KINKS AND CHARGED EXCITATIONS IN MICA

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Moscow, September 17, 2015.
Nuclear particle in a diffusion cloud chamber.

Image taken in the Pic du Midi at 2877m in a Phywe PJ45, 2014.

45x45cm
First positron identified, Anderson 1932

Positron passing across 6mm lead plate
Diameter 26 cm
Cloud chamber, 63 MeV

CD Anderson, The positive electron, Phys. Rev. 43 (1933) 491
Nuclear particle in a diffusion cloud chamber

- Supersaturated water (or methanol) vapor
- Charged swift particles act as centers for water droplet formation
- The alcohol vapor condenses around ion trails
Tracks in mica

- Positron track produced in the decay of K\(^{40}\) with 0.5 MeV.
- 3 per second per cm\(^3\)
- Tracks are Fe oxides, magnetite

FM Russell, From Nature 1967, Nature 216, 907; 217, 51 (1967) and many more
More positrons tracks

FM Russell, From Nature 1967, Nature 216, 907; 217, 51 (1967) and many more
Poston tracks in mica muscovite

- Produced in the decay of $\text{K}^{40}$ with 0.5 MeV.
- 3 per second per cm$^3$
- Tracks are Fe oxides, magnetite

Quodons: quasi one-dimensional excitations of the lattice in mica muscovite

Tracks: magnetite Fe$_3$O$_4$
Causes
- 0.1% Swift particles
  - antimuons: after neutrino interaction
  - Positrons: decay of 40K
  - Protons
- 99.9% Most in lattice closed packed directions

Anharmonic lattice excitations?
Mica muscovite. Cation layers

\[ K_2[Si_6Al_2]^{IV}[Al_4]^{VI}O_{20}(OH)_4 \]

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\( K^+ \): 2D lattice of repulsive particles
Rows of ions within the K layers
Experimental evidence of travelling excitations in mica muscovite

Trajectories were along lattice directions within the K⁺ layer.
Surface binding energy of ejected atoms unknown: typical values 3-8 eV

Quodons: what kind of lattice excitation?

- **Not phonons:**
  - too low energy with respect to thermal one
  - Spread because frequency is in the phonon bands

- **Breathers?**
  - Internal oscillation
  - Higher energy
  - Frequency outside the phonon bands

- **Kinks?**
  - No internal oscillation
  - Supersonic
  - High energy

- **Other?**
  - Peakons, compactons, polarons, solelectrons...?
Minimal Model

Normalized movement equations:

\[
\frac{\partial^2 u_n}{\partial t^2} = -\frac{1}{(1+u_{n+1}-u_n)^2} + \frac{1}{(1+u_n-u_{n-1})^2}
\]

\[
\nu_n = u_n - u_{n-1}
\]
Ziegler Biersack Litmark (ZBL) potential for high energy collisions

\[ U_{ZBL}(r) = \frac{Z_1 Z_2 e^2}{4 \pi \epsilon_0 a} f\left(\frac{r}{a}\right) \]

\[ a = \frac{0.98856 \ a_B}{Z_1^{0.23} + Z_2^{0.23}} \]

\( a_B \) Bohr radius

\[ f(x) = \sum_{i=1}^{4} a_i \exp(-b_i x) \]


**Simplification** up to 200 KeV:

\[ U_{ZBL}(r) = \frac{2650 \text{ eVÅ}}{r} \exp\left(-\frac{r}{0.3\text{Å}}\right) \]

\[ U_{ZBL}(x) = \frac{184}{x} \exp\left(-\frac{x}{0.06}\right) \]

**Coupling potential:**

\[ U(r) = \frac{1}{r} + \frac{\alpha}{r^2} \exp\left(-\frac{r}{\rho}\right) \]
Substrate potential (1)

O and Si in planes above and below.

Coulomb and ZBL potentials.

Gives the right Frequency 110 cm\(^{-1}\)

\[
U_s(x) = \sum_{n=0}^{4} U_n \cos(2\pi n \frac{x}{a})
\]
Comparison of potentials

Units
U 2.77 eV
R 5.19 Å

Coulomb (—); ZBL (— —); Coulomb+ZBL (thick —)
substrate potential (···)  Sum of all (— —)
Fundamental ansatz

\[ v_n = -\frac{A}{2}(1 + \cos(q(na - Vt))) \quad \text{with} \quad -\pi \leq q(na - Vt) < \pi \]

and \( v_n = 0 \) otherwise

\( \lambda = 2\pi/q \) is the wavelength

\( \text{magic wave number } q \approx \frac{2\pi}{3} \)

Wavelength \( \sim 3 \)

They are exact solutions for intermediate amplitudes for the system without substrate

Kink velocities in FPU (no substrate)

System with substrate (Klein-Gordon) Supersonic crowdions

Kosevich, A.M., Kovalev, A.S.: The supersonic motion of a crowdion...
Solid State Commun. 12, 763–764 (1973);
System with substrate: supersonic crowdions

Double kink: Easy to explain


Movement of the particles in a crowdion with the magic mode

\[ \langle V_p \rangle = \frac{1}{T} = \frac{V_c}{3} \]
Origin of the double kink
Fourier spectrum of the crowdion

Kinetic energy in a moving frame

\[ \bar{v} = \frac{V_c}{a} \]
Profile of the crowdion

(a) $t \simeq -T/6$
(b) $t \simeq -0.5T/6$
(c) $t \simeq 0$

$V_n = u_n - u_{n-1}$

It corresponds very closely to the magic mode but not exactly.
Phonons and crowdions

\[ \ddot{u}_n = -\omega_0^2 u_n + c_s^2 (u_{n+1} + u_{n-1} - 2u_n) \]

\[ u_n = \exp(i(qn - \omega t)) \]

\[ \omega^2 = \omega_0^2 + 4c_s^2 \sin^2 \left( \frac{q}{2} \right) ; \quad V_{\text{phase}} = \frac{\omega}{q} \]

\( c_s = \sqrt{2} \text{ or } 3.7 \text{ km/s} \)

(a) Dispersion relation  \hspace{1cm} (b) phase velocity  \hspace{1cm} (c) group velocity

Without substrate (----)  \hspace{1cm} Black dot: crowdion  \hspace{1cm} With substrate (___)
Crowdion phonon tail

Kink velocity approaches asymptotically to the crowdion’s one

The sinusoidal phonon tail phase velocity equal to the crowdion’s one

Excess energy (1)

Crowdion 26 eV
Excess energy (2)

Crowdion 26 eV
Thermalized medium FPU (without substrate)

300 K  1000 K

(a) 300 K  (b) 1000 K
Thermalized medium KG (With substrate)

300 K

1000 K
Properties of crowdions in mica

- Crowdions travel long distances

- Energy of the crowdion 26 eV can be provided by K40 decay (0-50 eV)

- Energy of the crowdion is enough to expel an atom (4-8 eV)

- Crowdions have large energy with respect to thermal one ~1000

- Crowdions survive to high temperatures 300 K, even 1000 K

- Crowdions transport positive charge.
More about charge: K-40 decay modes

Final ion: $\text{Ar}^+$, $\text{Ar}^{++}$ (CE 0.001%)

EC: electron capture from the shell. CE: conversion electron.

# K-40 decay modes (energy and charge)

<table>
<thead>
<tr>
<th>Decay</th>
<th>$\beta^-$</th>
<th>EC1</th>
<th>EC1+CE$^1$</th>
<th>EC2$^2$</th>
<th>$\beta^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td>89.25%</td>
<td>10.55%</td>
<td>0.001%</td>
<td>0.2%</td>
<td>0.001%</td>
</tr>
<tr>
<td>T (keV)</td>
<td>1311.07</td>
<td>1460</td>
<td>1460</td>
<td>1504.69</td>
<td>483.7</td>
</tr>
<tr>
<td>Emitted charged particle</td>
<td>e$^-$</td>
<td>e$^-$</td>
<td>e$^-$</td>
<td>e$^+$</td>
<td>e$^+$</td>
</tr>
<tr>
<td>Recoil from</td>
<td>$\nu$+e$^-$</td>
<td>$\gamma$</td>
<td>e$^-$</td>
<td>$\nu$</td>
<td>$\nu$+e$^+$</td>
</tr>
<tr>
<td>Max Recoil (eV)</td>
<td>42</td>
<td>29.2$^M$</td>
<td>49.7$^M$</td>
<td>31.1$^M$</td>
<td>10</td>
</tr>
<tr>
<td>Daugther ion (A=40)</td>
<td>Ca$^{++}$</td>
<td>Ar$^+$</td>
<td>Ar$^{++}$</td>
<td>Ar$^{++}$</td>
<td>Ar</td>
</tr>
<tr>
<td>Max V (Km/s)</td>
<td>14.4</td>
<td>12$^M$</td>
<td>15.7$^M$</td>
<td>12.2$^M$</td>
<td>7</td>
</tr>
<tr>
<td>Ionization of daughter (eV)</td>
<td>50.6</td>
<td>27.7</td>
<td>40.8</td>
<td>40.8</td>
<td>15.8</td>
</tr>
<tr>
<td>$\Delta q$ (e)</td>
<td>+1</td>
<td>0</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
</tr>
</tbody>
</table>

1 Subset of EC1 when the gamma is delivered to a shell electron; $^M$ Monocromatic
2 Direct decay to Ar ground state, recoil from neutrino emission; 3 KeV Auger e$^-$
EC: electron capture; CE: conversion electron; T: energy available excluding rest masses
Ionization energy of K$^+$ 31.6 eV
K-40 decay modes (energy and charge)

- Not only recoil energy is delivered but in most cases charge

- Charge is
  - ~90% positive with very different energies,
  - ~10% neutral,
  - ~0.001% negative

- Some decays are monochromatic but others have a wide range of recoil energies
  - $\text{beta } -$ from 0 to 50.6 eV($+\$)
  - $\text{beta } +$ from 0 to 15.8 eV($-$)

JFR Archilla, YuA Kosevich et al,
Some facts about dark tracks (magnetite)

- Swift particles recorded: positrons, antimuons, protons
- All with positive charge

- Quodon tracks are dark (magnetite)

- 90% of the K-40 decay leave behind a positive charge

- There are also many black dots

- Swift particles and positrons tracks have similar thickness
Tracks of positrons and quodons

- Positrons tracks have similar thickness when the positron is about to stop a near sonic speed

Epidote tracks

-There are some faint tracks of a semitransparente material often associated of positron tracks

A positron and the negative quodon produced by the recoil?

FM Russell (2015)
Hypothesis about quodons

1.-Quodons are localized anharmonic lattice excitations that transport charge.
2.-Positive quodons cause the dark tracks of magnetite seen in mica muscovite.
3.-Negative quodons are also produced and they may leave semi-transparent epidote tracks.

Crowdions are positive: they should leave a dark track is stable in 2D.
Many new interpretations of tracks

A primary quodon scatters and produce a secondary bare quodon which gets and loses a hole until decay

$q=$quodon with $+$ charge

Primary positive quodons, and bare ones
Some bibliography

Ultra-discrete kinks with supersonic speed in a layered crystal with realistic potentials, JFR Archilla, Yu A Kosevich, N Jiménez, VJ Sánchez-Morcillo and LM García-Raffi


FM Russell, Charge coupling to anharmonic lattice excitations in a layered crystal at 800K, arXiv:1505.03185