Nonlinear Energy Harvesting

Brent Cook; Luis Sanchez; Larissa Szwez; Joseph Tang; Yuhao Pan; Joshua Paul

Introduction

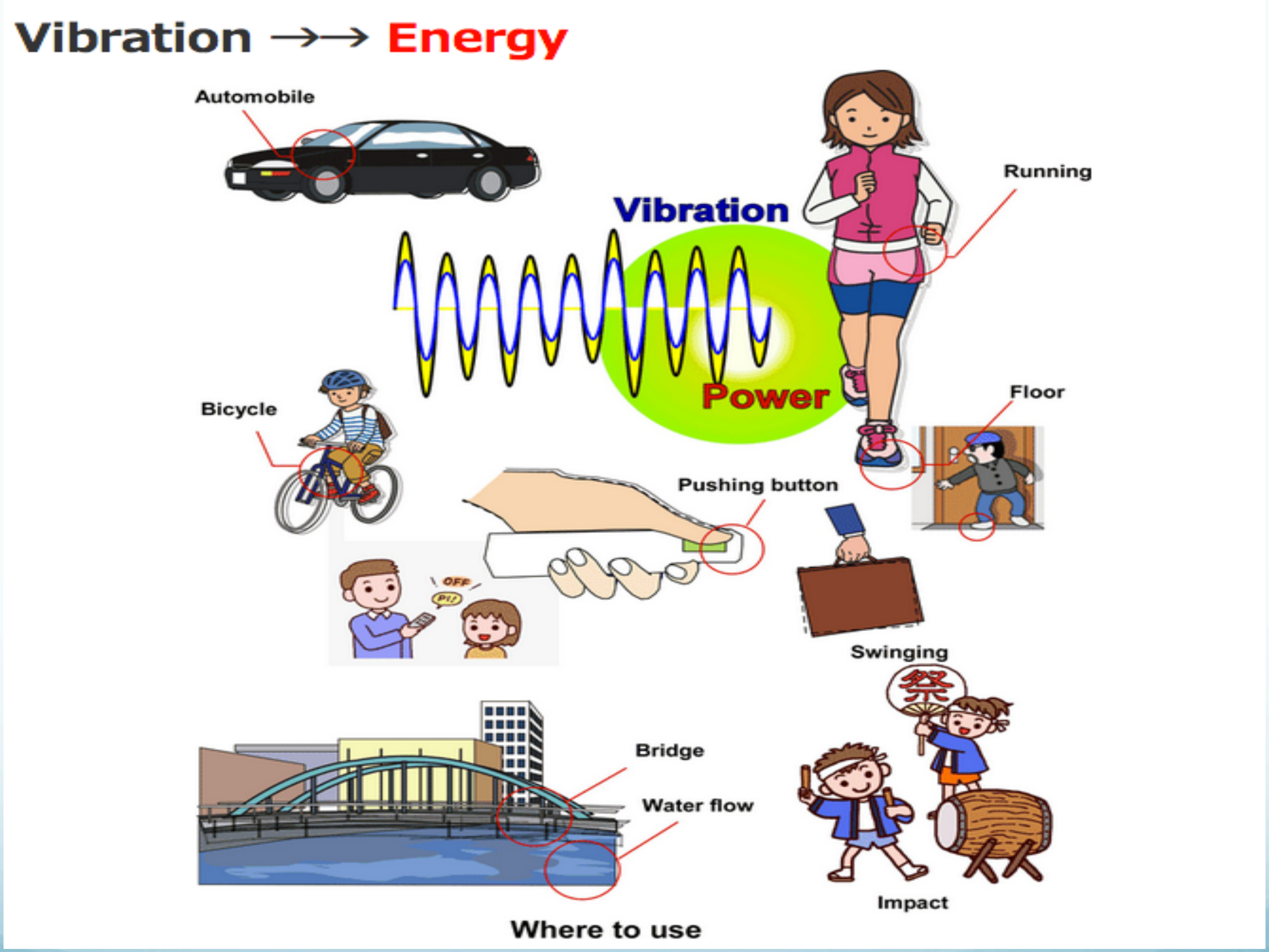


Image Source: http://vibpower.w3.kanazawa-u.ac.jp/about-e.html

Energy Harvesting

- Ambient Energy Harvesting becoming popular in research to charge mobile devices such as cell phones
- Multiple ways to harvest energy (convert kinetic energy to electrical energy)
  - Capacitive
  - Inductive
  - Piezoelectric

Image source: http://vibpower.w3.kanazawa-u.ac.jp/about-e.html

Application

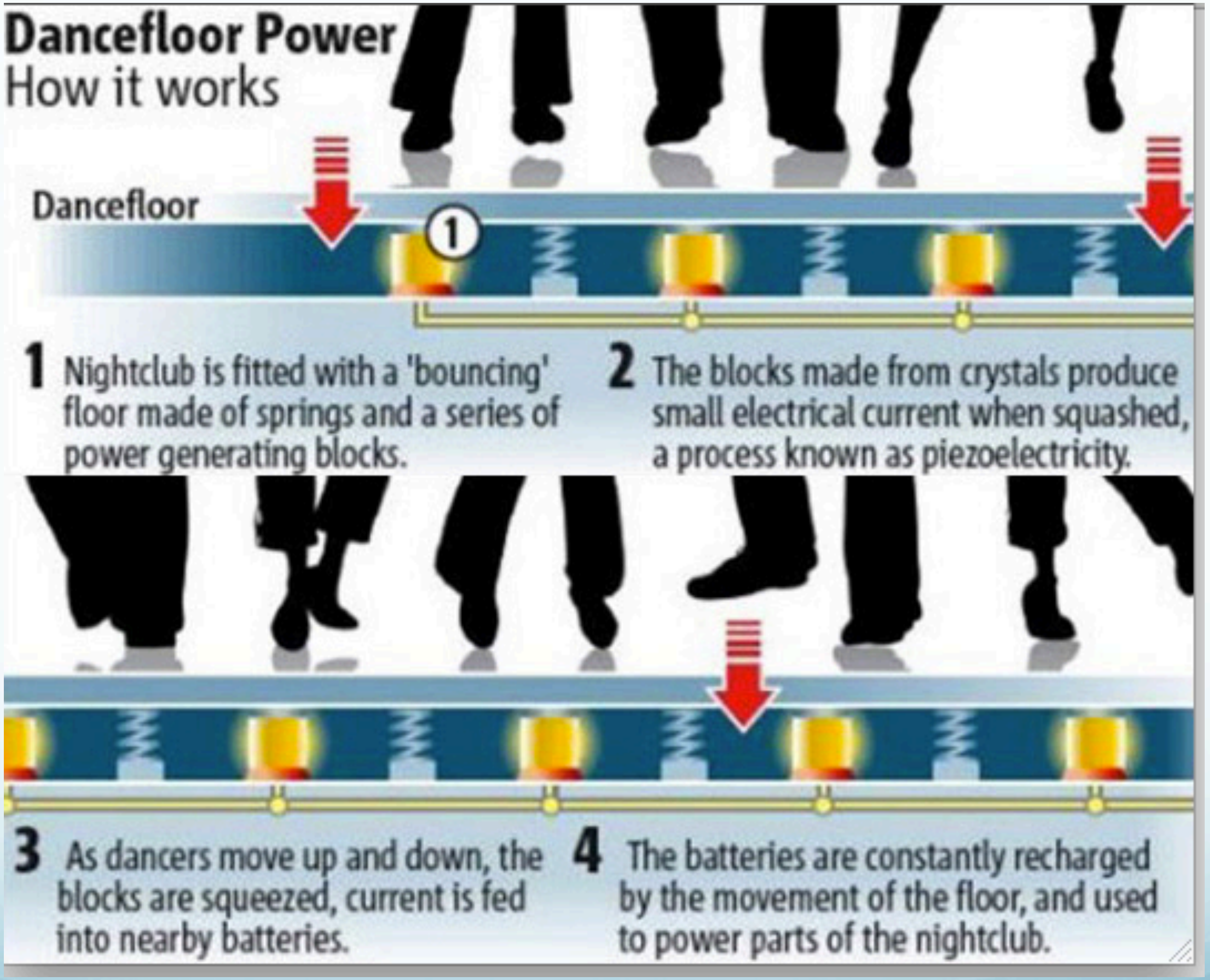


Image Source: http://inhabitat.com/green-a-go-go-at-londons-first-eco-disco

What is piezoelectricity?

Image source: http://leafcutterjohn.com/?p=1548

Crystal Structures

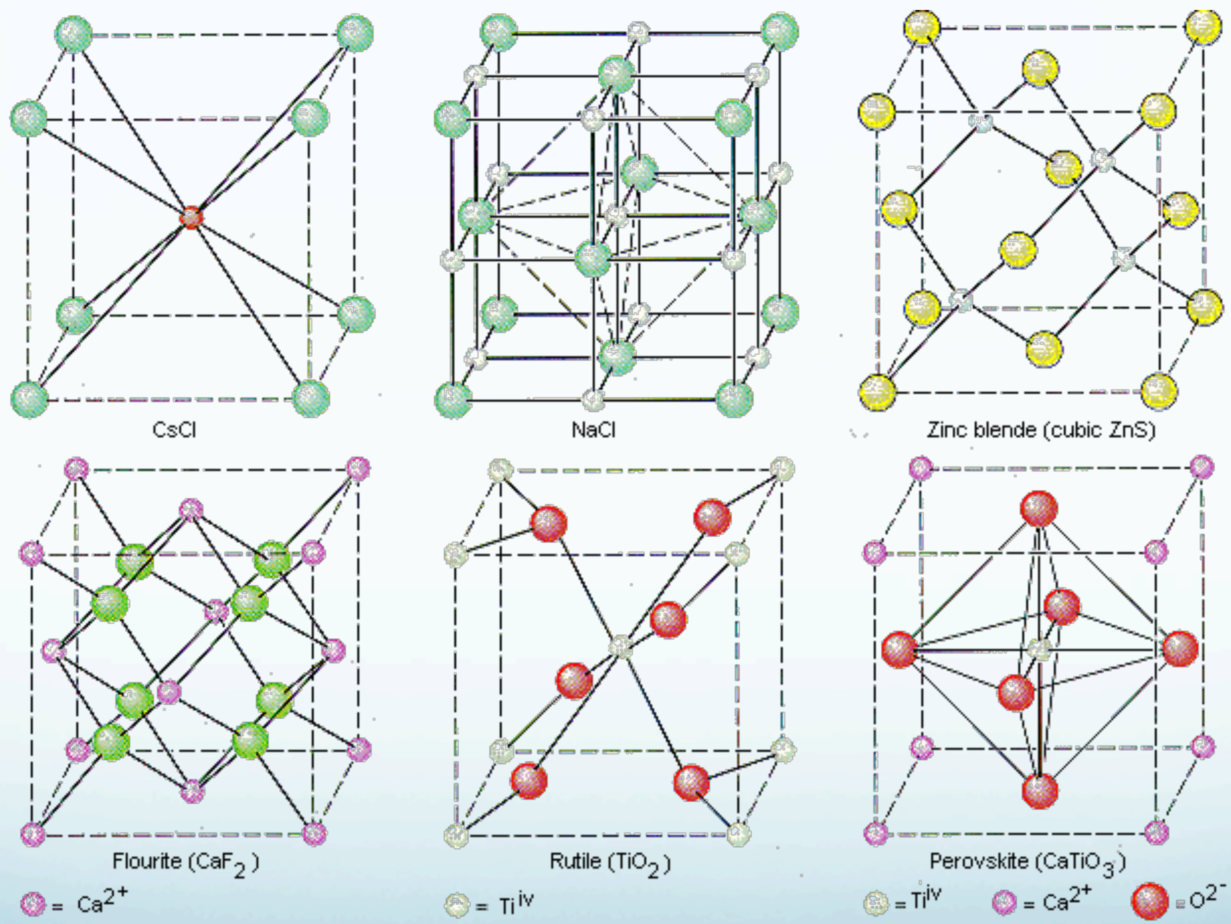
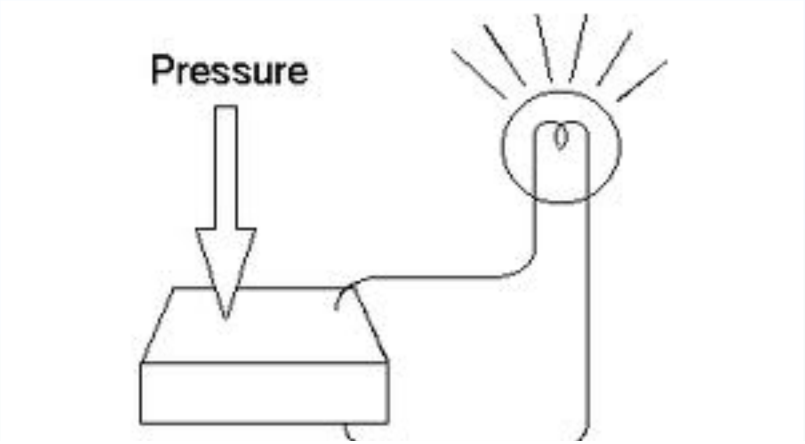


Image Source: http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch13/unitcell.php

Piezoelectric Effect



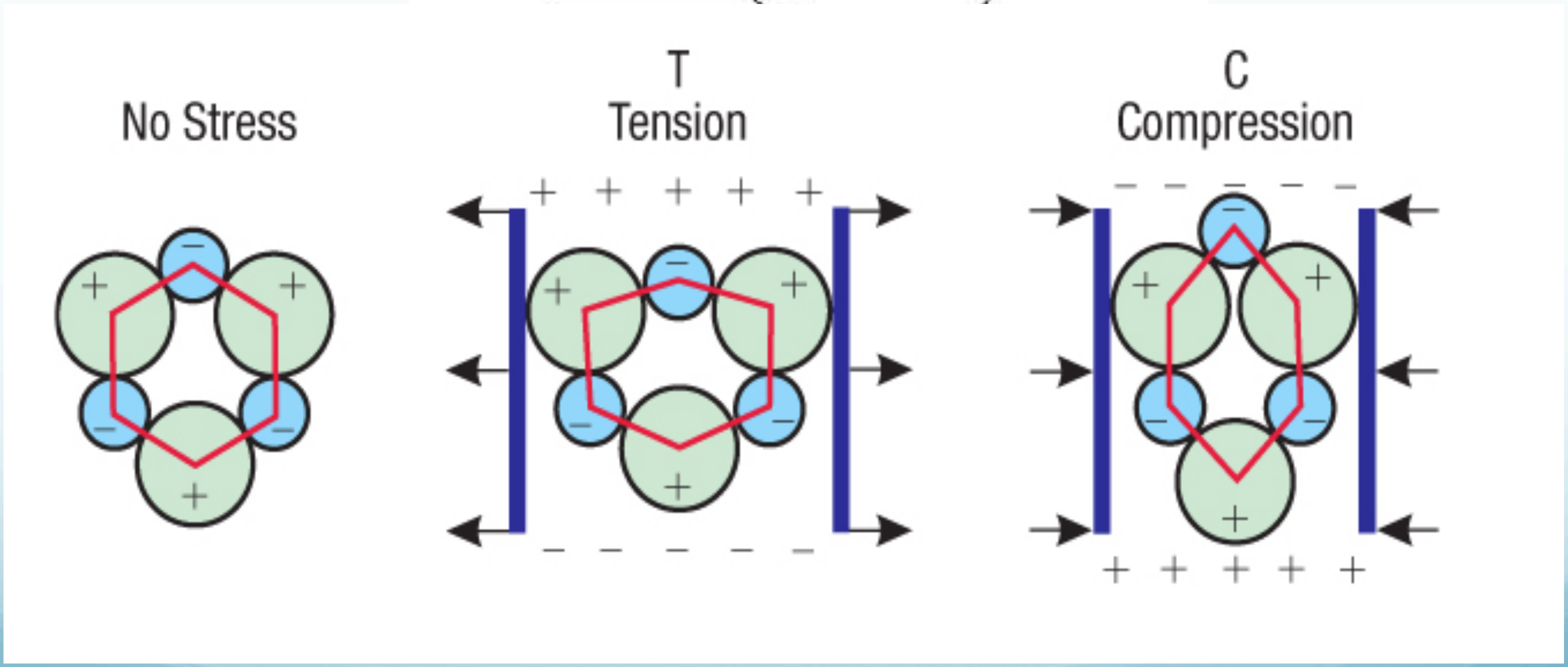
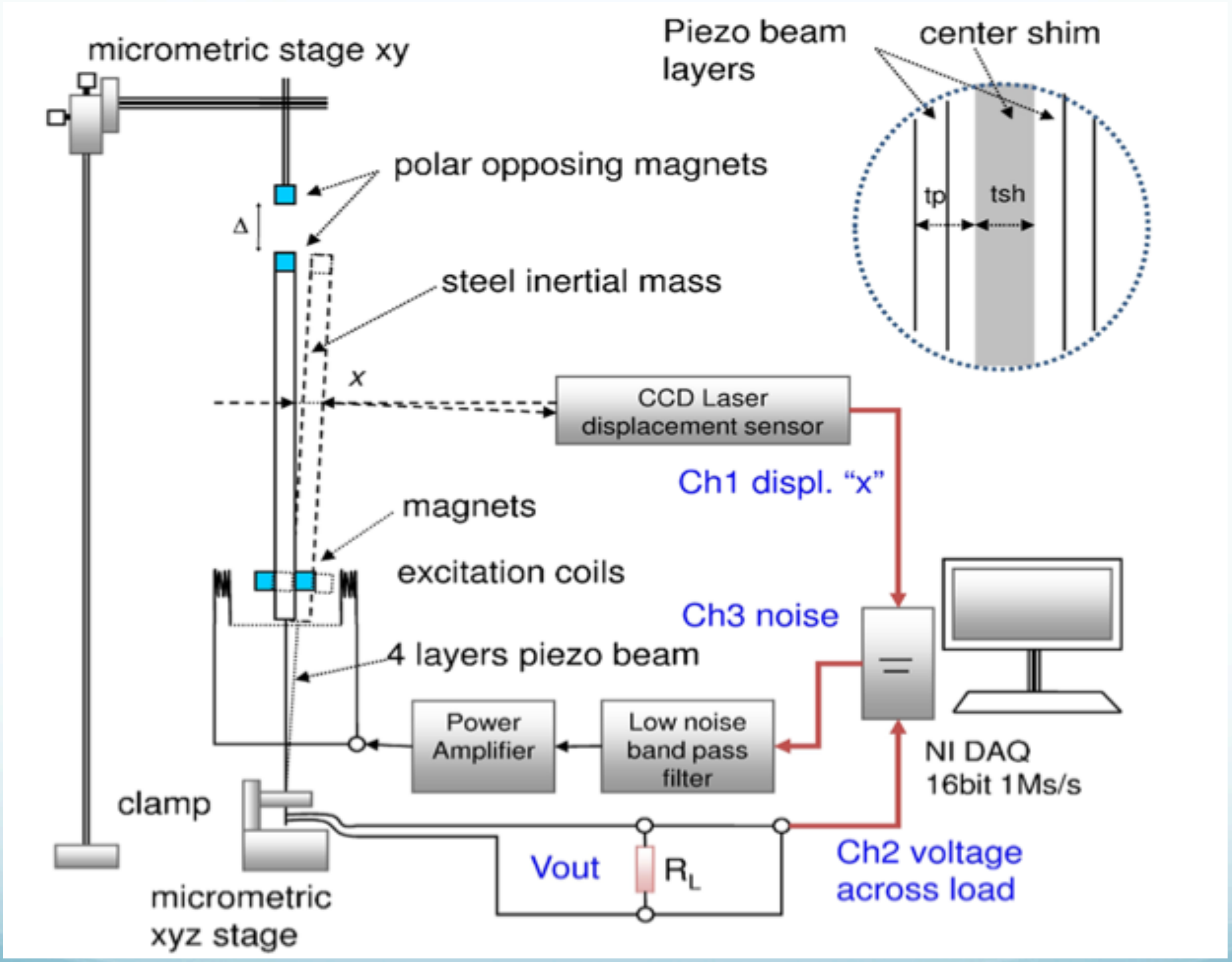


Image source:http://www.creationscience.com/onlinebook/Radioactivity3.html

Physical Model



Source: Cottone, F; Vocca, H; Gammaitoni, L; Phys. Rev. Lett. **102** 080601 (2009)

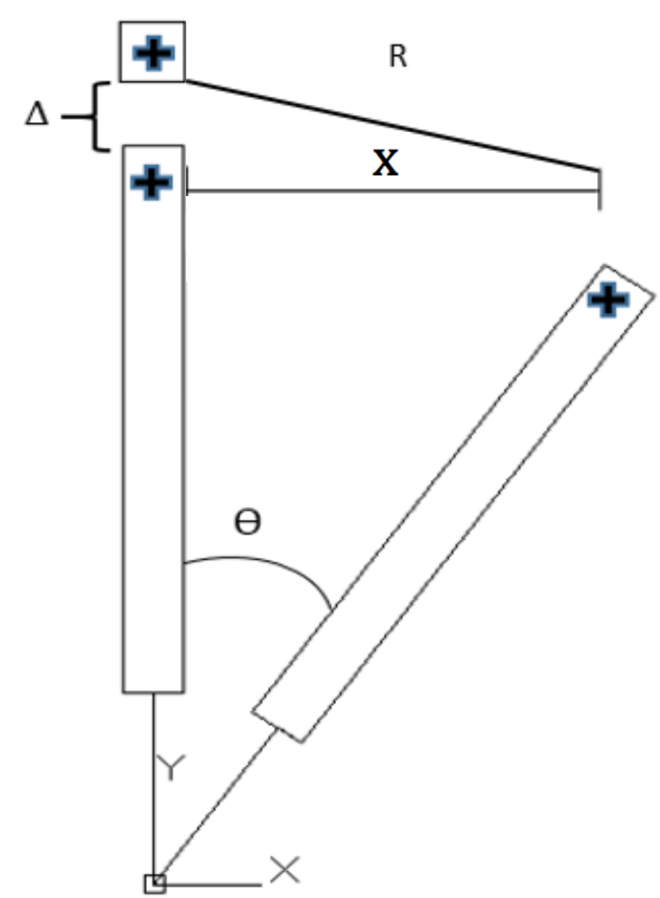
Equation of Motion

$$m_{eff}\ddot{x} = \frac{dU(x)}{dx} - \gamma\dot{x} - K_v V(t) + \sigma\varepsilon(t)$$

Equation	Meaning
$m_{eff}\ddot{x}$	The kinetic force of the oscillator
$U(x)$	The potential energy function of the oscillator
$\gamma\dot{x}$	Energy dissipation due to bending of the piezoelectric
$K_v V(t)$	Energy transferred to the resistor
$\sigma\varepsilon(t)$	Vibrational force that drives the oscillations; a stochastic process

Source: Cottone, F; Vocca, H; Gammaitoni, L; Phys. Rev. Lett. **102** 080601 (2009)

Physical Model



Deriving Equation

Assume $\theta \ll 1$

$$F_{res}=-K_B\cdot d \longrightarrow \int F_{res}=\int -K_B\cdot d \longrightarrow U_{res} = \frac{1}{2}d^2+C_1$$

$$F_m=\frac{\alpha}{R^4} \longrightarrow \int F_m=\int \frac{\alpha}{R^4} \longrightarrow U_m = \frac{\alpha}{-3R^3}+C_2$$

$$\Longrightarrow U_m = -\frac{\alpha}{3(x^2+\Delta^2)^{\frac{3}{2}}}+C_2$$

Analyzing

$$U(x) = Kx^2 + (ax^2 + b\Delta^2)^{-3/2} + c\Delta^2$$

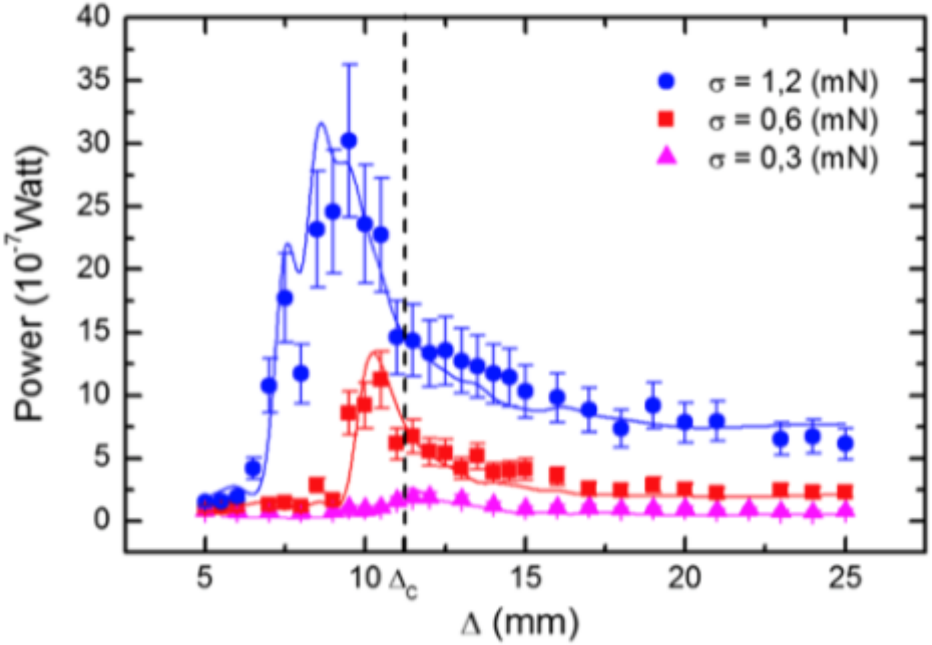
$$U(x) = \frac{K_{eff}}{2}x^2 + \left(d^2\left(\frac{\mu_0 M^2}{2\pi d}\right)^{-\frac{2}{3}} * x^2 + \left(\frac{\mu_0 M^2}{2\pi d}\right)^{-\frac{2}{3}} * \Delta^2\right)^{-3/2} + \frac{K_{eff}}{2d^2}\Delta^2$$

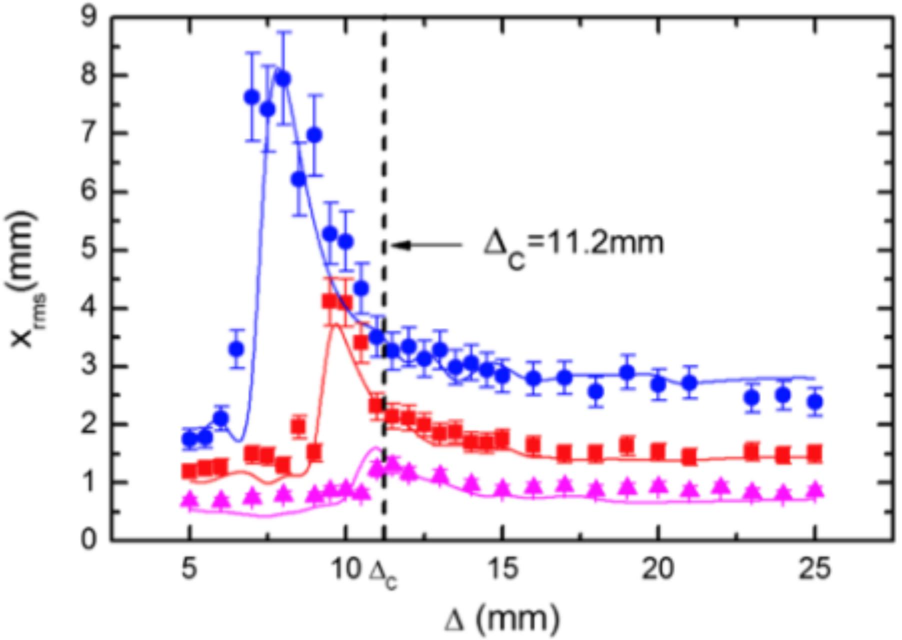
Equation	Meaning
K_{eff}	Effective elastic constant of the pendulum
μ_0	The permeability constant
M	Effective magnetic moment of both magnets
d	Geometrical parameter related to the distance between the measurement point and the pendulum length
C	Capacitance of the piezoelectric
R_L	Resistive load in the circuit
K_c	Coupling constant of the piezoelectric material

$$\dot{V}(t) = K_c\dot{x} - \frac{V(t)}{R_L C}$$

Source: Cottone, F; Vocca, H; Gammaitoni, L; Phys. Rev. Lett. **102** 080601 (2009)

Results





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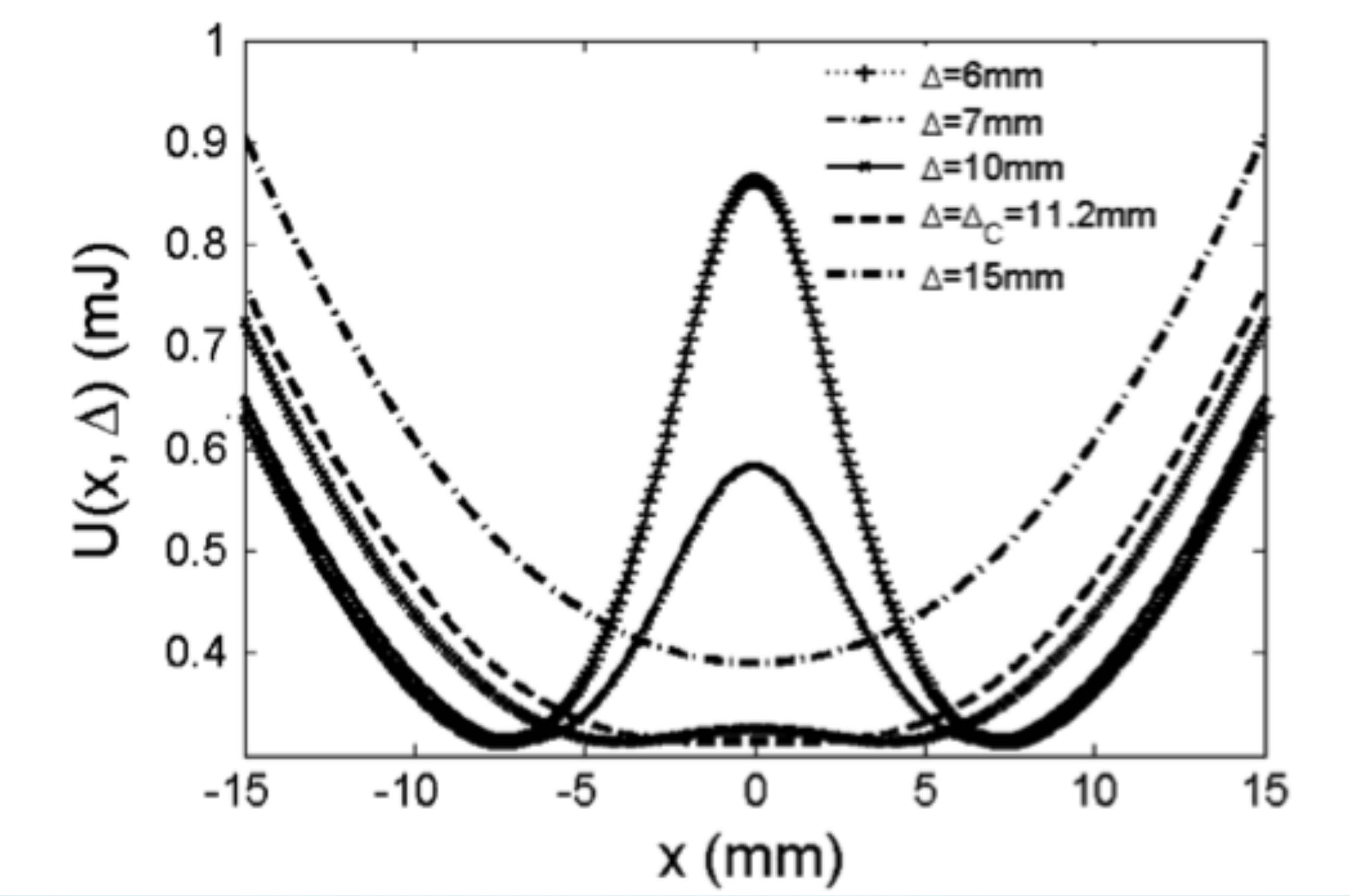
Results



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Our Problem

Image Source: consumers4safephones.com

Future Plan

General Idea:

- Determine how different positions of pendulum at varying initial angles affect energy output
- Create probability distribution of different phone orientations throughout the day
- Analyze gravity on pendulum in various positions and how this affects voltage generation

Questions?

Thank you!