

FUSION IN CONDENSED MATTER—A LIKELY SCENARIO

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COLD FUSION

TECHNICAL NOTE

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A large body of experimental observations has evolved with particular reference to deuterated palladium, a mechanism of fusion unique to condensed matter. The mechanism brings to focus the relevance of the electronic structure of the host lattice, indicating the features that are desired. Direct interaction of electronegative elements such as oxygen (as happens in electrolysis experiments) creates, through modification of the electronic structure, situations under which heavy electrons are manifested. In cases where an oxide interface is present, an analogous situation is created at the onset of an insulator-metal transition caused by the induced migration of deuterons through the layer. Screened by the heavy fermions, deuterons in such situations undergo transition to a more stable quasi-molecular state, $(D^+D^+)2e^-$, with substantially reduced nuclear separation. Through quantum mechanical tunneling, fusion takes place in such a cluster with a yield of $10^{-1.5} s^{-1}$, a value consistent with observed excess heat production and near-surface occurrence of the phenomenon.

INTRODUCTION

The quest for nuclear fusion in condensed matter,^{1,2} although stimulated by the possibilities underlying certain anomalies in nature (e.g., heat generation in the planet Jupiter and the Earth's mantle, the distribution of ^3He in various minerals, etc.), became intensive and worldwide only following the publication of the experimental results of Fleischmann, Pons, and Hawkins.³ Notwithstanding persistent skepticism in some quarters, supportive experimental evidence has steadily mounted ever since. An account of recent developments in the field is given by Storms.⁴ Developments in the experimental front led to the simultaneous emergence of a fairly large number of theoretical (conventional, not so conventional, and exotic) models, some of which were reviewed by Preparata.⁵ However, the phenomenon continues to remain unpredictable in its occurrence, defying all attempts to formulate a sure success recipe. Inability to reproduce or trigger the phenomenon at will clearly reflects the inadequacy of the current understanding of the mechanisms involved.

The aim of this technical note is to bridge this gap between perception and reality.

We approach the problem from an as yet unexplored angle and try to provide a cohesive picture that is consistent with the large body of experimental observations. In the formulation, besides the characteristics of the host lattice, we attribute pivotal roles to the following:

1. the presence of electronegative elements, which constitute a feature common to all types of successful experiments in the field
2. the surface and the interface of the host transition metal with an oxide coating
3. a desorption process that is a manifestation of the coherent approach and interaction of hydrogen or deuterium atoms from their equilibrium state in the lattice.

The choice, in fact, is based on the conclusions by Ray et al.,⁶ who, by way of a comprehensive review of the experimental observations by a large number of investigators in light of their own experience, have shown that the occurrence of the phenomenon is intimately related to these factors. A few selected examples covering different categories of experiments that amply illustrate the relevance of these factors are nevertheless given:

1. Large excess heat liberation and anomalies in the tritium distributions between the gas and the liquid phases were observed⁷ during electrolysis following entry of oxygen into the cathode compartment of a divided electrolytic cell.
2. Explosive cold fusion was brought about⁸ during electrolysis by deliberate exposure of portions of loaded cathodes to an oxygenated atmosphere, and transmutation products were found near the surface of the cathodes thereafter.
3. Abnormal heating ($>500^\circ\text{C}$) of electrochemically loaded palladium on exposure to air was observed at Kernforschungszentrum Karlsruhe.⁹
4. Heat and neutron bursts were observed¹⁰ during de-loading (induced by vacuum and potential gradient) of thin hydrogen- or deuterium-loaded palladium plates coated with MnO , AlO , or SiO on one side and gold on the other.
5. Tritium production and neutron emission were observed¹¹ in solid-state cell ($\text{Pd/PdO/SiO/silicon}$) experiments.

6. Neutron emission was observed in gas-phase experiments with titanium (known for its affinity to oxygen) only during deloading and warming to room temperature.¹²

The recent explosion at a Stanford University laboratory¹³ serves as yet another pointer in this direction.

These factors are mutually consistent in the sense that in the process of chemisorption, electronegative elements, by perturbing the state of equilibrium of a loaded cathode, induce desorption,⁶ which involves atomic recombination a few angstroms beneath the jellium surface.¹⁴ This recombination in the region influenced by the electronegative elements results in coalescence of the interacting atoms at times. (We use the term coalescence here as the process leading to fusion in such systems, which is radically different from the common concept of thermonuclear fusion.) In cases where an oxide interface is present by design, the destabilization force is, however, external in nature, e.g., injection of alternating current, heating, evacuation, etc.

Since screening of the Coulomb barrier to a distance of $<0.1 \text{ \AA}$ is required to match even the lowest experimental value,¹⁵ the question arises as to how these factors help achieve this condition. That the normal mass of conduction electrons is too small for effective screening of the Coulomb barrier is evident from the calculated¹⁶ fusion rate for D_2 in PdD. Koonin and Nauenberg¹⁷ nevertheless showed that the fusion rate in a free D_2 molecule can be as high as $10^{-9.1} \text{ s}^{-1}$, if the bonding electrons are endowed with a mass ten times larger than the normal value. Attempts^{2,18} have been made to explain the substantive phenomenon by following this line, but the presence of such heavy electrons has not been substantiated. While the presence and participation in the coalescence process of heavy electron-like particles, which retain their masses in the localized state, within the PdD lattice is most unlikely, it is recognized that the host metal matrix has a definite potential to provide, as a manifestation of collective behavior, electrons of high effective mass^a that can bring a pair of deuterons to close proximity through screening of the Coulomb barrier. This is, however, possible only in transition metals and perhaps in rare earths, where electrons of large effective mass are known to be manifested under certain circumstances. That the phenomenon has been observed only in titanium, nickel, and palladium (transition metals of series 3-*d* and 4-*d*) and their selective alloys is, therefore, not a mere coincidence; rather, it is indicative of the involvement of heavy fermions in cold fusion. The generalized observation by Myers¹⁹ that *d* electrons in metal oxides of the first transition series (3-*d*) form either localized nonbonding states or a narrow energy band with low mobility and high effective mass serves as a pointer for the active involvement and participation of heavy electrons and, in turn,

^aTo describe the transport properties of electrons in the periodic potential of a crystalline lattice in the same way as one describes the motion of free electrons under the influence of an applied electric or magnetic field, it is the usual practice in condensed matter physics to assign them an effective mass $m^* = \hbar^2 / (d^2 E / dk^2)$, where $E(k)$ represents the electron's energy in the band and k is the wave vector. All the effects of the lattice are thus concentrated into changing the inertial properties of the electron's wave packet. In the tight binding approach, m^* can be expressed in terms of overlap energy integral I as $m^*/m_e = \hbar^2 / 2m_e I a^2$, where m_e is the rest mass of the electron and a is a lattice parameter. If the overlap of atomic wave functions is very small (i.e., for a narrow bandwidth), the value of m^* will be much higher than m_e .

for the role of electronegative elements in the phenomenon. To substantiate this, we first briefly review, for the sake of clarity, the characteristics of the host lattice (with palladium as reference) and its interaction with hydrogen or deuterium and oxygen, with specific reference to their band structures, and then examine the influence of oxygen on PdD under different experimental conditions.

Palladium

Pure palladium, as shown in Fig. 1, has a fairly narrow ($\sim 5 \text{ eV}$), incompletely filled (0.36 holes), high-density *d*-band overlapped by and hybridized with a broad low-density conduction band of spatially diffused *s-p* states. According to the linear combination of atomic orbital interpolation of the augmented plane wave energy band calculations,²⁰ the density of states (DOS) at the Fermi level is $N(E_F) = 2.27 \text{ electron/eV}\cdot\text{cell}$. It was also shown²¹ that the DOS at $\sim 0.1 \text{ eV}$ below E_F is $\sim 4 \text{ electron/eV}\cdot\text{cell}$. While bandwidth consideration yields $m_{eff} = 7.57m_e$ for unhybridized *d* electrons²² in palladium, a lower value is consistent with an electronic specific heat coefficient $\gamma_{exp} = 9.48 \text{ mJ/K}^2\cdot\text{mol}$. The reduction is largely due to the overlapped low-density *s-p* states for which the effective electron mass is less than m_e . It is, therefore, apparent that palladium has an intrinsic potential to provide for heavy fermions, which can be realized fully only by minimizing the overlap of the low-density *s-p* states with the *d*-band.

Interaction of Hydrogen with Palladium

The electronic band structure of the host palladium lattice undergoes a drastic change on absorption of hydrogen, as shown schematically in Fig. 1. The essential features^{20,23} of the interaction are

1. lowering of the low-lying filled palladium states $\sim 1 \text{ eV}$ below the bottom of the *d*-band as a manifestation of bonding between hydrogen and palladium and interactions between hydrogens themselves
2. raising of the Fermi level through progressive filling of the holes in the *d*-band, modified *s-p* states, and *s-p* states characteristic of the host palladium lattice by the electrons of the added hydrogens.

A more than fivefold reduction in $N(E_F)$ accounts for the experimentally observed²⁴ drop in γ to $1.4 \text{ mJ/K}^2\cdot\text{mol}$ at $H/Pd = 0.81$. Insofar as coalescence is concerned, the implications of these features are apparent and go against the presumption of $m_{eff} = 3m_e$ made by some authors.²⁵

Interaction of Oxygen with Palladium

Interaction of oxygen with pure palladium brings about changes contrary to that of hydrogen interaction with palladium. Through extensive investigation, the following has been shown²⁶:

1. The interaction is superficial at room temperature wherein oxygen remains chemisorbed in atomic form with no modification of the core levels of palladium. The essential feature of the adsorbed phase is the lowering of states near the Fermi level.
2. At moderately high temperature ($\sim 300^\circ\text{C}$), much more oxygen is incorporated in the metal. The incorporated state

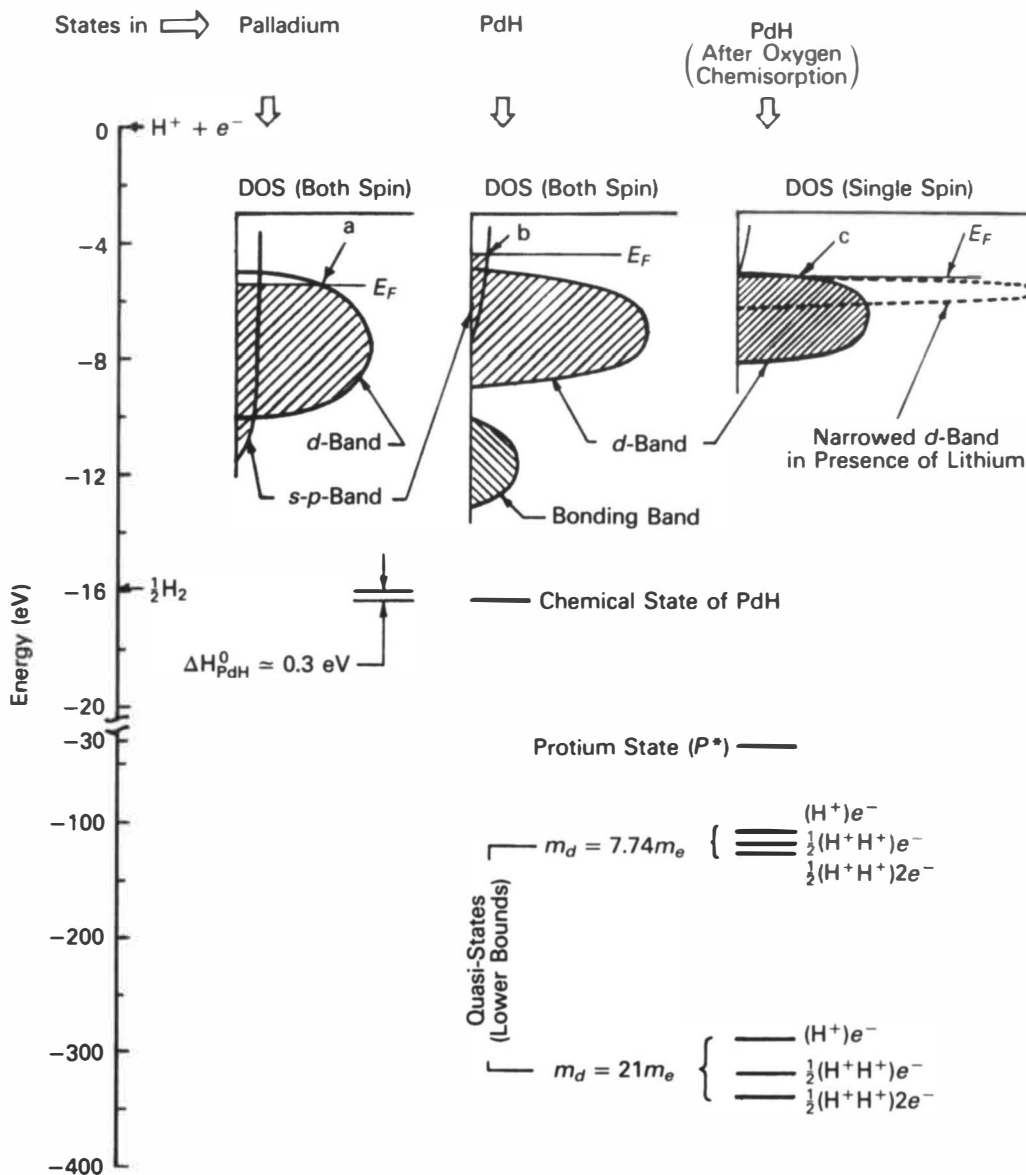


Fig. 1. Schematic of the effect of direct interaction of oxygen on PdD: the DOS (E_F) values at points a, b, and c are 2.27, 0.45, and >4 electron/eV·cell, respectively.

is characterized by subsurface oxide layer formation whence palladium begins to lose its metallic properties. Its metallic character is completely lost as palladium becomes fully oxidized at 550°C.

Self-consistent local density calculations by Gelatt et al.²⁷ show that transfer of electrons to the added electronegative element, i.e., oxygen, takes place preferentially from the low-density hybridized *s-p* states of palladium, resulting in lowering of the Fermi level to a region of higher DOS. Such transfer of non-*d* electrons from the energy region of *d* states of palladium results in increased purity of the *d*-band. Besides, expansion of the host metal lattice due to the insertion of the *s-p* element also results in a reduction in the width of the *d*-band. The overall effect of the interaction of oxygen with palladium is therefore significant enhancement of density of *d* states of purely *d* character. However, in PdO, com-

plete localization of electrons results in separation of the conduction band from the valence level. PdO is known to be a *p*-type semiconductor with a narrow forbidden gap (0.1 to 2.7 eV) (Refs. 28 and 29). The presence of impurities has a profound impact on the excitation energy. It has been reported²⁹ that the value could be as low as 0.04 eV, which is noteworthy in the current context.

SCENARIOS OF COALESCENCE

The interaction of hydrogen and oxygen with palladium as described earlier serves as the basis for the development of the mechanisms involving heavy fermions to bring about coalescence of deuterons within the palladium lattice. Scenarios are developed for three cases:

1. direct interaction of oxygen with PdD
2. indirect interaction of oxygen with PdD across a thin film of PdO
3. oxide-coated PdD on physical perturbation.

Case 1

Oxygen is known to react spontaneously with hydrided transition metals and rare earths. It is apparent from the observations mentioned earlier that such an interaction takes place under experimental conditions with deuterated^{6-9,13} and hydrided³⁰ palladium. A number of factors govern such interactions and are discussed later. Interaction of oxygen with PdD or PdH follows the same line as that with pure palladium. In the process of chemisorption, electrons from spatially diffused *s-p* states of PdD_x are transferred to fill the hole in the affinity level of O-2*p* states. As shown in Fig. 1, the result is a reduction in bandwidth and lowering of the Fermi level to a region of higher DOS in the PdD_x conduction band. Positive polarization and the resultant change in the electronic structure of the host lattice, in turn, alter the stability of the deuterons in the matrix. Owing to a nearly tenfold increase in $N(E_F)$ compared with that of 1.9×10^{34} state/erg·cm³ (typical³¹ of PdD), the screening length (Ref. 32), $\lambda^{-1} = [4\pi q^2 N(E_F)]^{-1/2}$, reduces to 0.134 Å. Also in this situation, the electronic ground state of the deuteron is no longer comparable with palladium *d* states. The natural consequence, therefore, is complete delocalization of deuterons in the matrix. The stabilization energy E_p of the resulting state (called the protium state, P^*), i.e., D^+ in jellium with its electron at E_F , is given by the following relation³²:

$$E_p = E_0 + \phi + E_{pol} + E_{rep} \quad (1)$$

where

E_0 = zero-point energy of D^+ in the lattice (~0.05 eV)

ϕ = work function (~4 eV)

E_{pol} = stabilization energy of D^+ in the polar cloud of conduction band screening electrons

E_{rep} = repulsion energy between screened D^+ and palladium ion core.

The term E_{pol} in Eq. (1) is expressed as

$$E_{pol} = -\frac{q}{2} \int_0^\infty V(r) \cdot \Delta n(r) \cdot 4\pi r^2 dr \quad (2)$$

where

q = proton charge

$V(r) = \frac{q}{r} \exp(-r\lambda)$ = screened potential

$\Delta n(r) = \frac{\lambda^2}{4\pi r} \exp(-r\lambda)$ = change in electron density at distance r from D^+ .

Substituting these in Eq. (2), we get

$$E_{pol} = -\frac{q^2}{4} [4\pi q^2 N(E_F)]^{1/2} \quad (3)$$

The expression for E_{rep} at large λ (applicable in this case) is

$$E_{rep} = \frac{Z' n q^2}{2r} \exp[-\lambda(r - r_0)] \quad (4)$$

where

$Z' = Z - ar_0 + a/\lambda$ = effective charge of the ion core

r_0 = core atom radius

r = equilibrium separation between the core and added atom (1.945 Å in PdD)

a = parameter characterizing the pseudopotential of ion core having normal valence Z .

With $N(E_F) = 1.9 \times 10^{35}$ state/erg·cm³, the stabilization energy E_p of the protium state P^* is estimated to be -30.9 eV. With a higher DOS at the surface layers,³³ where the interaction of oxygen is limited at this stage, if considered, the stabilization energy E_p will be still greater. As can be seen from Fig. 1, the P^* state lies well below the chemical state of PdH. The consequence of oxygen interaction with PdD_x is therefore transition of deuterons to this low-lying state and other (quasi-) states derived thereof by emitting electromagnetic radiation in the process. Such a precursor has in fact been conceived and claimed to have been observed by some investigators.³⁴ There are three possible outcomes of such transformations.

First, the deuterons, being completely delocalized, acquire high mobility and can undergo frequent incoherent collisions with their maximum available kinetic energy ($E_p - \phi$) of 25 eV. This deuteron state resembles the exotic plasma envisaged in the "swimming electron layer surface model,"³⁵ which, on the basis of a successful electrical double layer theory³⁶ for the surface energy of metals, postulates formation at the surface of PdD_x of a similar double layer consisting of D^+ and the swimming electrons. As the Coulomb barrier is reduced by the Debye energy e^2/λ_d (λ_d = Debye length of the degenerated electron plasma in the metal),³⁵ deuterons with kinetic energy of ~25 eV can approach each other to an average distance of 0.2 Å under such circumstances. At this approach (0.2 Å), the quantum mechanical tunneling probability T works out to be $1.2 \times 10^{-49} \text{ s}^{-1}$ using the semi-empirically derived power law, $1/T = 8.139 \times 10^4 \times d^{34.8}$ (d = separation between two deuterons in picometres).³⁵ Considering a D^+ density as high as 10^{23} cm^{-3} , the corresponding fusion yield in the 1-Å-thick surface layer is estimated to be $2.5 \times 10^{-21} \text{ s}^{-1} \cdot \text{cm}^{-2}$. It is obvious that even with an optimistic statistical consideration, the fusion yield from such interactions would still be too small (by tens of orders of magnitude) to be of any practical significance in the context of the observed excess heat liberation of tens of watts per square centimetre of PdD_x surface.

The second likely consequence is the formation of quasi-atoms $(D^+)e^-$, where deuterons acquire coherent stability through weak overlap of the Bloch states with their 1-*s* orbitals shrunken by the collective characteristics, i.e., dynamical mass m_d of the electrons in the *d*-band. The size of such a cluster can, at best, approach but never equal that of a dwarfed deuterium atom for reasons given later. According to the renormalized atom theory,³⁷ the value of m_d is given by the following equation:

$$m_d = \frac{12.5 \hbar^2}{W_d r_0^2} \quad (5)$$

where

$$W_d = \frac{6.83 \hbar^2 r_d^3}{m_e r_0^5} = \text{bandwidth} \quad (6)$$

r_0 = radius of the atomic sphere

r_d = *d*-state radius.

For pure palladium, r_0 and r_d are 1.52 and 0.94 Å, respectively. Use of these values yields the most conservative estimate of the dynamical mass: $m_d = 7.74m_e$. This implies that the size of the quasi-atom would be very nearly m_e/m_d times the normal Bohr radius; i.e., $0.53 \times m_e/m_d = 0.067$ Å. The value of m_d , being sensitive to both r_0 and r_d , would in fact be higher ($\sim 12m_e$) if expansion of the host lattice due to incorporation of oxygen and reduction in the d -state radius owing to positive polarization of the core atom are considered. Lithium, which is invariably incorporated into the cathode surface during electrochemical loading (LiOD as electrolyte), produces a 22% expansion²⁷ of the host lattice and has the most profound effect on the bandwidth W_d . Accordingly, the value of m_d works out to be $21m_e$. The limiting size of the quasi-atom under such consideration would be ~ 0.025 Å. As the quasi-atoms are an order of magnitude smaller than the de Broglie wavelength of the core electrons, their Coulomb scattering would be ineffective. This implies that the quasi-neutral species can easily penetrate the innermost electron shell of the core atom. Nucleonic particles with their energies in mega-electron-volts and higher mass can only cause Coulomb scattering in such quasi-atoms. Through the formation of quasi-atoms, therefore, deuterons get close accessibility to the nucleus of the core atom, which can result in disintegration of the deuteron and transmutation of the nucleus.

The third and the most likely outcome is formation of quasi-molecules $(D^+D^+)2e^-$, where the pair is partly bound and correlated by electrons of higher dynamical mass, described in terms of nonlocalized but weakly overlapping electronic states. Total occupation of the octahedral lattice positions at high loading, coupled with superdiffusion of D^+ in the protium state, leads to more frequent double occupancy, resulting in formation of quasi-molecules that have still greater stabilization energy. Under the prevailing situation, deuterons would remain in the quasi-molecular state rather than transforming to the molecular state, as formation of dwarfed molecules implies ultimate localization of the electrons and loss of their collective characteristics, the very cause of the stability of the parent state. Besides, spontaneous transformation of deuterons from the quasi-molecular state to the normal molecular state is not thermodynamically possible, as is apparent from Fig. 1. The internuclear separation in the quasi-molecule would again be governed by the dynamical mass m_d of the d -band electrons and would be very near to that of a dwarfed molecule, i.e., $0.74(m_e/m_d)$ Å. Owing to the small size, i.e., close proximity of deuterons in the quasi-molecule, there will be a significant increase in the overlap of their wave functions and therefore in the coalescence yield. The quantum mechanical tunneling probability for the coherent interaction can be, as enunciated by Koonin and Nauenberg,¹⁷ computed from the radial s -wave function satisfying the Schrödinger equation with the diatomic molecular potential modified by the scale factor m_e/m_d for the reduced internuclear separation. Fusion yields estimated¹⁷ for the diatomic molecules of hydrogen isotopes by endowing the bonding electrons with a mass m^* up to ten times the normal value m_e , show a linear relationship between $\log(\text{fusion yield})$ and $(m_e/m^*)^{0.5}$. Using this relationship for $D + D \rightarrow ({}^3\text{He} + n) + ({}^3\text{H} + p)$ in this case, the upper limits of the coalescence rates in a quasi-molecule with $m_d = 8m_e$ and $21m_e$, respectively, work out to be $10^{-11.7}$ and $10^{-1.5} \text{ s}^{-1}$.

Case 2

On continued exposure of PdD to oxygen, the scenario can change altogether. Because of the expanded state of the

host lattice, more oxygen can be incorporated, ultimately leading to the formation of a thin oxide layer on the surface. In such an eventuality, further adsorption of oxygen takes place over this PdO layer. In the process of adsorption, electrons tunnel through (as in the case of chemisorption of oxygen in metal) the semiconductor barrier like harpoons to become localized with oxygen, resulting in the formation of an electrical double layer across the PdO film. The positive polarization thus induced on the metal side is more diffused in this case. This implies only a nominal shift in E_F and a marginal rise in DOS (about three times that of PdD) in the affected region just beneath the oxide layer. The rise in DOS coupled with the induced field results in breaking of the Pd-D bond. Deuterons at this stage would remain preferentially as quasi-molecular ions $(D^+D^+)e^-$ constituting the double layer. Their size, however, would not be much smaller than the normal ones as, under this situation, the dynamical mass of electrons m_d is not significantly higher than m_e . This is because s - p states are not separated from the energy region of the d -band in the absence of direct chemical interaction with oxygen in this case. Coalescence, as such, is unlikely.

Under the influence of the established potential gradient, however, the molecular ions would migrate toward the negatively charged overlayer. This, in turn, results in diffusive flow of deuterons from deeper layers to fill the resultant vacancy in this stabilized region, thereby establishing a chain. During the passage through the relatively electron-deficient oxide layer, some of the $(D^+D^+)e^-$ ions undergo transition to the D_2^+ state and then either pick up an electron to escape as a D_2 molecule or combine with the negatively charged oxygen to form D_2O . But the rest of the quasi-molecular ions would acquire coherent stability by overlapping their electronic states with the d states in PdO that are normally localized. When their concentration n in this layer rises above a critical value,³⁸ $n^{1/2} \cdot a_H > 0.25 [a_H = (\hbar^2 \cdot K)/(m_e \cdot e^2)]$, the semiconductor layer undergoes a transition to the metallic state. In such a situation, adjacent d states can exchange their valence electrons using the overlapping quasi-molecular ion state. This is very similar to Mott transition for which there is ample evidence in transition metal oxides such as NiO. At the beginning of the transition, overlapping of d states is weak and bandwidth B is small in comparison with the fairly large correlation potential ($V_0 \sim 10$ eV). The onset of delocalized resonance is characterized by the bare minimum of vacant as well as doubly occupied states. To explain transport properties such as electrical conductivity in this region, one thus invokes³⁹ an effective mass $m^* = m_e/2C$, where C is the fraction of vacant as well as doubly occupied states. The value of m^* can be very high during the approach to the state of minimum metallic conductivity as defined by the Anderson localization parameter, $B/V_0 < 0.5$. As noted by Brinkman and Rice,⁴⁰ a value of m^* of the order of 30 to $50m_e$ is possible while attaining the minimum metallicity. Aided by these electrons, the quasi-molecules acquire higher stability, and the internuclear separation in them is proportionately (by a factor close to the value of m_e/m^*) reduced. The net outcome in this case is therefore similar to the one described earlier.

It is apparent from the scenarios of coalescence presented under cases 1 and 2 that the phenomenon is critically dependent on the interaction of oxygen with PdD. The sporadicity of the phenomenon can, in fact, be traced to the physico-chemical factors that govern chemisorption of oxygen at the cathode surface. Gaseous oxygen molecules must strike the surface of PdD and stick there to be chemisorbed eventually

to bring about substantive interaction. The scales and deposits that usually form on the cathode surface during electrolysis inhibit the process of chemisorption. The presence of poisons such as CN, sulfur, and carbon retard the oxidation⁴¹ of PdD by blocking the active sites and by reducing the local DOS at the Fermi level.⁴² They also reduce the surface mobility of hydrogen and deuterium and thereby prevent their recombination. Absence of occurrence of the phenomenon following the use of poisons⁴³ as well as in cathodes having a contaminated surface⁶ is noteworthy in respect of their effects. Surface activation, on the other hand, aids oxygen chemisorption. Similarly, absorption of hydrogen by palladium, which increases its chemical potential, prompts such interaction with oxygen. The presence of lithium on the surface layers also accelerates the chemisorption process. The extent and rate of chemisorption depend on surface coverage and exposure level (i.e., the number of molecules striking the surface). It is in the latter context that vigorous radial dispersion of the evolved gases observed in the electrolytic cells of Fleischmann et al.⁴⁴ and the like assumes significance.

Case 3

The mechanism of coalescence in cases where the surface of palladium is coated with oxides^{10,11} (SiO, AlO, and MnO) prior to loading is basically similar to the scenario described in case 2. The strong affinity of palladium for the formation of intermetallics establishes, on heat treatment, an interface consisting of either a binary or a ternary oxide. In these cases, positive polarization is weak beyond the interface because of the absence of a negatively charged oxygen overlayer. When such systems, following deuterium or hydrogen loading, are perturbed by evacuation or heating (which create a chemical potential gradient) and by passage of electric current, some of the deuterons migrate into the largely unoccupied interfacial oxide layer. While negative current injection prompts ambipolar diffusion, superimposed alternating current aids the out-of-phase transport of the deuterons. During their approach into the low-electron-density region, antibonding resonance is weakened, and bonding resonance increases, leading to formation of D_2/D_2^+ . Some of these, in turn, produce delocalized resonance of the otherwise localized d states in the interfacial layer. The coalescence process starts with the onset of this transition, as discussed earlier. Evidently, the outcome depends on the nature of the interface and therefore on the methods of preparation, as observed.¹¹

CONCLUSION

Founded on a large body of experimental observations, the scenarios of coalescence presented here offer a unique explanation of the phenomenon in the sense that they all involve the active participation of heavy fermions in the process. So far as the Ni/K₂CO₃ (aqueous) system⁴⁵ is concerned, the mechanism involved is no different. A narrower d -band, higher DOS (1.6 times that of PdD) close to E_F , greater sensitivity for incorporated cations, and higher affinity of nickel and NiH to oxygen, in fact, make the system more conducive. This groundwork brings to focus some of the governing factors and can form the very basis for tailoring systems. Nevertheless, greater understanding of the channels of coalescence that are possibly governed by the value of m_d is a prerequisite for realization of the full potential of the phenomenon of fusion in condensed matter.

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