IL NUOVO CIMENTO VOL. 12 D, N. 3 Marzo 1990
NOTE BREVI

Plasma and Surface Tension Model for Explaining the Surface Effect of Tritium Generation at Cold Fusion (*).

H. HORA and L. CICCHITELLI
Department of Theoretical Physics, University of New South Wales Kensington, Sydney, 2033, Australia

G. H. MILEY and M. RAGHEB
Fusion Studies Laboratory, University of Illinois, Urbana, Ill., 61801

A. SCHARMANN and W. SCHEID
Fachbereich Physik, University of Giessen - Giessen, B.R.D.

(ricevuto il 4 Gennaio 1990)

Summary. — For explaining the surface mechanism of deuterium reactions in palladium and titanium (clod fusion or neutron swapping) leading to strong tritium production and isotope shifts in palladium, the mechanism of an exotic deuterium plasma with possible short nuclear distance by thermal motion was introduced. Using a new model of the surface tension of metals, resulting in a «swimming electron layer», the increase of the concentration of deuterons and the decrease of their distance cause a higher cold fusion in the surface layer by orders of magnitudes compared with the bulk material.

PACS 50.00 – Fluid, plasmas and electric discharges.
PACS 25.88 – Fusion reactions.

(*) The work of one of the authors (H. Hora) was supported by the Wilhelm-Heinrich and Else Heraeus Foundation, Hanau, while being on leave at the University of Giessen, Germany.

Several experimental results on the cold-fusion experiments indicate that the mechanism is strongly related to the surface of the metal (palladium or titanium) after being filled with high concentrations of deuterium. After the plasma Debye screening aspect has been introduced into the discussion [1] we continue here the discussion of the model of an exotic plasma [2] under the special aspects of the recent result of a surface tension model for the degenerate electron gas in metals. We succeeded to apply this from the preceding plasma theory for metals [3, 4] and for the theory of surface tension of nuclei [5].

Could fusion was proposed by McNally [6] for mechanisms of nuclei with very low thermal energy such that their de Broglie wavelengths' overlap and «free» neutrons' tunnel under generation of enormous energy gain similar to the Oppenheimer-Phillips process [7]. This especially corresponds to the observed shift of the isotope ratio of palladium in favour of the isotope 106 (from 27% to 40%) at deuterium incorporation [8] similar to the earlier observation of shifts in the ratio of the isotopes of helium and lithium in metals [9].

While the anomalous heat production [10] is under re-examination yet, the generation of fusion neutrons form DD reactions above the background level has been confirmed [11]. However, instead of having the 1 : 1 ratio of the two possible reaction branches of the DD fusion

$$D + D = \begin{cases} T + H + 3.27\,\text{MeV}\,, \\ {}^{3}\text{He} + n + 4.03\,\text{MeV}\,, \end{cases}$$

it was measured in convincing details that, at cold fusion, the tritium branch is 10^9 times more probable [12]. This indeed results then in a reasonable energy production and is indicating that the very low temperature is favouring the neutron swapping process as predicted by McNally [6] for being characteristic for cold fusion. The neutron swapping would then also be understandable for the observed isotope shift reactions in palladium [8].

One of the not yet understood facts is that with most of the electrodes or even with the best highest current electrolytic commercial systems [12] it happens that after first loading of palladium with deuterium and a one-hour period of neutron burst emission simultaneously with tritium production, a many-hour phase without any reaction follows and then again an about one hour period with reactions after which mostly nothing happened. A poisoning of the electrode surface by sulphur and/or lithium coming from the electrolyte or from the surrounding glass vessel is considered as reason.

The exotic plasma model is not only of interest with respect to the screening but it explains uniquely why the deuterium ions within the heavy-metal lattice can move to closer distance thermally [2] and by space charge assisting conditions [1]. The usual situation in condensed matter at low temperatures is that the chemically bound electrons are keeping the nuclei at rigid distances (apart from vibrations etc.). For example, the distance of the deuterons in a heavy hydrogen molecule would permit a nuclear fusion probability of less than $10^{-78}\,s^{-1}$ only. Any swapping of neutrons despite some affinities exceeding 7 MeV energy gains between isotopes, or interaction with other nuclei is therefore strictly forbidden. This is very fortunate, otherwise condensed matter would be subject to nuclear reactions and apart from the high radioactivity it never could really become cold or even condensed.

It is therefore an exceptional state when palladium or tantalum (or similar metals) incorporate large amounts of hydrogen isotopes which should exist there in ionized form. It may well be that the electrons of the incorporated atoms are localized by stronger binding in unfilled lower shells for which the metals just above the rare earths or of the eighth group of transition are of an exceptional constitution. The ions, however, may consist in a nondegenerate plasma state of very high density and very low temperature moving nearly undisturbed between the bound electrons and the nuclei of the host metal. This is then the reason why deuterons thermally can move to much closer distances than in the usual bound states, both to produce the DD reactions as well as to move nuclei of the host crystal causing then the neutron swapping reactions, *e.g.*, depleting ^{105}Pd and increasing ^{106}Pd [8].

Furthermore, this exotic plasma state should provide a special condition with much closer possible distances between the deuterons and the nuclei at the crystal surface, if one considers the appearance of a double layer at the metal surface as discovered recently [3, 4]. The starting point was the numerical confirmation in inhomogeneous plasma at laser interaction that, against the usual assumption of space charge neutrality, there exist interior electric fields in the plasma with dynamic changes which lead, for example, to large amplitude longitudinal Langmuir oscillation driven by the laser light [13].

One special case were the long-known ambipolar fields turning out to be of much more general nature with further pressure terms, oscillations with the plasma frequency dampened by collisions and with second harmonics terms indicating a new resonance in superdense plasma driven at perpendicular laser incidence and a new type of second harmonics emission spread uniformly over the wide plasma corona despite strong variation of plasma density [13, 14]. All this clarified the existence of double layers (DLs) in plasma surfaces especially in the laser-produced plasma. Of the electrons and ions of equal temperature T, the light electrons are ahead of the expanding plasma letting behind positive ions. The space charge separation produces an electric field E_s and a DL of a Debye length thickness and a potential of 3 kT, reflecting other electrons from the plasma interior and letting only exceptionally fast electrons pass according to a thermionic work function of 3 kT [13].

As a surprise to the knowledge of surface tension in condensed dielectrics being caused there by unsaturated dipoles of molecules—not existing in fully ionized plasmas—plasmas do have a surface tension too [13]. This is simply given by the electrostatic field energy in the Debye length thick DL per surface area [3, 13]:

$$\sigma_E = \int_{\mathrm{DL}} (E_s^2/8\pi)\, \mathrm{d}^3\tau/\text{area}\,, \tag{1}$$

$$\sigma_E = 0.36\frac{1}{8\pi}\left(\frac{kT}{e}\right)^2 g^{3/2}\lambda_{\mathrm{D}}\,, \tag{2}$$

where the Debye length

$$\lambda_{\mathrm{D}} = (kT/4\pi n_{\mathrm{e}} e^2)^{1/2} \tag{3}$$

is used and where n_{e} is the density and e the charge of electrons, and the factor g usually is 3 but may vary between 1 and 10 [13]. Factor 0.36 is determined by the type of potential decay [3].

The action of the surface tension is evident from the usually smooth surface of the plasma plum developing from a laser-produced plasma with a stabilization of surface waves similar to water drops [3, 13]. If the range of stabilization of surface waves is exceeded, periodic jet structures will appear as observed. For high-density pellets, the surface tension is smoothing initially nonuniform plasma corona fronts into ideal spheres [13].

Applying this plasma model of surface tension to metals arrives at the following situation. Instead of the expanding plasma we have the rigid ion lattice. The electrons in between try to leave the plasma driven by their density mostly determined by the Fermi quantum energy. The electrons move outside the lattice until a DL is built up with such electric fields that the electrons cannot move further. The distance the electrons move out is then given by a Debye length where the temperature is to be substituted by the Fermi energy E_{F} to arrive at the Fermi-modified Debye length

$$\lambda_{\mathrm{dF}}^2 = \frac{2}{3}[E_{\mathrm{F}}/4\pi n_0 e^2]\,. \tag{4}$$

The resulting electric field in the DL causes an energy density per surface defining the surface tension

$$\sigma_E = \frac{1}{8\pi}0.27[E_{\mathrm{F}}/e]^2/\lambda_{\mathrm{dF}}\,, \tag{5}$$

where a rather good agreement with experimental values has been demonstrated [3].

This result teaches a basically new insight in the surface properties of metals. Before, it was well known that the electron density at the surface is decaying exponentially as given by the wave functions from the Schrödinger equation. One was considering this as the reason for the potential step where electrons are wave mechanically reflected or transmitted, *e.g.*, in thermionic of photoelectric emission [15]. The surface or exit potential of metals or solids was simply taken as known from Einstein's work function of photoemission or Richardson's results [15] without asking that this can be due only to an electric double layer and how this will look.

We now have the result: the Fermi energy drives the electrons out of the lattice by the distance of the degenerated Debye length and from then on the exponential decay of the electron wave functions will happen. The surface of a metal is then covered by a layer of electrons of thickness

$$\lambda_{dF} = \frac{h(3/\pi)^{1/3} n_e^{1/6}}{4e(m_e m_{e,eff} s^{2/3})^{1/2}}, \tag{6}$$

where m_e is the electron mass and $m_{e,eff}$ is the (relative) effective electron mass in the lattice, and s is the number of electrons (one or two) occupying the quantum state according to the spin. If the electron density is given in multiples of the density of solid hydrogen $n_s = (5.8 \cdot 10^{22} \text{cm}^{-3})$, $n_e n_s n_{eff}$, the thickness of the electron layer is

$$\lambda_{dF} = 1.17 \cdot 10^{-8}/(m_{e,eff} s^{1/3} n_{eff}^{1/6})\ \text{cm}. \tag{7}$$

Since there is only a very weak dependence on the electron density, one can roughly say that the electron layer above the ion lattice is about one angstrom thick. One has to note that any adsorbed molecule or any oxide to the metal will be separated by this electron layer from the lattice.

This layer of negative charge, however, is only one half of the DL. If positive charges cannot move within the lattice, the compensating positive charge layer is spread over the whole lattice. It may be assumed, however, that the electron layer attracts positive charges, and this may be very easy with the moving deuterons on the exotic plasma in palladium or titanium. These deuterons would then concentrate with a density up to two times higher than the lattice density in the immediate outermost crystal layer. Their closer distance is then the reason for a much higher probability of interaction including the neutron swapping and cold-fusion reactions.

The surface electron layer produces then a much stronger screening of the deuterons for the reaction. This rigid layer bound to the whole degenerate electron gas may act then as the partner of a heavy negative charge or Teller's meshuggeon [8].

The surface mechanism of cold fusion is evident from the commercial electrolyser [11, 12] where the produced tritium is appearing within the deuterium which had to move through the electrode and is the oxygen-free product taken from behind the cathode while, at the side of the cathode with the electrolyte, the released gas contains a considerable amount of tritium too. The sensitivity due to poisoning by sulphur or lithium etc. is another indication of the surface mechanism. The isotope shift in palladium electrodes was found in the surface only and no shift in the bulk material [8]. Knowing this one should concentrate to use all the extensive experience of surface physics to suppress the poisoning and to keep the surfaces clean for a continuous operation of cold fusion.

The model of the surface layer as a result of surface tension and of the work function is a newly derived property [3] of metals and is basically different from double layers due to the polarization effects of electrodes (Vollmer-Heyrovski) as mentioned, for example, in connection with cold fusion by Bockris [16].

REFERENCES

[1] M. VASELLI, M. A. HARITH, V. PASCELLI, G. SALVETTI and D. P. SINGH: *Nuovo Cimento D*, **11**, 927 (1989); M. VASELLI, V. PASCELLI, M. A. HARITH, G. SALVETTI and D. P. SINGH: *1989 International Conference on Plasma Physics, New Delhi*, Vol. 2, edited by A. SEN and P. K. KAW, vol. 2, p. 449.

[2] H. HORA, G. H. MILEY, L. CICCHITELLI, A. SCHARMANN, W. SCHEID and D. SCHWABE: *Emerging Nuclear Energy Systems, 1989*, edited by U. VON MOELLENDORFF (World Scientific, Singapore, 1989).

[3] H. HORA, GU MIN, S. ELIEZER, P. LALOUSIS, R. S. PEASE and H. SZICHMAN: *IEEE Trans. Plasma Sc.*, PS**17**, 284 (1989).

[4] H. HORA, S. ELIEZER, R. S. PEASE, A. SCHARMANN and W. SCHEID: *1989 International Conference on Plasma Physics, New Delhi*, Vol. 2, edited by A. SEN and P. K. KAW, p. 373.

[5] H. HORA: *Naturwissenschaften*, **76**, 214 (1989).

[6] J. RAND MCNALLY: *Bull. Am. Phys. Soc.*, 28, 658 (1983); *Fusion Technology*, 7, 331 (1985).

[7] J. R. OPPENHEIMER and M. PHILLIPS: *Phys. Rev.*, 48, 500 (1935); M. RAGHEB and G. H. MILEY: *Fusion Technology*, **16**, 172 (1989).

[8] D. WORLEDGE (Editor): Report on NSI/EPRI Workshop, Washington, 20 Oct. 1989, Contribution by D. R. ROLISON and W. O'GRADY, NRL; M. SRINIVASAN, Presentation at *1989 International Conference on Plasma Physics, New Delhi, Nov. 22-28*.

[9] B. A. MAMYRIN, L. V. KHABARIN and V. S. YUDENICH: *Sov. Phys. Dokl.*, **23**, 581 (1978); V. I. VYSOTSKII, R. N. KUZMIN and N. V. MAKSYUTA: *Sov. Phys. JETP*, **66**, 1150 (1950).

[10] M. FLEISCHMANN and S. PONS: *J. Electroanal. Chem.*, **261**, 301 (1989).

[11] S. E. JONES *et al.*: *Nature*, **338**, 737 (1989); P. K. IYENGAR: *Emerging Nuclear Energy Systems, 1989*, edited by U. VON MOELLENDORFF (World Scientific, Singapore, 1989).

[12] P. K. IYENGAR and M. SRINIVASAN (Editors): *BARC Studies in Cold Fusion*, Bhahba Atomic Research Centre, Bombay, No. 1500 (Dec. 1989).

[13] H. HORA, P. LALOUSIS and S. ELIEZER: *Phys. Rev. Lett.*, **53**, 1650 (1984); S. ELIEZER and H. HORA: *Phys. Rep.*, **172**, 339 (1989); P. LALOUSIS and H. HORA: *Laser and Particle Beams*, **1**, 283 (1983); A. LUDMIRSKY *et al.*: *Laser and Particle Beams*, **2**, 265 (1984); M. P. GOLDSWORTHY *et al.*: *Laser and Particle Beams*, **8**, No. 1/2 (1990).
[14] H. HORA and A. K. GHATAK: *Phys. Rev.*, **31**, 3473 (1985).
[15] P. GÖRLICH and H. HORA: *Optik*, **15**, 116 (1958); H. HORA and H. MÜLLER: *Z. Phys.*, **164**, 359 (1961).
[16] H. O'A. BOCKRIS *et al.*: private communication.