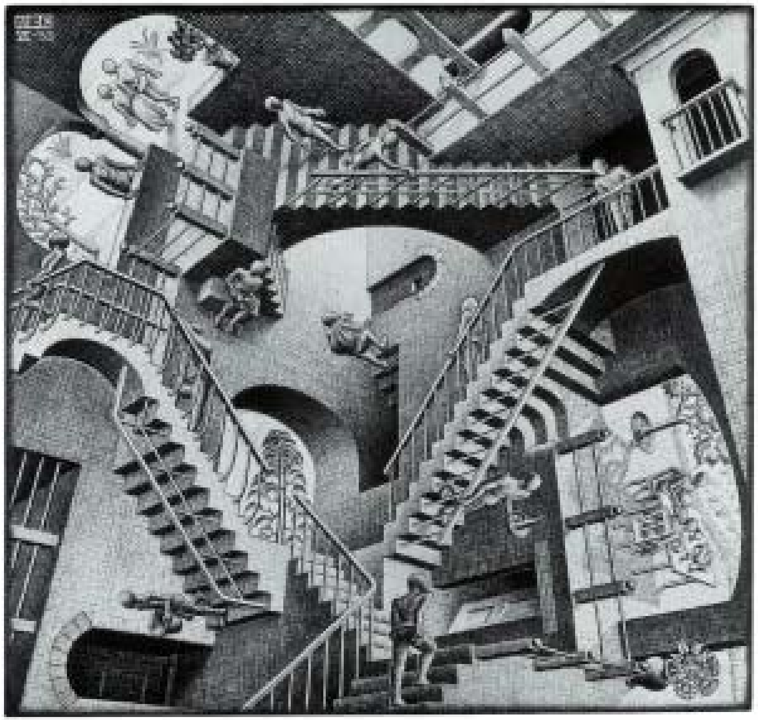
Nuclear Reactions

Collective Nuclear Reactions in Condensed Matter

Searching for Clean Nuclear Energy Sources



Presentation Given

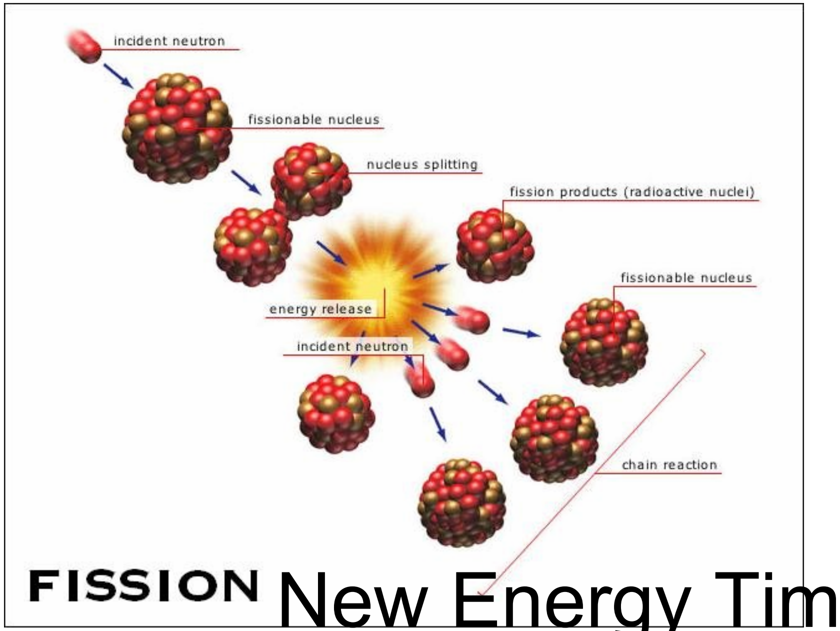
February 10, 2010
Army Research Laboratories

Allan Widom

Contents

Strong Interaction Nuclear Fission I

Conventional
Nuclear Power
Sources



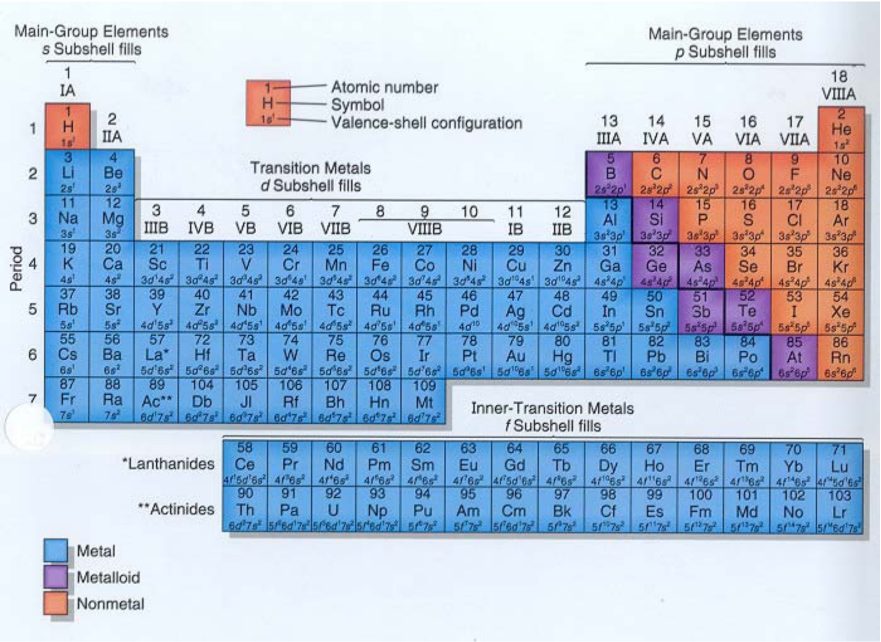
Fission Chain
Reactions

Strong Interaction Nuclear Fission II

High level waste appears from hot concentrated nitric acid solutions containing the dissolved spent fuel rods. The nuclear fission waste product is still so radioactive that it generates large amounts of heat.

Half of the chemicals from Zinc to the late lanthanides (Z=30 to Z=70) appear in radioactive isotopes in the high level fission waste products.

Chemicals with Z<30 are relatively safe with respect to long lived radioactive byproducts.



Main-Group Elements
s Subshell fills

Main-Group Elements
p Subshell fills

Transition Metals
d Subshell fills

Inner-Transition Metals
f Subshell fills

1 — Atomic number
H — Symbol
$1s^1$ — Valence-shell configuration

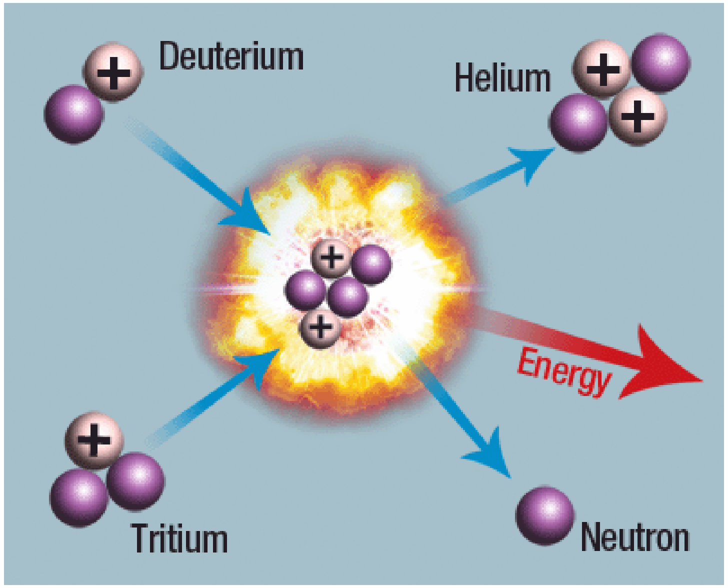
Period	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 H $1s^1$																	2 He $1s^2$
2	3 Li $2s^1$	4 Be $2s^2$											5 B $2s^22p^1$	6 C $2s^22p^2$	7 N $2s^22p^3$	8 O $2s^22p^4$	9 F $2s^22p^5$	10 Ne $2s^22p^6$
3	11 Na $3s^1$	12 Mg $3s^2$											13 Al $3s^23p^1$	14 Si $3s^23p^2$	15 P $3s^23p^3$	16 S $3s^23p^4$	17 Cl $3s^23p^5$	18 Ar $3s^23p^6$
4	19 K $4s^1$	20 Ca $4s^2$	21 Sc $3d^14s^2$	22 Ti $3d^24s^2$	23 V $3d^34s^2$	24 Cr $3d^54s^1$	25 Mn $3d^54s^2$	26 Fe $3d^64s^2$	27 Co $3d^74s^2$	28 Ni $3d^84s^2$	29 Cu $3d^{10}4s^1$	30 Zn $3d^{10}4s^2$	31 Ga $4s^24p^1$	32 Ge $4s^24p^2$	33 As $4s^24p^3$	34 Se $4s^24p^4$	35 Br $4s^24p^5$	36 Kr $4s^24p^6$
5	37 Rb $5s^1$	38 Sr $5s^2$	39 Y $4d^15s^2$	40 Zr $4d^25s^2$	41 Nb $4d^45s^1$	42 Mo $4d^55s^1$	43 Tc $4d^55s^2$	44 Ru $4d^75s^1$	45 Rh $4d^85s^1$	46 Pd $4d^{10}$	47 Ag $4d^{10}5s^1$	48 Cd $4d^{10}5s^2$	49 In $5s^25p^1$	50 Sn $5s^25p^2$	51 Sb $5s^25p^3$	52 Te $5s^25p^4$	53 I $5s^25p^5$	54 Xe $5s^25p^6$
6	55 Cs $6s^1$	56 Ba $6s^2$	57 La* $5d^16s^2$	72 Hf $5d^26s^2$	73 Ta $5d^36s^2$	74 W $5d^46s^2$	75 Re $5d^56s^2$	76 Os $5d^66s^2$	77 Ir $5d^76s^2$	78 Pt $5d^96s^1$	79 Au $5d^{10}6s^1$	80 Hg $5d^{10}6s^2$	81 Tl $6s^26p^1$	82 Pb $6s^26p^2$	83 Bi $6s^26p^3$	84 Po $6s^26p^4$	85 At $6s^26p^5$	86 Rn $6s^26p^6$
7	87 Fr $7s^1$	88 Ra $7s^2$	89 Ac** $6d^17s^2$	104 Db $6d^27s^2$	105 Jl $6d^37s^2$	106 Rf $6d^47s^2$	107 Bh $6d^57s^2$	108 Hn $6d^67s^2$	109 Mt $6d^77s^2$									

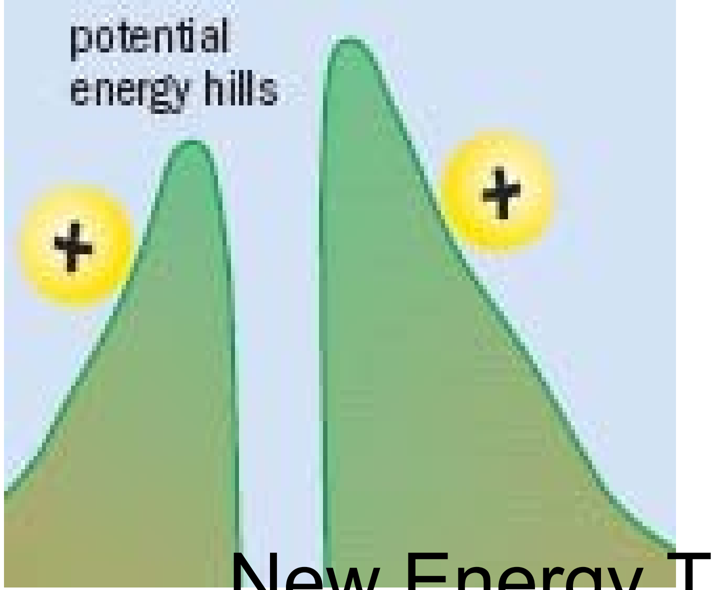
*Lanthanides	58 Ce $4f^15d^16s^2$	59 Pr $4f^36s^2$	60 Nd $4f^46s^2$	61 Pm $4f^56s^2$	62 Sm $4f^66s^2$	63 Eu $4f^76s^2$	64 Gd $4f^75d^16s^2$	65 Tb $4f^96s^2$	66 Dy $4f^{10}6s^2$	67 Ho $4f^{11}6s^2$	68 Er $4f^{12}6s^2$	69 Tm $4f^{13}6s^2$	70 Yb $4f^{14}6s^2$	71 Lu $4f^{14}5d^16s^2$
**Actinides	90 Th $6d^27s^2$	91 Pa $5f^26d^17s^2$	92 U $5f^36d^17s^2$	93 Np $5f^46d^17s^2$	94 Pu $5f^67s^2$	95 Am $5f^77s^2$	96 Cm $5f^76d^17s^2$	97 Bk $5f^97s^2$	98 Cf $5f^{10}7s^2$	99 Es $5f^{11}7s^2$	100 Fm $5f^{12}7s^2$	101 Md $5f^{13}7s^2$	102 No $5f^{14}7s^2$	103 Lr $5f^{14}6d^17s^2$

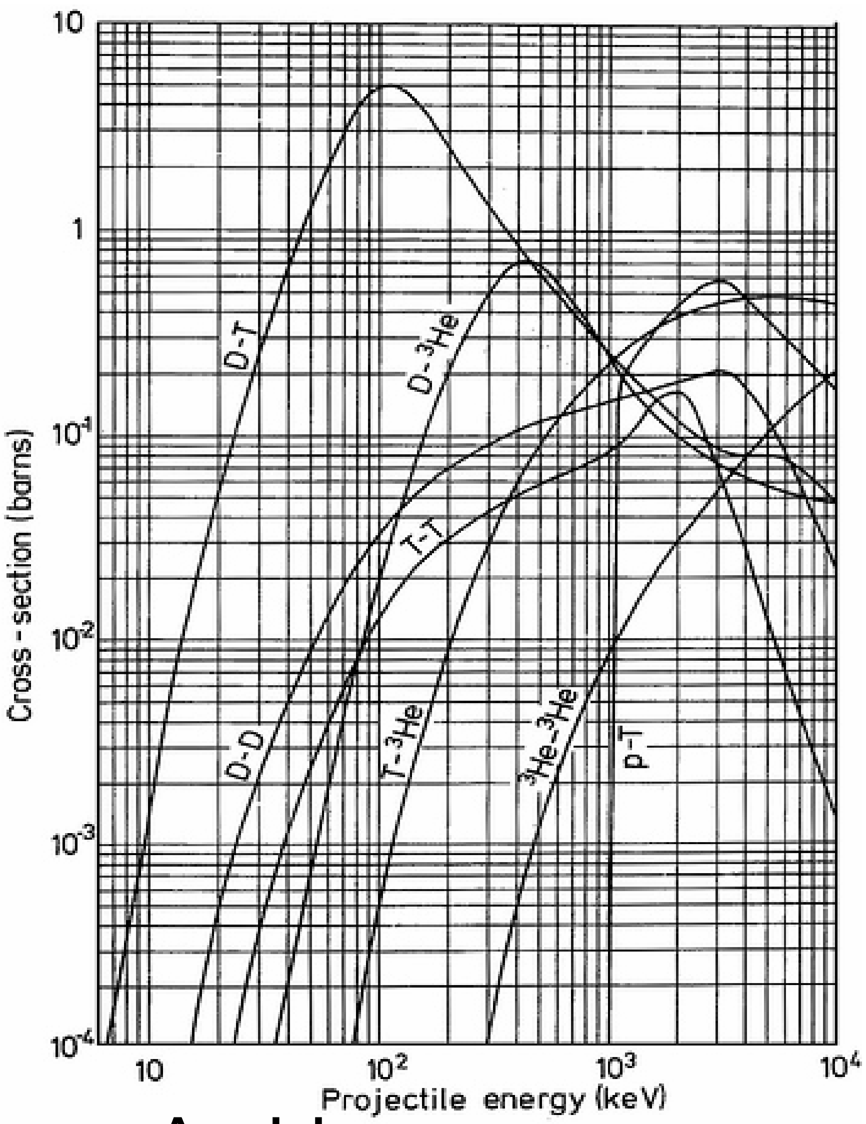
🟦 Metal
🟪 Metalloid
🟧 Nonmetal

Nuclear Reactions

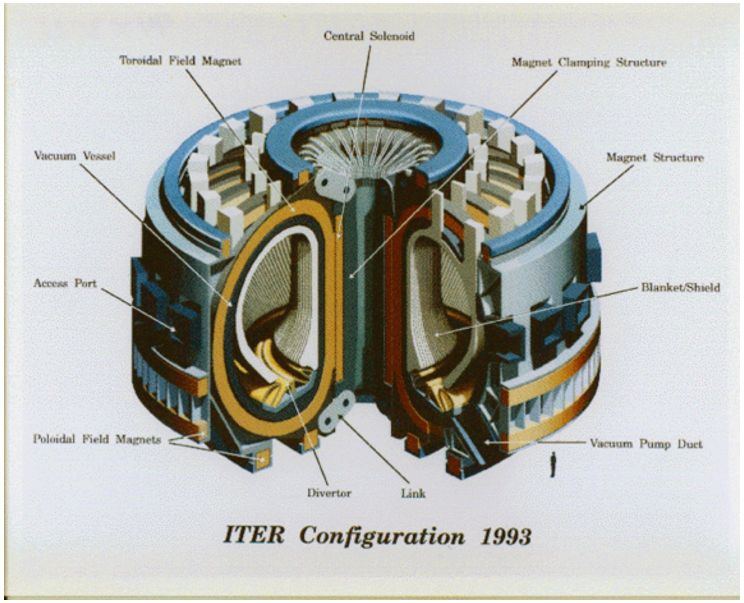
Strong Interaction Nuclear Fusion I

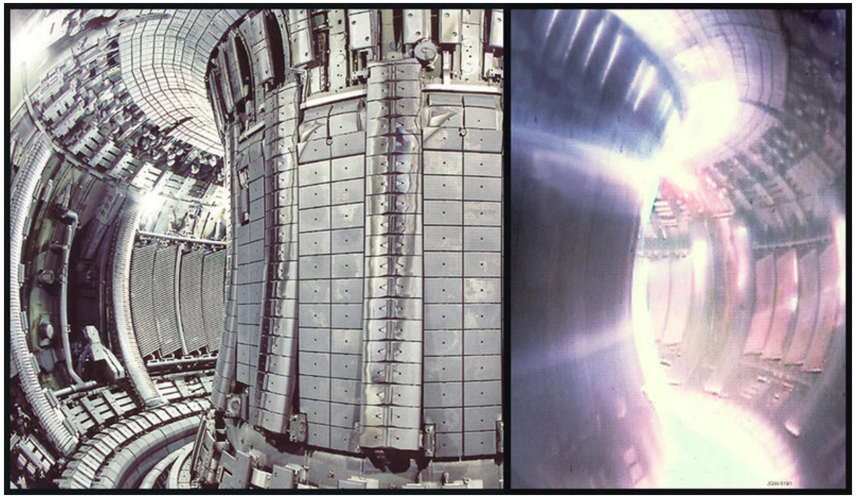






Strong Interaction Nuclear Fusion II





European confinement ITER "Magnetic Bottle" for a hot fusion reactor power source

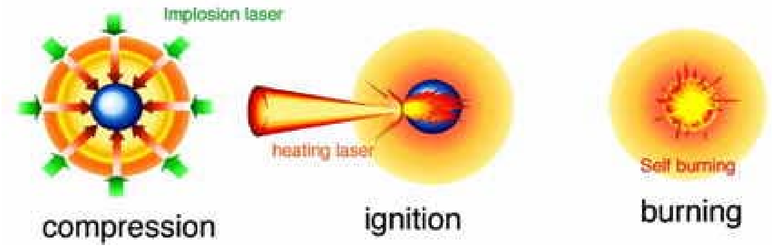
American confinement tokamak "Magnetic Bottle" for a hot fusion reactor power source

Hot fusion magnetic bottles have not been working after ~40 years because confinement times are too short to derive appreciable output energy.

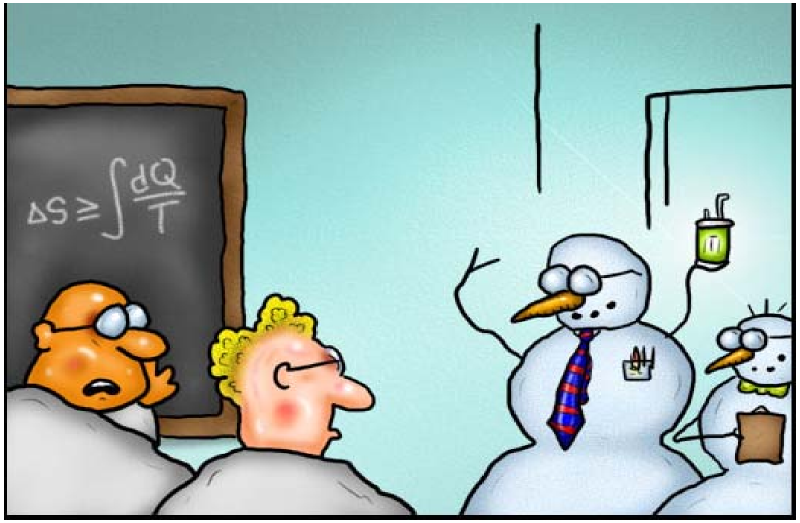
Strong Interaction Nuclear Fusion III

Lawrence Livermore National Laboratory's National Ignition Facility. No success after ~40 years. Explosion asymmetry is said to be the problem.

A chain of laser amplifiers (CEA in France).
No experimental success yet.



Strong Interaction Nuclear Fusion IV



"It's those cold fusion guys again."

There was clearly excess heat (also present in light water experiments) on a scale that made purely chemical sources unlikely. The central questions concern the nature of nuclear process. The reaction (d+d → α+heat) was initially presumed but is unlikely in other fusion nuclear physics contexts.

New Energy Times Archives

Strong Interaction Nuclear Fusion V

Shown are credible fusion reactions which in principle are capable of inducing chemical battery excess heat *only if the Coulomb barrier could be overcome*. Proposed condensed matter mechanisms for overcoming the Coulomb barrier to fusion *involve the intervention of new condensed matter physics that does not hold true in the other condensed matter systems*. Two examples will suffice.

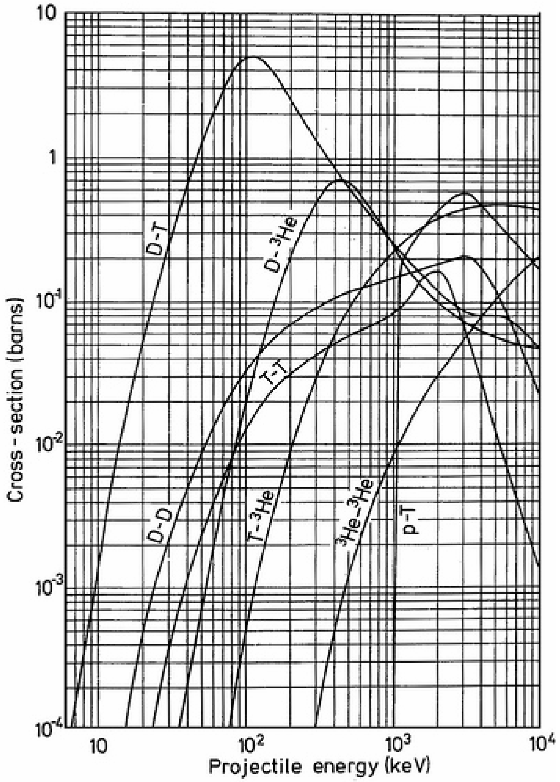
$$ {}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{1}H + {}^{1}_{1}H $$

$$ {}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + n $$

$$ {}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + n $$

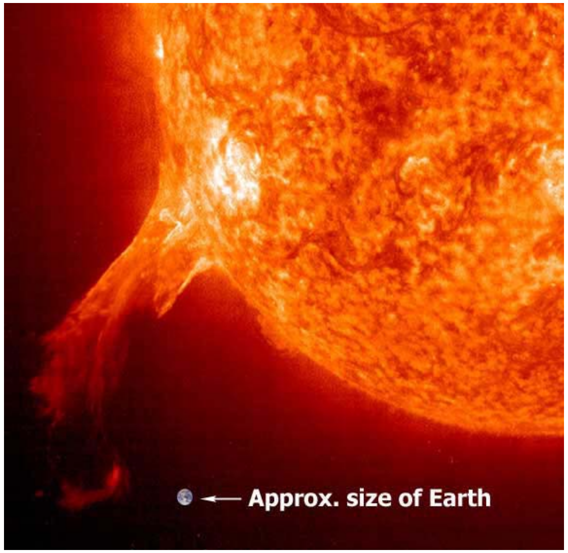
(i) **One theory demands a strong version of broken gauge invariance so that charge is not locally conserved. The charges then get inside the barrier without having to pass through it. In no other system has this been observed.**

(ii) **Another theory asserts that deuterons Bose condense at room temperature and above. Since deuterons have a thermal quantum wave length of $\lambda=1.232[({}^{o}K/T)^{1/2}]$ *nanometer* at temperature T, one cannot expect Bose condensation for room temperature and above. Even for the closest packing distance d, one has $d >> \lambda$.**

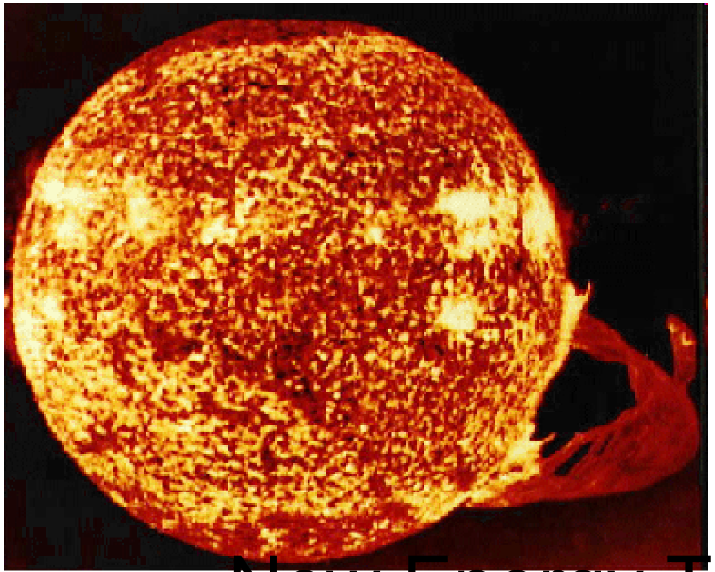


Strong Interaction Nuclear Fusion VI

Among the incorrect rumors which have been spread about the structure of the sun, is that the heat we get from the sun arises from strong interaction fusion. The true fact is that the heat producing nuclear chemistry of the sun requires weak interactions. One example should suffice. We choose the burning of Hydrogen into Helium.



$$4\,{}^{1}_{1}H(\text{atom}) \rightarrow {}^{4}_{2}He(\text{atom}) + 2\nu_e$$

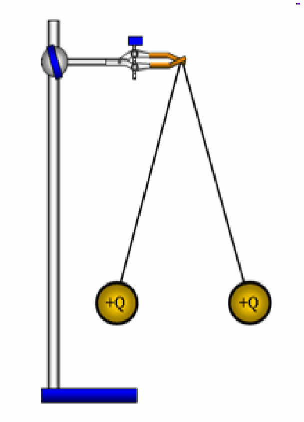


The neutrino production, electron and proton destruction and neutron creation are all signatures of the weak interaction heating from $e^- + p^+ \rightarrow \nu_e + n$. Weak interactions are *certain* from the direct observation of solar neutrinos.

The final incorrect rumor asserts that solar structure arises out of ideal gases.

Electromagnetic Interactions I

Coulomb Forces



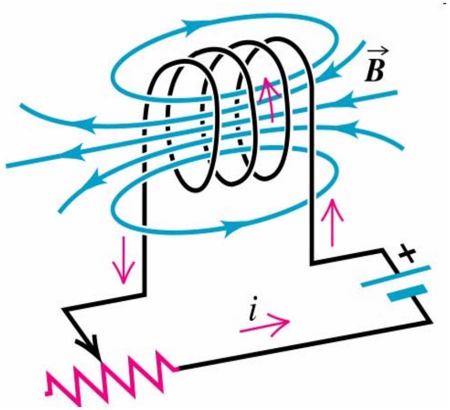
$$\tilde{U}_{Coul} = \frac{1}{8\pi}\int |\mathbf{E}(\mathbf{r})|^2 \, d^3\mathbf{r}$$

$$\mathbf{E}(\mathbf{r}) = \sum_a \mathbf{E}_a(\mathbf{r}) = e\sum_a \frac{z_a(\mathbf{r}-\mathbf{r}_a)}{|\mathbf{r}-\mathbf{r}_a|^3}$$

$$U_{Coul} = \frac{1}{2}\sum_{a,b\neq} U_{ab} \;\Rightarrow\; U_{ab} = \frac{1}{4\pi}\int \mathbf{E}_a(\mathbf{r})\cdot\mathbf{E}_b(\mathbf{r})d^3\mathbf{r}$$

$$U_{ab} = \frac{e^2 z_a z_b}{|\mathbf{r}_a-\mathbf{r}_b|}$$

Ampere Forces



$$\tilde{K}_{Amo} = \frac{1}{8\pi}\int |\mathbf{B}(\mathbf{r})|^2 \, d^3\mathbf{r}$$

$$\mathbf{B}(\mathbf{r}) = \sum_a \mathbf{B}_a(\mathbf{r}) = e\sum_a \frac{z_a\mathbf{v}_a\times(\mathbf{r}-\mathbf{r}_a)}{c\,|\mathbf{r}-\mathbf{r}_a|^3} = \sum_a \frac{\mathbf{v}_a}{c}\times\mathbf{E}_a(\mathbf{r})$$

$$K_{Amo} = \frac{1}{2}\sum_{a,b\neq} K_{ab} \;\Rightarrow\; K_{ab} = \frac{1}{4\pi}\int \mathbf{B}_a(\mathbf{r})\cdot\mathbf{B}_b(\mathbf{r})d^3\mathbf{r}$$

$$K_{ab} = \frac{e^2 z_a z_b}{2c^2\,|\mathbf{r}_a-\mathbf{r}_b|}\left(\mathbf{v}_a\cdot\mathbf{v}_b + \mathbf{v}_a\cdot\mathbf{n}_{ab}\mathbf{n}_{ab}\cdot\mathbf{v}_b\right)$$

$$\mathbf{n}_{ab} = \frac{(\mathbf{r}_a-\mathbf{r}_b)}{|\mathbf{r}_a-\mathbf{r}_b|}$$

Electromagnetic Interactions II

Non-Relativistic
Gauge Invariant
Darwin
Lagrangian

$$L = K - U = \sum_a m_a c_a^{\,2} + \sum_a \frac{1}{2} m_a \mathrm{v}_a^{\,2} + \sum_{a<b} K_{ab} - \sum_{a<b} U_{ab}$$

$$U_{ab} = \frac{e^2 z_a z_b}{r_{ab}}$$

$$K_{ab} = \frac{e^2 z_a z_b}{2c^2 r_{ab}} \left(\mathbf{v}_a \cdot \mathbf{v}_b + \mathbf{v}_a \cdot \mathbf{n}_{ab} \mathbf{n}_{ab} \cdot \mathbf{v}_b \right) \quad \text{wherein} \quad \mathbf{n}_{ab} = \frac{\mathbf{r}_{ab}}{r_{ab}}$$

$$E = K + U$$

Non-Relativistic
Gauge Invariant
Chemical Potential

$$\mu = E_{N+1} - E_N$$

$$\mu = mc^2 + \frac{1}{2} m\mathrm{v}^2 + ze\left(\Phi + \frac{\mathbf{v} \cdot \mathbf{A}}{c} \right)$$

$$\Phi = \sum_{a\neq} \frac{z_a e}{|\mathbf{r} - \mathbf{r}_a|}$$

$$\mathbf{A} = \frac{1}{2} \sum_{a\neq} \frac{z_a e}{|\mathbf{r} - \mathbf{r}_a|} \left(\frac{\mathbf{v}_a}{c} + \left(\frac{\mathbf{v}_a}{c} \cdot \frac{(\mathbf{r} - \mathbf{r}_a)}{|\mathbf{r} - \mathbf{r}_a|} \right) \frac{(\mathbf{r} - \mathbf{r}_a)}{|\mathbf{r} - \mathbf{r}_a|} \right)$$

Nuclear Reactions

Electromagnetic Interactions III

Thermodynamics of Chemical Reactions

$$dE = TdS - PdV + \sum_j \mu_j dN_j$$

$$\sum_j \nu_j C_j \Leftrightarrow 0 \quad \text{Chemical Reaction}$$

$$dN_j = \nu_j d\xi$$

$$A = \sum_j \nu_j \mu_j$$

$$d\xi = (\text{degree of reaction})$$

$$A = (\text{chemical activity})$$

$$dE = TdS - PdV + Ad\xi$$

Nuclear Reactions

Electromagnetic Interactions IV

Activity of a Weak Interaction

$$e^{-} + p^{+} \rightarrow n + \nu_e$$

$$-A = \mu_n + \mu_{\nu_e} - \mu_{e^-} - \mu_{p^+}$$

The chemical potential for a non-relativistic charged particle.

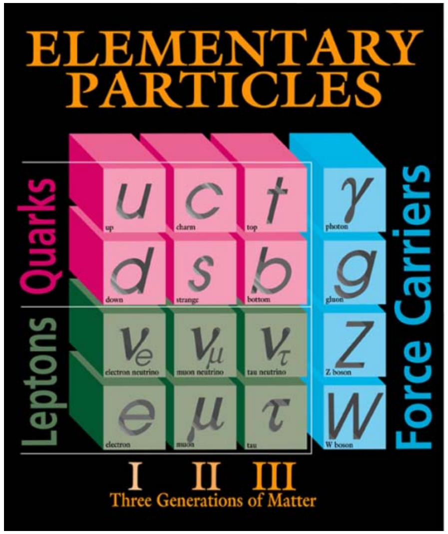
$$\mu = E_N - E_{N-1}$$

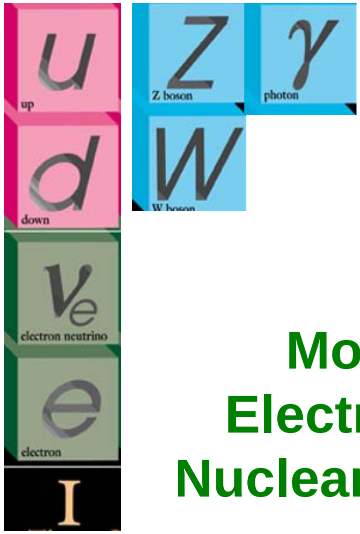
$$\mu = mc^2 + \overline{\frac{1}{2}m\mathrm{v}^2} + \overline{e\left(\Phi + \frac{\mathbf{v}\cdot\mathbf{A}}{c}\right)}$$

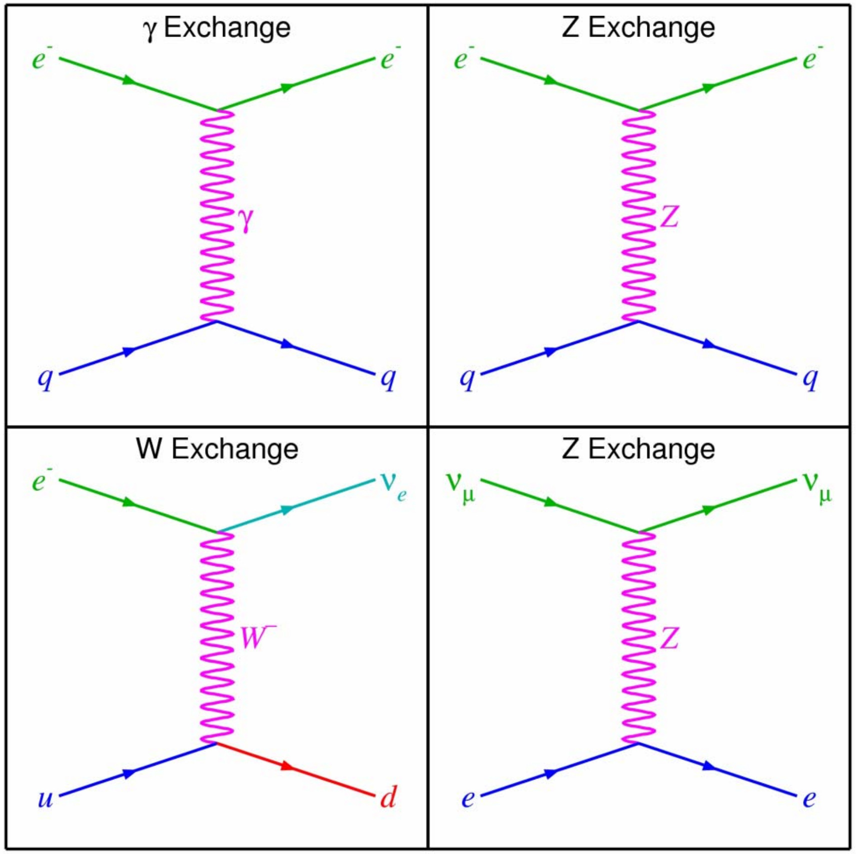
In the dilute gas phase, the dominant chemical potential of a charged particle is the rest mass first term on the right hand side of the above equation. Nuclear physicists have generally calculated the activity by the calculating mass differences and conclude that the above weak interaction is energetically unfavorable. However, if the electromagnetic third term on the right hand side of the above chemical potential equation is taken into account, then the other charges can electromagnetically collectively contribute to the chemical potentials of the charged particles.

The reaction can be energetically favorable *if many of the other charged particles contribute some energy* when the electron and proton are destroyed. The is the essence of condensed matter enhancement of reactions.

Weak Interactions I

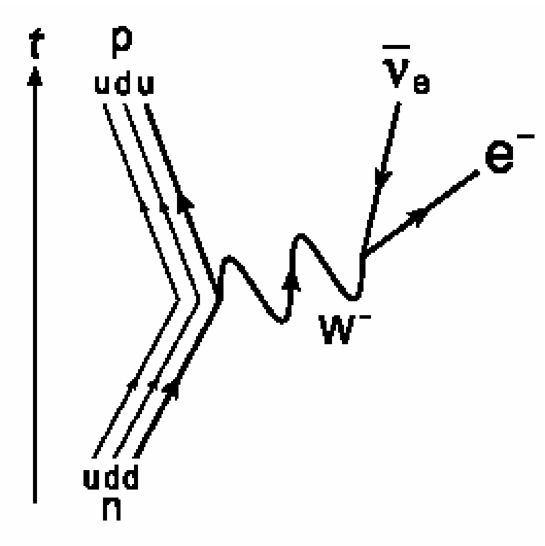






Most of Electroweak Nuclear Physics

Weak Interactions II



$$n \rightarrow p^+ + e^- + \bar{\nu}_e$$

Weak Decay of the Neutron

$$n + {}^{A}_{Z}X \rightarrow {}^{A+1}_{Z}X + \gamma$$

Strong Nuclear Transmutation

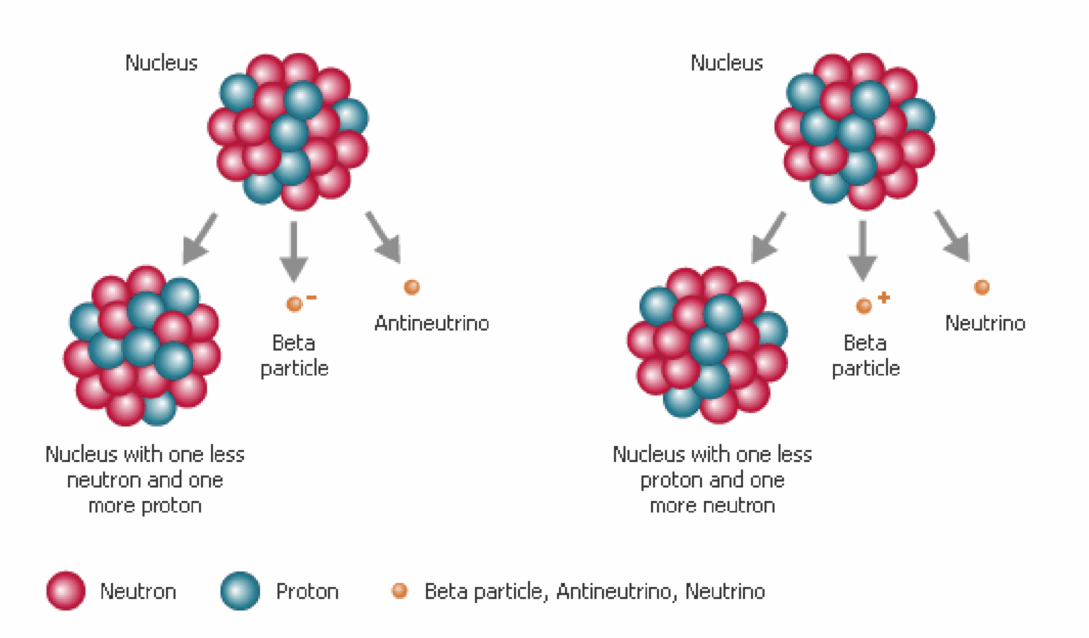
***Z*=Charge Number**

***A*=Baryon Number**

$$e^- + p^+ \rightarrow n + \nu_e$$

Weak Production of the Neutron

Weak Interactions III



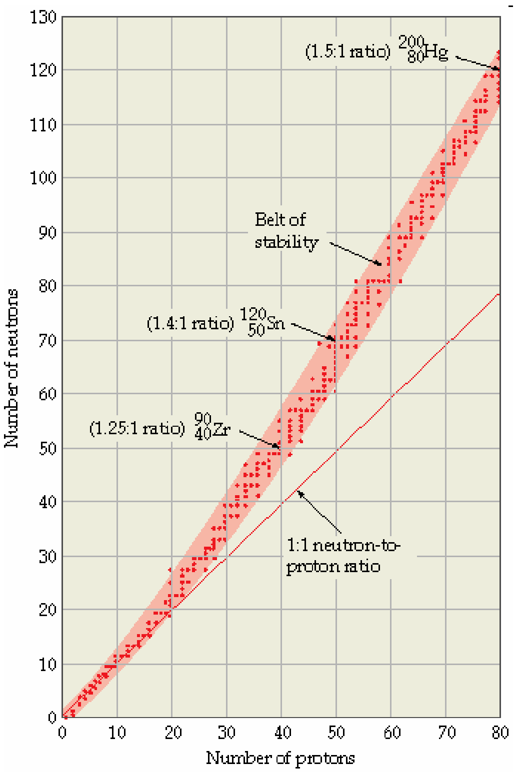
$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}X + e^{-} + \overline{\nu}_e $$

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}X + e^{+} + \nu_e $$

$$ e^{-} + {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}X + \nu_e $$

Weak Nuclear Transmutations

Weak Interactions IV



$$M(Z,A)c^2 = AM_n c^2 + Z(M_p - M_n)c^2 - B(Z,A)$$

$$-B(Z,A) = -\varepsilon_1 A + \varepsilon_2 A^{2/3} + \varepsilon_3 \left(\frac{Z^2}{A^{1/3}}\right) + \varepsilon_4 \frac{(A-2Z)^2}{A} + \varepsilon_5 \frac{\lambda}{A^{3/4}}$$

$$\varepsilon_1 = 15.75 \text{ MeV} \qquad \varepsilon_2 = 17.8 \text{ MeV} \qquad \varepsilon_3 = 0.71 \text{ MeV}$$

$$\varepsilon_4 = 23.7 \text{ MeV} \qquad \varepsilon_5 = 34 \text{ MeV}$$

$$\lambda = +1 \quad \text{if} \quad \text{odd} - \text{odd}$$

$$\lambda = 0 \quad \text{if} \quad \text{odd} - \text{even}$$

$$\lambda = -1 \quad \text{if} \quad \text{even} - \text{even}$$

The nuclear voltage is Φ(Z,A).

$$e\Phi(Z,A) = c^2 \frac{\partial M(Z,A)}{\partial Z}$$

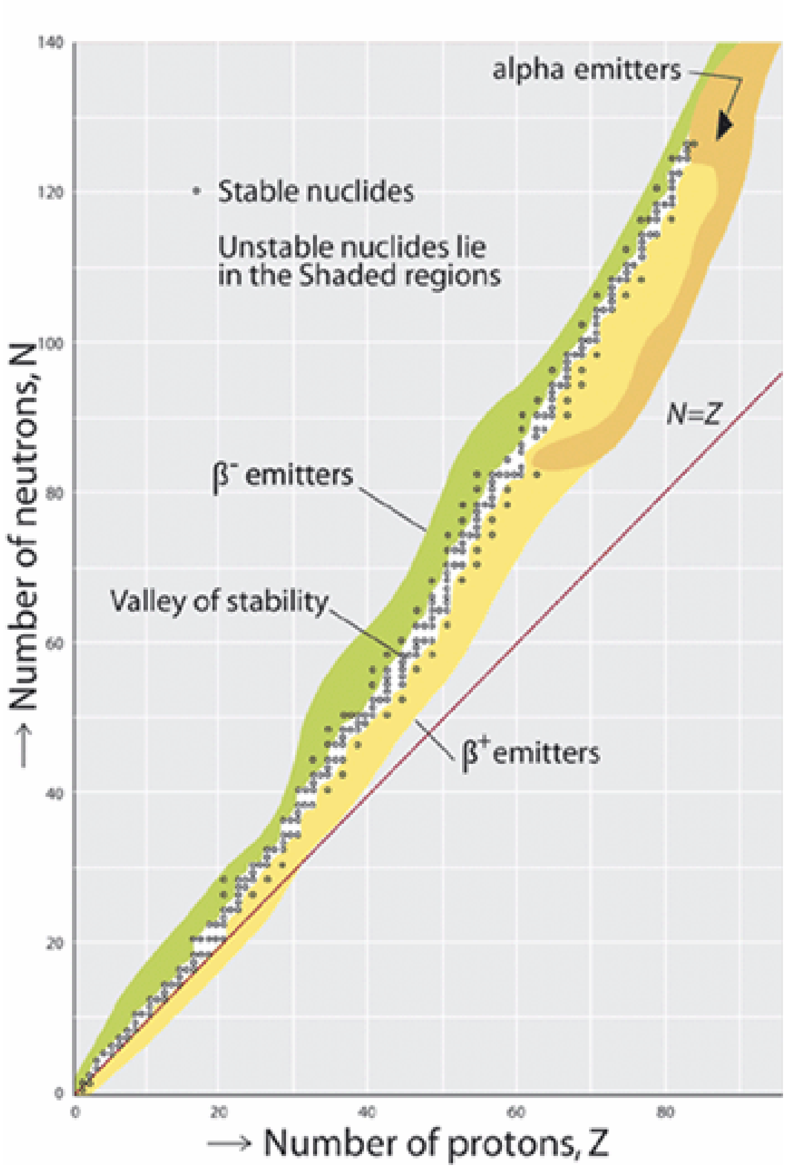
$$\Phi(Z^*,A) = 0$$

$$Z^* = \frac{A}{2 + (\varepsilon_3 / 2\varepsilon_4) A^{2/3}} \approx \frac{A}{2 + 0.015 A^{2/3}}$$

The stable nuclei lie on a plot of

N*=A-Z* vs Z*.

Weak Interactions V



The stable nuclei for Z<50 arise from β⁻ decay from the neutron rich unstable nuclei and arise from β⁺ decay from the proton rich unstable nuclei.

Low (negative) voltage Φ⁻ yields β⁻ decay.

High (positive) voltage Φ⁺ yields β⁺ decay.

Weak Interactions VI

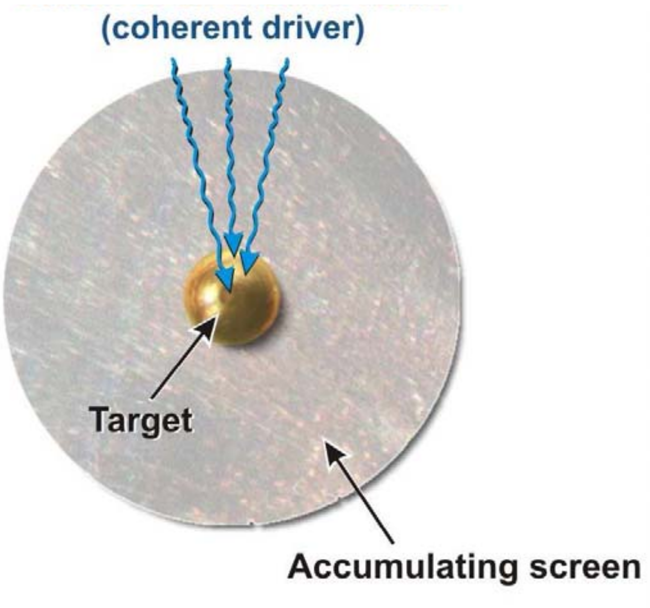
$$\overline{\Phi}_a = e\left\langle \sum_{b\neq a}\frac{Z_b}{|\mathbf{R}_a-\mathbf{R}_b|} - \sum_j \frac{1}{|\mathbf{R}_a-\mathbf{r}_j|}\right\rangle$$

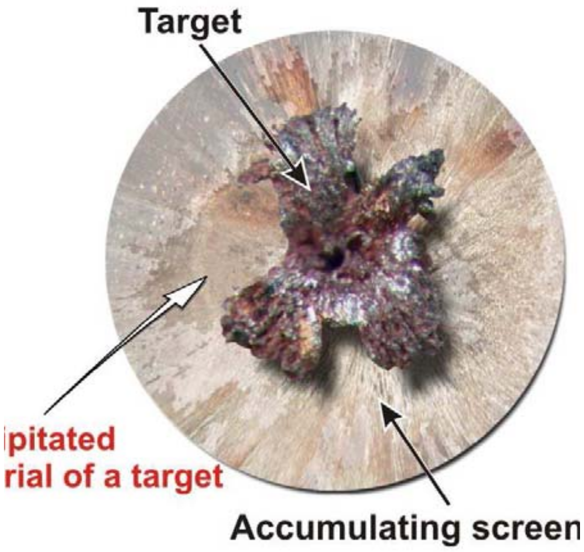
$$+\,e\left(\frac{\mathbf{v}_a}{2c^2}\right)\cdot\left\langle \sum_{b\neq a}\frac{Z_b(\mathbf{1}+\mathbf{n}_{ab}\mathbf{n}_{ab})\cdot\mathbf{V}_b}{|\mathbf{R}_a-\mathbf{R}_b|} - \sum_j\frac{(\mathbf{1}+\mathbf{n}_{aj}\mathbf{n}_{aj})\cdot\mathbf{v}_j}{|\mathbf{R}_a-\mathbf{r}_j|}\right\rangle$$

Coupling Between One Charge and all of the Others

Nuclear Reactions

Weak Interaction Sources I

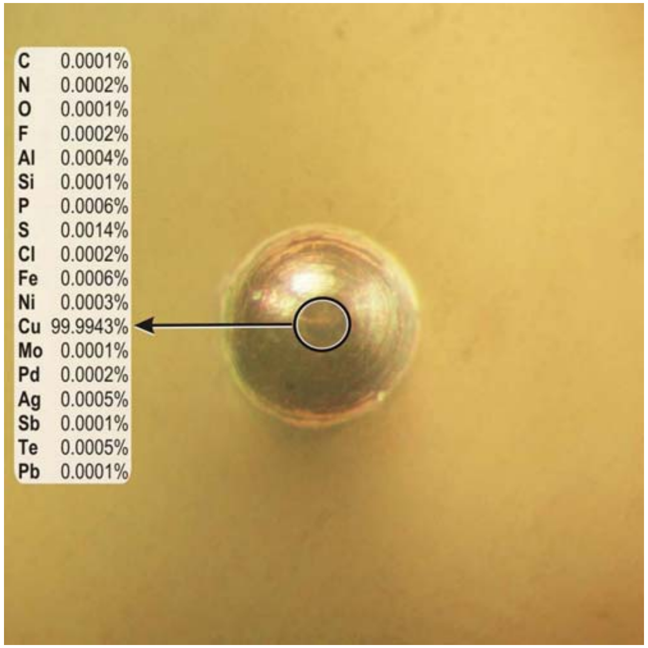




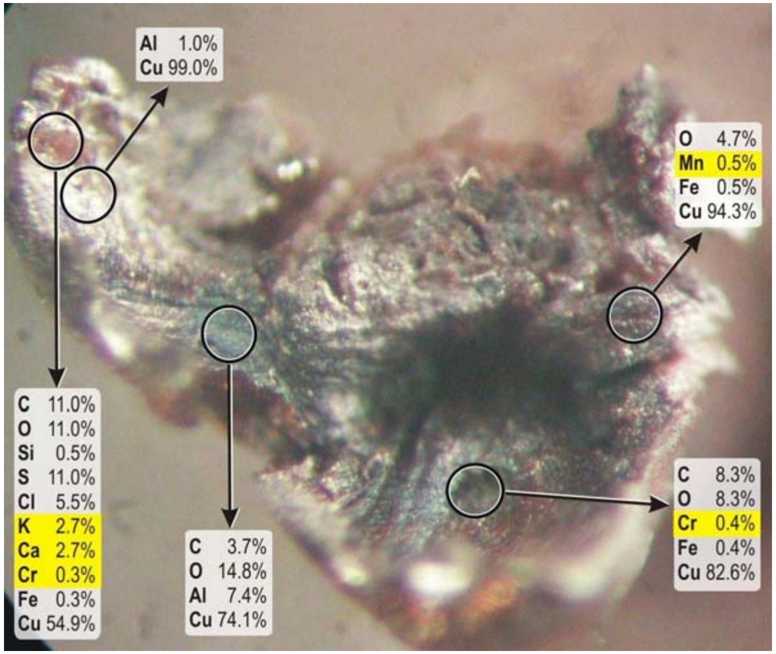
Proton21 Electron Beam is sent into a very pure Copper on the Screen Target

Proton21 After the pulse one looks for Nuclear Transmutation Products in the Remains

Weak Interaction Sources II



C	0.0001%
N	0.0002%
O	0.0001%
F	0.0002%
Al	0.0004%
Si	0.0001%
P	0.0006%
S	0.0014%
Cl	0.0002%
Fe	0.0006%
Ni	0.0003%
Cu	99.9943%
Mo	0.0001%
Pd	0.0002%
Ag	0.0005%
Sb	0.0001%
Te	0.0005%
Pb	0.0001%



Al	1.0%
Cu	99.0%

O	4.7%
Mn	0.5%
Fe	0.5%
Cu	94.3%

C	11.0%
O	11.0%
Si	0.5%
S	11.0%
Cl	5.5%
K	2.7%
Ca	2.7%
Cr	0.3%
Fe	0.3%
Cu	54.9%

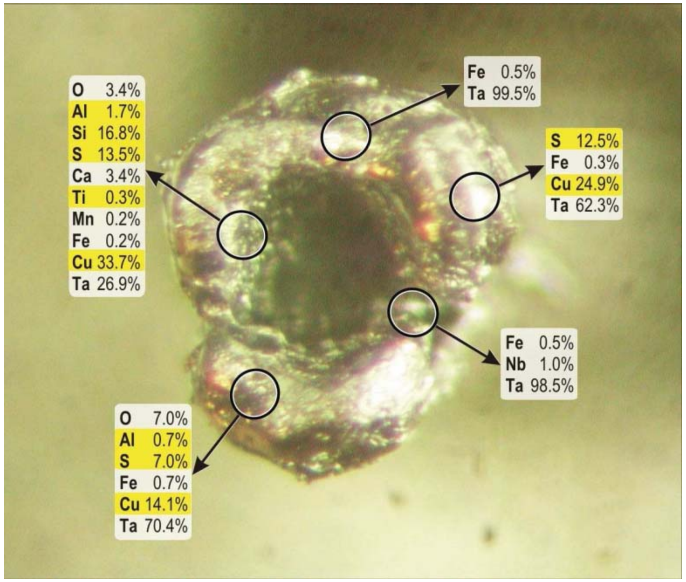
C	3.7%
O	14.8%
Al	7.4%
Cu	74.1%

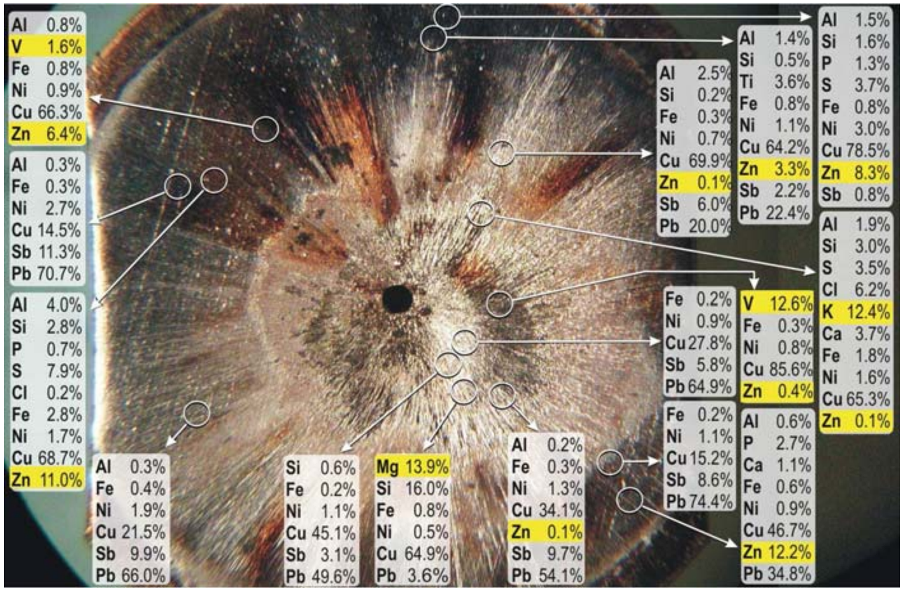
C	8.3%
O	8.3%
Cr	0.4%
Fe	0.4%
Cu	82.6%

Proton21 **Chemical Composition Before and After Electron Pulse**

Nuclear Reactions

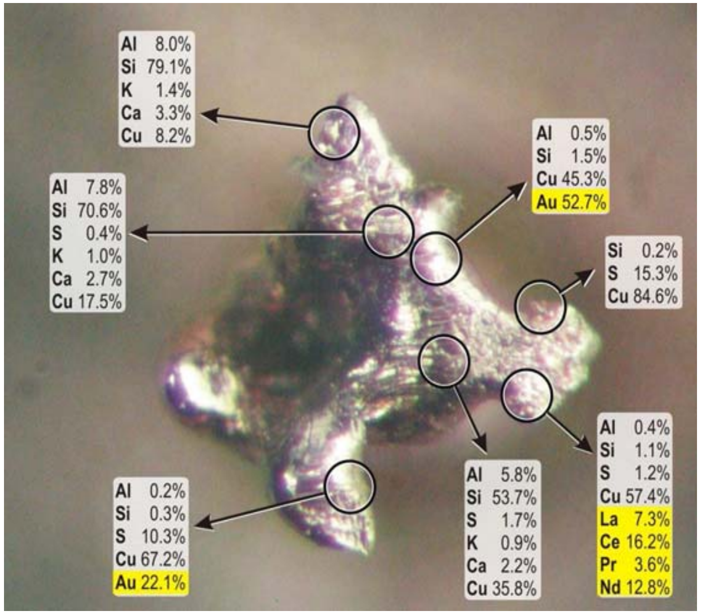
Weak Interaction Sources III

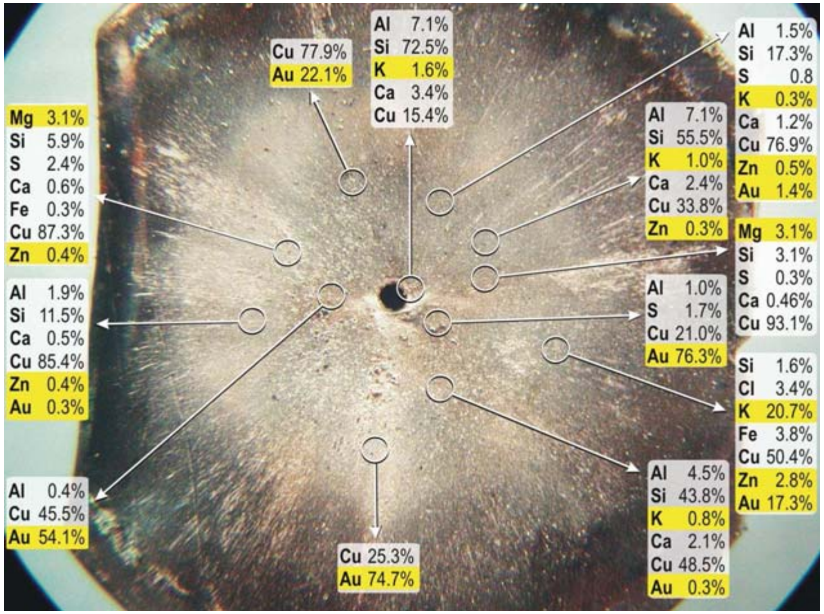




Proton21 Chemical Composition on Different Samples within the Sample Remains and on the Detection Screen

Weak Interaction Sources IV

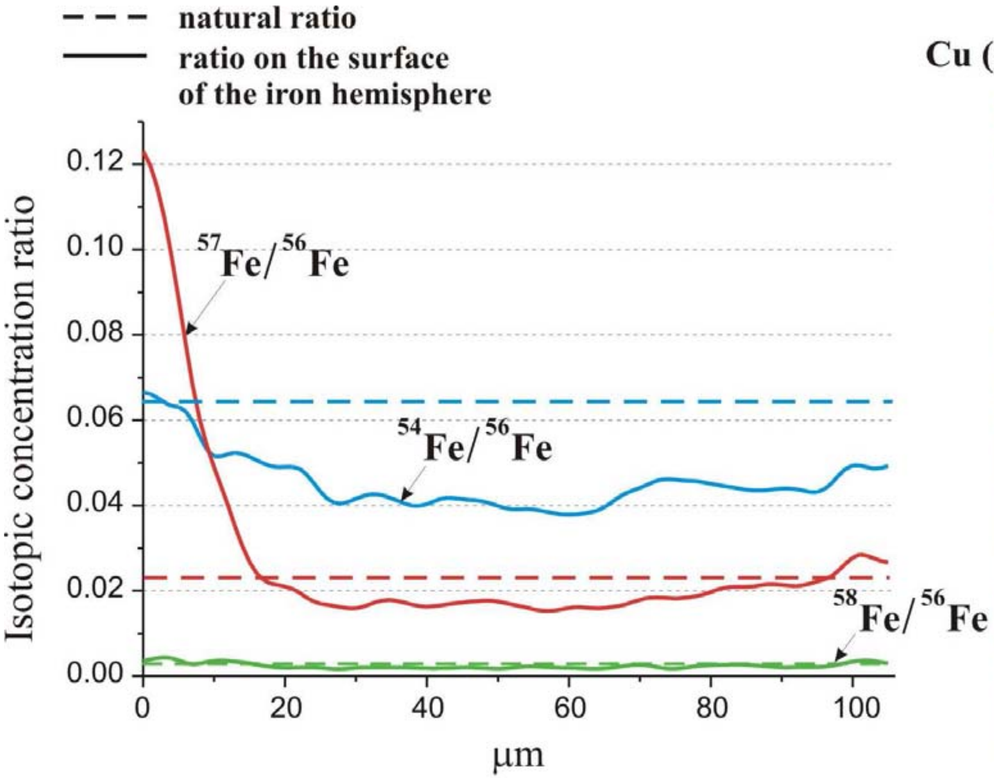


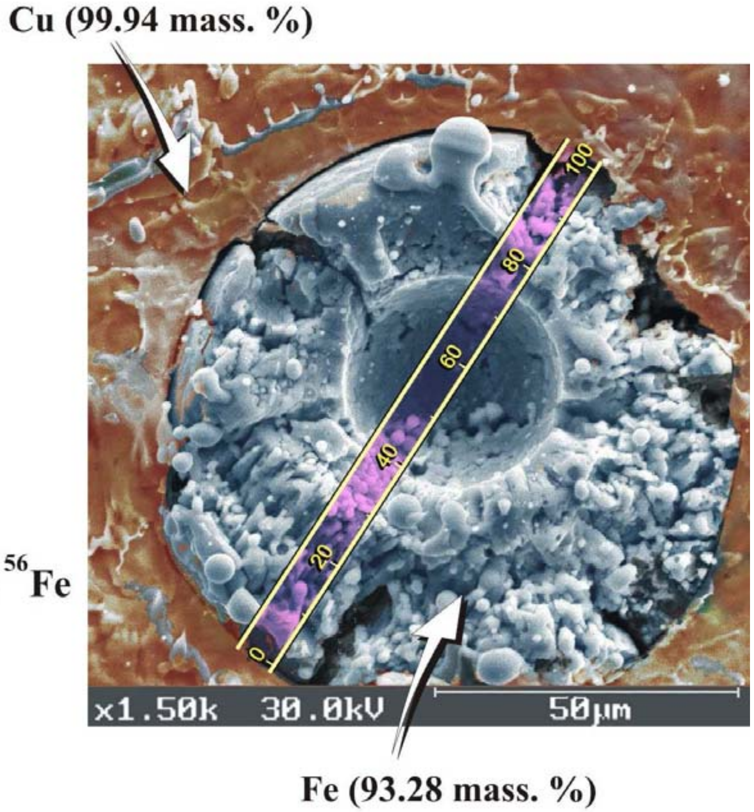


On this sample one transmutes copper into gold.

Nuclear Reactions

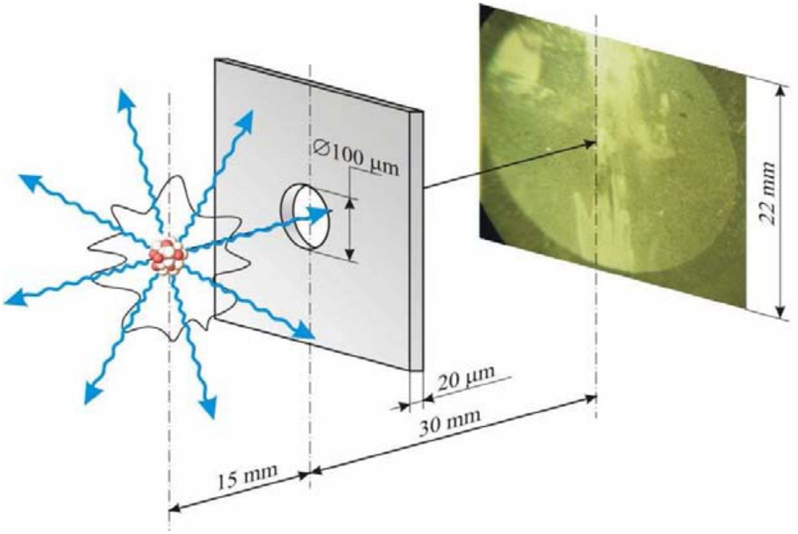
Weak Interaction Sources IV





Nuclear Transmuted Isotope Distribution does not Match the Natural Distribution of Isotopes

Weak Interaction Sources V



Measured Picture of the Plasma Flash. The plasma radiations distributions are very similar to those observed being emitted by astrophysical objects

Astrophysical Object Producing Radiation	Energy Range in KeV	Correlation
Quasar 3C273	10-4000	0.94
Crab Nebular Cluster	10-4000	0.92
Gamma Burst	20-800	0.99
Supernova CH1987A	10-700	-0.23
Sun	200-5000	-0.9 6
Deceleration Emission	20-500	0.24

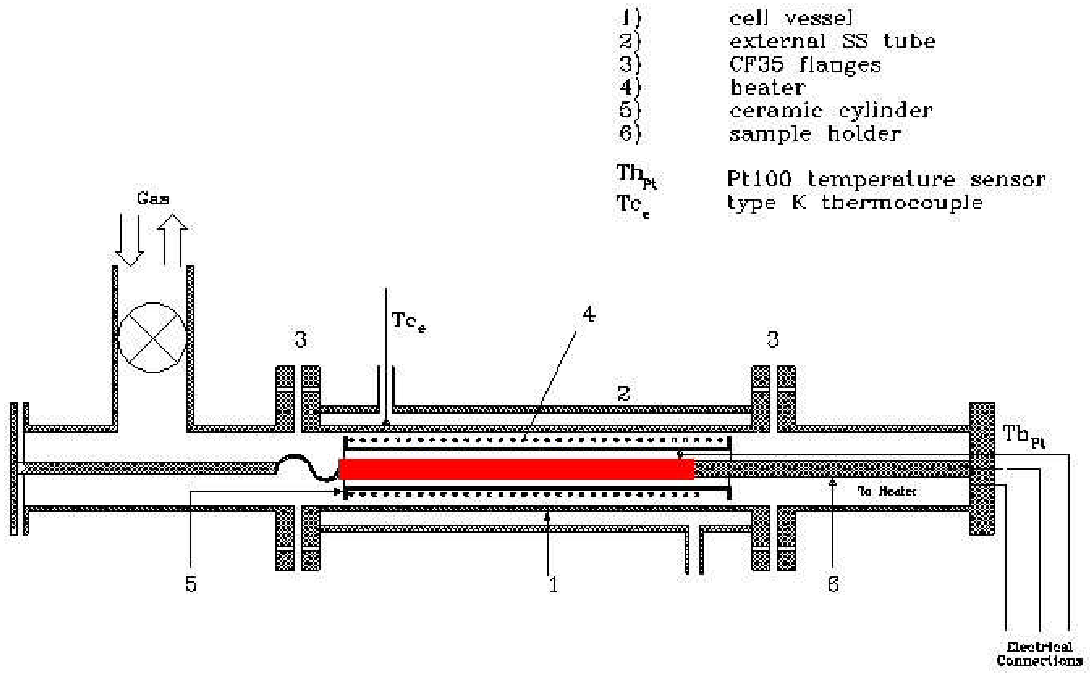
Nickel Hydride Sources I

E. Campari*, S. Focardi*, V. Gabbani, V. Montalbano**, F. Piantelli**, S. Veronesi+****

*** Dipartimento di fisica, Università di Bologna –Centro I.M.O.**
**** Dipartimento di fisica, Università di Siena –Centro I.M.O.**
+ I.N.F.M. –UdR Siena

Heated Nickel Hydride bars ran at a temperature T~700 C at steady state for ~6 months. The heat input P(in)~100 Watt while the heat output P(out)~150 Watt.

Nickel Hydride Sources II

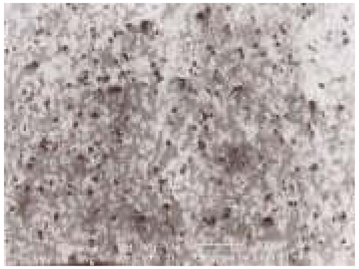


1)	cell vessel
2)	external SS tube
3)	CF35 flanges
4)	heater
5)	ceramic cylinder
6)	sample holder
Th_{Pt}	Pt100 temperature sensor
Tc_e	type K thermocouple

Experimental Setup

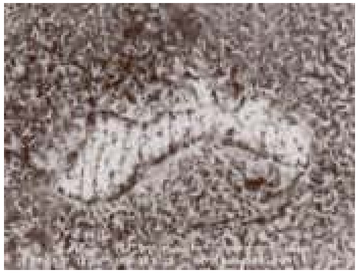
Nuclear Reactions

Nickel Hydride Sources III



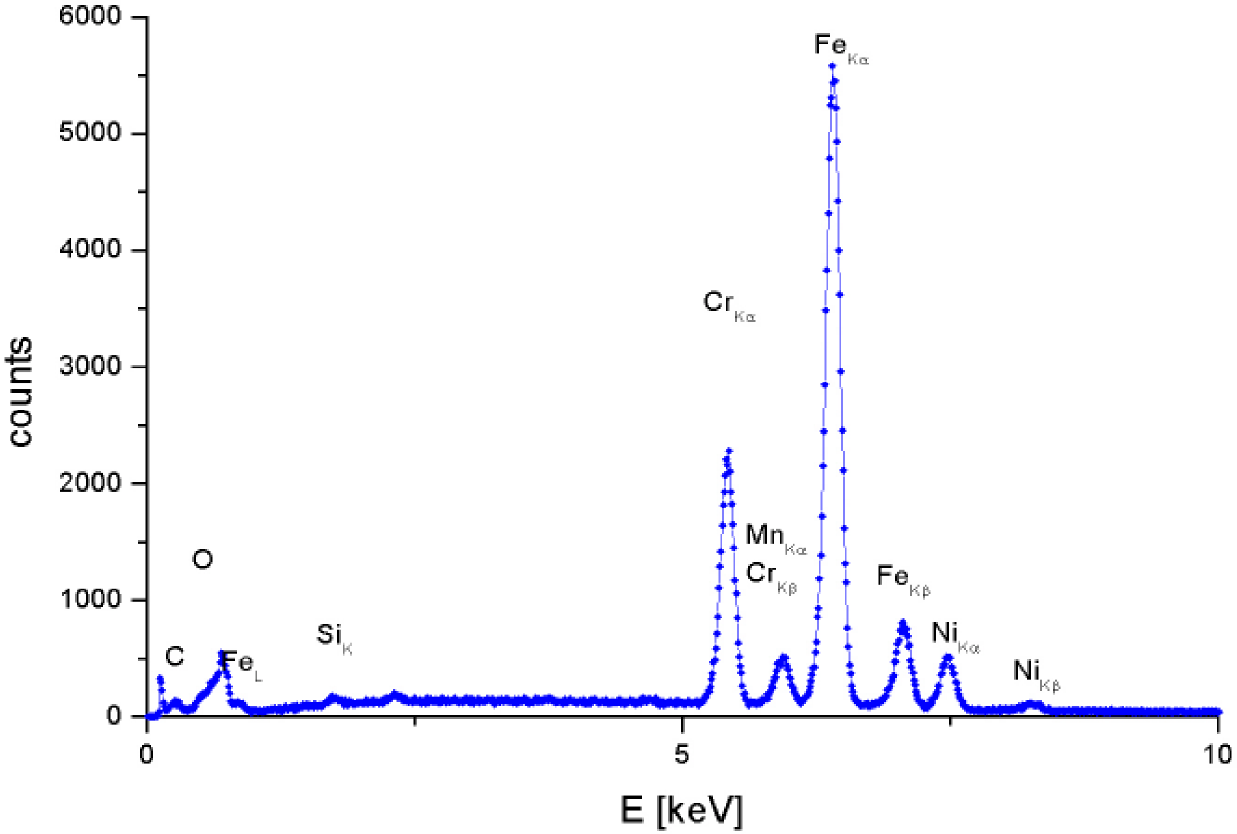
200 micron length scale

50 micron length scale



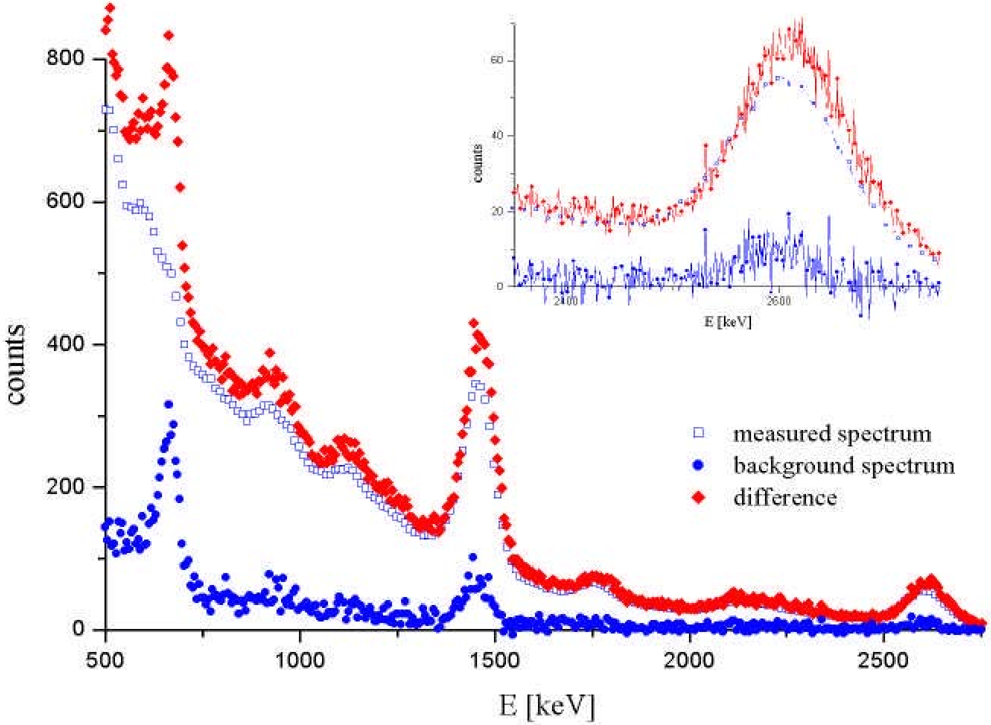
10 micron length scale

Nickel Hydride Sources IV



Chemical Composition

Nickel Hydride Sources V



Radiation Distribution

Nuclear Reactions

Nickel Hydride Sources VI

$$e^- + {}^{58}_{28}Ni \rightarrow {}^{58}_{27}Co + \nu_e$$

$$e^- + {}^{58}_{28}Ni \rightarrow {}^{57}_{27}Co + n + \nu_e$$

$$e^- + {}^{58}_{28}Ni \rightarrow {}^{56}_{27}Co + 2n + \nu_e$$

$$e^- + {}^{58}_{28}Ni \rightarrow {}^{55}_{27}Co + 3n + \nu_e$$

$$e^- + {}^{58}_{28}Ni \rightarrow {}^{54}_{27}Co + 4n + \nu_e$$

$$e^- + {}^{58}_{28}Ni \rightarrow {}^{53}_{27}Co + 5n + \nu_e$$

Weak Interaction production of five different isotopes of Co.

Nuclear Reactions

Nickel Hydride Sources V

$$ {}^{58}_{27}Co \rightarrow {}^{58}_{26}Fe + e^{+} + \nu_e $$

$$ {}^{57}_{27}Co \rightarrow {}^{57}_{26}Fe + e^{+} + \nu_e $$

$$ {}^{56}_{27}Co \rightarrow {}^{56}_{26}Fe + e^{+} + \nu_e $$

$$ {}^{55}_{27}Co \rightarrow {}^{55}_{26}Fe + e^{+} + \nu_e \rightarrow {}^{55}_{25}Mn + 2e^{+} + 2\nu_e $$

$$ {}^{54}_{27}Co \rightarrow {}^{54}_{26}Fe + e^{+} + \nu_e $$

$$ {}^{53}_{27}Co \rightarrow {}^{53}_{26}Fe + e^{+} + \nu_e \rightarrow {}^{53}_{25}Mn + 2e^{+} + 2\nu_e \rightarrow {}^{53}_{24}Cr + 3e^{+} + 3\nu_e $$

Ni goes into isotopic mixtures of Co which then decays into Fe, Mn and Cr

Conclusions

1. **Strong Interaction fission works well but for Z > 30 has badly behaved end products**
1. **Strong hot fusion has products with low Z < 30, but has hard confinement problems.**
2. **LASER induced fusion has not yet passed a large enough fusion production.**
3. **Weak Interaction LENR effects show the best prospects with the nuclear burning of Ni proved possible with significant heating outputs.**
4. **Clean nuclear fuels have promising future prospects.**