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Three Types of dd Fusion

Talbot A. Chubb

Research Physicist, 5023 N. 38th St., Arlington VA 22207, tchubb@aol.com

There seem to be 3 different processes by which deuterons can be made to fuse so as to release nuclear energy. The conventional approach is thermonuclear fusion, which uses collisions between energized deuterons to create a transient ^{4}He nucleus that decays by energetic particle emission. Deuteron-deuteron (dd) fusion is modeled by scattering theory. Quantum wave mechanics uses wave functions to describe the colliding particles as plane waves. The waves are treated as if arriving from infinity, and as going away to infinity after scattering or reaction. Gamow factors calculating the probability of transmission through the dd Coulomb barrier are used in calculating fusion rates.

The other 2 dd fusion processes are catalytic processes. Catalysis substitutes configuration change for kinetic impact in promoting reaction. Catalytic processes usually use surface and interface science to reduce the temperature at which exothermic reactions can take place.

The one catalytic process that is generally accepted as leading to dd fusion is based on creating an anomalously high deuteron density. This high density is achieved in a D_2^+ molecule by replacing the ion's electron by a negative muon. The process is called muon-catalyzed fusion. The mass of the muon is 200 times the mass of the electron and creates a 200 times smaller molecule. The effective density is increased by a factor ~10^7. At this density, quantum mechanics tunneling through the Coulomb barrier separating the 2 deuterons leads to a significant wave function overlap and fusion reaction rate. The nuclear products are the normal products of thermal plasma fusion. The process is not practical in a commercial heat source because of the short lifetime of the negative muon against decay.

The other catalytic method uses the reverse strategy. It works at normal density and uses a catalyzed configuration change to reduce dd Coulomb repulsion in a metal deuteride. The configuration change is called coherent partitioning, and the wave function describing the altered configuration is called a Bloch function. When the Bloch function configuration applies to deuterons hosted in a metal crystal, energy-minimizing quantum mechanics replaces a 2-body wave function with Coulomb barrier by a 2-body wave function with anti-correlation. The anti-correlation factor reduces, but does not prevent wave function overlap and the associated possibility of fusion. The change in wave function configuration occurs when partitioning exceeds a critical value, namely, the point at which the quantum mechanics kinetic energy density associated with the dd repulsion singularity becomes greater than the potential energy density.

When the anti-correlation wave function configuration applies, wave function overlap occurs and coordinate exchange symmetry becomes established. The strong force nuclear interaction is then no longer blocked, and deuteron pairs can fuse to produce a helium nucleus of the same Bloch array configuration. A zero-spin 2-body Bloch-geometry configuration is modeled using a Schrodinger Hamiltonian ***H***

$$\boldsymbol{H}(\mathbf{r},\mathbf{r}_{12}) \cong \left\{- \frac{\hbar^2}{4m_d}\nabla^2 + U_{lattice}(2e)\, N_{well}(\mathbf{r}, N_{well})\right\} +$$

$$\left\{- \frac{\hbar^2}{m_d}\nabla_{12}^2 + \sum_{\substack{j=1 \\ \text{coherent} \\ \text{volume}}}^{N_{well}} e^2/\left(N_{well}^2\ \left|\left(\mathbf{r}_{12} + \mathbf{R}_{12_j}\right)\right|\right)\right\} + E_{nuc}(\mathbf{r}_{12})\ ,$$

where $(\mathbf{r},\mathbf{r}_{12})$ are center-or-mass, separation coordinates, $\mathbf{R}_{12_j}$ is a lattice vector in Bloch separation space, $U_{lattice}$, is lattice potential, N_{well} is the coherent volume measured in terms of the number of occupied unit cells in the lattice, $E_{nuc}(\mathbf{r}_{12})$ is the dd strong force potential. A trial electrostatic solution

$\Phi_S\,(\mathbf{r},\mathbf{r}_{12}) = \psi(\mathbf{r}_{cm})\ g(\mathbf{r}_{12})$, and

$$g(\mathbf{r}_{12}) = C[1+b \sin(|\mathbf{r}_{12}|/4r_{sc})]/(1+b) \quad |\mathbf{r}_{12}| < 2r_{sc}$$
$$g(\mathbf{r}_{12}) = g(2r_{sc})\ C \quad |\mathbf{r}_{12}| > 2r_{sc}$$

was used in a variational calculation to minimize system energy. C is a normalizing constant, g is a cusp function, b measures "cusp amplitude", r_{sc} is a screening radius, and (1-b) replaces the factor used by J. D. Jackson[1] in calculating "'leakage' through the barrier to zero separation" in muon-catalyzed fusion. At b = 0.1, system energy is minimized at N_{cell} = 7000. Theory shows that b decreases with increasing amounts of coherent partitioning. Because $\mathbf{R}_{12}$ is an independent lattice vector, the dd effective Coulomb repulsion goes to zero at large N_{well}. A dd nuclear square well applies at <30 fm separation.

1. J. D. Jackson, *Phys. Rev.* **106**, 330 (1957.