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SUMMARY OF PROGRESS IN HYDRON PHYSICS

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Abstract: Electromagnetic scattering resonances in the e^-p^+, e^-d^+, e^-t^+ systems produce short-lived, charge-neutral, particles called hydrons. These particles provide the screening of repulsive Coulomb forces so that nuclear reactions between a hydron nucleus and a reaction partner are possible. Hydron formation, reactions, and applications to anomalous nuclear observations in the laboratory and geophysics are summarized.

Introduction: Many researchers are now aware that, in recent years, there have been numerous experiments which appear to be associated with nuclear reactions, but in an energy regime so low as to make them, in effect, impossible. The so-called "cold fusion" observations are but one class of such seemingly impossible nuclear reactions. These experiments, and others such as "cluster impact fusion" and some quite anomalous geophysical observations of the earth, all point to new physical processes that allow nuclear reactions to be accessed by a mechanism other than by overcoming the Coulomb barrier by highly energetic particles.

We have suggested$^{(1,2)}$ that the new process is the creation of compact, unstable, hydrogenic particles that we have called *hydrons*. They are of three types: the π, the δ, and the τ, corresponding to the three hydrogen isotopes. We expect that hydrons and their reactions will play a role in the understanding of a number of astrophysical problems. These range from the geophysical modeling of the earth's interior to the "missing neutrino problem" in solar physics.

Hydron Formation: Hydrons are small, charge-neutral, unstable particles formed in resonant scattering of an electron and a hydrogen nucleus. An electron with just the right energy may be "captured" for a relatively long time in a deep, attractive potential well, but because it is a scattering process, the electron is released after its natural lifetime or sooner if other forces, for example due to collisions, perturb the system to disassemble. We have suggested$^{(2)}$ that the potential providing the scattering resonance between the two particles is the magnetic dipole-dipole (MDD) interaction, going as $V_m = -2\mu_1\mu_2/r^3$. At large distances ($\approx$ Å), the Coulomb potential, $V_c = -e^2/r$ dominates, whereas at very short distances ($\approx$fm), the MDD potential dominates. We have made a simple square-well model of the scattering calculation to determine the well-depth and radius for the scattering resonances to exist. The radius of the charge-neutral object is estimated to be of the order $a_{12} \approx [(32/\pi)\mu_1\mu_2/(\hbar c)]^{1/2}$. For the e^-e^+ resonance, this gives $a_{ee} \approx [(8/\pi)r_e\lambda_c]^{1/2} = 53$ fm. Spence$^{(3)}$ and Vary, from a quantum electrodynamics model, find $a_{ee} \approx 30$ fm. In the π-hydron case, we find $a_{ep} \approx 2$ fm, whereas Benesh$^{(4)}$, Spence and Vary find a value of "a few fermis", adequate agreement given the simplicity of our model. Figure 1 shows the results from the square-well calculations including the V_m and V_c potentials for the e^-e^+ and e^-p^+ cases. δ- and τ-hydrons have comparably small sizes. Being neutral, the hydron penetrates close to the nucleus of a reaction partner, with quantum tunneling penetrating the "residual" barrier to allow nuclear reactions to proceed.

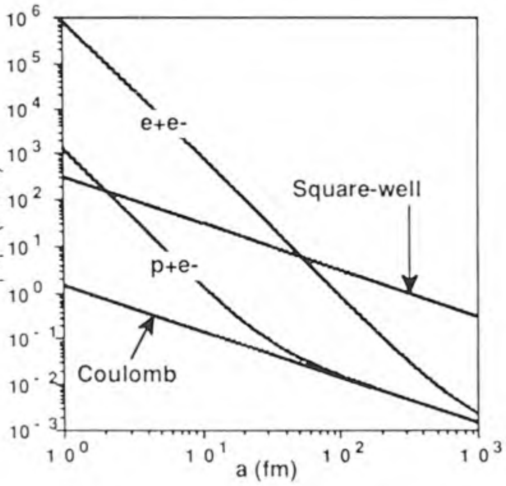


Figure. 1

Plot of the interaction potentials (evaluated at a/2) as a function of a, along with the square-well potential required for the first scattering resonance.

Nuclear Reaction Rates and Cluster Impact Fusion: Hydrons may participate in both fusion and resonant direct nuclear reactions$^{(1)}$ (RDNRs). In RDNRs, the hydron's electron may, due to it's close proximity, carry away some reaction energy. We have examined$^{(2)}$ cluster impact fusion data with hydron generation. The notation is specialized to the case of a δ-hydron reacting with a deuteron, but generalization of the formulae for the π- and τ-hydrons and reactions are straightforward. Averaging over a Maxwell-Boltzmann energy distribution (at temperature T), the reaction rate for the "screened" δ-d rate is given by,

$$<\sigma v>_s = 1.5\times10^{-15}T^{-1/2}S(0)\,P \quad \text{cm}^3/\text{s} \qquad (1)$$

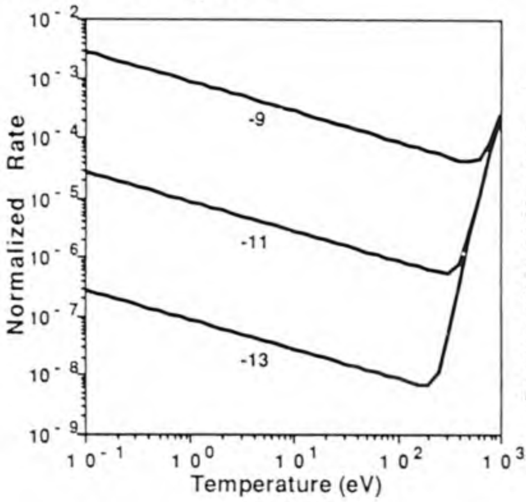
with S(0) in keV-barns, T in eV, and P is the "residual" Coulomb barrier factor. The usual "unscreened" d-d rate is given by,

$$<\sigma v>_u = 7.2\times10^{-19}\,\zeta^2 \exp(-\zeta)S(0) \quad \text{cm}^3/\text{s} \qquad (2)$$

with $\zeta = 197\,T^{-1/3}$. The total reaction rate (per cm^3) of a mixture of δ and d particles is then given by,

$$r = n_\delta n_d<\sigma v>_s + (n_d n_d/2)<\sigma v>_u \qquad (3)$$

where n_d is the deuteron number density. An example of the effect of the δ-hydrons upon the total d-d nuclear reaction rate is shown in Figure 2 where we have taken, P = 1 (complete screening), and S(0) = 55 keV-b. These curves show that substantial reaction rates are possible even with relatively small numbers of δ-hydrons.



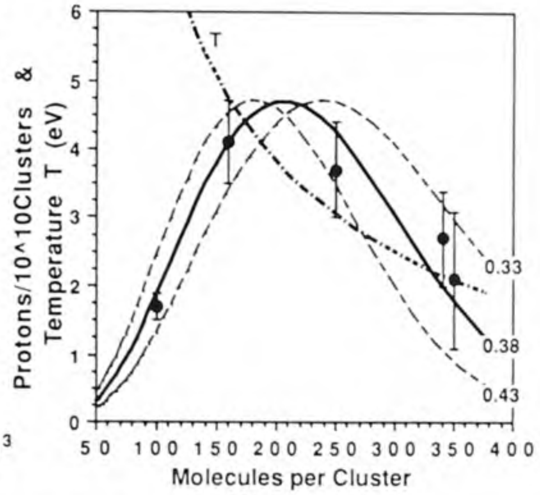


Figure 2 The normalized total reaction rate ($r10^{19}/n_d^2$) as a function of temperature. The parameter is $\text{Log}_{10}[n_\delta/n_d]$.

Figure 3 The proton yield data (points) produced in the experiments of BCFFK (with E_{cl} = 300 keV) vs. the number of water molecules in a cluster. The solid & dashed curves are the model results.

In our plasma model$^{(2)}$ for the "cluster impact fusion" experiments of Buehler, Chu, Friedlander, Friedman, and Kunnmann$^{(5)}$(BCFFK), the cluster kinetic energy is shared between the cluster neutrals, electrons, and ions and a larger amount of target material (≈ f times the cluster mass). The cluster kinetic energy deposited is then equated to the thermal energy given by,

$$E_{dep} = N_{cl}[(3/2)(3 + x_e)T + E_i + 9]\,f \qquad (4)$$

where N_{cl} is the number of heavy water molecules in the cluster (≈ 200), x_e is the number of electrons per heavy water molecule at the self-consistent electron temperature T, E_i is the ionization energy supplied per D_2O molecule, and 9 eV for each dissociated D_2O molecule.

Figure 3 shows a plot of N_p (the proton yield) versus N_{cl} for three different values for the maximum electron thermal conduction (usually about 0.32) and where the lifetime τ_n has been adjusted for a "best fit". Also shown is the self-consistent temperature for the experiments. The "best fit" δ-hydron lifetime extracted from these data is 1.5×10^{-8} seconds.

Other Experiments: The most controversial of these has been the "excess" heat, tritium, and neutrons in "cold fusion" experiments. We have suggested(1) that production of δ- and τ-hydrons, in a metal lattice, may remove the conflicts between theory and experiments in deuterated metals. The new class of nuclear reactions (RDNRs) is a resonant analogue of the direct nuclear reactions in which a neutron is transfered (with positive Q) between a projectile and target nuclei. These resonant reactions are also analogous to low-energy, neutron absorption resonances. Both (d,t) and (t,d) reactions may be operable in cold fusion experiments, allowing for both tritium production and/or consumption but with little or no neutrons or high-energy gamma rays being released. There is some evidence in experiments(1) that RDNRs are responsible for the "excess" heat, tritium, and possibly MeV particle production.

In the experiment of Klyuev(6), et al, a crystal of LiD was fractured by a shock wave produced by the impact of a 0.2 km/s projectile, producing both ionization and dislodged deuterons. These conditions are favorable to the production of a small number of δ-hydrons which can react with deuterons, producing a small number of d-d neutrons.

Arzhannikov and Kezerashvili(7) report small, but statistically significant numbers of d-d neutrons were produced when LiD pellets were dropped into a test-tube of "heavy" water. In this case, some δ-hydrons could have been produced from the slight ionization in the chemical reaction, with the hydrons then producing d-d neutrons.

Implications for Astrophysics and Geophysics: Hydrons may play a role in astrophysical situations. One case is the heat generated in Jupiter, about twice as much as it receives from the sun. We have developed(8) a model calculation based upon hydron generation which may account for this "excess heat". Another well-known astrophysical paradox is that of the "missing" solar neutrinos. π-hydrons in the sun may allow the "burning" of protons in π-p reactions at much lower energy, thereby providing the same nuclear energy at a lower average temperature. With the sun's central temperature slightly lower, many of the higher energy neutrinos expected from the "standard" solar model would be much reduced if not eliminated altogether(8).

The third example is that of the Earth's heat and helium flux. Jones(9) et al, have suggested that fusion reactions may be occuring inside the Earth given the observation that tritium is released from active volcanoes. Geologists believe that the radiogenic nuclides can account for only about five percent(10) of the heat flow out of the earth. Although mostly iron, the Earth's core contains lower density components including, perhaps, some hydrogen(11). We consider the possibility of hydron-mediated fusion reactions as the source of the observed heat and helium fluxes(12); the reactions are: $d(p,\gamma)He^3$, $d(d,p)t$, $d(d,n)He^3$, and $d(He^3,p)He^4$. The total nuclear power generated/cm^3 is obtained from the appropriate rate equations. We find the surface fluxes of He^3, He^4, and heat to be $1.6\times10^5/sec\text{-}m^2$, $2.4\times10^{10}/sec\text{-}m^2$, and 87 mW/m^2, respectively, in reasonable agreement with the measured values(13).

Discussion and Conclusions: The existence of relatively long-lived scattering resonance states in electron-hydrogen nuclei systems allows nuclear reactions in metals and plasmas with sufficiently high hydrogen densities and temperatures. Both fusion reactions and a new type of reaction, RDNRs, have been identified in various experiments. The RDNRs have a unique characteristic -- they do not release neutrons, potentially important for the development of these reactions in nuclear reactors.

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EDITORIAL NOTE TO THE PAPER "SUMMARY OF PROGRESS IN HYDRON PHYSICS" BY F.J. MAYER AND J.R. REITZ

Some grave flaws can be pointed out in the assumptions of this article. See the following contribution of Prof. Mc Neil, and Preparata's report.