Theoretical and practical challenges of hyper-conductivity above room temperature

Review of background, the present position and development program.

F. Michael Russell
Group of Nonlinear Physics, Department of Applied Physics I
ETSII, Universidad de Sevilla, Spain
March 6, 2017

Days on hyperconductivity. Sevilla 2016-17
The original sheet of mica in the USA that caught my attention in 1963. Photo taken in 1995 when I revisited the museum.

Photo in 2016 with the apparatus for ejection exp’t with picture of Scott-Russell.
Topics covered.

Solving a problem: track width versus speed of positron.
Evidence that quodons carry unit charge: decoration is the same as for positrons.
Doping of crystals changes how they respond and the recording process.
   This suggests that better materials than mica might be possible.
Evidence for current flow through mica crystal: early experiment data re-analysed.
Prediction of hyper-conduction and validation by Sevilla experiment.
From academic to practical application: the challenges.
A small puzzle: where is the argon from K-decay in mica?
Basic result No: 1. about 1966
Identification of positron tracks from decay of $^{40}$K.

The recording process is charge-sensitive.
In presence of positive charge excess Fe is precipitated as black magnetite $\text{Fe}_3\text{O}_4$. In presence of negative charge excess Ca forms clear epidote and Mg forms green glauconite.

Positrons identified by Rutherford Scattering Law $\sin^2\Theta$, which is unique to non-relativistic charged particles.
Basic result No: 2. about 1990.

When a positron is emitted the nuclear recoil generates a lattice excitation that moves.

It is some kind of ILM.

The recording process is charge-sensitive.
In presence of positive charge excess Fe is precipitated as black magnetite Fe$_3$O$_4$.
In presence of negative charge excess Ca forms clear epidote and Mg forms green glauconite.
Calibration of recording process. About 1980

The amount of decoration on tracks of positrons from decay of $^{40}$K is used to calibrate the recording process. (sensitivity: 1eV per 10,000 atoms along path !)

The precipitation of magnetite is due to the presence of a positive charge. The amount depends on speed of positron. *It was thought that the amount of precipitation was proportional to the time spent by moving particle in a unit cell.*

Measurements showed that the amount of decoration (the width) reached a maximum before the end of the decoration on the track.

This was a problem and difficult to understand. Where did the positron stop?

The answer came from studying ‘star-shaped’ patterns.
Charged particles and quodons probe the local composition and structure of crystals.

X-ray analysis of crystals with almost none up to many black lines shows the ratio of Fe$_2$O$_3$/Al$_2$O$_3$ is nearly constant at about 6.3/31 or about 1 atom of Fe per two unit cells.

The recording process uses only a very small excess of Fe (~10$^{-4}$ of total Fe) to decorate the tracks.

Moving particles and ILMs (quodons, breathers, kinks) probe the structure and composition of the crystals.

Usually, crystals show three different regions:

a. Damaged lattice or insufficient Fe to record.

b. Region showing no tracks but many ‘star-shaped’ patterns.

c. Normal region of good single crystal showing tracks and also many ‘dots’ of decoration.
### Chemical analysis of mica.

<table>
<thead>
<tr>
<th>Sample name</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>TiO₂</th>
<th>MnO</th>
<th>P₂O₅</th>
<th>LOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mica-01</td>
<td>44.89</td>
<td>31.73</td>
<td>0.45</td>
<td>0.85</td>
<td>n.d.</td>
<td>0.10</td>
<td>10.353</td>
<td>0.275</td>
<td>0.077</td>
<td>n.d.</td>
<td>5.00</td>
</tr>
<tr>
<td>Mica-02</td>
<td>45.54</td>
<td>31.16</td>
<td>6.44</td>
<td>0.93</td>
<td>n.d.</td>
<td>0.08</td>
<td>10.489</td>
<td>0.269</td>
<td>0.075</td>
<td>n.d.</td>
<td>4.89</td>
</tr>
<tr>
<td>Mica-03</td>
<td>45.92</td>
<td>31.18</td>
<td>6.20</td>
<td>0.86</td>
<td>n.d.</td>
<td>0.10</td>
<td>10.615</td>
<td>0.261</td>
<td>0.072</td>
<td>n.d.</td>
<td>4.43</td>
</tr>
<tr>
<td>Mica-04</td>
<td>46.02</td>
<td>31.02</td>
<td>6.21</td>
<td>0.89</td>
<td>n.d.</td>
<td>0.04</td>
<td>10.648</td>
<td>0.254</td>
<td>0.084</td>
<td>n.d.</td>
<td>4.69</td>
</tr>
<tr>
<td>Mica-05</td>
<td>46.24</td>
<td>29.92</td>
<td>6.39</td>
<td>1.53</td>
<td>n.d.</td>
<td>n.d.</td>
<td>10.816</td>
<td>0.539</td>
<td>0.050</td>
<td>n.d.</td>
<td>4.46</td>
</tr>
<tr>
<td>Mica-06</td>
<td>45.97</td>
<td>30.73</td>
<td>6.28</td>
<td>1.26</td>
<td>n.d.</td>
<td>n.d.</td>
<td>10.571</td>
<td>0.367</td>
<td>0.048</td>
<td>n.d.</td>
<td>4.16</td>
</tr>
</tbody>
</table>

**Test samples**

- **Region b stars & dots**
- **Region c quodons, etc**
- **Clear region**
- **Faint, good muon tracks**
- **Heavy fans**
- **Good quodon tracks**
Region ‘b’ shows many star-shaped patterns. Decoration strains the lattice.

‘b’ regions are in very thin layers between thick ‘c’ layers.

Probable cause of ‘b’ regions is local variation of elements in fluid during crystal growth.

Nucleation sites needed for decoration. Most probable cause is lattice damage at K-decay sites.

Extent of decoration with magnetite similar to that for single positive charge.

Recording process inhibited for quodons and muons.

Stars resemble percussion figures.
Stars lines lie in the black directions

Stars decorated with magnetite, epidote and glauconite.
Excess Ca and Mg.
Quodons propagate in these red directions

Decoration of stationary defects.

Scale: 10mm
When a positron stops and annihilates it leaves a **stationary positive charge**. *This continues to trigger the precipitation.*

As the amount of precipitation increases it stresses the lattice and *grows in the directions of lattice weakness.*

This explains the decreasing width part. [2016]
Basic result No: 3. (early 2016, with Juan Archilla)

The decoration shows quodons can carry a single unit of positive charge.

There is good evidence that quodons can also have no charge or can carry a negative charge.
Demonstration of quodons by ejection of atoms.

[26/01/2005]
A possible problem with this experiment.

With such small currents electrostatic problems and other parameter changes can influence the results.

As the crystal was rotated in front of the detector the shape of the electric field between the crystal and the detector changed.

This might have allowed creation of strong field gradients that could pull ions out from the surface of the crystal.

What was needed was a test with the only variable the alpha flux.
Basic result No: 4. (Done in 2005 but only analysed in 2016)

Count rate of ejected particles.  Expected alpha flux.
This gave three results:

1. The count rate of ejected particles was proportional to the alpha flux. Hence, the ejected particles were not due to local field extraction from the surface.

2. The ejected particles carried a positive charge. This was consistent with the previous experiment.

3. A current flowed through the crystal. The evidence from track widths showed that quodons can carry the same positive charge as a positron. (2016) This indicated that a current flowed through the crystal from the alpha source in absence of an applied electric field across the crystal.

This was evidence for infinite charge mobility at room temperature. It prompted the Sevilla experiment.
This led to a new alpha-source for the Sevilla experiment.
Designated and constructed in my own laboratory.

My excuse to come back to Sevilla.

About $4 \times 10^4$ alphas per sec.
Chemistry of muscovite: isomorphous replacements.

Natural crystals always contain impurities and isomorphous atomic substitutions.

Ideal formula: \( K_2 \text{Al}_4 \text{[Si}_6\text{Al}_2\text{O}_{20}]\text{(OH,F)}_4 \)

Most probable substitutions are:
- for K: Na, Ca
- for Al: Fe\(^{2+}\), Fe\(^{3+}\), Mg
- for Si: Al, Fe\(^{3+}\)

Typical analysis of mica showing tracks:
- \( 2K \) \( \rightarrow \) \([1.7K + 0.17Na + 0.05Ca +] \)
- \( 6\text{Al} \) \( \rightarrow \) \([5.5\text{Al} + 0.4\text{Fe} + 0.02\text{Mg} +] \)

Abundance in Earth’s crust:
- O 49
- Si 26
- Al 7.5
- Fe 4.7
- Ca 3.3
- Na 2.5
- K 2.4
- Mg 2.1
Basic result No: 5. known in 1995.
Persistence of quodon(+) tracks and degradation.

Quodon(+) tracks can be > 40cm in length. They are scattered only by major lattice defects and skate over point-defects of which there are many millions.

Scattering generates more than 50 daughter quodon tracks. If initial energy of quodon was 20 eV then average energy of daughters is < 1 eV.

Further scattering gives quodons(+) of even lower energy, of ~0.1eV but still stable and able to trap charge at 700°K.

It simply is not possible for natural crystals to have perfect lattices over such distances.

The quodons must have survived crossing many dislocations, but how?
Dislocations in mica.

S. Tolansky in 1947 showed mica contains screw dislocations.

The large unit cell size in the direction normal to the cleavage planes makes crossing a dislocation a formidable task for any localized lattice excitation.

How do quodons do it?
No sub-division of charge.

At a dislocation quodons scatter and generate secondary quodons. They can loose energy and momentum but still exist.

But the charge they carry cannot be sub-divided and continues with the strongest quodon.

The secondary quodons have no charge until they find a free charge.
Perhaps it is the collective actions of atoms in a quodon envelope that allows quodons to cross dislocations.

Since at a dislocation quodons can go from one K-sheet to another sheet might they be able to cross from one chain to an adjacent chain in the same K-sheet?
Will we ever know the detailed structure of a quodon?

It is possible that it depends on the chemical composition of the crystal. **For practical applications it is not very important.** Knowing more about the structure might help in finding better materials for HC.

We already know that different kinds of mobile excitations can exist in mica. For example the ‘fans’. I think studying ‘fans’ might help to better define a quodon.
The fans.

Perhaps it is time to think about quantum aspects of quodons?
Quantum aspects of quodons.

Direction and momentum of $^{40}\text{K}$ recoil atom, $p_r$.

The positrons are diffraction scattered by the lattice to give a forward peak in a chain direction. This peak is independent of momentum and of the de Broglie $\lambda$.

Conservation of momentum means the recoil atom must be directed in the opposite direction on the same chain and have similar momentum {but -} and so have similar de Broglie $\lambda$ as the positron.

The forward peak has symmetrical side-wings.

Ejected electrons do not show this forward peak so the momentum $p_r$ of the recoil atom can be in any direction. The resolved component of $p_r$ in a chain direction gives a quodon(+).

This means the $p_r$ of some recoils can be directed out of the (001)-plane.
Future research topics.

A major R&D task is how to generate quodons efficiently and how to control their direction of motion. Side irradiation with $\alpha$ worked but no control on p direction of q.

Is a quodon also diffraction scattered like the positron? If the neutrino energy is small then the momentum of the recoil nucleus is about the same magnitude as that of the positron but of opposite sign. They have about the same de Broglie $\lambda$.

Doping to give p or n-type material.

Reflection of charged quodons. Could this be used to create closed loops? The different masses and structure of the adjacent layers of Si,Al,O do not resonate with the motions of the potassium atoms. Who will be the first to make a HC magnet?
Total internal reflection of quodons to create a current circuit giving a magnetic field.

Crystal shape

quodons circulating

energy too low energy to eject ions

alphas

Would need a good small crystal to avoid dislocations.

Who will be first?
How to go from academic studies to real applications?

If the infinite charge mobility in mica is confirmed independently then it will attract attention. There will be some important questions.

We need to co-operate with solid-state and materials people or we will be pushed to one side.

We must not confuse them with details of theory or experiments.

Who might want HC? Who will pay for the R&D to make cables for HC?
Finally, an interesting question.

Where is the Argon from the K-decays?
About 10% of K-decays give argon.

In addition to decoration with magnetite, epidote and glauconite some sheets show delineation of tracks by local distortion of the lattice, as shown by reflected light.

This might be caused by diffusion of argon after the available Fe has been depleted by creation of magnetite and epidote. The argon comes from the decay of $^{40}$K. The gas pressure distorts the lattice locally, which shows up when mica crystals expand at low hydrostatic pressure at the Earth’s surface.
Thank you.