SOME THOUGHTS ON A SIMPLE MECHANISM FOR THE $^2H + ^2H \rightarrow ^4He$ COLD FUSION REACTION

COLD FUSION

TECHNICAL NOTE

KEYWORDS: *ground-state fusion, compressed-rotational-shielded fusion, rotating ground states*

ALDEN E. PARK *404 North Alvord Street, Ridgecrest, California 93555*

Received November 10, 1992
Accepted for Publication April 26, 1993

A speculative mechanism for the creation of ^4He using cold fusion is proposed. The nuclear transformation can be made by the fusion of two excited rotating ground states of deuterium into a highly excited rotating ground state of ^4He. Under compression and relatively stable conditions, the formation of such a bound, stretched-out pnnp state of ^4He would be favored (with respect to Coulomb repulsion) over other nuclear ground states without as much angular momentum. The reaction likely occurs at the surface of palladium. A more descriptive name for this reaction is compressed-rotational-shielded (CRS) fusion. Potential experimental conditions for enhancing the initiation of CRS fusion are discussed.

INTRODUCTION

References 1 through 6 collectively provide evidence that ^4He production correlates with excess heat production during cold fusion experiments. This can be explained by invoking the nuclear reaction

$$^2H + ^2H \rightarrow ^4He + 23.8\ \text{MeV} \ .$$

This cold fusion reaction is called compressed-rotational-shielded (CRS) fusion in this technical note.

This nuclear fusion of deuterium to form helium in the CRS fusion reaction will likely involve the lowest nuclear energy states of ^4He if it is to occur under the influence of atomic processes. There are many reports in the literature of unbounded virtual excited states of ^4He that are greater than the 19.8-MeV disassociation energy of ^4He into $p + ^3H$ (see, for example, Refs. 7 and 8). Both of these references present virtual-state evidence for energies less than the 20.6-MeV disassociation energy of ^4He into $n + ^3He$. One meaning that can be attached to the many theoretical and experimental reports of virtual states of ^4He only above 19.8 MeV (and the absence of reports of bound states below 19.8 MeV with the important exception of the helium ground state at 0.0 MeV) is that the angular momentum of $\hbar = h/(2\pi)$ (where h represents Planck's constant) is quite large with respect to the ^4He nuclear system. The value of $\hbar$ is the angular momentum corresponding to the first-angular-momentum virtual excited state of the ^4He nucleus.

The many reports of only unbounded excited states of ^4He do not prove that bound rotating variations of the ^4He ground state cannot exist. A very low energy (when measured on a mega-electron-volt scale) rotating ground state should be physically possible if either the quantum ground state of ^4He is not perfectly isotropic or a slightly excited ground state of ^4He is not isotropic perhaps by virtue of slightly protruding protons. As space is isotropic, a new Hamiltonian could be considered that is a slight spatially rotating variation of another Hamiltonian and thus could have a slightly perturbed ground-state solution with a change in the angular momentum by much less than $\hbar$. A series of such small angular-momentum transformations could cause a series of perturbations of ground-state solutions. Prior to CRS fusion studies, it was quite difficult and impractical to experimentally create highly excited nuclear ground states. Some of these highly perturbed ground states might be the states progressing to the normal near-zero-angular-momentum ^4He ground state at the completion of the CRS fusion reaction. The normal nuclear ground states of ^4He with zero-angular-momentum quantum numbers (at a temperature above absolute zero) generally have some residual (nonzero) angular momentum that is much less than $\hbar$. This means that only at the thermodynamically forbidden temperature of absolute zero would an ensemble of ^4He nuclear ground states have precisely zero internal angular momenta (to an arbitrarily large number of significant figures) for each and every nuclear ground state in the ensemble.

PROPOSED MECHANISM

A high-angular-momentum excited "ground" state of ^4He might be created in two dependent stages during the CRS fusion reaction. One stage brings the deuterium (D = ^2H) nuclei closer via momentum, compression, and internal ground-state rotations in the presence of excess negatively charged electrons at the palladium's surface. The ground-state rotations might be in the presence of a magnetic field. Another greatly compressed and internally rotating stage with charge-shielded deuterons approaches the condition of having interior neutrons (one from each of the two deuterons) attract via nuclear forces. The second stage culminates in the nuclear fusion of the excited deuterium atoms to form a highly excited ground state of ^{4}He. There is no clear-cut boundary between the two stages.

An alternative pathway might be a compression as in the first stage, followed by a shielded rotating-deuterium tunneling to the highly excited ^{4}He when there is proper angular momentum. This alternative tunneling for the second stage would be more favorable with respect to required charge-shielding requirements although less favorable with respect to tunneling requirements. If there is an appreciable amount of tunneling, the CRS fusion should be called CRST fusion (where T represents tunneling).

Either of these possible pathways leads to a highly excited ground state of ^{4}He that can liberate energy as it decays into a normal nuclear ground state. The ground-state decay is a third stage of CRS or CRST fusion.

FIRST STAGE OF FUSION

The first stage of CRS fusion (or CRST fusion) is a momentum, compression, and internal ground-state rotation stage at the surface of palladium in the presence of excess negative charges. These excess negative charges are due to either (a) a cathode surface or (b) chance electron occurrence when the surface is not a cathode. The presence of extra electrons (either in a surface charge layer or in quantum electron states about the externally and internally rotating pair of deuterons within which the neutrons and protons periodically exchange roles) increases the probability of electrons occurring between the positive deuterium nuclei, allowing the two nuclei to compress much more closely. Assuming a palladium cathode, the surface is the location on the cathode with the largest concentration of excess negative charges. Cylindrical cathodes with small radii have smaller surface areas and thus, for a given charge, can have a larger charge per unit area on their surfaces. The interior lattice of the hydrogen-absorbing palladium should be as fully loaded with deuterium as is practical so that greater surface pressures can cause CRS fusion to occur more readily. During full loading, one deuterium atom corresponds to every interior palladium atom. The reaction should be more likely (a) with greater pressure (such as in the case with cylindrical cathodes of smaller radii), (b) with higher concentrations of deuterium, and (c) with larger currents.

Helping to bridge the first and second stage are internal rotational motions, possibly in the presence of a magnetic field in addition to strong internal nuclear forces. The magnetic field could predominantly be either an externally imposed field or a locally occurring field (e.g., due to nearby fusions). Internal deuterium rotations (internal relative to any external rotations of deuterium about deuterium) may allow extended nucleon-nucleon interactions and occasionally provide stretched-out situations over which the nuclear interactions occur, thus increasing the effective proton-proton interaction distance by placing neutrons and neutral virtual mesons between the protons.

Cathodes in many CRS fusion experiments have a magnetic field caused by current going up through the cathode. For cylindrical cathodes, the magnetic field B at the surface lies nearly in the surface (perpendicular to the macroscopic surface normal) and has an approximate value of $B = \mu\mu_0 i/(2\pi r)$ outside the cathode or $B = \mu\mu_0 ir/(2\pi r_s^2)$ inside the solid conducting cathode, where i is the current at that portion of the cathode, r is the radius, and r_s is the radius at the surface. The magnetic field B is thus a maximum of $\mu\mu_0 i/(2\pi r_s)$ at the surface, which is larger for cylinders with small values of r_s.

Given a magnetic field B, classically, the centripetal force $MV^2/R = (qVB) + S$ corresponds to a charge traveling in a circle at speed $V = 2\pi R/T$ perpendicular to the B field, where S is a strong nuclear attractive force. The mass is M. The charge after shielding is q. The radius is R.

The angular frequency of the system is

$$\omega = \frac{2\pi}{T} = \frac{V}{R} = \frac{qB}{M} + \frac{S}{VM} .$$

If $S/(VM)$ is either nearly a quantum constant or small, then the angular frequency is nearly a constant.

If $S/(VM)$ were negligible, the angular frequency would be the cyclotron frequency, $\omega = qB/M$. For example, since the mass of deuterium is approximately twice the mass of a proton p, then the cyclotron frequency for deuterium is about half the cyclotron frequency for a proton, $\omega_D = \omega_p/2$. With identical charge shielding, one deuterium atom might "externally" rotate about another distant deuterium atom with their angular frequency vectors $\boldsymbol{\omega}_D$ parallel. Simultaneously, each of the protons could "internally" rotate about its neutron-proton center of mass with its angular frequency vector $\boldsymbol{\omega}_p$ similarly parallel to one of the $\boldsymbol{\omega}_D$ and with $\omega_p \geq 2\omega_D$. The equality would apply if the strong attraction within each deuteron could somehow be negligible.

It is possible for the external rotations to be initially blocked by the palladium structure so that external values of ω_D would be zero while internal values of ω_p could be large.

When $S/(VM)$ is large within each deuteron but negligible between deuterons, the internal angular frequencies ω_p could be much greater than the external ω_D. One possible arrangement of the four rotating particles at one instant is a stretched-out configuration of *pn pn* with internal rotations on each deuterium end and the interior nucleons not yet close enough for nuclear interaction. A rotating *pn pn* system could have roughly equal distances between the protons, which would mean a nearly constant Coulomb repulsion. Prior to fusion, a rotating *pn pn* system could change to a rotating *pn np* system (as shown in Fig. 1) via a charged virtual meson transfer within the deuterium that contained the innermost proton. Such a charge transfer would temporarily reduce the Coulomb repulsion between the protons.

It is supposed that one source of internal rotational energy for the deuterons is compressive situations that favor internal rotations as a means of reducing the Coulomb repulsion energy. The Coulomb repulsion and the compressive pressures could cause a rotating *pn np* system (as illustrated in Fig. 1) with greater internal angular momentum within each deuteron to be favored Coulomb energetically over any deuterium-deuterium (D-D) system with less internal angular momentum because the average distance between protons in the more extended temporary *pn np* system would be larger. The Coulomb potential energy is $q_1 q_2/(4\pi\epsilon_0 d)$, where q_1 and q_2 are the shielded charges, and d is the distance between the

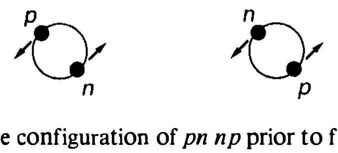

Fig. 1. Example configuration of *pn np* prior to fusion of excited deuterium ground states.

shielded protons. This larger internal angular momentum situation can occur if one of the exchanged virtual mesons within each internally rotating deuteron is charged to prevent the *pn np* system (as shown in Fig. 1) from rotating into an *np pn* system with greater repulsion and/or there is a slight temporary D-D separation, thus avoiding a larger Coulomb repulsion. Any such slight D-D separation might more favorably be done as part of a surface reaction rather than an interior reaction. The exchanged meson carrying along a charge could simply occur as the energetically preferred situation to avoid the larger Coulomb repulsion that would occur otherwise.

The shielding (of the protons by electrons) may increase as the electron wave functions surrounding the spatially rotating protons are flung inward at the "moment" the protons are transformed into neutrons (by the virtual charged meson transfers). Such a sling effect (as suggested by Fig. 1) while under atomic compression and in the presence of surface electrons would need to be studied theoretically to determine the amount of shielding that it can produce.

Assuming nearly equal magnitudes for each ω_p, it is further supposed that rotational states with the $\boldsymbol{\omega}_p$ vectors parallel, in the same direction, and perpendicular to the line between deuterium centers would be more stable and preferred from a Coulomb repulsion standpoint than when the $\boldsymbol{\omega}_p$ vectors are not parallel. This means that while a magnetic field can initially help keep the $\boldsymbol{\omega}_p$ vectors parallel, any later internal rotations that are further influenced by nuclear forces would tend to keep the $\boldsymbol{\omega}_p$ vectors parallel. The line segment between the deuterium centers would thus need to be initially perpendicular to the B field. Such a surface site might be in an opening of a hexagonally close-packed surface of the palladium lattice near the center of three mutually touching surface palladium atoms. For such a site, the palladium close-packed surface normals would most favorably need to be perpendicular to the local surface magnetic fields to encourage fusion.

Internal rotational kinetic energy might be caused by interactions with low-energy photons coming from a source such as black-body radiation. Some kinetic energy might be available from the temporarily reduced Coulomb potential energy. Some kinetic energy might be lost to the internal-deuterium-nuclear potential energy. Photon interactions may be needed to provide any net energy required for slightly larger internal-deuterium angular momentum. If the black-body temperature is larger, this might increase the probability of having enough proper photon interactions. Such proper photon interactions might occur, for example, by the Compton effect to increase the angular momentum of each proton and thus to elevate each deuterium ground-state energy.

SECOND STAGE OF FUSION

The second stage of fusion ends with the nuclear fusion of excited ground states of deuterium, which forms a highly excited ground state of ^{4}He. The second stage of of CRST fusion consists of tunneling when the compression, angular momentum, and shielding conditions are proper. The second stage of CRS fusion (without tunneling) is the more compressed extension of the first stage, which approaches the condition of nuclear attraction between deuterons and results in the nuclear fusion of excited ground states.

The condition of nuclear attraction between the innermost nucleons (a neutron from each deuteron) needs to be considered. The nuclear force depends on the relative spin orientation and the relative velocities of the nucleons. The force is generally considered to fall off to zero beyond 1.4×10^{-15} m. One could speculate a doubling of the range of the nuclear force under the special condition of near-zero radial velocities between nucleons. Doubling the range of the nuclear force (assuming it is somehow possible) could assist the CRS fusion process. Even if the range of the nuclear force cannot be doubled, this will not keep fusion from occurring. Suppose (though different from conventional one-way theory) that the usual nuclear interaction (at the normal range limits) is due to a back-and-forth exchange of a single virtual meson within the confines of the uncertainty principle. A charge could be present on one or more of the legs. If, instead of this supposed typical back-and-forth exchange by a single virtual meson, one allows simultaneous one-way transfers between the nucleons of two virtual mesons (each going in the opposite direction); then this allows the range of the nuclear force to double and still not violate the uncertainty principle ($\Delta E \Delta t \gtrsim \hbar$). In both the normal range and the doubled range cases, the same amount of mass (or energy = mc^2) is missing (from a nucleon giving up a virtual meson) for the same amount of time. A similar viewpoint (to mutual meson exchange) but with different virtual meson motions assumes a coordinated central "touching" of the virtual mesons. Each meson proceeds to the middle, touches the other meson, and returns. Such a central touching viewpoint (if possible) allows the extended ranges (up to twice the normal range limit) and more obviously follows the uncertainty principle. If mutually coordinated meson motions were to occur less frequently at any extended ranges, this could cause weaker nuclear forces. Based on the longer virtual meson transit time, one might guess a frequency of virtual-meson-nucleon contacts for any extended ranges that is inversely proportional to the total distance between the nucleons. As the nuclear force might be proportional to the frequency of virtual-meson-nucleon contacts, this would give a force inversely proportional to distance and a logarithmic internucleon potential at extended ranges (for the special case of near-zero radial velocities).

If enough energy is transferred into the internal deuterium rotations and if there is enough compression on the charge-shielded system, then the innermost nucleons (neutrons) will be close enough during the second stage of CRS fusion (without tunneling) for nucleon interaction (via neutral meson interchange) to form a high-angular-momentum, high-energy ground state of ^{4}He. Just prior to fusion, enough strong interaction could occur between the innermost nucleons to increase the magnitude of external $\boldsymbol{\omega}_\mathrm{D}$ until it becomes nearly identical to each of the internal $\boldsymbol{\omega}_p = \boldsymbol{\omega}_n$ of decreased magnitude within a deuteron. This means that upon ground-state fusion, the nucleons would be in nearly a stretched-out line *pnnp* rotating with a common angular frequency, $\omega_p = \omega_\mathrm{D}$. Figure 2 shows this *pnnp* line.

The second stage of CRST fusion would require proper external and internal angular momenta so that upon tunneling to the excited helium ground state in Fig. 2, the internal and external deuterium angular frequencies would be identical.

EXCITED GROUND-STATE FORMATION EXAMPLES

A large numerical scaling ratio between the atomic and nuclear sizes needs to be bridged if CRS or CRST fusion is

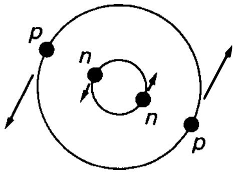

Fig. 2. Example configuration of *pnnp* upon fusion of excited deuterium ground states at formation of excited helium ground state.

to form excited ground states of ^{4}He. Twice the Bohr radius is $2 \times 5.29 \times 10^{-11}$ m, but the nuclear force has been considered to fall off to zero beyond 1.4×10^{-15} m. The ratio of these sizes is 75 600. Combining the following straw-man set of four proton-separation factors shows how such a size gap might be bridged:

1. A factor of 12 600 could correspond to spatial diminution due to momentum from the attraction toward the electron layer and due to compressive pressure on internally rotating deuterons, which are charge shielded by electron quantum states.

2. There is almost a factor of 3 increase in the geometry of *pnnp* over ordinary D-D geometry.

3. A factor of 2 increase in the nuclear force range might correspond to the mutually coordinated motion of virtual mesons for small radial velocities between nucleons.

4. Finally, a factor of ~1 (corresponding to no tunneling) might be achieved by the tunneling of rotating deuterium through any remaining Coulomb barrier.

As this is a straw-man calculation with guesses for individual factors, some factor(s) could be much smaller if other factor(s) were comparably larger so that their product would still be on the order of 75 600. For example, the spatial diminution factor could be decreased to unity if the tunneling of rotating deuterium were allowed to increase to 12 600.

The proton separation factors and the charge-shielding factors will reduce the Coulomb barrier. The last three proton-separation distance factors have a product of δ, which was initially guessed to be $3 \times 2 \times 1 = 6$. Because the Coulomb repulsion potential energy is inversely proportional to distance, a separation factor of $\delta = 6$ would mean that the Coulomb barrier is effectively reduced from its charge-shielded value by a factor of δ. Of course, its charge-shielded value is less than its "bare" value by the square of the charge-shielding factor s, occurring at a separation factor of δ, assuming the charge shielding is about the same for each proton. Together, these factors diminish the effective Coulomb barrier by s^2/δ, substantially lower than its bare value. The presence of the charge shielding of rotating-disappearing protons and mutually coordinated internal-deuterium rotations reduces or eliminates the most rapidly increasing (the steepest) portion of the Coulomb barrier. With $\delta = 6$, a greatly reduced Coulomb potential of 1 eV, for example, would require a temporary $s = 0.0024$ at a distance of $\delta \times 1.4 \times 10^{-15}$ m. As another example, with a different $\delta = 3 \times 2 \times 12\,600 = 75\,600$ (corresponding to a tunneling factor of 12 600), the greatly reduced Coulomb potential of 1 eV would only require a temporary $s = 0.27$ at the greater distance of $\delta \times 1.4 \times 10^{-15}$ m.

THIRD STAGE OF FUSION

During the third stage of CRS or CRST fusion, the highly excited ground state of ^{4}He decays to the normal ground state. The nucleons in a highly excited ground state of ^{4}He are at first nearly stretched-out versions of *pnnp* (as shown in Fig. 2) rotating as a single linear unit, but they gradually collapse into the normal low-angular-momentum nuclear-ground-state "ball" as energy and angular momentum are given off.

The decay might occur when the rapidly rotating protons interact with their surrounding black-body radiation via the Compton effect. (Low-energy photons can have their energies and momenta increased by interaction with rapidly rotating protons.) We assume that a charged particle would experience a decrease in its linear momentum as it travels through the cavity of a black body because of its interaction with the black-body photons. If the cavity were long enough, the particle would eventually come to a Brownian motion "rest" in the reference frame of the container. A similar situation could apply to the loss of angular momentum by a pair of charges rotating inside a black body. They would lose angular momentum by interaction with the photons until they reach a Brownian angular-momentum rest. This situation might be thought of as a high-"temperature" nuclear ground state that "cools" off as it interacts with its surrounding low-temperature black-body spectrum.

Another explanation for the decay might be that the two rotating protons drag part of the surrounding electron wave functions around with them, and these disturbed wave functions propagate energy outward from the CRS fusion site.

A highly excited high-angular-momentum CRS fusion rotating ground state could not change directly via a single spin-one photon to the normal nuclear ground state. Such a transition is forbidden because of the distributed and generally noninteger h angular-momentum gap between the two states that could not be connected by a single photon (which needs to carry away an angular momentum of $\hbar$).

A highly excited 23.8-MeV or higher bound-and-stable ground state of ^{4}He could not change to any lower energy unbound state (such as ^{3}H + ^{1}H or ^{3}He + n) because of the large binding inherent in the intermediately located neutrons. These neutrons can be understood as contributing to the binding when compared to completely unbound $p + n + n + p$, whose large disassociation energy from ^{4}He is 28.3 MeV. From another perspective, the high-angular-momentum bound CRS fusion state is bound relative to the completely disassociated $p + n + n + p$; thus, any virtual unbound states of ^{4}He would presumably not be at a lower energy than the highly excited CRS fusion state if their individual virtual-state particles internally contained the same total amount of angular momentum.

SUMMARY

A preliminary mechanism for the nuclear transformation of deuterium into ^{4}He during CRS fusion has been presented in this technical note. Rotations of deuterium ground states can allow (a) more penetration of the Coulomb barrier (by neutrons and neutral virtual mesons) and (b) a high-angular-momentum stretched-out *pnnp* excited ground state of fused ^{4}He. Such a high fractional h angular-momentum ground state of ^{4}He may release its energy through interaction with large numbers of low-energy photons. The formation and decay modes for highly excited ground states of ^{4}He need further study.

The CRS fusion of rotating ground states is likely a surface reaction because the surface is (a) the location of the largest magnetic fields, assuming cylindrical palladium cathodes, (b) the location of the greatest concentration of excess electrons for charge-shielding purposes, and (c) the location where the deuterium atoms may separate slightly at times of greater temporary Coulomb repulsion. The surface site for CRS fusion may be near the center of three mutually touching hexagonally close-packed surface palladium atoms.

Experimental procedures for enhancing the initiation of CRS fusion may include one or more of the following:

1. Use a higher temperature black-body radiation spectrum to enhance the likelihood of increasing the internal angular momentum for the deuterium (while being compressed against another deuterium).

2. Align as many local palladium close-packed surface normals as is practical so that they are perpendicular to the local surface magnetic fields.

3. Use cylindrical cathodes with small radii to have larger surface pressures, magnetic fields, and charge densities.

4. If there is an appreciable amount of tunneling, and assuming that the charge shielding can somehow be estimated, then use the surface magnetic field B that provides the external deuterium nonfused angular frequency that allows proper angular momentum matching prior to tunneling so that at fusion (after compression and tunneling), the internal and external deuterium angular frequencies will be identical.

Electron wave functions during CRS fusion need to be theoretically investigated to explore the possible sling effect of electrons being thrown inward (prior to fusion because protons become neutrons via charged meson transfer), thus increasing the charge shielding of the protons.

REFERENCES

1. B. F. BUSH, J. J. LAGOWSKI, M. H. MILES, and G. S. OSTROM, "Helium Production During the Electrolysis of D_2O in Cold Fusion Experiments," *J. Electroanal. Chem.*, **304**, 271 (1991).

2. B. Y. LIAW, P.-L. TAO, P. TURNER, and B. E. LIEBERT, "Elevated-Temperature Excess Heat Production in a Pd + D System," *J. Electroanal. Chem.*, **319**, 161 (1991).

3. M. H. MILES, B. F. BUSH, G. S. OSTROM, and J. J. LAGOWSKI, "Heat and Helium Production in Cold Fusion Experiments," *Proc. 2nd Annual Conf. Cold Fusion*, June 29–July 4, 1991, p. 363, SIF (1991).

4. C.-C. CHIEN, D. HODKO, Z. MINEVSKI, and J. O'M. BROCKRIS, "On an Electrode Producing Massive Quantities of Tritium and Helium," *J. Electroanal. Chem.*, **338**, 189 (1992).

5. E. YAMAGUCHI and T. NISHIOKA, "Direct Evidence for Nuclear Fusion Reactions in Deuterated Palladium," *Proc. 3rd Int. Conf. Cold Fusion*, Nagoya, Japan, October 21-25, 1992, p. 179, Universal Academy Press (1993).

6. A. B. KARABUT, Ya. R. KUCHEROV, and I. B. SAVVATIMOVA, "Nuclear Product Ratio for Glow Discharge in Deuterium," *Phys. Lett. A*, **170**, 265 (1992).

7. N. JARMIE, M. G. SILBERT, D. B. SMITH, and J. S. LOOS, "Proton-Triton Elastic Scattering Below 1 MeV," *Phys. Rev.*, **130**, 1987 (1963).

8. S. B. BORZAKOV, H. MALECKI, L. B. PIKEL'NER, M. STEMPINSKI, and E. I. SHARAPOV, "Features of the Departure from the $1/v$ Law of the Cross Section for the Reaction ^{3}He(n,p)T. Excited Level of the ^{4}He Nucleus," *Sov. J. Nucl. Phys.*, **35**, 307 (1982).