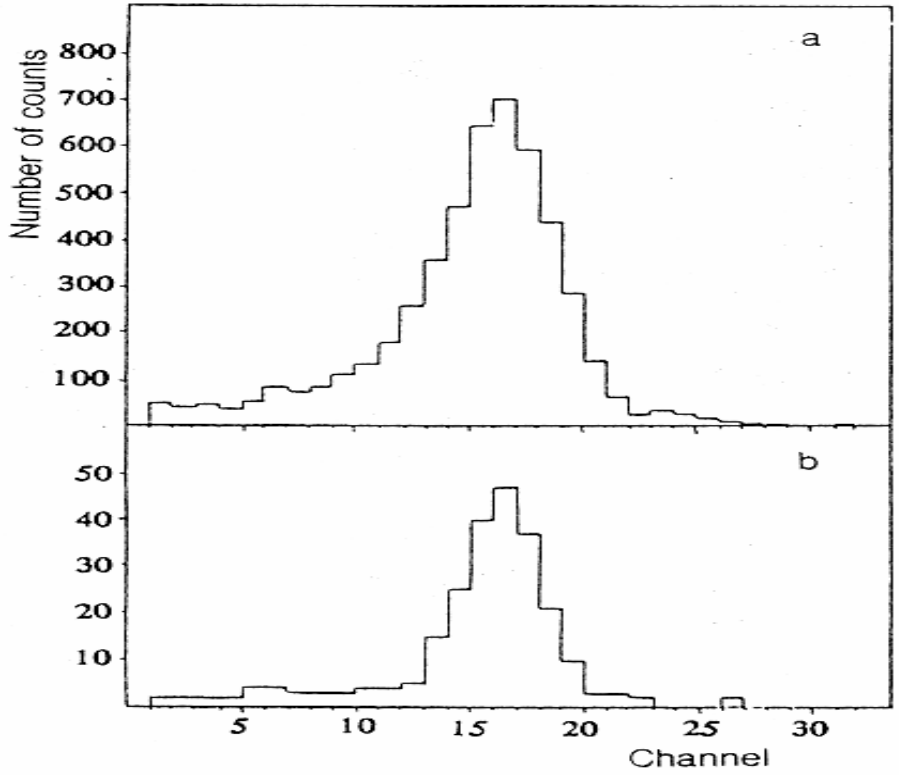


FIG. 1. Distribution of the pulses arriving at the neutron detector among channels of the pulse height analyzer. a—From the Cf^{252} neutron source; b—during temperature cycling of DKDP crystals near T_c.

Neutron Emission vs. Spontaneous polarization (TSD)

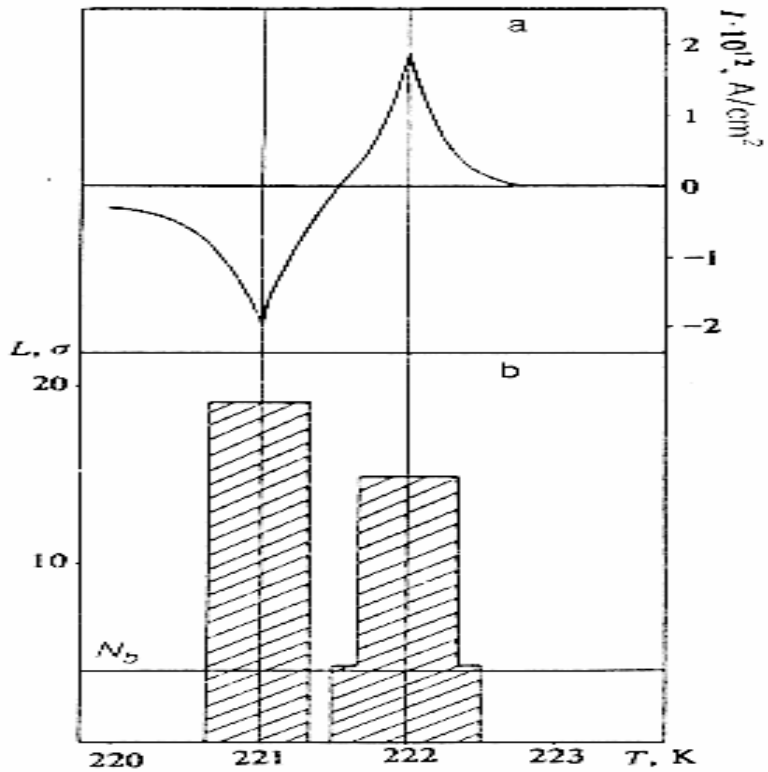
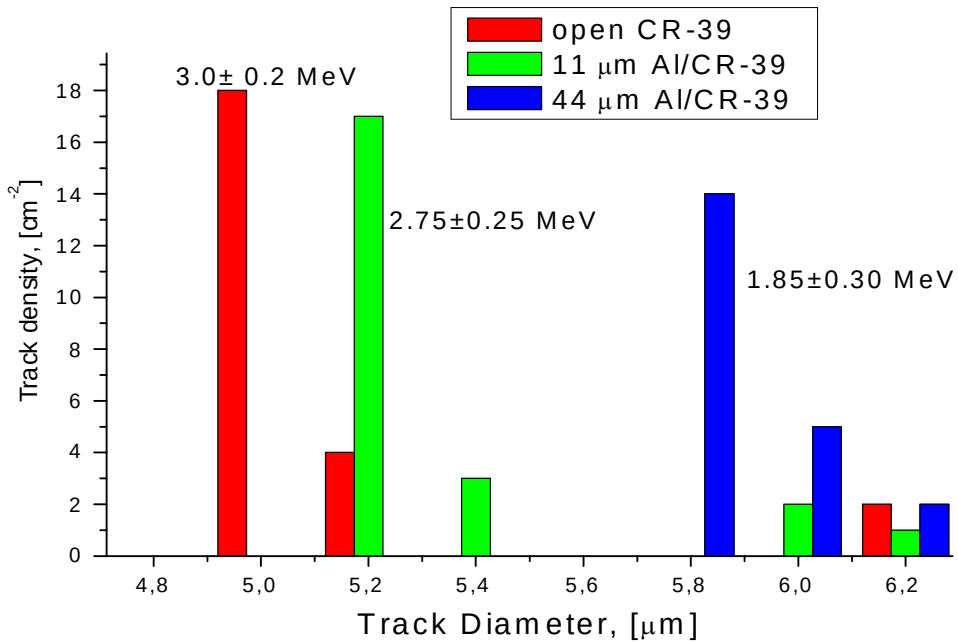


FIG. 4. a—Spectrum of thermal depolarization during the heating of DKDP sample near T_c; b—corresponding histograms of neutron bursts. Here L, σ, is the confidence level of the observed neutron bursts, and N_0 is the average background level.

Parameters of Neutron emission in KH2PO4 and KD2PO4 single crystals

Crystal	Temperature interval: ΔT, K	Foreground-Background, cps	Neutron emission Φ_n, n/s
KH_2PO_4 (m=0.8 g)	121-125	0.000±0.005	-
KH_2PO_4 (m=0.8 g)	219-223	0.001±0.005	-
KD_2PO_4 (m=0.8 g)	210-215	0.001±0.005	-
KD_2PO_4 (m=0.5 g)	219-223	0.012±0.004	0.40±0.13
KD_2PO_4 (m=0.8 g)	219-223	0.020±0.004	0.61±0.16
KD_2PO_4 (m=0.8 g)	221.0±0.5; 222.0±0.5	0.025±0.004	0.75±0.15

3 MeV Proton Emission: 40 transitions through Curie point in a row with attached open and filtered CR-39 detectors: The detected track diameters are consistent with 3 MeV proton energy losses in Al foils



Tritium concentration measurements by liquid scintillator technique (in units of 10^9 T-atoms per gram of DKDP)

# sample	DKDP crystal	Cell glass	Cell atmospher	Total
control	5.0 ± 0.2			5.0±0.2
*100 cycles through T_c	5.9 ± 1.1	8.3 ± 1.3	9.2 ± 1.5	23.4 ± 1.8

*The DKDP sample m = 0.5 g was subjected to 100 heating – cooling cycles in isolated glass cell at atmospheric pressure. Accordingly to this measurement the yield of tritium was found to be Yt = (1.82 ±0.25)x10^8 [t/transition].

Neutron and proton emission Yields per transition through Curie point

- Neutron yield from d(d, n)He^3 reaction was found to be Y_n = 20 ± 4 [n/transition-g] in the range of 219-223 K.
- Branching ratio between neutrons and tritium should be: Y_n/Y_t ~ 10-7.
- Recently measured (with CR-39) 3.0 MeV proton yield from d(d,p)t reaction, taking into account efficiency of CR-39 detection of 3.0 MeV protons (ε_p = 0.076) at $\langle N_p \rangle$ = 0.5 ± 0.1 count/transition was found to be

$$Y_p = 12 \pm 3 \text{ [p/transition-g]}$$

No significant difference between DD-reaction channels when 3.0 MeV proton and neutron yields are compared.

Ways to enhance neutron emission from DKDP

- Use double crystal DKDP system (cathode and anode) in deuterium atmosphere p~ 10 mtor (Double ferroelectric system gives 200 keV deuterons: J. A. Geuther and Y. Danon, J. Appl. Phys., 97, 074109 (2005))
- Simultaneous transition through Curie Point (Tc=220 K) of both crystals
- To keep constant positive electric charge at the cathode surface, the back face of the DKDP cathode is grounded via an ohmic contact

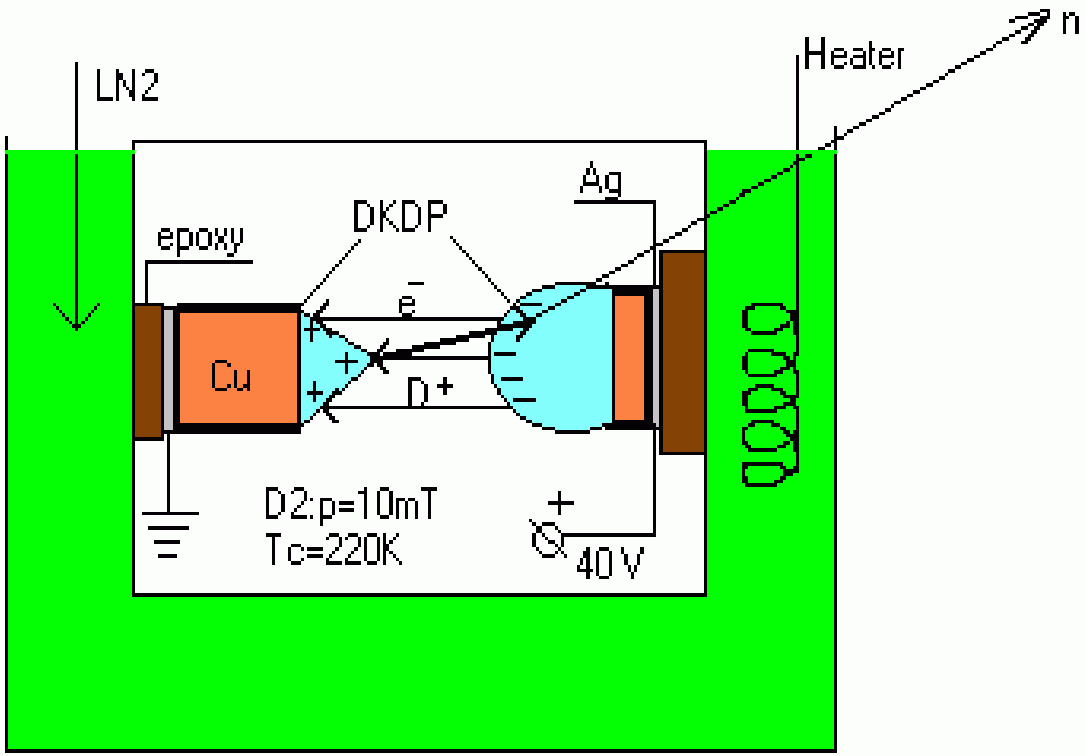
Deuteron energy estimate

- During simultaneous transition through Curie point both cathode and anode are triggered to a spontaneous polarization state (P_s ~ 5.0×10^{-6} C/cm^2, electric field E ~ 3×10^7 V/cm).
- The deuterons from the anode are accelerated in this field in the interelectrode gap toward the DKDP cathode and bombard it with an energy Ed ≥100 keV.

Neutron Yield estimation

- The electron current density is of order: $J_e \sim 1.0\ \mu A/cm^2$. Assuming a secondary ion emission coefficient ~ 1 and taking into account the possibility of direct deuteron field emission from the DKDP anode tip, the D+ current density would be the same order of magnitude as the electron emission one. Thus, at $E_d \sim 100$ keV and $J_d \sim 1\ \mu A/cm^2$, the neutron yield is 10^5-10^6 n/s in 4π ster.

Sketch of 2.45 MeV neutron source based on a high voltage discharge between DKDP cathode and anode during their passage through Curie point.



Advantage and applications

- Advantages include the very compact small size and elimination of a massive power supply, making this truly a portable source.
- This monoenergetic tabletop neutron source with moderate neutron yield could be used for airport security checking, geological and bio-medical purposes.

Conclusions I

- Generation of DD-reaction resulting in neutron and 3 meV proton emissions in DKDP ferroelectric crystal during passage through Curie point has been established.
- It was shown that neutron and proton channels in DKDP crystal give comparable nuclear yields. Large amount of tritium production (~ $2x10^8$ T^3 at./transition) cannot be referred to usual DD-reaction.
- The factor of spatial separation of deuteron source and target in deuterated ferroelectrics can be used to obtain large neutron yield during transition of these ferroelectrics to spontaneously polarized state.

Conclusions II

- New type of neutron source based on electric discharge between two ferroelectric KD2PO4 (DKDP) crystals during their polarization reversal at T = 220 K in D2/T2 atmosphere is proposed. No high voltage power supply. Small size. Projected intensity $Y_n = 10^6(D_2)$-10^8 (T_2) n/s.
- Potential applications include Homeland security and oil exploration as a bore hole source.
- **References**:
- 1. A.G. Lipson, et al, JETP, **76**(6), 1070 (1993),
- 2. B. Naranjo et al., Nature, **434**, 1115, (2005).