IL NUOVO CIMENTO Vol. 101 A, N. 5 Maggio 1989
NOTE BREVI

First Steps Toward an Understanding of «Cold» Nuclear Fusion.

T. Bressani

Dipartimento di Fisica Sperimentale dell'Università - Torino
Istituto Nazionale di Fisica Nucleare - Sezione di Torino

E. Del Giudice

Istituto Nazionale di Fisica Nucleare - Sezione di Milano

G. Preparata

Dipartimento di Fisica dell'Università - Milano
Istituto Nazionale di Fisica Nucleare - Sezione di Milano

(ricevuto il 26 Aprile 1989)

Summary. — We point out that the first steps in understanding the recent results reported on cold nuclear fusion can be made by considering the important role that the coherent interactions with the quantized e.m. field play in condensed matter. Indeed we find natural mechanisms to decrease the Coulomb repulsion and to suppress the usual nuclear-fusion channels with respect to the transfer of the excess energy directly to the electrons of the metal.

PACS. 25.70 – Heavy particle induced reactions and scattering.
PACS. 71.55 – Impurity and defect levels.
PACS. 67.00 – Quantum fluids and solids; liquid and solid helium.

Since the first announcement by Fleischmann and Pons [1] (hereafter referred to as FHP) of an electrochemically induced nuclear fusion of deuterium, several other reports have been given of analogous phenomena in different experimental conditions [2,3].

---

(1) M. Fleischmann, M. Hawkins and S. Pons: *J. Electroanal. Chem.*, **261**, 301 (1989).
(2) S. E. Jones *et al.*: Brigham Young University preprint (1989).
(3) F. Scaramuzzi *et al.*: press report.

It is now rather clear that cold nuclear fusion is a real physical process. However the evidence, given so far, can be classified in two distinct categories. FHP report about an electrolytical procedure for stocking deuterium ions inside palladium electrodes which lasts for prolonged times and includes a release of large quantities of heat, accompanied by a very modest release of neutrons (1 out of 10 estimated fusions). Other groups [2,3], on the other hand, seemingly have reported the observation of typical signals of nuclear fusion, such as neutrons in the relevant energy ranges, in experimental conditions which differ from those of FHP, both in duration and the flux of deuterium stocking and in the metal used as a catalyzer (titanium instead of palladium).

The great surprise and consequent scepticism that have enshrouded the results are easily understood in terms of the prevailing views about both condensed matter and nuclear physics. Indeed, the very fact that a metal can induce nuclear fusion on the absorbed deuterons means that energies and effects which were believed to be in the eV range turn out in fact to be in the MeV range (or, put differently, the distances involved are fm instead of Å). Furthermore the large amount of heat produced, without any large flux of neutrons or γ-rays of a few MeV, seems to indicate that the fusion process in the FHP set-up must take place in ways but have never been observed *in vacuo*.

It is the purpose of this paper to provide a few hints that might lead to a theoretical understanding of the fascinating phenomena that have been revealed in the last few weeks.

The problems that the generally accepted views on condensed matter and nuclear physics encounter in making sense of cold nuclear fusion are twofold:

i) why and how can the lattice of metals such as Pd and Ti «catalyze» a nuclear-fusion process;

ii) why and how the fusion process, under certain conditions, takes place differently than *in vacuo*, *i.e.* without the production of neutrons.

It is our view that one cannot overcome this dilemma without a major shift in our perception of the fundamental ways in which condensed matter organizes itself, while, of course, keeping the fundamental laws of electromagnetism and quantum mechanics, that have been corroborated in a countless number of observations.

This is just the basis of a research program that has been initiated a couple of years ago [4-6] which aims to describe, by the methods of quantum field theory

(4) G. PREPARATA: *Phys. Rev. A*, 38, 233 (1988).

(5) E. DEL GIUDICE, G. PREPARATA and G. VITIELLO: *Phys. Rev. Lett.*, **61**, 1085 (1988); E. DEL GIUDICE and G. PREPARATA: *Is high-T superconductivity a superradiance phenomenon?*, Milano preprint (1988).

(6) G. PREPARATA: *Lectures at Folgaria INFN School* (February 1989), to appear.

(QFT), condensed matter in *collective* interactions through the quantized electromagnetic field (*).

The basic observation is that the charged particles existing in a lattice (electrons, absorbed hydrogen, etc.) can be looked at as comprising a plasma performing oscillations around their classical equilibrium positions with the typical plasma frequency (we shall set $\hbar = c = 1$)

$$\omega_p = \frac{e}{m^{1/2}}\left(\frac{N}{V}\right)^{1/2}, \tag{1}$$

where e is their charge, m their mass and N/V their density. Quantum mechanically one can show that the classical equilibrium configuration is unstable when the coupling to the quantized electromagnetic field is brought into the picture. As a result the charged particles of the same kind will perform *coherent* oscillations with frequency and amplitude that depend on the appropriate parameters [6].

Let us look, in particular, to the Z electrons that oscillate coherently around the metal nuclei (**).

Calling d_0 the minimum distance between two nuclei of the lattice, their plasma frequency is

$$\omega_{ep} = \frac{e}{m_e^{1/2}}\left(\frac{1}{d_0}\right)^{3/2} Z^{1/2} = 4.28 \cdot 10^5\, Z^{1/2}\,\mathrm{cm}^{-1} \tag{2}$$

and the dispersion of the plasma oscillation is than given by

$$\delta = \frac{1}{(2m_e\,\omega_{ep})^{1/2}} = \frac{6.7 \cdot 10^{-9}}{Z^{1/4}}\ \mathrm{cm}. \tag{3}$$

It should now be clear how these oscillations can exhibit a catalytic property. The «cloud» of Z electrons in a ball of radius δ investing two deuterons distort their Coulomb potential $V_C(r) = \alpha/r$ as

$$V'(r) = \frac{\alpha}{r}\left[1 - \frac{Z}{2}\frac{r^3}{\delta^3}\right] \tag{4}$$

(*) The first application of this program to free electron laser, water, and to high T_c superconductors [4,5] appears now extremely promising.

(**) Incidentally the electric dipoles generated by such coherent motion should have a major role in the cohesion of the crystal, as they lead to net attractions with a $1/r^3$ law instead of the typical $1/r^6$ behaviour of London-type forces.

and the classical turning point is then given by

$$R_0 = \delta\left(\frac{2}{Z}\right)^{1/3}. \tag{5}$$

It is now a trivial excercise to compute the barrier penetration factor D between R and r_N ($r_N \simeq 5\,\mathrm{fm}$) when the nuclear attraction overcomes the Coulomb repulsion. One obtains (μ is the reduced mass)

$$D \sim \exp\left[-2(2\mu\alpha R_0)^{1/2}\int_{r_N/R_0}^{1}\frac{\mathrm{d}x}{x^{1/2}}(1-x^3)^{1/2}\right] = \exp[-4(2\mu\alpha R_0)^{1/2}(0.87)]. \tag{6}$$

Putting now the appropriate Z, 46 and 22 for Pd and Ti respectively for dd, one computes $D_{\mathrm{Pd}} \sim 10^{-40}$ and $D_{\mathrm{Ti}} \sim 10^{-49}$, which must be compared with $D_{\mathrm{d}_2} \sim 10^{-94}$ that one computes for the d_2 molecule ($Z = 2$). However, due to the crudeness of our calculation we should not be surprised if our estimate of the argument in the exponent is in error of a few percent. Once the barrier gets penetrated (with probability D) the system will undergo a fusion process. Will fusion proceed as it does *in vacuo*? The answer must be no for the following reasons. Once the deuterons reach equilibrium in the lattice they will also be subject to collective plasma oscillations with frequency

$$\omega_{\mathrm{dp}} = \frac{e}{m_{\mathrm{d}}^{1/2}}\left(\frac{N}{V}\right)^{1/2} f^{1/2} = 0.7\cdot 10^4 f^{1/2}\,\mathrm{cm}^{-1}, \tag{7}$$

where f is the number of deuterons per metal atom. The domain in which the deuterons will oscillate coherently has the linear size $\lambda_{\mathrm{dp}} = 2\pi/\omega_{\mathrm{dp}} = 9\cdot 10^{-4} f^{-1/2}\,\mathrm{cm}$. Inside the coherence domain the deuterons will act collectively and are described by a single quantum-mechanical wave function (the classical limit of the «wave field» [4-6]).

The transition between the excited state $^4\mathrm{He}^*$ (the compound nucleus of the fusing deuterons) and the ground state $^4\mathrm{He}$ is the source of an oscillating electric field

$$\boldsymbol{E} = \frac{2e}{\omega}\boldsymbol{v}\exp[-i\omega t]\left(\frac{N}{V}\right)\frac{f}{2}D^{1/2}, \tag{8}$$

where $\omega \simeq 24\,\mathrm{MeV}$ is the energy difference between $^4\mathrm{He}^*$ and $^4\mathrm{He}$, and $\boldsymbol{v}$ is a typical value of the velocity of the deuterons inside $^4\mathrm{He}$, $|\boldsymbol{v}| = 0.1$. The important aspect of $\boldsymbol{E}$ (eq. (8)) is its independence from the space coordinate, within, of course, the coherence domain, within which all the plasma electrons are acted upon coherently. A simple calculation shows that the perturbative transition field (eq. (8)) is given by

$$A(t) \sim \frac{\sin(\omega/2)\,t}{\omega^2/2}\,\frac{|v|e^2}{(2m_e\,\omega_{ep})^{1/2}}\left(\frac{N}{V}\right) f D^{1/2} N_e\,, \tag{9}$$

where $N_e = Z(N/V)(\lambda_p)^3 = Zf^{-3/2}\cdot 3.7\cdot 10^{12}$ is the «superradiant» factor due to the coherent electromagnetic interaction inside the coherence domain. We can now estimate the e.m. transition rate:

$$\Gamma_{\text{e.m.}} = \left|A\left(\frac{\pi}{\omega}\right)\right|^2 \frac{\omega}{\pi} = 2.35 f\cdot 10^{29} D\,\text{s}^{-1}\,, \tag{10}$$

which must be compared with the nuclear rate Γ_N ($\Gamma_0 = 1\,\text{MeV}$)

$$\Gamma_N = f^2 D\Gamma_0 \simeq f^2 D\cdot 10^{21}\,\text{s}^{-1}\,. \tag{11}$$

We can now determine the specific power released in dd fusion from

$$W = \Gamma_{\text{e.m.}}\,\omega\left(\frac{N}{V}\right) \simeq 3\cdot 10^{40} f D\,\text{W/cm}^3\,. \tag{12}$$

We end this paper with a brief discussion of some of the experimental findings in the light of the present theoretical conclusions:

i) A comparison between eqs. (10) and (11) shows that the suppression factor of the nuclear channels is ($f \simeq 1$) about nine orders of magnitudes. This is in agreement with the findings of FHP.

ii) The mentioned suppression factor cannot apply when the stocking of deuterons is not in equilibrium. In this case the fusion must go through the nuclear channels. This might account for the observations in ref. [2,3].

iii) According to eq. (6) the fusion rate in Ti should be suppressed, with respect to Pd, by about 10 thus accounting for the very small heat rate reported in ref. [2,3].

iv) According to eq. (6) the reaction pd → He + 5.4 MeV should be enhanced with respect to dd → He + 23.8 MeV six orders of magnitude, being the relevant reduced mass a factor 2/3 smaller.

* * *

Interesting discussions with R. A. Ricci are gratefully acknowledged. We should also like to thank Drs. E. Campochiaro and A. Nicoletti for their encouragement.