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POSITRONS AND ELECTRONS IN LiF

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Planar Channeling Radiation from Relativistic Positrons
and Electrons in LiF

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ABSTRACT

Channeling radiation has been measured for planar-channeled 54- and 83-MeV positrons and 17-, 31-, and 54-MeV electrons in the ionic crystal LiF. The results are shown to be in reasonable, but not perfect, agreement with the results of many-beam calculations based upon a model of the crystal as an array of isolated Li^+ and F^- ions.

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We have measured channeling radiation from the compound binary crystal LiF. This material was chosen because its low average atomic number (6) and high Debye temperature (≈ 730 K) ensure relatively small scattering of channeled particles by thermal vibrations of the crystal atoms. Our 25- μm -thick LiF crystal was prepared by polishing, followed by etching with water.

LiF crystals have rocksalt structure. For such crystals, the planes whose Miller indices are all odd are segregated: planes consisting entirely of Li atoms alternate with planes of F atoms. Planes with even indices are mixed, and to first order will appear to a channeled particle to be simple planes of $Z \approx 6$.

The measurements were performed with charged-particle beams from the Lawrence Livermore National Laboratory Electron-Positron Linear Accelerator. The experimental apparatus and procedures are described in Refs. 1-3. Channeling-radiation spectra for LiF were obtained at two positron-beam energies, ~ 54 and ~ 83 MeV, and at three electron-beam energies, ~ 17 , ~ 31 , and ~ 54 MeV. Details specific to these measurements (including exact energies and beam divergences) are given in Refs. 4 and 5. Axial channeling-radiation spectra were obtained as well.⁵

Calculated planar-averaged potentials for charged particles channeled along the three major planes in LiF are shown in Fig. 1 for positrons and in Fig. 4 for electrons, along with the eigenvalues for ~ 54 MeV. The calculations use the many-beam approximation, described in Ref. 6, which takes into account the periodicity of the potential, and models the LiF crystal as an array of isolated Li^+ and F^- ions (further details can be found in Refs. 4 and 5).

The potentials for the mixed (110) and (100) planes are not qualitatively different from those for monatomic crystals. For the segregated (111) planes, however, the potential for positrons (Fig. 1c) is composed of two shallow "Li" wells inside a deep "F" well and that for electrons (Fig. 4c) has the deep F wells alternating (with equal spacing) with the shallow Li wells. This contrasts with the double-well structure for the (111) planes in diamond or silicon, where the spacing between wells is uneven (see Ref. 7).

The measured spectra for all the major planes are shown in Figs. 2 and 3 for 54- and 83-MeV positrons and in Figs. 5-7 for 54-, 31-, and 17-MeV electrons, respectively. Also shown, as vertical lines in Figs. 2 and 5 are our theoretical predictions for the spectral lines calculated with the potentials of Figs. 1 and 4, respectively. The positions of these lines are the Doppler-shifted transition energies, and their heights are relative intensities, assuming equal initial level populations. The vertical lines in Figs. 6 and 7 result from the potential of Fig. 4, but with eigenstates appropriate to 31- and 17-MeV electrons, respectively. The high density of states bound by the potentials of Fig. 1 for 83-MeV positrons precludes this convenient kind of representation of the theoretical predictions in Fig. 3, but the calculated results are qualitatively similar to those shown in Fig. 2.

We note the following features of the positron spectra (Figs. 2 and 3):

- (i) The main peaks in the (110) and (100) spectra (parts a and b) are asymmetric, corresponding to the anharmonicity of the potentials.
- (ii) The (111) spectrum, unlike all other channeling-radiation results for positrons published to date, is fragmented into several structures, corresponding to transitions in the "F" well, transitions in the "Li" well, and $\Delta n = 3$ transitions [for a discussion of $\Delta n = 3$ transitions (in Si), see Ref. 8].

- (iii) Although the calculated line energies are in moderate agreement with the data, they are systematically and significantly too high.
- (iv) The positron transition energies scale almost exactly as $\gamma^{3/2}$, as they should.

For the electron spectra (Figs. 5-7), we note the following:

- (i) Here the calculated line energies are significantly too high for the 54- and 31-MeV data (with the exception of the $1' \rightarrow 0'$ Li-well transition at 20.6 keV) but are somewhat too low for the 17-MeV data.
- (ii) The agreement of experiment and theory for the $1' \rightarrow 0'$ line for 31 MeV, where it is not obscured by any F-well transition, establishes that the thermal-vibration amplitude for Li is correct.
- (iii) Increasing the thermal-vibration amplitude for F improves the agreement for the 54- and 31-MeV cases, but makes that for the 17-MeV case worse. Therefore, the calculated values for the transition energies cannot all be brought into agreement with the measured ones merely by varying the thermal-vibration amplitudes.
- (iv) Calculated linewidths (given in Ref. 5; see also Ref. 3) are in good agreement with the measured ones for the (110) and (111) planes; yet for the (100) plane, the measured widths are significantly larger (in some cases by as much as 30 to 50%) than the calculated values.
- (v) The scaling of the transition energies with incident beam energy varies, as it should, from the power of γ of $\sim 5/3$ for low- n transitions, corresponding to a linear "V"-shaped potential, to ~ 2 for high- n transitions, corresponding to a nearly flat potential. The $1' \rightarrow 0'$ transition scales as a low- n transition.

We conclude that although the simple many-beam calculations using an array of isolated Li^+ and F^- ions as a model for the LiF crystal are largely successful in describing semi-quantitatively the observed channeling-radiation spectra, there still remain a number of serious disagreements in detail, which in turn imply significant deficiencies in the theory. Thus, it is clear that LiF, and perhaps other binary crystals as well, provides us with a very useful testing ground for theories of channeling radiation and of crystalline potentials.

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Figure captions

1. Calculated potentials for positrons channeled along the major planes in LiF, along with the eigenvalues appropriate for ~ 54 MeV.
2. Measured photon spectra (with random spectra subtracted) for ~ 54 -MeV positrons channeled along the major planes in LiF. The vertical lines represent theoretical predictions (see text).
3. Measured photon spectra for ~ 83 -MeV positrons in LiF.
4. Calculated potentials for electrons channeled along the major planes in LiF, along with the eigenvalues appropriate for ~ 54 MeV.
5. Measured photon spectra (with random spectra subtracted) for ~ 54 -MeV electrons channeled along the major planes in LiF. The vertical lines represent theoretical predictions (see text).
6. Measured photon spectra and theoretical predictions for ~ 31 -MeV electrons in LiF.
7. Measured photon spectra and theoretical predictions for ~ 17 -MeV electrons in LiF.

Figure 7

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7