Nuclear Physics Approach

Anomalous Energy Transfer between Nuclei and the Lattice

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1. Introduction

We have continued our theoretical efforts to develop models that are relevant to the experimental claims of the observation of anomalies in metal hydrides. Of these anomalies, we have been particularly interested in heat generation both in heavy water and in light water systems, electrochemically induced radioactivity, tritium production and neutron emission. There have been a rather significant modification in our direction over the course of the past year, resulting in new models that appear to be more closely related to the experimental claims.[1]

2. Failure of the Neutron Hopping Model

We proposed that inelastic neutron hopping might account for the claimed heat and tritium production in experiments involving metal hydrides and deuterides.[2] The potential advantage of neutron hopping as a mechanism was that neutrons experience no Coulomb barrier, thus removing the Coulomb barrier problem. Neutron hopping with the exchange of low momentum virtual neutron states appeared to be the only possible mechanism for tritium production, which must be produced with nearly zero kinetic energy to be consistent with the observed lack of secondary *dt*-fusion neutrons that would accompany energetic tritium nuclei.

Potential problems associated with this proposal were recognized early on by this author and by other theorists. The basic problem is that it is not obvious that neutrons can hop from one nucleus to a distant (on the Fermi scale) nucleus. While it was clear that significant energy exchange with the lattice would be required for heat and tritium production, the initial attempts at developing a model for this process suggested that neutron delocalization might occur without MeV-level energy input from the lattice.

Subsequently, the neutron hopping model was analyzed in great detail. A basic quantitative understanding of both elastic and inelastic neutron hopping is now believed to be in hand, and the results indicate that no neutron hopping is possible without MeV-level energy transfer from the lattice. While a very large sub-threshold virtual neutron hopping effect is predicted, the effect would require more than 5 MeV input energy from the lattice, which was not appreciated in our previous work. There are two important consequences of this observation: (1) neutron hopping driven by such large lattice energy transfer would be accompanied by real neutron emission (not in agreement with experiment); and (2) that many other observable effects are predicted to be observable at much lower energy transfer. We have therefore turned our attention back to lattice-induced reactions at lower energy transfer.

3. The basic energy transfer model

Atomic and nuclear reactions that occur within a lattice (and that involve energy transfer with the lattice) can be be described in general through Fermi's Golden Rule using coupled lattice and nuclear states

$$\Gamma = \frac{2\pi}{\hbar} |\langle \Psi_f | \hat{V} | \Psi_i \rangle|^2 \rho(E_f) \tag{1}$$

where the interaction operator depends on both nuclear and lattice coordinates. The prototypical interaction operator includes recoil and lattice rearrangement; these effects can be modeled using site-dependent interaction operators of the form

$$\hat{V}_j \sim e^{i\mathbf{k}\cdot\hat{\mathbf{R}}_j} e^{-i\hat{S}_D} \tag{2}$$

The first term on the RHS describes momentum exchange through recoil; the second term describes lattice mode rearrangement ($e^{-i\hat{S}_D}$ is a Duschinsky operator).[3]

Modeling anomalous energy transfer requires operators that are capable of transferring large amounts of energy when a reaction occurs. The recoil operator is well known in condensed matter, and in our view cannot support anomalous energy transfer. Mode rearrangement fundamentally involves operations on all excitation present; consequently, the Duschinsky operator is potentially capable of mediating anomalous energy exchange, given a large initial excitation of an initial state mode that projects into final state modes with a finite energy spread.

For anomalous energy transfer through this mechanism, we require an initial strong excitation of a phonon mode, either through the presence of a phonon laser or through strong coherent excitation. We have conjectured that exothermic desorption may drive a phonon laser. For this mode to project into final state modes with a large energy spread, it probably needs to be in the band gap away from other modes (we are considering nonlinear frequency shifting of a mode near the band gap). Mode rearrangement would be driven by a change in the vacancy distribution, and hence involve vacancy modes. The resulting energy transfer would then occur as fluctuations, with an energy transfer on the order of

$$\Delta E \sim \sqrt{N_{ph}}\, \hbar \delta\omega \tag{3}$$

We suggested previously[4] that a larger energy exchange (proportional to N_{ph}) might be possible; but this can be shown to be inconsistent with moment theorems that apply to phonon mode rearrangement.

The resulting theory leads to reaction rate predictions of the form

$$\Gamma = \int P(\epsilon)\, \gamma_0(\epsilon)\, d\epsilon \tag{4}$$

where $\gamma_0(\epsilon)$ is the reaction rate assuming that an energy ϵ is transferred, and $P(\epsilon)$ is the associated probability. For energy transfer by fluctuations, the probability would be described locally by a Gaussian distribution

$$P(\epsilon) = f_0 \exp\left\{-\left(\frac{\epsilon}{\delta\epsilon}\right)^2\right\} \tag{5}$$

4. Understanding experimental claims with the model

Within the framework of the model, different effects would be induced depending on the amount of energy transfer, the number of vacancies present, and on the type and abundance of impurities. For energy transfer on the order of 10s to 100s of eV, atomic recoil would be predicted; a possible observable might be atomic hydrogen or deuterium ejection from the surface. At the keV-level of energy transfer, deuteron recoil would lead to low level *dd*-fusion neutron production and electron recoil from light isotopes. Above about 100-200 keV of energy transfer, beta decay and electron capture reactions would be induced; these would be sensitive to the presence of vacancies since the recoil energy imparted to moderately heavy nuclei is low. Above about 1.5 MeV of energy transfer, alpha decay reactions would become dominant. Significantly larger energy transfer (more than about 5 MeV) does not presently appear to be likely, but would induce other more energetic effects.

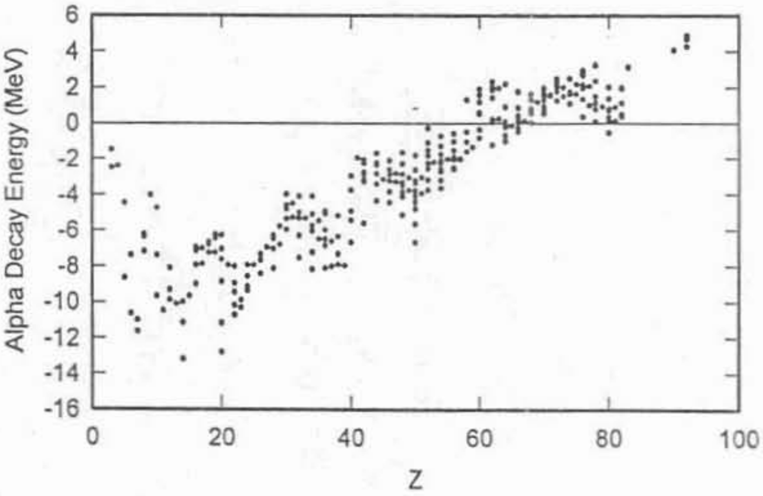

Figure 1: Alpha decay energy as a function of Z.

Heat production in this model would come about from lattice-induced exothermic alpha decays of heavy nuclei that are present (see Figure 1). The optimum naturally occurring "fuel" isotope in this picture is ^{147}Sm; others are listed in Table I. For example, Pt is present in many heat-producing experiments at low levels; in this model, some of the Pt are candidate fuels for heat production (see Figure 2 for a comparison of the lattice-induced decay rate for Pt compared with that of other elements). If this basic mechanism is correct, then significant prompt gamma emission should be observable as lattice-induced alpha decay would give a finite yield of excited state daughters.

Tritium production would come about from lattice-induced alpha decay of ^{7}Li (at 2.47 MeV of energy transfer). The reaction rate is computed to approach its maximum for lattice transfer energies only a few keV above threshold; such a mechanism has the potential to account for slow tritium formation at low levels. The related lattice-induced decay of ^{6}Li (at 1.47 MeV of energy transfer) would similarly produce deuterons with keV-level energy, that could result in low-level *dd*-fusion neutrons. Lattice-induced alpha decay of light nuclei, if it occurs, could be studied through lattice-induced ^{9}Be decay which would lead to fast neutron production as a primary observable.

Parent Nucleus	Abundance %	Daughter Nucleus	Abundance %	Q_α (MeV)	$\Delta\epsilon^{(1)}$ (MeV)	Daughter half-life
^{147}Sm	15	^{143}Nd	12.2	2.31	2.40	
^{144}Nd	23.8	^{140}Ce	88.48	1.91	2.59	
^{152}Gd	0.20	^{148}Sm	11.3	2.20	2.71	
^{148}Sm	11.3	^{144}Nd	23.8	1.99	2.72	
^{149}Sm	13.8	^{145}Nd	8.3	1.87	2.83	
^{151}Eu	47.8	^{147}Pm		1.97	2.84	2.62 y
^{234}U	0.005	^{230}Th		4.86	2.91	8×10^4 y
^{145}Nd	8.3	^{141}Ce		1.58	2.91	32.5 d
^{142}Ce	11.08	^{138}Ba	71.7	1.31	2.97	
^{235}U	0.72	^{231}Th		4.68	3.08	25.5 h
^{190}Pt	0.01	^{186}Os	1.58	3.25	3.10	

Table I: Lattice-induced alpha decays of alpha unstable naturally occurring isotopes. Q_α is the alpha decay energy. The isotopes in this table are ordered by the characteristic lattice energy $\Delta\epsilon^{(1)}$ required for a 1 sec^{-1} decay rate.

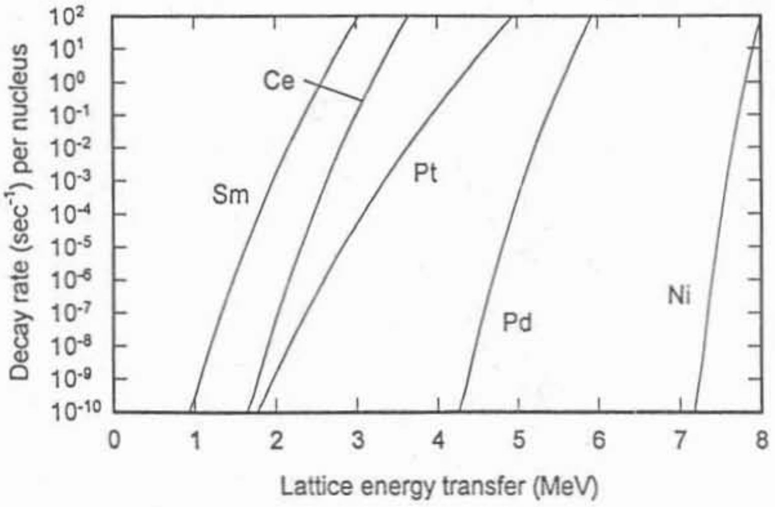

Figure 2: Element-averaged lattice-induced alpha decay rates per nucleus.

5. Modeling cathode activation

Cathode activation in this model could come about in the absence of heat through lattice-induced beta decay. Calculations for some of the attractive candidates for lattice-induced beta decay are shown in Figure 3.

Such a mechanism is proposed to account for the cathode activation described by Passell at ICCF5.[5] We attempted to use the model to fit some of the experimental data from this experiment, assuming that the observed radioactivity is due to lattice-induced beta decay of Pd and ppm levels of Ru, Rh, Ag, and Cd impurities. While the comparison is imperfect, the data appears perhaps to be most consistent with a Gaussian energy transfer model described by $f_0 \sim 0.05$ and $\delta\epsilon \sim 350$ keV. This level of energy transfer is too low to produce detectable heat production. The relatively large value of f_0 within the model would have the interpretation that energy transfer was allowed on essentially a CW basis throughout the activated region, presuming the presence of host lattice vacancies at the per cent level.

The results of this comparison are inconsistent with the presence of an optical phonon laser, as we had proposed earlier. It is more consistent with an acoustic phonon laser, combined with nonlinear coupling between acoustic modes and vacancy modes within the band gap as we proposed at ICCF5.

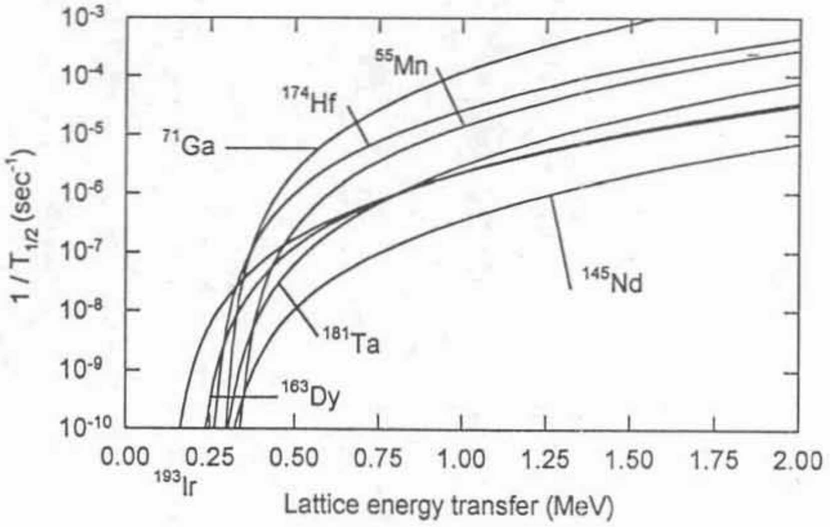

Figure 3: Lattice-induced beta decay rates for isotopes with low thresholds for allowed transitions.

References

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3. P. L. Hagelstein, *Hyperfine Interactions* **92** 1059 (1994).
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5. T. Passell, ICCF5 Proceedings (1995).