The Science Behind NanoDays: Part 2

NanoDays™

The Biggest Event for the Smallest Science!

March 29 to April 6th 2014

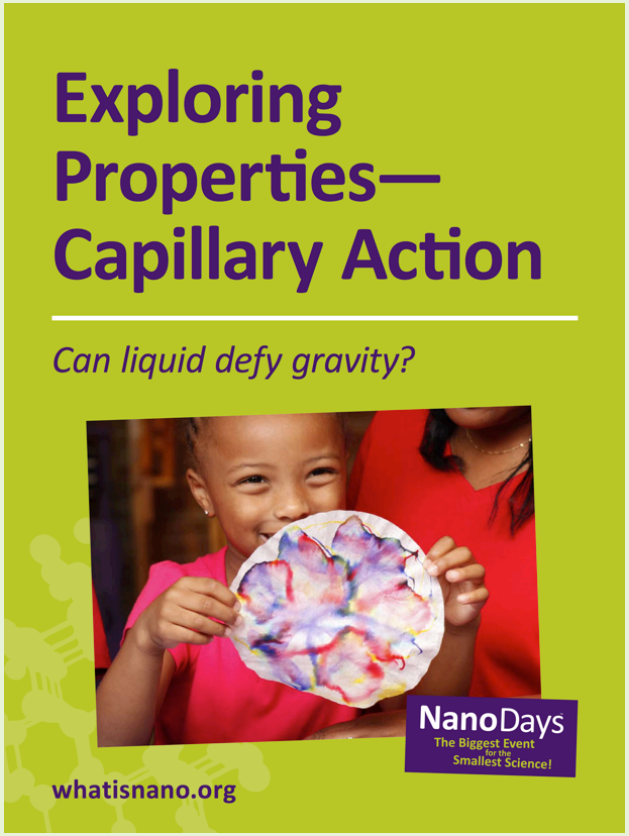
Digital kits available @
http://nisenet.org/nanodays/NanoDays-2014-digital-kit

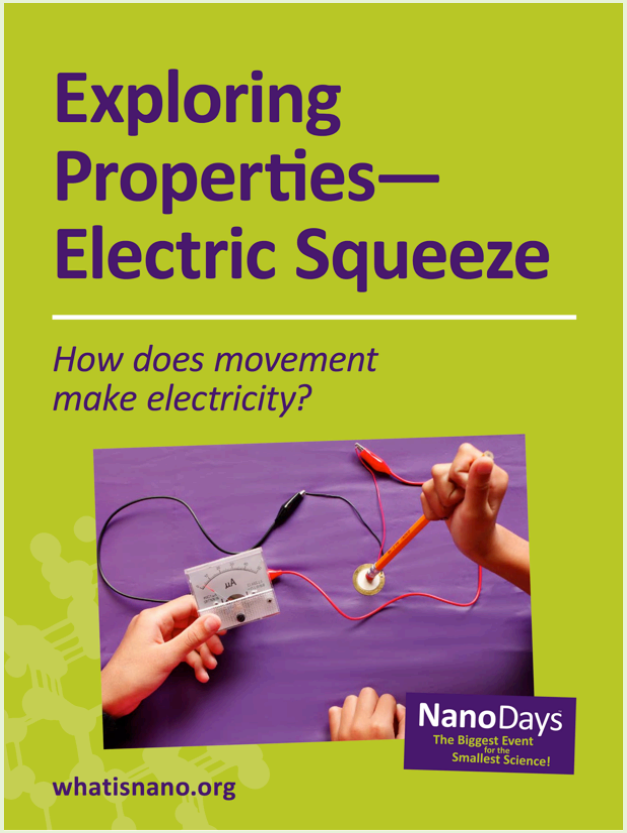
NISE network
NANOSCALE INFORMAL SCIENCE EDUCATION

NSF

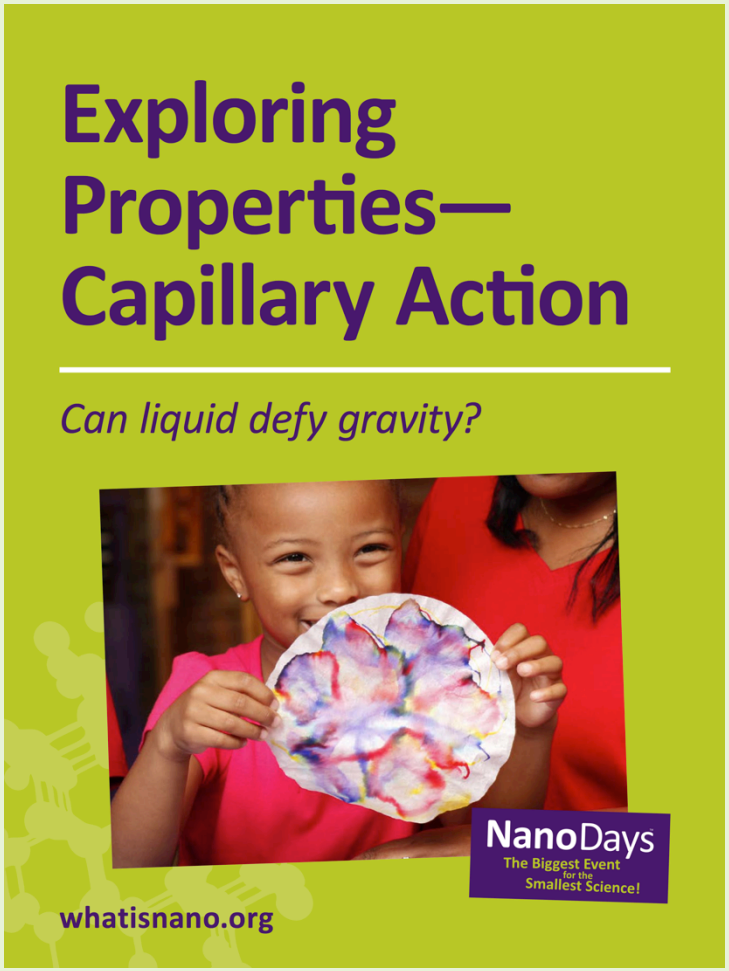
March 18, 2014

Activities We'll Cover Today

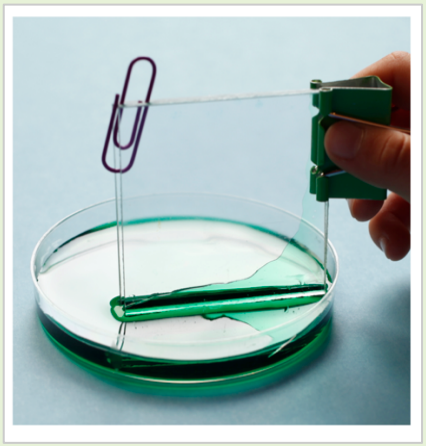




Capillary Action



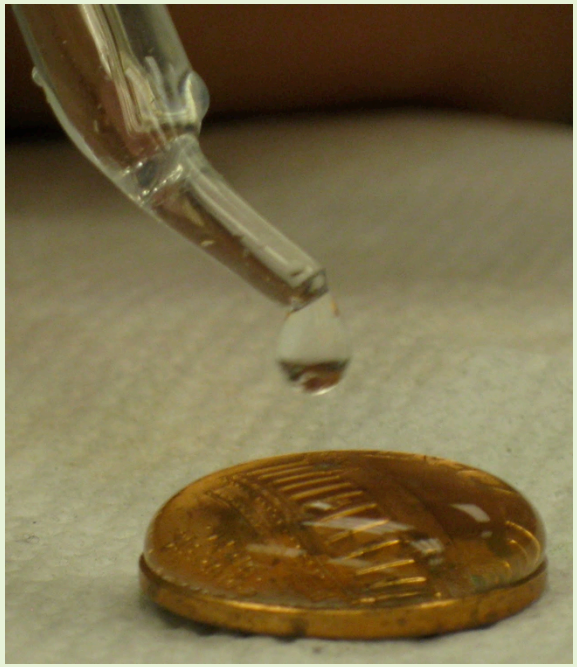
Capillary action is the ability of a liquid to flow in narrow spaces—even against gravity.

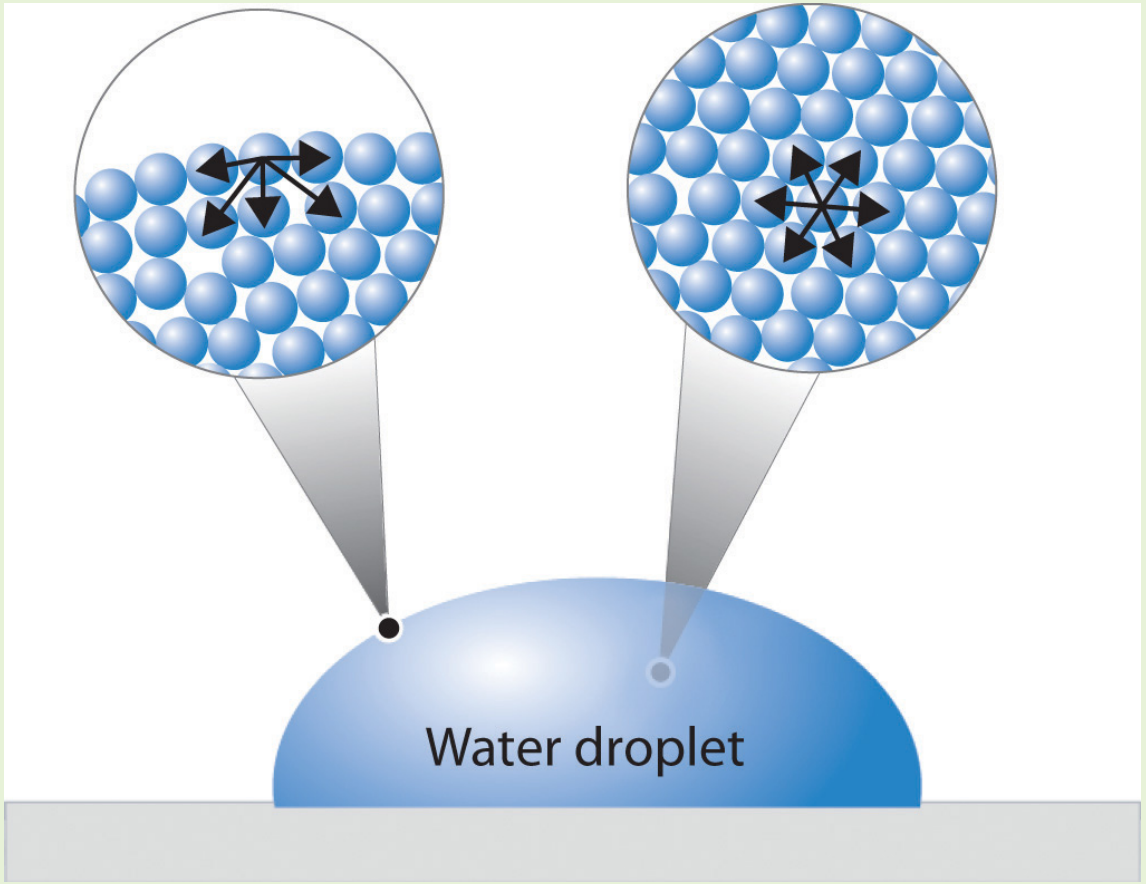


Color moving on paper

Capillary Action in Nature

Surface Tension

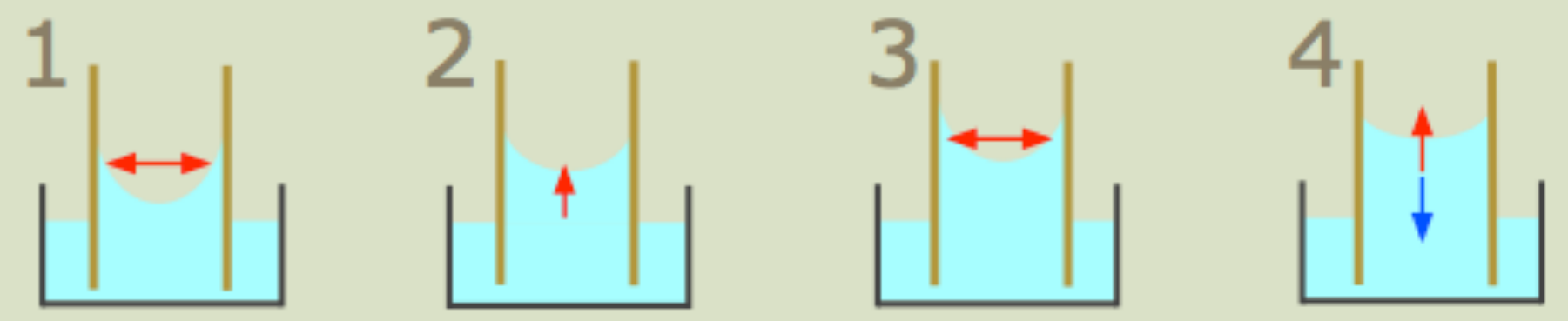




http://campillos.ucmerced.edu/~dmartin5/research.html

http://www.pdesas.org/module/content/resources/16283/view.ashx

Capillary Action



Liquid wets walls of tube, increasing surface area.

Surface tension acts to decrease surface area, pulling liquid up.

Wetting continues from a higher level, causing liquid to continue rising.

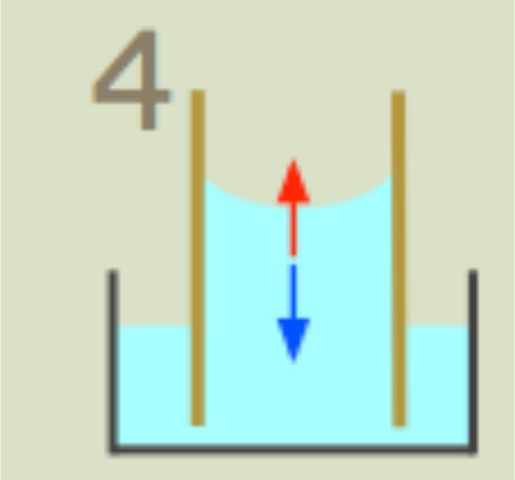
Eventually the liquid reaches a height at which **its weight is balanced by surface tension.** After this, the height stays constant.

http://chemwiki.ucdavis.edu/Under_Construction/chem1/States_of_Matter/Liquids_and_their_Interfaces

Capillary Action – Size Matters!

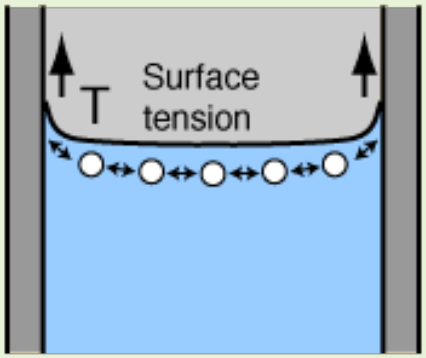
Surface tension pulls fluid up

Gravity pulls fluid down (as usual)



So why is the radius (r) important?

- Gravity is proportional to r^2
- Surface tension is proportional to r



http://hyperphysics.phy-astr.gsu.edu/hbase/surten2.html

Capillary Action – Size Matters!

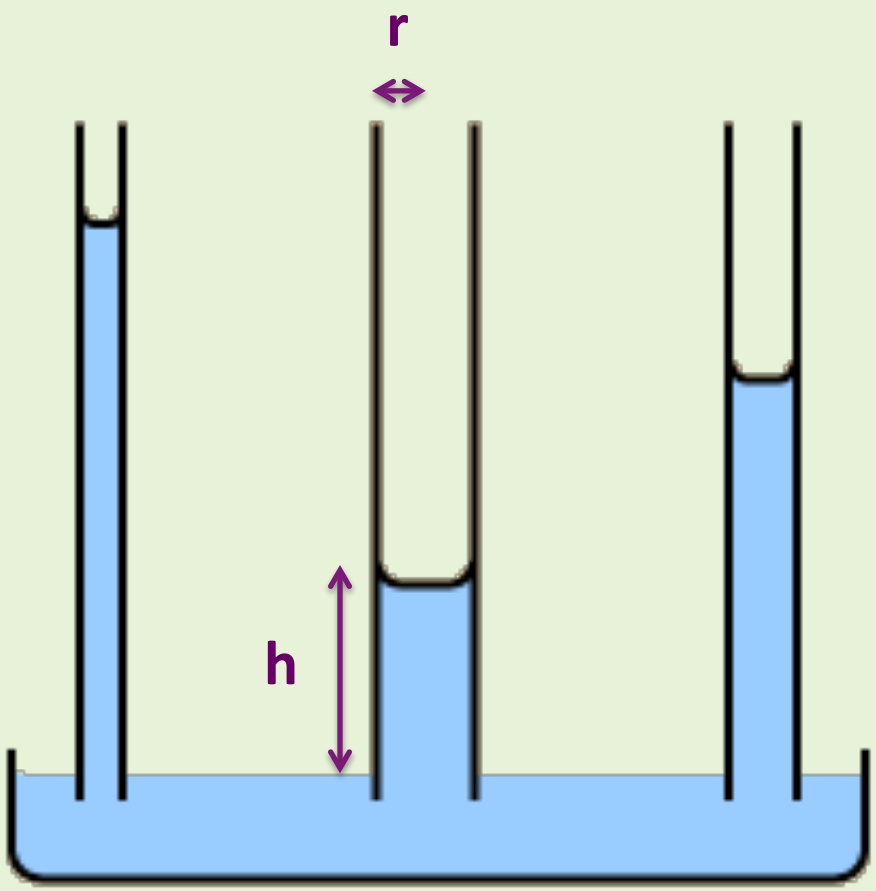
Surface tension pulls fluid up

Gravity pulls fluid down

$$(T_{surf})(\text{Circum}) = (\text{mass})g$$

$$(T_{surf})(2\pi r) = (\rho \bullet \pi r^2 h)g$$

$$\left(\frac{1}{g}\right)\left(\frac{T_{surf}}{\rho}\right)\left(\frac{2}{r}\right) = h$$



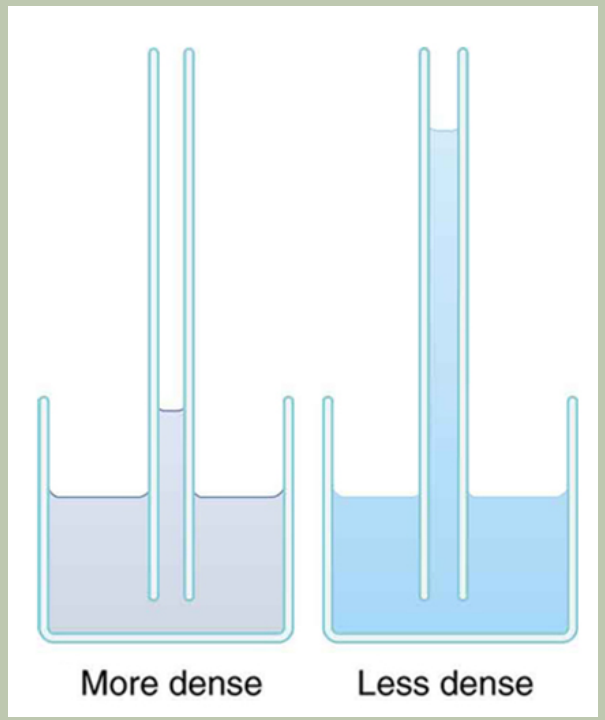
How this relates to Nanodays activity

This explains why the water level in the acrylic setup is higher on the side where the pieces are closer together.

http://hyperphysics.phy-astr.gsu.edu/hbase/surten2.html

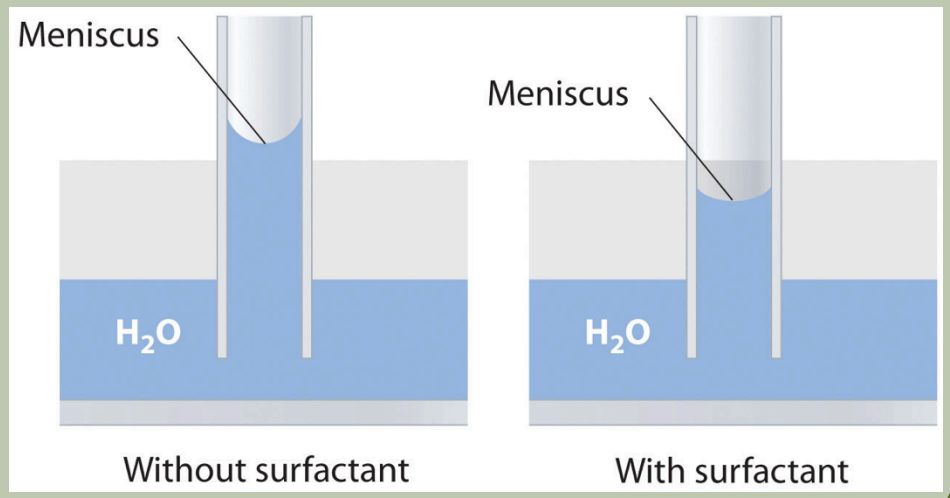
More on Capillary Action

Density (ρ) matters, because it affects the force from gravity



$$\left(\frac{1}{g}\right)\left(\frac{T_{surf}}{\rho}\right)\left(\frac{2}{r}\right) = h$$

Adding a surfactant decreases the surface tension (T_{surf})



Does Surface Tension Sound Familiar?

Exploring Forces – Gravity

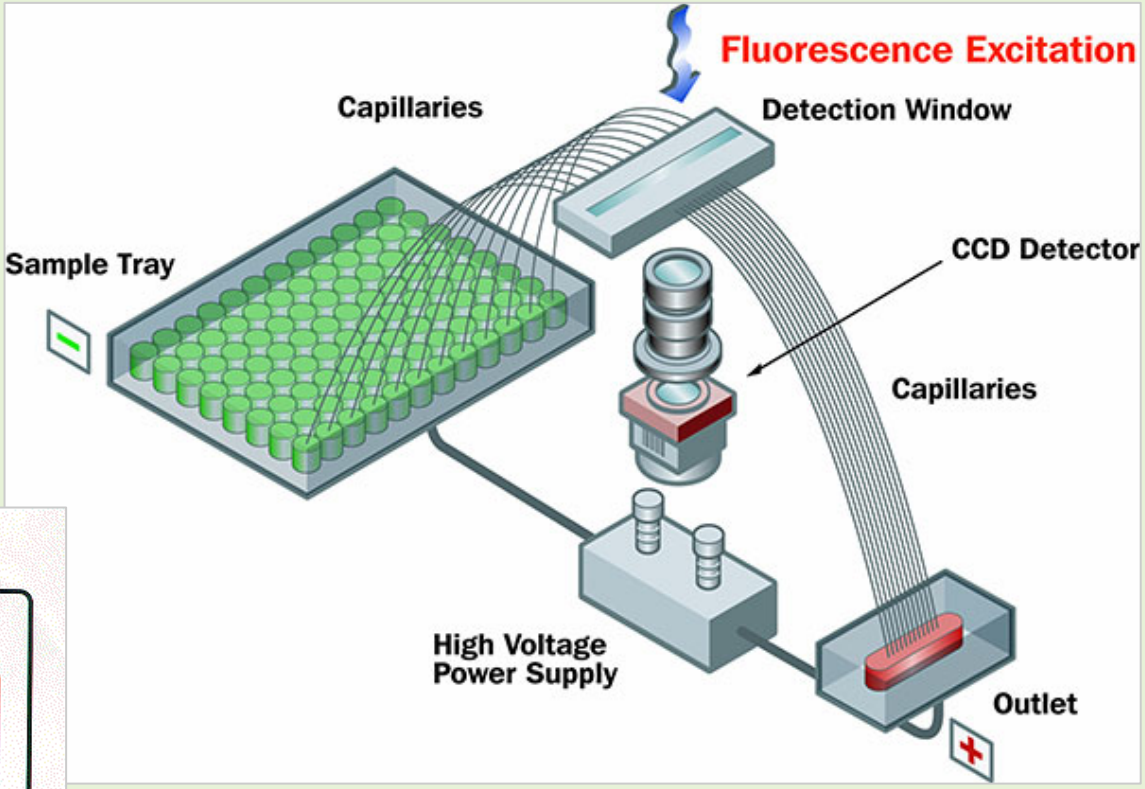
What does the *Exploring Forces – Gravity* NanoDays activity have to do with this one?

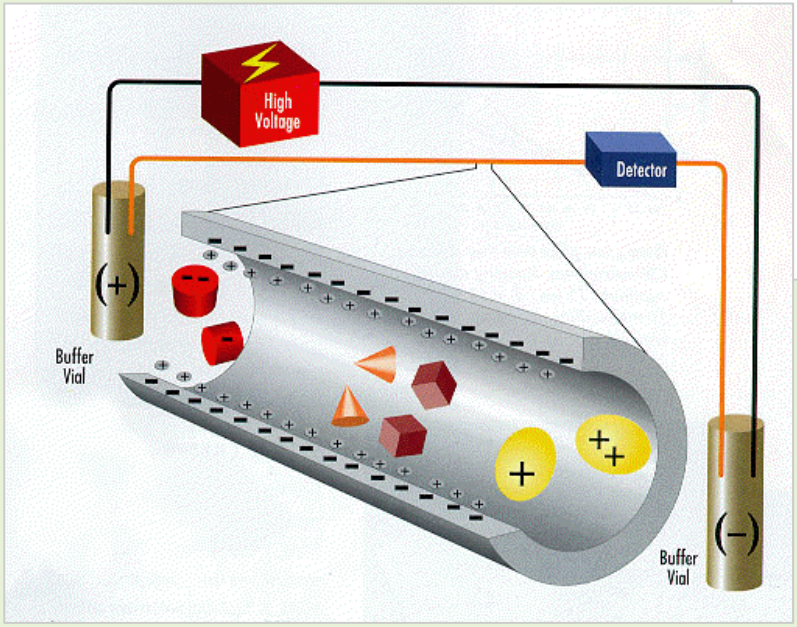
Surface tension

Gravity

DNA Sequencing

Capillary Electrophoresis



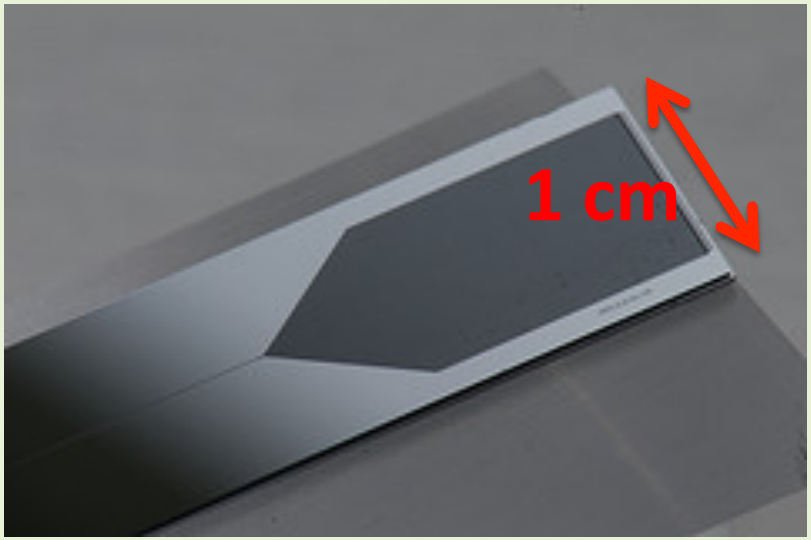


http://www.cs.stedwards.edu/chem/Chemistry/CHEM48/CEfull.html
http://www.aati-us.com/instruments/fragment_analyzer/ce-review.html

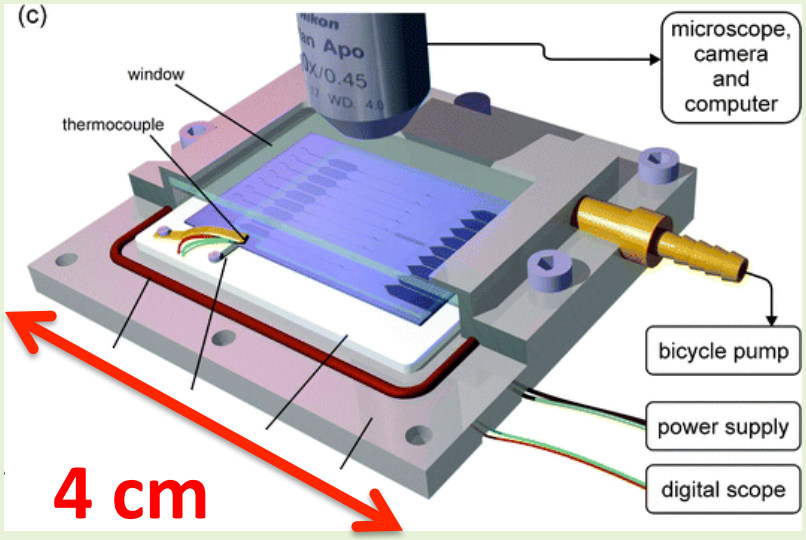
Lab-on-a-Chip: Point-of-Care Testing

These are “self-contained, portable devices that can be used by non-specialists to detect and diagnose disease”

As a result of these devices, “the way in which doctors care for patients will change dramatically and the role patients take in their own health care will increase. Health care will become more personalized through tailoring of interventions to individual patients.” ***NIH***

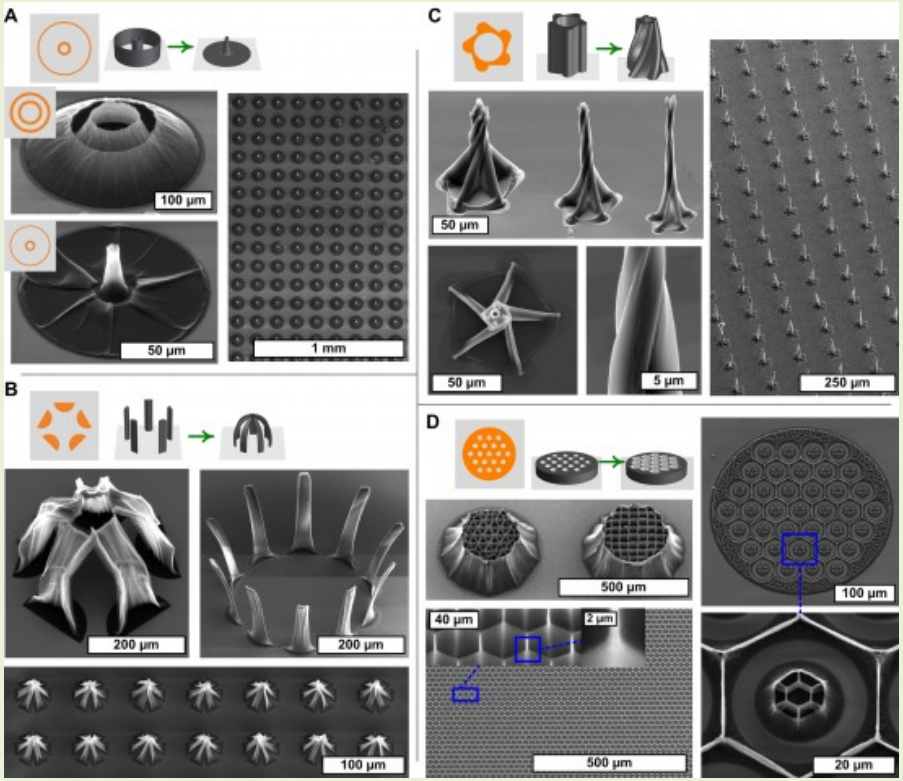


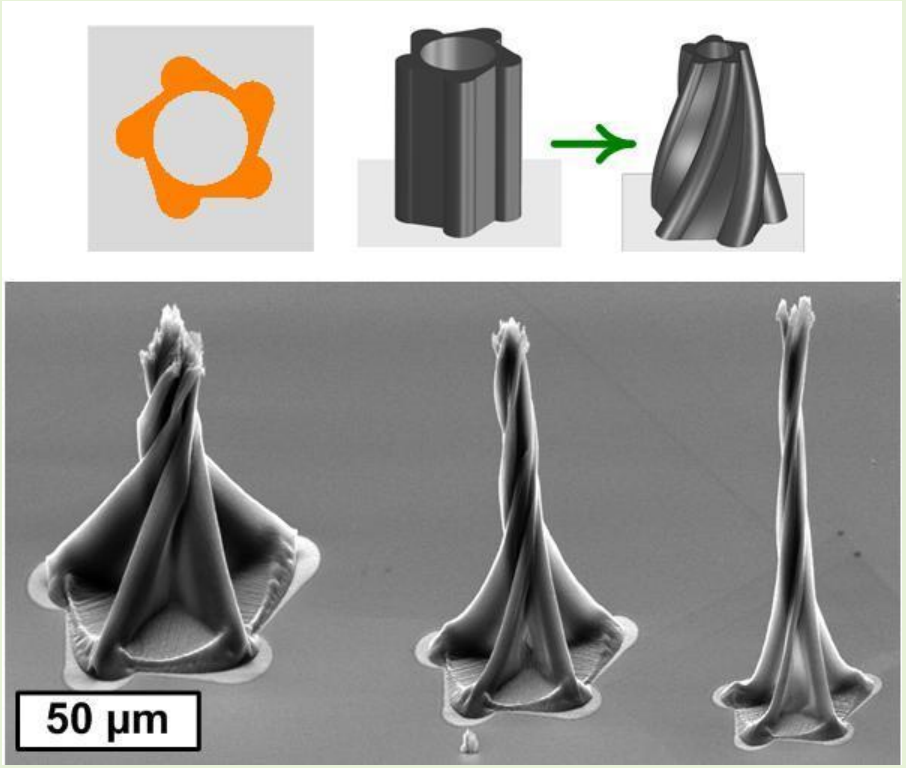
http://www.zurich.ibm.com/news/09/lab_on_a_chip.html



http://pubs.rsc.org/en/content/articlehtml/2012/lc/c2lc00015f

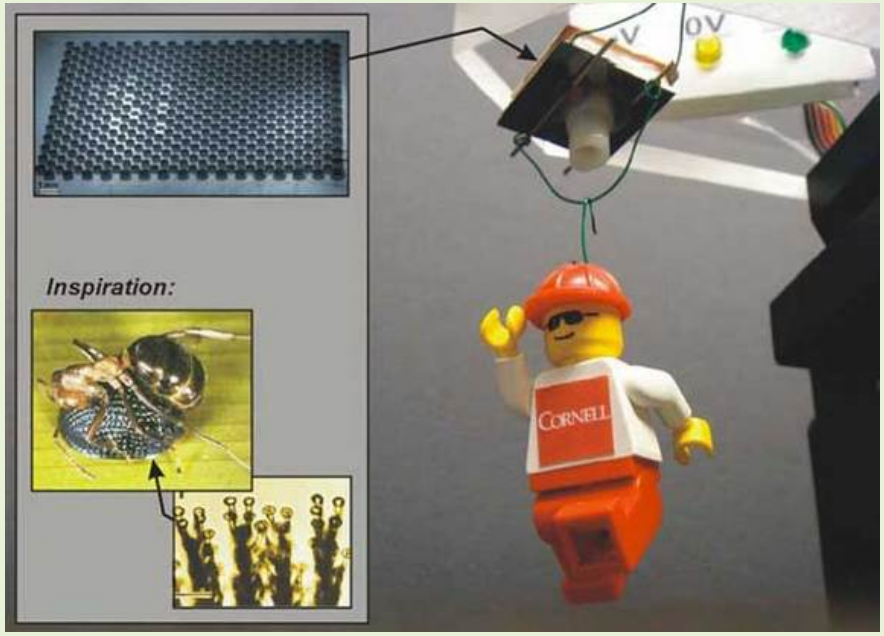
Capillary Forming – A New Manufacturing Process

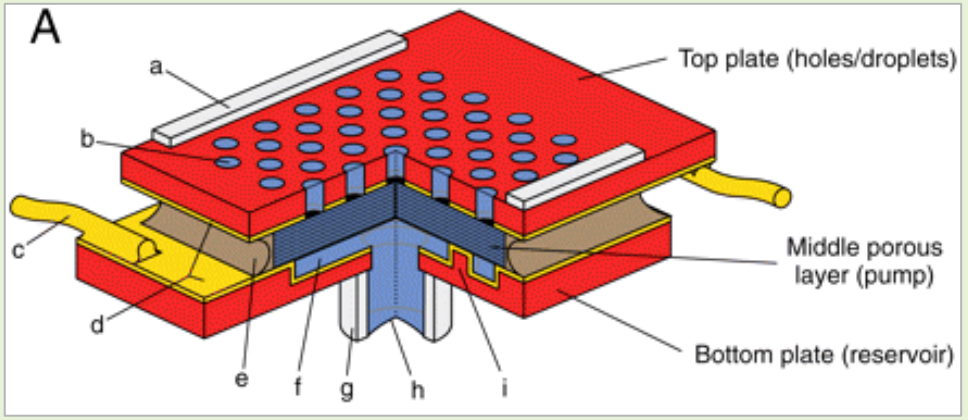


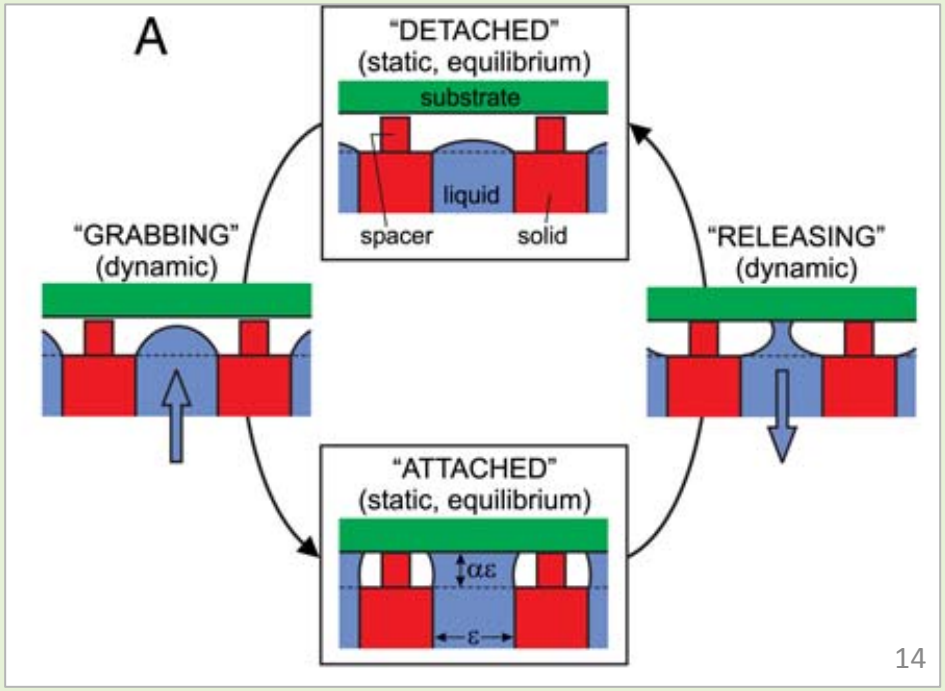


http://www.sciencedaily.com/releases/2010/10/101019132052.htm

Switchable Adhesives







Uses capillarity-based adhesion

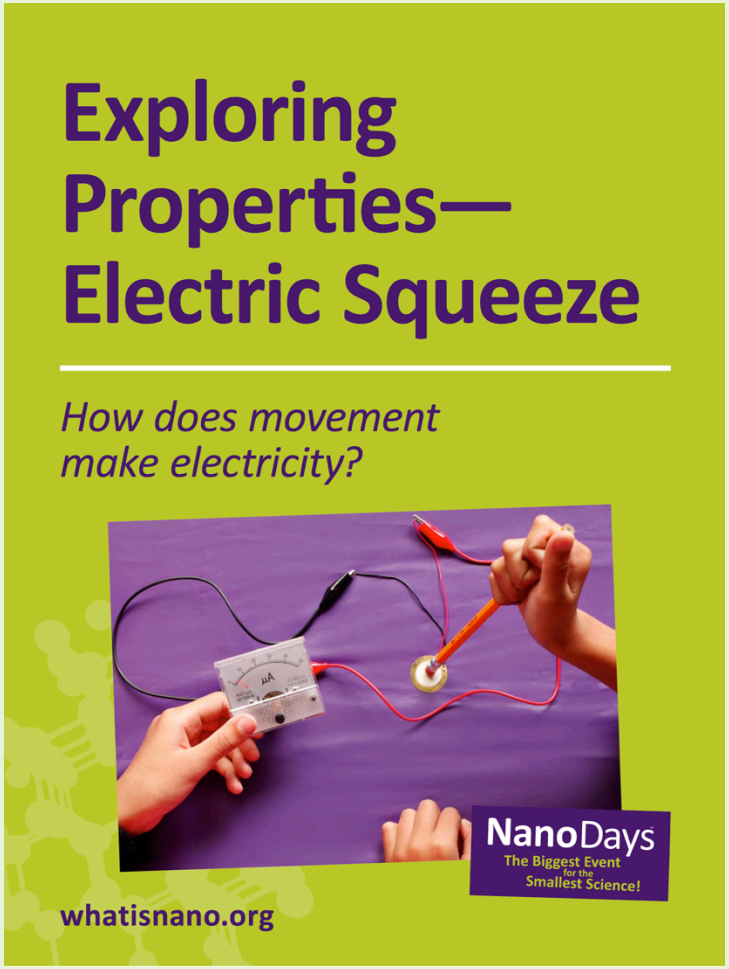
Switchable: contacts can be quickly made or broken with electronic control

http://www.livescience.com/6038-spider-man-device-humans-walk-walls.html
Vogel and Steen, *PNAS,* 2010

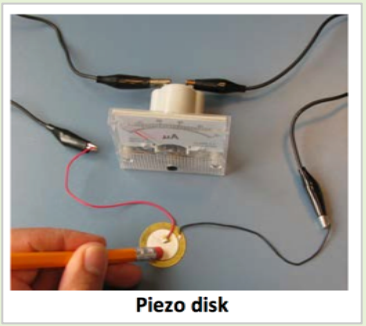
A New Type of Calendar

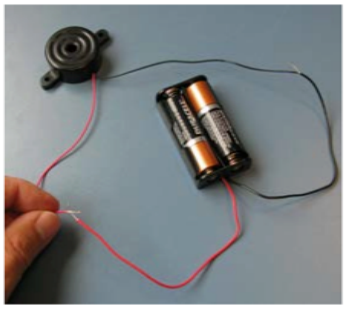
http://www.dezeen.com/2009/07/17/ink-calendar-by-oscar-diaz/

Piezoelectric Effect



When you squeeze a piezoelectric crystal, the length of the crystal may only change a few nanometers, but that small change is enough to generate electricity.


Piezo disk


Piezo buzzer


Floor tiles generate electricity by walking on them

What is Piezoelectricity?

- Piezo: to squeeze or press (Greek)

- Piezoelectric materials produce a voltage when they change their shape (by being stretched or squeezed) *and they change their shape when a voltage is applied across them.*

- But, *why* do piezoelectric materials produce a voltage when squeezed?

What Creates Voltages?

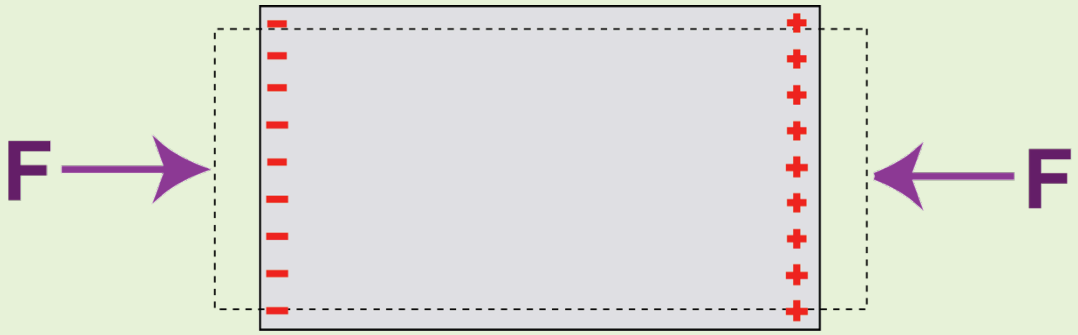
Voltages are created when…

Electrical charges of opposite signs are separated

Examples: a battery has a voltage due to chemical reactions

a solar cell has a voltage due to energy from the sun

piezoelectrics have a voltage due to mechanical force

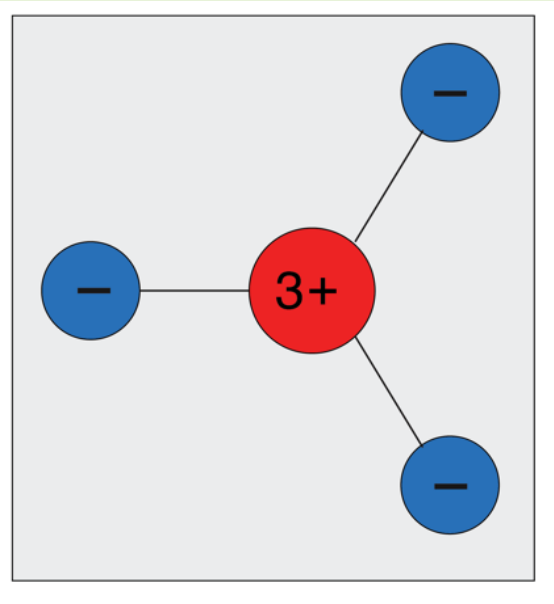


What makes these charges become separated?

Small shifts in atomic positions (at the nano scale)

Piezoelectrics at the Nanoscale

Before force

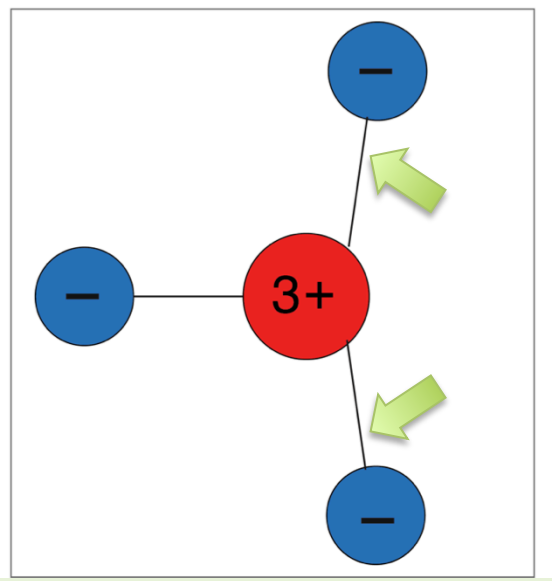


When a force is applied, the atomic positions shift

-- This changes the distribution of charges

Piezoelectrics at the Nanoscale

After force



When a force is applied, the atomic positions shift

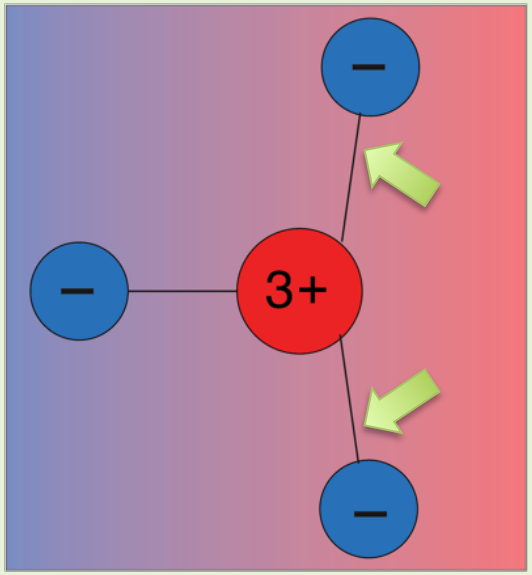
-- This changes the distribution of charges

Initially the charge distribution was symmetric around the center point

But now the charge distribution is *not symmetric*

-- Some regions are more positively charged, some are more negatively charged

Piezoelectrics at the Nanoscale

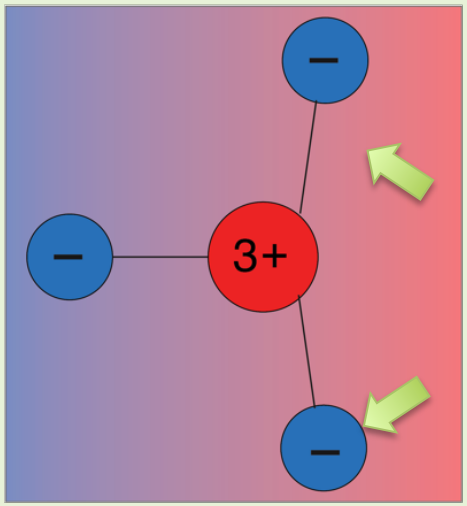


Background shading indicates regions that are more positively *(red)* or negatively *(blue)* charged

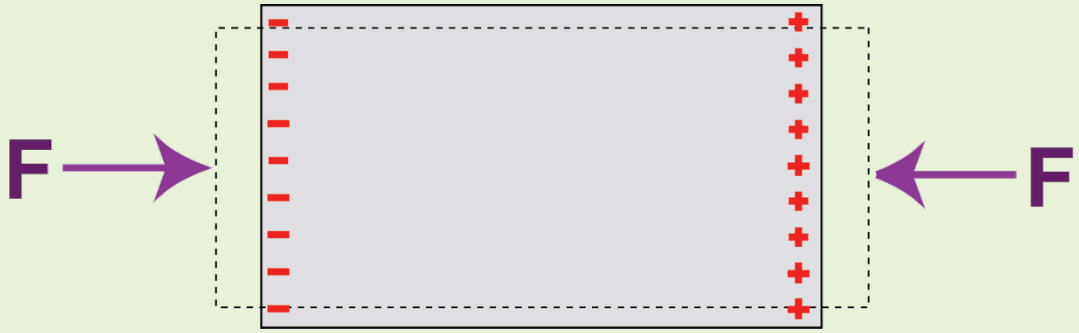
Because there are regions that are more positively charged, and others that are more negatively charged, there's now a *voltage across the material*

This process (of atoms shifting due to force) happens throughout the material, producing effects we see at the macroscale

Piezoelectricity: A review



Nanoscale



Macroscale

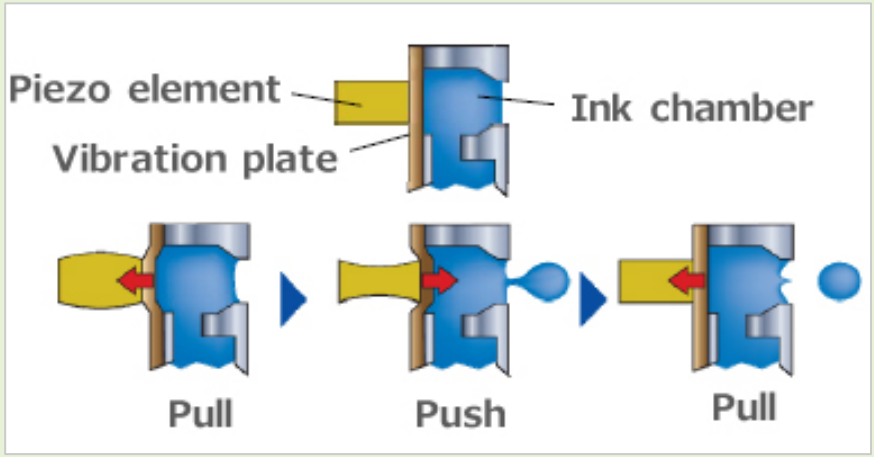
Piezoelectrics produce a voltage when their shape is changed.

The way a material behaves on the macroscale is affected by its structure on the nanoscale.

Wide Range of Applications

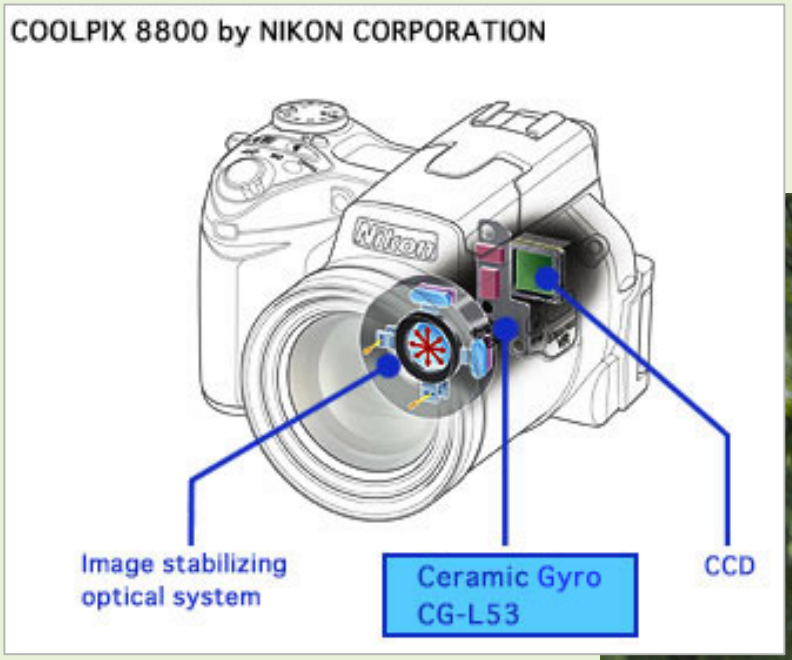
- Generators (mechanical → electrical): sensors
  - Can sense changes in force, acceleration, pressure

- Actuators (electrical → mechanical): motors



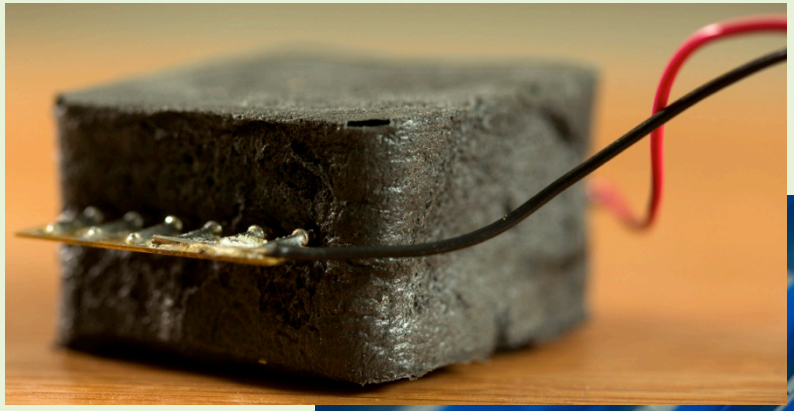
http://global.epson.com/innovation/technology_articles/201306_03.html

Gyroscopes



http://sunglidetours.wordpress.com/
http://www.nec-tokin.com/english/product/piezodevice2/ceramicgyro.html

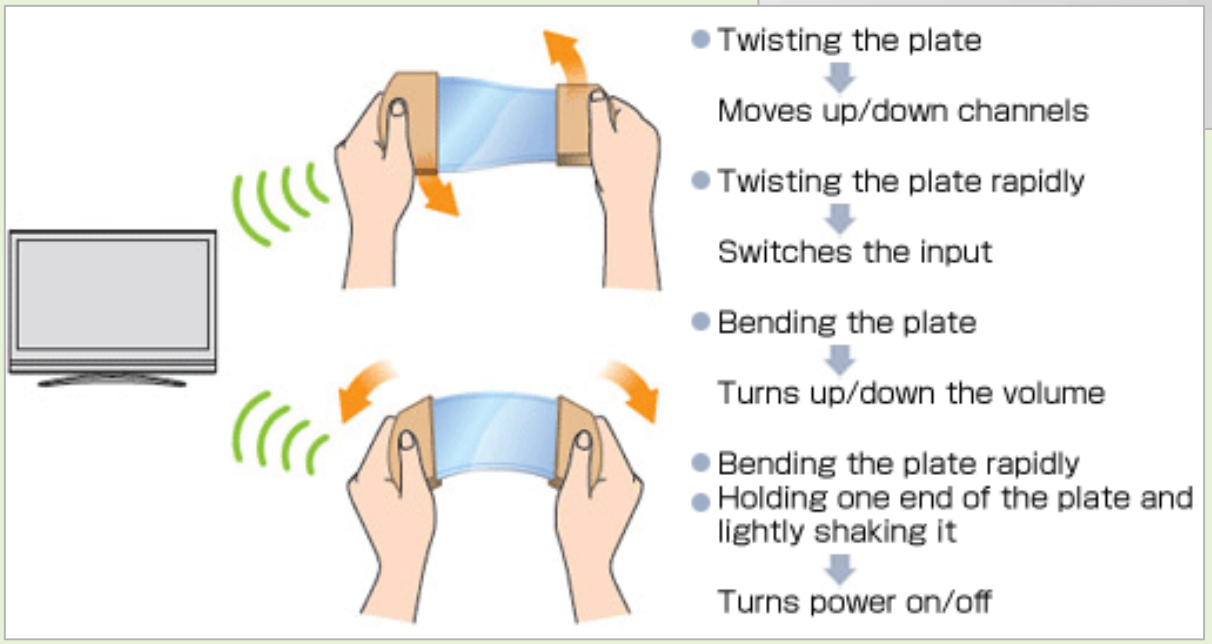
Sensors for Detecting Concussions



http://news.byu.edu/releases/archive13/Nov/helmetsmartfoam/1310-76%20117.jpg

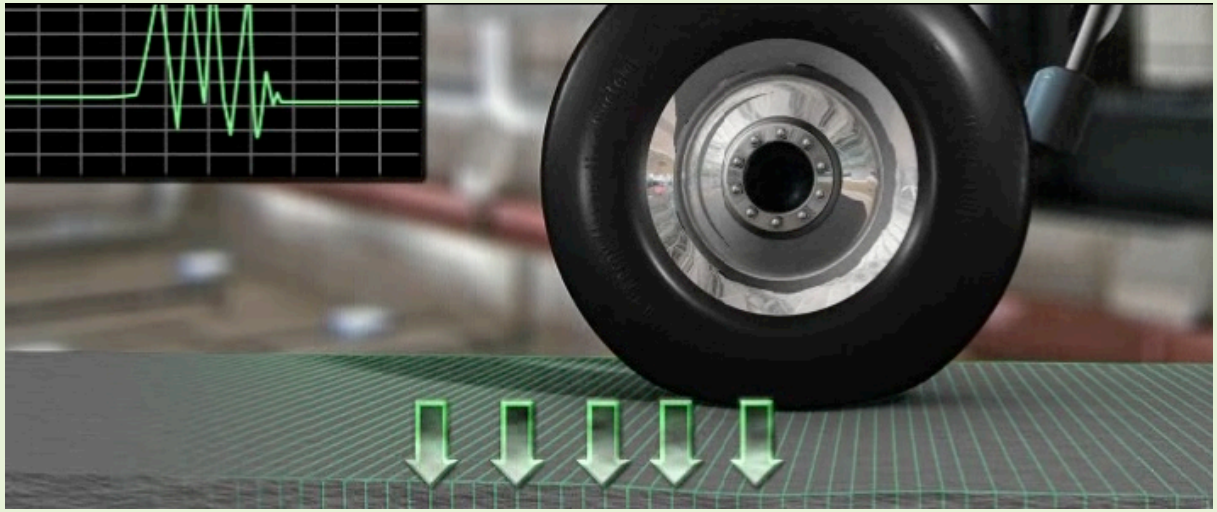
TV Remote Control

"Conventional piezoelectric films are usually subject to a **pyroelectric** effect, which is a disadvantage because they cannot detect bending and twisting vibrations separately from changes in temperature."



http://www.murata.com/new/news_release/2011/0921/

Harvesting Energy From Roads



Innowattech has already done pilot projects in Israel

- They estimate 200 kW/hour along a 1 kilometer stretch of road
- Per kilometer: 3,000 generators ($30 each)

Innowattech thinks they'd get a return on their investment in 4-7 years

http://innowattech.co.il/index.aspx http://www.jpost.com/Health-and-Sci-Tech/Can-we-generate-electricity-as-we-drive

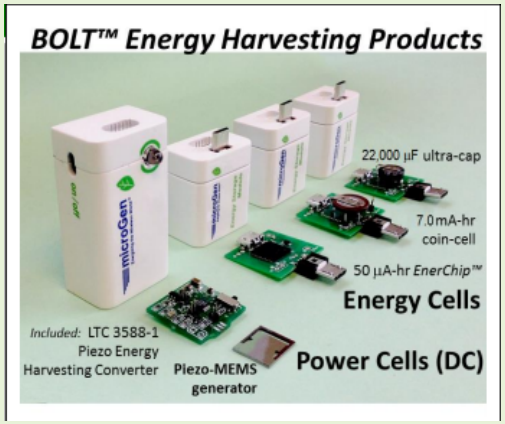
Other Examples of Energy Harvesting

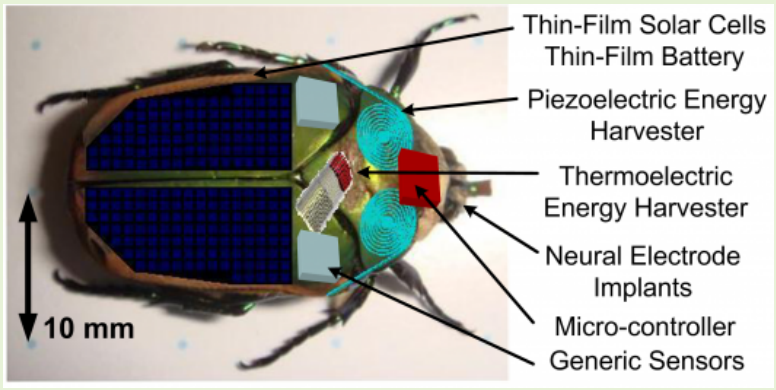
Floor tiles generate electricity by walking on them

http://www.gizmag.com/in-shoe-energy-harvester/19623/
http://inhabitat.com/green-a-go-go-at-londons-first-eco-disco/

Creative Fun

There are so many other possibilities for energy harvesting – what can your visitors think of?





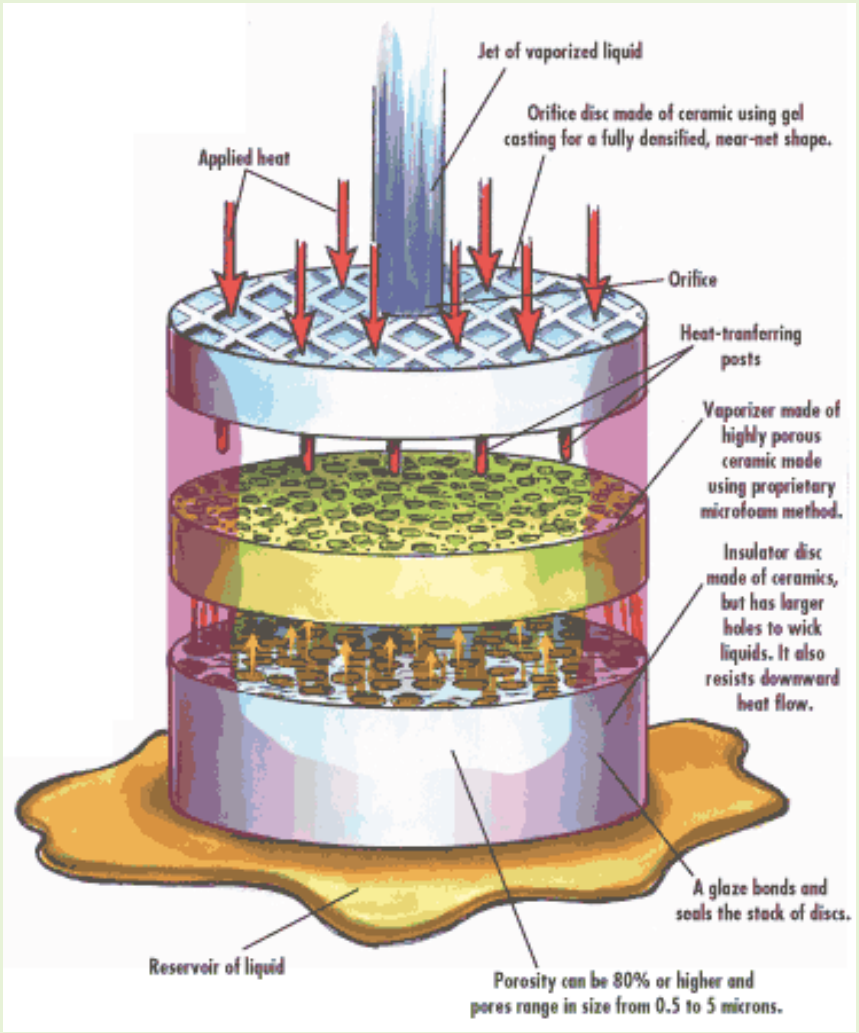
http://www.microgensystems.co/content/MicroGen_BOLT-INDUSTRIAL_Jun2013.pdf
http://www.treehugger.com/clean-technology/piezo-shower-heats-water-without-electricity.html
http://www.gizmag.com/insect-cyborgs/20596/

Related Topics

- **Gravity (related to Capillary Action)**
  - Exploring Forces: Static Electricity (2012)
  - Exploring Forces: Gravity (2010)

- **Smart Materials (related to Piezoelectric Effect)**
  - Exploring Materials: Oobleck (2014)
  - Exploring Products: Liquid Crystal Display (2013)
  - Exploring Materials: Memory Metal (2013)

Fuel Vaporizer



Uses capillary action to pull the fuel up through pores; uses heat to vaporize the fuel

http://machinedesign.com/archive/pump-no-moving-parts

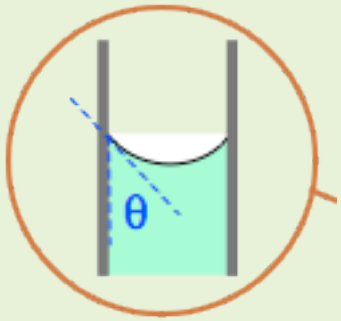
More on Capillary Action

$\theta_{water/glass} = 0°$ $\theta_{mercury/glass} = 140°$

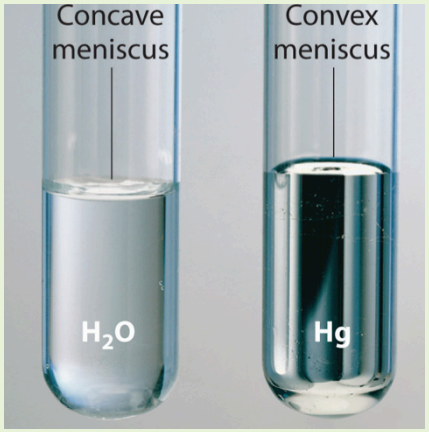
$$\left(\frac{1}{g}\right)\left(\frac{T_{surf}}{\rho}\right)\left(\frac{2}{r}\right) = h$$

$$\frac{2T_{surf}}{g\rho r} = h$$

$$\frac{2T_{surf}\cos\theta}{g\rho r} = h$$

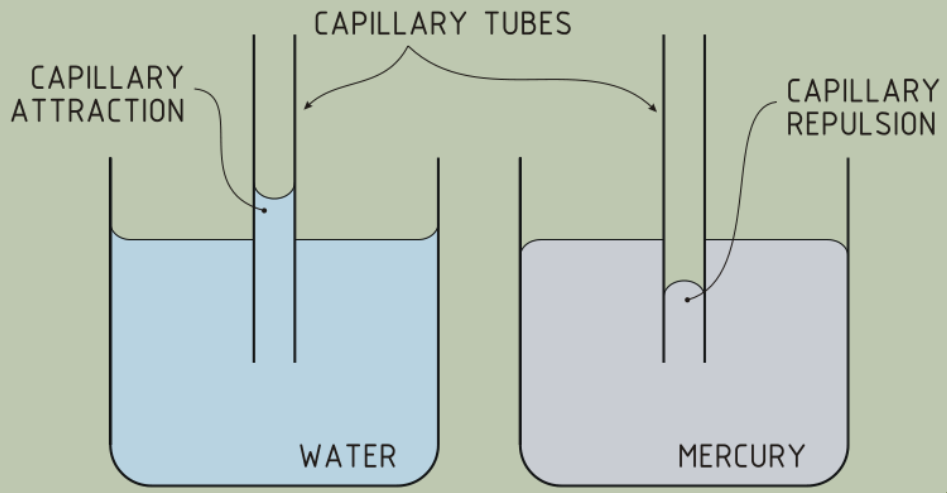


$\theta < 90°, h > 0$

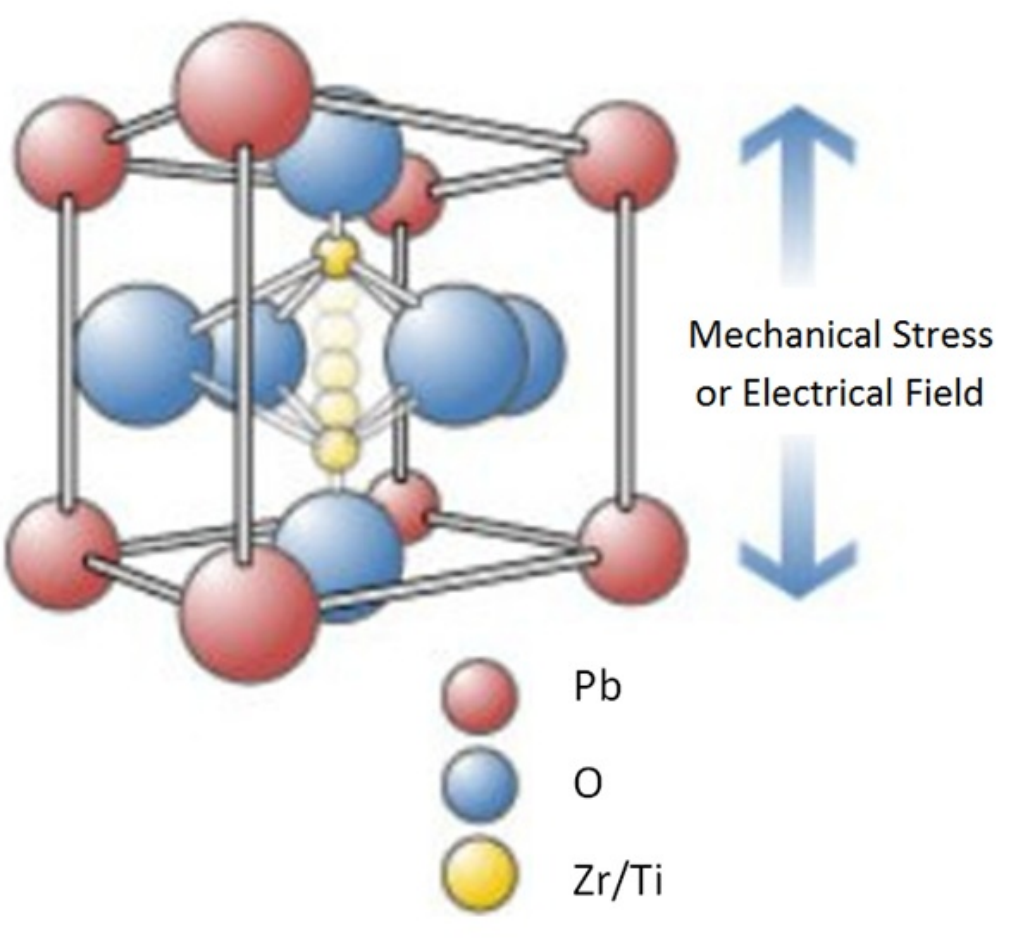


Mercury undergoes very strong metallic bonding, so it prefers to bond with itself

Capillary action doesn't always make fluids rise!



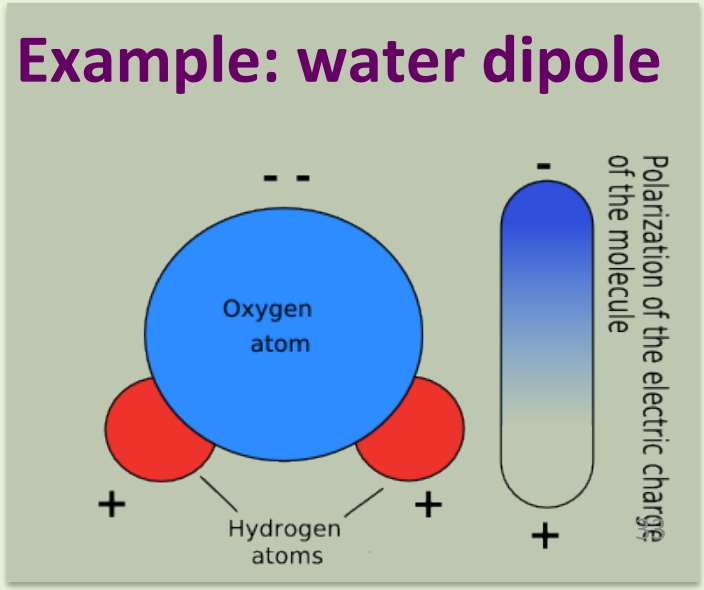
More on Dipoles



PZT is asymmetric, since Zr/Ti is not in the center

Since Zr/Ti carrier a 4+ charge, when it moves it creates a dipole

Example: water dipole



https://uspace.shef.ac.uk/docs/DOC-51945