Neutron Production from Crushing Piezoelectric Rocks

Allan Widom
Physics Department, Northeastern University
Boston Massachusetts 02115 USA
Piezoelectric Solids I

Strains in a crystal produce voltages across the crystal and vice versa.
Piezoelectric Solids II

The strain produces a voltage. The voltage produces a spark.
Piezoelectric Solids III

In the equivalent circuit, $C_0$ represents the geometric capacitance of the upper arm. $C_1$ represents the quartz oscillator spring constant and $L_1$ represents the oscillator mass in the mechanical lower arm circuit element. The resistance $R_1$ represents the slight mechanical oscillator damping due to mechanical viscosity.
Japanese Earthquake Takes Place around the times the light is emitted.
Earthquake Lights II

Day and Night Earthquake Lights
Earthquake Lights III

Satellite Pictures of the L’Aquila Region Around the Time of the 2009 Earthquake
Earthquake Sounds and Seismic Waves I

Seismic Waves can describe compression (P wave) strain or shear (S wave) strain.

P waves travel faster than do S waves.
Earthquake Sounds and Seismic Waves II

Fracture produced sound.
Fractured Granite Stone from a Mechanical Engineering Laboratory
Hydraulic Fracturing I
1. Drilling for maximum effect
The drilling turns horizontal at about 9,000 feet, hitting multiple fissures and increasing the volume of available natural gas.

2. Putting the Pressure On
A mixture of water, sand and chemicals is pumped into the pipe-line, which has small holes through which the mixture is forced.

3. Increase Gas Flow
The small fissures are widened by the pressure. The water mixture is pumped back out of the well and natural gas follows back up the pipeline to the wellhead.
Thermodynamics I

\[ du = Tds - \mathbf{P} \cdot d\mathbf{E} - \sigma : d\mathbf{w} \]

\[ \beta_{i,jk} = \left( \frac{\partial P_i}{\partial w_{jk}} \right)_{E,s} = \left( \frac{\partial \sigma_{jk}}{\partial E_i} \right)_{w,s} \]

\( u = \) energy per unit volume
\( T = \) temperature
\( s = \) entropy per unit volume
\( \mathbf{P} = \) polarization
\( \mathbf{E} = \) electric field
\( \sigma = \) stress tensor
\( \mathbf{w} = \) strain tensor
\( \beta = \) piezoelectric coefficient
Thermodynamics II

Feynman Diagram

Engineering Diagram

Mechanical Power = \( Fv = F \frac{dx}{dt} \)

Electrical Power = \( Ui = U \frac{dq}{dt} \)
Tensile Strength I

\[ \sigma_F = \text{tensile strength of a material beyond which the material fractures} \]

If the matter is held together by Coulomb's law, then in order of magnitude the electric fields \( E_F \) associated with fracture is determined.

\[ \sigma_F = \frac{E_F^2}{4\pi} \]
Tensile Strength

Brittle Fracture

Tensile Stress

\[ \sigma_F = \frac{E_F^2}{4\pi} \]
Micro-Cracks and Brittle Fracture I

Understanding fast macro-scale fracture from micro-crack post mortem patterns

C, Guerra, J. Scheibert, D. Bonamy, D. Dalmas

Proc Natl Acad Sci USA 109, 190 (2012)
Micro-Cracks and Brittle Fracture II

Micro Cracks on a Length Scale of 100 microns
Micro-Cracks and Brittle Fracture III

Micro Crack Energy per Unit Area is Related to The speed of Micro Crack Propagation Speed
Micro-Cracks and Brittle Fracture IV

Physical Micro Crack

Cartoon Drawing
Micro-Cracks and Brittle Fracture V

$Y = \text{Young's Modulus}$

$\nu = \text{Poisson Ratio}$

$\gamma_s = \text{surface tension}$

$a = \text{crack width}$

$\sigma_F = \text{tensile fracture stress}$

$u = \gamma_s a = \text{Min}_b \left( 4\gamma_s b - \pi b^2 \left[ \frac{(1 - \nu^2)\sigma_F^2}{Y} \right] \right)$

$a = \frac{2\gamma_s}{\pi} \left( \frac{Y}{(1 - \nu^2)\sigma_F^2} \right)$

$\sigma_F = \sqrt{\frac{2\gamma_s Y}{\pi (1 - \nu^2)a}}$
Electromagnetic and neutron emissions from brittle rocks failure: Experimental evidence and geological implications

A CARPINTERI1, G LACIDOGNA1, O BORLA1,2, A MANUELLO1 and G NICCOLINI3

1Politecnico di Torino, Department of Structural Engineering and Geotechnics, Corso Duca degli Abruzzi 24 – 10129 Torino, Italy
2National Institute of Nuclear Physics, INFN Via Pietro Giuria 1 – 10125 Torino, Italy
3National Research Institute of Metrology, INRIM Strada delle Cacce 91 –10135 Torino, Italy
Neutron Production Within Micro Cracks II:


Neutron production from the fracture of piezoelectric rocks

A Widom¹, J Swain¹ and Y N Srivastava²

¹ Physics Department, Northeastern University, Boston MA, USA
² Department of Physics & INFN, University of Perugia, Perugia, Italy
Neutron Production Within Micro Cracks III:

\[ \dot{p} = eE \]

\[ p^2 = \frac{e^2 E^2}{\omega_0^2} \]

\[ Mc^2 = m^2 c^4 + c^2 p^2 \]

\[ M = m \sqrt{1 + \left( \frac{E^2}{E_0^2} \right)} \]

\[ E_0 = \left( \frac{mc^2}{|e|} \right) \frac{\omega_0}{c} = \left( \frac{mc^2}{|e|} \right) \]

\[ p = \text{electron momentum} \]
\[ e = -|e| = \text{electron charge} \]
\[ E = \text{field} \]
\[ m = \text{vacuum electron mass} \]
\[ M = \text{Electron renormalized mass within the micro-crack} \]
\[ \omega_0 = \text{resonant field frequency} \]
\[ E_0 = \text{threshold electric field} \]

Forces on an Electron in a Micro-Crack
Neutron Production Within Micro Cracks IV:

\[ M = m \left( 1 + \left( \frac{4\pi \sigma_F}{E_0^2} \right) \right)^{1/2} \]

\[ N = m \left( 1 + \left( \frac{E}{E_0} \right)^2 \right)^{1/2} \]

\[ E_0 = \left( \frac{mc^2}{|e|} \right) \frac{\omega_0}{c} \]

\[ \sigma_F \sim 10^8 \text{ erg/cm} \]

\[ E \sim 10^5 \text{ Gauss} \]

\[ E_0 \sim 10^3 \text{ Gauss} \]

Piezoelectric Sound Coupling to Electromagnetic Fields determines the frequency \( \omega_0 \).

The electron mass renormalization is very large. \((M/m) \sim 10^2\).
Neutron Production Within Micro Cracks V:

The large mass enhancement of the electrons in the neighborhoods of the micro-cracks allow for the production of neutrons via the reaction

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

There Should be Considerable Microwave Radiation
Conclusion

Granite is a Piezoelectric Solid
Earthquake Lights and Sound Depend on Piezoelectricity
Laboratory Rock Fracturing is a Small Scale Earthquake
Hydraulic Fracturing Depends on Granite Rock Crushing
Micro-Cracks are Formed During Brittle Fracture
There is Neutron Production and Microwave Radiation