Interferometry and Photonic DeBroglie Waves: Loss Effects

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The quantum optics community has taken interest recently in photon configuration space concepts [1], notably in the work of Bjork *et. al.* [2] and Fonseca *et. al.* [3]. These studies explore the notion that photons, like other particles, can be constituents of larger particles. This is interesting in part because an interference experiment which deals with many-photon particles, should exhibit sub-wavelength interference effects. Such effects may have application to resolving small phase shifts, and are in any case interesting and quite different from conventional interferometry.

Here, we investigate the effects of loss on the inherent phase-resolving ability of quantum entangled states. The inherent properties of the entanglement give a performance bound for phase measurement. Designing a realistic interferometer and determining its phase resolving ability is a far more substantial problem for future research.

In Figure 1, we see a schematic multi-photon interferometer. One possible mode of operation, described in [4, 5], is that *all photons* are coupled together into one of the two paths at each of the two nonlinear couplers. If the photons can be kept together (by an attraction binding the photons, for example [6]), then we have a many-photon composite particle with momentum $2\pi\hbar\hat{n}/\lambda$. Thus, an optical path length difference of λ/n between the two paths gives a total phase shift of 2π for an n photon state. For large photon number, the possibility of observing λ/n-scale structure is remarkable. It is consistent, however, with the more commonplace interference of other composite particles, such as atoms or molecules.

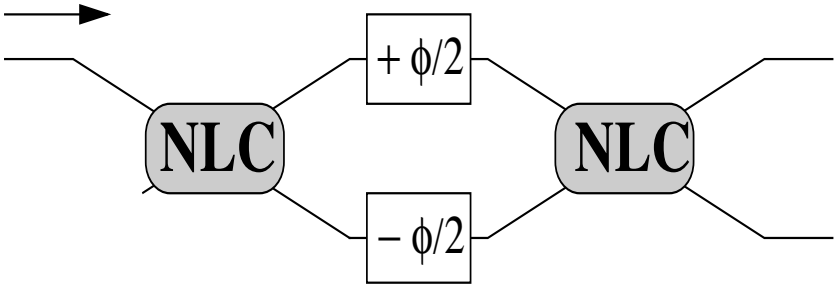

Figure 1: A Mach-Zehnder interferometer with special nonlinear couplers (NLC) in place of beamsplitters may show striking new effects. Unlike conventional beamsplitters, a nonlinear coupler can support attraction and binding of photons. Bound multi-photon particles then traverse the beamsplitter.

It has been recognized [2] that the most desirable states for phase-resolution,

$$|\psi\rangle = (|0, n\rangle + |n, 0\rangle)/\sqrt{2} \tag{1}$$

are also some of the most fragile to loss. Using [2] as a starting point, we have quantified the trade off between robustness and resolution. The basic idea is that, as long as each component of the superposition has some background photons in both paths, then all components will survive moderate losses. In the limit that photon number of the arms is approximately equal, loss interactions have

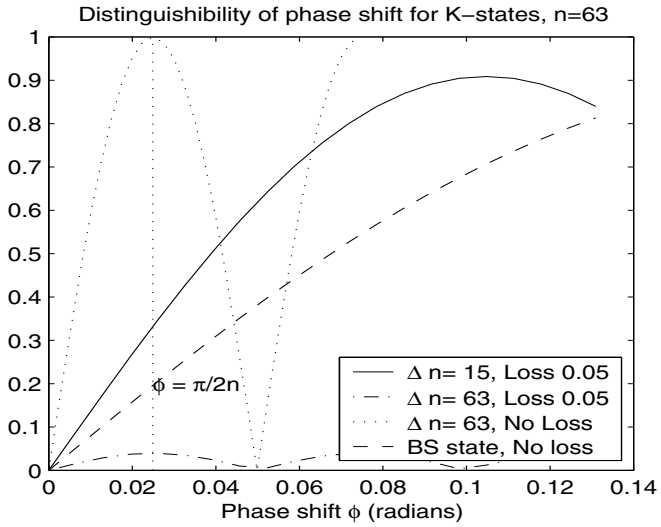

Figure 2: Distinguishability of phase shift ϕ for several quantum states. Total photon number before loss, $n = 63$. Shown for comparison is the "beamsplitter state," or output of a conventional beamsplitter with n input photons.

a very small effect on the superposition. However, in this same limit, the phase resolving ability vanishes completely. Using the formalism below, we confirm and quantify the trade-off between raw resolving power and robustness.

An exact metric for distinguishability is available from theory of quantum hypothesis testing [7, 2]. The physical question is, with what certainty can we detect a fixed phase shift ϕ operating on a quantum state described by density operator ρ? The mathematical answer is D, with $0 \leq D \leq 1$, which indicates how close to orthogonal the phase-shifted and unshifted states are.

We define a convenient set of states for exploring the resolution/robustness tradeoff: an n-photon state with phase-resolution $\pi/2K$ and definite $|\Delta\hat{n}| = K$ is given by

$$|\psi_K\rangle = \frac{\left|\frac{n+K}{2}, \frac{n-K}{2}\right\rangle + \left|\frac{n-K}{2}, \frac{n+K}{2}\right\rangle}{\sqrt{2}} \tag{2}$$

Intuitively, small K states have a large background in both modes and are more robust, while large K states have higher sensitivity to phase in the absence of loss. Figure 2, which plots distinguishability versus ϕ for a few example states, demonstrates this clearly: large-K states perform well with no loss, but are quickly surpassed by smaller K states as loss is introduced.

Ultimately, we would like an estimate of the minimum resolvable phase $\Delta\phi$ as a function of the power loss level $\mathcal{L}$. Numerical calculations involving density matrices are impractical for large n. We can use calculations for moderate n to test analytical approximations. Following the spirit of [8], we have estimated the effect of finite loss $\mathcal{L}$ as a simple combination of $n\mathcal{L}$ individual photon loss events in the limit of small K/n. This simple intuitive estimate agrees surprisingly well with the exact calculation.

To first order in K/n, each photon lost reduces the distinguishability by the factor

$$1 - \frac{K^2}{2n^2}.$$

A useful approximation for the K state is

$$D \approx \left(1 - \frac{K^2}{2n^2}\right)^{\mathcal{L}n} = e^{-K^2\mathcal{L}/2n}.$$

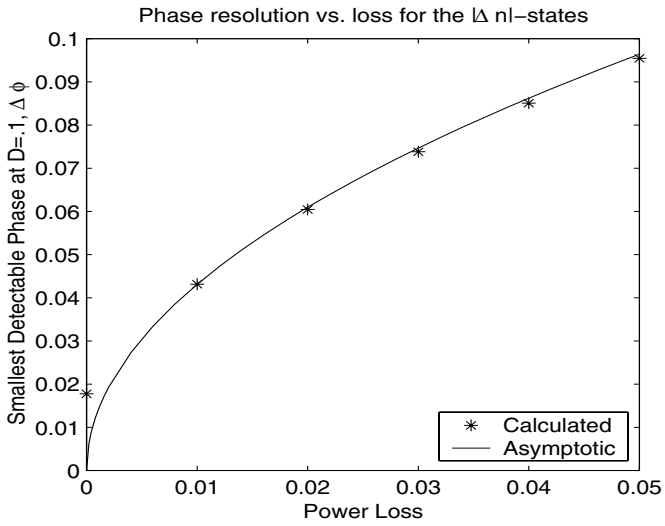

Figure 3: Phase resolution achievable as a function of power loss, using k-states. We see good agreement between the calculated values and the asymptotic curve. We have used $n = 63$, $D_{\rm tol} = 0.9$

Since a K-state resolves phases $\Delta\phi = \pi/2K$, we obtain

$$\Delta\phi^2 = \frac{\mathcal{L}\pi^2}{8n\ln(1/D_{\rm tol})},$$

where $D_{\rm tol}$ is the distinguishability tolerance. The theory is validated by the comparison with numerics shown in Figure 3. We expect this trend to be useful in designing interference devices, even when more general states are considered.

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Bandgap Calculations for "Nearly Isotropic" Reflection Vector Designs

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Design of photonic bandgap devices through explicit reflection vector placement was recently proposed[1]. The basic idea is that by explicit placement of the "reflection vectors," or Fourier components of the dielectric profile, $\epsilon^{-1}(\mathbf{r})$, one might reduce the mismatch in periodicity for different propagation directions and thereby achieve larger total bandgaps. We have calculated bandgaps for some two-dimensional (2D) device designs. We are developing intuitive guidelines for why bandgaps open, and efficient methods of calculating the performance of complex $\epsilon^{-1}(\mathbf{r})$ profiles.

The scalar eigenmodes of a dielectric structure are determined by the Helmholtz equation,

$$-c^2(\mathbf{r})\nabla^2\mathbf{u_l} = \omega_l^2\mathbf{u_l}.$$

One way to design a dielectric profile is through explicit placement of N reflection vectors:

$$c^2(\mathbf{r}) = \frac{1}{\mu\epsilon(\mathbf{r})} = \mathbf{c_0^2}\left[\mathbf{1} + \sum_{\mathbf{j=1}}^{\mathbf{N}} \mathbf{A_j e^{2ik_{rj}\cdot r}}\right] \tag{3}$$

Specifically, a 2D "nearly isotropic" device has $\mathbf{k_{rj}}$'s evenly placed on a circle. The motivating concept is that for a given material dielectric contrast, $\epsilon_{\max}/\epsilon_{\min}$, we might achieve larger bandgaps by adding complexity to the spatial dielectric pattern.

A one-dimensional bandgap device can be designed and implemented in a purely perturbative regime—the fiber Bragg grating, for example. No matter how small the coupling of waves, there is a bandgap. In contrast, 2D structures will only exhibit bandgaps for finite dielectric contrast. Simple perturbative mode-coupling approximations are accurate only if the perturbation parameter (coupling) is small enough. We are following up on an analytic theory [1] based on a perturbative approach [2]. Analytical expressions have previously described the coupling of two or three plane-waves. It is very desirable to obtain such a few-wave theory, since they provide a basic physical picture of how the device works. Unfortunately, because bandgap structures require finite coupling, we have found all analytically tractable theories to be inaccurate.

We have found an improved few-wave theory which predicts the qualitative structure of the eigenmodes. Although it does not give precise bandgap estimates, it can be used as a starting point for rapid calculation of bandgaps for some devices. We hope to generalize these results and understand all devices described by expression (3). Essential is an understanding of which plane waves are involved in eigenmodes at the bandedge: rather than calculate eigenmodes exhaustively, we would like to focus on those that determine the size of the bandgap. Figure 4 shows the geometrical construction hypothesized in [1] to approximate the lower bandedge, along with our improved construction. The ring of resonant points is more correct according to perturbation theory, since all points are degenerate. If we assume the ring lies on the lower bandedge and a straight-on reflection lies on the upper bandedge, then the opening of a bandgap can be sketched to lowest order in coupling strength $|A|$, as in Figure 5. Our numerics for $N = 8$ show bandgaps opening up in a qualitatively similar way, but with large departures from the linear trends shown.

We calculated approximate eigenmodes and frequencies numerically by coupling sampled plane waves in a $\mathbf{k}$-space grid. The ring construction allowed us to selectively choose relevant plane waves, and speed up the calculation. This technique produced accurate bandgap estimates in some cases, including $N = 8$. In other cases, the eigenmodes seemed to involve other plane waves. In these cases, exhaustive calculation of eigenfrequencies were successfully used to calculate bandgaps.

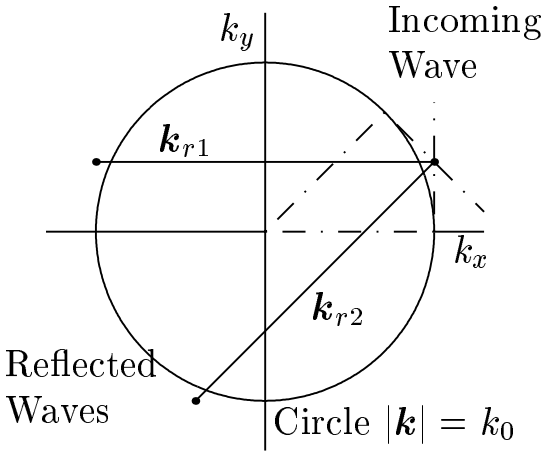

Figure 4: The old three-wave theory uses three coupled waves to estimate the lower bandedge. This geometric construction gives an incident wave coupled to two exactly resonant reflected waves. The new analytical theory includes the full set of N resonant plane waves, all coupled in a topological ring.

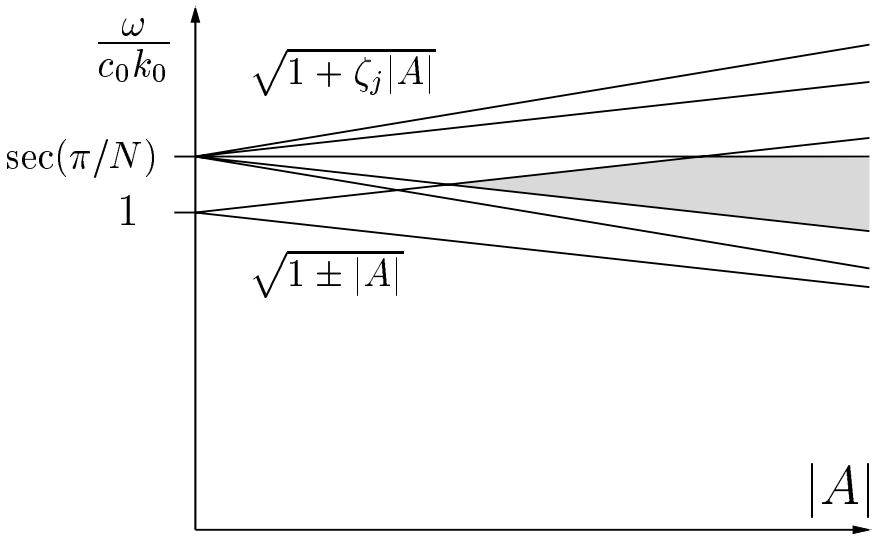

Figure 5: Schematic of the revised analytical dependence of upper and lower band edges on coupling strength $|A|$, to lowest order. The resulting bandgap is shaded.

Given our progress in calculating and understanding device performance, we anticipate that design tools will soon allow efficient design and optimization according to the nearly isotropic strategy. What is needed is an understanding of eigenvalue structure when the coupling between waves is no longer small.

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Electron screening in palladium deuteride

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A variety of anomalies have been reported during the last decade in metal deuterides. These anomalies include temperature increases, excess power production, helium generation, tritium production, induced radioactivity, and fast particle ejection. We have been interested in developing theoretical models for the anomalies. One of the key parameters that is required for the development of any such theory is the deuteron-deuteron overlap probability. For example, one would expect to observe neutron emission from PdD if the deuteron-deuteron overlap probability is sufficiently large. The reaction rate γ for this process is usually computed according to [1]

$$\gamma \;=\; A\;|\psi(0)|^2$$

where $\psi(0)$ is the probability amplitude for a deuteron pair at zero separation, and A is a physical constant that contains information about the reaction probability. It is convenient to associate a nuclear volume V_n with the probability density $|\psi(0)|^2$, such that the overlap probability is defined as

$$P_0 \;=\; V_n\;|\psi(0)|^2$$

The neutron production rate is then

$$\gamma \;=\; \gamma_n\;P_0$$

where $\gamma_n = A/V_n$ can be interpreted as the rate at which neutrons are created once two deuterons touch.

The overlap probability P_0 between two deuterons depends strongly on the local chemical environment. In molecular D_2, the overlap probability is on the order of 10^{-90}, which can be considered to be vanishingly small. In metal deuterides, this overlap probability can be much greater. Ichimaru has estimated that the overlap probability in PdD is closer to 10^{-50} [2]. If the overlap probability P_0 gets to be as large as 10^{-45}, then neutron emission should be detectable directly. Such an effect would provide an important probe for assessing close range particle-particle correlations in the solid state. Such information is not easily obtained by other means.

The overlap probability P_0 is determined primarily through the associated Gamow factor G according to

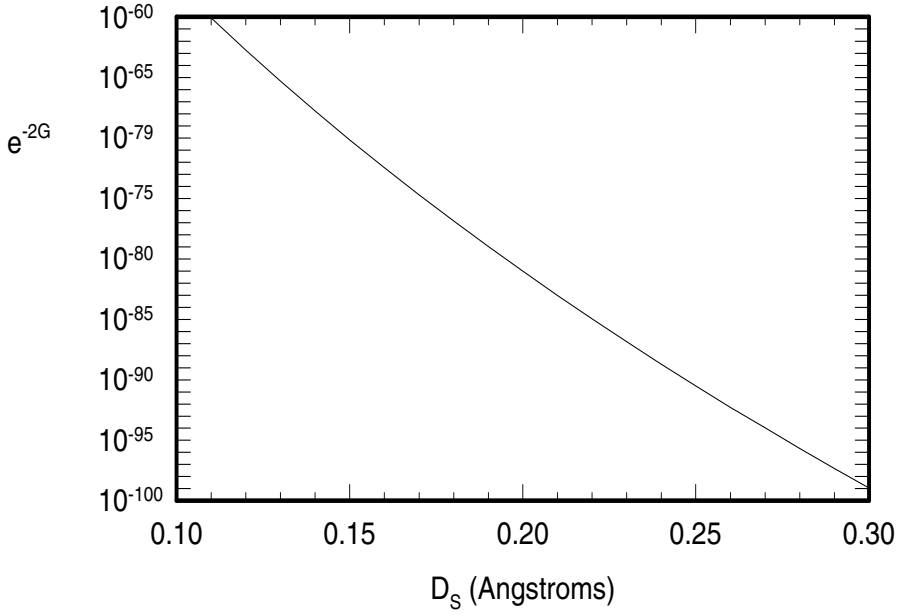

Figure 6: Gamow estimate of the overlap probability as a function of the screening distance D_S.

$$P_0 \ \sim \ e^{-2G}$$

The Gamow factor is given by

$$G \ = \ \int \ \sqrt{\frac{2\mu}{\hbar^2} \ [V(r) - E]} \ dr$$

The integral ranges over the forbidden region where the potential $V(r)$ exceeds the energy E.

The overlap probability is determined by the deuteron-deuteron potential $V(r)$, which is not known particularly well in metal deuterides. Other factors are also very important. For example, the two deuterons might be centered at different sites, in which case one must face the question of where the overlap occurs. Estimates that we have made seem to favor heavily situations in which two deuterons are present at the same site. The probability for this tends to be low in bulk metal deuterides. If the loading is very high, or else if many metal atom vacancies are present, then the probability for two deuteron occupation is greatly increased.

The interaction potential for two deuterons within a site is complicated, but the Gamow factor is dominated by contributions from close range. Consequently, we can make progress by examining a screened Coulomb potential of the form

$$V(r) \ = \ \frac{e^2}{r} e^{-r/D_S}$$

where D_S is the screening distance. The Gamow factor contribution to the overlap probability is illustrated in Figure 6.

Literature estimates for the screening distance D_S in metal deuterides tend to be on the order of 0.2 A. Kasagi has investigated neutron emission from various metal deuterides bombarded by deuterons

in the keV range, and has reported a screening energy U_S for PdD of 250 eV [3] (the theoretical estimate of Ichimaru is about 75 eV). This screening energy would correspond to a screening distance of

$$D_S \;=\; \frac{e^2}{U_S} \;=\; 0.058 \text{ A}$$

It is not obvious what physics could produce such a small screening distance. Experiments in molecular D_2 give a screening energy of 25 eV, with an associated D_S of 0.58 A. Results for titanium deuteride targets give a screening energy of 19 eV. For ytterbium deuteride, the screening energy is found to be 60 eV [4] (with a corresponding D_S of 0.24 A). While we might suspect that a contribution from channeling is present in the PdD results, it is not obvious *a priori* why channeling effects would show up in PdD, but not in TiD or YbD. Further experimental work on PdD and other metal deuterides will be necessary to clarify this situation.

There is perhaps some confusion surrounding the theoretical situation. One of the most sophisticated treatments of screening between deuterons in PdD has been reported by Ichimaru [2]. The overlap probability P_0 which is consistent with Ichimaru's results is in the vicinity of 10^{-50}, which would actually be consistent with a screening energy near 250 eV in the naive interpretation outlined above. However, Ichimaru's result is due to a combination of two factors: A screening energy on the order of 75 eV, and the introduction of a short range core dielectric response ϵ that is taken to be on the order of $1.25\epsilon_0$. If we were to apply this idea to the present discussion, we would adopt a modified screened interaction of the form

$$V(r) \;=\; \frac{e^2}{\epsilon r} e^{-r/D_S}$$

While such a dielectric constant is in the right range of what might be expected for a uniform longitudinal electric field in PdD, but it is not at all obvious that such a strong response would be expected locally between two deuterons at short range.

To investigate this, we are developing a new model for deuteron-deuteron screening that is based on a hybrid molecular orbital picture. If one focused on the electronic orbitals in the vicinity of the two deuterons when they are close, one would conclude that the electronic orbitals must be reasonably well approximated by the corresponding orbitals for molecular D_2. The interaction with electrons localized around nearby atoms should then be describable using perturbation theory. Such a picture leads immediately (with the aid of infinite order Brillouin-Wigner theory) to a model of the form

$$\hat{H} \;=\; \frac{|\mathbf{P}_1|^2}{2M_1} \;+\; \frac{|\mathbf{P}_2|^2}{2M_2} \;+\; \frac{e^2}{|\mathbf{R}_1 - \mathbf{R}_2|} \;+\; V_c(\mathbf{R}_1, \mathbf{R}_2) \;+\; E_e(|\mathbf{R}_1 - \mathbf{R}_2|)$$

$$+ \;\sum_j \;\left\langle \frac{e^2}{|\mathbf{R}_1 - \mathbf{r}_j|} [E - \hat{H}_0]^{-1} \frac{e^2}{|\mathbf{R}_2 - \mathbf{r}_j|} \right\rangle \;+\; \sum_j \;\left\langle \frac{e^2}{|\mathbf{R}_2 - \mathbf{r}_j|} [E - \hat{H}_0]^{-1} \frac{e^2}{|\mathbf{R}_1 - \mathbf{r}_j|} \right\rangle$$

Two local deuterons have kinetic and potential energy (the first line of the equation), and they interact with electrons at other sites (the second line) by inducing a polarization response. The summation in j and the expectation values indicated are taken over electronic orbitals centered elsewhere. In the limit that the two deuterons are far apart, the polarization terms lead to the usual model for dielectric response.

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A model for coupled nuclear-phonon interactions

Few claims have provoked more controversy in scientific circles than the claimed observations of anomalies in metal deuterides. As we have reported in previous RLE reports, we have been interested in developing models that may be relevant. Here we describe briefly progress that we have made in formulating and analyzing a new model that captures some essential physics of the interaction between nuclei and phonons in a lattice.

The basic model that we have been studying for the past several years can be expressed through the Hamiltonian [1], [2], [3]

$$\hat{H} \;=\; \frac{\Delta E}{2}\;\sum_j \hat{\sigma}_z[j] \;+\; \sum_m \hbar\omega_m\;\hat{a}_m^\dagger \hat{a}_m \;+\; \sum_k \epsilon_k\;\hat{b}_k^\dagger \hat{b}_k$$
$$+\;\sum_j U_n\;e^{-\alpha|\Delta\mathbf{R}|_j^2}\;\left(\hat{\sigma}_+[j] \;+\; \hat{\sigma}_-[j]\right) \;+\; \sum_m\sum_k V_{mk}\;\left(\hat{a}_m^\dagger + \hat{a}_m\right)\left(\hat{b}_k^\dagger + \hat{b}_k\right)$$

Ths model posits three quantum systems (nuclei, phonons and dissipation channels) that are coupled together through two interactions (coupling betwenn the nuclei and phonons, and coupling between the phonons and dissipation channels). The nuclear system assumes that deuteron pairs are present in the lattice, either as neighboring deuterium atoms, or else combined into a ^{4}He state. A simple two-level model is used for this system, which presumes that both the initial and final states are in local ground states. A full multi-mode phonon description is used, with diagonal quadratic terms indicated. A generalized dissipation model is employed, where the different dissipation channels can be phononic, electronic or nuclear as required. To fuse, the two deuterons must approach to within 10 fermi or closer. We have used a simple Gaussian interaction to model this, where the relative distance operator is assumed to be linear in the phonon operators. The coupling between the phonons and the dissipation channels is presumed to be linear.

Incoherent interactions

Under most conditions, this model gives rise to very weak coupling, and little or no anomalous effects. To generate an anomaly, there has to be some way for the nuclear energy quantum ΔE to be delocalized, in order for subsequent effects to occur. As each interaction between deuteron pairs is localized to within fermis, there does not appear *a priori* to be any mechanism through which the excitation can be transferred to other sites. Mathematically, this difficulty appears as a strong destructive interference between the different intermediate states, which causes all highly off-resonant effects to be localized.

The only way that other site in the lattice could participate is if a small number of intermediate states were coupled to preferentially. For example, if one intermediate state were somehow singled

out over all of the other possible intermediate states, then the strong destructive interference would be broken, and only an algebraic reduction of the interaction strength would occur. The question then becomes how it might be possible for one intermediate state to dominate the interaction with nuclei at disparate locations.

Dicke coherence

There exists something of an analog for this in the interaction between light and atoms. In the event that many atoms couple in-phase to a single photon mode (either due to localization of the atoms, or else due to restricting the available modes), it is possible for the coupling to be enhanced coherently. Such a coherent enhancement is known as Dicke coherence. To make use of Dicke coherence within the present model, we would require a Hamiltonian of the form

$$\hat{H} \;=\; \frac{\Delta E}{2} \sum_j \hat{\sigma}_z[j] \;+\; \hat{u} \sum_j \left(\hat{\sigma}_+[j] \;+\; \hat{\sigma}_-[j]\right) \;+\; \cdots$$

For a coherent interaction to arise, we must have all of the two-level systems interact in the same way with the phonon field (modeled here through $\hat{u}$). A cursory inspection of the Hamiltonian that we have proposed indicates that the interaction of the nuclei with the phonons is not of this form. Moreover, as the microscopic interactions between deuterons are highly localized, it is not readily apparent that there could be any coherent response.

Approximation for the coherent part of the interaction

Nevertheless, a great many experiments indicate that somehow energy can be delocalized, so we have been motivated to investigate further. The key question that we must address is the computation of the coherent part of the interaction between phonons and nuclei. To understand whether the model predicts any delocalization of the energy or not, we must evaluate the coherent part of the interaction. We require a separation

$$\hat{U} \;\;=\;\; \sum_j U_n \, e^{-\alpha |\Delta \mathbf{R}|_j^2} \, \left(\hat{\sigma}_+[j] \;+\; \hat{\sigma}_-[j]\right) \;\;=\;\; \hat{U}_{coh} \;+\; \hat{U}_{inc}$$

There are no papers or textbooks of which we are aware that explain how to extract the coherent part of an operator of this form. For many years, we thought that the coherent part of $\hat{U}$ was probably exponentially small. During the past year, we have succeeded in developing arguments that have ultimately produced a suitable decomposition as required.

The essential trick was to assume that if $\hat{U}$ did in fact have a coherent part, then repeated applications of $\hat{U}$ to a function would eventually be dominated by the coherent part of the interaction. We imagine an image being constructed by overlaying more and more points, some of which are the same each time (the coherent part), and some of which are random. The coherent addition of signal time after time will eventually produce a nice image that rises out of the noise. And so perhaps with operators. Using these ideas, one computes

$$\left[\sum_j U_n \, e^{-\alpha |\Delta \mathbf{R}|_j^2} \, \hat{\sigma}_+[j]\right]^N \Phi_0 \;\approx\; \left[U_n e^{-(\alpha/N) \sum_j |\Delta \mathbf{R}|_j^2} \sum_j \hat{\sigma}_+[j]\right]^N \Phi_0$$

where N is the number of pairs, and Φ_0 is the ground state of the nuclear system. This is consistent with the approximation

$$\hat{U}_{coh} \;\approx\; U_n \, e^{-\alpha \sum_j |\Delta \mathbf{R}|_j^2 / N} \sum_j \left(\hat{\sigma}_+[j] \;+\; \hat{\sigma}_-[j]\right)$$

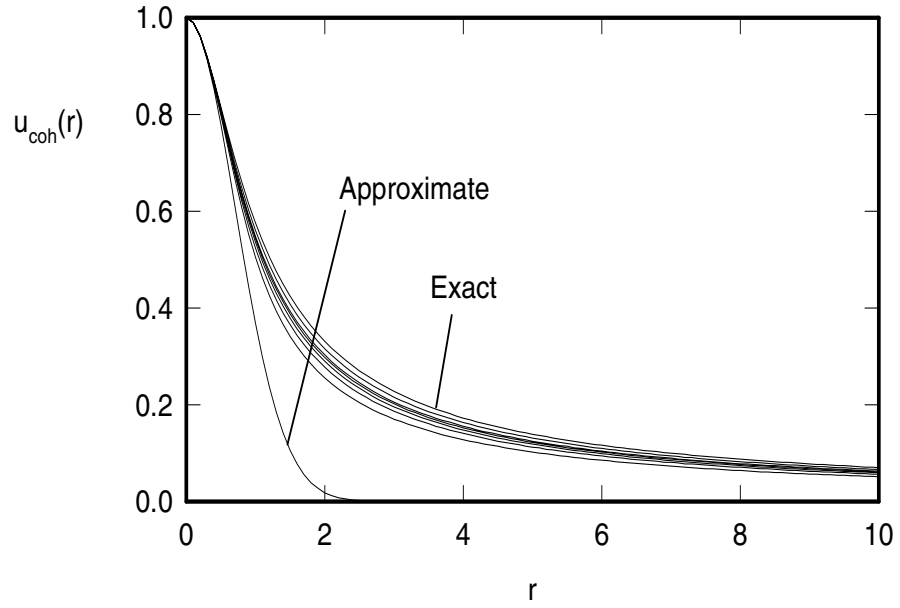

Figure 7: Functional form of the coherent interaction. Indicated is a dotted curve that indicates the Gaussian approximation discussed in the text, and solid curves for $2, 3, 4, \cdots$ pairs.

This result is important for two reasons. Firstly, this our the first indication that the coherent part of the interaction might be both computable and useful. Secondly, this construction indicates that there exists a preferred collective phonon coordinate

$$r^2 \;=\; \sum_j |\Delta \mathbf{R}|_j^2$$

that the nuclei respond to preferentially.

This latter point is of considerable interest, as it is possible to develop a lattice model that separates this degree of freedom from other less important degrees of freedom. It is also possible to derive the coherent part of the interaction much more directly by taking as an ansatz that the coherent part of the interaction can be isolated by determining the dependence of the local interaction at each upon this collective coordinate. The results are illustrated in Figure 7.

Model that focuses on the coherent part of the interaction

A modified version of the model can then be isolated that focuses only on the coherent part of the interaction between the nuclei and the phonons. This model can be cast into the form

$$\hat{H} \;=\; \frac{\Delta E}{2} \sum_j \hat{\sigma}_z[j] \;+\; \hat{H}_{ph} \;+\; \sum_k \epsilon_k \; \hat{b}_k^\dagger \hat{b}_k$$
$$+ \; U_n \; \hat{u}_{coh}(r) \sum_j \; (\hat{\sigma}_+[j] \;+\; \hat{\sigma}_-[j]) \;+\; \sum_m \sum_k \; V_{mk} \; (\hat{a}_m^\dagger + \hat{a}_m) \; (\hat{b}_k^\dagger + \hat{b}_k)$$

The simplest possible relevant phonon model is one that involves two radial coordinates in a high

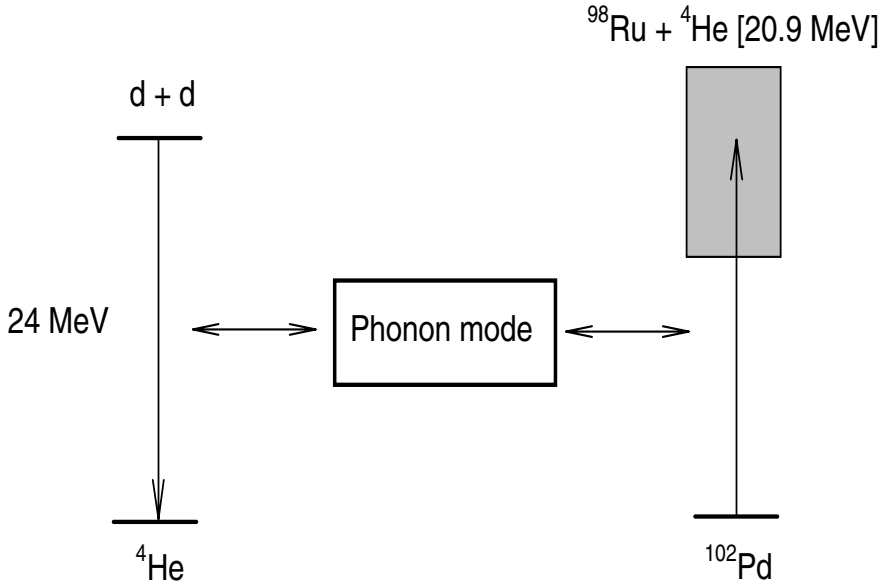

Figure 8: Schematic of second order lattice-induced ion ejection process relevant to the NRL experiment, in which alpha particles up to 21 MeV were observed.

dimensional space. We have indicated it here simply as $\hat{H}_{ph}$. Interaction matrix elements based on this model can be computed approximately with no particular difficulty.

Application of the model to anomalous fast ion emission

A number of experiments have claimed to observe anomalous fast ion emission from various metal deuterides. For example, a group at NRL observed alpha emission with energies between 18 and 21 MeV from PdD [4]. Cecil and coworkers at the Colorado School of Mines reported the observation of a variety of low mass fast ions from TiD [5]. Here we consider the application of the model to fast ion emission.

Within the framework of the model, fast ion emission would occur when a nuclear transition between the two-level systems is coupled through phonon exchange to the lattice, and then the lattice interacts with a nuclear dissipation channel in a highly off-resonant second order process [1],[2]. This is indicated schematically in Figure 8. In this case, the dissipation channel involves the ejection of a low mass object from a mid-Z nucleus. The application of second order perturbation theory leads to an emission rate formula of the form

$$\Gamma \;=\; \frac{2\pi}{\hbar}\;\left|\left\langle \Psi_f|\;\hat{U}[E-\hat{H}_0]^{-1}\hat{V}\;+\;\hat{V}[E-\hat{H}_0]^{-1}\hat{U}\;|\Psi_i\right\rangle\right|^2\;\rho(E_f)$$

Here we have used $\hat{U}$ to represent the nuclear transitions involving deuterons, and $\hat{V}$ to indicate the dipole-induced ion ejection from mid-Z nuclei.

There is qualitative agreement between this model and the experimental observations for PdD and TiD. A deuteron-deuteron fusion energy of 24 MeV coupled in this way to Pd nuclei, would lead to the ejection of alpha particles in the range of 18-21 MeV as observed. The same basic mechanism

as applied to TiD would lead to the emission of protons, deuterons, ^{3}He with energies corresponding to the observations of Cecil and coworkers.

For energy delocalization to occur within the model, the basic process must be stimulated by a strongly excited collective phonon mode as discussed above, as a coherent effect with associated energy delocalization as outlined above can only be brought about in response to such excitation. The reaction rate computed from second order perturbation theory as given here exhibits explicit Dicke factors corresponding to a coherently enhanced process. The magnitude of the rate is proportional to the overlap probability, which has a substantial (many order of magnitude) uncertainty associated with it, which precludes a quantitative comparsion between theoretical and experimental reaction rates. This uncertainty will likely be reduced in the future. There are also issues relating to the origin and degree of coherence possible. We are considering models in which coherence factors are due to accidental (random) alignment of phases at different sites.

The importance of the model, in spite of the present difficulties associated with uncertainties in the parameters required for predictions, is that it represents one of the simplest possible models which can be put on a solid physical basis that can describe an anomaly in metal deuterides. Verification of this mechanism now becomes possible, in that the process would be accompanied in some cases by gamma emission. Observation of a correlation between fast ion emission and gamma emission would have the potential to uniquely establish the origin of the fast ions.

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