Excess Energy and Nuclear Products

Slow Nuclear Excitation Model

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Abstract
Phonon modes in a two - component lattice produce an oscillating non- uniform electric field that interacts with nuclear quadrupole moment. This dipole- quadrupole interaction in combination with nuclear spin alignment and a presence of a vacancy in a light sublattice can produce very significant energy transfer from the phonon mode to the nucleus. Accumulated energy can exceed nuclear reaction barrier

1. Introduction

The idea that nuclear reactions in solids can be related to lattice phonon system was suggested by J.Schwinger and P. Hagelstein in 1989 - 1990 [1, 2]. If we accept that nuclei excitation comes through the phonon system, there should be a specific phonon mode which allows excitation of nuclear reactions. As phonons are lattice vibrations, probably this excitation can be imagined as nuclei parts interaction with an oscillating lattice electric field. To large extent this situation has an optical analogy with solid state lasers, i.e. Nd^{+++} in glass. Phonon interaction with atomic quantum levels resulting in energy up - conversion is described in [3]. Most of the optical formalisms can be applied to phonon interaction with a nucleus. One of the obvious cases is the Anderson's localization theorem [4]. It states that for interactions decreasing faster than distance in minus third power (dipole - dipole interaction) energy transfer can happen only with high density of (phonon) population. Application of this principle to nucleus - phonon system requires intensive phonon mode in order to get energy transfer. The other sequence of this principle is the existence of a threshold excitation below which the effect goes away. Nuclear acoustic resonance (between spin and quadrupole levels) achieved by AC magnetic field showed anomalies in line shape with TaH system [5]. Anderson's condition was not realized in this experiment and lattice oscillations were random.

2. Nuclear excitation model

Stable nuclei do not have dipole moment and there are no dipole interaction. To feel oscillating field nucleus must be non-spherical, i.e. it must have a pronounced quadrupole moment. According to [6] a list of naturally abundant nuclei with quadrupole moment looks like: ^{2}H; $^{6,7}Li$; ^{9}Be; ^{11}B; ^{17}O; ^{23}Na, ; ^{25}Mg; ^{27}Al; ^{33}S; $^{35,\,37}Cl$; $^{39,41}K$; ^{43}Ca; ^{45}Sc; $^{47,49}Ti$; ^{53}Cr; ^{55}Mn; ^{59}Co; ^{61}Ni; $^{63,65}Cu$; ^{67}Zn, ^{73}Ge, 75As, $^{79,81}Br$; ; ^{85}Rb; ^{87}Sr; ^{91}Zr; ^{93}Nb; ^{97}Mo; ^{101}Ru; ^{105}Pd; and nuclei with charge numbers 57- 71 which includes most of lantanoids, $^{177,179}Hf$; ^{181}Ta; ^{185,187} Re; ^{189}Os;^{191,193} Ir;^{197}Au; $^{199,201}Hg$; ^{209}Bi; ^{235}U. The champions among this group are ^{179}Hf, ^{181}Ta, and lantanoids ^{165} Ho, ^{167}Er, ^{173}Yb, and ^{175}Lu, having quadrupole moment around 3 x 10^{-24} cm^2 (barns). It should be noted that deuteron has quadrupole moment (0.0028 barn) and though it is 2 - 3 orders smaller than that of most of listed metals, in principle it can be excited as well.

Let us now address the issue of how the excitation can be transferred to the nuclei. The nucleus itself is a slow system and estimations from quadrupole gamma - transitions half life

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times [7] give oscillation time constant at 1 KeV energy of 10 - 10^3 s. In a lattice we have a slow oscillations of a heavy nuclei system and fast reaction of electron system. Nuclear oscillations create distortions in electronic field, thus creating charge displacement, which in its turn create dipole electric field. Electric field change due to nuclei system harmonic oscillations will be effectively screened by electrons distances larger than lattice parameter and it is highly unlikely that neighboring sites will have strongly different sustained phonon modes as they will tend to attenuate each other. It can happen with anharmonic modes but it is difficult to visualize sustainable anharmonic modes. The situation is different when we have two - component lattice. In this case neighboring sites have nuclei with different mass and harmonic oscillations frequencies (phonon spectra) of each sublattice are basically different, providing strong oscillating electric field at nucleus location. As is known, it is impossible to transfer energy in an ideal lattice, so to get coupling to the heavy component there must be a vacancy in the light component. From geometric considerations ideal case in a lattice with cubic symmetry, i.e. PdH_x corresponds to x = 0.875 or x = 0.125, the former is much more preferable in many aspects (not discussed here). The situation is illustrated in fig. 1. We can consider that heavy nucleus has a fixed coordinate, which is an extremely good approximation for Pd-H system, where for a given phonon energy nucleus displacement differs by a factor of 50. The trouble is that the heavy nucleus is not oriented and net transfer is zero. To change the situation magnetic field must be applied. All the listed nuclei have spins (quadrupole moment exists only for nuclei with spin $S \geq 1$.) and application of a sufficient magnetic field orients it. The problem of magnetic field strength will not be treated here, but depending on various parameters it is in the interval between 0.5 and 100 Oe, and can be easily achieved. If we align orientations of magnetic field and phonon oscillations we obtain a situation preferable to energy coupling into the nucleus which is illustrated in fig. 2 . Here an electric field of three light atoms and a vacancy is modeled by one oscillating electric charge. This charge is created by a combination of electronic and ionic electric fields. As electronic system is much faster than ionic, it oscillates with the same frequency. Electric field gradient on the nucleus itself is about the same as in the absence of the electrons or larger due to antishielding effect [5] Typical values of electic field gradient are 10^{20} - 10^{22} V/m^2 [5], which is about 10^{10} times more than in any other experimental situation, except direct nuclear interactions.

Dipole moment of a nucleus in the ground state is zero, and the nucleus dipole interaction with oscillating electric field does not exist. The situation is different for the quadrupole interaction which gives additional energy [8]:

$$E = \frac{e_o D}{6} \cdot \frac{\partial^2 \varphi_o}{\partial\alpha\partial\beta}, \qquad (1)$$

where D - quadrupole moment e_o - elementary charge, α, β - coordinates and φ_o - electric potential at the beginning of coordinates, in our case at the lattice site. With this model slow nuclear deformation looks at fast oscillations of asymmetric electric field and if the field is sustained we simply build this energy on and on. Integration of (1) gives time dependence for energy transfer to the nucleus:

$$E(\tau) = \frac{4 e_o e^* D\omega}{x_o^3} \cdot \frac{\hbar\omega}{E_v} \cdot \tau, \quad (2)$$

were τ is time, ω - phonon frequency; x- axis corresponds to xx components of both nuclear quadrupole and electric field gradient tensors, x_o - distance from the nucleus to the vacancy, e* - vacancy effective charge, E_v - vacancy formation energy, $\hbar$ - Plank's constant. Evaluations using formula (2) for an intense phonon resonance in $PdH_{0.87}$ lattice and ^{105}Pd isotope component are given in the table 1.

ω, Hz	ΔE,eV	$\partial E/\partial \tau$, eV/s
10^{11}	10^{-10}	10
10^{12}	10^{-9}	10^{3}
10^{13}	10^{-8}	10^{5}

Here ω - phonon frequency, ΔE - energy transfer in one phonon oscillation and $\partial E/\partial \tau$ - energy transfer rate. I.e. 1 MeV can be accumulated in 10 seconds. Evaluations of phonon energy replenishment from neighboring lattice sites (from phonon dipole - dipole interaction and phonon spectral density) give maximum values of energy transfer about 10^{-4} eV. Phonon density is a limiting factor here and requires excitation to meet Anderson's condition.

Building a phonon resonator is within known engineering and will not be discussed here. From quantum mechanics point of view, in the absence of magnetic field (degenerate levels) energy levels due to thequadrupole interaction look like [5]:

$$E_o = \frac{e_o D q}{4I(2I-1)} \quad (3)$$

where $q = \frac{\partial^2 \varphi}{\partial x^2}$, electric field gradient, I - nuclear spin, D - quadrupole moment, e_o - elementary charge. Number of levels is I + 1/2. Level spacing is 10^{-10} - 10^{-8} eV.

When Anderson's condition is met, on top of the levels (3) new levels will be accumulated in each cycle:

$$E_i = \frac{e_o D q}{4\pi I(2I-1)} \cdot N, \qquad (N = \pm 1, \pm 2 ...). \quad (4)$$

Quantum number N is the integer part of ωt, where ω - phonon frequency and t - time. Time dependent quantum number N represents virtual energy levels. Total number of levels will be $(I + 1)2^N$, or in the presence of a magnetic field $(I + 1)2^{N+1}$.

3. Excitation relaxation

The described kind of excitation is entirely different from normal situation, when nuclear reactions occur at large energy portions transfer, allowing for energy relaxation on unoccupied energy levels. With a slow excitation all nuclear energy levels are being gradually filled from the nuclear ground level, thus forbidding energy relaxation in the form of gamma - emissions. On top of usual selection rules slow excitation probably requires stable nuclear shells for resulting products, as they have a lot of time to form a state with minimum energy (stable shells). Nevertheless, conservation of energy, momentum, spin, parity must be observed in all cases. Out of about 70 isotopes listed above, only four allow energy release with beta - decay (Re, Pm, In, Mo), but all are forbidden by both Fermi and Gamov - Teller selection rules, so no betas.

Alpha - decay with positive energy release (Q) is allowed in some cases and can give positive Q, i.e.:

$^{197}Au\ (s=3/2)$ --> α + $^{193}Ir\ (s=3/2)$ + 1.045 MeV. (5)

Resulting iridium is a stable isotope. It is known that alpha - decay is very sensitive to low level excitations, at least for ^{235}U, where 10 KeV excitation changes decay rate dramatically. Probably the same is true here.

With atomic mass less than 145 alpha - decay has negative Q even if it is allowed. The examples of negative Q alpha - decay are ^{105}Pd --> $^{101}Ru + \alpha$ - 2.9MeV; ^{135}Ba --> $^{131}Xe + \alpha$ -1.87 MeV.

Paradoxical situation happens with isotopes for which all three channels of energy relaxation are forbidden and they are cornered into nuclear fission. Fission will also compete with alpha - decay that requires high negative Q, i.e. for ^{105}Pd isotope fission reactions

^{105}Pd --> $^{25}Mg + {}^{80}Se$ + 2.53 MeV. (6)

^{105}Pd --> $^{17}O + {}^{88}Sr$ + 0.311 MeV (7)

are about 10^2 times more probable than alpha - decay at low excitation level from barrier considerations.

For some elements even normal fission is forbidden and something like multi - particle decay can be expected, which can be the source of tritium etc.

When transfer process is stopped with energy accumulation short of nuclear reaction level, there is one fast relaxation process with low probability - through the electron system. In this case low level emissions of photons and Auger electrons can happen. Two other possibilities are quadrupole - dipole relaxation and quadrupole - spin relaxation. Spin relaxation requires oscillating magnetic field and can only be done artificially. Dipole relaxation is associated with electric field potential at vacancy location due to nuclear quadrupole of 10^5 - 10^6 times weaker than other way around with expected relaxation times longer by the same factor. To de - excite one single level from (4), assuming I = 5/2, the following condition must be met:

$$5 \cdot 10^{-2}\, e_o q D = h\omega_o (n + 1/2), \qquad (8)$$

where ω_o - lattice phonon frequency, h - Plank' constant, n - quantum number for dipole oscillations. Even for n = 0, ω_o corresponds to 10^6 - 10^8 Hz , where the phonon density is very low. This process requires a decay of higher frequency phonons to populate this region, i.e. lattice thermal non - equilibrium.

Conclusion

The proposed slow nuclear excitation model allows the explanation of most of the experimental data accumulated to date, i.e. excess heat in nickel- hydrogen system is the result of impurities, like ^{197}Au or ^{105}Pd "burning", as shown in equations (5)-(7). ^4He accumulation is the result of induced alpha - decay rather than d-d fusion, etc.. Engineering for energy generation on the basis of nuclear resonance in solids (not discussed here) becomes straightforward and understandable.

References

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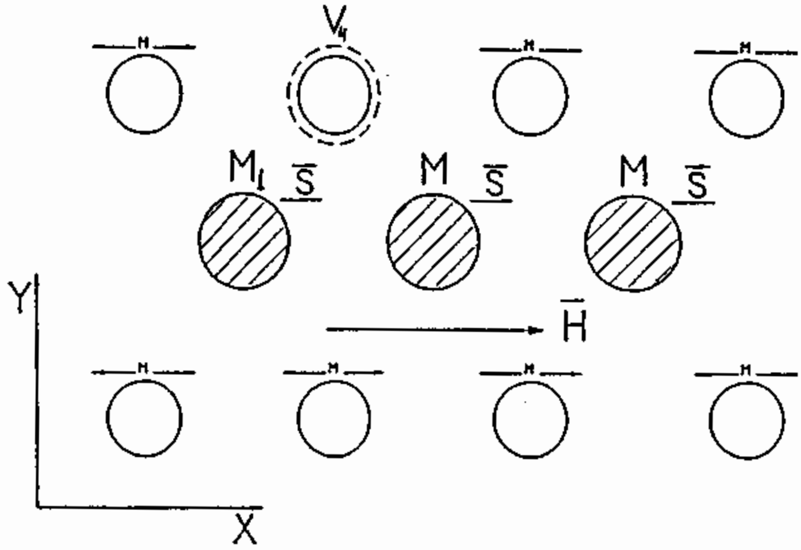

Fig. 1. Illustration of a two - component lattice, having a heavy component element M (i.e. palladium 105 isotope), which has a nucleus with a quadrupole moment, with nuclear spin **S** aligned along the magnetic field vector **H**, and a light component m (i.e. hydrogen), with phonon oscillations oriented along the X - axis, and having a stable vacancy V_4 .

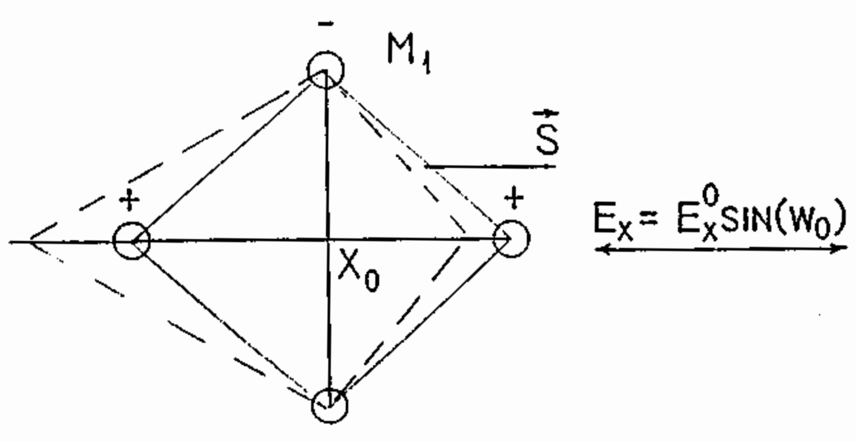

Fig. 2. Illustration of a nucleus M_1 from fig. 1, shown as quadrupole in the oscillating electric field gradient created by a vacancy. Dotted line shows quadrupole deformation caused by this field.