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Coherent and Semi-Coherent Neutron Transfer Reactions

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Abstract

The novel process of coherent neutron transfer in the presence of a lattice is proposed to be the basis of a number of anomalous phenomena which have recently been reported in investigations of the Pons-Fleischmann effect.

1. INTRODUCTION

We have examined mechanisms for the coherent neutron capture onto, and the coherent neutron removal, from nuclei in the presence of a lattice. Under fairly restrictive circumstances, it appears to be possible to satisfy both energy and momentum conservation requirements between the microscopic nuclear system and the macroscopic lattice such that coherent nuclear,energy transfer to and from the lattice occurs.

This mechanism enables coherent neutron donor and acceptor reactions to occur, with deuterium as the optimum donor nucleus. Coherent reaction pathways leading to heat, tritium, and helium generation are proposed: Heat generation in Pons-Fleischmann cells would result from coherent neutron capture onto ^{6}Li in the lattice; tritium generation would result from coherent neutron capture onto deuterium; coherent neutron capture onto ^{7}Li would lead to ^{8}Li, which would beta decay to ^{8}Be, and ultimately alpha decay to form two ^{4}He nuclei.

Semi-coherent reactions, in which the neutron capture part of the reaction would yield energetic products, are also proposed to account for fast triton production and secondary fast neutron generation.

The present conference proceedings contains a very abreviated version of results and discussions that will appear elsewhere. For detailed references, extended discussions, further comments about notation, etc., the reader is referred to Ref. 1.

2. Coherent Neutron Capture in the Presence of a Lattice

The coherent transfer of a neutron to or from a nucleus in the presence of a lattice in our model is mediated by an electromagnetic transition as depicted in Figure 1. The initial state for coherent neutron removal would include a donor nucleus X and an initial lattice L_X; the final state would include a product nucleus Y, a Bragg state neutron, and a final state lattice L_Y. The transition between the initial state and final state is mediated through near-field $\mathbf{d} \cdot \mathbf{E}$ or $\mu \cdot \mathbf{B}$ hamiltonians, with the electric or magnetic fields being long wavelength macroscopic fields imposed externally, or in the case of electric fields, perhaps arising internally.

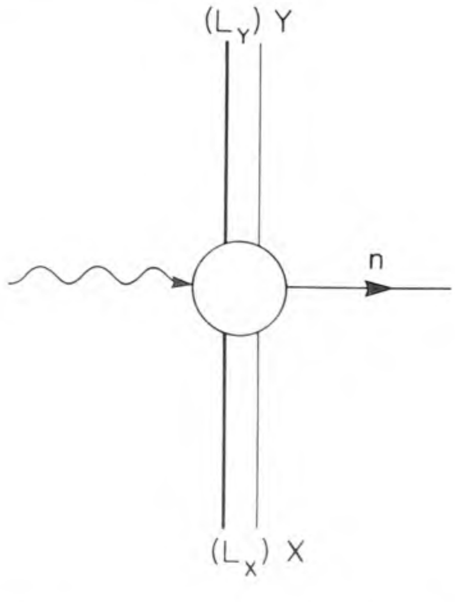

Figure 1. Feynmann-like diagram for a single coherent neutron transfer reaction.

The transition hamiltonian which corresponds to the magnetic version of this process is described in second quantization through $\hat{H}_{-\mu\cdot\mathbf{B}}$, which is

$$\int d^3\mathbf{r}_1\cdots\int d^3\mathbf{r}_N\left[\hat{\Psi}_Y^\dagger(\mathbf{r}_1,\cdots,\mathbf{r}_{N-1})\wedge\hat{\Psi}_n^\dagger(\mathbf{r}_N)\right]\left[-\sum_j\mu_j\cdot\mathbf{B}(\mathbf{r}_j)\right]\hat{\Psi}_X(\mathbf{r}_1,\cdots,\mathbf{r}_N)$$
$$+\int d^3\mathbf{r}_1\cdots\int d^3\mathbf{r}_N\hat{\Psi}_X^\dagger(\mathbf{r}_1,\cdots,\mathbf{r}_N)\left[-\sum_j\mu_j\cdot\mathbf{B}(\mathbf{r}_j)\right]\left[\hat{\Psi}_Y(\mathbf{r}_1,\cdots,\mathbf{r}_{N-1})\wedge\hat{\Psi}_n(\mathbf{r}_N)\right] \tag{2.1}$$

where the nucleon field operators are defined elsewhere[1]; for example

$$\hat{\Psi}_X(\mathbf{r}_1,\cdots,\mathbf{r}_N)=\sum_i\sum_{\alpha_X}\hat{b}_{X,\alpha_X}(i)\Phi_X^{\alpha_X}\left(\mathbf{r}_1-\hat{\mathbf{R}}_i,\cdots,\mathbf{r}_N-\hat{\mathbf{R}}_i\right) \tag{2.2}$$

The center of mass position is determined as a function of the phonon mode amplitudes through $\hat{\mathbf{R}}_i=\mathbf{R}_i^o+\sum_m\hat{q}_m\mathbf{u}_m(i)$

Upon substituting in our expressions for the various operators which occur in the transition operator we obtain

$$\begin{aligned}\hat{H}_{-\mu\cdot\mathbf{B}} &= \sum_i\sum_{\alpha_n}\sum_{\alpha_X}\sum_{\alpha_Y}\sum_{\mathbf{k}}\hat{b}^\dagger_{n,\alpha_n,\mathbf{k}}\hat{b}^\dagger_{Y,\alpha_Y}(i)\hat{b}_{X,\alpha_X}(i)\left[-\mu_{Y,n,X}^{\alpha_Y,\alpha_n,\alpha_X}\left(\hat{\mathbf{R}}_i^{X_i},\hat{\mathbf{R}}_i^{Y_i}\right)\cdot\mathbf{B}_i\right]\\ &+ \sum_i\sum_{\alpha_n}\sum_{\alpha_X}\sum_{\alpha_Y}\sum_{\mathbf{k}}\hat{b}^\dagger_{X,\alpha_X}(i)\hat{b}_{n,\alpha_n,\mathbf{k}}\hat{b}_{Y,\alpha_Y}(i)\left[-\mu_{X,Y,n}^{\alpha_X,\alpha_Y,\alpha_n}\left(\hat{\mathbf{R}}_i^{X_i},\hat{\mathbf{R}}_i^{Y_i}\right)\cdot\mathbf{B}_i\right]\end{aligned} \tag{2.3}$$

where the first magnetic dipole operator appearing in this equation is defined by

$$\begin{aligned}\mu_{Y,n,X}^{\alpha_Y,\alpha_n,\alpha_X}\left(\hat{\mathbf{R}}_i^{X_i},\hat{\mathbf{R}}_i^{Y_i}\right)=\int\cdots\int&\left[\Phi_Y^*\left(\mathbf{r}_1-\hat{\mathbf{R}}_i^{Y_i},\cdots,\mathbf{r}_{N-1}-\hat{\mathbf{R}}_i^{Y_i}\right)\wedge\Phi_{n,\mathbf{k}}^*(\mathbf{r}_N)\right]\left[\sum_j\mu_j\right]\\ &\Phi_X\left(\mathbf{r}_1-\hat{\mathbf{R}}_i^{X_i},\cdots,\mathbf{r}_N-\hat{\mathbf{R}}_i^{X_i}\right)d^3\mathbf{r}_1\cdots d^3\mathbf{r}_N\end{aligned} \tag{2.4}$$

Some brief discussion of the physical content of this model is in order; the model describes a transfer of a neutron from X whose center of mass is located "at" $\hat{\mathbf{R}}_i^{X_i}$, resulting in the product nucleus Y whose center of mass is located "at" $\hat{\mathbf{R}}_i^{Y_i}$. The positions of the initial and final state nuclei are determined by the degree of lattice excitation and by the lattice displacement vectors, both of which will differ between the initial and final states due to the neutron transfer. The spatial overlap integral given in equation (2.4) ensures that a transfer occurs only when the initial and final center of mass coincide to within fermis; no transfer occurs for large separation. Hence, the magnetic dipole operator is a highly nonlinear function of the lattice phonon mode amplitudes; we have found an approximate Gaussian dependence on relative separation ($\mu \sim e^{-\frac{1}{2}B|\hat{\mathbf{R}}_i^X - \hat{\mathbf{R}}_i^Y|^2}$, with B on the order of fermi^{-2}) .

3. Energy and Momentum Transfer Between Nuclei and a Lattice

The fundamental theoretical dilemma that presents itself is: how can a large MeV nuclear energy quanta can be transferred to a lattice whose energy levels are quantized on the meV scale? Our initial efforts were focussed on transferring the energy one phonon quanta at a time; this approach, however, appears to be unproductive. The only alternative is to transfer the nuclear quanta in a single step, which requires a large nonperturbative nonlinearity on the part of the lattice in order to accept the energy.

We may view the neutron transfer process as involving a collision between a lattice and a nucleus; the hamiltonian for the lattice may be taken to be of the form

$$H = \sum_m \frac{p_m^2}{2M} + \sum_m \frac{1}{2} M \omega_m^2 q_m^2 + V(t) e^{-\frac{B}{2} \sum_{m,m'} D_{m,m'} q_m q_{m'}} \qquad (3.1)$$

The lattice is composed of a large set of oscillators, each with mode amplitude q_m and momentum p_m. We may construct a large dimensional vector $\mathbf{q}$ from the individual mode amplitudes $\mathbf{q} = \sum_m \hat{i}_m q_m$ which would represent the position of the lattice in a N-dimensional space where N is the total number og phonon modes. The nucleus exists in 3-space, but since the center of mass position coordinates are functions of the phonon mode amplitudes, the nuclear scattering potential is mapped into the N-dimensional space as indicated in the above hamiltonian. As a result, the problem that we are interested in analyzing is basically of simple inelastic collisions in q-space between the lattice and nucleus.

We know from an analysis of kinematics in 3-D that energy and momentum must be separately conserved, and that the constraints imposed through conservation determine the essential features of the reaction. We would like to understand how energy and momentum conservation works in this case, especially since it is generally believed that the low energy phonon modes of the lattice cannot accept a nuclear energy quantum; the arguments against this ultimately have to do with whether energy and momentum can be conserved simultaneously.

We may formulate the problem simply: we require that

$$E_i + \Delta E_N = E_f \tag{3.2}$$

and

$$\mathbf{p}_i + \Delta \mathbf{p} = \mathbf{p}_f \tag{3.3}$$

be satisfied at the same time, where E_i and E_f are the total initial and final lattice energies, and where $\mathbf{p}_i$ and $\mathbf{p}_f$ are the total N-dimensional lattice momenta. The nuclear energy transfer is ΔE_N. The lattice may be thought of for the purposes of the present argument as a wave incident on a time-dependent perturbation localized around the origin in q-space; diffraction effects give rise to $\Delta \mathbf{p}$. We find that energy and momentum can be matched simultaneously since

$$\Delta E_N \approx \frac{|\Delta \mathbf{p}|^2}{2M} \approx \frac{\hbar^2 B}{2M} \tag{3.4}$$

by the uncertainty principle.

The diffraction of the lattice off of the localized nuclear potential in q-space is responsible for the momentum transfer, and we have argued here that this momentum transfer can be consistent with the large energy transfer since the phonon mode amplitudes must be localized to within fermis for a coherent neutron transfer reaction to take place. The effect is purely quantum mechanical, since it is diffractive, with no classical analog. The arguments given above can also give constraints on lattice size and total lattice energy required for transitions to occur: these constraints entail the requirement that many modes must be present so that the momentum transfer to each is small, and that sufficient energy be present in each mode so that in an endothermic reaction the energy is available for extraction. We shall discuss these issues further elsewhere.

References

1. P. L. Hagelstein, "Coherent and Semi-Coherent Neutron Transfer reactions. I-IV," submitted to *J. Fusion Tech.* (1991).