Phonon-mediated nuclear excitation transfer

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Introduction

- Interested in modeling excess heat process (and many other anomalies)
- Pursuing models based on phonon-nuclear interaction
- Phonon-mediated excitation transfer is lowest-order observable process
- Applications include:
    - Angular anisotropy experiments
    - Delocalization experiments
    - Up-conversion, collimated x-rays, gamma rays
    - Low-level nuclear emission
    - First step in excess heat production
    - Energy exchange through many sequential excitation transfers

Phonon-nuclear coupling

Relativistic problem

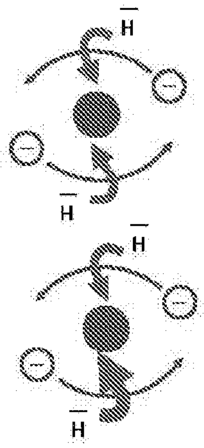
Relativistic Hamiltonian: $H = \sum_j \boldsymbol{\alpha}_j \cdot c\mathbf{p}_j + \sum_j \beta_j mc^2 + \sum_{j<k} V_{jk}\left(\mathbf{r}_k - \mathbf{r}_j\right)$

Incomplete F-W rotation: $H' = e^{iS}\left(H - i\hbar\frac{\partial}{\partial t}\right)e^{-iS}, \; S = -i\frac{1}{2Mc^2}\sum_j \beta_j \boldsymbol{\alpha}_j \cdot c\mathbf{P}$

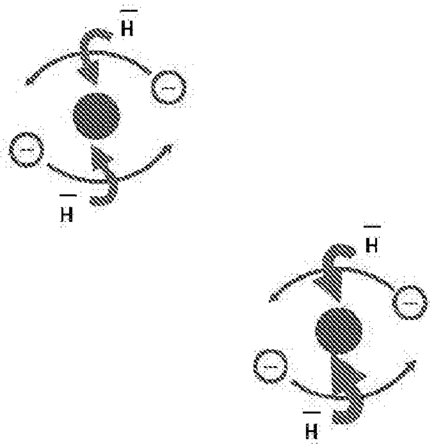
$$H' \rightarrow \boxed{\frac{|\mathbf{P}|^2}{2M}} + \boxed{\sum_j \boldsymbol{\alpha}_j \cdot c\boldsymbol{\pi}_j + \sum_j \beta_j mc^2 + \sum_{j<k} V_{jk}\left(\xi_k - \xi_j\right)} + \boxed{\sum_j \mathbf{a}_j \cdot c\mathbf{P}}$$

nucleus as a particle — internal nuclear model — coupling

Boost of magnetic field



Boost of magnetic field



Relativistic problem

- Center of mass and relative coordinate separation is not clean
- Get a coupling between motion and internal nuclear states
- First noticed by Breit in 1937
- Nuclear forces are momentum dependent
- (like magnetic field)
- So would expect a boost correction for a moving nucleus
- Does not contribute for linear motion (can rotate out)
- Does contribute for oscillatory motion

Nuclei in condensed matter

Include coupling to nuclei

$$H = \sum_j \mathbf{M}_j c^2 + \sum_j \mathbf{a}_j \cdot c\mathbf{P}_j + \sum_j \frac{\left|\mathbf{P}_j\right|^2}{2M_j} + \sum_j \frac{\left|\mathbf{p}_j\right|^2}{2m_e}$$
$$+ \sum_{j<k} \frac{Z_j Z_k e^2}{4\pi\left|\mathbf{R}_k - \mathbf{R}_j\right|} + \sum_{j<k} \frac{e^2}{4\pi\left|\mathbf{r}_k - \mathbf{r}_j\right|} - \sum_{j,k} \frac{Z_k e^2}{4\pi\left|\mathbf{R}_k - \mathbf{r}_j\right|}$$

Adiabatic model

$$H = \sum_j \mathbf{M}_j c^2 + \sum_j \mathbf{a}_j \cdot c\mathbf{P}_j + \sum_j \frac{\left|\mathbf{P}_j\right|^2}{2M_j} + \sum_{j<k} \frac{Z_j Z_k e^2}{4\pi\left|\mathbf{R}_k - \mathbf{R}_j\right|} + E_e\left(\{\mathbf{R}\}\right)$$

Phonons and nuclei

$$H = \sum_k \hbar\omega_k a_k^\dagger a_k + \sum_j \mathbf{M}_j c^2 + \sum_j \mathbf{a}_j \cdot c\mathbf{P}_j$$

with

$$\mathbf{P}_j = \sum_k \frac{\partial \mathbf{P}_j}{\partial a_k} a_k + \sum_k \frac{\partial \mathbf{P}_j}{\partial a_k^\dagger} a_k^\dagger$$

Models with phonons and nuclei

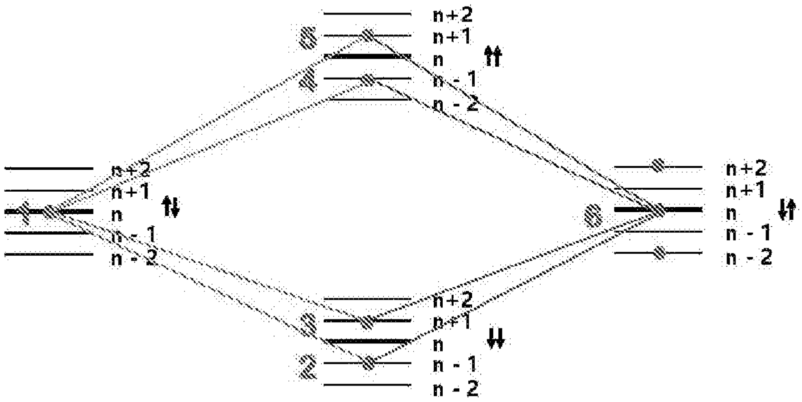
- Motion of a nucleus is a phonon operator
- Expect intimate coupling between vibrations and internal nuclear states

Excitation transfer

Processes

- Phonon-nuclear coupling is **a.cP**
- Phonon creation/destruction along with raising/lowering of nuclear state
- Photon-nuclear coupling is **–j.A**
- Photon creation/destruction along with raising/lowering of nuclear state
- Excited state nucleus can radiate one photon…
- …but not one phonon (no phonon modes at keV or higher)
- Look to 2^{nd} order two-phonon processes
- Lowest-order process that we might see is excitation transfer

Resonant excitation transfer



Relevant for two E1 transitions in a homonuclear molecule

Excitation transfer

- Excitation transfer moves excitation from one nucleus to another
- No direct coupling between initial and final state
- Weak second-order coupling involving off-resonant intermediate states
- Effect predicted theoretically
- But does it happen?

Monatomic crystal excitation transfer

E1 Excitation transfer

- Most work focused on E1 transitions so far
- Get severe cancellation under normal conditions
- (Lossy spin boson model proposed to remove destructive interference)
- Check monatomic crystal problem for E1 transitions

E1 Crystal model

$$H = \sum_{\mathbf{k},\sigma} \hbar\omega_{\mathbf{k},\sigma} a^\dagger_{\mathbf{k},\sigma} a_{\mathbf{k},\sigma} + \sum_j \mathbf{M}_j c^2 + \sum_j \mathbf{a}_j \cdot c\mathbf{P}_j$$

$$= \sum_{\mathbf{k},\sigma} \hbar\omega_{\mathbf{k},\sigma} a^\dagger_{\mathbf{k},\sigma} a_{\mathbf{k},\sigma} + \sum_{m_0} \left|J_0 m_0\right\rangle M_0 c^2 \left\langle J_0 m_0\right| + \sum_{m_1} \left|J_1 m_1\right\rangle M_1 c^2 \left\langle J_1 m_1\right| +$$

$$\sum_{j m_1 m_2} \left(\left|J_0 m_0\right\rangle \left\langle J_0 m_0\right| \mathbf{a}_j \left|J_1 m_1\right\rangle \left\langle J_1 m_1\right| + \left|J_1 m_1\right\rangle \left\langle J_1 m_1\right| \mathbf{a}_j \left|J_0 m_0\right\rangle \left\langle J_0 m_0\right| \right) \cdot c \sum_{\mathbf{k},\sigma} \mathbf{u}_{\mathbf{k},\sigma} \sqrt{\frac{M\hbar\omega_{\mathbf{k},\sigma}}{2N}} \left(\frac{a_{\mathbf{k},\sigma} e^{i\mathbf{k}\cdot\mathbf{R}_j^{(0)}} - a^\dagger_{\mathbf{k},\sigma} e^{i\mathbf{k}\cdot\mathbf{R}_j^{(0)}}}{i} \right)$$

Indirect coupling matrix element

$$\left(V\left(E - H_0\right)^{-1} V\right)_{\text{resonant}} = \sum_{j,j'} \sum_{\mathbf{k},\sigma} \frac{Mc^2\hbar\omega_{\mathbf{k},\sigma}}{2N} \left[\sum_{m_0 m_1} \left|J_0 m_0\right\rangle \left\langle J_0 m_0\right| \mathbf{a}_j \left|J_1 m_1\right\rangle \left\langle J_1 m_1\right| \right]$$

$$\left[\sum_{m_0 m_1} \left|J_1 m_1\right\rangle \left\langle J_1 m_1\right| \mathbf{a}_{j'} \left|J_0 m_0\right\rangle \left\langle J_0 m_0\right| \right] \left(\frac{\hbar\omega_{\mathbf{k},\sigma}}{\Delta E_{10} - \hbar\omega_{\mathbf{k},\sigma}} e^{i\mathbf{k}\cdot\left(\mathbf{R}_j^{(0)} - \mathbf{R}_{j'}^{(0)}\right)} - \frac{\hbar\omega_{\mathbf{k},\sigma}}{\Delta E_{10} + \hbar\omega_{\mathbf{k},\sigma}} e^{-i\mathbf{k}\cdot\left(\mathbf{R}_j^{(0)} - \mathbf{R}_{j'}^{(0)}\right)} \right)$$

$$+ \text{H.c.}$$

E1 Excitation transfer

- Destructive interference for E1 molecular excitation transfer
- Also destructive interference for E1 lattice excitation transfer
- Need loss to ameliorate destructive interference

M1,E2 Excitation transfer

- Low energy M1, E2 transitions much more common
- Have been working with Fe-57 M1+E2 transitions
- Need two-phonon exchange for single nuclear transition
- Think about modeling excitation transfer

M1,E2 Crystal model

$$H = \sum_{\mathbf{k},\sigma} \hbar\omega_{\mathbf{k},\sigma} a^{\dagger}_{\mathbf{k},\sigma} a_{\mathbf{k},\sigma} + \sum_j \mathbf{M}_j c^2 + \sum_j \mathbf{a}_j \cdot c\mathbf{P}_j$$

$$= \sum_{\mathbf{k},\sigma} \hbar\omega_{\mathbf{k},\sigma} a^{\dagger}_{\mathbf{k},\sigma} a_{\mathbf{k},\sigma} + \sum_{m_0} |J_0 m_0\rangle M_0 c^2 \langle J_0 m_0| + \sum_{m_1} |J_1 m_1\rangle M_1 c^2 \langle J_1 m_1| + \sum_{m_2} |J_2 m_2\rangle M_2 c^2 \langle J_2 m_2|$$

$$+ \sum_{j m_0 m_2} \left(|J_0 m_0\rangle\langle J_0 m_0| \mathbf{a}_j |J_2 m_2\rangle\langle J_2 m_2| + |J_2 m_2\rangle\langle J_2 m_2| \mathbf{a}_j |J_0 m_0\rangle\langle J_0 m_0| \right) \cdot c \sum_{\mathbf{k},\sigma} \mathbf{u}_{\mathbf{k},\sigma} \sqrt{\frac{M\hbar\omega_{\mathbf{k},\sigma}}{2N}} \left(\frac{a_{\mathbf{k},\sigma} e^{i\mathbf{k}\cdot\mathbf{R}_j^{(0)}} - a^{\dagger}_{\mathbf{k},\sigma} e^{i\mathbf{k}\cdot\mathbf{R}_j^{(0)}}}{i} \right)$$

$$+ \sum_{j m_1 m_2} \left(|J_1 m_1\rangle\langle J_1 m_1| \mathbf{a}_j |J_2 m_2\rangle\langle J_2 m_2| + |J_2 m_2\rangle\langle J_2 m_2| \mathbf{a}_j |J_1 m_1\rangle\langle J_1 m_1| \right) \cdot c \sum_{\mathbf{k},\sigma} \mathbf{u}_{\mathbf{k},\sigma} \sqrt{\frac{M\hbar\omega_{\mathbf{k},\sigma}}{2N}} \left(\frac{a_{\mathbf{k},\sigma} e^{i\mathbf{k}\cdot\mathbf{R}_j^{(0)}} - a^{\dagger}_{\mathbf{k},\sigma} e^{i\mathbf{k}\cdot\mathbf{R}_j^{(0)}}}{i} \right)$$

Indirect coupling matrix element

$$\left(V (E - H_0)^{-1} V \right)_{\text{resonant}} \rightarrow \sum_{j,j'} \sum_{\mathbf{k},\sigma} \sum_{\mathbf{k}',\sigma'} \frac{Mc^2\hbar\omega_{\mathbf{k},\sigma}}{2N} \frac{Mc^2\hbar\omega_{\mathbf{k}',\sigma'}}{2N} e^{i\mathbf{k}'\cdot\left(\mathbf{R}_{j'}^{(0)} - \mathbf{R}_j^{(0)}\right)} e^{-i\mathbf{k}\cdot\left(\mathbf{R}_{j'}^{(0)} - \mathbf{R}_j^{(0)}\right)}$$

$$\left[\sum_{m_0 m_1 m_2} |J_1 m_1\rangle\langle J_1 m_1| \mathbf{u}_{\mathbf{k}',\sigma'} \mathbf{a}_j |J_2 m_2\rangle\langle J_2 m_2| \mathbf{u}_{\mathbf{k},\sigma} \mathbf{a}_j |J_0 m_0\rangle\langle J_0 m_0| \right]$$

$$\left[\sum_{m_0 m_1 m_2} |J_0 m_0\rangle\langle J_0 m_0| \mathbf{u}_{\mathbf{k}',\sigma'} \mathbf{a}_j |J_2 m_2\rangle\langle J_2 m_2| \mathbf{u}_{\mathbf{k},\sigma} \mathbf{a}_j |J_1 m_1\rangle\langle J_1 m_1| \right]$$

$$(n_{\mathbf{k},\sigma} + 1)(n_{\mathbf{k}',\sigma'} + 1) \frac{1}{\Delta E_{10}} \left(\frac{1}{\Delta E_{21}^2} - \frac{1}{\Delta E_{20}^2} \right)$$

$$+ \cdots$$

M1,E2 Excitation transfer

- Large number of terms (only showed first 2 out of 64)
- Analyzed in detail 16 out of 64 (4 separate cases of interference)
- No destructive interference!
- Wondering why…
- It is because the system is unbalanced
- Needed loss to break destructive interference for E1 system
- Nothing needed to break destructive interference for M1,E2 system

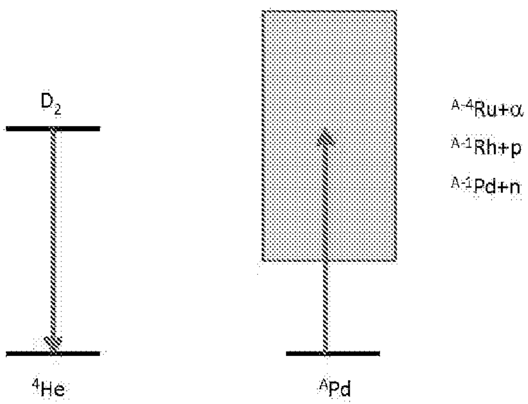
Low-lying E1, M1 transitions

isotope	E(keV)	$T_{1/2}$	multipolarity
Ta-181	6.237	6.05 μsec	E1
Dy-161	25.65135	29.1 ns	E1
Gd-157	63.929	0.46 μsec	E1
Dy-161	74.56668	3.14 ns	E1
Gd-155	86.5479	6.50 ns	E1
Eu-153	97.43100	0.198 ns	E1
Dy-161	103.062	3.60 ns	E1
Gd-155	105.3083	1.16 ns	E1
F-19	109.9	0.591 ns	E1
Dy-161	131.8	0.145 ns	[E1]
Eu-153	151.6245	0.36 ns	E1

isotope	E(keV)	$T_{1/2}$	multipolarity
Hg-201	1.5648	81 ns	M1+E2
Tm-169	8.41017	4.09 ns	M1+E2
Kr-83	9.4057	156.8 ns	M1+E2
Os-187	9.756	2.38 ns	M1(+E2)
U-235	12.975	0.50 ns	(M1+E2)
Fe-57	14.4129	98.3 ns	M1+E2
Eu-151	21.541	9.6 ns	M1+E2
Sm-149	22.507	7.33 ns	M1+E2
Sn-119	23.870	18.03 ns	M1+E2
Hg-201	26.34	630 ps	M1+E2
K-40	29.8299	4.25 ns	M1
Hg-201	32.19	60 ps	M1+E2
Te-125	35.4925	1.482 ns	M1+E2
Os-189	36.144	0.52 ns	M1+E2
Sb-121	37.1298	3.46 ns	M1+E2
Xe-129	39.5774	0.97 ns	M1+E2
Dy-161	43.8201	0.83 ns	M1+E2
U-235	46.21	14 ps	M1+E2
W-183	46.4838	0.185 ns	M1+E2

Application of incoherent excitation transfer

Low-level nuclear radiation



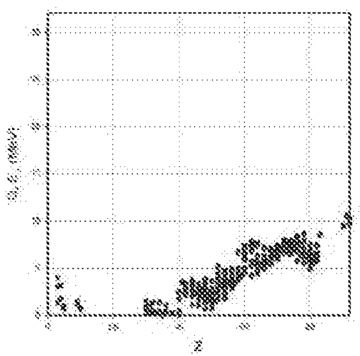
P L Hagelstein, Proc ICCF9

Low-level nuclear emission

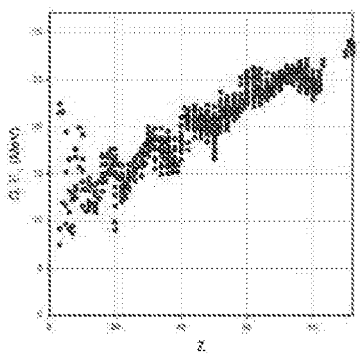
- Energetic alphas, protons, neutrons claimed in F&P type experiments
- Experiments by Roussetski et al, by Lipson et al, by Boss et al
- Can be accounted for by (incoherent) excitation transfer reactions
- Interested in a systematic study to verify

Low-level α ejection

$HD + {}^{A}Z \rightarrow {}^{3}He + {}^{(A-4)}(Z-2)$

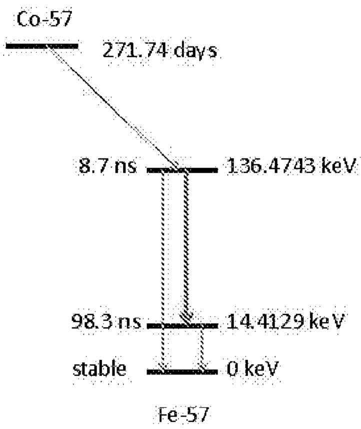


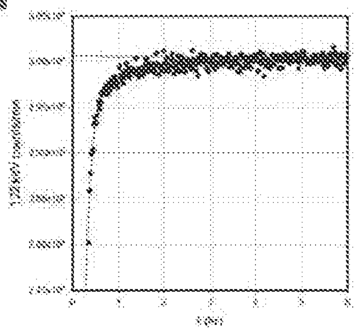
$D_2 + {}^{A}Z \rightarrow {}^{4}He + {}^{(A-4)}(Z-2)$



Resonant excitation transfer

Excitation transfer experiment





Angular anisotropy

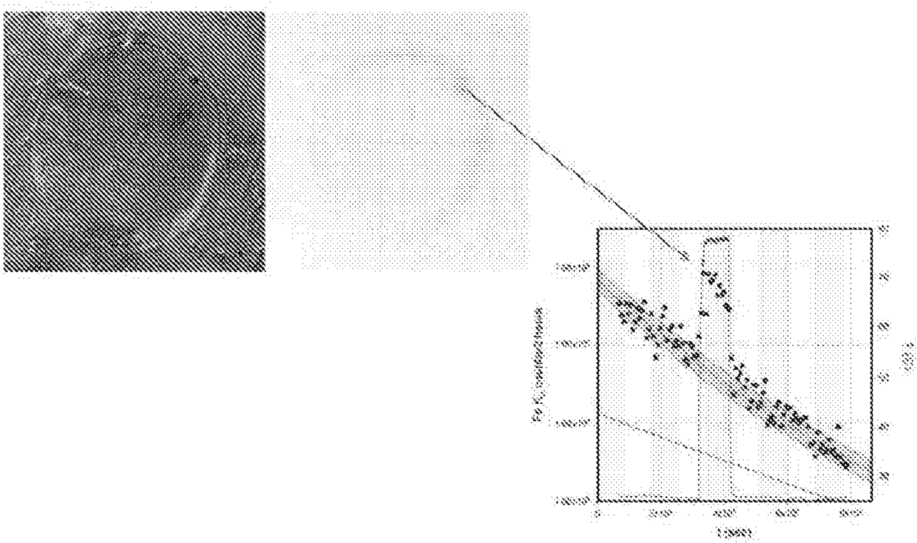
- For weak coupling expect resonant excitation transfer to dominate
- Resonant excitation transfer produces phase coherence
- Phase coherence + order can produce angular anisotropy

Delocalization

Beyond simple excitation transfer

- Have considered excitation transfer in weak coupling limit above
- What happens when the coupling is stronger?
- (lower energy nuclear transition, more nuclei involved, longer coherence time)
- Sequential excitation transfer could lead to delocalization
- Possibility also of energy exchange
- Mechanism for excess heat production

Delocalization experiment



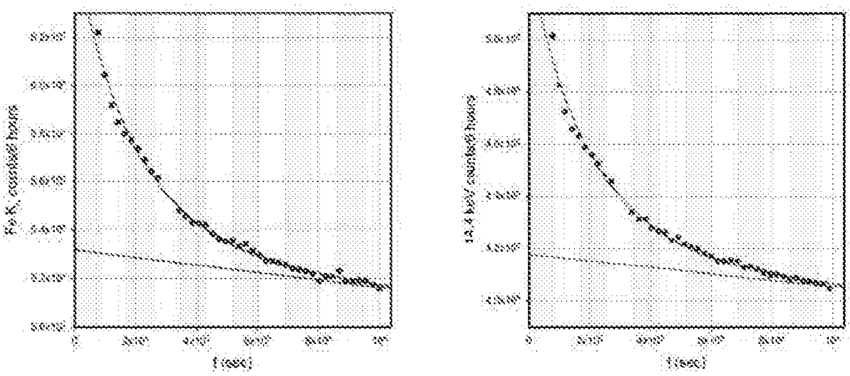
Delocalization of excitation

- Observe increase of emission at "hot spot" when sample, clamps heated
- Residue believed to be mostly Fe-57
- Excitation appears to transfer from regions with less Fe-57 to regions with more
- Each excitation transfer step for THz phonon exchange limited to less than 100 A
- Observed increase implies delocalization of excitation at least several hundred μ

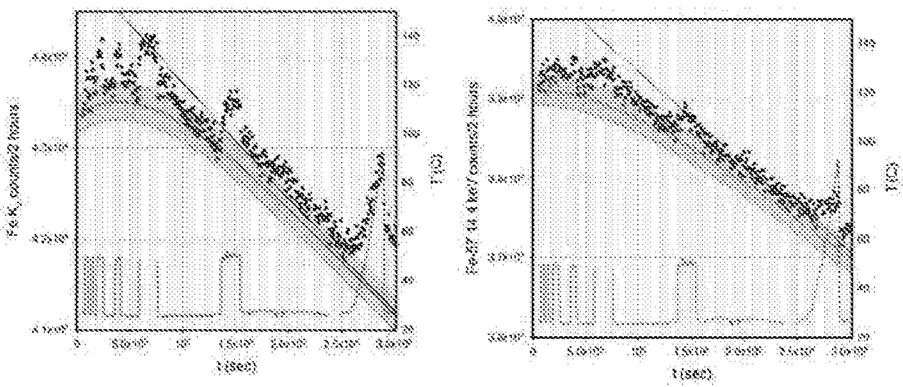
Ratio of Fe K_α to 14.4 keV gamma

- Observe significant, also dynamic variations in Fe K_α to 14.4 keV gamma
- Not expected based on known physics
- Excitation transfer involves off-resonant states with two excited nuclei
- Double internal conversion energetically possible
- Would produce excess of Fe K_α emission
- We have seen this kind of effect
- Supports excitation transfer mechanism
- Also suggests occupation of off-resonant states with more 14.4 keV excitation
- Possible reduction of excited state decay if substantial occupation of states far off of resonance

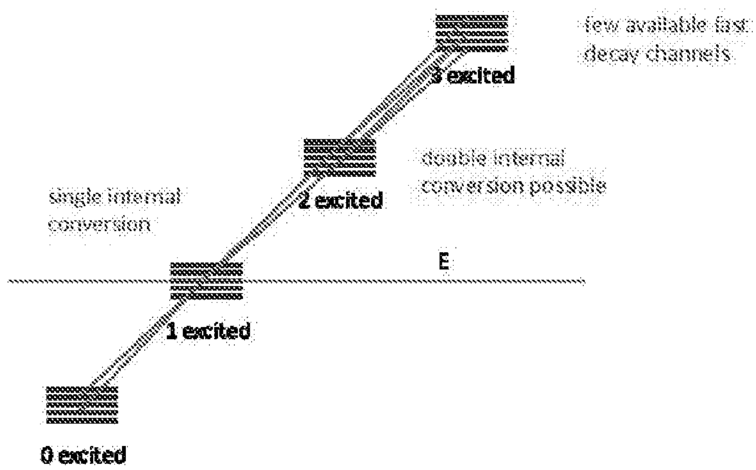
May 20, 2017 exp't



Aug. 10, 2017 exp't



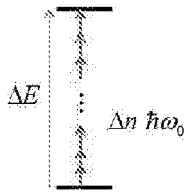
Strong coupling



Higher-order effects

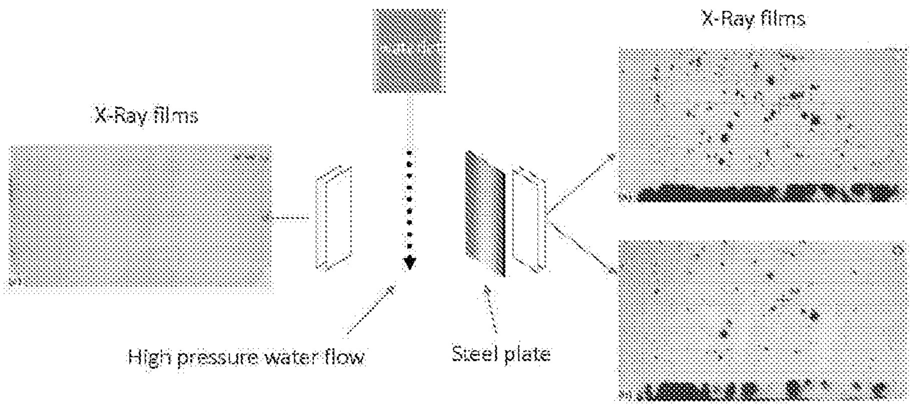
Up-conversion, down-conversion

- Many sequential non-resonant excitation transfer steps…
- …leads to possibility of net energy exchange



- model that describes up-conversion (lossy spin-boson model)
- …also describes down-conversion

Kornilova, Vysotskii et al exp't



Experiments

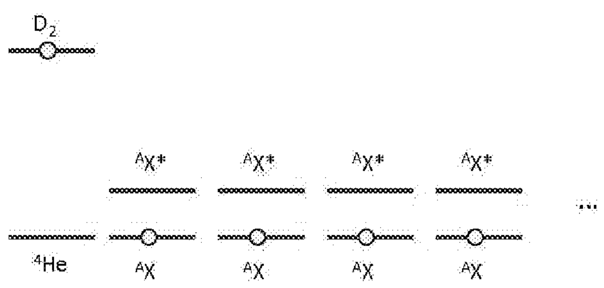
- Collimated emission of x-rays, gamma-rays in experiments …
- … Gorazdovskii et al, Karabut et al, Gozzi et al, Kornilova et al, Ivlev et al
- possible to interpret them as due to up-conversion of vibrations…
- …more work needed to confirm (different explanations put forth by Vysotskii and by Ivlev)

Mechanism for excess heat

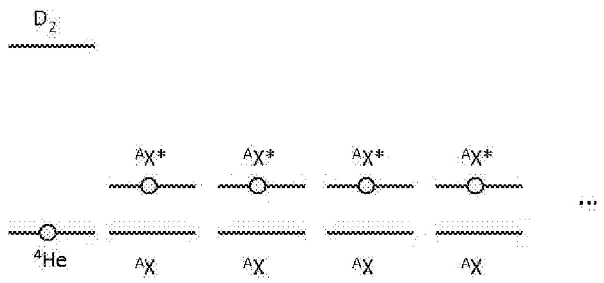
Modeling excess heat

- Formalism for including coupling to nuclei in condensed matter outline above
- Predicts excitation transfer effects (observed)
- Predicts up-conversion, down-conversion (consistent with experiment)
- Also can apply to excess heat production
- Simple down-conversion is most straightforward conceptually…
- …but numbers don't work out
- Numbers much better for multi-step scheme based on excitation transfer, subdivision, and down-conversion

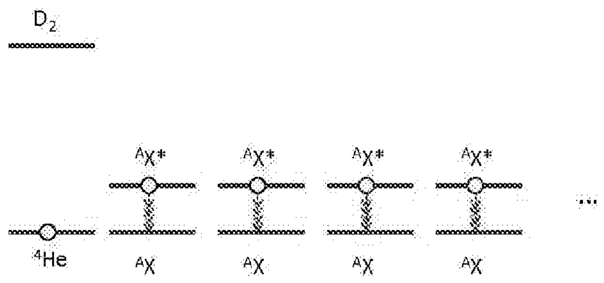
Start with:



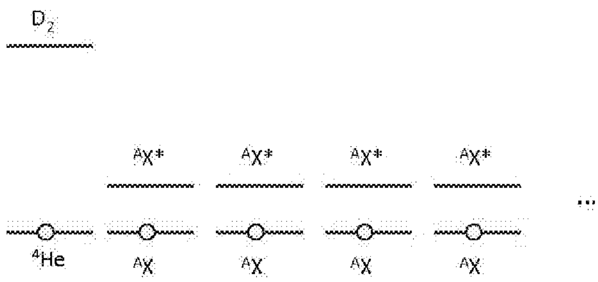
Subdivide:



Down-convert



Energy ends up in vibrations



Modeling excess heat

- Model for this process looks good
- Excess power in experiment consistent generally with reaction rates expected from model (but lots of unknown or unmeasured parameters)
- Reaction rate linear in $D_2/^4He$ matrix element (quadratic for incoherent reactions) so tunneling factor only comes in once (not twice)
- Model works for $D_2/^4He$ on same footing as $HD/^3He$ for light water reactions
- (evidence for ^4He as product from heavy water experiments)
- Weaker D_2/HT mechanism for tritium production

Connection with experiment

- Model consistent with phonon gain, phonon laser effect
- Need initial excitation of vibrational models to get started
- Consistent with Letts 2-laser experiment
- Consistent with Didyk, Wisniewskii experiment, with gamma scattering off of nuclei route to create THz phonons
- Swartz Raman experiment with nanor consistent with phonon laser effect

Conclusions

Conclusions

- Excitation transfer lowest-order observable process with phonon-nuclear coupling
- New experiments (angular anisotropy, delocalization) consistent with excitation transfer
- E1 transitions with single-phonon exchange suffer destructive interference effects
- M1,E2 transitions with two-phonon exchange free of destructive interference effects
- Interpretation of energetic nuclear products in low-level nuclear emission from F&P experiment as due to excitation transfer
- Many sequential excitation transfers while maintaining coherence leads to energy exchange

Observation of non-exponential decay of x-ray and γ lines from Co-57 on steel plates

F Metzler, S Lu, P L Hagelstein

June 6, 2018

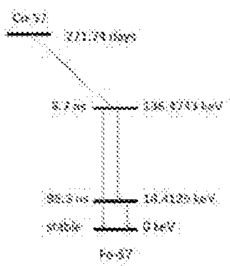
Introduction

- Would like to understand physical mechanism responsible for excess heat
- Not possible to see much in a successful excess heat experiment
- Motivated to try different experiments to look at mechanism
- Have phonon-nuclear theory for excess heat
- …and for other anomalies
- Would like to develop experiments to test theory
- If phonon-nuclear coupling is real, can we see it, prove it?

Concept

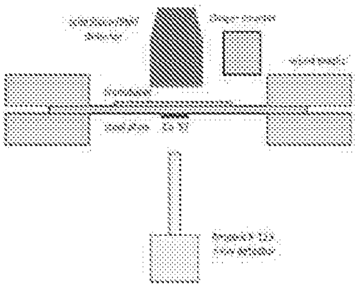
Concept for experimentation

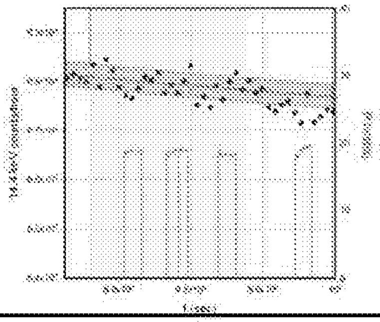
- Start with an excited nucleus...
- (Co-57 to make excited state Fe-57)
- Make phonons
- Check to see if anything happens



Exp'ts with MHz vibrations

- Tried experiments with MHz vibrations
- Did not see a prompt response
- Conclude that not much happens with MHz vibrations



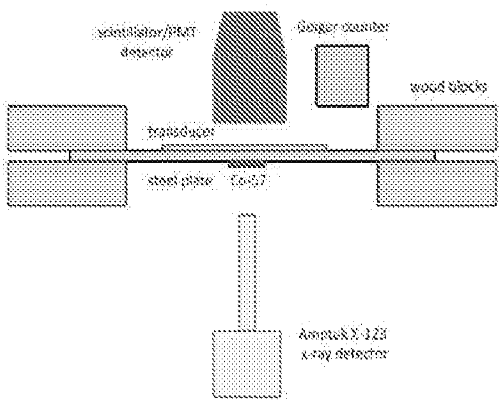


Non-exponential decay

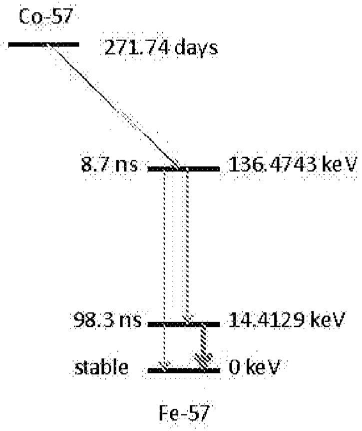
- But we did see a non-exponential decay effect
- Provided a basis for an experimental effort
- Issues:
    - reproducibililty
    - real or artifact?
    - use different detectors
    - control
    - why does it happen?

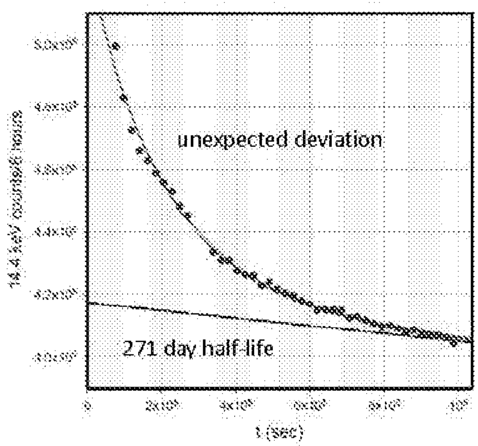
Unexpected non-exponential decay

May 10, 2017 exp't

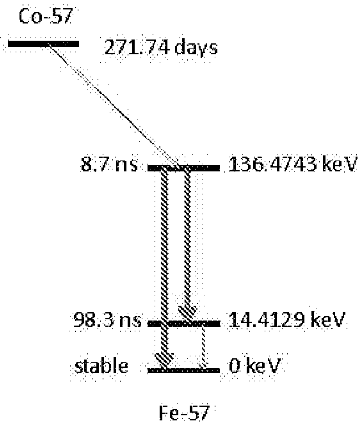


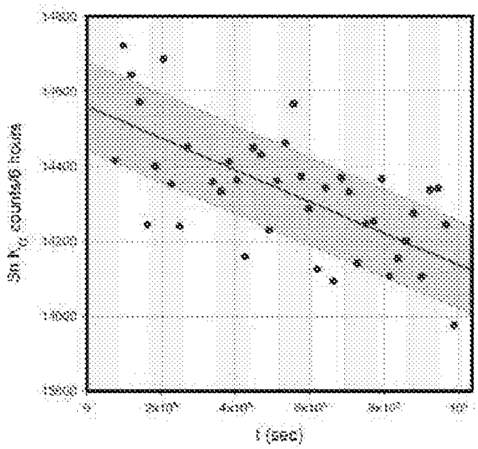
Non-exponential decay: 14.4 keV γ





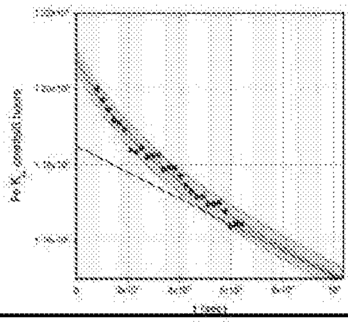
Sn photionized by 122, 136 keV γ's





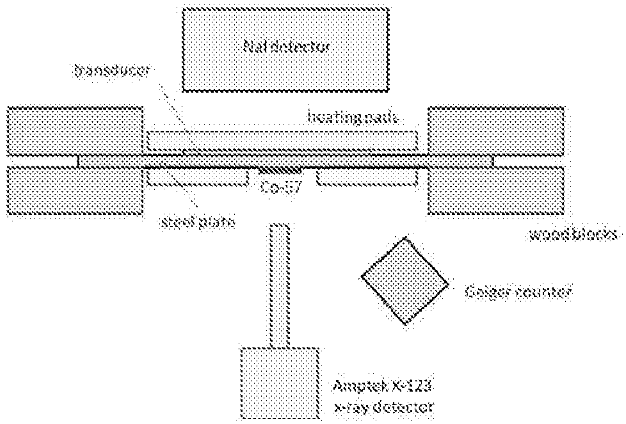
Unexpected non-exponential decay

- 19% increase in 14.4 keV gamma at start of experiment
- 17% increase in Fe K_{α}
- <1% change in Sn K_{α}
- Not a result of accelerated decay of Co-57
- Non-exponential decay in subsequent tests
- ... but weaker

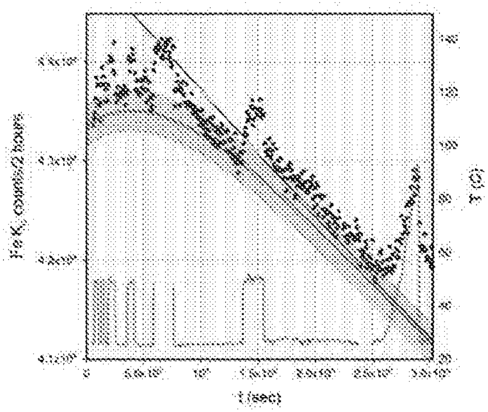


Heat pulses

Aug. 10, 2017 exp’t



Non-exponential decay: Fe K_{α}



Heat pulse experiment

- Initial reduction in Fe K_{α} due to tightening clamps prior to exp't
- Increase due to heat pulses
- Reproducible for given configuration
- Bigger effect with more temperature
- Slow decay after heat pulse (due to wood relaxation)

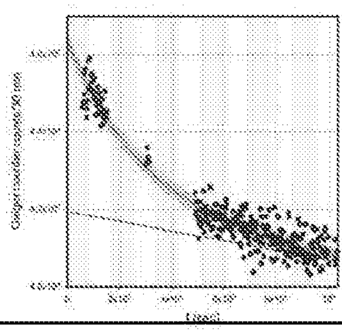
Angular anisotropy

Connection with theory

- Think about excitation transfer mechanism
- Weak effect dominated by resonant excitation transfer
- ... which can produce phase coherence
- ... which can give rise to angular anisotropy if order present

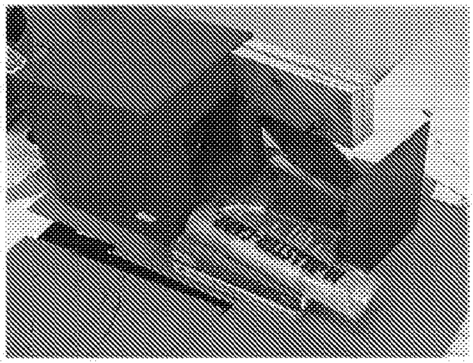
Angular anisotropy

- First recognized in Aug. 10, 2017 experiment
- Back side Geiger counter signal in May 10, 2017 experiment interpreted as due to angular anisotropy
- Old GM data from Dec. 2016 interpreted as due to angular anisotropy

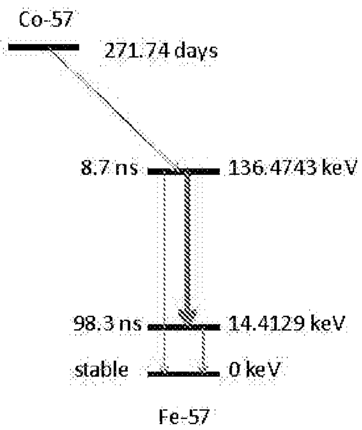


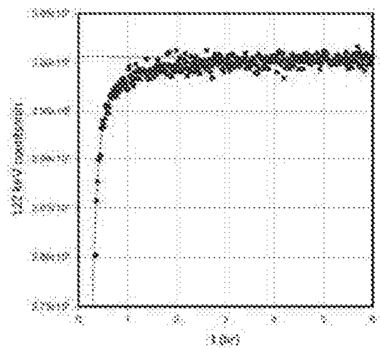
April 13, 2018 exp't

- Tighten wood clamps
- Place near HPGe x-ray detector at shallow angle



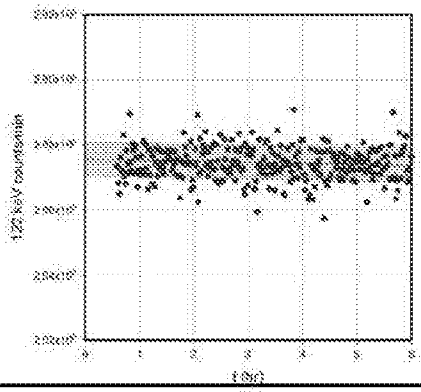
Fast transient in 122 keV γ





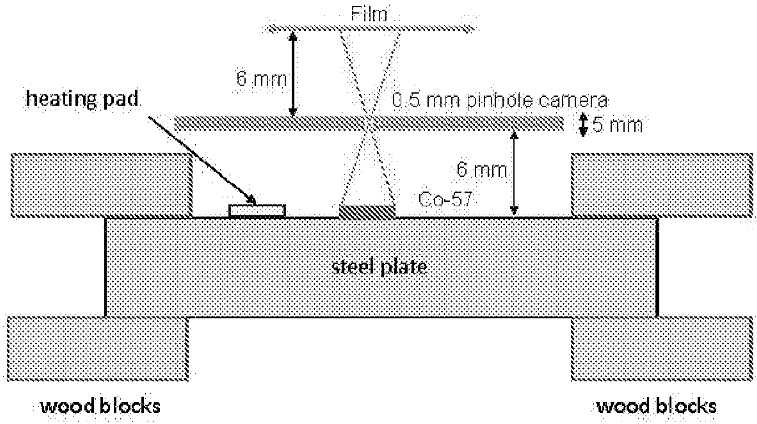
May 8, 2018 exp’t

- Let plate, clamps remain unperturbed for 2 hours
- Block path to detector with ¼ inch Pb plate
- Remove Pb plate

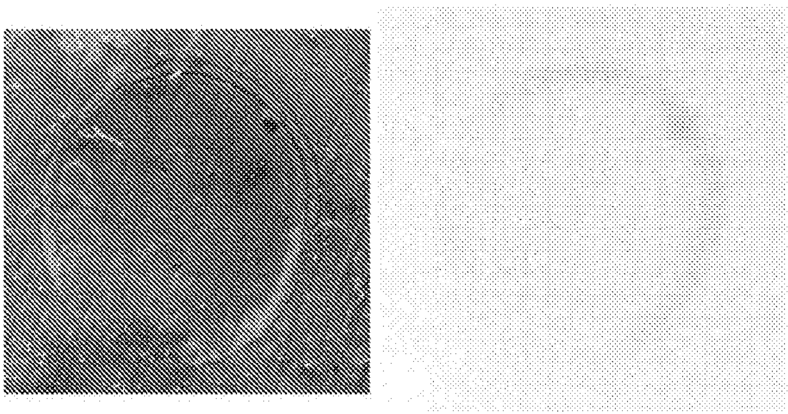


Pinhole/film exp’t

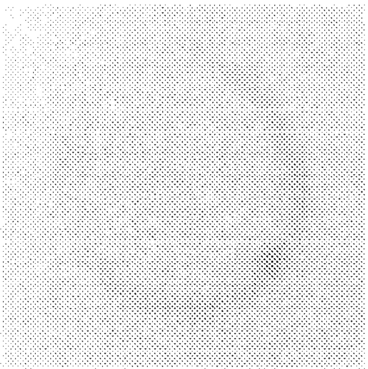
Schematic



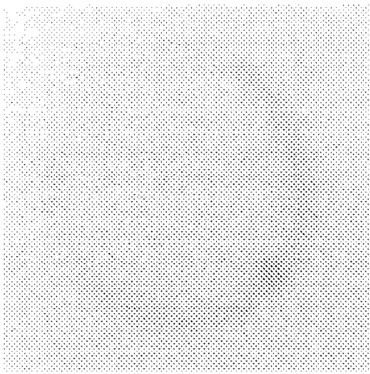
Ring and dark spot



March 14, 2018 exp't



Cold film image at 25C



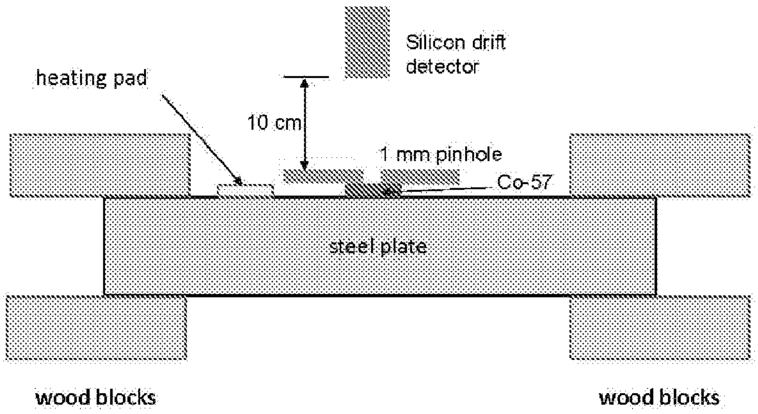
Hot film image > 100C

Film comparison

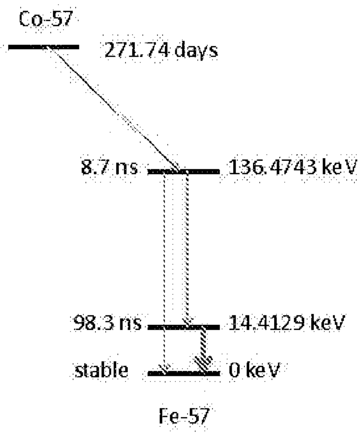
- January brainstorm: possible delocalization of excitation?
- Can we see it?
- Mar. 14, 2018 exp't attempt to capture change in emission, hot vs cold
- Can see minor differences in images
- Quantitative analysis of images shows minor differences
- Conclude that radiography not conclusive for delocalization

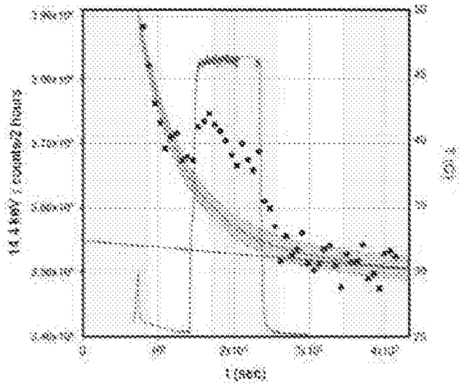
Pinhole/SDD exp’t

Aril 12, 2018 exp’t

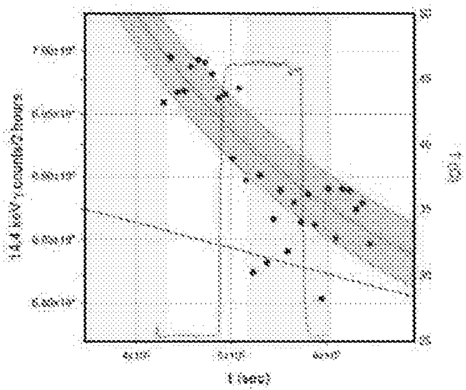


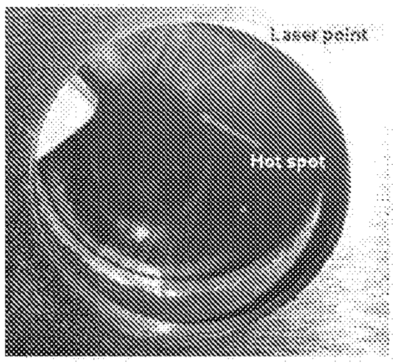
Near hot spot



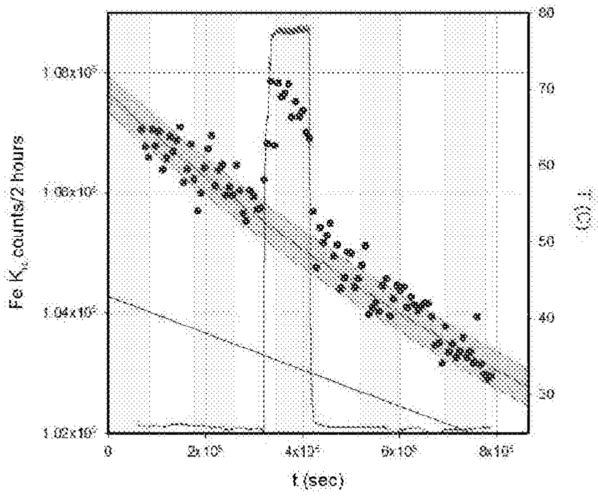


April 16,2018 exp't

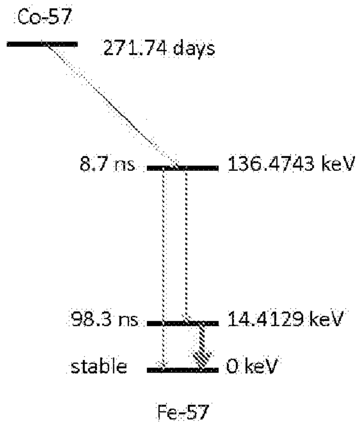


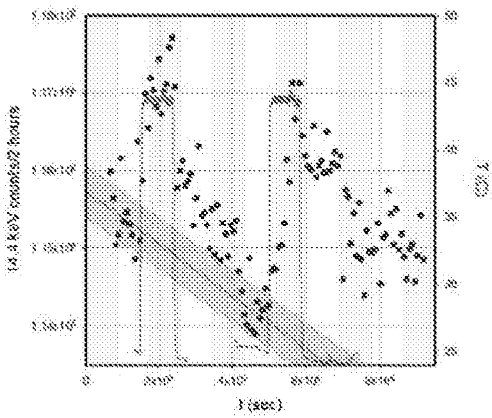


May 8, 2018 exp't at hot spot



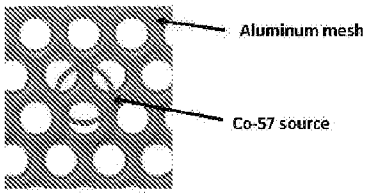
Hot spot





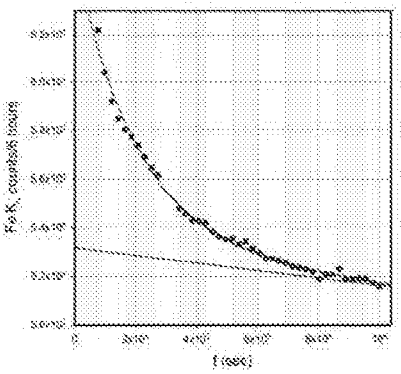
Delocalization

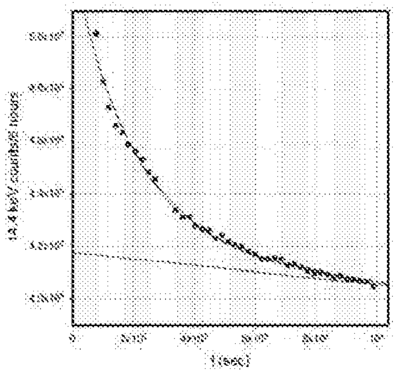
- Film/SDD experiments consistent with delocalization of excitation
- Effect appears restricted to residue
- (Excitation transfer into the steel would give loss due to absorption)
- Excitation goes from regions of less Fe-57 to regions of more Fe-57
- Can understand May 10, 2017 exp't:



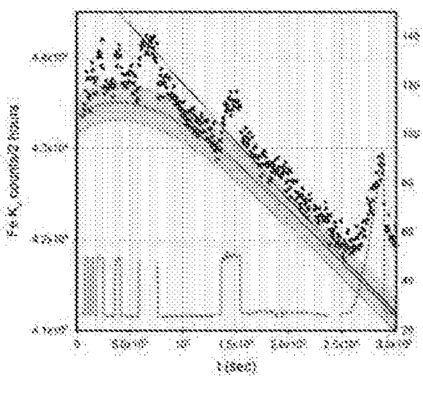
Relative line strength

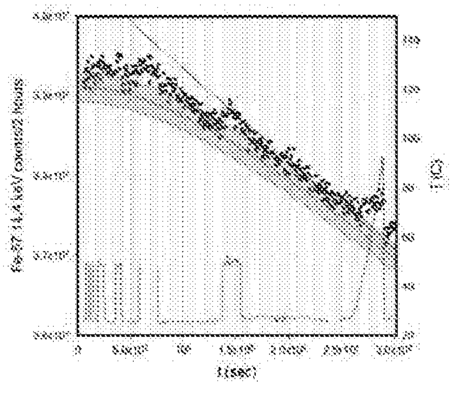
May 20, 2017 exp't





Aug. 10, 2017 exp't





Varying line strength

- Incremental Fe K_α and 14.4 keV gamma similar in May 20, 2017 exp't
- But incremental Fe K_α is bigger in Aug. 10, 2017 exp't
- Wondering why
- K-shell hole produced in Fe-57 from beta decay of Co-57
- Internal conversion decay of 14.4 keV state can produce K-shell hole
- Would not normally expect incremental ratio to change

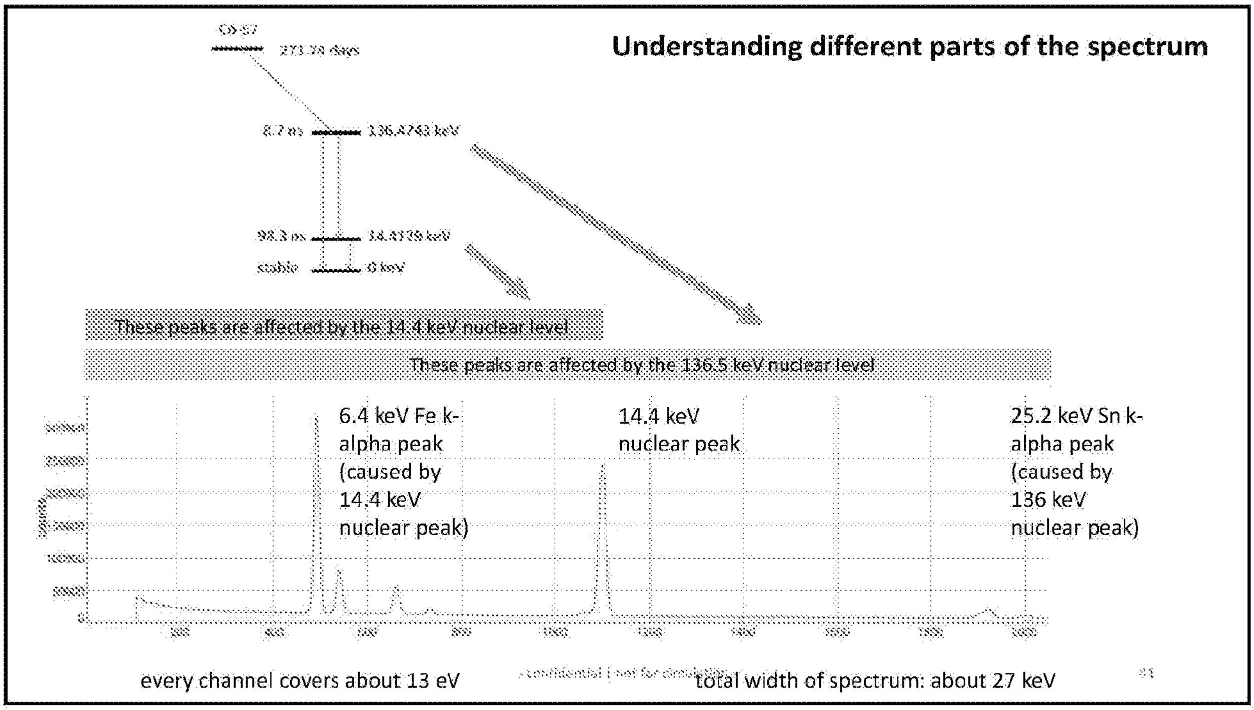
New loss channel

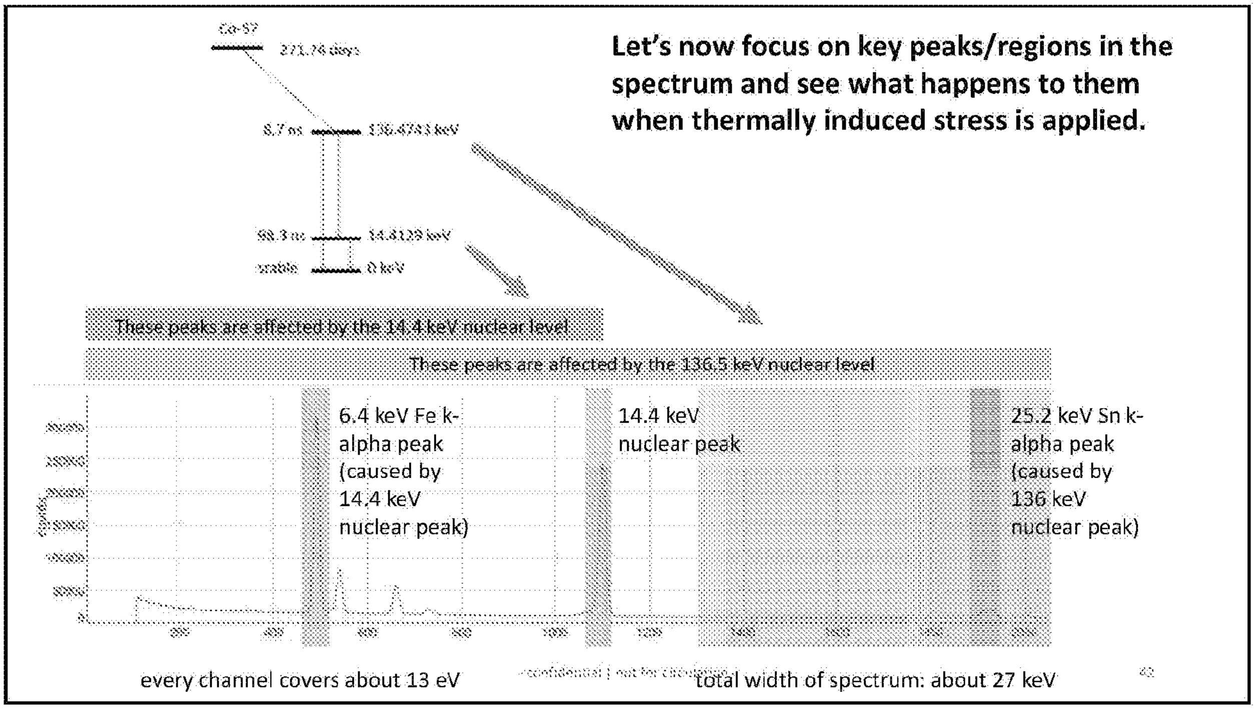
- Excitation transfer in weak coupling has off-resonant states with 2 excited 14.4 keV states
- Possible for both to decay (14.4 keV > 2 x 7.11 keV)
- Excitation transfer in strong coupling has highly off-resonant states with multiple excited 14.4 keV states
- No open decay channels, so 14.4 keV decay suppressed
- Strong coupling regime favors more Fe K_α relative to 14.4 keV gamma

Conclusions

Conclusions

- Experiments with Co-57 source looking for excitation transfer effects
- Hoping to provide tests for theory
- Angular anisotropy implies phase coherence, which implies resonant excitation transfer for 136 keV state
- Delocalization implies fast excitation transfer for 14.4 keV state
- Increase in incremental Fe K_α relative to 14.4 keV gamma consistent with excitation transfer in strong coupling regime


Understanding different parts of the spectrum
Co-57
271.74 days
8.7 ns
136.4743 keV
98.3 ns
14.4129 keV
stable
0 keV
These peaks are affected by the 14.4 keV nuclear level
These peaks are affected by the 136.5 keV nuclear level
6.4 keV Fe k-alpha peak (caused by 14.4 keV nuclear peak)
14.4 keV nuclear peak
25.2 keV Sn k-alpha peak (caused by 136 keV nuclear peak)
every channel covers about 13 eV
total width of spectrum: about 27 keV


Let's now focus on key peaks/regions in the spectrum and see what happens to them when thermally induced stress is applied.
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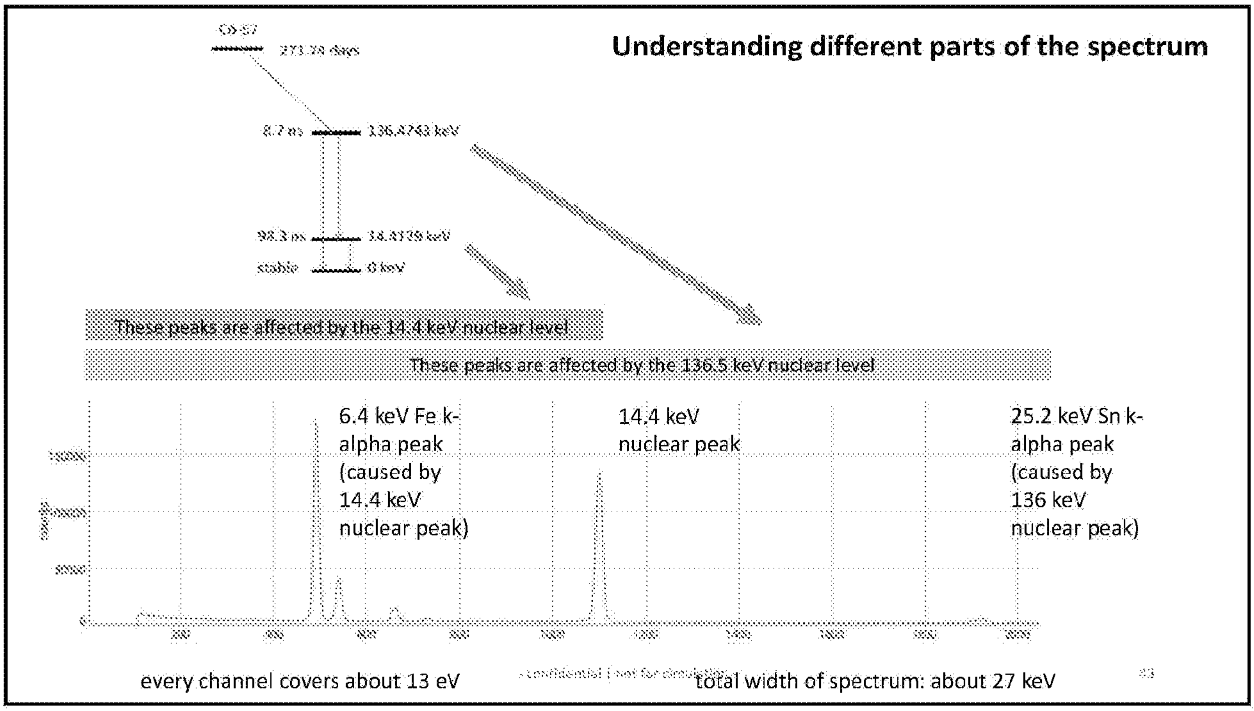
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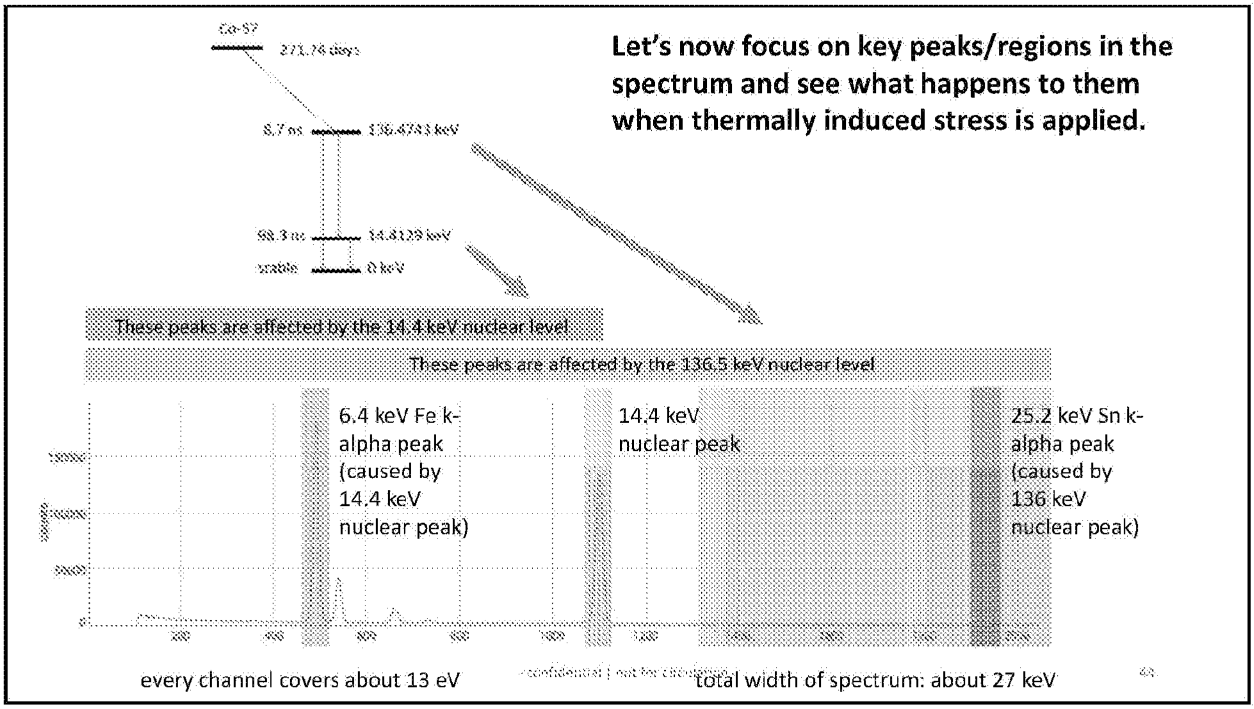
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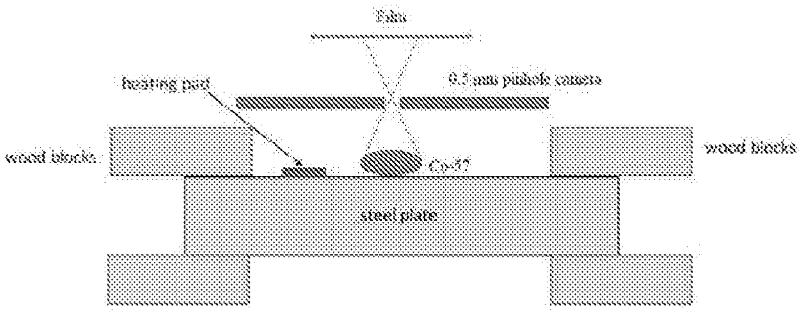
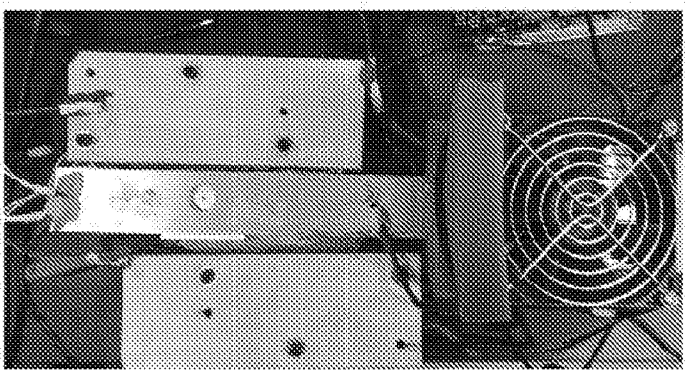
25.2 keV Sn k-alpha peak (caused by 136 keV nuclear peak)
every channel covers about 13 eV
total width of spectrum: about 27 keV

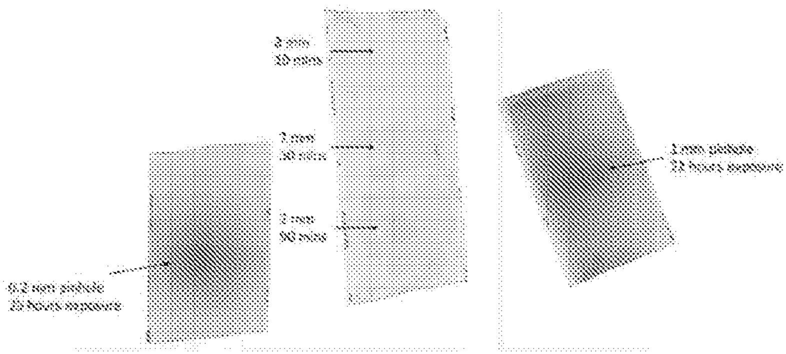
Schematic for pinhole camera setup



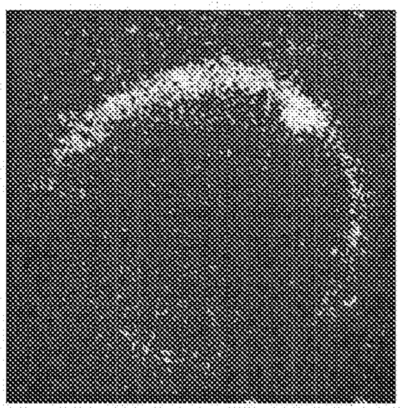
The pinhole X-ray camera as it is being assembled



First results with high-ISO film

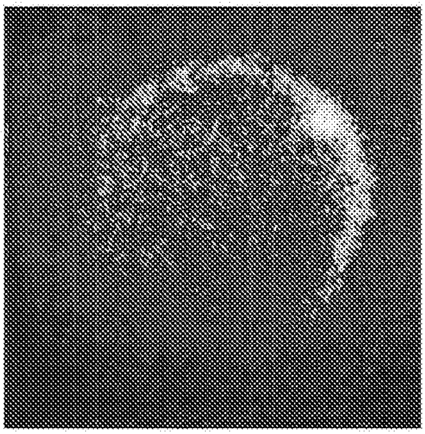


Comparing optical image with X-ray image

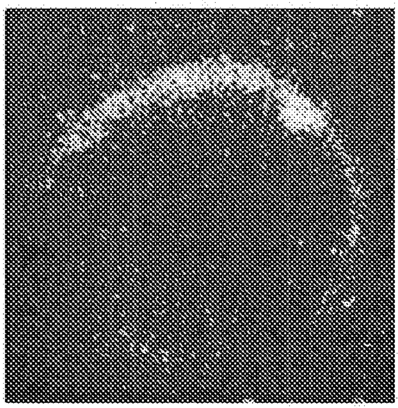


DSLR076

Comparing two X-ray images at different states



Siyuan cell phone

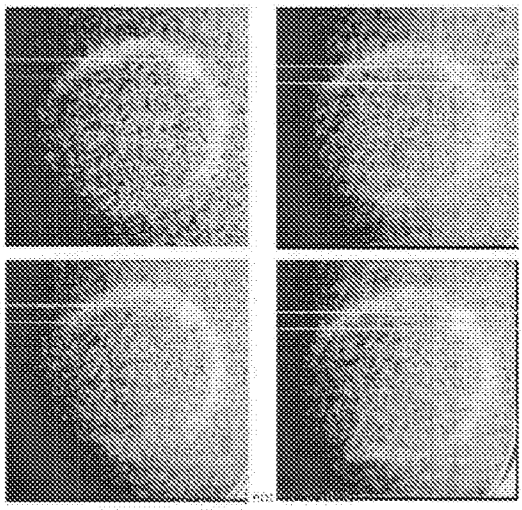


DSLR076

Quantifying X-ray images (1)

before cold

hot



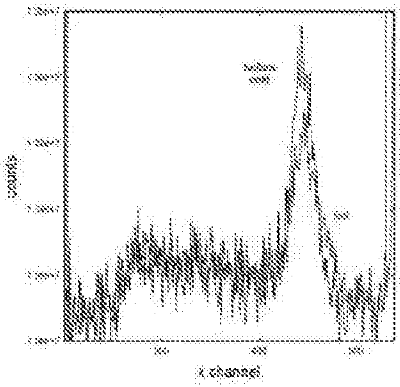
after cold1

after cold2

In the following slides, this one-dimensional slice (between the white lines) will be quantitatively analyzed and compared.

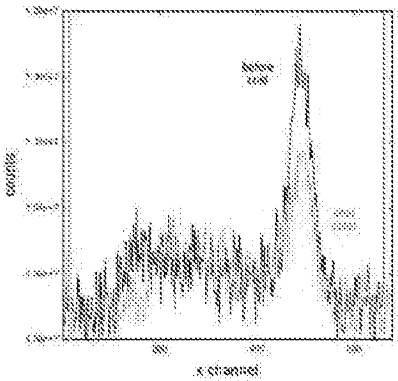
Quantifying X-ray images (2)

Compare before cold with hot



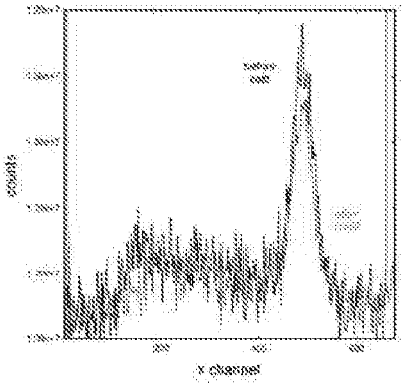
Quantifying X-ray images (3)

Compare before cold with after cold1



Quantifying X-ray images (4)

Compare before cold with after cold2



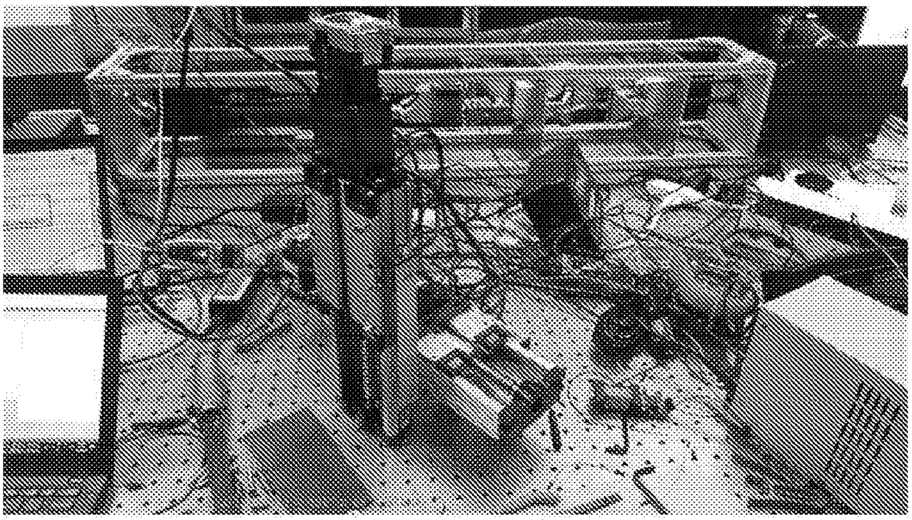
8. Outlook and next steps

Raster scanning (1)

- The previous slides described experiments centered around spectral (energy related) diagnostics; and experiments centered around spatial diagnostics.
- As raster scanning mechanism would combined the best of both worlds.
- We built an XZ stage that can be moved in X and Z direction at 2 micron precision. The plan is to mount the sample on the stage pod and move it along a grid (see next slide) and take spectral data at each grid point. This way we will obtain combined spectral and spatial data.

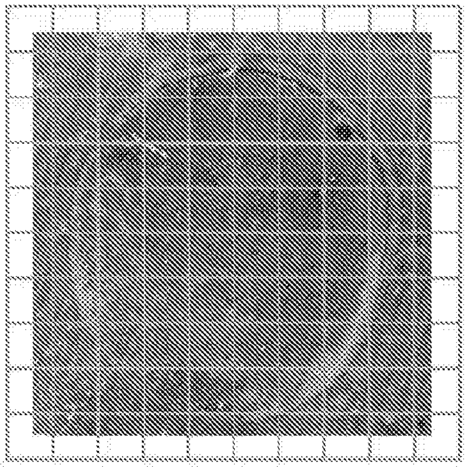
Raster scanning (2)

Parker Automation XZ stage almost ready for deployment



Raster scanning (3)

Example grid for raster scanning. We'll start with a coarse grid and will move to incrementally finer grids for high resolution images.

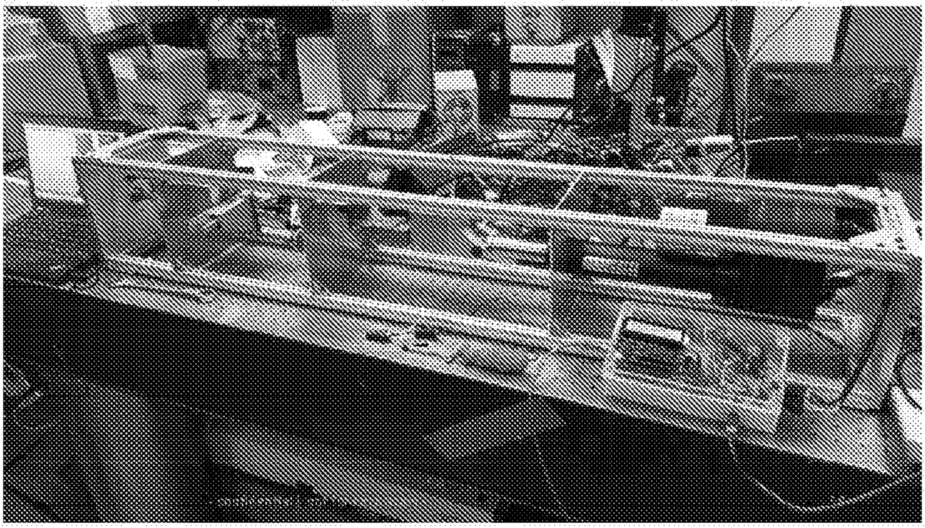


Controlled mechanical excitation (1)

- Our earliest experiments serendipitously exhibited a radiation effect from manually tightening clamps on our samples and cause a high, but ultimately uncertain amount of mechanical stress.
- We later advanced these experiments to increase stress temporarily and in situ through heating-pad-induced thermal expansion within the constraints of applied clamps. This gave us better ways to correlate cause and effect, however, higher temperatures introduced a whole set of other, undesired challenges.
- The ideal configuration involves a stress/strain station where we can both control and measure mechanical stress and strain.
- Florian designed, built, and tested such a station (see next slide).

Controlled mechanical excitation (2)

Stress/strain station with up to 2000 lbf force capability ready for deployment with radioactive samples.



Deliberate sample preparation to maximize effects (1)

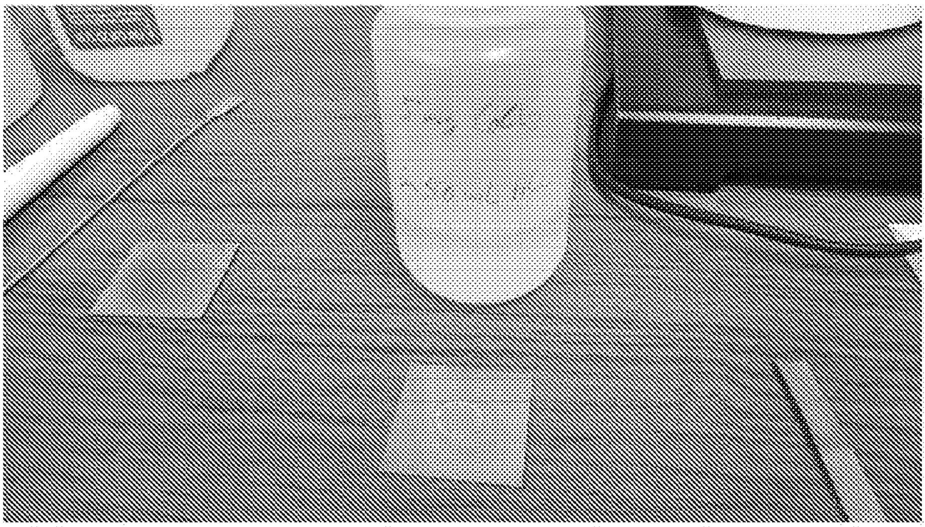
- Recent results suggest that in our experiments transfer of nuclear excitation ("excitation transfer") takes place within the evaporated sample on top of the steel plate. The evaporated source naturally takes the shape of a ring. We know that this source ring contains Co-57/excited Fe-57* nuclei from ongoing decay as well as lots of ground state Fe-57 that resulted from previous decay. Those ground state Fe-57 nuclei in the ring can all act as potential recipients of the nuclear excitation from excited Fe-57* nuclei.
- In order to maximize the effect, we would like to add more ground state Fe-57 nuclei in the vicinity of the source. This way we should be able to transfer nuclear excitation away from the original source ring.

Deliberate sample preparation to maximize effects (2)

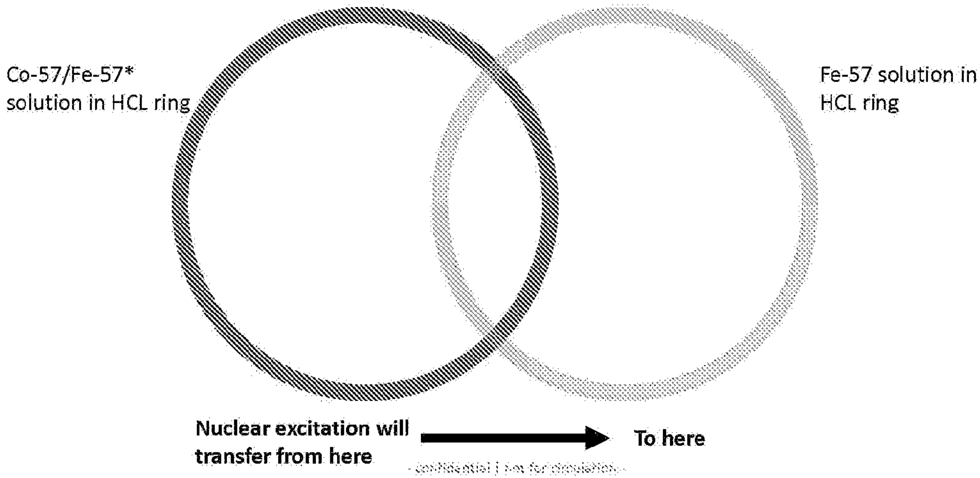
- We have procured Co-57 in HCL solution which we can use to evaporate more source rings similar to the two that we already have.
- We have also procured Fe-57 powder which we can dissolve in HCL and use to evaporate an Fe-57 which we can have overlap with the evaporated Co-57 ring.
- In such a configuration, we would expect nuclear excitation to transfer from the radioactive ring to the nonradioactive ring. This would demonstrate nuclear excitation transfer unambiguously.

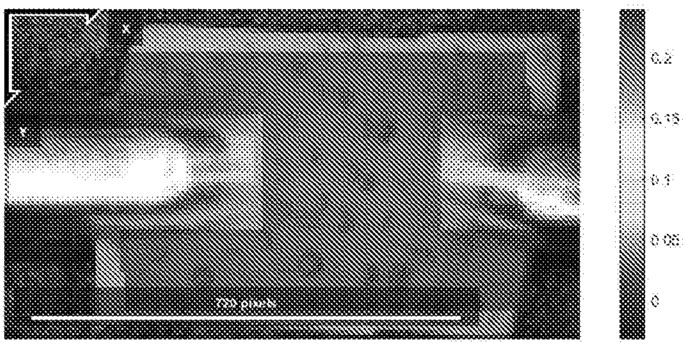
Deliberate sample preparation to maximize effects (3)

Evaporation of a (nonradioactive) CoCl2 in HCL sample which also forms a ring.



Deliberate sample preparation to maximize effects (4)





Claims

1. A method and system comprising

A condensed matter medium

A device for generating phonons in the medium

Whereas in the medium desired nuclear reactions are enabled by creating fast/preferred pathways for phonon-mediated energy exchange which lead to these reactions to manifest dominantely.

2. The method and system of claim 1 whereas the desired nuclear reactions are coherent.

3. The method and system of claim 2 whereas the desired nuclear reactions are coherent fission.

4. The method and system of claim 3 whereas the desired nuclear reactions are coherent asymmetric fission.

5. The method and system of claim 1 whereas the desired nuclear reactions are transmutations.

6. The method and system of claim 2 whereas the desired nuclear reactions are coherent fusion.

7. The method and system of claim 1 whereas certain nuclei are placed in the condensed matter medium at such densities to obtain desired phonon-nuclear coupling strengths which determine the dominant pathways/dominant phonon-nuclear coupling based mechanisms and desired rates.

7b. The method and system of claim 1 whereas certain nuclei are placed in the condensed matter medium at such configurations to obtain desired phonon-nuclear coupling strengths which determine the dominant pathways/dominant phonon-nuclear coupling based mechanisms and desired rates.

8. The method and system of claim 1 whereas nuclei with one of M1, E2, M3, E3 transitions are used to obtain strong phonon-nuclear coupling and accelerate the rates of the desired pathways.

9. The method and system of claim 1 whereas Hg-201 nuclei are used to obtain strong phonon-nuclear coupling and accelerate the rates of the desired pathways.

10. The method and system of claim 8 whereas Hg-201 nuclei are used to obtain strong phonon-nuclear coupling and accelerate the rates of the desired pathways.

11. The method and system of claim 1 whereas silver nuclei are used to obtain strong phonon-nuclear coupling and accelerate the rates of the desired pathways.