Modeling Karabut’s collimated x-rays, and excess heat in the Piantelli NiH exp’t

Peter Hagelstein
Research Laboratory of Electronics
MIT

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CMNS model

$$\hat{H} = \hbar\omega_0 \hat{a}^\dagger \hat{a} + \sum_j \left(\mathbf{M}_j c^2 + \mathbf{a}_j \cdot c\mathbf{P}_j \right)_{\text{stable}} + \sum_j \left(\mathbf{M}_j c^2 + \mathbf{a}_j \cdot c\mathbf{P}_j \right)_{\text{unstable}}$$

$$- i \frac{\hbar \hat{\Gamma}(E)}{2}$$

Model describes coherent dynamics of stable nuclear states in the presence of a highly excited phonon mode.

Focus on oscillator coupling with unstable transitions

$$\hat{H} = \hbar\omega_0 \hat{a}^\dagger \hat{a} + \sum_j \left(\mathbf{M}_j c^2 + \mathbf{a}_j \cdot c\mathbf{P}_j \right)_{\text{unstable}} - i\frac{\hbar\hat{\Gamma}(E)}{2}$$

- many ground state nuclei at many sites in the lattice
- relativistic coupling to highly excited states [O(100 MeV)]
- excited states very unstable
- highly-excited phonon mode
- oscillator loss for off-resonance conditions

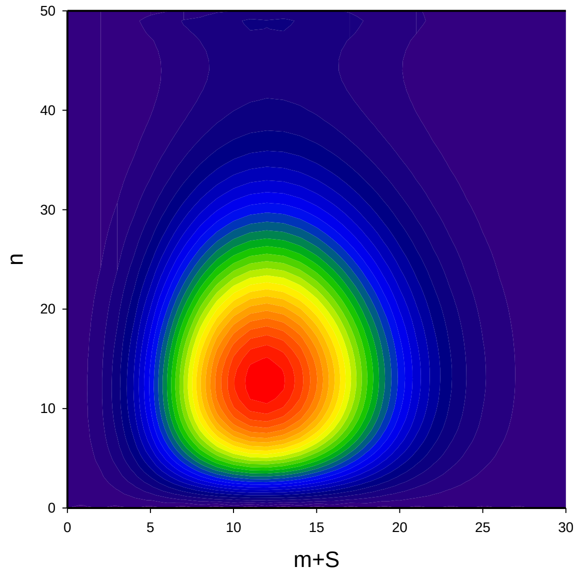
Approximate product solution

$$\Psi = \boxed{u_n} \boxed{\prod_{\beta,\kappa} \left[(-1)^{N_\kappa^{(\beta)}} \, a_{N_\kappa^{(\beta)}}^{(\beta)} \right]}$$

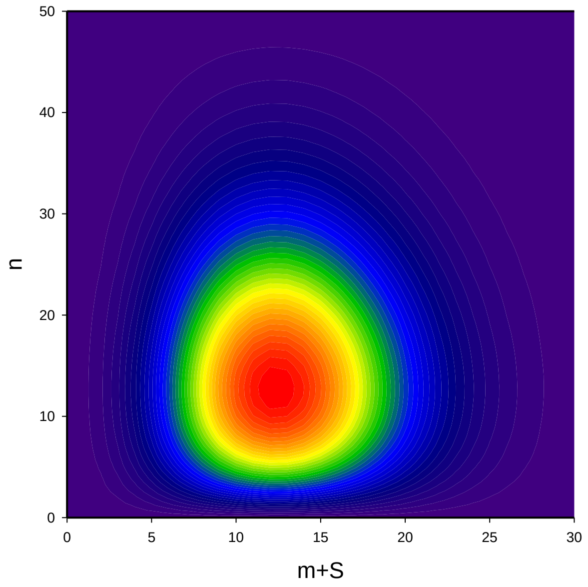
oscillator distribution | excited state distributions

Coupling of degrees of freedom is complicated, but we can get a good approximation using a self-consistent Hartree type of approximation

Two-level system model test problem



exact solution



approximate
product solution

Incremental oscillator distribution

$$u_n \;\to\; u(n) \;=\; \mathrm{Ai}\left(\frac{n}{\left(2g_u\right)^{1/3}} - 2.83310 \right)$$

$$g_u \;=\; \sum_{\beta,\kappa} N_1^{\beta} \frac{2\left[V_{1\kappa}^{(\beta)}\right]^2 n_0}{\hbar\omega_0 \left(E_{\kappa}^{(\beta)} - E_1^{(\beta)}\right)}$$

Incremental oscillator distribution now available for general case

Coherent dynamics with two-level systems

oscillator

two-level systems

$$\hat{H} = \boxed{\hbar\omega_0 \hat{b}^\dagger \hat{b}} + \boxed{\Delta E \frac{\hat{S}_z}{\hbar} + V \frac{2\hat{S}_x}{\hbar}\left(\hat{b} + \hat{b}^\dagger\right)}$$

$$+ \boxed{\sum_j \left(\mathbf{M}_j c^2 + \mathbf{a}_j \cdot c \frac{\partial \mathbf{P}_j}{\partial b}\left(\hat{b} + \hat{b}^\dagger\right) \right)_{\text{unstable}}}$$

$$\boxed{-i \frac{\hbar \hat{\Gamma}(E)}{2}}$$

N-level systems with unstable upper states

oscillator loss

Coherent energy exchange

two-level systems

$$\Psi(t) = \sum_m c_m(t) \boxed{|S,m\rangle} \boxed{\Phi_{n_0 - m\Delta n}}$$

coupled oscillator and unstable transitions

Assuming resonance:

$$\Delta E = \hbar\omega_0 \Delta n$$

Evolution equation

$$
\begin{aligned}
i\hbar \frac{d}{dt} c_m \;&=\; \left\langle \Phi_{n_0} \middle| b + b^\dagger \middle| \Phi_{n_0+\Delta n} \right\rangle \sqrt{(S+m)(S-m-1)}\, c_{m-1} \\
&+\; \left\langle \Phi_{n_0} \middle| b + b^\dagger \middle| \Phi_{n_0-\Delta n} \right\rangle \sqrt{(S-m)(S+m-1)}\, c_{m+1}
\end{aligned}
$$

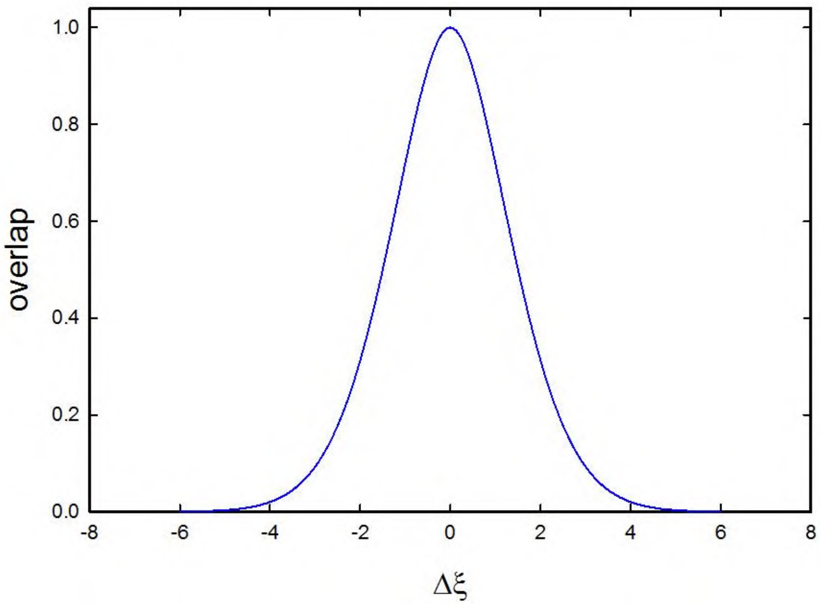
Model describes coherent energy exchange between two-level systems and oscillator (coupled to N-level systems).

Whether significant energy exchange occurs depends on phonon matrix elements

Phonon matrix element

$$\frac{1}{2}\left\langle \Phi_{n_0} \left| \hat{b} + \hat{b}^{\dagger} \right| \Phi_{n_0+\Delta n} \right\rangle = \frac{\int_{-2.83310}^{\infty} \mathrm{Ai}(\xi)\,\mathrm{Ai}(\xi+\Delta\xi)\,d\xi}{\int_{-2.83310}^{\infty} \mathrm{Ai}^2(\xi)\,d\xi} = f(\Delta\xi)$$

$$\Delta\xi = \frac{\Delta n}{(2g_u)^{1/3}}$$



Assessment

- Coherent energy exchange between (stable) two-level systems and oscillator (coupled to N-level systems)

- Coupled oscillator and N-level systems fractionates large quantum

- Stronger coupling $\leftarrow\rightarrow$ larger g_u $\leftarrow\rightarrow$ more quanta can be exchanged

- No exchange in absence of oscillator loss effects

Can we go the other way?

- Donor receiver model developed for converting donor energy to oscillator excitation
- But can we go the other way?
- Is it possible to start with an excited oscillator, and transfer the energy to two-level systems
- Is it possible to excite nuclei with vibrational excitation?
- New models would say yes

Can it be demonstrated?

- Model predicts coherent energy exchange between equivalent two-level systems with a large transition energy, and an oscillator with a low transition energy
- Two-level systems can be atoms, molecules, nuclei, spin systems
- Oscillator can be vibrational, electrical, plasmonic, electromagnetic
- Many possibilities for systems to show the effect
- But can be demonstrate it between phonons and nuclei?

Critical parameters

$$\Delta\xi = \frac{\Delta n}{\left(2g_u\right)^{1/3}}$$ needs to be near unity

$$g_u = \sum_{\beta,\kappa} N_1^{\beta} \frac{2\left[V_{1\kappa}^{(\beta)}\right]^2 n_0}{\hbar\omega_0\left(E_\kappa^{(\beta)} - E_1^{(\beta)}\right)}$$

Want Δn to be small; want ω_0 to be large, want low energy transition, need highly excited oscillator

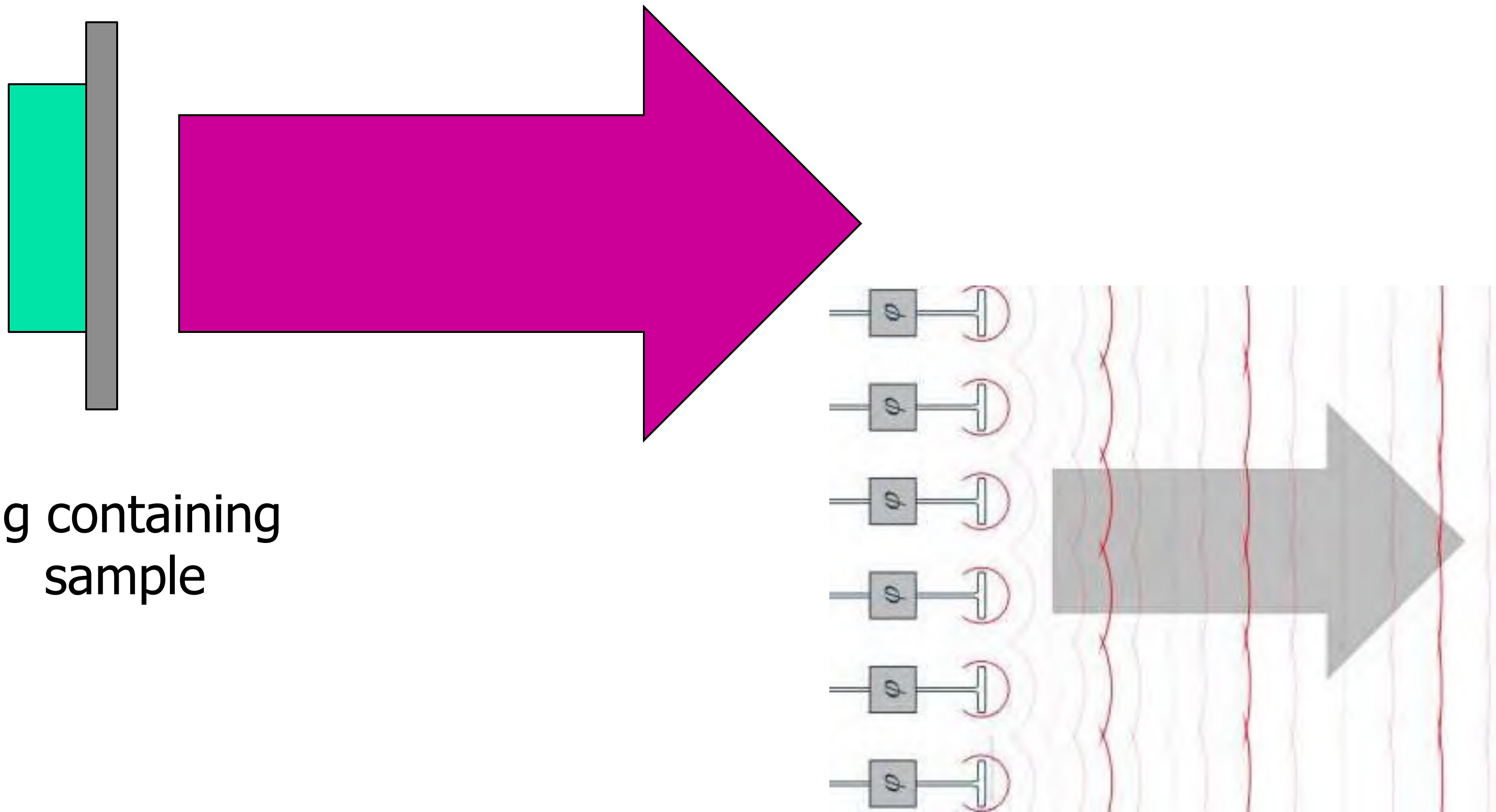
What are lowest energy nuclear transitions?

Nucleus	Excited state energy (keV)	half-life	multipolarity
^{201}Hg	1.5648	81 ns	M1+E2
^{181}Ta	6.240	6.05 μs	E1
^{169}Tm	8.41017	4.09 ns	M1+E2
^{83}Kr	9.4051	154.4 ns	M1+E2
^{187}Os	9.75	2.38 ns	M1(+E2)
^{73}Ge	13.2845	2.92 μs	E2
^{57}Fe	14.4129	98.3 ns	M1+E2

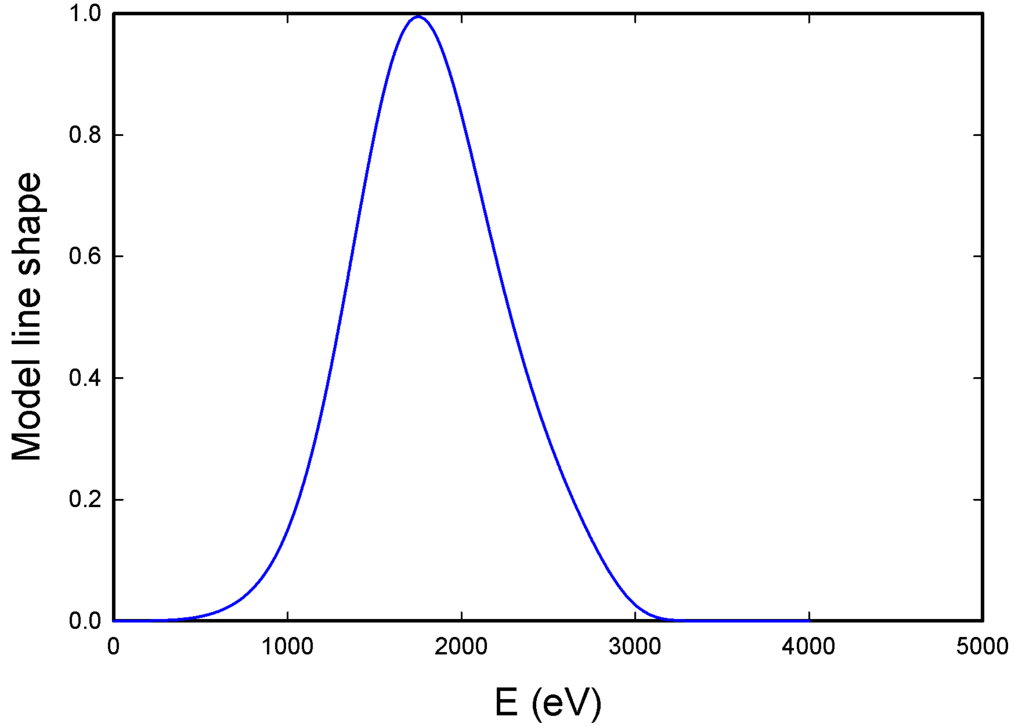
P. L. Hagelstein, “Bird’s eye view of phonon models for excess heat in the Fleischmann-Pons experiment,” *J. Cond. Mat. Nucl. Sci.* (in press)

^{201}Hg transition at 1565 eV is optimum candidate among stable nuclei to demonstrate effect.

Conceptual design



Predicted spectrum is broad

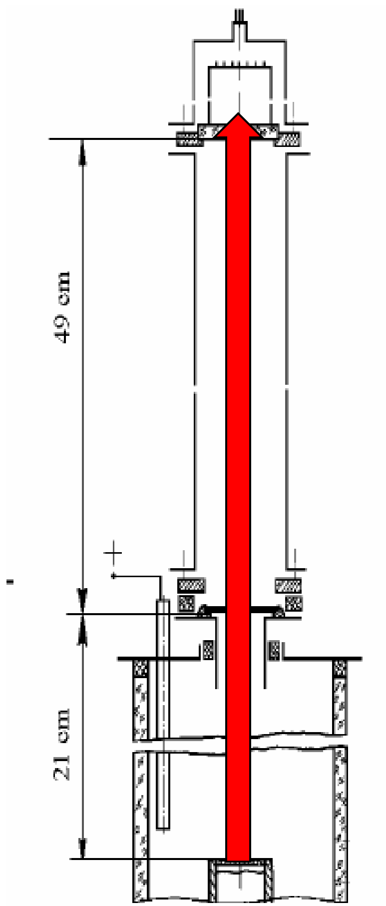


Spread in phonon distribution that causes excitation will show up in the broadening of the line, and shift due to E^2 in photon density of states.

Karabut experiment

- Alexander Karabut (Luch Institute, Moscow) showed up at ICCF10 talking about having demonstrated an x-ray laser
- Karabut was working with a high-current glow discharge
- Karabut observed collimated x-ray radiation near 1.5 keV
- (No way for there to be an x-ray laser in this experiment)
- Must be some alternate explanation…

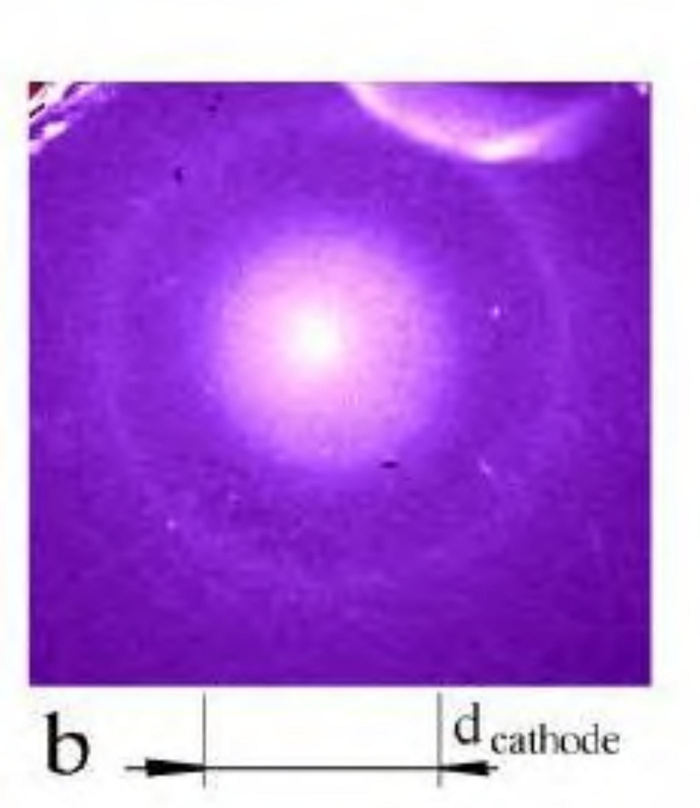
Karabut experiment (ICCF10)



Collimated x-ray effect seen with different metals (Al, V, Fe, Zn, Mo, Pd, W, others)

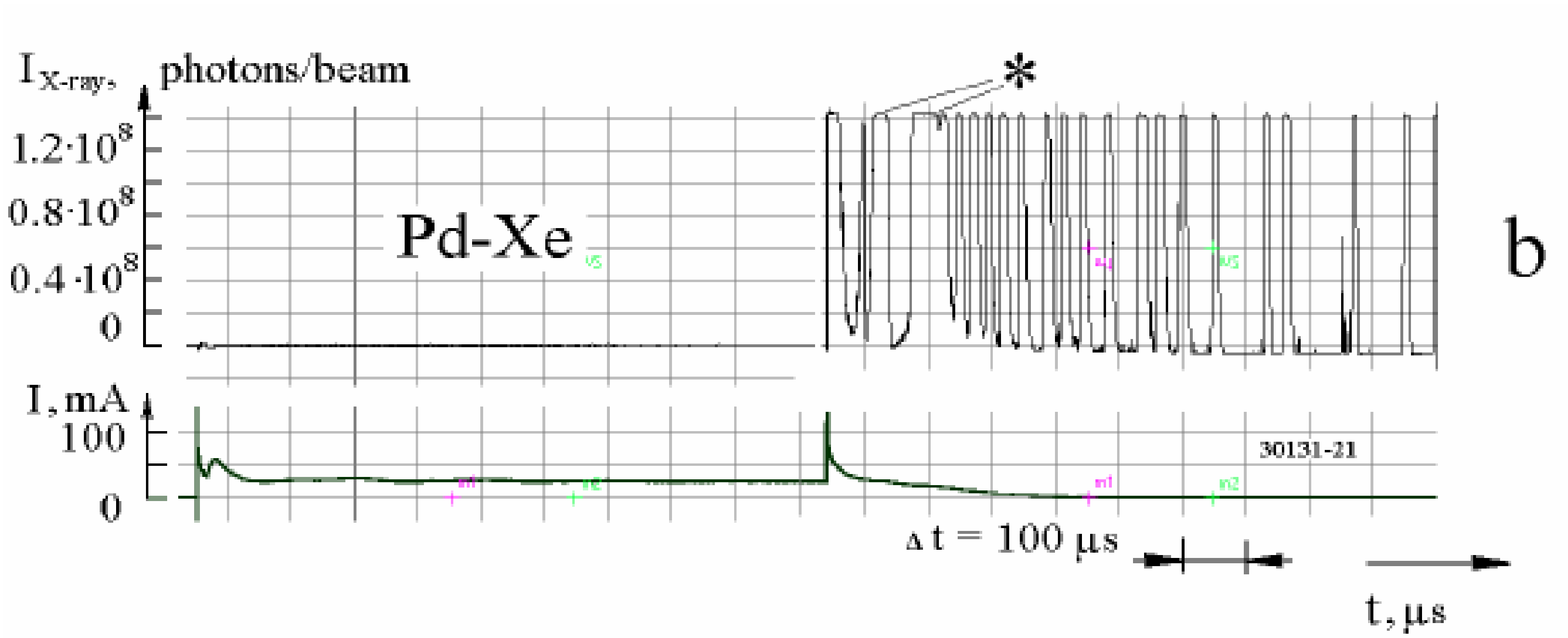
…and with different gasses (H_2, D_2, Kr, Xe)

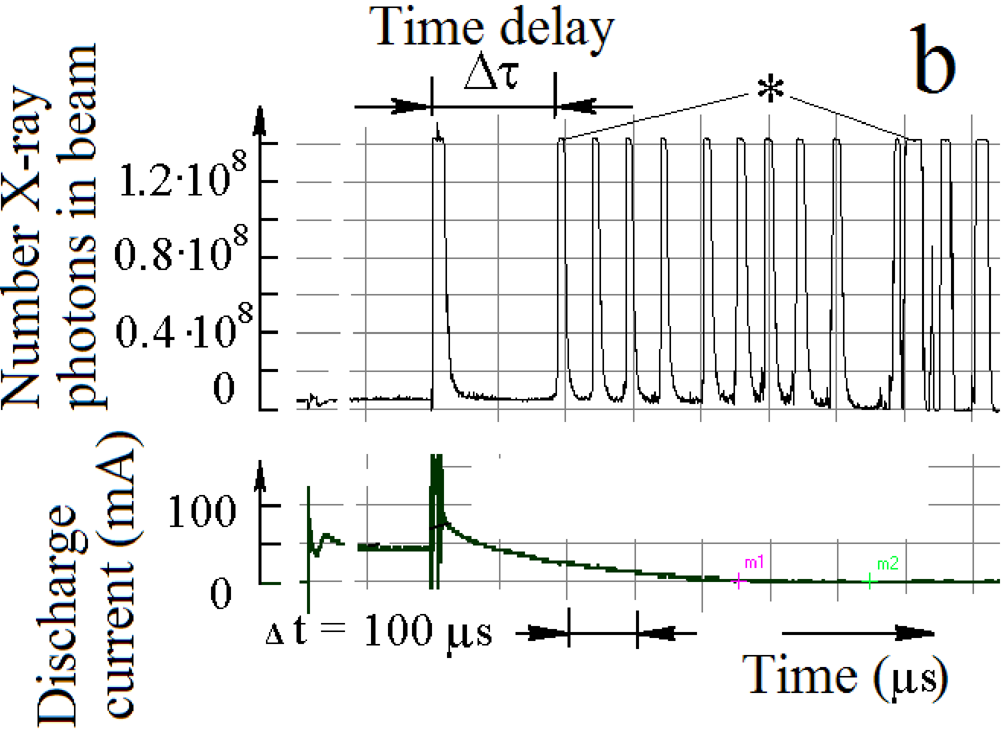
Pinhole camera image of cathode



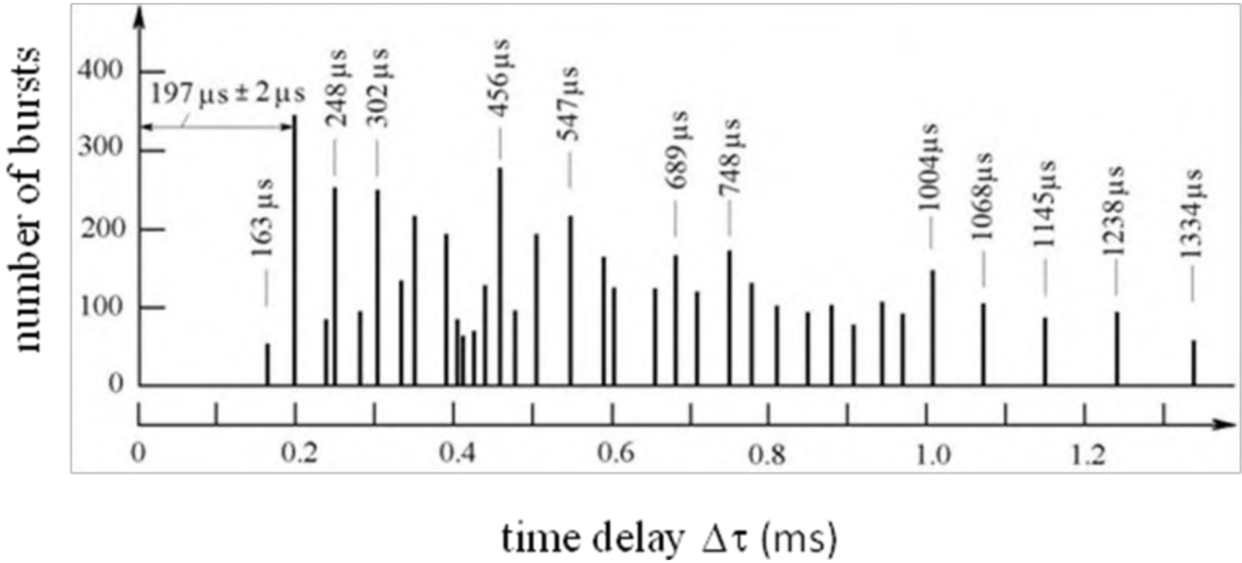
Collimated x-rays very bright, originate from cathode surface

Emission after turn off



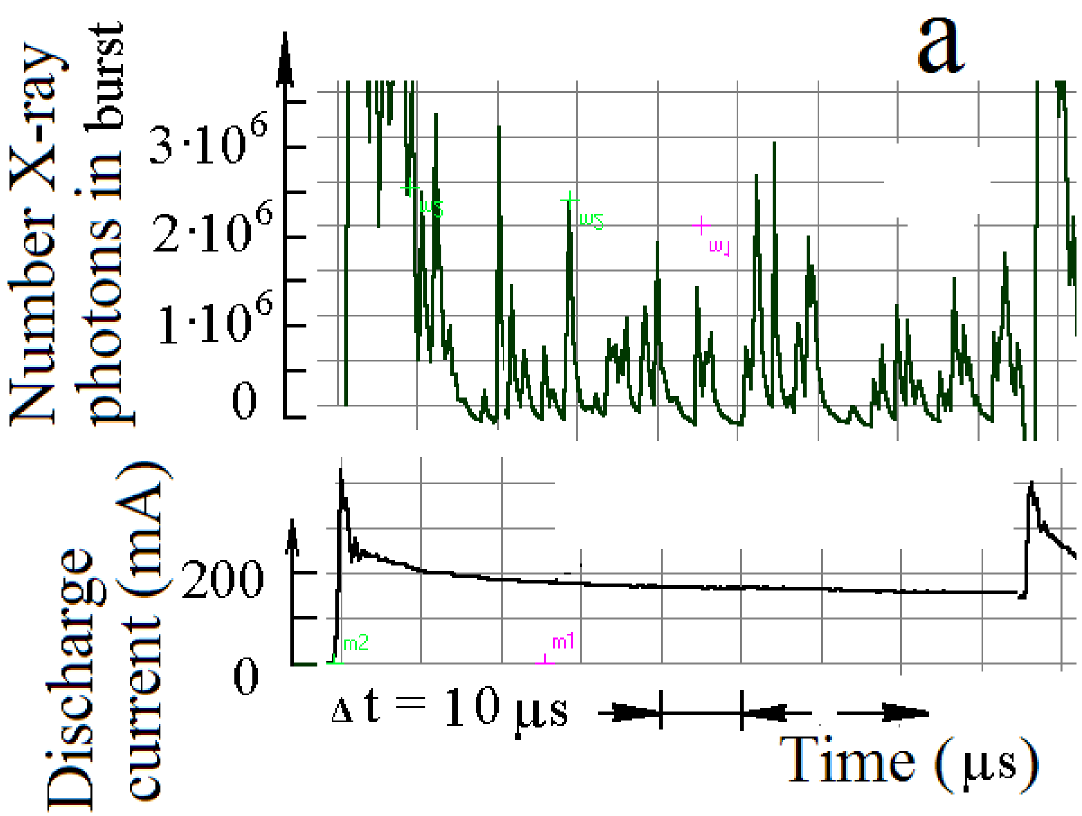


A. B. Karabut, E. A. Karabut, P. L. Hagelstein, "Spectral and temporal characteristics of x-ray emission from metal electrodes in a high-current glow discharge," *J. Cond. Mat. Nucl. Sci.* (in press).

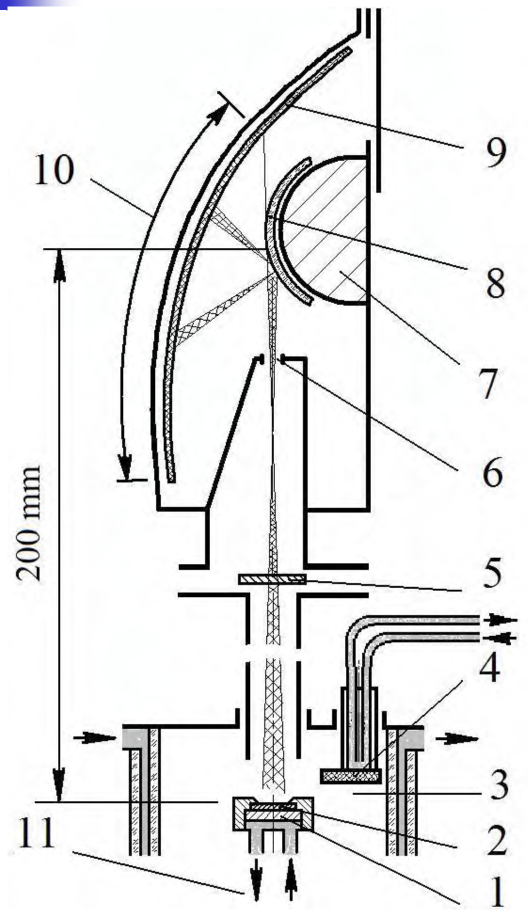


Collimated emission appears after discharge is turned off, up to 1 msec and more

Diffuse emission during discharge

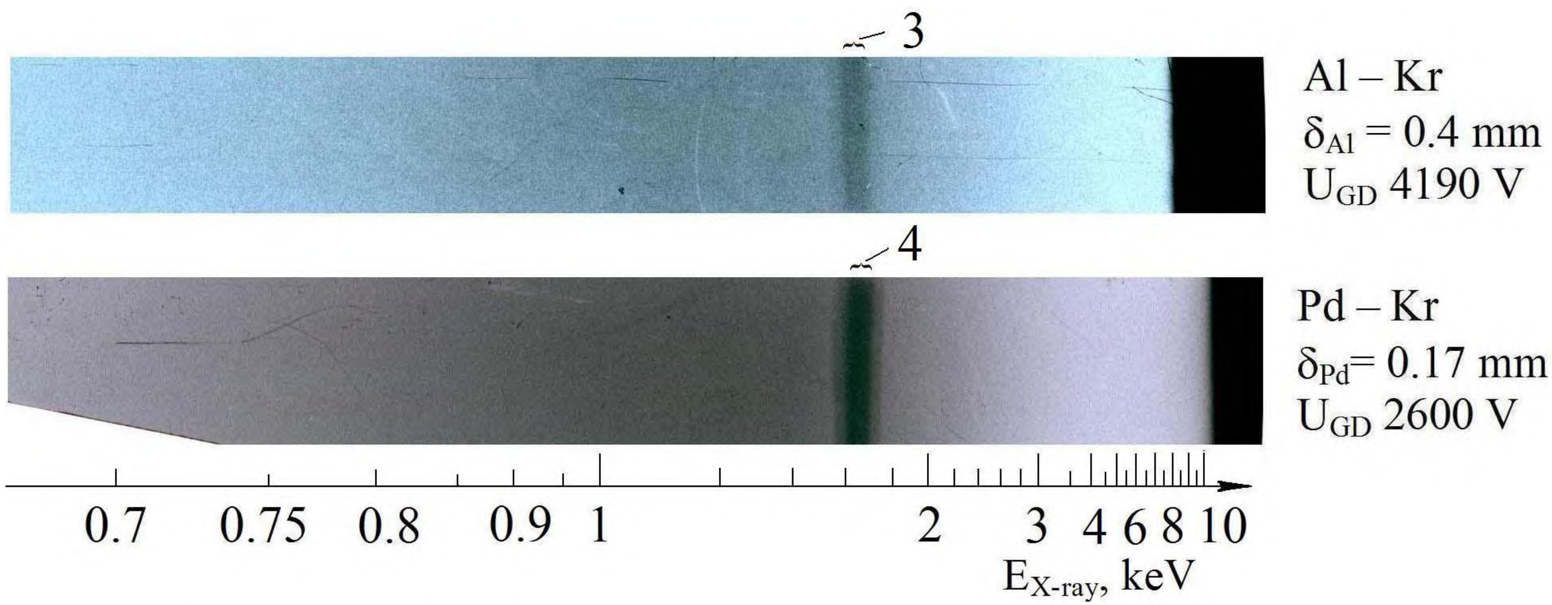


Bent mica spectrometer



X-ray spectrometer:
1– cathode holder,
2– cathode sample,
3 – vacuum discharge chamber,
4 – anode,
5 –15 μ Be screen ,
6 – input slit of spectrometer,
7 – crystals holder,
8 – curved mica crystal,
9 – x-ray film,
10 – area of reflection spectra ,
11 – input and output cooling water.

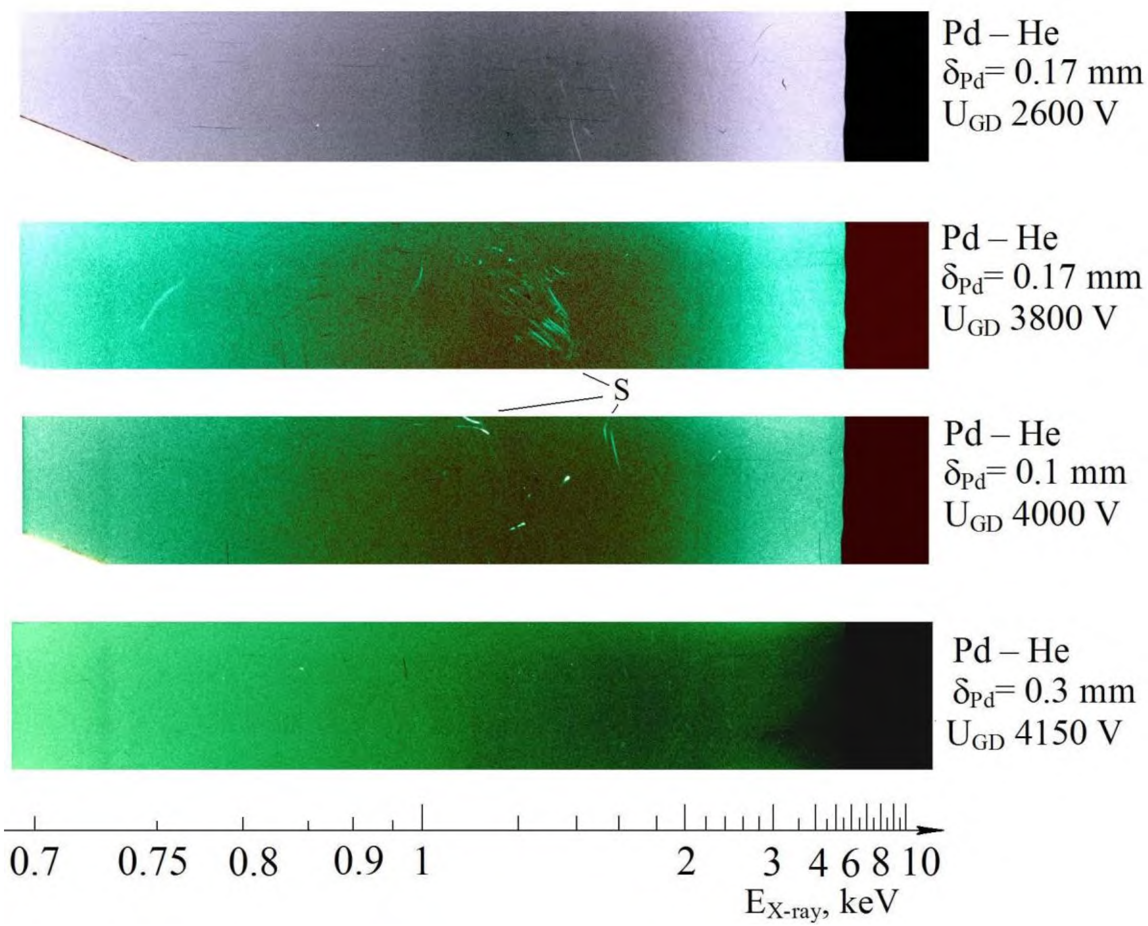
Diffuse Kr L-shell emission



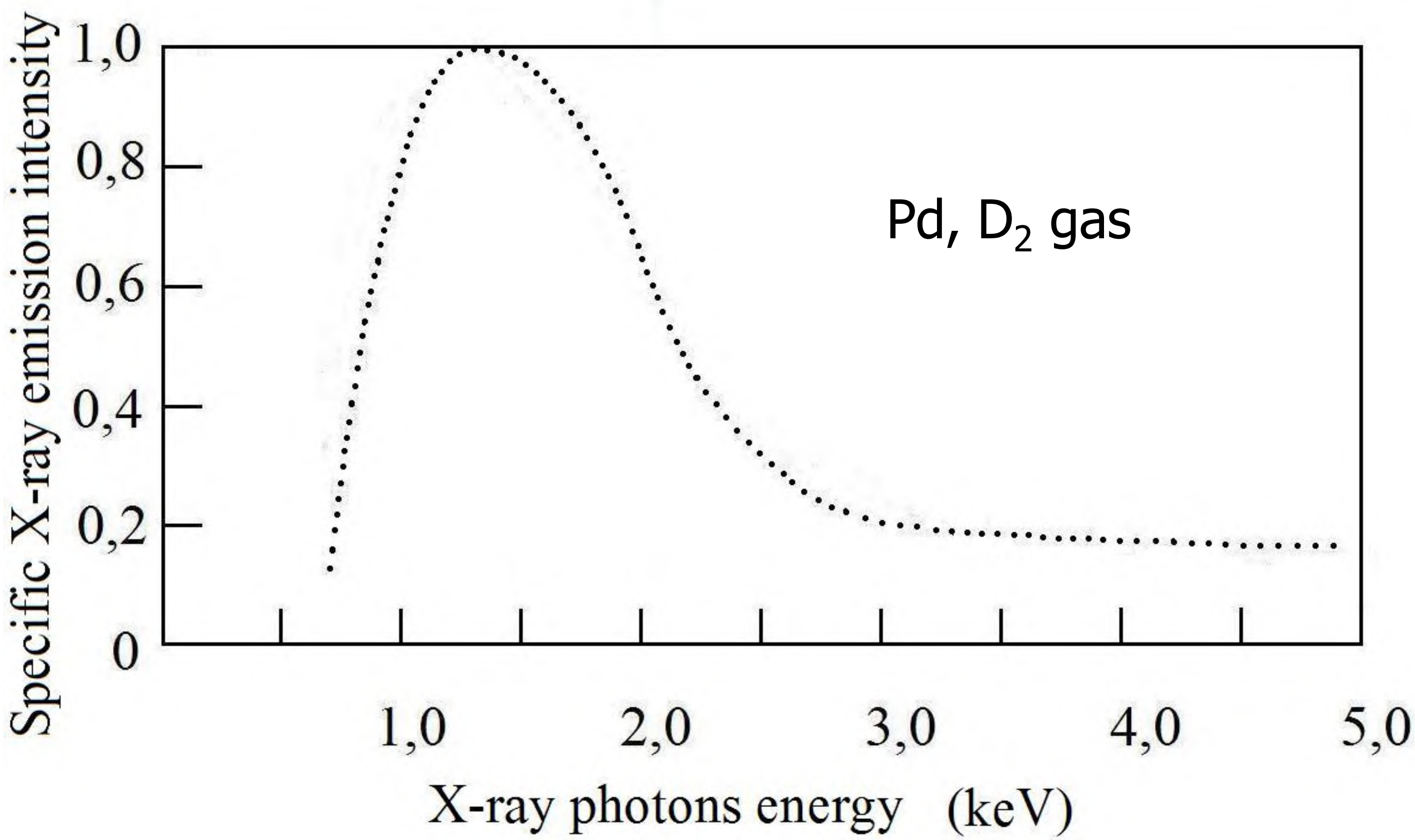
X-ray spectra for Pd and Al cathodes taken in Kr gas showing characteristic L-shell emission (denoted as 3 and 4 in the spectra) near 1.6 keV (the $L_{\alpha 1}$ and $L_{\alpha 2}$ transitions are listed at 1.581 keV and at 1.580 keV). Minor differences between the observed and known energy may be due to the use of the normal incidence grating formula.

The Kr L-shell line is diffuse and originates from the cathode surface (not from the gas). It shows up in the spectrum a bit off due to the way the data was analyzed.

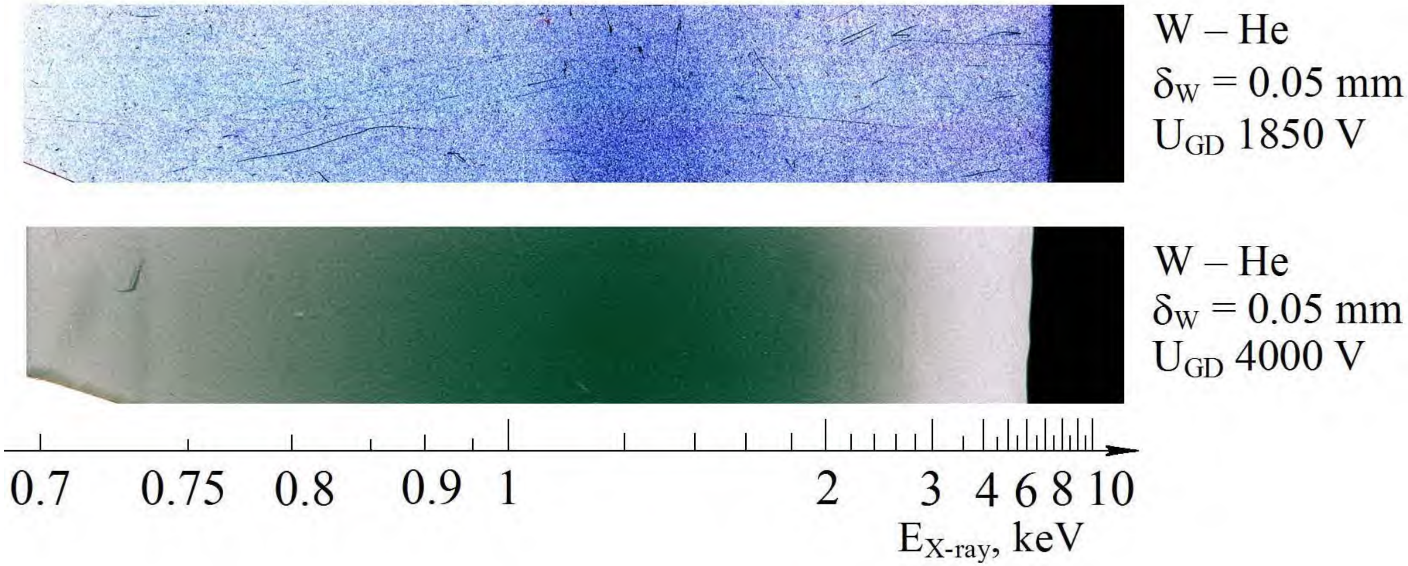
Diffuse continuum emission



Spectrum of continuum

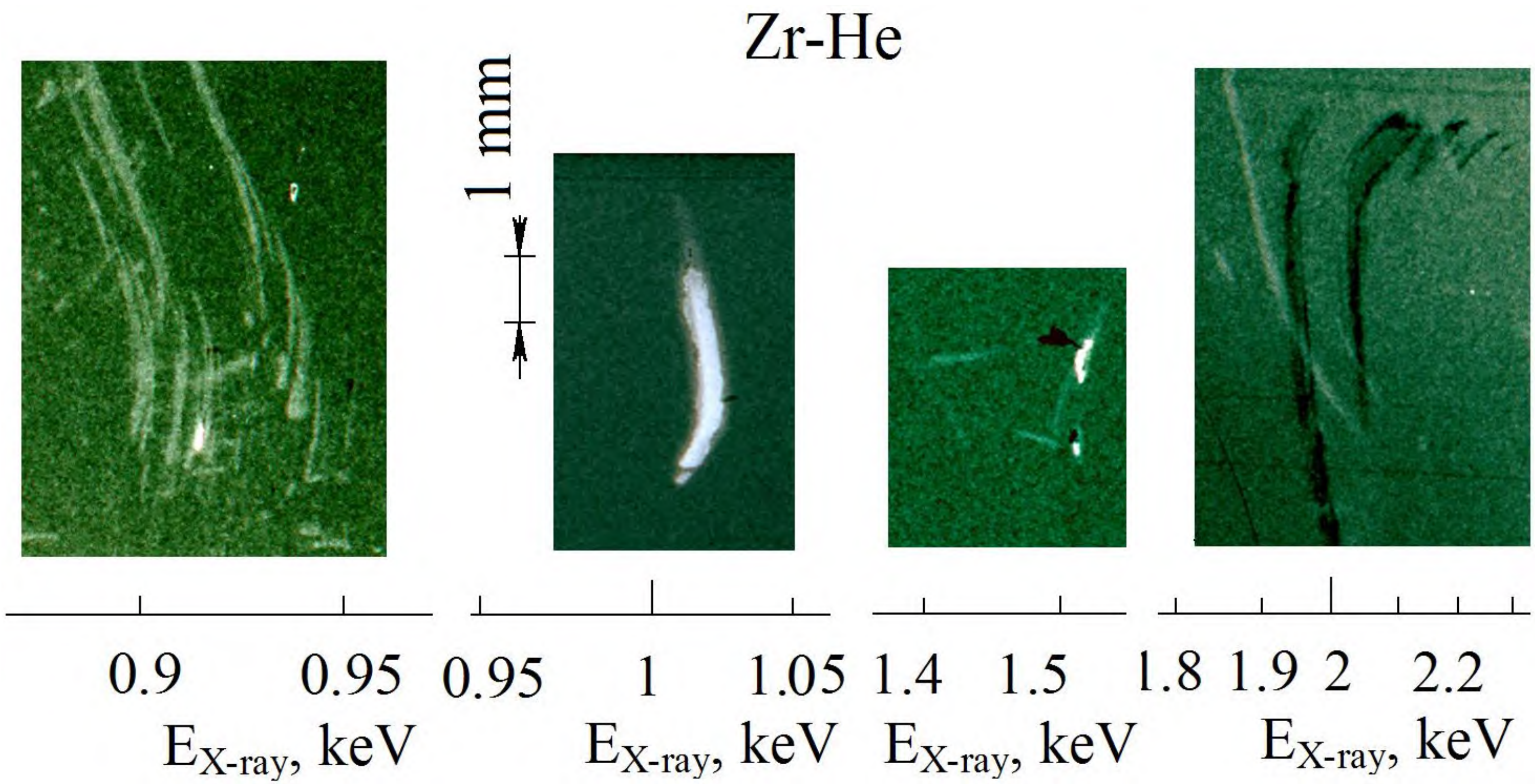


Voltage dependence

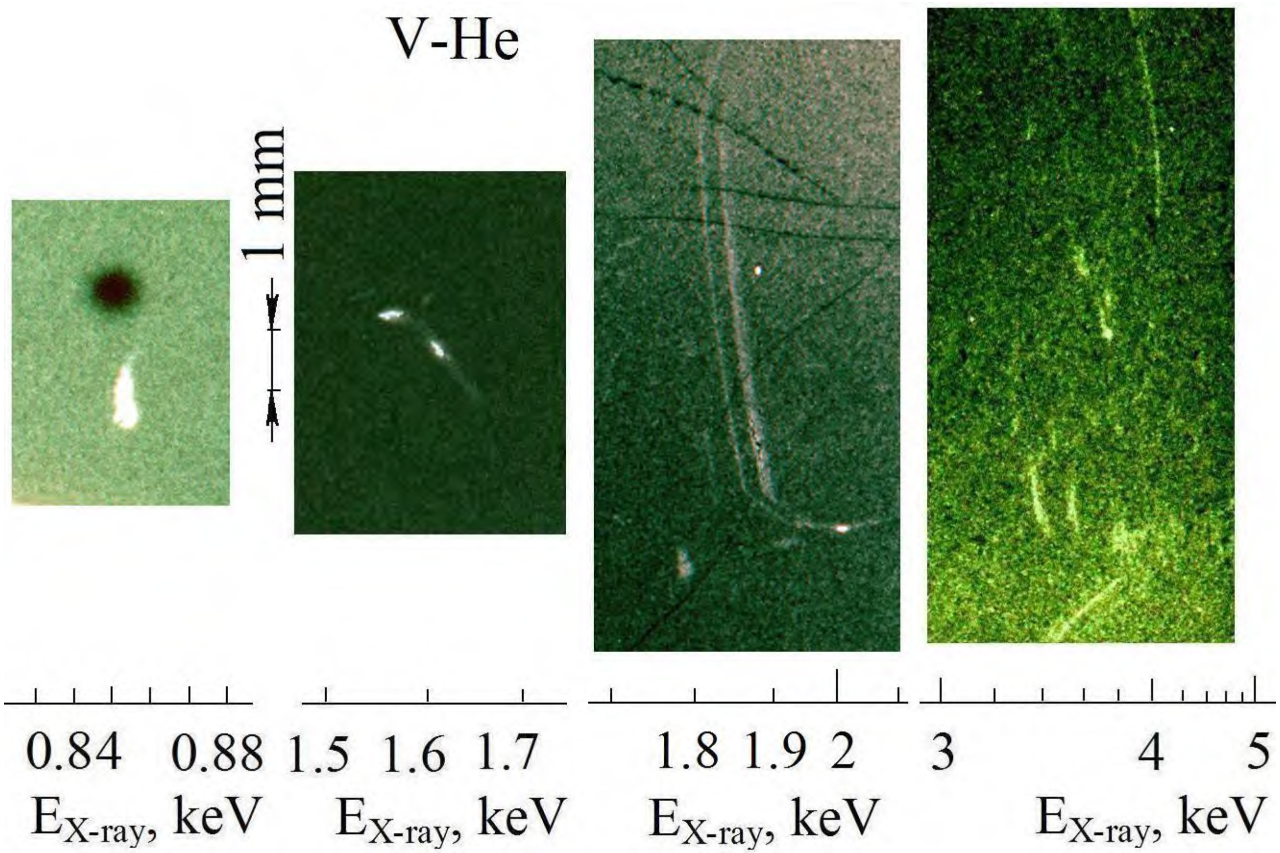


The diffuse continuum emission is a broad feature that originates from the cathode surface. The width depends on the applied voltage (and hence current).

Collimated beamlets

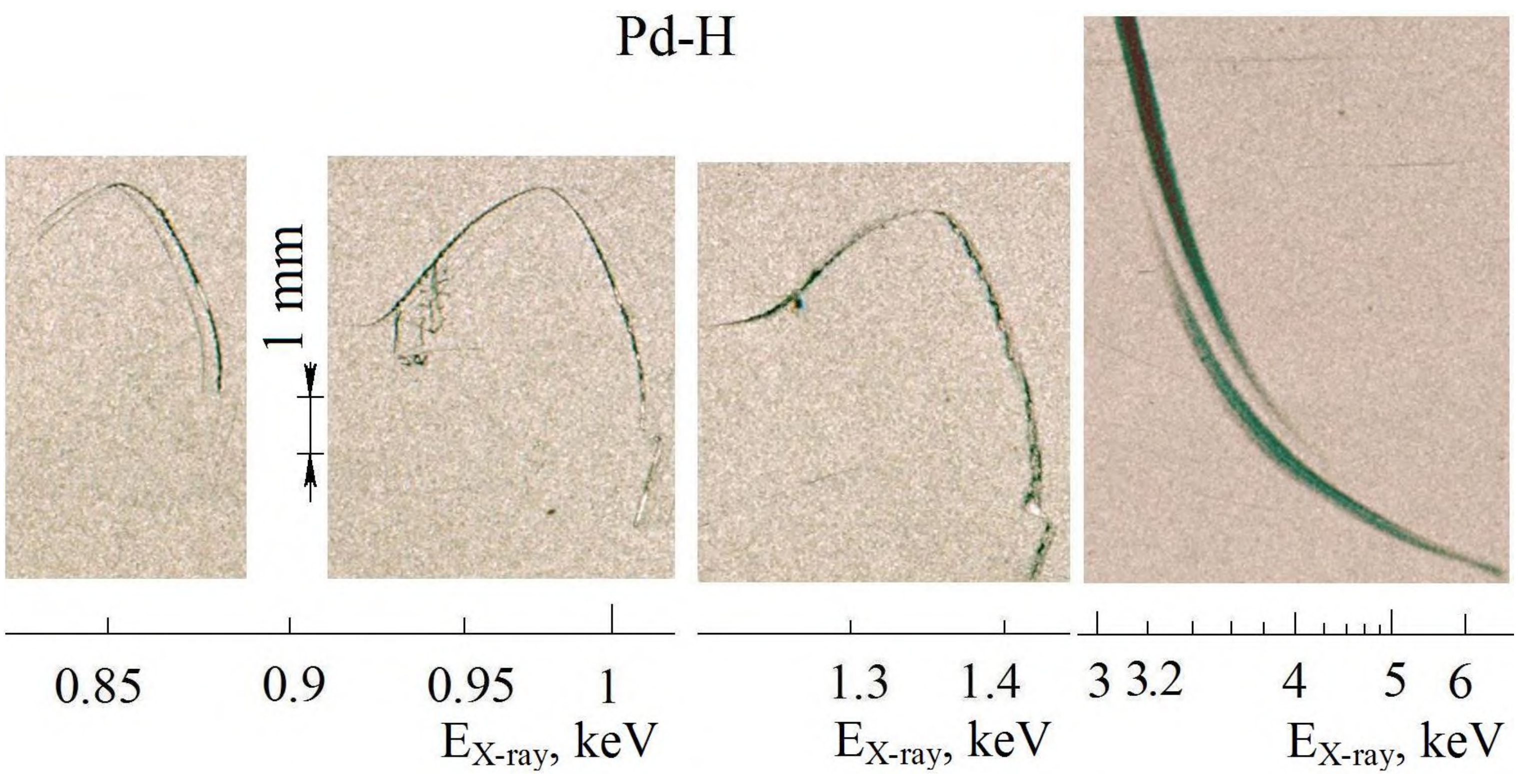


Interpret the curves as due to a minor change in direction of the beam during the emission. The emission is sufficiently bright to damage (cause solarization) film.



V-He
1 mm
0.84 0.88
$E_{X\text{-ray}}$, keV
1.5 1.6 1.7
$E_{X\text{-ray}}$, keV
1.8 1.9 2
$E_{X\text{-ray}}$, keV
3 4 5
$E_{X\text{-ray}}$, keV

Beams seen long after discharge



Data collected for 20 hours after the discharge turned off

Collimated emission taken long after the discharge is turned off is particularly interesting because effect can only be due to vibrational effects (no possible residual from the discharge).

Collimated emission

- Collimated emission due to coherent energy exchange from O(50 MHz) vibrational modes

- Hg sputtered into surface from gas contamination by discharge

- Phase coherence only possible for narrow (and almost random) frequencies within broad line width due to random positions of Hg nuclei [based on simulations]

Diffuse emission

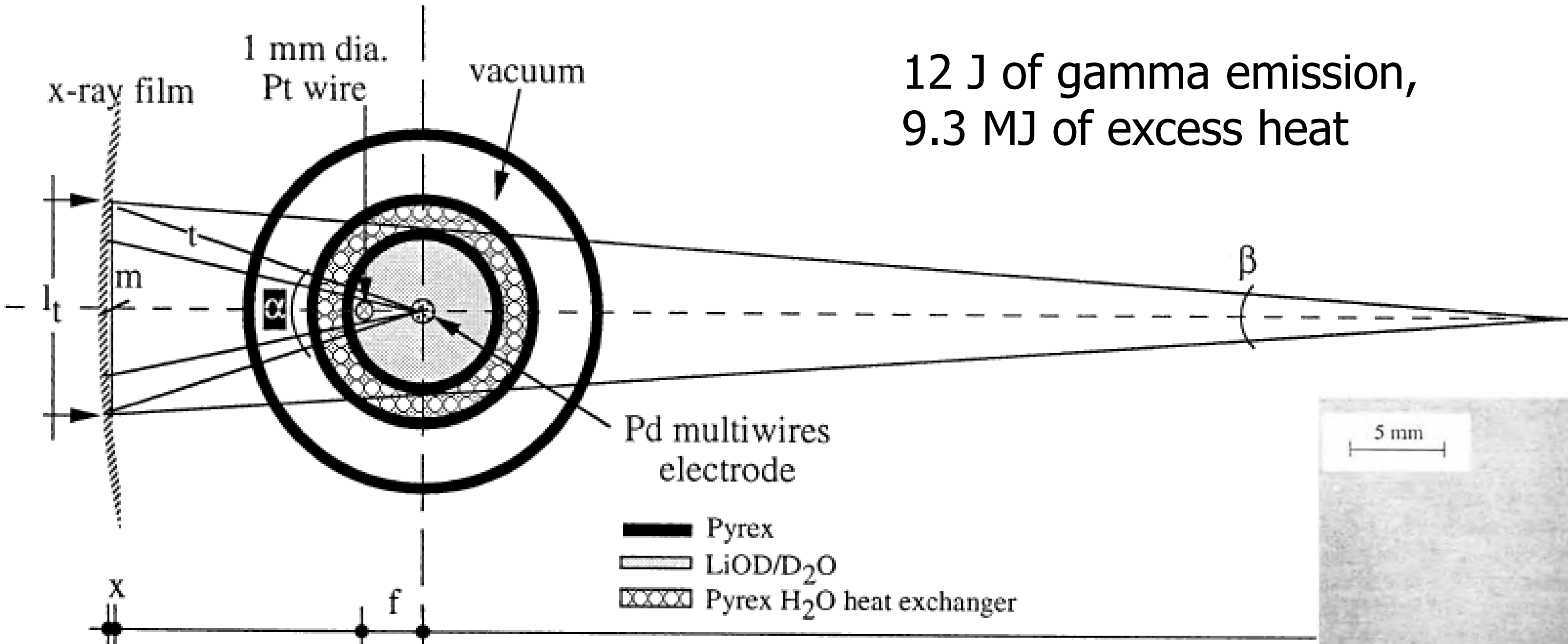
- Diffuse emission due generally to coherent energy exchange with THz phonon modes excited by discharge ion bombardment

- Broad feature due to ^{201}Hg nuclear transition

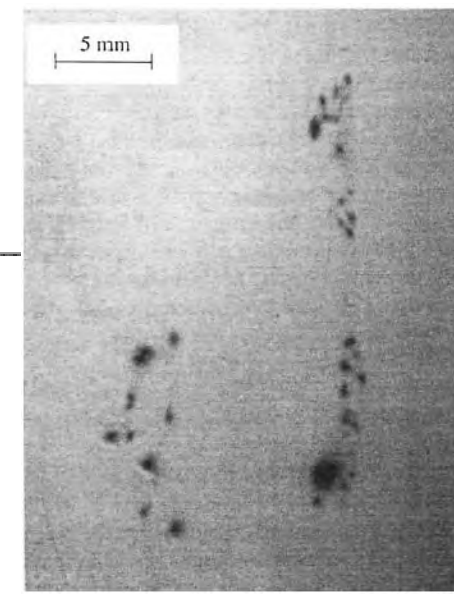
- Characteristic gas line emission due to energy exchange with ^{201}Hg excited state (Kr, Ar correlated in space with Hg)

- Characteristic host line emission due to similar energy exchange effect

Gozzi's experiment (ICCF6)



12 J of gamma emission,
9.3 MJ of excess heat



From absorption coefficient of Pd cathodes, can estimate the energy of the gamma signal. Gozzi et al obtained an energy of 89 keV, and suggested that it was due to ^{109m}Ag

Before looking at expts…

•Excess heat seen in NiH experiments

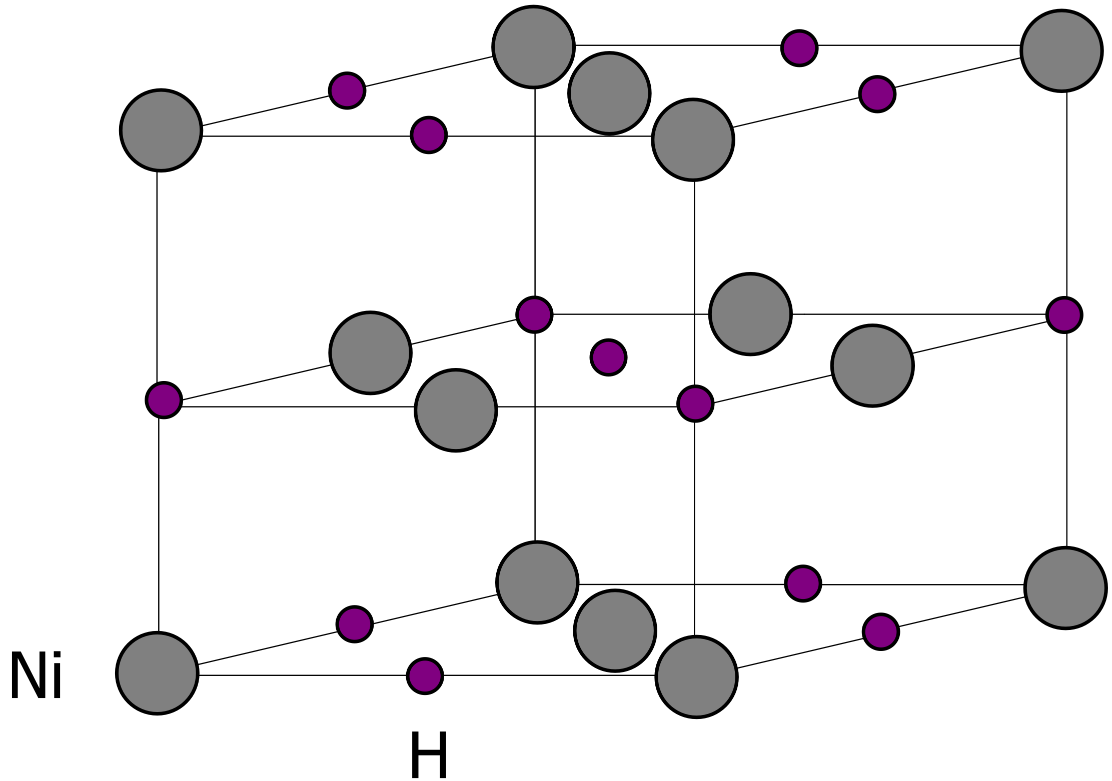
•Effect first reported in electrolysis experiments by Mills and Kneizys (1991)

•Excess heat in gas loading experiments reported by Piantelli et al (1994)

•NiH is not PdD

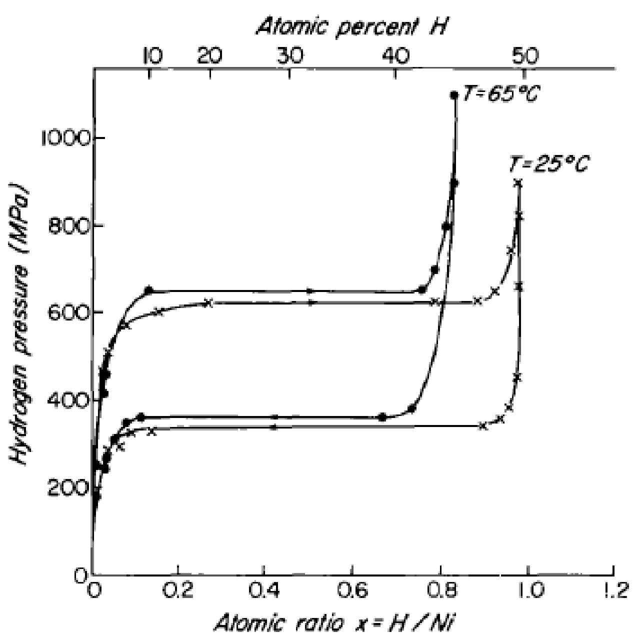
•Differences are important

NiH lattice structure (fcc)



Phase diagram

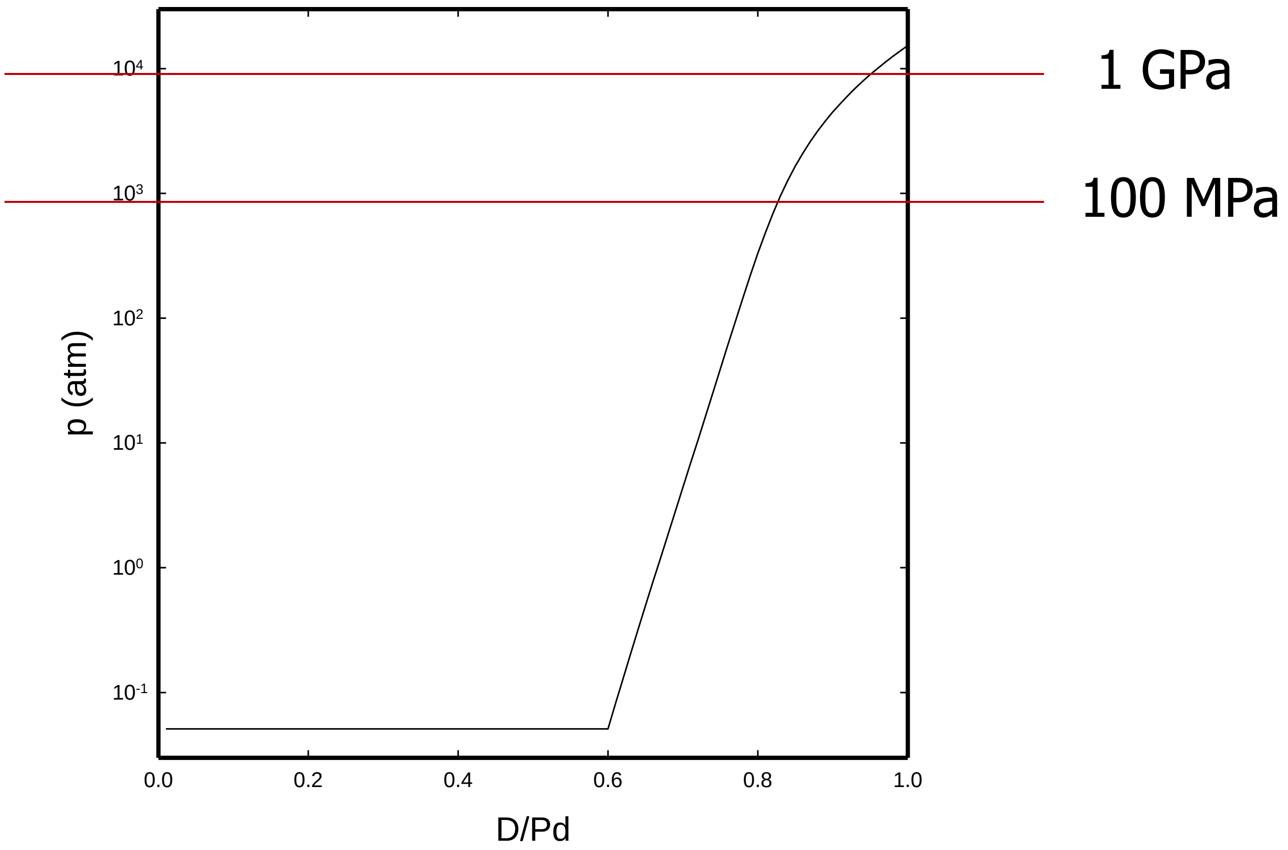
Fig. 4 Absorption and Desorption Isotherms at 25 and 65 °C for the Ni-H System



From [78Bar]. M. Wayman and G.C. Weatherly, 1989.

Note: 400 Mpa = 3948 atm

Pressure vs loading



X-ray diffraction data in electrochemical loading

Juskenas et al, *Electrochimica Acta* **43** 1903 (1998)

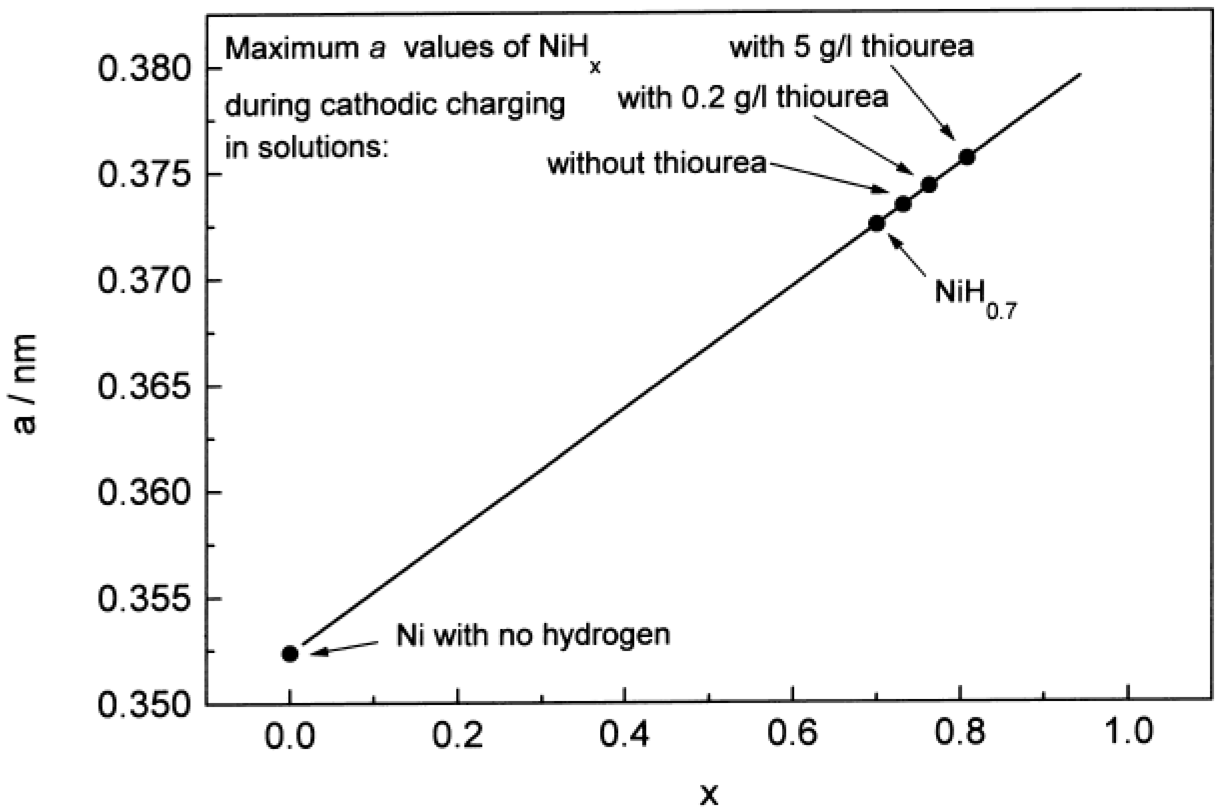
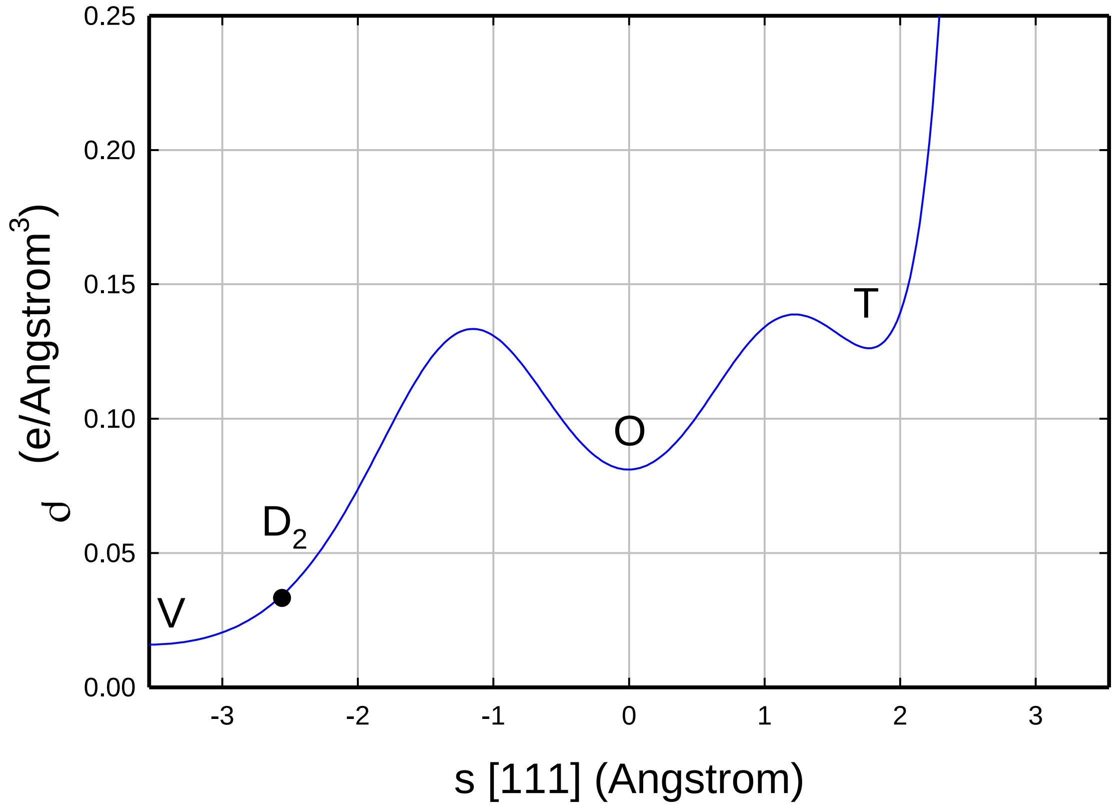


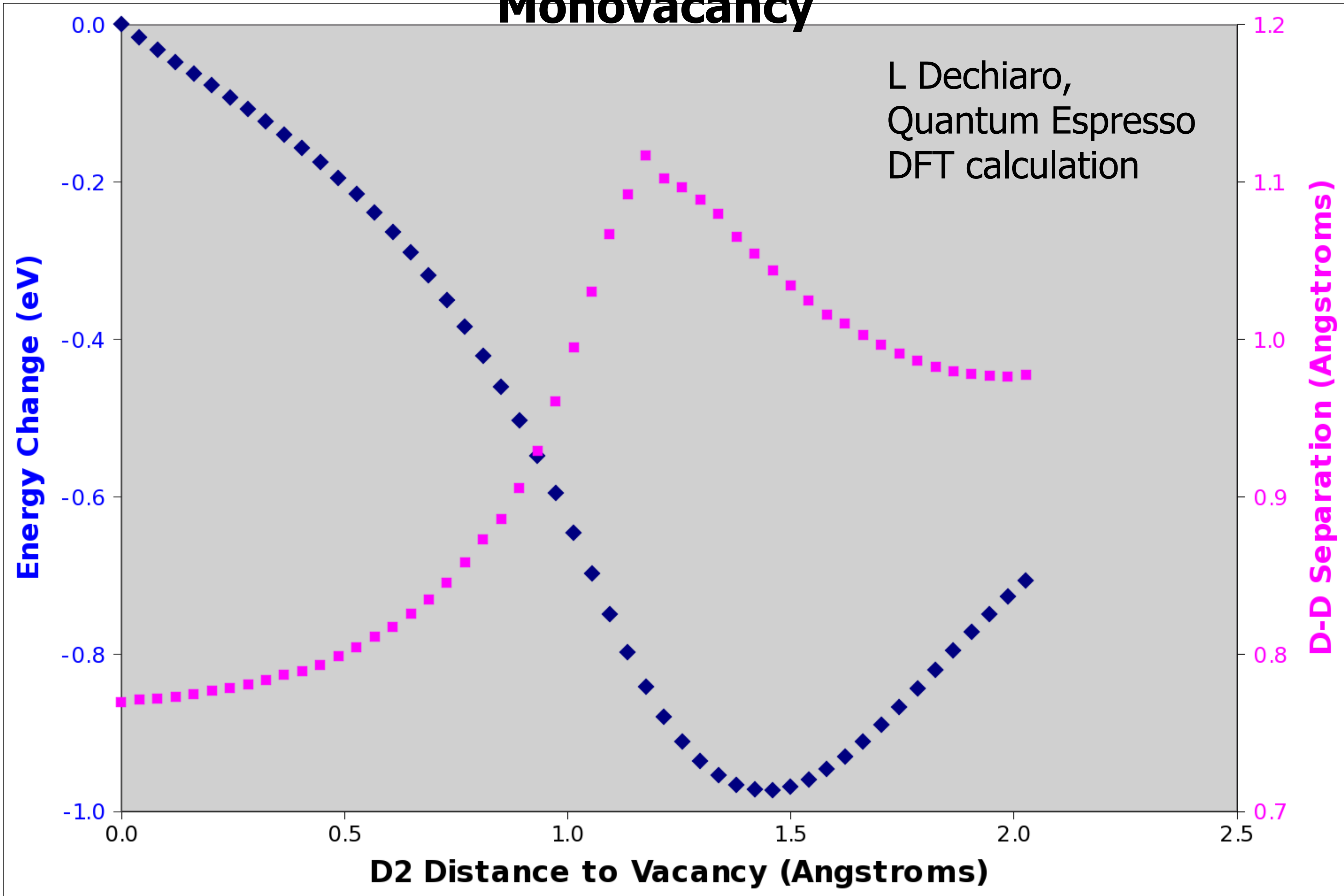
Fig. 8. Dependence of calculated (solid line) and experimental (•) values of the lattice parameter a of β-NiH_x phase on the stoichiometric coefficient x of the hydride phase.

No evidence for intermediate a values for loadings in the α-β phase region. Observed only is the change in volume occupied by β-phase NiH.

Recall electron density near vacancy in Pd…

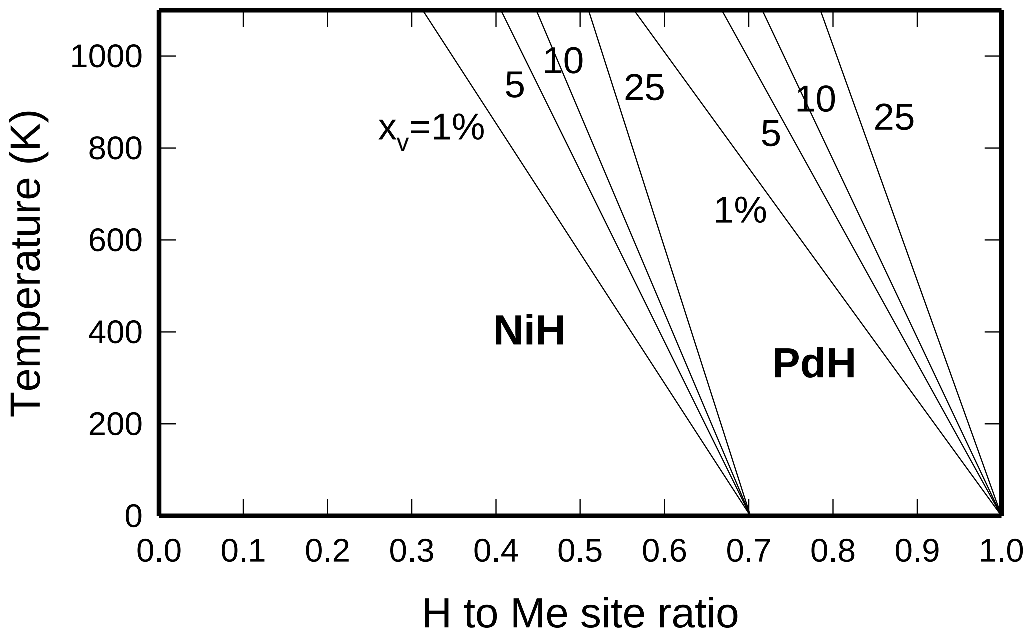


[100] Displacement of D_2 in PdD Supercell Monovacancy

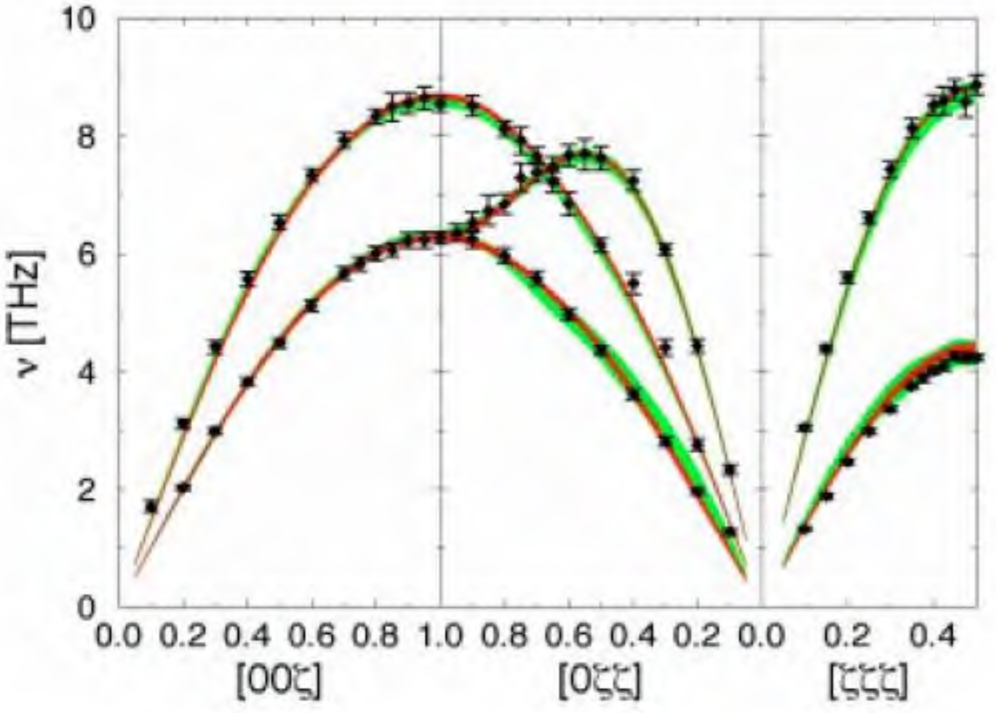


Electron density even higher in Ni (which is why H doesn't load well). But electron density reduced near a vacancy, and can form H_2. Ni is closest analog of Pd for H_2/D_2 formation near vacancy. Expect issues for vacancy creation and HD molecule formation to be similar.

Vacancies made more readily



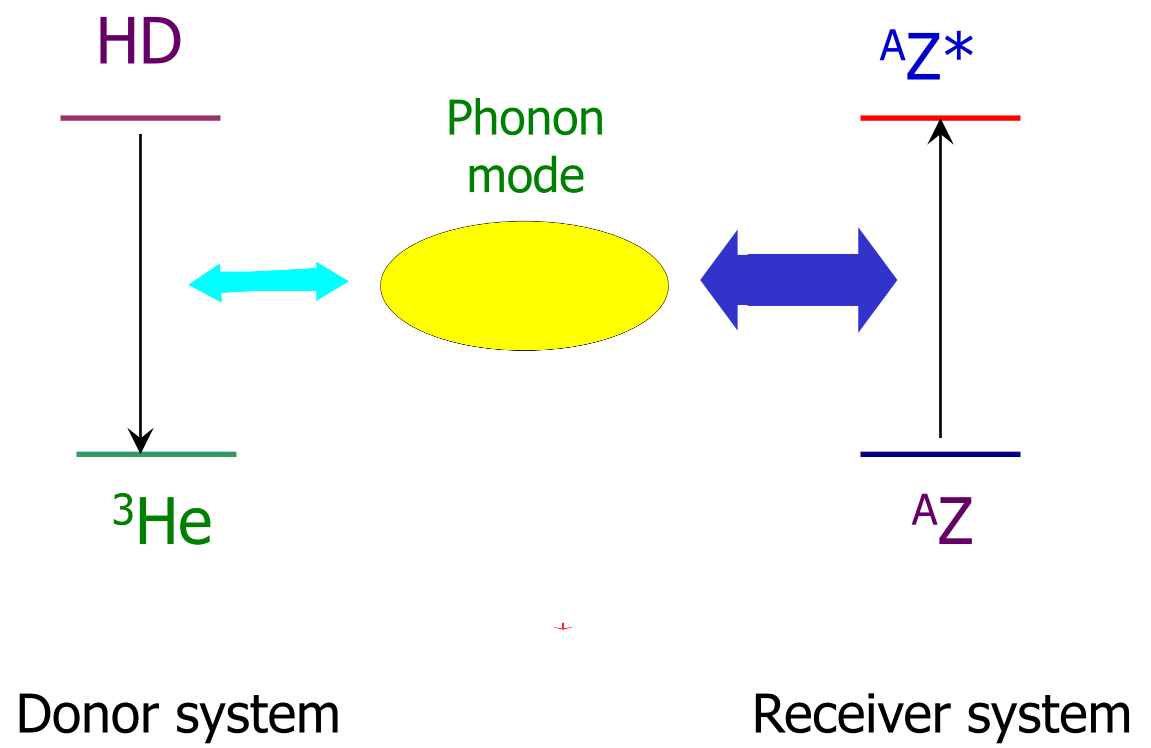
Ni phonon modes



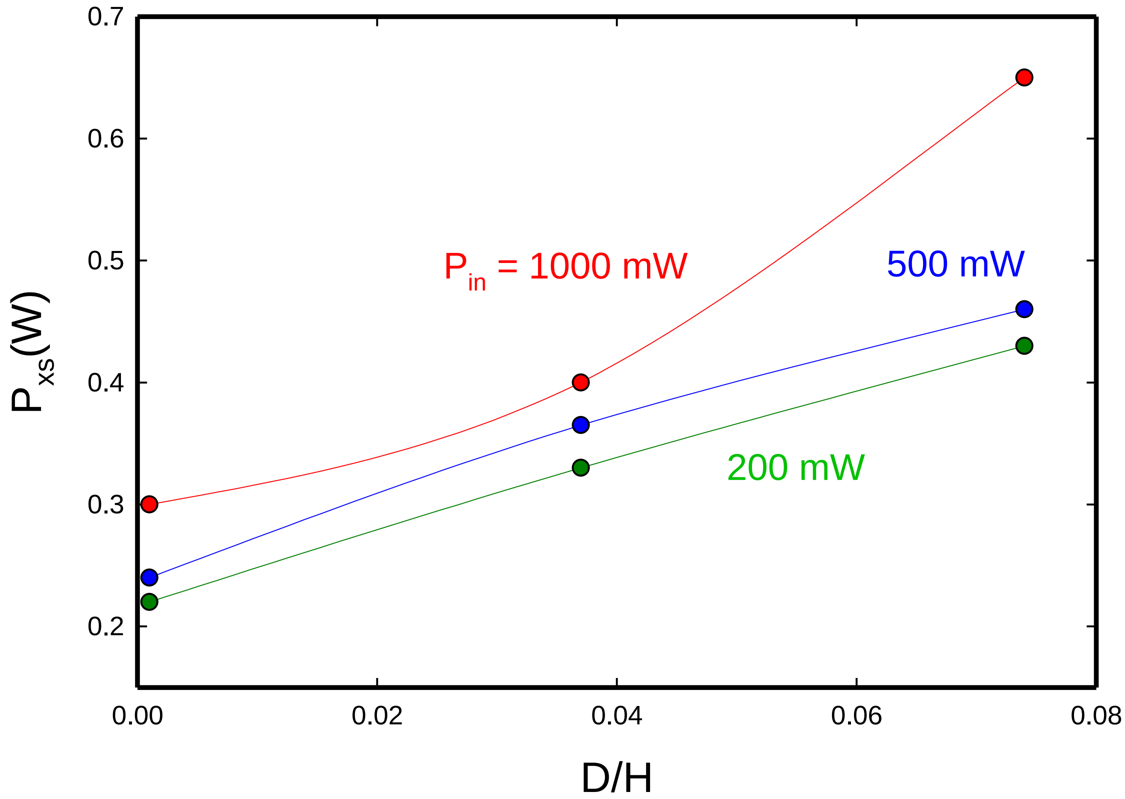
D. A. Dimitrov et al *Phys. Rev. B* **60** 6204 (1999)

Issues with the development of optical phonon modes in gas loading since H concentration is low

Donor-receiver model



More P_{xs} with D added



M. R. Swartz, G. M. Verner, and A. H. Frank, *Proc. ICCF9* p. 335 (2002).

More issues

- HD/^{3}He transition fine for donor
- Reduced mass smaller than for D_2/^{4}He system

$$\frac{1}{\mu} = \frac{1}{m_1} + \frac{1}{m_2} \qquad \mu_{DD} = \frac{M_D}{2} = M_H \qquad \mu_{HD} = \frac{2}{3} M_H$$

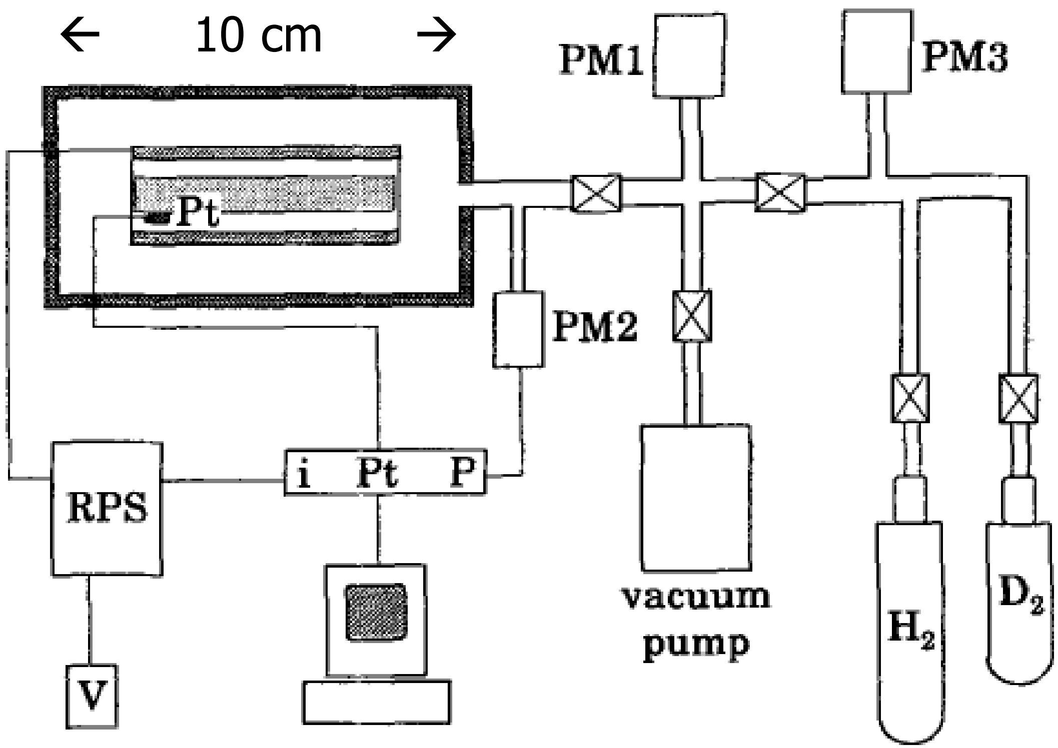
- So tunneling is orders of magnitude larger
- Deuterium natural abundance is 1/6240 of hydrogen
- ΔE = 5.49 MeV, so need to exchange few quanta

Take away message

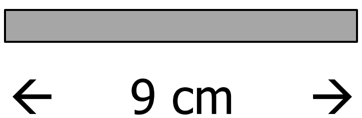
- Excess heat seen in NiH
- Electrochemical systems, gas systems
- Harder to load
- Easier to make vacancies
- HD formation good
- Donor-receiver model happy
- Is some D in H
- Larger interaction matrix element since Gamow factor smaller

Piantelli experiment

Piantelli experiment



Ni rod:



0.5 cm diameter

S Focardi, R Habel, and F Piantelli, *Il Nuovo Cimento*, **107A** 163 (1994)

Calibration

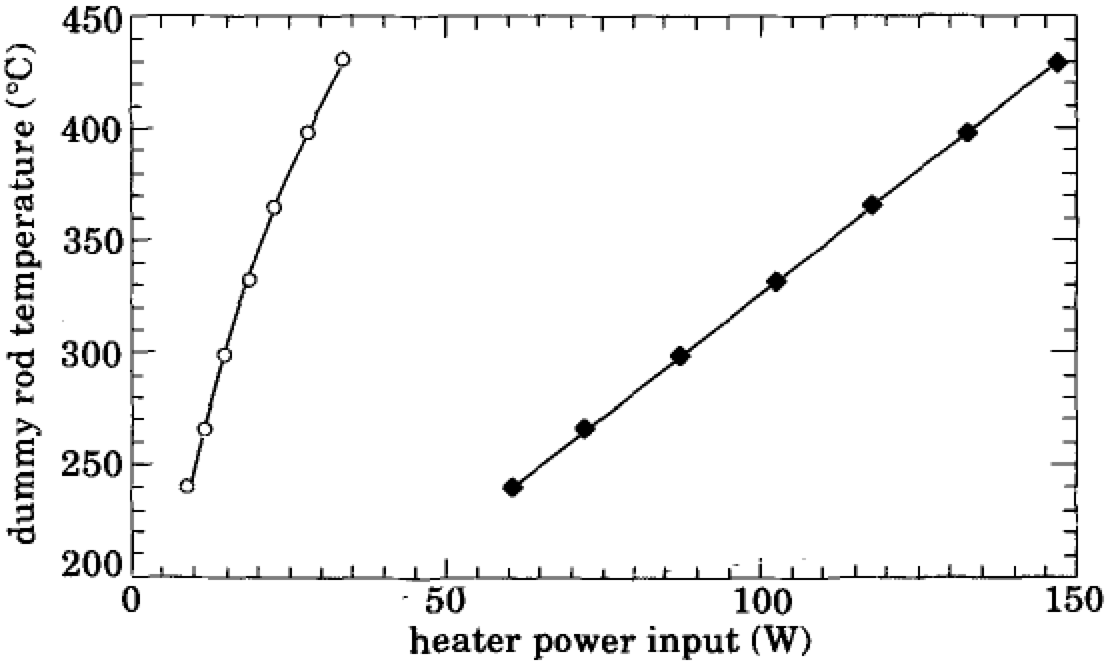


Fig. 2. – Power-temperature relations for the dummy rod at different values of the pressure inside the chamber. ◆ Hydrogen (p = 570 mbar), ○ vacuum.

Data showing P_{xs}

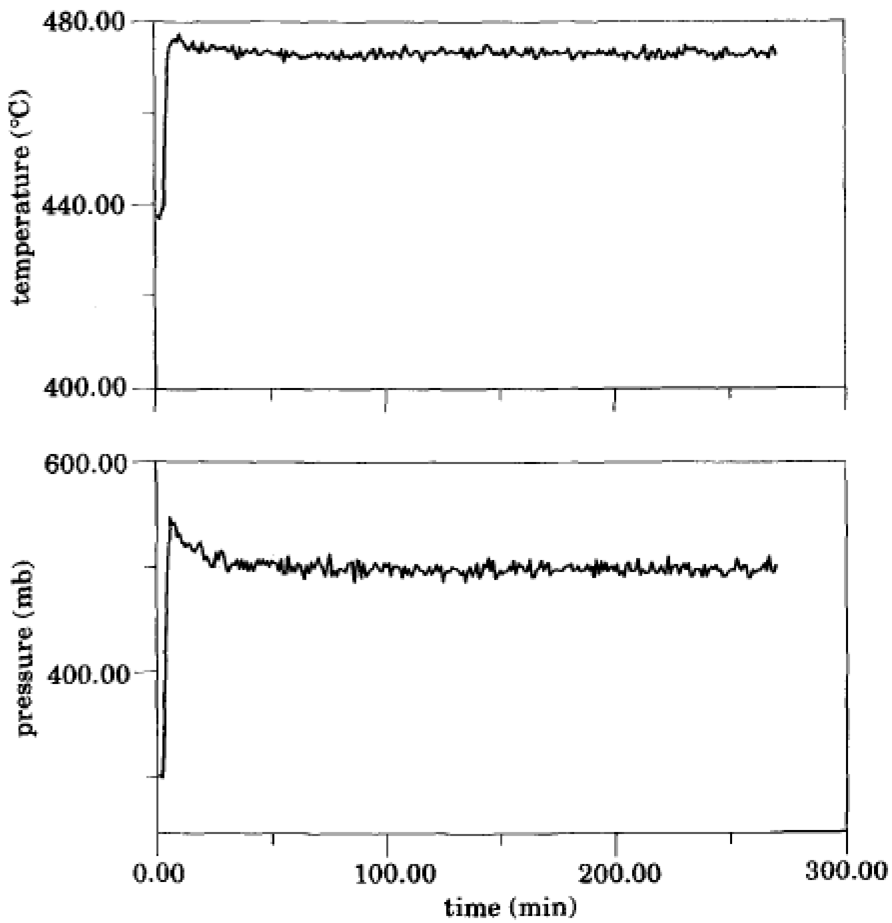


Fig. 3. – Sample temperature and hydrogen pressure *vs.* time, during an «anomalous» loading step.

Input power: 140? W
Excess power: 20 W

T vs P_{in} for P_{xs} = 0, 20, 50W

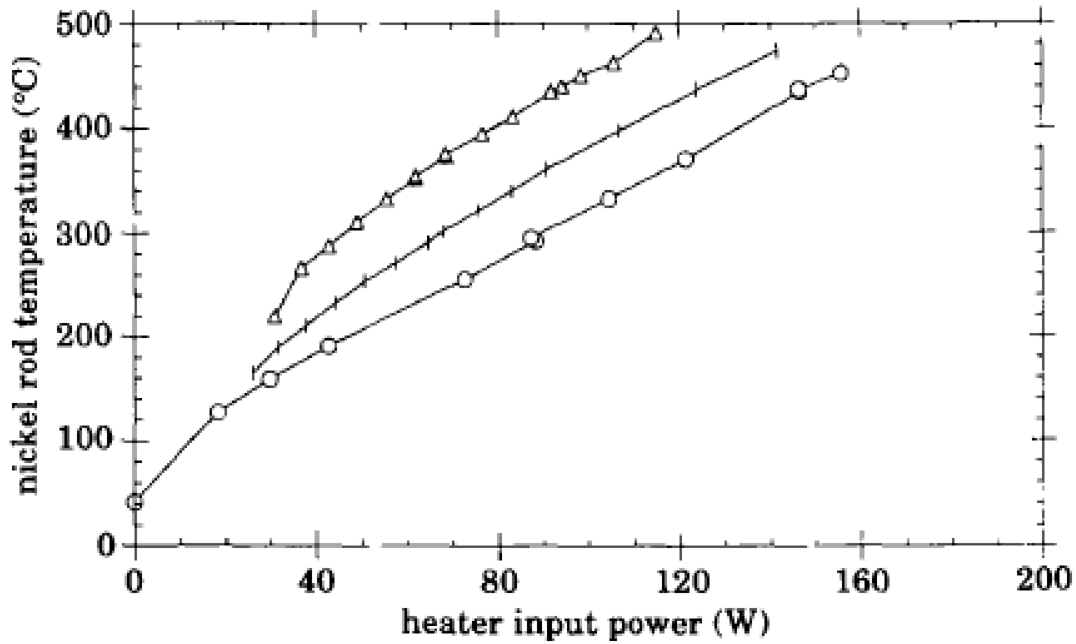


Fig. 4. – Temperature *vs.* heater-power curves family for a loaded nickel sample at different values of power «imbalance». ○ 0 W, —+— 20 W, △ 50 W. The dummy rod and the unloaded Ni rod are represented by the 0 W lower «imbalance» curve.

1998 Piantelli experiment

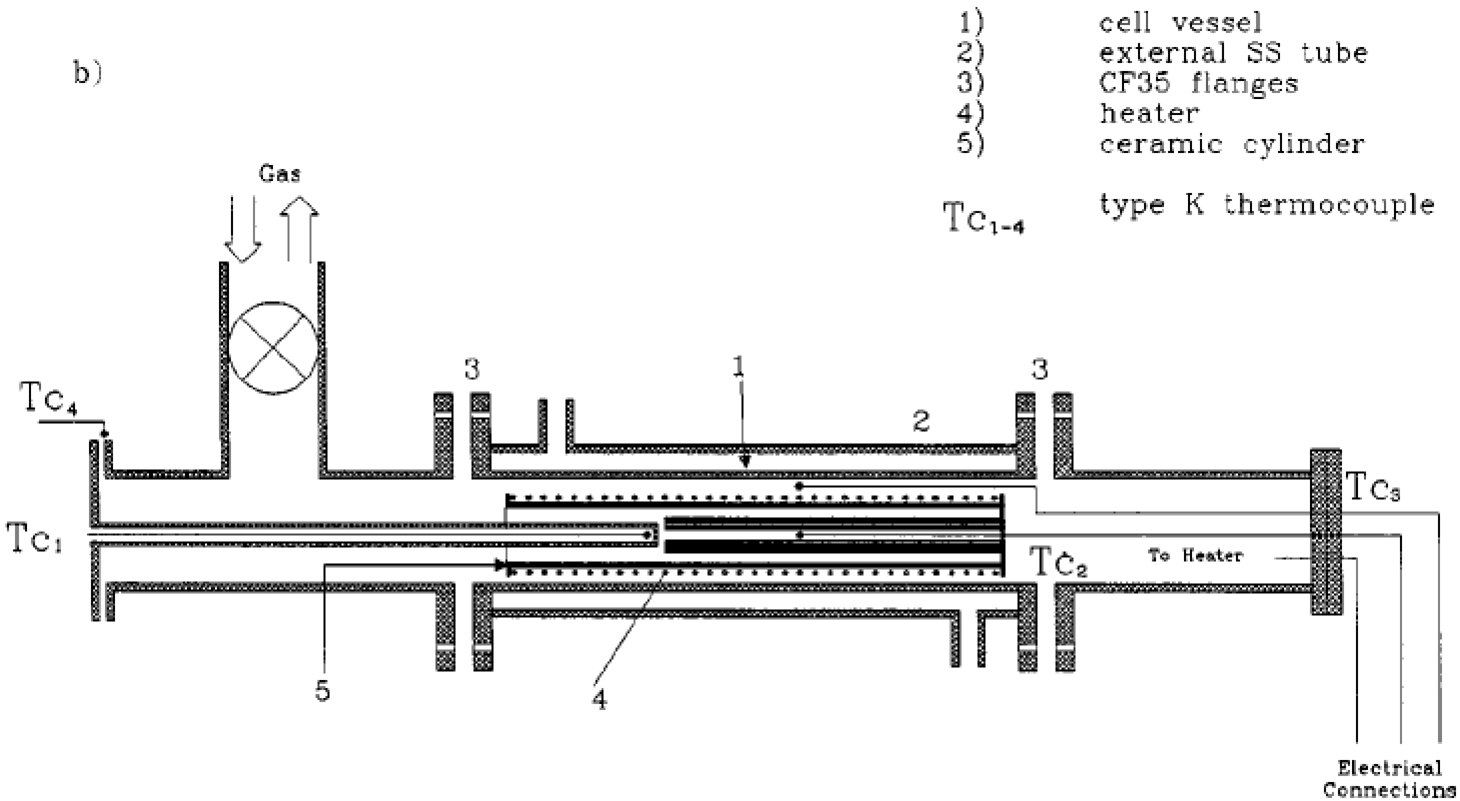


Fig. 1b. – Schematic drawing of cell B. Tc_1, Tc_2, Tc_3 and Tc_4 show the thermocouples positions.

S Focardi, V Gabbani, V Montalbano, F Piantelli, S Veronesi,
Il Nuovo Cimento **111** 1233 (1998)

Calibration curves

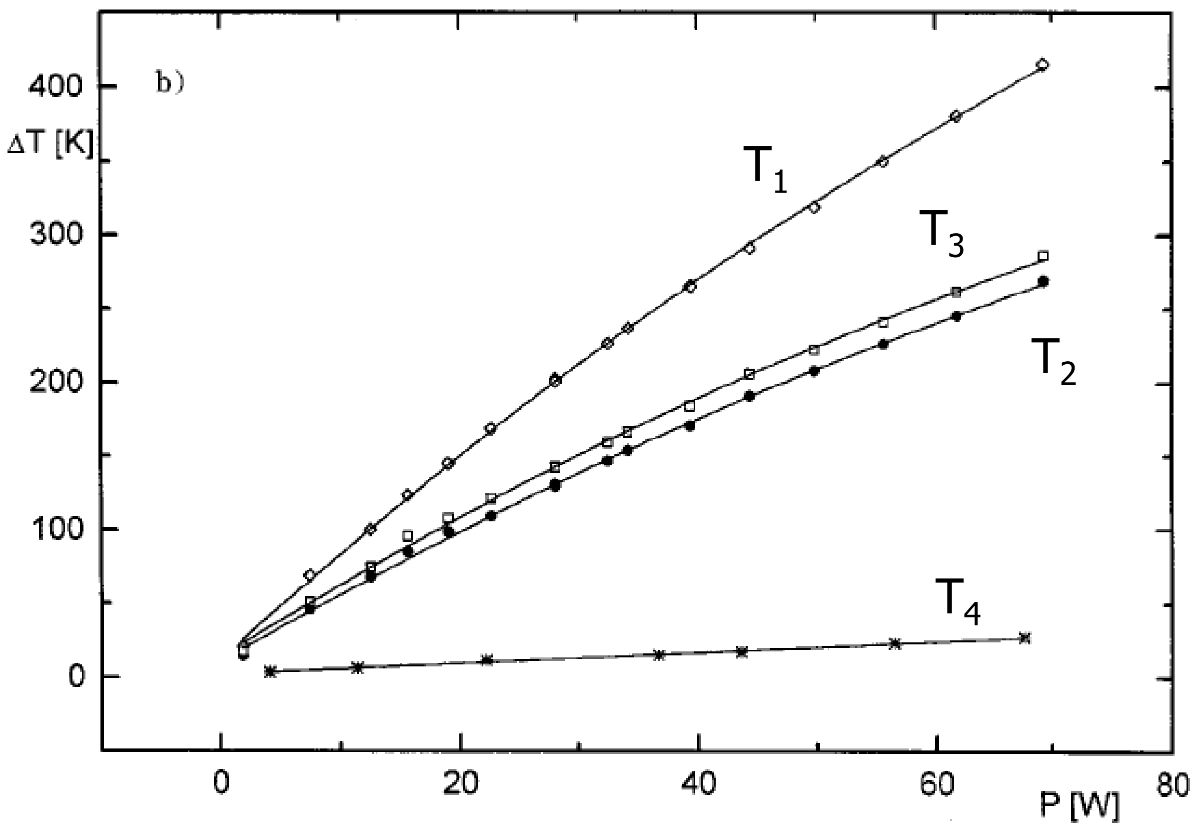
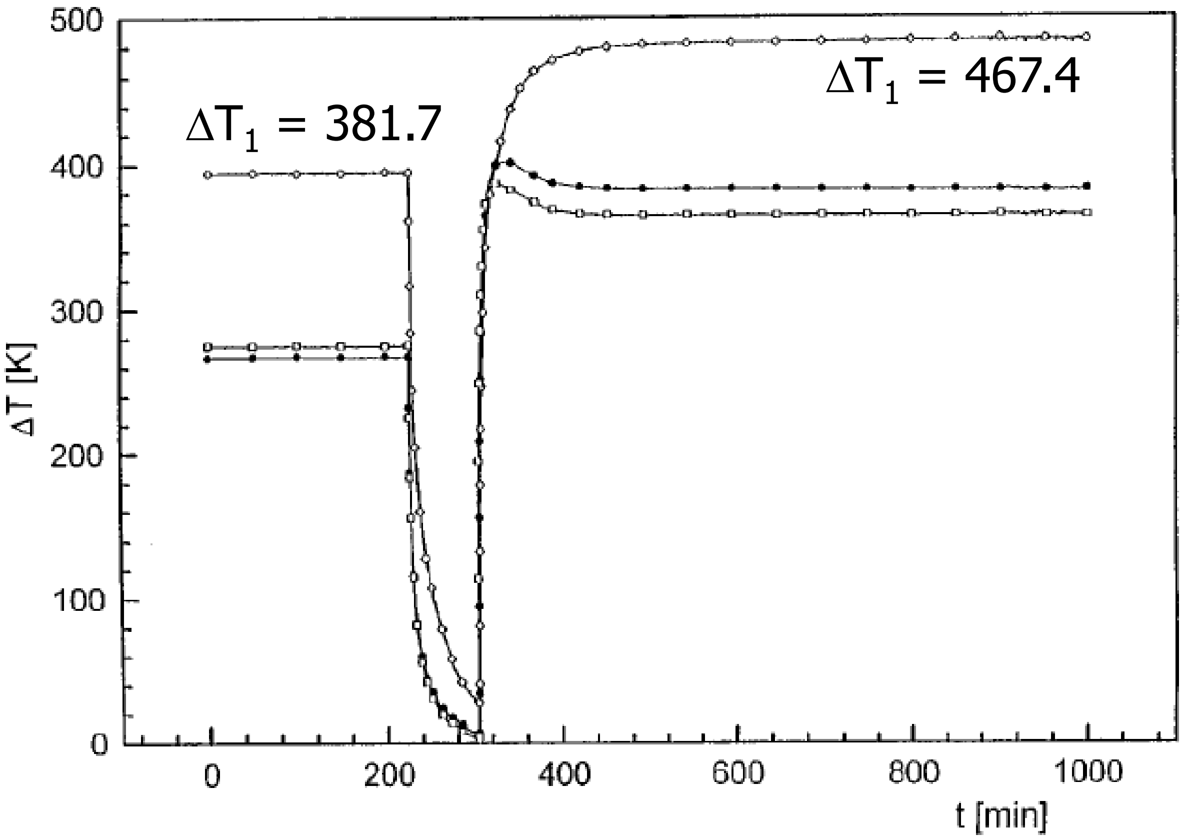


Fig. 2. – a) Cell A. Calibration curves; temperature (relative to the room temperature) *vs.* power ($T_{\mathrm{Pt}}(\diamond)$ and $T_e(\bullet)$). b) Cell B. Calibration curves; temperature (relative to the room temperature) *vs.* power ($T_1(\diamond)$, $T_2(\bullet)$, $T_3(\square)$ and $T_4(*)$).

Excitation of the sample



Approx:
P_{in} = 60 W
P_{xs} = 20 W

Fig. 4. – A sample excitation performed with a temperature jump for cell B ($T_1(\diamond)$, $T_2(\bullet)$, $T_3(\square)$). An inversion between T_2 and T_3 can be observed. Such an effect is due to the extra power produced by the nickel rod.

Pressure-composition isotherms

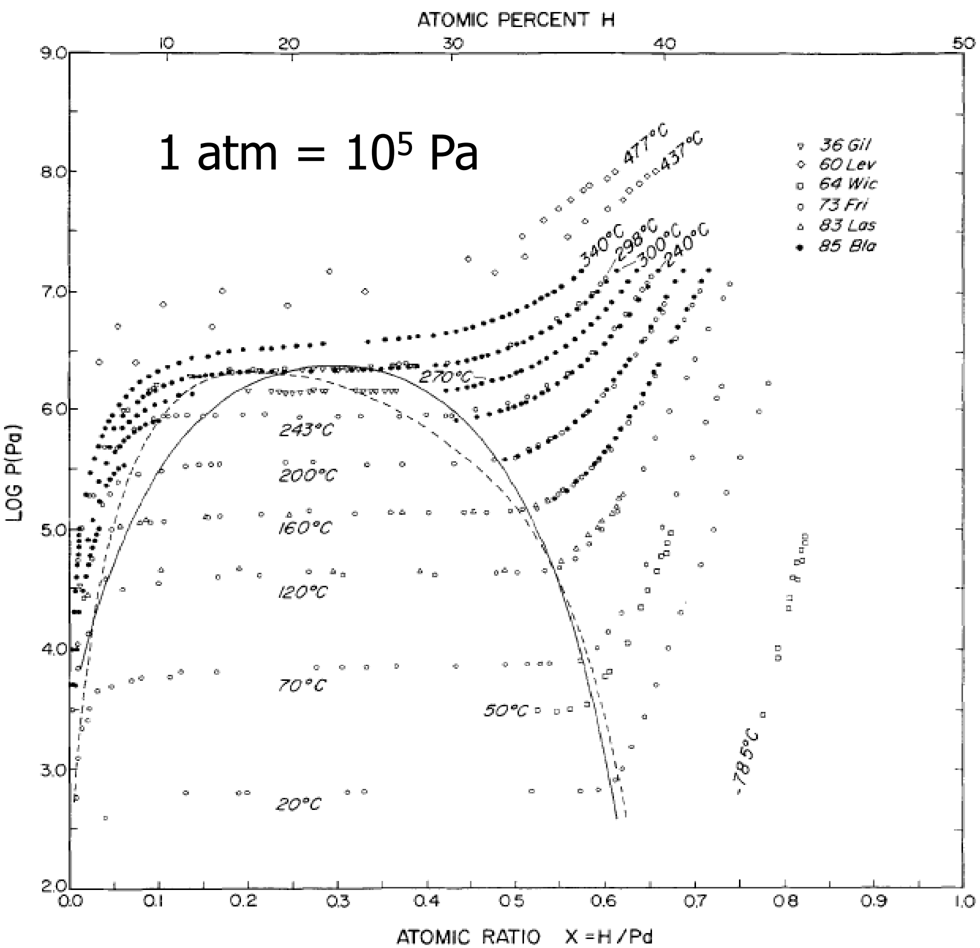
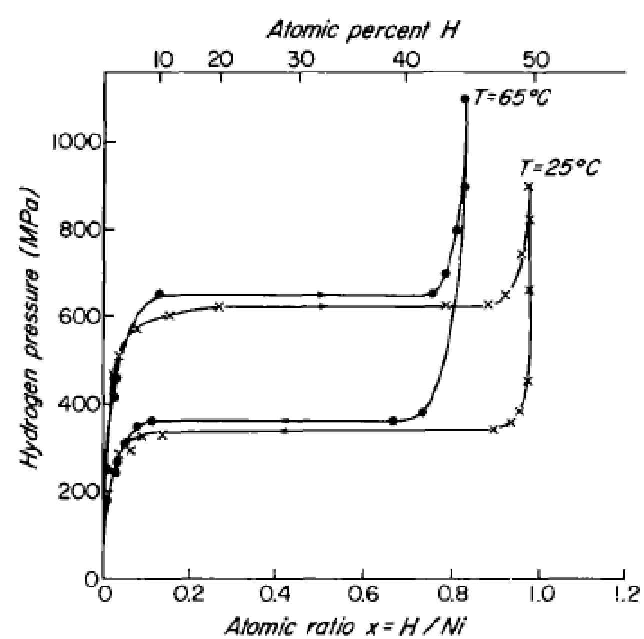


Fig. 4 Absorption and Desorption Isotherms at 25 and 65 °C for the Ni-H System



From [78Bar]. M. Wayman and G.C. Weatherly, 1989.

Solubility of H at low pressure

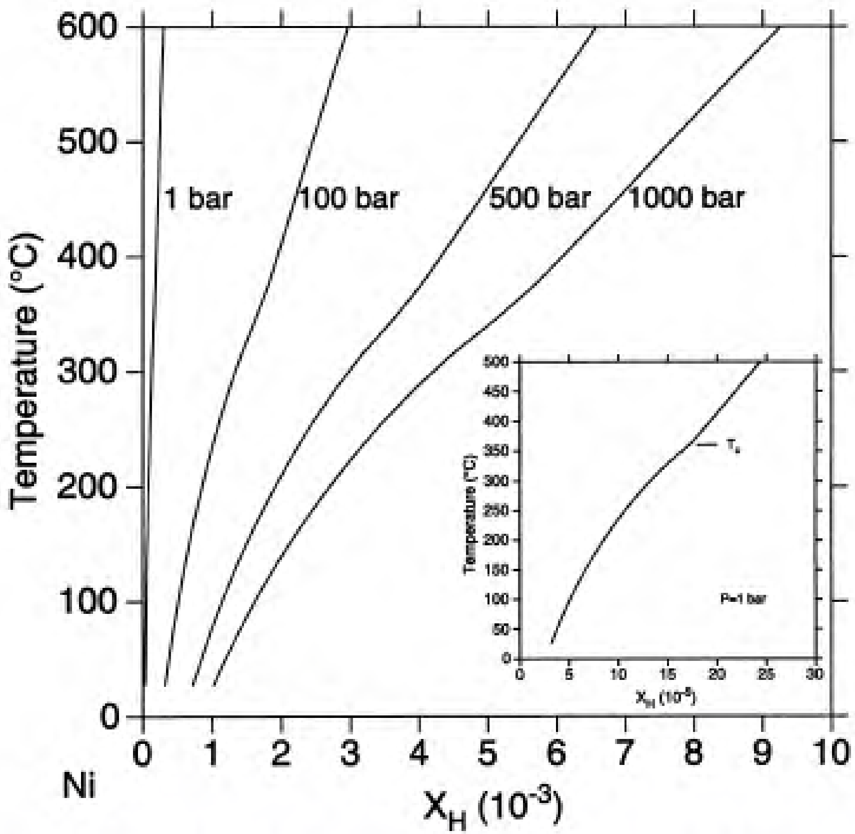


Fig. 7. Calculated solubility curves of hydrogen in nickel at different pressures, showing jogs at the Curie temperature. The insert is an enlarged diagram of the curve at 1 bar.

Uptake of H_2 after several loading cycles

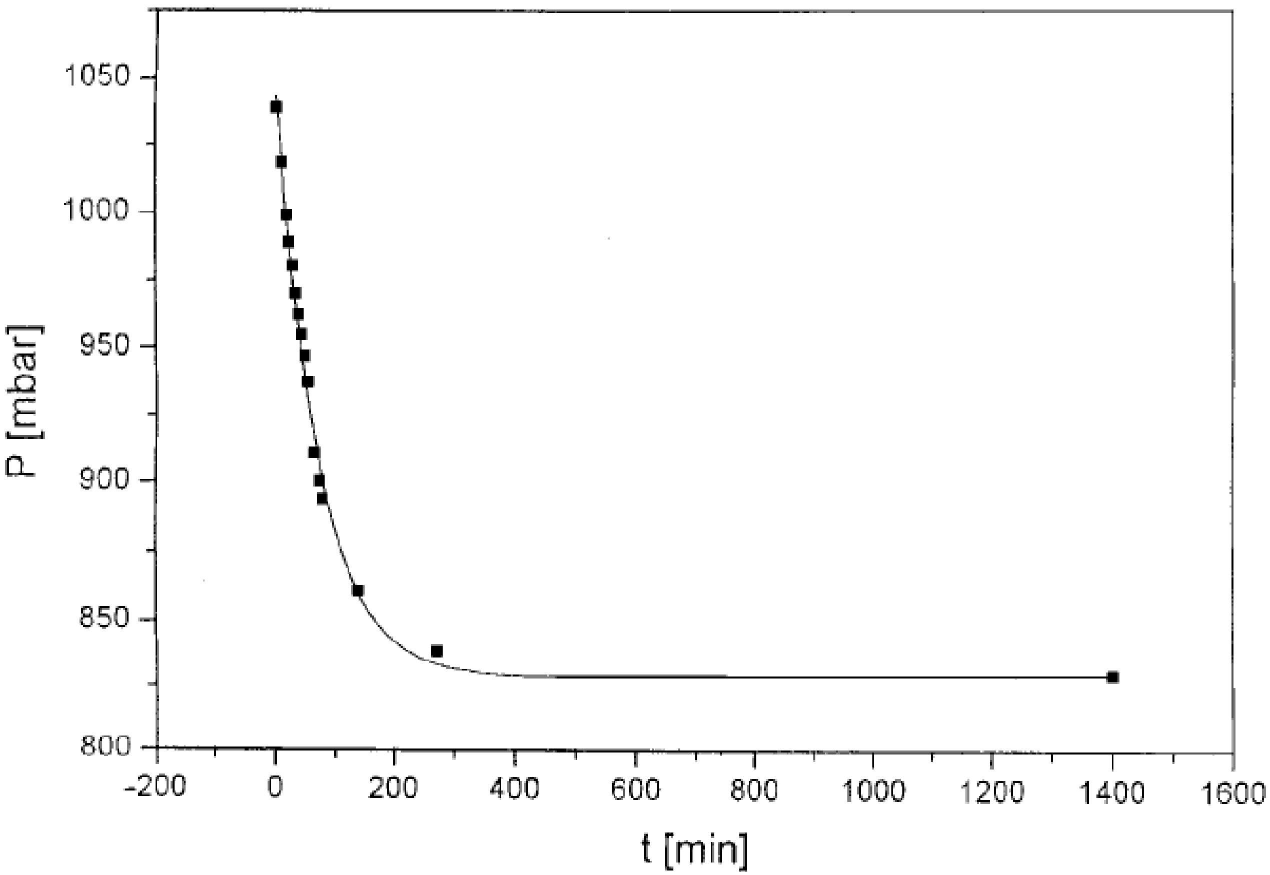


Fig. 3. – A typical hydrogen loading of a sample. The plot refers to cell B. The experimental data can be fitted with an exponential law. The characteristic time for this data set is $\tau = 72$ min.

Thinking about result

- Bulk Ni does not load much ($5\text{-}20\times10^{-5}$) near 1 atm
- Need O(6000 atm) to pressure-load bulk Ni with H_2
- But some loading observed nonetheless in Piantelli expts
- Number of H atoms absorbed is several times $O(3\times10^{21})$
- Number of Ni atoms in sample (1994) is $O(4\times10^{23})$
- Loading in Cammarota replication from H_2 absorption is $NiH_{0.2}$
- Must be (non-bulk) special sites (defects or impurities)
- But not enough impurities in Cammarota version!

X-ray diffraction data in electrochemical loading

Juskenas et al, *Electrochimica Acta* **43** 1903 (1998)

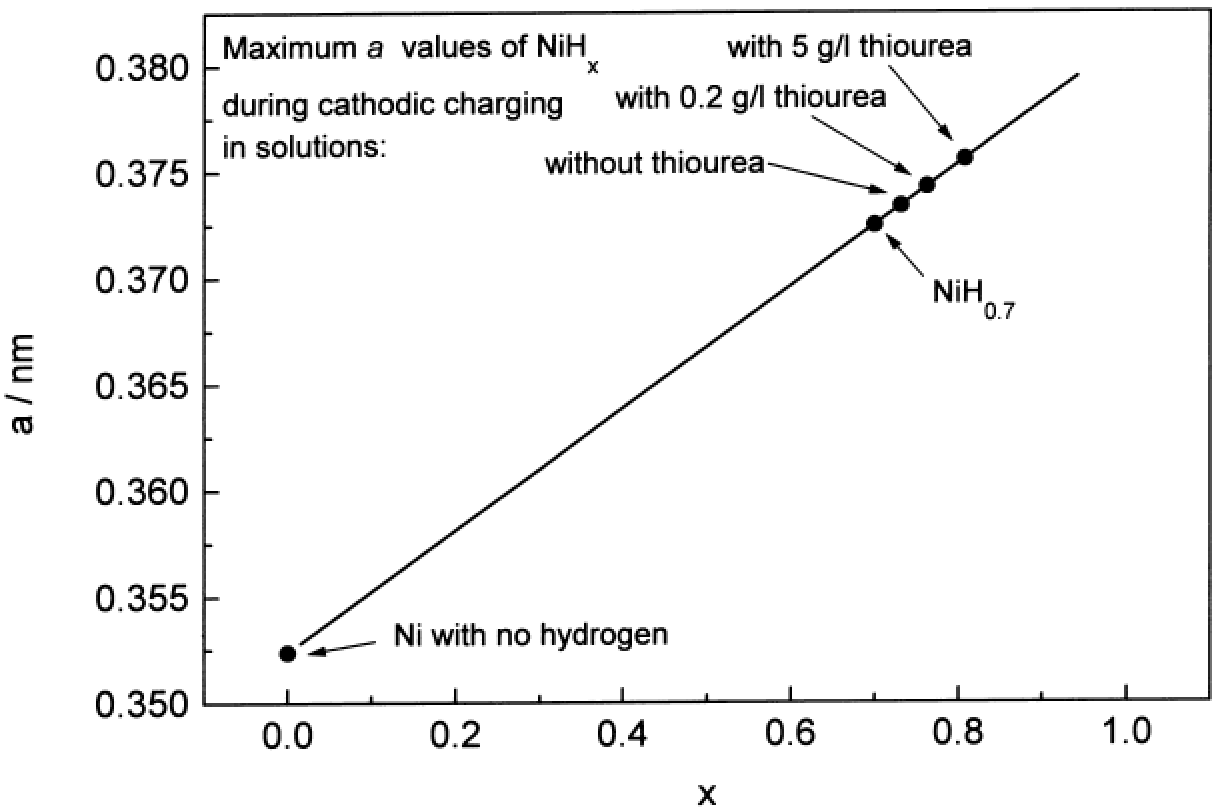


Fig. 8. Dependence of calculated (solid line) and experimental (•) values of the lattice parameter a of β-NiH$_x$ phase on the stoichiometric coefficient x of the hydride phase.

No evidence for intermediate a values for loadings in the α-β phase region. Observed only is the change in volume occupied by β-phase NiH.

Diffusion of H

- Diffusion of H in Ni is much slower than in Pd

$D = D_0 \, e^{-\Delta E/kT}$

$D_0 = 7.04 \times 10^{-3}$ cm^2/sec

$\Delta E = 409$ meV

$D(300K) = 9.5 \times 10^{-10}$ cm^2/sec (NiH)

$D(300K) = 5.5 \times 10^{-7}$ cm^2/sec (PdD)

- Elevated temperature D in NiH is similar to D in PdD at 300 K

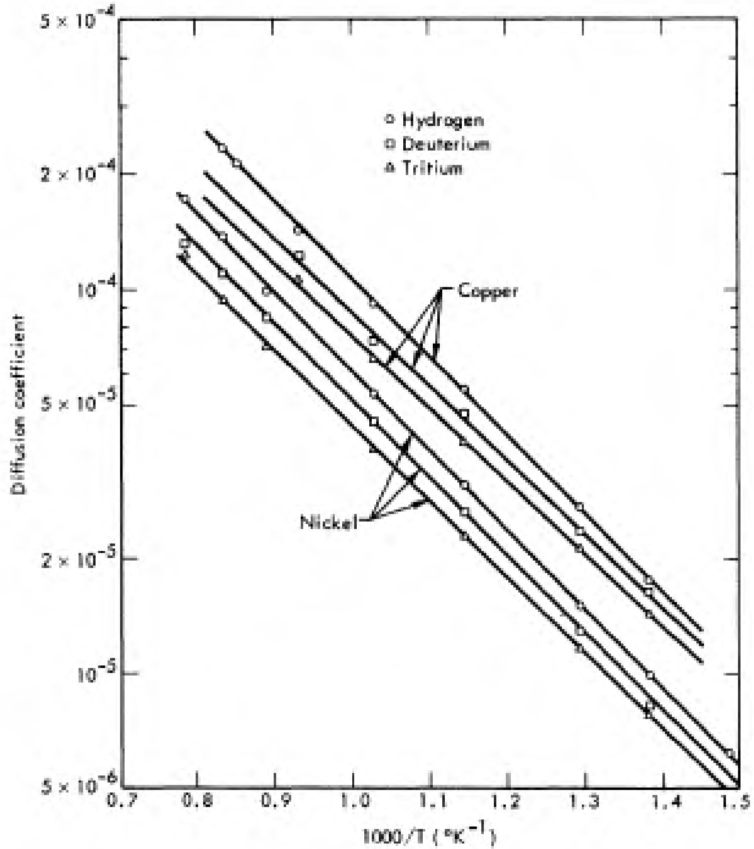
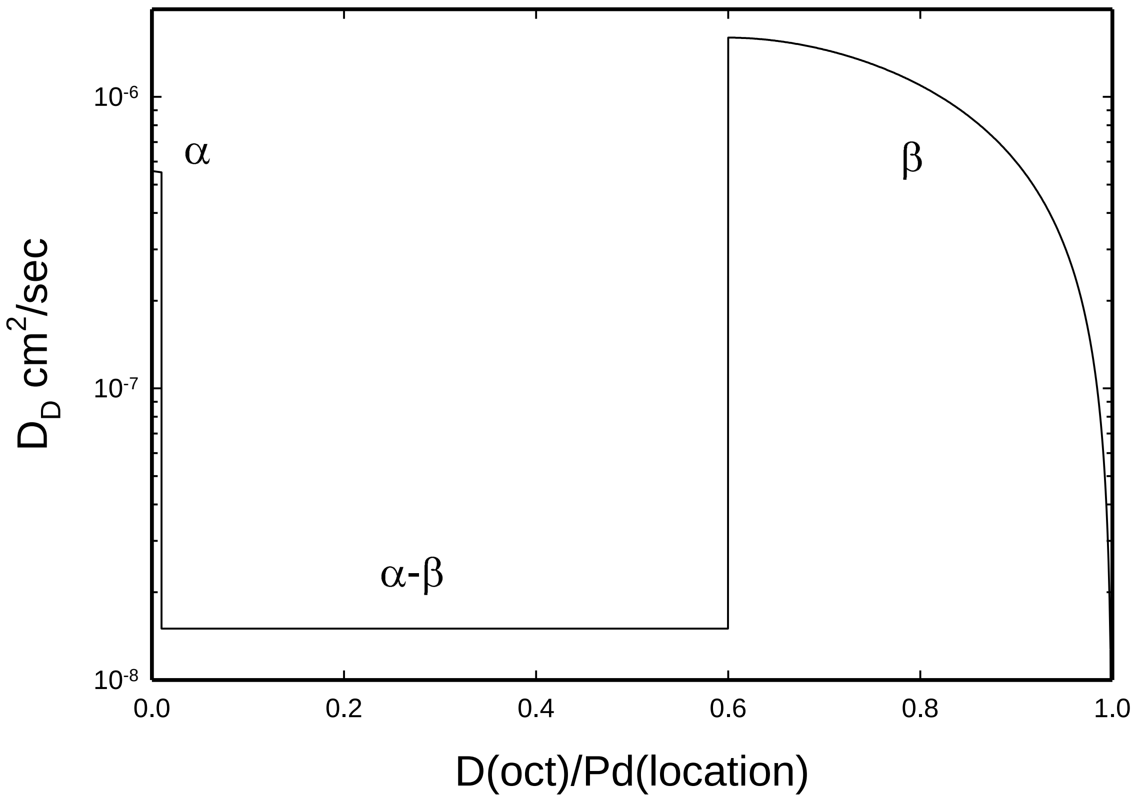
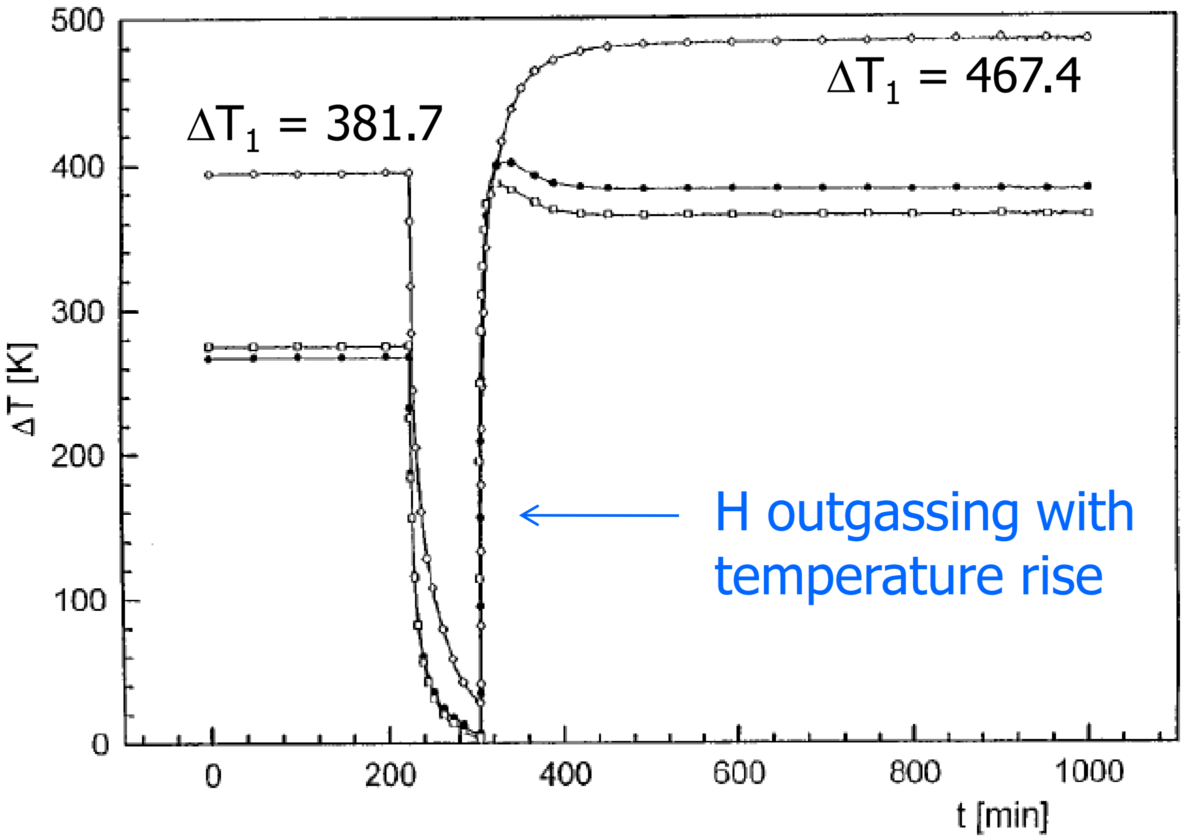


FIG. 3. Arrhenius plots for H_2, D_2, and T_2 diffusing in Cu (upper graphs) and Ni (lower graphs).

PdD diffusion model at 300 K



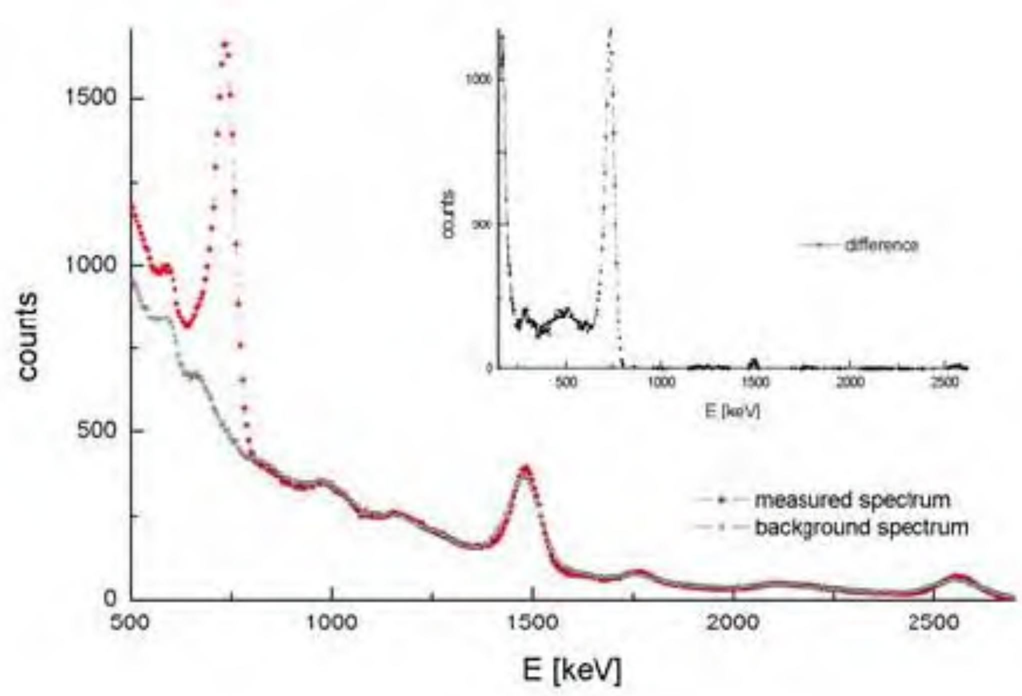
Excitation of the sample



Approx:
P_{in} = 60 W
P_{xs} = 20 W

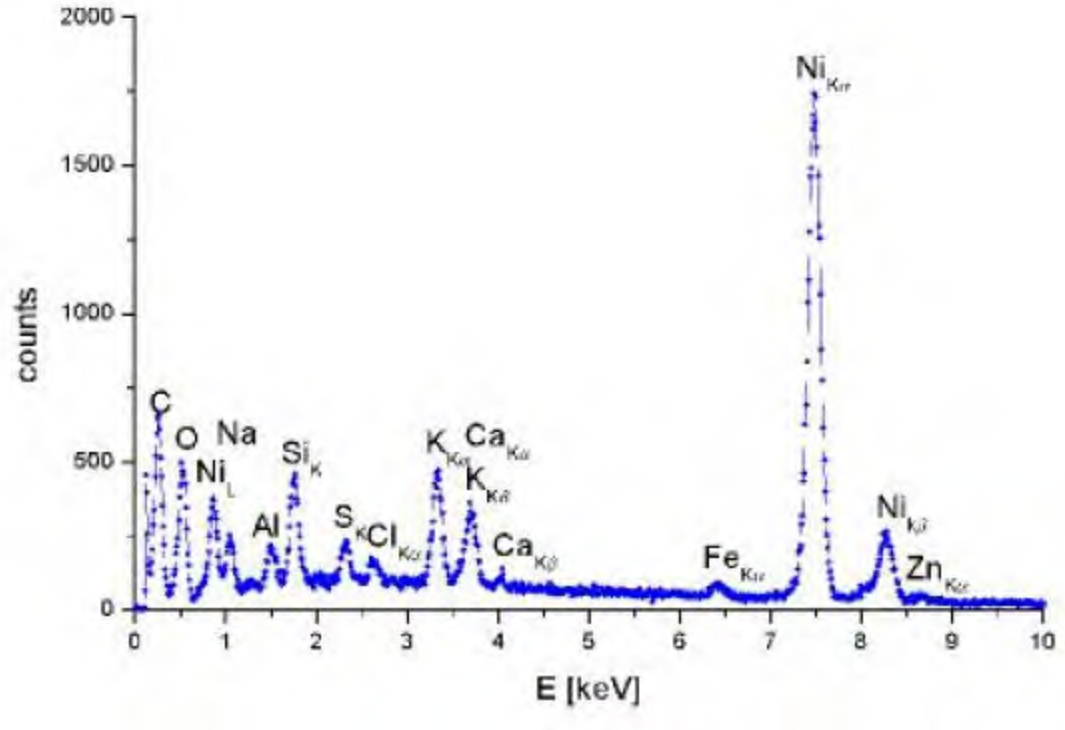
Fig. 4. – A sample excitation performed with a temperature jump for cell B ($T_1(\diamond)$, $T_2(\bullet)$, $T_3(\square)$). An inversion between T_2 and T_3 can be observed. Such an effect is due to the extra power produced by the nickel rod.

γ-emission events



S Focardi and F Piantelli, "Produzione de energia e reazioni nucleari in sistemi NiH a 400 C" (2000)

New elements in Piantelli expt



•Low H loading in NiH gas systems
•Not enough H for good optical phonon mode
•NiH systems so far probably work based on acoustic mode excitation
•Ni then participates strongly in vibrations
•Coupling of energy through nuclear excited states in Ni
•Some long-lived ones will have fission decay pathways
•Lattice-induced fission produces new elements
•Eats up significant amount of produced energy