THE POSSIBLE HOT NATURE OF COLD FUSION

NUCLEAR REACTIONS IN SOLIDS

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Based on the model of micro hot fusion, the neutron emission rate of cold fusion is determined without the need for fine-tuning parameters. Moreover, the experimental conditions that are essential to reproduce fusion are determined.

INTRODUCTION

More than 100 teams claim to have confirmed cold fusion. These experiments are reviewed in Refs. 1 through 4. However, the mechanism for cold fusion is still unknown. The most promising model for the reported neutron emissions is micro hot fusion (MHF), which is discussed in Refs. 1 and 5 through 19. Micro hot fusion is supported by many experimental data,[4,20] and explains why many experiments have failed to reproduce cold fusion.[20]

In this paper, MHF is discussed. New results include the theoretical determination of the neutralization factor for deuterid bubbles, the explanation of why deuterons are accelerated at all, why several teams observed bursts for seconds and minutes, and the determination of the experimental conditions that are required to reproduce MHF.

FORMATION OF DEUTERID BUBBLES

It is known that hydrogen isotopes are absorbed exothermally by palladium and titanium. Deuterid bubbles can be formed where impurities and dislocation nuclei exist.[13] These bubbles grow preferentially where external parameters (e.g., pressure, temperature, or current) are varied.[13] Indeed, Wampler et al.[21] observed bubbles of sizes 6, . . . ,0.2 μm and number densities of $2 \times 10^6, \ldots, 10^{10}$ cm^{-3} in copper. Bubbles of certainly similar sizes and number densities were detected in palladium by Segre et al.[13] Claims that cold fusion requires electrodes of high purity[22,23] contradict the early experiments,[24-28] where no special care for high purity was taken, as was pointed out by Williams et al.[29] Instead of this, Menlove et al. observed neutron emissions only where the electrodes were not cleaned too well.[17] Finally, the need for off-equilibrium conditions was clearly expressed by Jones.[17] Moreover, it is shown in Ref. 20 that during most of the experiments that failed to detect fusion products, the foregoing parameters were not varied.

FORMATION OF CRACKS

Hydrogen and palladium have different electronegativities. Therefore, the hydrogen is charged by +0.45e per nucleus,[1] and the palladium is negatively charged. Moreover, the absorption of hydrogen gives rise to a deformation and expansion of the metal lattice. This expansion enhances the formation of larger metal ions (anions). As the chemical binding energy is typically of the order of electron volts, the attractive force of an electron by the metal lattice is about $F_m = 1$ eV/1 Å $= 10^8$ eV/cm.

The charge of the surface $4\pi r_b^2$ of the deuterid bubble (which for simplicity is assumed here to be a bowl) is $Q = 4\pi r_b^2 ef/l_d^2$, where $l_d \sim 3$ Å is the lattice constant and f is a neutralization factor that we will determine. If one regards the action on an electron, one can regard small territories. Thus, small parts of the space between the bubble and the metal lattice can be considered as a flat capacitor of the capacity $C = \epsilon_0 r_b^2/d_c$, where ϵ_0 is the permittivity of vacuum. The attractive force on an electron by the bubble becomes $F_e = eE = e^2 f/\epsilon_0 l_d^2$. If $F_e > F_m$, then the bubble will be neutralized until $F_e = F_m$. In this case, the neutralization factor is of the order $f = 0.1$, independent of the bubble size r_b and the crack size d_c.

The deformation of the lattice gives rise to cracks. In palladium, crack formation should occur preferentially near its surface,[30] whereas titanium is porous enough to allow crack formation in its inner parts, as is discussed by Preparata.[12] The formation of cracks should also give rise to acoustical emissions and deuterium desorption. In fact, acoustical emissions were recorded by Tsarev,[1] Menlove et al.,[31] and Golubnichyi et al.[32] Deuterium emission was observed by Tsarev,[1] Yamaguchi and Nishioka,[33] and Arata and Zhang.[34] That cold fusion behaves like a surface process in palladium is supported by the experiments of Jones et al.[24,25] and Wada and Nishizawa.[35] Jones et al. have used palladium foils of 0.05 g and a 3-cm^2 surface and mossy palladium of 5 g and therefore over a 4-cm^2 surface. If their neutron emissions had arisen by a volume process, they should have recorded a ratio of ~100 between the neutron rates of high and low neutron emission runs. However, the reported ratio is at best 4 or 5, as is expected for a surface process.

For titanium, the crack growth rate reaches its maximum at temperatures of $-100, \ldots, 0$°C (Refs. 17 and 36). In fact, Jones,[17] Menlove et al.,[31,37] Izumida et al.,[38] and Zhu et al.[39] recorded neutron bursts from titanium preferentially at these temperatures.

We saw earlier that the bubbles and therefore the crack sides, too, are charged. Electric fields of $E = F_e/e = 10^8$ V/cm should arise and give rise to radio emission, electrification, and low electron emission. Radio emission has been detected by Golubnichyi et al.[32]; electrification has been found by Kornfeld[40] and Golovin et al.[41]; kilo-electron-volt electron emission has been recorded by Deryagin et al.,[12] Wolbrandt et al.,[42] Dickinson et al.,[43] and Lipson et al.[44]; and kilo-electron-volt ions have been observed by Dickinson et al.[45]

ORIGIN OF NUCLEAR FUSION

As F_e and F_m are independent of the distance of the bubble from the metal lattice and therefore of the crack size, the electrons will remain bound by the metal lattice (only high temperature and tunneling effects should allow electron emission). This means that the deuterons of the bubble are accelerated by the electric field and are able to cross the whole crack, so that they obtain the energy of the field. From observations, we know the crack sides to be of the order $d_c = 1, \ldots, 10$ μm (Refs. 1 and 13). Hence, the deuterons can obtain energies of $W_d = eEd_c = 10, \ldots, 100$ keV, which is enough to generate deuteron-deuteron (*d-d*) fusion reactions.

As the deuterons will quickly lose their kilo-electron-volt energies by collisions with the atoms of the metal, cold fusion is expected to occur in very short bursts.[7] This means also that most of the kilo-electron-volt deuterons will not be able to fuse, so that a heat-to-neutron ratio of the order 10^{10} is expected.[4,46] Segre et al.[13] calculated the expected neutron ratio by MHF to be $10^4, \ldots, 10^7$ n/cm^3 for $W_d = 10, \ldots, 100$ keV. A similar result was obtained by Tsarev.[1] In fact, many cold fusion experiments indicate that cold fusion is burst-like (reviewed in Refs. 1 and 4). The duration of these bursts was 10^{-4} s (Menlove et al.[31,37,47]), $1, \ldots, 2$ s (Yamaguchi and Nishioka[33]), 1 min (Golubnichyi et al.[32]), and 4 min (Gozzi et al.[48,49]). Heat-to-neutron ratios of the order 10^{10} were detected by Gozzi et al.,[48,49] Yamaguchi and Nishioka,[33,50] Mathews et al.,[51] and Scott et al.[52,53] It should be noted that some reported heat emissions (e.g., the one of Refs. 33 and 50) might have arisen by the out-gassing of hydrogen from the lattice. Neutron rates of the expected order were recorded by Klyuev et al.,[5] Jones et al.,[24,25] Menlove et al.,[31] Gozzi et al.,[48,49] Yamaguchi and Nishioka,[33,50] Bertin et al.,[54,55] De Ninno et al.,[56,57] Lipson et al.,[58] Deryagin et al.,[59] Arata and Zhang,[60,61] and Celani et al.[62,63] Charged particles of the same rates were detected by Taniguchi et al.[64] and by Jones et al.[65]

As the neutron production rate is limited ($10^4, \ldots, 10^7$ n/cm^3), the active period of the electrodes should also be limited. As the bubbles are expected to grow within $0.1, \ldots, 10^5$ s (Ref. 13) and the fracture time is typically 10^4 s (Ref. 1), the active period is expected to be of the order of hours. In fact, the emissions of Celani et al.,[62,63] Klyuev et al.,[5] Lipson et al.,[58] and Deryagin et al.[59] terminated after ~10 min, those of Bertin et al.[54,55] after 3 h, those of Jones et al.[24,25] and Emmoth et al.[66] after 8 h, and the random neutron emissions of sample ^{1}Ti of Menlove et al.[31] after 17 h.

UNEXPLAINED PHENOMENA

Because the foregoing scenario cannot account for the recorded bursts of seconds and minutes, we must modify the model.

The cracks give rise to kilo-electron-volt deuterons that will rapidly lose their energies by collisions, so that small areas of high temperature will arise.[46,67] As a metal lattice can store heat,[16,46] further fusion reactions might occur.[46,67] Because of the high inner pressure, these small areas will explode,[16,46,67] where these explosions might give rise to further cracks.[16,46,67] Where such cracks collide with deuterid bubbles, further electric fields will arise and give rise to kilo-electron-volt deuterons. This means that a chain reaction might occur that could last for seconds and eventually minutes.[46,67]

It must be noted that the fusion reactions are certainly *d-d* reactions because neutron spectra by Jones et al.,[24,25] Bertin et al.,[54,55] and Wolf et al.[68] yielded 2.5-MeV neutrons. In addition, Taniguchi et al.[64] observed charged particles of energies up to 3 MeV (which supports the formation of 3-MeV particles because charged particles lose their energy rapidly within metals[69]). Moreover, Beuhler et al.[70] reported to have detected charged particles of 1 and 3 MeV, but later, they retracted their claims. Finally, Jones et al.[65] observed spectra as expected for 3-MeV protons. It is somewhat surprising that Cecil et al.[71,72] observed charged particles with energies of 4.5 MeV, and Chambers et al.[73,74] observed charged particles with energies of 5.08 MeV.

The experimentalists assume that these might be tritons of unknown nuclear origin.

Micro hot fusion cannot account for the tritium-to-neutron ratios reported by Gozzi et al.,[48,49] Wolf et al.,[68] Krishnan et al.,[75] Radhakrishnan et al.,[76] Rout et al.,[77] Sanchez et al.,[78] and Sona et al.[79,80] However, these high tritium levels detected by chemical methods could not have been confirmed by experiments that searched for charged particles. However, the rates of the charged particles detected by Zelenskii et al.,[1] Taniguchi et al.,[64] and Jones et al.,[65] are comparable with the neutron rates of the "Jones level."

SUGGESTED EXPERIMENTAL CONDITIONS

Finally, experimental conditions that are essential to reproduce MHF must be determined:

1. The electrodes must not be cleaned too well.[17] I suggest a purity of 99.8% because this was the purity of the D_2O used by Jones et al.[25]

2. While the metal is deuterated, MHF occurs. Therefore, the metal may not be covered by an oxide layer. Consider that Jones et al.[24,25] found oxide layers in those samples where the emissions stopped after 8 h. The experiment of Alber et al.[81] might have failed because of the thick crusts that they detected on their electrodes. However, this idea is not generally accepted. Claytor et al.[82] argue that oxide layers on their samples are critical to obtaining a result.

3. The emissions can terminate minutes or hours after the start of deuterating. This means that the metal must not be predeuterated.[1] According to Tsarev, this might explain why so many experiments failed to reproduce cold fusion: The examination began just after the end of the active period.[1]

4. The deuterid bubbles grow preferentially where external parameters are varied.[13] Note that Jones[17] stated that the variation of these parameters was essential. The nonvariation by many teams might explain why they were not successful.[20]

5. The maximum crack growth rate was reached at temperatures of $-100, \ldots, 0°C$ (Refs. 17 and 36). Therefore, one should choose these temperatures by examining gas-loaded cells.

6. Of course, the counters must be sensitive enough to detect the low emission rates. The Jones level is of the order 10^{-24} fusion/s$\cdot d\text{-}d$.

7. Large bursts seldom occur. Menlove et al.[31,37] observed bursts of $10, \ldots, 280$ n within 10^{-4} s preferentially at temperatures of $-100, \ldots, 0°C$. At these temperatures, they recorded 34 bursts during 400 h by using a mean 80 g of titanium.[31] This means that one burst occurred per 1000 g/h, only at the foregoing temperatures. This explains why experiments[83,84] to reproduce Menlove's claim have not been successful.

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