Reazioni nucleari con materiali “Smart”
[Nuclear reactions induced by “Smart” materials]

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Il Piano dell’ seminario: Plan of the talk

- Un breve reassunto di teoria per innescare reazioni nucleari a bassa energia:
  
  [Brief review of Low Energy Nuclear Theory [LENT]]

- Applicazioni a tre materiali “Smart”: piro e piezo-elettrici, piezo-magnetici
  
  [Application to Pyro-electrics, Piezo-electric and Piezo-magnetic rocks - examples of three “smart” materials]
The Early Theoretical Explorers [I primi esploratori teorici]

Julian Schwinger

Giuliano Preparata
Important Issues

Between Schwinger and Preparata, they looked at essentially all aspects of the experimental phenomena and provided possible theoretical reasons — much more than that by their critics —

- Coulomb Barrier
- Intermittency
- Coherence and Collectivity
- Neutron Haloes
- Resonant Tunneling
- Loading
- Burst; Shut-down; Cracking
The Missing Links:

What was missing in the analyses of Schwinger and Preparata?

Two important elements that would be discovered only through experiments after their demise:

- A: The Japanese CF results showed that all the action is from a few atomic layers near the surface. They are not volume effects.

- B: Neither included the weak interactions. Widom would introduce that.
Widom added the Weak Force for LENT following the Fermi dictum:

Give me enough neutrons
And I shall give you the Entire Periodic Table

\[ n + {}^A X_Z \rightarrow {}^{A+1} X_Z + \gamma \]

\[ {}^A Y_Z \rightarrow {}^A Y_{Z+1} + e^- + \bar{\nu}_e \]
Electrons and protons in condensed matter have low kinetic energy and the inverse beta decay [electron capture by Wick]

\[ e^- + p \rightarrow n + \nu_e \]

has a Q-value deficit of about 0.78 MeV. This means an energy \( W \geq 0.78 \text{ MeV} \) needs to be put into the system for the reaction

\[ W_{in} + e^- + p \rightarrow n + \nu_e \]

to proceed. \( W \) can be

(i) **Electrical Energy:** Widom-Larsen

(ii) **Magnetic Energy:** Widom-Larsen-Srivastava

(iii) **Elastic [Piezoelectric & Piezo-magnetic] Energy:** Widom-Swain-Srivastava

We have examples in Nature for all three
Threshold Energy Input for EW LENT

\[ W = \gamma mc^2 \]

\[ W > W_{\text{threshold}} \sim 1.28 \text{ MeV} \]

\[ \gamma_{\text{threshold}} \sim 2.5 \]

Lack of this energy in usual condensed matter systems is why we have electromagnetic devices and not electroweak devices. Special methods are hence necessary to produce neutrons.
Rate of Neutron Production

• Once the threshold is reached, the differential rate for weak neutron production is

$$\Gamma_2 \approx \left( \frac{3g_V^2 + g_A^2}{2\pi^2} \right) \left( \frac{G_F m^2}{\hbar c} \right)^2 \left( \frac{mc^2}{\hbar} \right) n_2 (\gamma - \gamma_{\text{threshold}})^2$$

$$\Gamma_2 \approx \omega \left( \gamma - \gamma_{\text{threshold}} \right)^2$$

$$10^{12} \frac{Hz}{cm^2} < \omega < 10^{14} \frac{Hz}{cm^2}$$

A robust production rate for neutrons
Rome group claims: neutrons unlikely
Experimentally Untrue!
Experimental Evidence of Neutron Production in a Plasma Discharge Electrolytic Cell

Domenico Cerillo, Roberto Germano, V. Tontodonato, A. Widom, YS, E. Del Giudice, G. Vitiello

Key Engineering Materials, 495 (2012) 104
Plasma Cell XV: Neutron Flux

![Graph showing neutron flux over exposure time with markers for CR39-sample1 and CR39-sample2.](image-url)
The Promete Naples Experiment XIV: Evidence for Nuclear Transmutation

Cathode: Pure Tungsten in K2CO3

Substances found afterwards on the surface:

1. Rhenium [always]
   With less abundance
2. Osmium
3. Tulium
4. Yttrium
5. Gold
6. Hafnium
7. Strontium
8. Calcium
9. Tin
10. Germanium
11. Zirconium
Electric Field Acceleration

• Excitation of surface plasma modes at a mean frequency $\Omega$, yields a fluctuating electric field $E$. These QED fluctuations renormalize the electron energy

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

$$W + M_p c^2 > M_n c^2$$

$$W = \gamma(mc^2) = mc^2 \sqrt{1 + \left(\frac{e^2 \bar{E}^2}{m^2 c^2 \Omega^2}\right)}$$
Electric Field Mode II

- Electric Mode $[W-L]$

Surface Plasmon Polariton $[SPP]$ evanescent resonance modes can be set up on a metallic hydride surface generating strong local electric fields to accelerate the electrons.

\[
W_{\text{electric}} + e^- + p \rightarrow n + \nu_e
\]

The relevant scale of the electric field and the plasma frequency needed to accelerate the electrons to trigger neutron production is given by:

\[
\Omega \sim 0.5 \times 10^6 \text{ Volts}
\]

Hence when requisite electric field and the frequencies are reached, very low momentum $[\text{called Ultra Cold}]$ neutrons can be produced.
4 Acid tests for LENT

For truly conclusive evidence that LENT has indeed occurred in a given experiment, we must have:

1. EM radiation [gamma’s in the (100 KeV-MeV) range]

2. Neutrons must be observed

3. Observance of materials not initially present
LENT in Nature: Neutrons from Lightning

Mean Current about 35 Kilo Amperes

\[(I/I_0) \sim 2\]

Neutron generation in lightning bolts

G. N. Shah, H. Razdan, C. L. Bhat* & Q. M. Ali

Bhabha Atomic Research Centre, Nuclear Research Laboratory,
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Strong Flux of Low Energy Neutrons Produced by Thunderstorms

Salient results and conclusions derived by the experimentalists:

- Most of the observed neutrons are of low energy in contrast to cosmic ray measurements where higher energy neutrons dominate.
- Measured rates of neutrons are anomalously high and to accommodate them an extra ordinarily large intensity of radiation in the energy range (10–30) MeV, of the order of (10–30) quanta/cm²/sec. is needed to obtain the observed neutron flux.
- The obtained γ-ray emission flux was about 0.04 quanta/cm²/sec., 3 orders of magnitude less than the needed value.
- In all these observations the radiation intensity was observed at moderate energies (50–200) KeV [3 orders of magnitude lower than that needed]
We show that the source of a strong neutron flux at low energy is not theoretically anomalous. The explanation, employing the standard electroweak model, as due to the neutron producing reaction

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

which is energetically allowed via the large high current electron energy renormalization inside the core of a lightning bolt.
Consider an initially large number \((N + 1)\) of interacting electrons contributing to the electric current within the lightning bolt undergoing a weak process:

\[
(N + 1)e^+ + p^+ \rightarrow (N)e^- + n + \nu_e
\]

The importance of having a large number of “spectator” electrons is the induction of a coherent Darwin interaction between the electrons.

Although only one electron disappears, many electrons are required to yield a high collective contribution to the reaction energy which thereby enhances the nuclear activity. We have shown that the
Large values of the parameter Gamma

Rome group claims that maximum:

\[ \gamma \approx \left( \frac{2}{3} \right) \]

Experimentally untrue: With laser wakefields

1. Imperial College (2004) \[ \gamma \approx 140 \]
2. Berkeley (2004): \[ \gamma \approx 170 \]
3. LOA, France (2004): \[ \gamma \approx 340 \]
4. Berkeley (2006) \[ \gamma \approx 2000 \]
2nd Session – Experiments performed Multi-TW table top laser systems – Recent historical landmarks – First Mono-Energetic LWFA experiments

Mangles et al, Imperial College, UK: 70 MeV beam

Geddes et al, Lawrence Berkeley, USA: 85 MeV beam

Faure et al, LOA, France: 170 MeV beam

All images taken from Nature, 431
2nd Session – Experiments performed Multi-TW table top laser systems – Recent historical landmarks – First Mono-Energetic GeV experiment

Leemans et al,
Lawrence Berkeley, USA:
1000 MeV beam

Long interaction length, i.e. 33 mm, via guiding through a Hydrogen filled, discharge capillary

Note: Maximum electron acceleration ~ 100 GeV in km long linear accelerators

Image taken from Leemans et al., Nature Physics, 2 (2006)
Two Smart Materials

1. **Pyroelectric crystals**: when heated or cooled produce electric fields

2. **Piezoelectric crystals**: when crushed produce electric fields
Piezoelectric Solids

Strains in a crystal produce voltages across the crystal and vice versa.
Magnetite: piezomagnetic material

Magnetic counterpart of a piezo-electric material

Elastic energy is converted into Magnetic energy.
Theoretical explanation is provided for the experimental fact that fracturing piezoelectric rocks produce neutrons.

The mechanical energy is converted by the piezoelectric effect into electrical energy.

In a piezoelectric material [quartz, bone, hair, etc.], forming a class called “smart materials”, conversion of elastic energy can occur into electrical energy.
Neutron production from fracturing rocks [WSS]: II

\[ H_{int} = - \int \beta_{i j k} E_i w_{j k} d^3r \]

\( \varepsilon \)
Electric field

\( \omega \)
Strain tensor

\( \beta \)
Piezoelectric constant
Neutron production from fracturing rocks [WSS]: III

\[ D = E + 4\pi P, \]
\[ \epsilon_{ij}(\zeta) = \delta_{ij} + 4\pi \tilde{\chi}_{ij}(\zeta), \]
\[ \tilde{\chi}_{ij}(\zeta) = \chi_{ij}(\zeta) + \beta_{i,jk} D_{lknm}(\zeta) \beta_{j,nm} \]

- \( D_{ijkl} \) is the phonon propagator
- \( \epsilon_{ij} \) is the dielectric response tensor; it appears in the polarization part of the photon propagator
- The Feynman diagram shows how the photon propagator is affected by \( \beta_{ijk} \)
- The above makes us understand why mechanical acoustic frequencies occur in the electrical response of piezoelectric materials
Neutron production from fracturing rocks [WSS]: IV

Numerical Estimates:

(i) vs velocity of sound vs. c is $\sim 10^{-5}$
hence

$\frac{\omega_{\text{phonon}}}{\omega_{\text{photon}}} \sim 10^{-5}$ for similar sized cavities

(ii) The mean electric field $E \sim 10^{5}$ Gauss

(iii) The frequency of a sound wave is in the microwave range $\Omega \sim 3 \times 10^{10}$/sec.

$\Gamma(e^- + p^+ \rightarrow n + \nu_e) \sim 0.6$ Hz

$\omega_2 \sim 10^{15} \frac{\text{Hz}}{\text{cm}^2}$.
A pyroelectric crystal develops an electric field due to (adiabatic) changes in its temperature and its opposite: an applied electric field causing an adiabatic heating or cooling of the system is called the electrocaloric effect.

Examples of natural pyroelectric crystal are: tourmaline, bone, tendon.

It was experimentally shown that pyroelectric crystals when heated or cooled produced nuclear dd fusion evidenced by the signal of 2.5 MeV neutrons. The system was used to ionize the gas and accelerate the ions up to 200 KeV sufficient to cause dd fusion. The measured yields agree with the calculated yields.
Pyroelectrics II

• In a single domain of a pyro-electric crystal, the mean electric induction is not zero:
  \[ <\mathbf{D}> \neq 0 \]

• When such a crystal is heated or cooled, it gets spontaneously polarized: produces an electric field

• The effective electric field (E_{eff}) generated in the crystal is assumed proportional to the change in the temperature (\Delta T): 
  \[ E_{eff} = \phi \Delta T \]

• Lithium Tantalate [LiTaO3] has a large 
  \[ \phi = 17 \text{ KV/cm K} \]
Pyroelectrics III

- The energy given to an ion of charge e may be written as $eV = 4\pi et \phi(\Delta T)/\varepsilon$ [t is the thickness; $\varepsilon$ is the dielectric constant]

- For a two Lithium tantalate crystal set up, each 1 cm thick, $\varepsilon = 46$, $\Delta T = 100$ C, the energy should be

  $$E = (2e) \text{ Voltage} = 933 \text{ KeV}$$

- Instead the measured value is 200 KeV [In the core of the Sun it is only about 1.5 KeV]

- This energy is much more than sufficient for say two accelerated deuterons to overcome the Coulomb repulsion and cause fusion.

- Pyro fusion has been observed in several laboratories around the world.
$d + d \rightarrow ^3\text{He} + n$

**FIG. 1.** Neutron time-of-flight spectrum. Neutrons were detected 62 cm from the target using a 7 mm thick plastic scintillator. The peak occurs at $2.45 \pm 0.2$ MeV, characteristic of DD fusion.
Real photons and virtual photons [from electron scattering] have been used for over 50 years to disintegrate nuclei through giant dipole resonances. In the past, accelerators have produced the needed [10-50] MeV photons for breaking up nuclei. Our suggestion: accelerate electrons up to...
Electro-strong LENT II

Processes usually studied are 1 & 2 neutron production

\[ \gamma + A \rightarrow n + A^*; \gamma + A \rightarrow 2n + A^{**} \]

A* & A** are excited nuclei.

We have a synthesis of electromagnetic and strong forces in condensed matter via giant dipole resonances [GDR] to give an effective

“electro-strong interaction”

- a large coupling of electromagnetic and strong interactions in the tens of MeV range.
GDR are well-studied and represent a strong coupling between all atomic nuclei and photons in the range of (10-25) MeV.

GDR are well-known to be excited by electrons with a few tens of MeV with significant neutron yields (often 10−3 or more) per electron on thick targets, and both fast and slow neutrons can be produced.

GDR are very well understood and used, both theoretically and practically in devices well outside the scope of nuclear physics proper [for example in medical physics].
Electro-strong LENT IV

- When electrons are accelerated to tens of MeV in condensed matter systems, then in addition to producing neutrons via electroweak processes, we expect, and at much higher rates, what we call “electrostrong processes”, where nuclear reactions take place mediated by GDR.

- In this case one expects slow neutrons from evaporation of GDR’s as well as some fast ones, and additional nuclear reactions when those neutrons are absorbed.
Electro-strong LENT V

Once electrons are accelerated to tens of MeV in condensed matter systems, then we expect both endothermic and exothermic nuclear fission & appearance of new nuclei due to further reactions of the decay products including subsequent decays and/or the absorption of
AN EXAMPLE: ALUMINUM AND SILICON FROM IRON

\[ \gamma + ^{56}_{26} Fe \rightarrow 2[^{28}_{14} Si + e^- + \bar{\nu}_e] \]

\[ \gamma + ^{56}_{26} Fe \rightarrow 2[^{27}_{13} Al + n] \]

If electrons are accelerated to several tens of MeV in condensed matter systems containing iron, then one may expect the appearance of aluminum and silicon.

Experimental data: A. Carpinteri et al. [Politecnico Torino]
At tens of MeV, all three forces of the Standard Model of Particle Physics: electromagnetic, weak, and strong processes can all be expected to occur in bulk condensed matter.
The Preparata Project at Perugia

At University of Perugia, we have assembled a group of experimentalists who have begun a set of Proof of Concept experiments to implement and check the theoretical results obtained by our group.

Presently we have a 3-year doctoral candidate [EM] and a Laurea Specialistica student and we are expecting to add a Post-doctoral researcher depending upon the availability of funds.

Technical and research support is being provided by ENEL, who are our Collaborators.

Giuliano Preparata (1942-2000)
As stated before, for the completion of the project our goal would be to make all 4 Acid tests for LENT


2. Evidence of some produced neutrons

3. Evidence of some nuclear transmutations [new elements found after which were absent before]
The Preparata Project at Perugia III

Brief Description of the Proof of Concept phase

A: Electron Excitation via Surface Plasmons:
   A1: Selection and composition of materials
   A2: Induction of Surface Plasmon Polaritons
   A3: Detailed study of the resonance phenomena

B: Induction of nuclear reactions
   B1: Study of rates vs. materials
   B2: Spatial distribution of reaction regions [hot spots]

C: Detection of products of nuclear reactions
Synthesis of Electroweak & Electrostrong, fulfills the Fermi dictum to reproduce the entire periodic table given enough neutrons.

We dedicate it to the memory of the two J/Gulians: Julian Schwinger and Giuliano Preparata who worked so hard and suffered so much.
Summary and Future Prospects

Since, over a decade ago, when the pioneers in Italy GP, Emilio Del Giudice, De Ninno and their group were doing experiments, some theoretical and technical advances have occurred.

But more than that, the paradigm about low energy nuclear reactions has been shifting, albeit slowly.

Hence, our optimism. Time will tell.
Which is more likely? Electro-Weak LENT or this?
Spare Slides
A Sad Petition against Piezo nuclear processes

According to news reports, 1300 ricercatori Italiani have signed and sent a petition to the Italian Minister against nuclear reactions from piezoelectric materials and low energy nuclear reactions in general. There have been devastating articles in all major Italian newspapers: Corriere della Sera, La Stampa, La Repubblica, Il Manifesto,…

It saddens me that a majority of physicists who have signed, do not know much about piezo-electric effect even after signing.

They obviously do not know that Russian groups have reported [during the period 1953-1987] high energy particle production from fracturing certain crystals. They do not know that there is supporting Japanese work published in 1992 and that there is a serious discussion about this subject in a book published by the Cambridge University Press in 1993.
They do not know that fracture induced nuclear transmutations and neutron production have been reported by Russian groups in three papers [published in Nature, JETP and Physica], by an Indian group [published in Phys Lett A] and two papers by a Japanese group [published in Nuovo Cimento and Jap. J of App Phys]. We have ourselves published three papers in reputable journals on this subject.

As the Nobelist Julian Schwinger, might have said, have they forgotten that physics is an experimental science?

Let us turn to piezo electric theory.

How many of the signers know that there is a well studied Hamiltonian which describes how elastic energy is directly converted to electrical energy and vice versa?
How many have bothered to learn about Griffith’s law about micro-cracks? It teaches us that stresses needed to create a micro crack can be about a thousand times smaller than the stress needed to break all chemical bonds?

How many know that Carrara marble is not piezoelectric but quartz is? Quartz marbles when crushed would produce large electromagnetic radiation thanks to a direct transformation of piezoelectric elastic energy into electromagnetic energy.

How many theorists amongst the signers have bothered to draw and compute a one-loop Feynman diagram and check that the photon propagator inherits the acoustic frequencies in the microwave range?

How many have bothered to estimate the size of the electric fields generated through a microcrack in a piezoelectric crystal? And thence estimate how large an acceleration is imparted to an electron.
How many have bothered to estimate the chemical potential [which an electron sees] in order to find that it can easily be in several tens of MeV’s when a piezoelectric rock is crushed and hence more than capable of producing neutrons?

Alas, had they done so they would have shed their negative attitude and realized that a recent proposal to employ piezoelectric sensors for advanced warning against earthquakes has a lot of merit and certainly worthy of investigation by researchers for the general good of Italy.

Failure to do so would lead us to buy such devices in the near future from Japan most probably.

It is a reasonable fear that this petition would very soon lead to articles in Nature and Science [science equivalent of Moody’s or Standard & Poor for the financial world] trashing Italian physics, once a jewel of Italian and international science.
Rutherford had teamed up with British chemist Frederick Soddy to find that thorium produced argon:

They realized the implication with something akin to horror.
'The element was slowly and spontaneously transforming itself into argon gas!', Soddy later wrote. At the time, he was shocked.

Rutherford reportedly stammered to his colleague in the lab, `this is transmutation: the thorium is disintegrating."

`For Mike's sake Soddy', Rutherford thundered back, `don't call it transmutation. They'll have our heads off as alchemists.'

But transmutation was truly what it was.