Excess Energy and Nuclear Products

Field Screened Long Range Nuclear Reactions by Thermal Protons

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Abstract

Confirmation of the model of field screened long range nuclear reactions has been obtained from the isotopes produced by nuclear Reactions In a Film-Excited CompleX (RIFEX) using nickel and nickel/palladium films, electrolytically loaded with hydrogen. The isotopes result from thermal proton (or deuterium or triton) reactions. The process is based on high Coulomb screening including the Swimming Electrons of the double Layer (SEL) at the surface of metals or at the interfaces between different metals due to the differences of the Fermi levels. These long range reactions for the low energy (nearly thermal) impact nuclei permits very long interaction times at the large distances. The quantum relations for the values of the energies, distances and times involved are discussed and compared with the situation for the high energies at shorter distances in the usual hot fusion and MeV nuclear reactions. Comparing these long range reactions with fission thermal reactions leads to the suggestion that the missing exchange of large momenta lead to the emission of lower energy gammas. from rotational and vibrational or surface states of the daughter nuclei. These may account for the large amount of energy of the exothermic reactions measured in the RIFEX experiments.

1. Introduction

The recent measurement of nuclear reactions in 2000-Angstrom films of nickel or nickel-palladium, electrolytically loaded with very high concentrations of hydrogen [1] are believed to be due to long range nuclear reactions with thermal protons. These reactions of hydrogen (or its isotopes) with medium or heavy weight nuclei are basically different from the cold fusion reactions [3] for which the long range nuclear reactions at very large Coulomb screening theory was developed [3].This treatment suggests consideration of other possible reactions between nuclei over large distances, picometers (pm) compared with the usual few femtometers (fm) of nuclear reactions when hadrons or light nuclei of MeV energy or more and heavy nuclei of more than 100 MeV energy collide.

The usual hot fusion reactions, involving nuclei with energies in the 1-10 keV range are reproducible and well understood. We consider a screening model which in certain metals allows much closer nuclear approach than the usual binding conditions [3]. We derive a limiting condition, relating interaction times to distances, for the nuclear reaction interaction parameters determined by quantum mechanics It can be proved that these conditions are obeyed by the long range interactions [3]. Finally we consider long range nuclear reactions in metals where high concentrations of isotopes have been produced (nuclear transmutations by thermal protons) which are different from the cold fusion reactions in platinum or similar metals. We suggest a mechanism which results in the production of softer gammas of short range hadrons or betas rather than the usual reaction products, MeV neutrons or gammas.

2. The Long Range Anomaly for Hot Fusion

Consider the minimum nuclear reaction distance r to which nuclei approach under central collision for a point like Coulomb repulsion. The kinetic energy of the particles E is then equal to the potential Coulomb energy E_c (in cgs units)

$$E = E_c = e^2/r \qquad (1)$$

where the electron charge e is 4.806×10^{-10} cgs units. If the energy of collision E is 1 MeV, the distance r is 1.43 fm, about the radius of the deuteron. A cross section of this radius corresponds to 64 mbarns, just the value common to nuclear reactions with colliding energies of dozens of MeV.

What is evident is that r = 14.3 fm for a collision energy E of 100 keV corresponds to the cross section of the DT reaction at the 100 keV with the well known cross section radius (impact parameter) r_c = 12.61 fm. This cross section is considered as an exceptionally large value due to "resonances" etc.. We know from the electron scattering experiments after Hofstadter [4][5] that the entire radius of the charge distribution of deuterons is in the range of 1 fm.

While this view of resonances may still be acceptable, we know that fusion reactions can occur - with low probability - at collision energies of 10 keV though the radius of the collision cross section (impact parameter) for DT is then down to a value r_c = 0.25 fm. What is astonishing is that the minimum reaction distance r, Eq. (1), for central collision at this 10 keV energy E is 142 fm = 0.142 pm, in the order of hundred times the entire radius of the deuteron! How can such a nuclear reaction happen [if there were a Gamov factor one has to realize that $\exp(-100)=10^{-43}$]. Hot fusion reactions measured every day show that it does happen however.

As we had shown before [3], this real measured value and the reaction time together with the distance for the hot fusion of the D and T can be compared with the measurements of a myonic fusion reaction. It can further be compared with the measured reaction time combined with the separation of D and T in a hydrogen molecule and the expected reaction time of 10^{80} s [3]. The result is a straight power law arriving in a reaction probability time U, in seconds, for a distance r, in picometers,

$$U = 8.139 \times 10^4 r^{34.8} \qquad (2)$$

We use this relation below for reactions at larger distances than r = 0.142 pm and up to one order of magnitute larger than in the case of the measured myonic fusion reaction (r = 0.45 pm). Time U and length r are indeed large number quantum statistical values as knwon e.g. from the time of nuclear decay.

3. High Coulomb Screening and the Swimming Electron Layer

The following model was developed [3] to explain some of the reversibly measured cold fusion results of Yamaguchi et al [7] and of Prelas et al [8]. The highly concentrated 50% to 200% hydrogen or deuterium loaded into metals as palladium or titanium [9] is assumed to be not located at fixed points in the crystal, as ligands or other kinds of chemical bond, but to behave like a Maxwellian gas. The degenerate conduction electrons are at least acting as a Coulomb screen and one may assume that the lower bound metal electrons are causing less interaction where the hydrogen or deuterium ions are penetrating, similar to the Ramsauer effect.

While the reduction of the Coulomb field within the bulk material may be of a considerable magnitute, there is a further screening by the swimming electron layers at clean or neutral surfaces (i.e. free of adsorbed molecules or of oxide) or stable and clean interfaces between hydrogen absorbing metals of different kinds. These can be constructed as a series of layers, e.g. nickel-palladium, iron-titanium, nickel-platinum or similar combinations chosen to have the highest possible Fermi level difference [3][9]. These swimming electron layers are the result of a plasma model of the surface tension for metals, in analogy to a plasma surface or interface. The faster degenerate electrons like to leave the lattice of the metal ions until they are stopped by the generated high electric field. This generates an electric double layer which becomes equal to the electrons' exit potential, the work function. The surface tension calculated on this quantum mechanical basis is in good agreement with experimental values [10]. The surface tension always produces positive values unlike some other previously used phenomenological models.

These electron layers, of about 1 Angstrom thickness, should be sufficient to permit a very high suppression (screening) of the Coulomb repulsion of the positive charges of the hydrogen or deuterium ions. Using Eq. (2) above and the very few fully reproducible cold fusion experiments with D-D reactions [7][8] concluded that this screening reduces the Coulomb repulsion by a factor of 14. We further concluded that the distance r of the reacting deuterons is in the range of 3 pm. The screening means that the deuterons behave as if they had an energy of 470 eV, an adequate value for hot fusion, but with a real energy of only 2.3 eV. Only the very few ions, in the Maxwell tail of the energy distribution, which exceed the 2.3 eV will react. This agrees then with room temperature measurements. Higher temperatures, 100°C or more, can well increase the reactivity [3].

The high screening by a factor 14 is not unusual even for bulk materials as plasma theory indicates [11] but the swimming electron layer [10] may strongly help in arriving at the factor 14. The distance of r = 3 pm between the reacting deuterons come from detailed comparison with experimental parameters and are comparable with basically different other models of Preparata and the theory of Vigier, see [3]. Our swimming electron model motivated us to look for experiments with large surfaces and to use multilayers e.g. Ni/Pd for fully reversible low energy nclear reactions [1]. The experiments with 5 g palladium black (0.4 mm diamter) producing large amounts of ^4He in cells with deuterium electrolysis [12], can be evaluated to arrive at r = 2 pm. The details of the nuclear reaction e.g. of protons within the swimming electron layer has been carefully elaborated by Kim et al [13]. The increase of d-d reaction cross sections (though at 2 keV energy) due to screening of the Coulomb field has been measured [14].

4. A Quantum Condition for the Long Range of Interaction

Cold fusion observations indicate that nuclear reactions may occur at inter nuclear separations 21.1 times greater than those common to hot fusion. Myonic fusion also occurs at large separations. We should like to consider the quantum mechanical implications of these interaction processes at distances in the range of 3 pm.

There is a mathematical physics way "how to understand quantization"[15]. It describes reality by observables and states. With this "natural language we can say that quantum mechanics is a deformation of classical mechanics in a framework...where Planck's constant is the deformation parameter".

A less mathematically formal way is to understand quantum theory form the empirical fact that all quantities with the dimension of an action can occur only as multiples of Planck's constant h (or h/2p). If a free moving electron in a zero potential has a momentum $p = mv = (2mE_o)^{1/2}$ with a mass m, velocity v and kinetic energy E_o, it has a de Broglie wave length l_{dB} where the product of momentum p times length l_{dB} has the dimension of an action and has to be equal to h or multiples of it. This results in the de Broglie wave length

$$l_{dB} = h/p = h/(2mE_o)^{1/2} \qquad (3)$$

It should be realized that the de Broglie wave length l_{dB} and the electron energy E_o are well defined, no inaccuracy ranges or error bars etc., but simple numbers.

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The quantization has to be expressed by the h in the case of the de Broglie wavelength, Eq. (3). For the atom mechanics of Bohr's planetary model the quantity of the action had to be h/2p. A modified Bohr model can be used where the problem of orbiting and therefore dipole radiation emitting electrons in the s-state can be avoided and only in p- and higher states orbiting and radiation emission is possible. This model [16, Section 2.3] asks why does an electron not fall into the positive atomic nucleus. There is Coulomb energy gained from the reduction of the distance r between electron and nucleus. On the other hand there is quantum energy E_q (Fermi-Dirac) to be increased if the radius r

$$r(2mE_q)^{1/2} = h/2\pi \tag{4}$$

is becoming smaller. For a simply charged nucleus, both energies are equal at a radius equal to the Bohr radius $r_B = (h/2\pi)^2/(me^2)$. It is important to note that in the case (4) the quantization is not given by h but by $h/2\pi$. Using multiples n = 1,2,3,... of the right-hand side of Eq. (4) one arrives at energies E_n equal to the Rydberg terms.

One should be aware that the meaning of quantum mechanics is simply the atomistic structure of action. This appears indeed also in Born's statistical interpretation by functional analytical expressions. If a quantum state is given by

$$\Psi(\mathbf{r},t) = \int A(\mathbf{p})\exp\{(2\pi\iota/h)[\mathbf{p}\cdot\mathbf{r}-(\mathbf{p}^2/2m)t]\}d\mathbf{p} \tag{5}$$

a localization can be expressed by a width Δr for the density distribution $\Psi(r)$ of a state in the configuration space determined by the spectrum A(p) of a momentum distribution. The functional analytical relation between the states Ψ and p is given by an integral equation of the first kind (in the case of Eq. (5) as a Fourier's integral equation solved by Fourier transform). It was the discovery of Heisenberg with his uncertainty relation to realize that the widths of the spectra

$$\Delta r\, \Delta p = ah \tag{6}$$

where the number a is in the order of unity. If the spectrum of A(p) is a Gaussian error function, the spectrum of $\Psi(r)$ is also Gaussian and both distributions (spectra) have the narrowest width, resulting in an $a = 1/4\pi$. If Ψ is a box, the spectrum of p is a type of a (1/u)(sin u) function and a=1/2.

The Fourier transform defines widths which can well vary with the resulting a. It is no surprise that the rule of quantization *also* refers to these spectral widths of functional analytical distribution functions as seen in Eq.(6) but this does not exclude that quantization also refers to simple numbers as e.g. in Eq. (3). Hermann Weyl's transformation theory explained the relation between the Schrödinger picture (expressed by eigenvalues of differential equations) and the Heisenberg picture (expressed by the elements of the matrix evolution of the integral equations corresponding to the differential equations) as explained by Johann von Neumann [17]. In the Heisenberg picture the initial access to quantization was the non commutative matrix product of space [r] and momentum [p] matrices to be

$$[r][p] - [p][r] = ih/2\pi \tag{7}$$

and in the Schrödinger case it was the question of Debye in Schrödinger's seminar report about de Broglie's results (3) in 1924 "if there are electron waves with a wave length and frequency, where is the related wave equation?" The later answer was then the Schrödinger equation which also can be derived in mathematical symbolics of quantization [16, Appendix A]. In the latter case one defines the operator for the momentum $p = -i(h/2\pi)d/dx$ and the energy $E=i(h/2\pi)d/dt$ derived as a symbolic product p dx = "h" and E dt= "h" to be substituted in the classical Hamilton function where the resulting Hamilton operator defines a differential equation resulting in distributions functions Ψ to determine expectation values in the sense of statistics.

5. Soft Gamma Emission of the Reaction Energy

We now consider the quantum mechanical concepts in the preceding section applied to long range nuclear reactions. The question involves energies E and times t (or the corresponding velocities v) for nuclear reactions at distances r, as large as 3 pm, such that $Et= h/2\pi$. Expressing $E = (h/2\pi)v/(2r)$ with the assumption that the incident particle has a velocity v and the interaction with another particle (nucleus or atom) appears within the length of two radii (2r), we find a limiting energy for the quantum interaction between the incident particle of mass m and the other particle

$$E > (h/2\pi)^2/(2mr^2) \qquad (8)$$

For electrons the energy E for interaction over a distance of $r = 10^{-8}$cm has to be lager than 3.7 eV. This indeed seems to be the limit below which no (inelastic) quantum interaction of electrons with atoms appears and the electrons move through atoms without interaction (Ramsauer effect). Interaction is possible only with larger entities, e.g. when the conduction electrons in a metal or semiconductor are colliding and causing ohmic resistivity; in this case the entity of collision is e.g. a lattice vibration, characterized by an acoustic wave length of 10nm permitting the transfer of energy above 0.37 meV. In general, any particle needs to have a deBroglie wave length

$$l_{dB} < r/(2\pi) \qquad (9)$$

otherwise it will not perform an inelastical quantum interaction with an object of radius r.

For alpha particle interaction with particles within a radius r of 1 fm (nuclear dimension) one arrives at E > 1.27 MeV. This is reasonable since it is well known that alphas with energies above MeV may produce nuclear reactions. No nuclear reactions at all are possible for alphas of lower energy, if not a larger interaction length r is considered. For deuterons taking a value r = 143 fm, the central collision distance at 10 keV energy, the limit is E > 500 eV, in agreement with observed fusion reactions. For deuterons at a distance of 3 pm, as derived for the cold fusion reactions [3], the limit is E > 1.13 eV. This value is in agreement with the concluded [3] energy of 2.3 eV of deuterons in the energetic tail of the Maxwellian distribution which result in the cold fusion reactions. This restriction to the energetic protons or deuterons in the same way also for the following other long range nuclear reactions is a natural controll against too hefty reactions. The energy output of a mutlilayer energy source with up to kW/cm^3 power density could be controlled by the temperature using heat exchangers and by the concentration of the protons.

We have to distinguish between the cold fusion reactions where only isotopes of hydrogen are involved from the present long range nuclear reactions where thermal hydrogen isotopes react with heavy nuclei, resulting in a nuclear transmutation. The first indication of this kind of reactions came from cold fusion experiments [18]. However this may have been an Oppenheimer-Williams neutron swapping (or hopping) process [3]. There was an alteration of the ratio of the isotopes in the outermost layers near the surface of the palladium, indicating that a (d,p) reaction had taken place for exothermic reactions. Deeper layers of the palladium showed the unchanged isotope ratio. Contrary to this, the observation of RIFEX [1] or the similar case of strong heat generation at palladium nickel interfaces [19] resulted in the generation of nuclei with different atomic number. This type of measurements with long range nuclear reactions were observed [1] where high concentrations of hydrogen in palladium reacted and produced silver isotopes and other elements. These reactions at distances r of few fm, are governed by Eq. (8) and involve Coulomb screening, especially with swimming electron layers SEL [3] at the clean surface at intermetallic interfaces.

No MeV neutrons nor energetic gammas have yet been observed, only some thermal energy has been measured in these long range nuclear reactions[1]. It may be asked whether the resulting nucleus loses energy in the form of only larger numbers of low energy gammas or of usual short range alphas or betas. The energies involved are rather large, e.g.

$$Pd^{108} + p = Ag^{109} + 6.664\ \text{MeV} \quad (10)$$

$$Pd^{106} + p = Ag^{107} + 5.957\ \text{MeV} \quad (11)$$

There seems to be a similarity to the reaction of thermal neutrons with U^{238} where the momentum transfer is small because of the thermal energy and - since no fission occurs for compensating the momenta of MeV reaction products - one has to follow up gamma emissions. One may speculate whether lower energetic rotational states or surface oscillations are involved as indicated from the surface energy of the nuclei [20]. This may be different when a long range nuclear reaction in a metal, with a high hydrogen concentration, results in a nuclear fission, e.g. with deuterium in platinum

$$Pt^{196} + H^2 = Xe^{136} + Mn^{60} + 2n + 104.3\ \text{MeV} \quad (12)$$

since there are several branches for compensating the momenta.

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References

[1] G.H. Miley, G. Marne, M.J. Willimas, J.A. Patterson, J. Nix, C. Cravens, and H. Hora, 6th Int. Conf. Cold Fusion Hokkaido 1996; Jerry E. Bishop, Wall Street Journal 29 Jan. 1996, p. A9A
[2] M. Fleischmann and S. Pons, J. Electroanalyt. Chem. **251**, 301 (1989)
[3] H. Hora, J.C. Kelly, J.U. Patel, Mark A. Prelas, G.H. Miley, and J.W. Tompkins, Phys. Lett. **A175,** 138 (1993; G.H. Miley, H. Hora, E.G. Batyrbekov, R.L. Zich, Trans. Fusion Technol. **26**, 4T, Part 2, 313 (1994)
[4] R. Hofstadter, Ann. Rev. Nucl. Sci **7** (1957) 231; Australian Physicist **24**, 236 (1987)
[5] T. Meyer-Kuckuk, *Kernphysik* (Stuttgart 1984) p. 28
[6] H. Hora, G.H. Miley, L. Cicchitelli, A. Scharmann, W. Scheid, Nuovo Cimento **D12** (1990) 393
[7] E. Yamaguchi, and J. Nishioka, *Frontier of Cold Fusion* H. Ikegami ed. (Universal Academy Press, Tokyo) p. 179
[8] M. Prelas, F. Boody, W. Gallaher, E. Leal-Quiros, D. Mencin, S. Taylor, J. Fusion Energy, **9** (1990) 309
[9] H. Hora, G.H. Miley, M. Ragheb, and A. Scharmann, in *Proc. 8th World Hydrogen Conf. July 1990, Cold Fusion Symposium* (Hawaii Natual Energy Inst., Univ. Hawaii, 1990) p. 169
[10] H. Hora, Gu Min, S. Eliezer, P. Lalousis, R.S. Pease, and H. Szichman, IEEE Trans. Plasma Sci. **PS-17** (1989) 290
[11] S. Ichimaru, Rev. Mod. Phys. **65** (1994) 255
[12] Yeong E. Kim and A.J. Zubarev, 6th Int.Conf. Cold Fusion, Hokkaido 1996, 0-033
[13] Y. Arata and Y.C. Zhang, 6th Int. Confl Cold Fusion, Hokkaido 1996, 0-003
[14] J. Kasagi et al 6th Int. Conf. Cold Fusion, Hokkaido 1996, 0-032
[15] L.D. Faddeev, Physik. Blätter **52** (1996) 689
[16] H. Hora, *Plasmas at High Temperature and Density* (Springer, Heidelberg 1991)
[17] Johann von Neumann, *Mathematische Grundlagen d.Quantenmechanik* (Springer, Berlin 1933)
[18] D.R. Rollison, W.O. Grady, R.J. Doley and P.T. Trzaskoma. Progr. 1st Ann. Conf Cold Fusion, Salt Lake City, March 1990 (Nat. Cold Fusion Inst. 1990) p. 36
[19] S. Szpak, P.A. Mosier-Boss, Phys. Letters **A221**, 141 (1996)
[20] H. Hora, *Plasma model of Surface Tension of Nuclei and the Phase Transition to the Quark Plasma*, CERN-PS/DL-Note-91/05, August 1991