LENR Experiment & Theory

From Fleischmann & Pons

To Defkalion & Rossi

And Beyond

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What are we doing here?

1. Rossi and Defkalion have built LENR power generators

2. I'm going to tell you how these generators work

3. Then I'll tell you how to make them work better

Goals of the talk

1. Describe a nuclear model that can explain the remarkable excess power results obtained by Rossi and by Defkalion (and very probably by others)

2. Show how key experiments have directed evolution of the model

3. Suggest how the model may direct further evolution of LENR technology

Initial Evidence and Interpretations

1. **Fleischmann and Pons** (F&P)
   - Electrolysis of D_2O on Pd cathode
   - Excess heat
   - Tritium

   Interpretation: Possible student prank?
2. **Oriani**
   - Electrolysis of D_2O on Pd cathode
   - Excess heat confirms F&P

   Interpretation: No prank — must be nuclear
3. **Miles**
   - Electrolysis of D_2O on Pd cathode
   - Helium in proportion to heat

   Interpretation: Probable D fuel, He ash
4. **Oriani**
   - Electrolysis of H_2O on Ni cathode
   - Energetic particles (CR39 tracks)

   Interpretation: Polyneutron theory

Polyneutron Theory

1. Constraints
   - Quantum mechanics
   - Coulomb barrier
   - Neutral reactants required
   - Neutrons? Too few seen
   - Polyneutrons? The only possibility
2. Polyneutrons
   - Bound neutron clusters $^{A}\mathbf{n}$
     (Indicated by bold)
   - $A \geq 6$, no upper limit
3. Charged Poly-n Nuclei
   - Bound nucleon clusters $^{A}\mathbf{H}$, $^{A}\mathbf{He}$, ...
     (Indicated by bold)
   - $A \geq 6$, no upper limit
   - New family of isotopes

Some LENR Reactions

1. Polyneutron growth

$$^{A}\mathbf{n} + {}^{2}\mathrm{H} \longrightarrow {}^{A+1}\mathbf{n} + {}^{1}\mathrm{H}$$
$$^{A+1}\mathbf{n} + {}^{2}\mathrm{H} \longrightarrow {}^{A+2}\mathbf{n} + {}^{1}\mathrm{H}$$
$$^{A+2}\mathbf{n} + {}^{2}\mathrm{H} \longrightarrow {}^{A+3}\mathbf{n} + {}^{1}\mathrm{H}$$
$$^{A+3}\mathbf{n} + {}^{2}\mathrm{H} \longrightarrow {}^{A+4}\mathbf{n} + {}^{1}\mathrm{H}$$

2. Poly-n isotope beta decay

$$^{A}\mathbf{n} \longrightarrow {}^{A}\mathbf{H}$$
$$^{A}\mathbf{H} \longrightarrow {}^{A}\mathbf{He}$$
$$^{A}\mathbf{He} \longrightarrow {}^{A}\mathbf{Li}$$

3. Poly-n isotope alpha decay

$$^{A}\mathbf{He} \longrightarrow {}^{A-4}\mathbf{n} + {}^{4}\mathrm{He}$$
$$^{A}\mathbf{Li} \longrightarrow {}^{A-4}\mathbf{H} + {}^{4}\mathrm{He}$$

Heat and Helium

1. **Step-by-step:**

   Four growth reactions:

   $$^{A}\mathbf{n} + 4\,(^{2}\mathrm{H}) \;\longrightarrow\; ^{A+4}\mathbf{n} + 4\,(^{1}\mathrm{H})$$

   Two beta decays:

   $$^{A+4}\mathbf{n} \quad\longrightarrow\quad ^{A+4}\mathbf{He}$$

   One alpha decay ($^{A}\mathbf{n}$ restored):

   $$^{A+4}\mathbf{He} \;\longrightarrow\; ^{A}\mathbf{n} + {}^{4}\mathrm{He}$$

2. **Overall:**

   $$4\,(^{2}\mathrm{H}) \longrightarrow 4\,(^{1}\mathrm{H}) + {}^{4}\mathrm{He} + 21\,\mathrm{MeV}$$

   - 21MeV per ^{4}He
     agrees with experiment
   - $4\,(^{1}\mathrm{H})$ per ^{4}He
     predicted ratio not yet measured

Heat After Death

Pons & Fleischmann

1. Electrolytic D/Pd reactor
2. Boils dry (death)
3. Fluid mixing stops
4. No growth reaction
5. Beta and alpha decays continue
6. Heat continues
7. Poly-n concentration goes to zero
8. Heat stops
9. Heat after death lifetime: about 3 hours
10. Skewed toward long lifetime (Swartz)
    Very long lifetime tail to $^{A}\mathbf{n}$ (theory)

The Initial Poly-n Isotope

1. Assume LENR reactions occur in nature
   - Big bang? Solar? Terrestrial?
   - Very low concentration, very long lifetime decay tails to $^{A}\mathbf{n}$
2. Virgin laboratory
   - Very rare natural poly-n decay
   - Long wait for $^{A}\mathbf{n}$ in early days
3. Contaminated laboratory
   - Successful cathode from successful laboratory brings poly-n isotopes
   - Poly-n contamination of personnel & equipment from initial success
   - Short wait for $^{A}\mathbf{n}$

Transmutation

1. Iwamura evidence

$$\mathrm{Sr} \longrightarrow \mathrm{Mo}, \quad \mathrm{Cs} \longrightarrow \mathrm{Pr}, \quad \mathrm{Ba} \longrightarrow \mathrm{Sm}$$

2. Transmutation reactions transfer neutrons

$$^{\mathrm{A+C}}\mathbf{n} + {}^{\mathrm{D}}\mathrm{Z} \longrightarrow {}^{\mathrm{A}}\mathbf{n} + {}^{\mathrm{C+D}}\mathrm{Z}$$

3. Beta decay of $^{\mathrm{C+D}}\mathrm{Z}$ creates new element:

$$^{\mathrm{C+D}}\mathrm{Z} \longrightarrow {}^{\mathrm{C+D}}(\mathrm{Z}+1)$$

4. Transmutation releases energy
5. Reduces the number of neutrons bound in poly-n isotopes

Neutron Isotope Fission

1. Growth and decay reactions conserve the number of poly-n isotopes.
2. But the number of poly-n isotopes can decrease by
   (a) diffusion of ${}^{A}\mathbf{n}$ from the reactor (Oriani)
   (b) the breakup reactions (theory)

$$^{6}\mathbf{He} \longrightarrow {}^{4}\mathrm{He} + 2\mathrm{n}$$

$$^{6}\mathbf{H} \longrightarrow {}^{3}\mathrm{H} + 3\mathrm{n}$$

3. Polyneutron fission is required to build up and maintain a large poly-n isotope population. Each fission reaction adds one polyneutron:

$$^{A+B+C}\mathbf{n} + {}^{D}\mathrm{Z} \longrightarrow {}^{A}\mathbf{n} + {}^{B}\mathbf{n} + {}^{C+D}\mathrm{Z}$$

   and competes with the transmutation reaction

$$^{A+B+C}\mathbf{n} + {}^{D}\mathrm{Z} \longrightarrow {}^{A+B}\mathbf{n} + {}^{C+D}\mathrm{Z}$$

   - Each fission reduces by C the number of nucleons bound in poly-n isotopes
   - This loss plus loss from the associated transmutation reaction must be less than the gain from growth reactions
   - Hence the concentration of fission fuel ${}^{D}\mathrm{Z}$ must be sufficiently small

Heat and Helium Revision

1. *Recall:* 4 growth reactions, 2 beta decays, and 1 alpha decay produce
   Overall: $4\,(^2\mathrm{H}) \longrightarrow 4\,(^1\mathrm{H}) + {}^4\mathrm{He} + 21\,\mathrm{MeV}$
   - 21MeV per ^{4}He
     agrees with experiment
2. **Overall energy** of 21 MeV must be
   (a) *Reduced* by the undetectable kinetic energies of two neutrinos released in the beta decays
   (b) *Increased* by the energy released in the fission and associated transmutation reactions that build up and maintain a steady-state polyneutron isotope population
   - These two corrections are small and have opposite signs
3. After correction we have (with small uncertainty)

$$4\,(^2\mathrm{H}) \longrightarrow 4\,(^1\mathrm{H}) + {}^4\mathrm{He} + \sim{}_{21}\mathrm{Mev}$$

✓ Still in agreement with experiment

Hagelstein Criterion

1. **Experiment:** Almost no neutrons are observed in LENR
2. **Hagelstein Criterion:** Energetic alpha particles would produce observable knock-on neutrons

   Hence, either

   (1) There must be no energetic LENR alpha particles

   (2) Neutrons must be captured before they can be observed
3. Hegelstein has investigated the possibility that LENR reaction energy is released as phonon excitations and that no energetic particles are produced
4. *Polyneutron theory* proposes that knock-on neutrons are captured in these reactions:

$$\mathrm{n} + {}^{A}\mathbf{H} \longrightarrow {}^{A}\mathbf{n} + {}^{1}\mathrm{H}$$

$$\mathrm{n} + {}^{A}\mathbf{He} \longrightarrow {}^{A}\mathbf{H} + {}^{1}\mathrm{H}$$

$$\mathrm{n} + {}^{A}\mathbf{Li} \longrightarrow {}^{A}\mathbf{He} + {}^{1}\mathrm{H}$$

...and so on

5. **Conclusion:** The Hagelstein Criterion is met

The Role of Fluid Mixing

1. Fleischmann–Pons reactor produces D in solution at cathode
   - Solution becomes supersaturated with D
2. Bubbles of D are nucleated at cathode irregularities
   - Rapid bubble growth causes high shear rate in bubble
3. Shear deformation mixes potential reactants $^{A}\mathbf{n}$ and D in bubble
   - LENR rate increases
4. Diffusion rate in hot vapor mixes reactants still more rapidly
   - LENR reaction rate is dramatically increased
   - Temperature of vapor rises exponentially
5. A micro-explosion
   - Produces a flash of radiant heat
   - Enough energy to melt palladium cathode surface
6. Bubble nucleation site is blown clear of electrolyte
   - Electrolysis is interrupted at that site
7. The site cools down
   - Electrolyte returns
   - Electrolysis resumes
8. Another LENR cycle produces another micro-explosion
9. Sparkling thermal energy flashes cover the cathode surface

To Rossi and Beyond
As I see it

Polyneutron Growth Fuels

Fleischmann & Pons	Deuterium in D_2O
Iwamura	Deuterium gas
Defkalion	Deuterium (in hydrogen gas?)
Rossi	Deuterium (in hydrogen gas?)
Beyond	Deuterium in natural H gas? Deuterium in natural H_2O? Cerium? Other fuels?

To Rossi and Beyond
As I see it

Polyneutron Fission Fuels

Fleischmann & Pons	Palladium? Sulfur? Oxygen?
Iwamura	Calcium
Defkalion	Nickel (even mass-number isotopes)
Rossi	Nickel? Secret ingredient?
Beyond	Argon? Other gas?

Reaction Control Methods

Fleischmann & Pons	Micro-explosive dispersal
Mizuno	Explosive boiling dispersal?
Iwamura	Cooling by deuterium flow? Micro-explosive dispersal?
Defkalion	Cooling water flow
Rossi	External power reduction
Beyond	Growth and fission fuel gas flow rates Radiant energy gate

How far have we come?

Key Experiments	Nuclear Connection	Significance
F&P	Heat	Established nuclear reaction
Miles	Heat and He	Established nuclear ash
P&F	Heat after death	Established product decay
Iwamura	Ca fuel	Established second fuel
Defkalion	^{A}Ni (even A) fuel	Confirmed second fuel
H + Ni	Not nuclear	Motivated Rossi, Defkalion
Rossi, Defkalion	High temp. gas reaction	Path to future power

Essential ingredients for practical power generation

1. Polyneutron growth fuel
    - Deuterium
2. Polyneutron fission fuel
    - Calcium, even-A nickel, other
3. Reaction starters
    - Pre-used material or equipment for first polyneutron
    - Heat pulse ignition for gas reactors
4. Mixing (to bring polyneutrons and fuels together)
    - Solid state diffusion (only possibility for solid micro-power devices)
    - Mechanical stirring (liquid and low power gas reactions)
    - Hot gas diffusion (high power devices)
5. Control system
    - Self-supporting LENR is unstable, produces exponential growth
    - Need control system or fuel flow limitation
        - Normal heat loss for micro-power and low power
        - Rossi cooling system too wasteful? Radiation gate?
        - Defkalion cooling system too slow? Fuel flow limitation?
        - Fuel dilution with hydrogen or other?

Refine and Teach

I believe that now, on the 25th anniversary of the F&P discovery

1. A significant level of power generation has been achieved
2. A basis for theoretical understanding has been achieved
3. These insights must be refined and taught to the science and innovation communities