Electron Screening Constraints for the Cold Fusion

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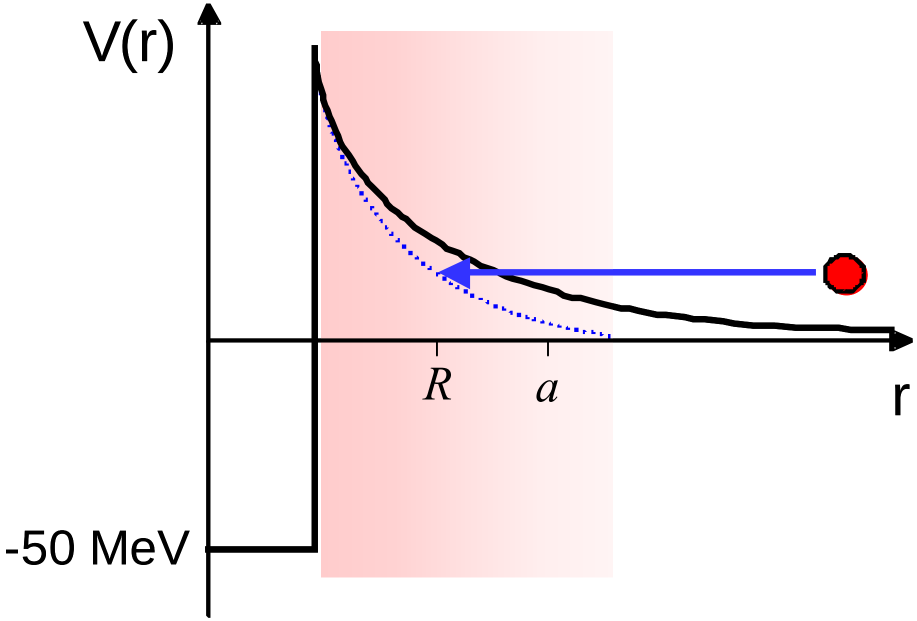
Electron Screening in Nuclear Reactions I



$$V(r) = \frac{Z_1 Z_2 e^2}{r} \exp(-r/a)$$

$$\approx \frac{Z_1 Z_2 e^2}{r} - U_e$$

$$\boxed{U_e = \frac{Z_1 Z_2 e^2}{a}}$$

screening energy

$$\boxed{P(E) = \sqrt{\frac{E_G}{E}} \exp\left(-\sqrt{\frac{E_G}{E}}\right)}$$

s-wave penetration factor

$$P(E) \longrightarrow P(E+U_e)$$

Electron Screening in Nuclear Reactions II

cross section

$$\sigma\ (E) = \frac{1}{E}\, S(E)\, \exp\left(-\sqrt{\frac{E_G}{E}}\right) = \frac{1}{\sqrt{EE_G}}\, S(E)\ P(E)$$

E_G - Gamow energy

$S(E)$ - astrophysical S-factor

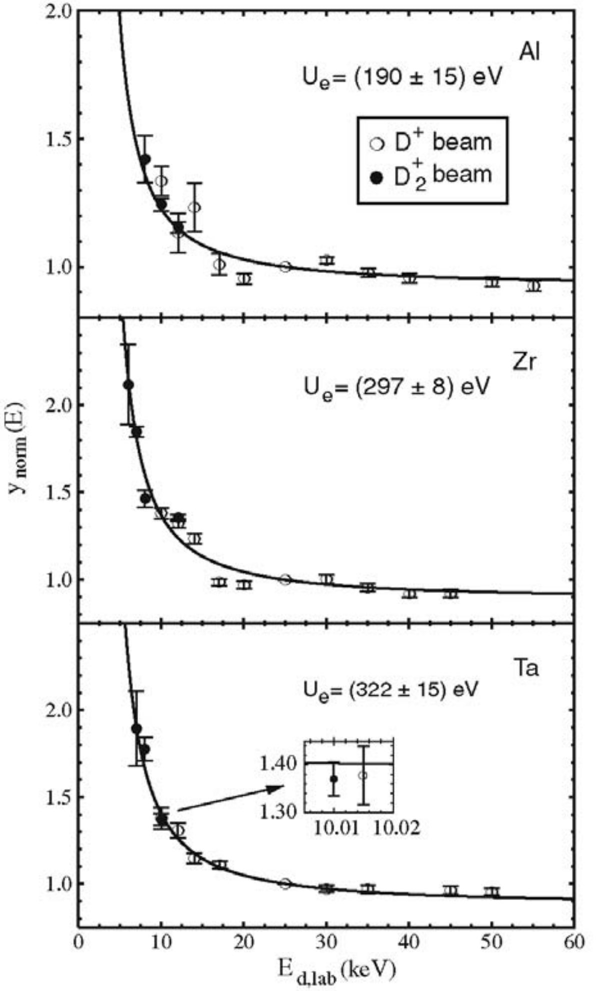
$P(E)$ - penetration factor

enhancement factor

$$f = \frac{\sigma_{scr}}{\sigma_{bare}} \neq \frac{\sigma(E+U_e)}{\sigma(E)}$$

$$= \frac{P(E+U_e)}{P(E)}$$

Experimental Results



$$d + d \longrightarrow {}^{3}He + n$$

$$d + d \longrightarrow {}^{3}H + p$$

metal target

Europhys. Lett. 54 (2001) 449

Similar results:

J. Kasagi et al., J.Phys.Soc.Jap. 71 (2002) 2281
F. Raiola et al., Eur.Phys.J. A13 (2002) 337

gas target

$U_e = 25 \pm 5$ eV

U.Greife et al., Z.Phys. A351 (1995) 107

Dielectric Function Theory

$$V(r)=\frac{e^2}{r}\,\Phi(r)=\frac{1}{(2\pi)^3}\int\frac{4\pi(e\varphi(q))^2}{\varepsilon_v(q)\;\varepsilon_c(q)\;q^2}\,\exp(i\vec{q}\vec{r})\;d^3q\;\xrightarrow[\varepsilon_v=\varepsilon_c=1]{}\;\frac{e^2}{r}$$

self-consistent charge formfactor $\varphi(q)=1-z+zq^2/(q^2+k_{TF}^2)$

z number of bound electrons

k_{TF} Thomas-Fermi wave number

valence-electron dielectric function $\varepsilon_v(q)=1-\dfrac{v(q)P(q)}{1+v(q)G(q)P(q)}$

$P(q)$ Lindhard RPA polarizability

$G(q)$ local field correction

core-electron dielectric function $\varepsilon_c(q)$ from f-sum rule

Cohesion Screening Contribution

Plasma: screening arising from interaction between positive ions

Solid: difference in binding energy of He atom and two deuterons in solid

universal screening potential ZBL

$$V(r) = \frac{Z_1 Z_2 e^2}{r} \, \Phi(x)$$

where

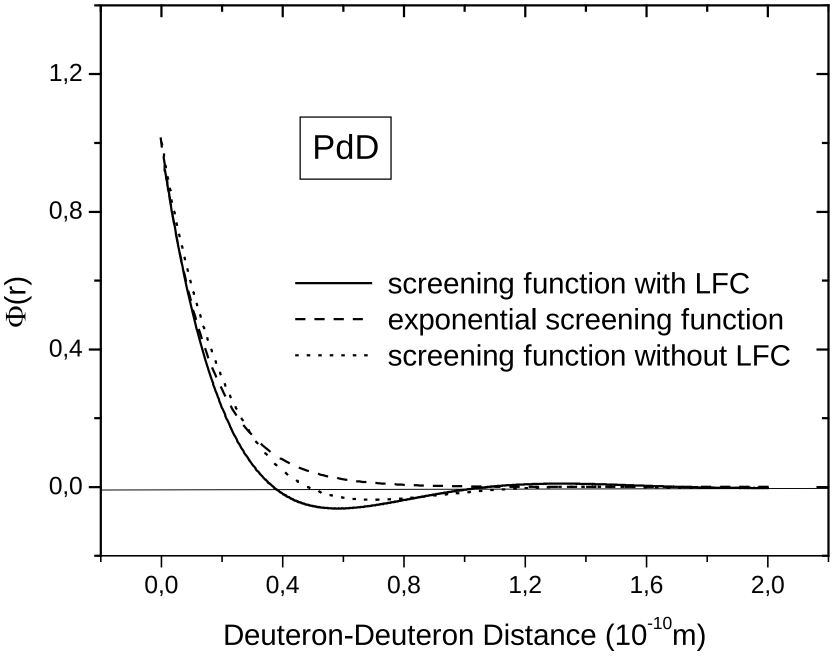
$$\Phi(x) = \sum_{i=1}^{4} A_i \exp(-B_i x)$$

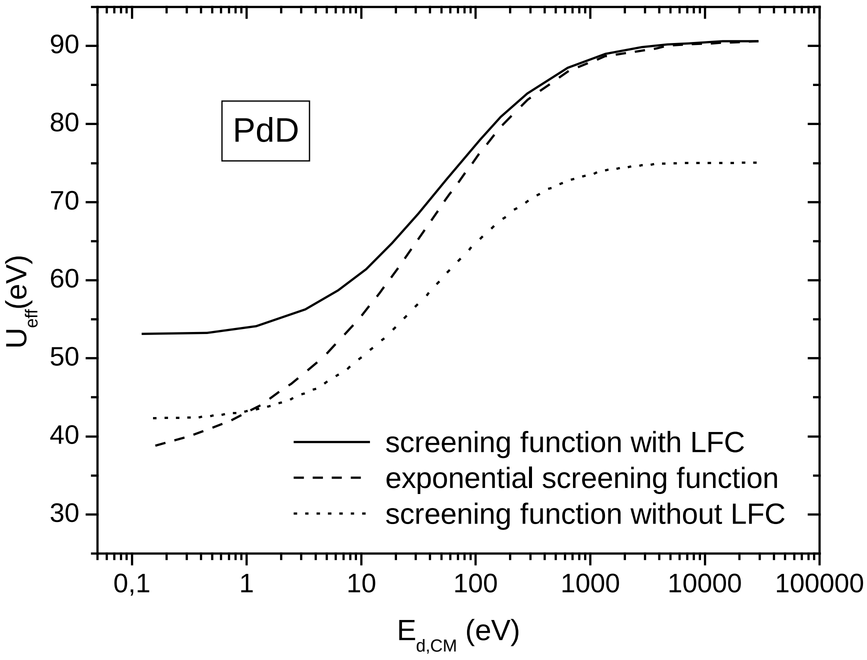
with $x = r/a$

$$\boxed{a \text{ (He+metal)} \neq a \text{ (d+metal)}}$$

$$a = \frac{0.8854 \; a_o}{Z_1^{0.23} + Z_2^{0.23}}$$

Results: Screening Function & Screening Energy

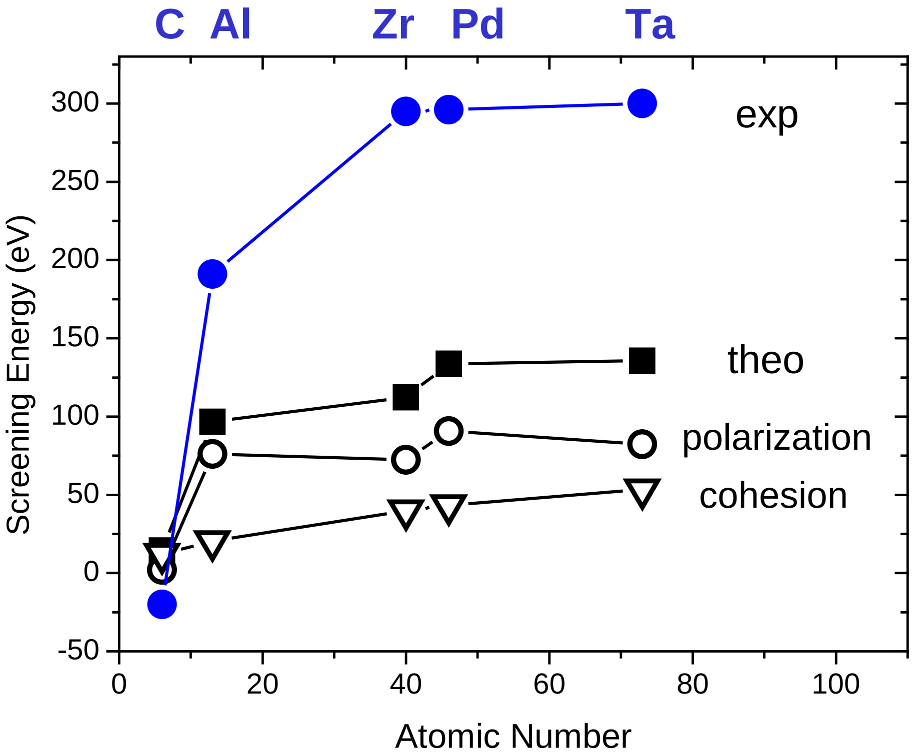




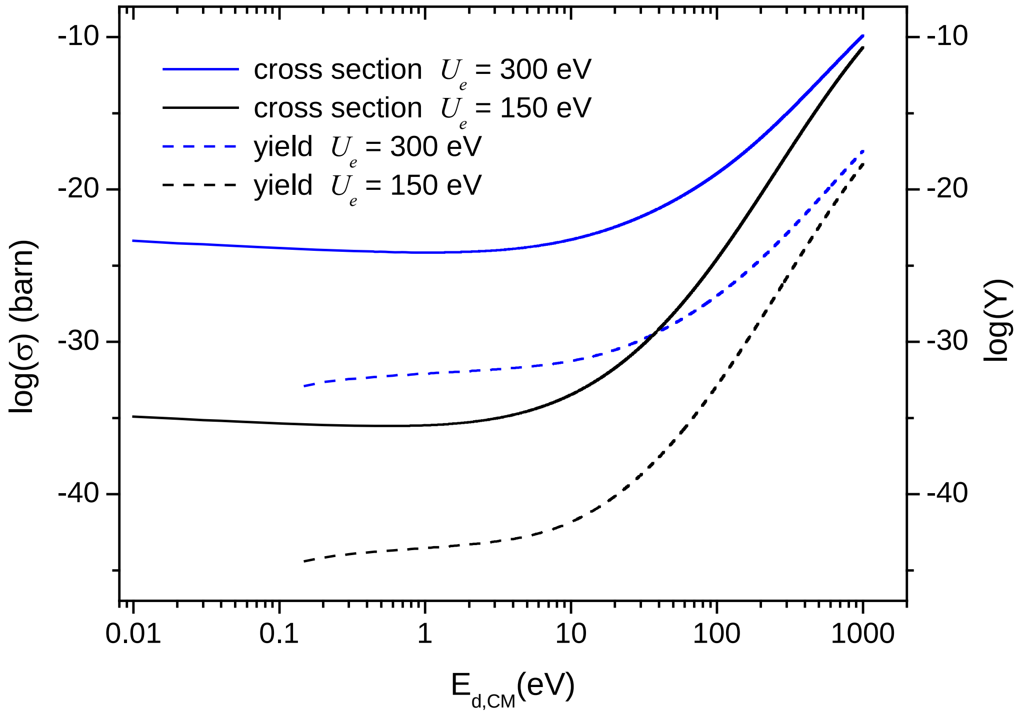
high energy limit:

$$U_e = \lim_{r \to 0}\left(\frac{e^2}{r} - \frac{e^2}{r}\Phi(\mathrm{r})\right)$$

Results: Screening Energy



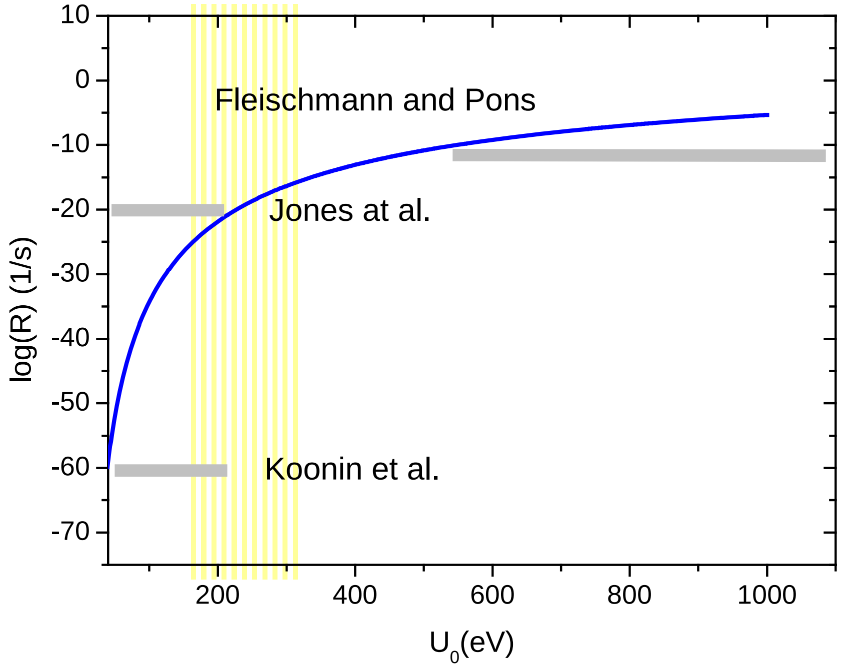
Results: Cross Section & Yield (PdD)



$$\sigma_{scr}(E) \cong \frac{1}{\sqrt{U_0 E}} S_0 \exp\left(-\sqrt{\frac{E_G}{U_0}}\right) \propto \frac{1}{\sqrt{E}}$$

$$Y_{scr}(E) = \int_{E_0}^{E} \frac{\sigma_{scr}(E)}{A\sqrt{E}}\, dE \propto \ln\frac{E}{E_0}$$

Results: Reaction Rate (PdD)



low energy limit:

$$U_0 = \lim_{E \to 0} U_{eff}(E)$$

$$U_0 = 0.72\ U_e$$

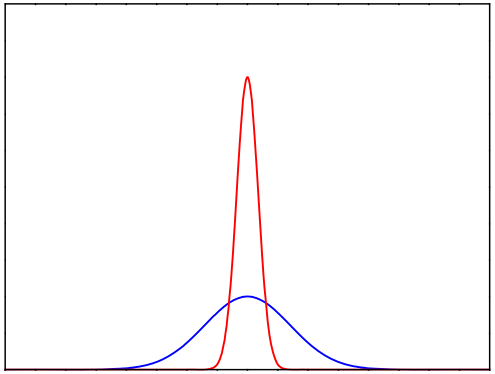
$$R_{scr}(E) = N\sigma_{scr}(E)v_{rel} = N\sigma_{scr}(E)\sqrt{\frac{4E}{M}} \cong \frac{2NS_0}{\sqrt{MU_0}}\exp\left(-\sqrt{\frac{E_G}{U_0}}\right)$$

Hypothetic Resonance in ^{4}He

resonance width $\Gamma_{sp} = 2\,k\,P\,\gamma^2 \;\sim\; 10\text{ MeV}$ for $P = 1$

$\sim\; 10\text{ eV}$ for $P \ll 1$

resonance maximum $\sigma_{max} = \dfrac{4\pi}{k^2}\,\dfrac{\Gamma_i \Gamma_f}{\Gamma^2}$

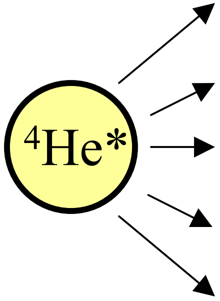


resonance narrowing

$\sigma_{max} \nearrow\!\!\nearrow 10^6$

Resonance Branching Ratios

resonance decay channels



$^4He + e^-$	internal conversion	$E_e \sim 24$ MeV	
$^4He + d$	internal conversion	$E_\alpha \sim 8$ MeV	$E_d \sim 16$ MeV
$^4He + \gamma$	γ decay	$E_\gamma \sim 24$ MeV	
$^3H + p$	stripping reaction	$E_p \sim 3.6$ MeV	$E_t \sim 1.2$ MeV
$^3He + n$	stripping reaction	$E_n \sim 2.4$ MeV	$E_\tau \sim 0.8$ MeV

branching ratio

$$\frac{\text{energy production}}{\text{neutron emission}} = \frac{\text{conversion}}{\text{stripping}} \approx 10^6$$

$$\Rightarrow \quad \frac{\gamma^2{}_d}{\gamma^2{}_n} \approx 10^8 \ ?\,?$$

quenching of neutron channel

Conclusions (High Energy)

- observed target material dependence of the screening energy

  for heavier metals $U_e \rightarrow 300\ \mathrm{eV}$

  for gas target $U_e = 25 \pm 5\ \mathrm{eV}$

- theoretical screening energies (polarization of valence and core electrons + cohesion screening) smaller by a factor of 2

  dynamical effects ?

- effective screening energy approach $U_0 = 0.72\ U_e$

Conclusions (Room Temperature)

- deuterons captured in the metallic lattice → theoretical reaction yields smaller by a factor of 10^{10} than the observed neutron emission

- quasi-free deuterons → neutron emission can be explained by means of the electron screening effect (enhancement by a factor of 10^{40})

- narrow resonance in ^{4}He → additional enhancement by a factor 10^6, possible explanation of the energy production and quenching of the neutron channel