Particle-based display technologies

Ian Morrison

Cabot Corporation

Particle based displays

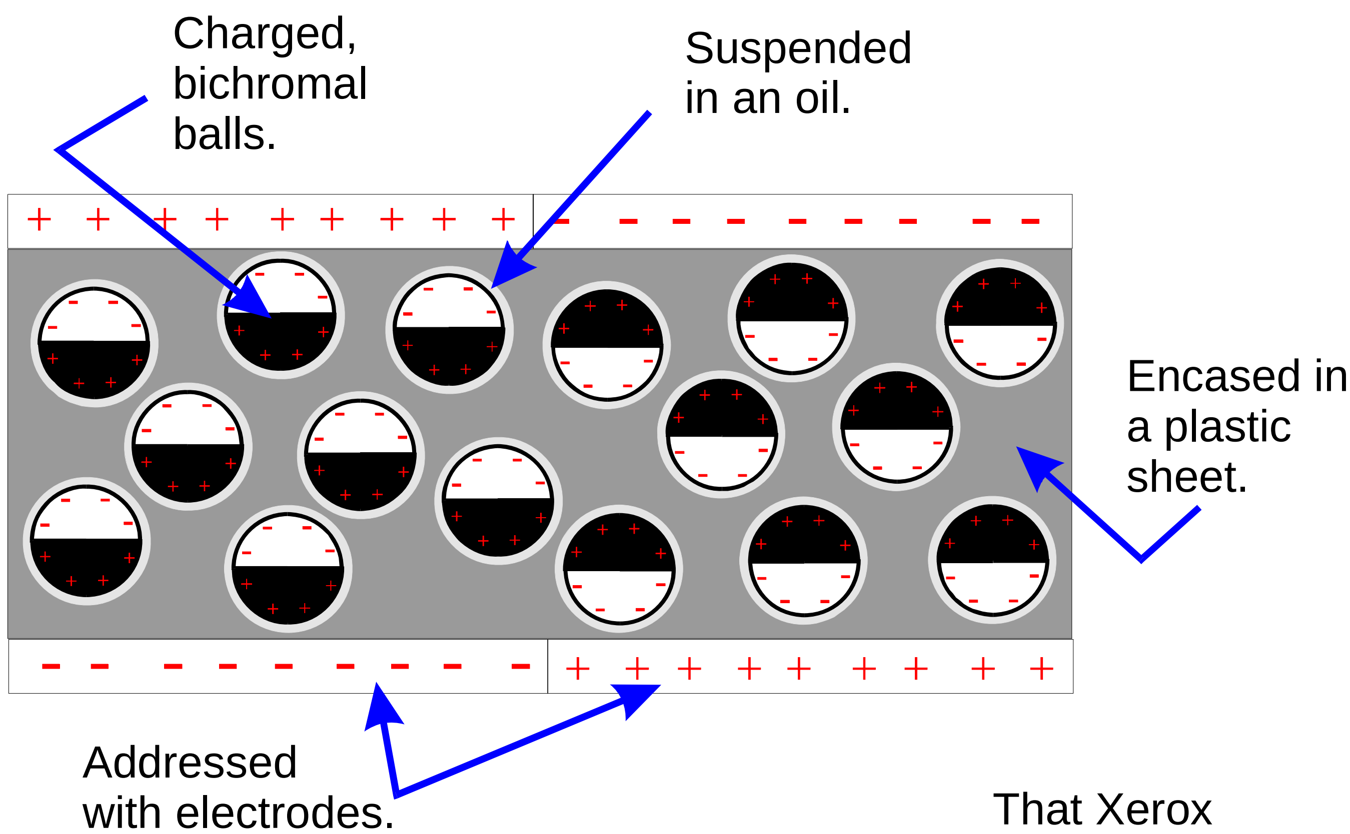
- Reflective not emissive
- "Adjusts" with ambient light
- Thin, flexible, low power?
- The electronics is a real challenge.

- Require high resistivity so particles move, not ions therefore – nonaqueous dispersions

To create a display – start with a print

and invent ways to make it change:

The Gyricon Display

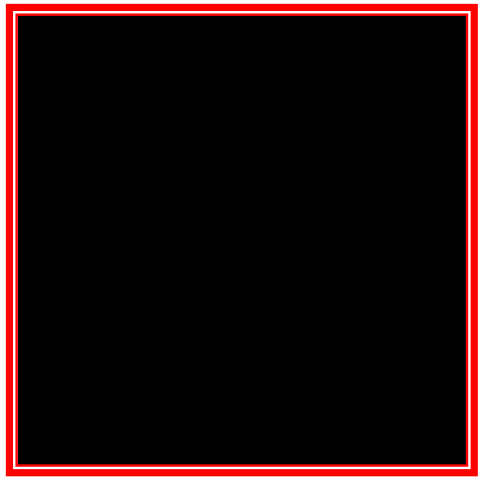


That Xerox built.

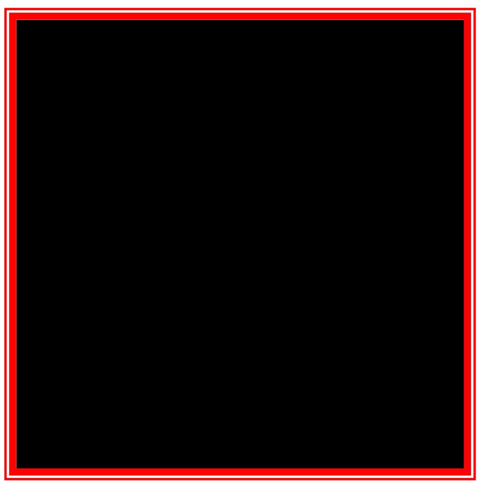
Gyricon ball dynamics*

(*Rick Lean, MIT)

Un-damped

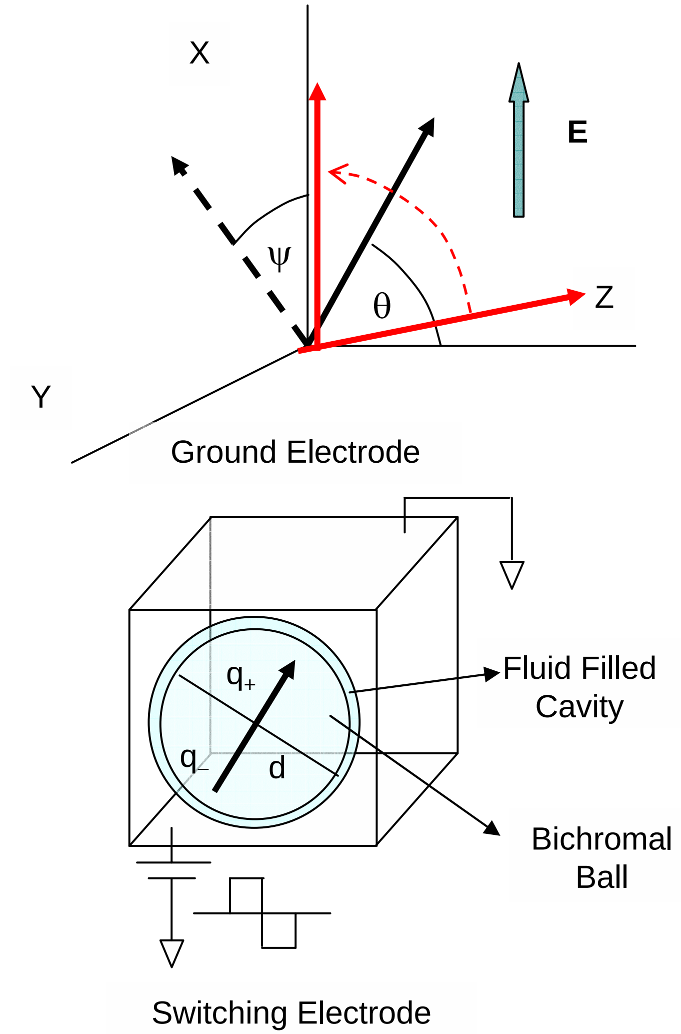


Under-damped

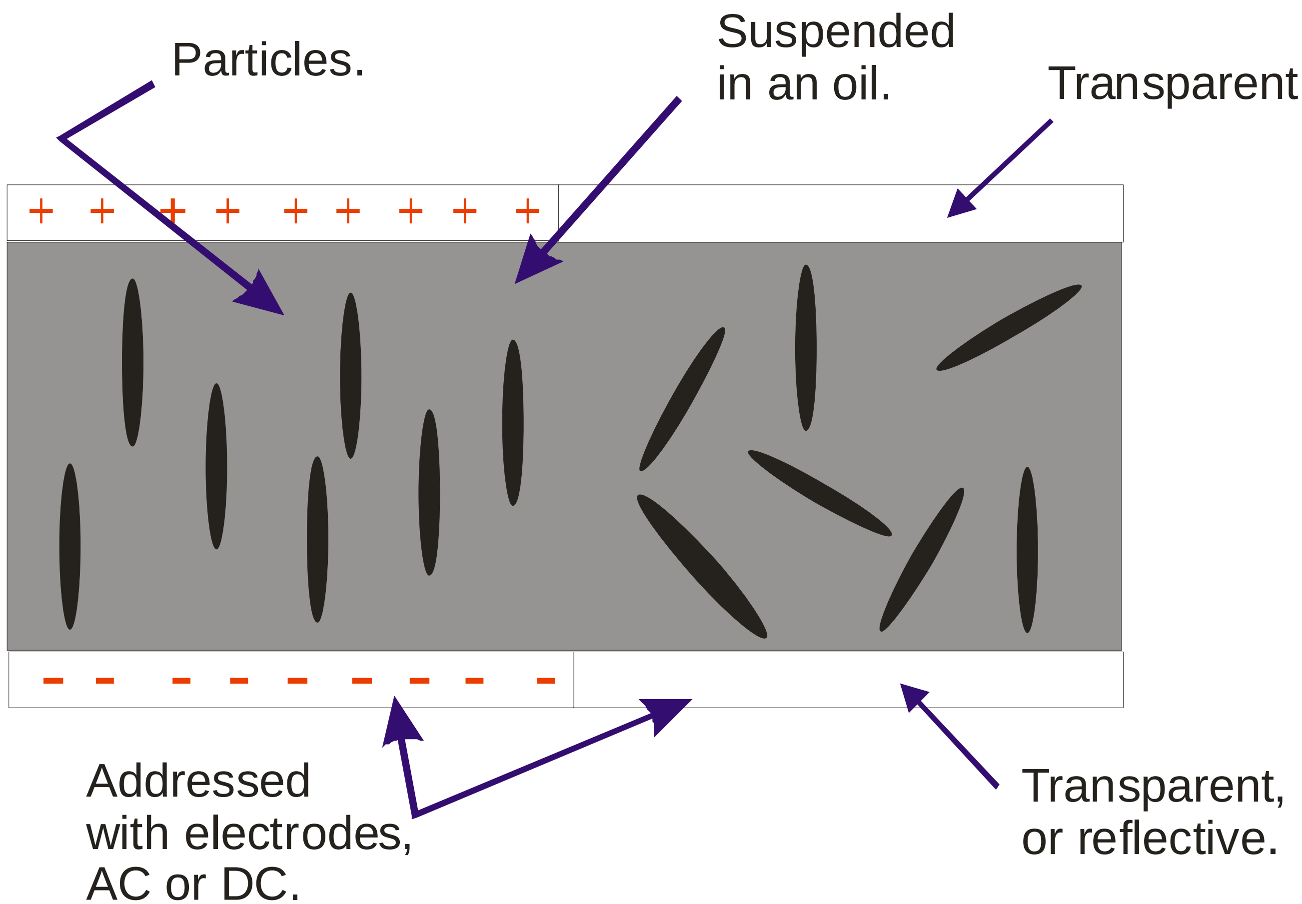


Critical-damped

Over-damped

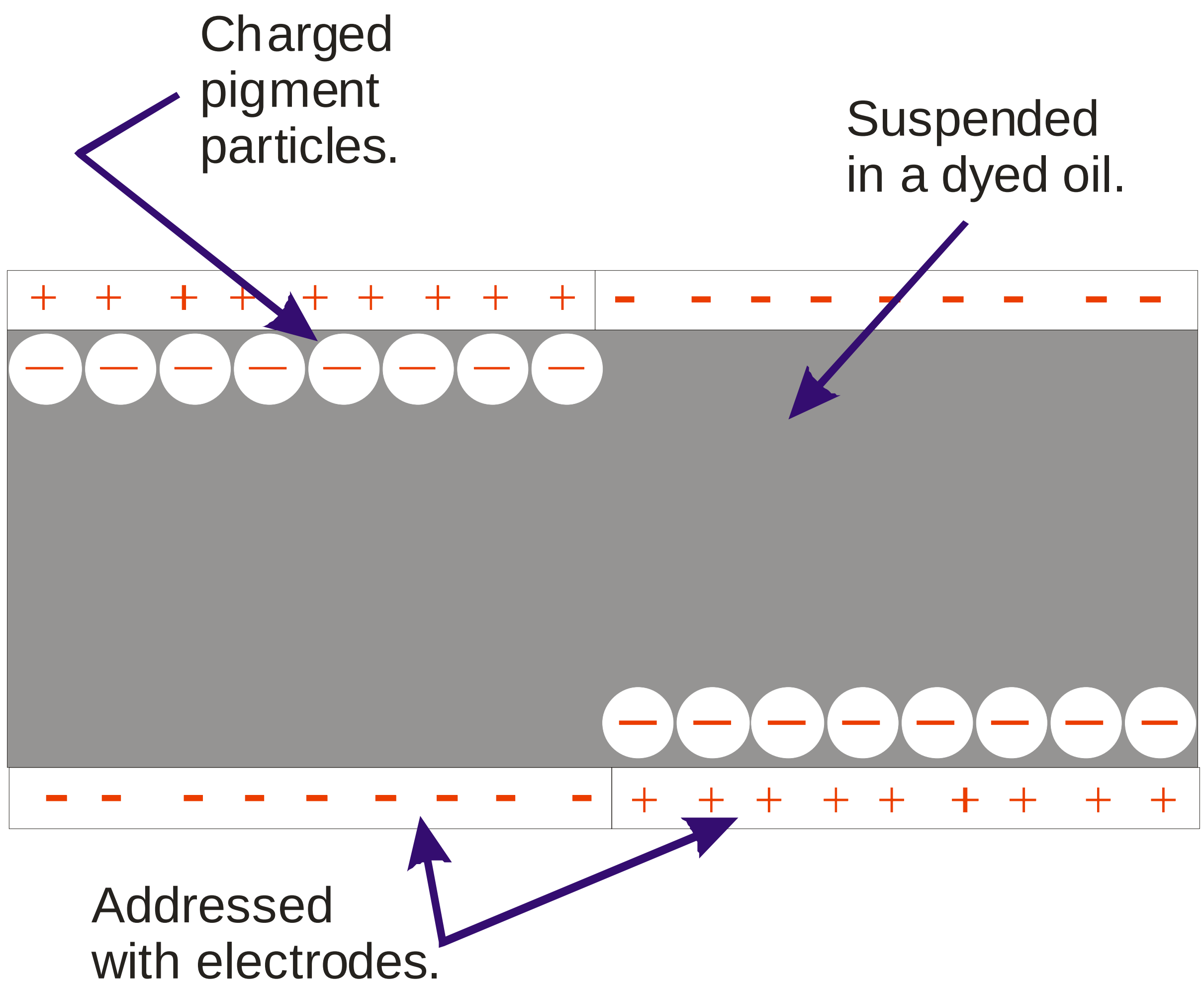


Suspended particle displays*



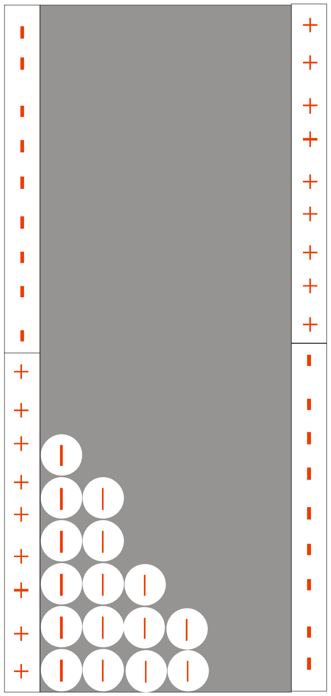
Invented by E.H. Land in 1934

Electrophoretic displays

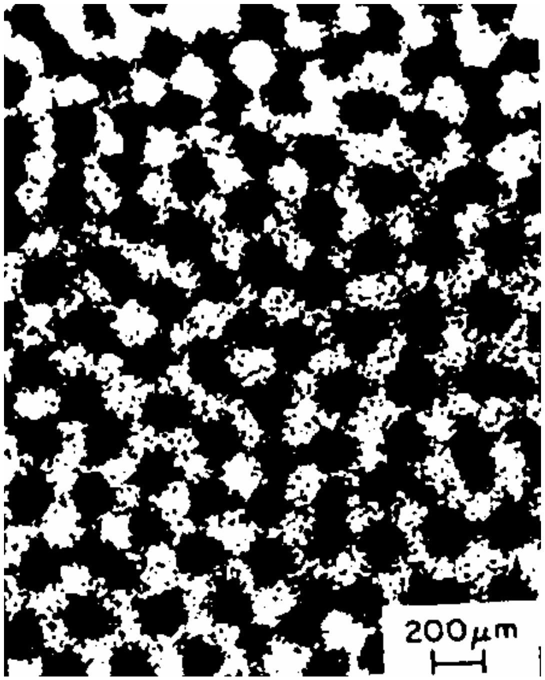


Problems with particle displays

Sedimentation:

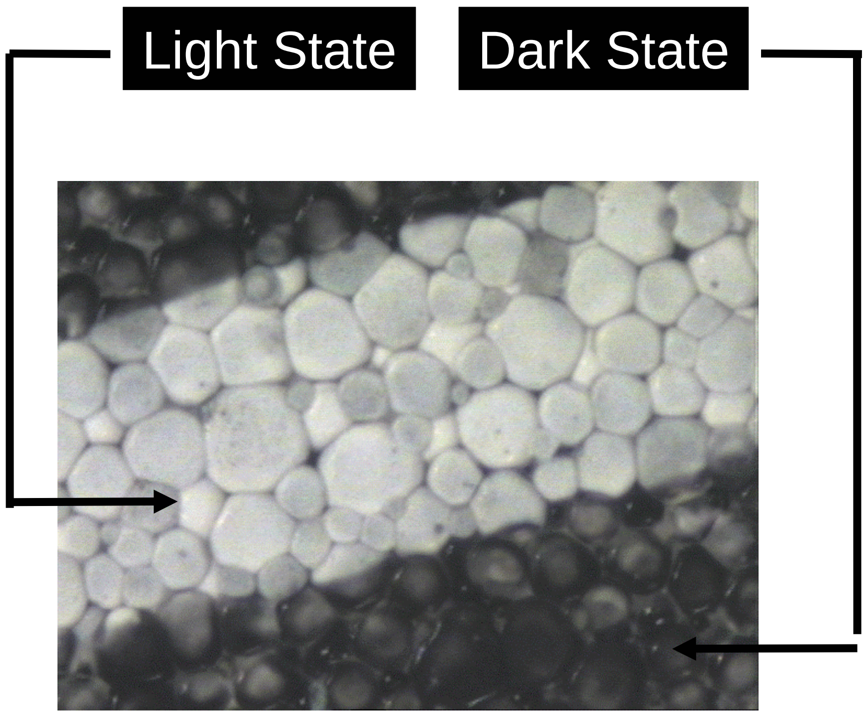


Electrohydrodynamics:



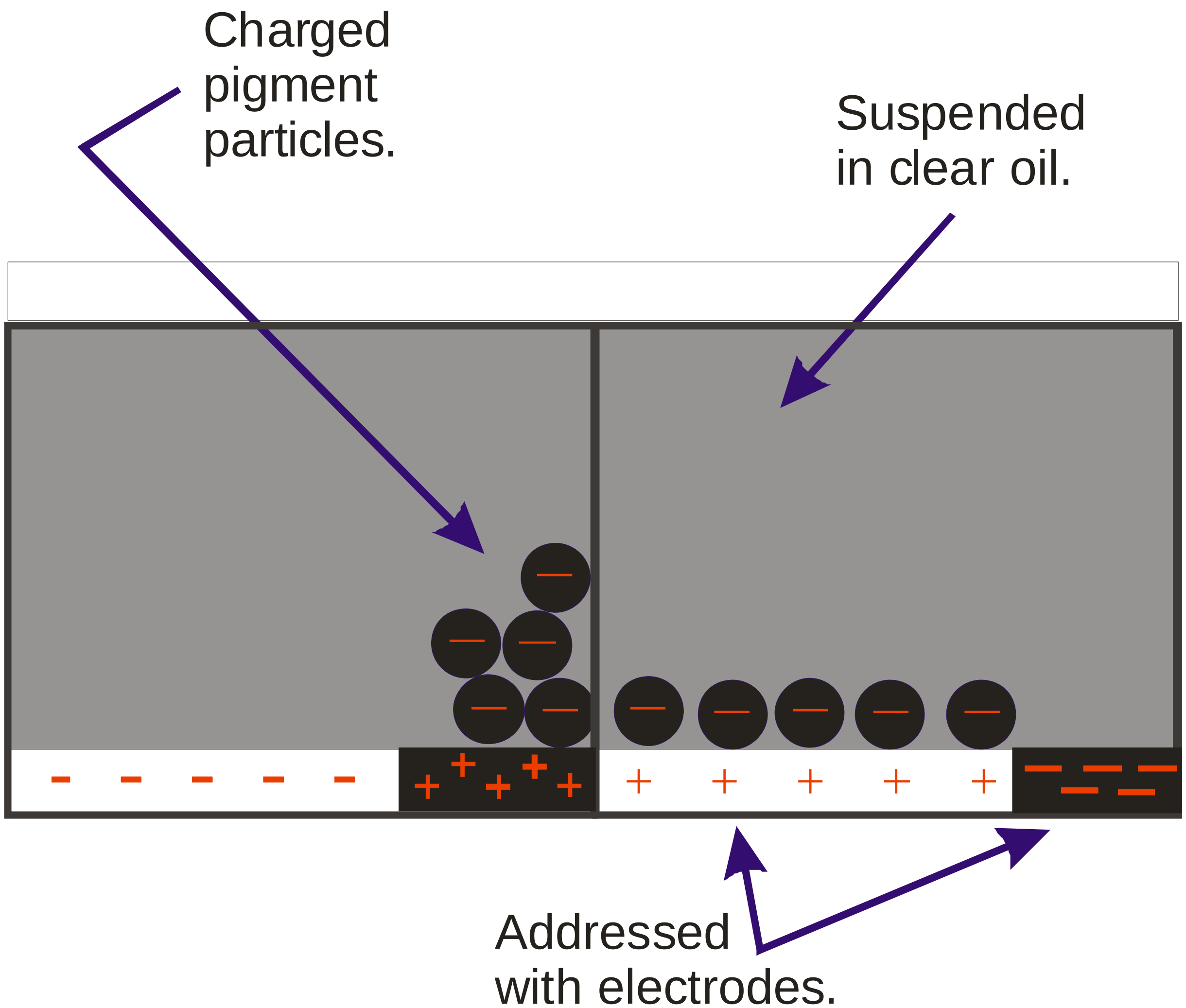
A solution - encapsulation

- “Solves”
  - Particle setting
  - Electrohydrodynamic effects
- “Creates”
  - Self-spacing electrodes
  - “Coatable” displays



NOTE: These capsules are ~ 100 microns in diameter.

Shutter mode



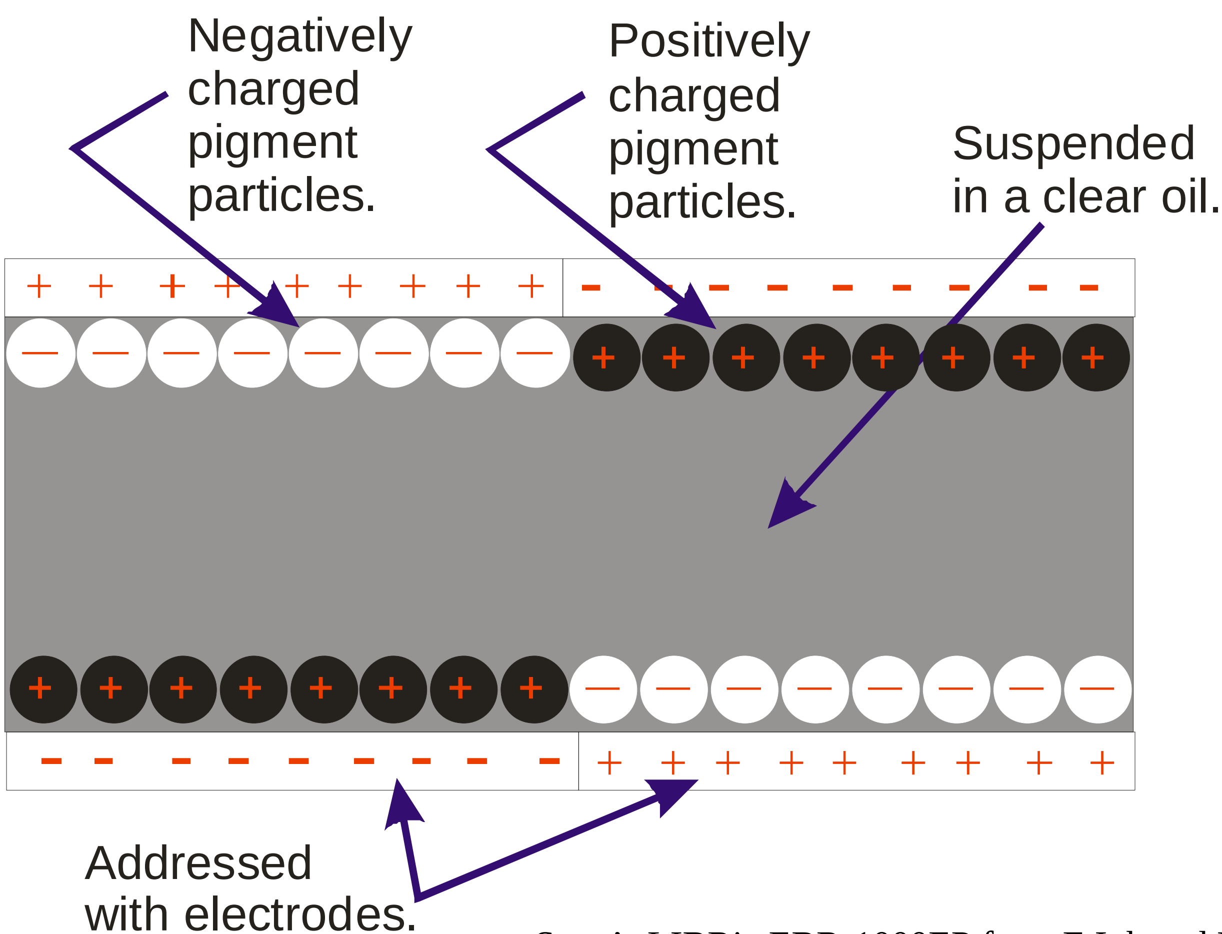
Switching speed? – use two different pigments

- Switching time goes as square of thickness:

$$\tau_{transit} \propto \frac{d^2}{V\mu}$$

- The necessary thickness is determined by the optical density.
- Dye solutions have much lower optical density than pigments.
- Therefore dual pigments enables thinner.

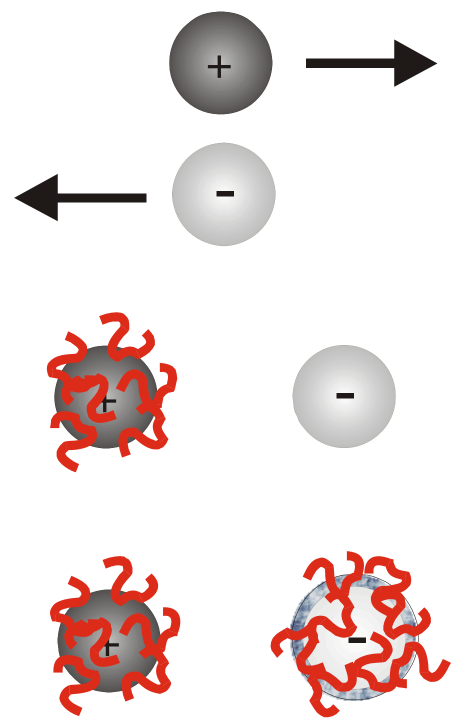
Dual particle displays



Sony's LIBRie EBR-1000EP from E Ink and Phillips Electronics

Dual particle displays

Dispersions of oppositely charged particles



How to image with flocculated particles

The field necessary to separate charged particles is:

$$Field^{separation} = \frac{Force^{total}}{|q_1 - q_2|} = \frac{Force^{vdw} + Force^{elec}}{|q_1 - q_2|}$$

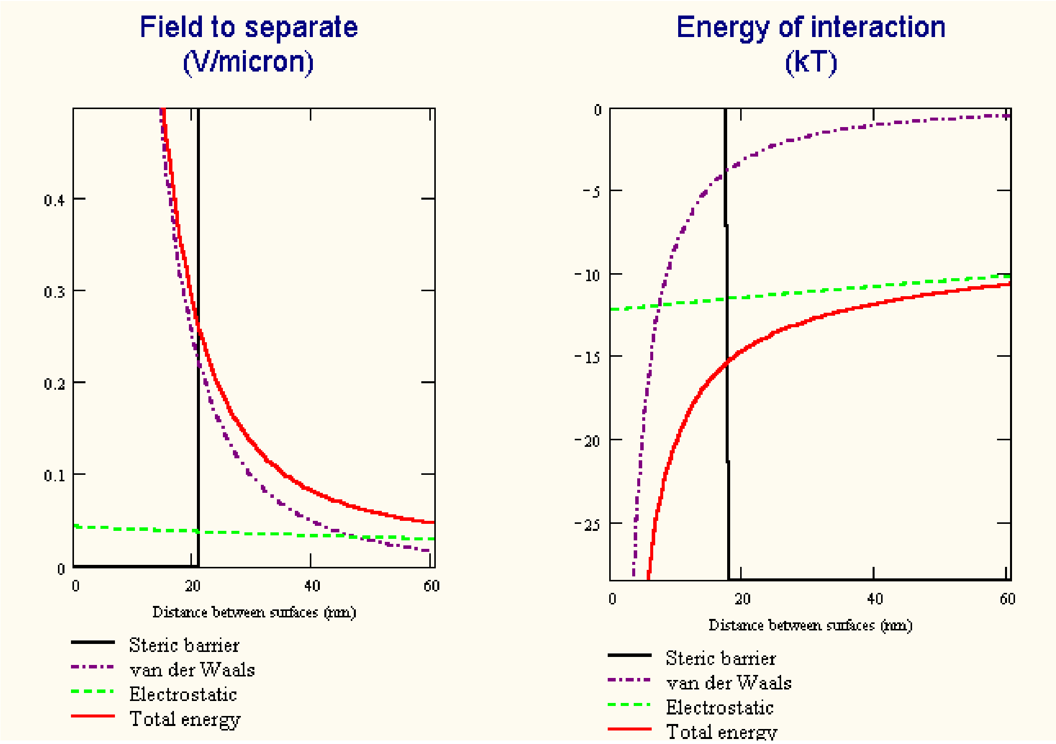
n.b. The force varies with the product of particle charges, but the field also varies with the difference.

Practical considerations set an upper limit of about 0.5 V/μm.

A steric barrier is necessary to limit the maximum attractive force.

Steric barrier necessary for typical pigments in oil

For particle radii of 150 nm, zeta potentials of +52 mV and –52 mV (corresponding to 12 charges per particle!), the background conductivity of 50 pS/cm, and a Hamaker constant of 4.05×10^{-20} J.



Control of interparticle spacing

- Electrostatic and dispersion forces are short range compared to the applied electric field.

- Therefore we produce particles that only move above a limiting electric field – an electric yield point.

- Manipulating the steric barriers and uneven surface charges controls the “yield” point.

- This enables simple threshold addressing – “line-by-line”.

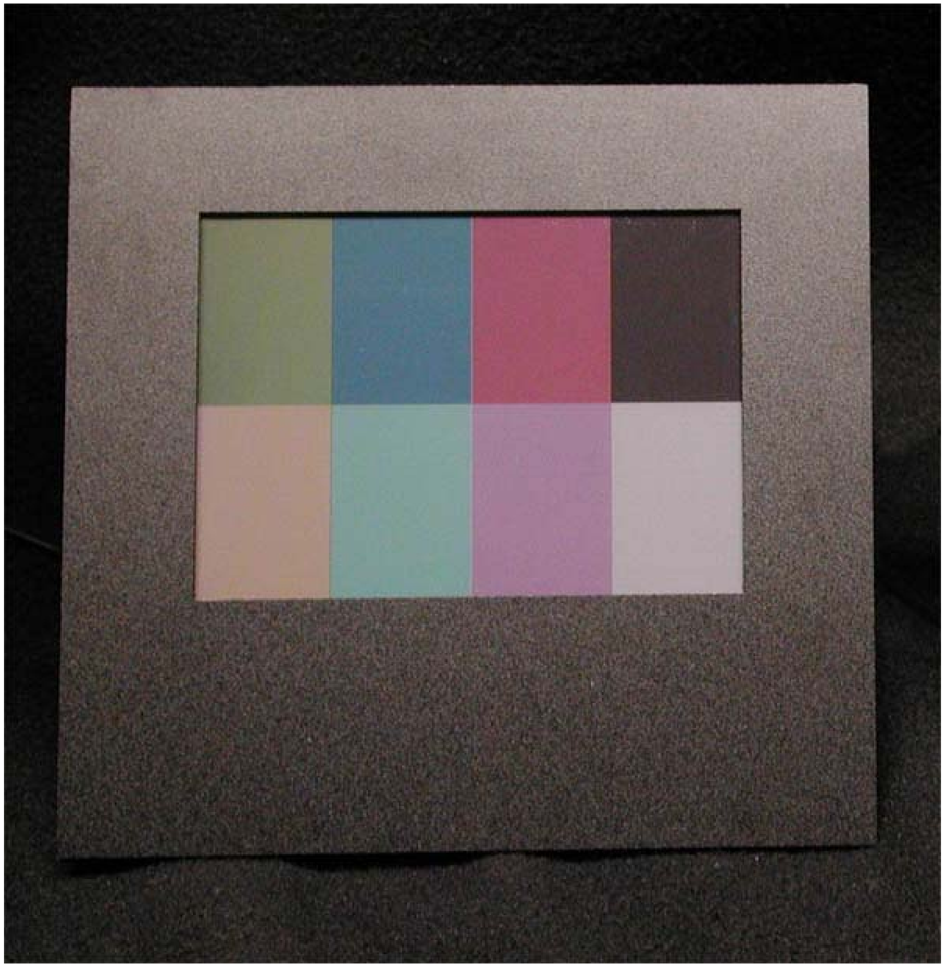
Threshold addressing by other means

From the physics of colloids:

- “Inverse” electrorheological fluids
- Field dependence of zeta potential
- AC electric fields – time dependencies
- Particle-particle or particle-wall adhesion
- Structures in fluid (particles or wide variety of polymer gels)

What about color?

Color filter arrays



Simple, but 2/3rds loss in brightness.

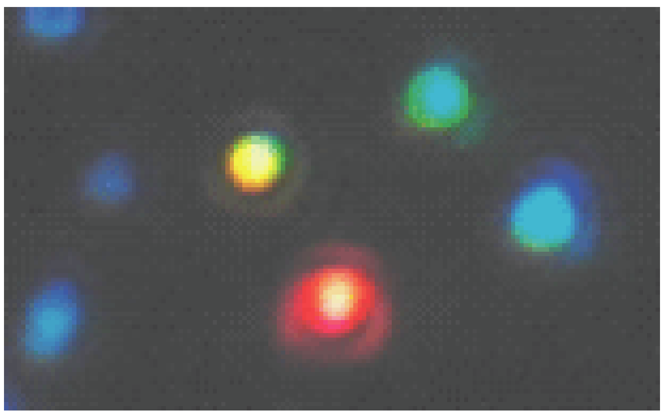
Photoelectrophoretic displays

- Photosensitive pigments
- Light + electric field produces change in charge
- Particles migrate in the field – in or out of view
- Also a passive addressing scheme

Color via plasmon resonance

The magnitude, peak wavelength, and spectral bandwidth of the plasmon resonance associated with a nanoparticle are dependent on the particle's size, shape, and material composition, as well as the local environment.

Silver nanoparticles



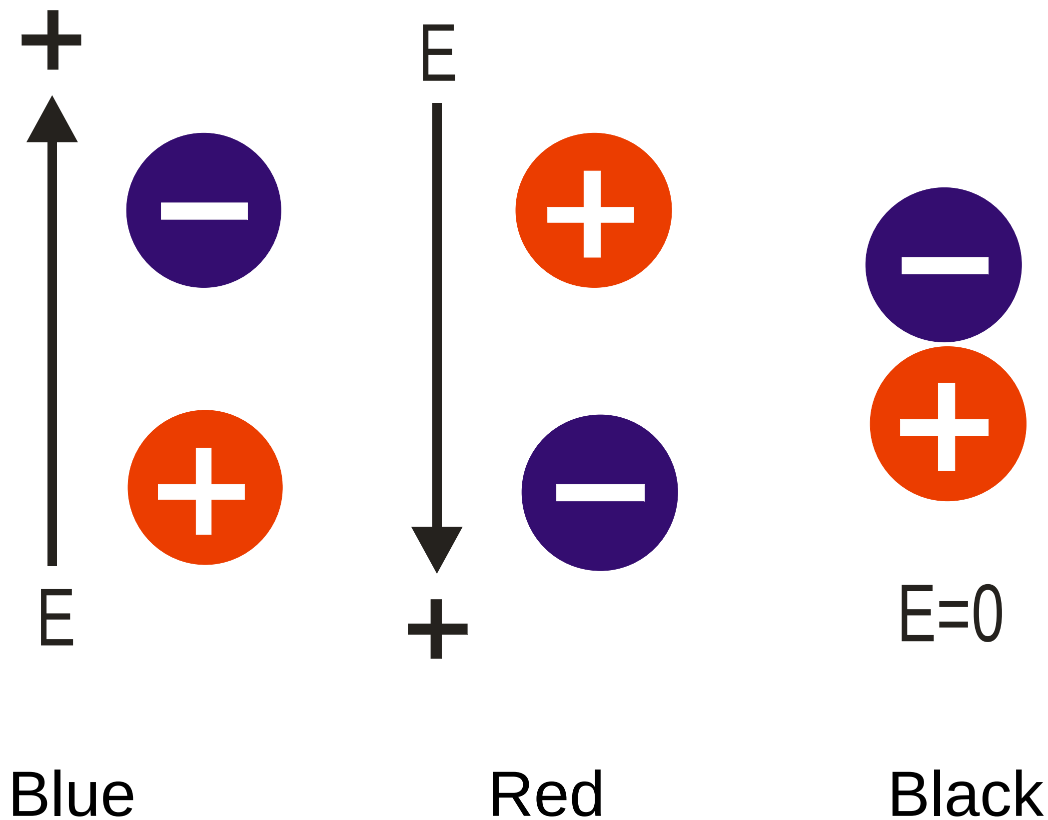
http://physics.ucsd.edu/~drs/plasmon_research_home.htm#what

Au and thin gold layers on silica.

http://www.ece.rice.edu/~halas/

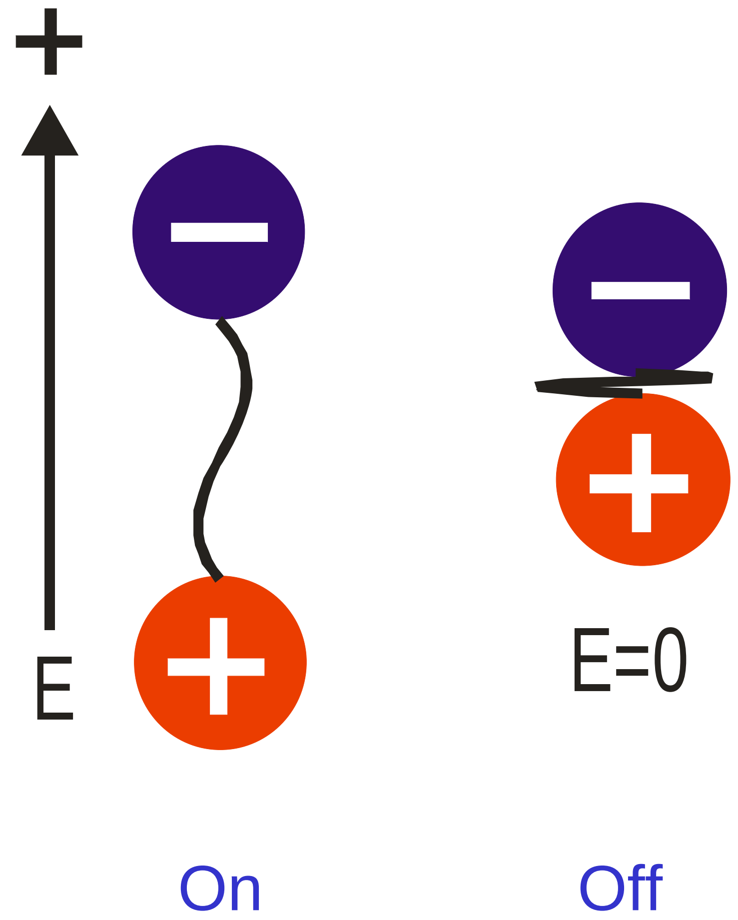
Plasmon resonance – color depends on interparticle distance

Three color states when viewed from the top, depending on the electric field.

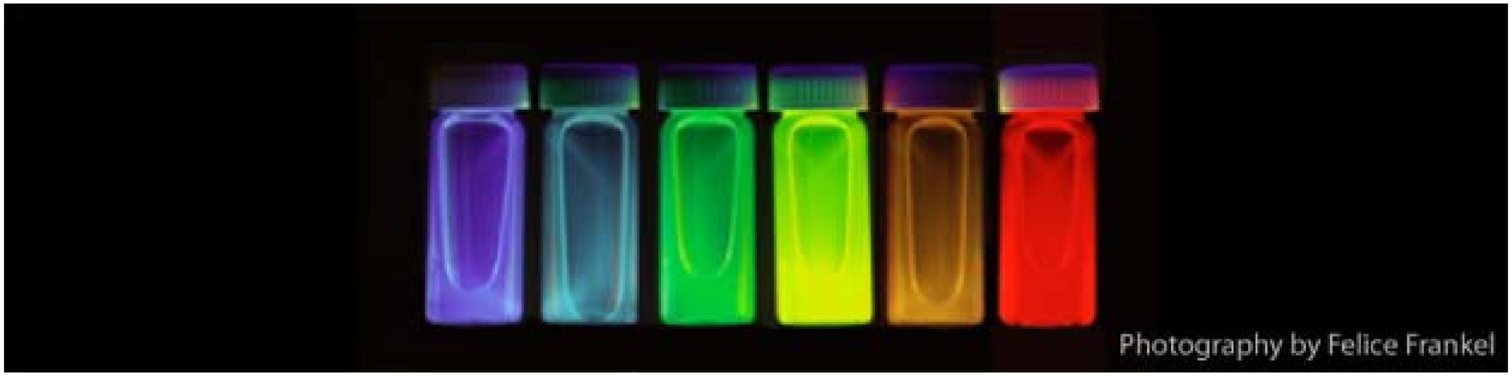


Control of spacing with tethers

Polymer tethers keep particles within 10’s of nanometers – switching times are very short.



Quantum effects



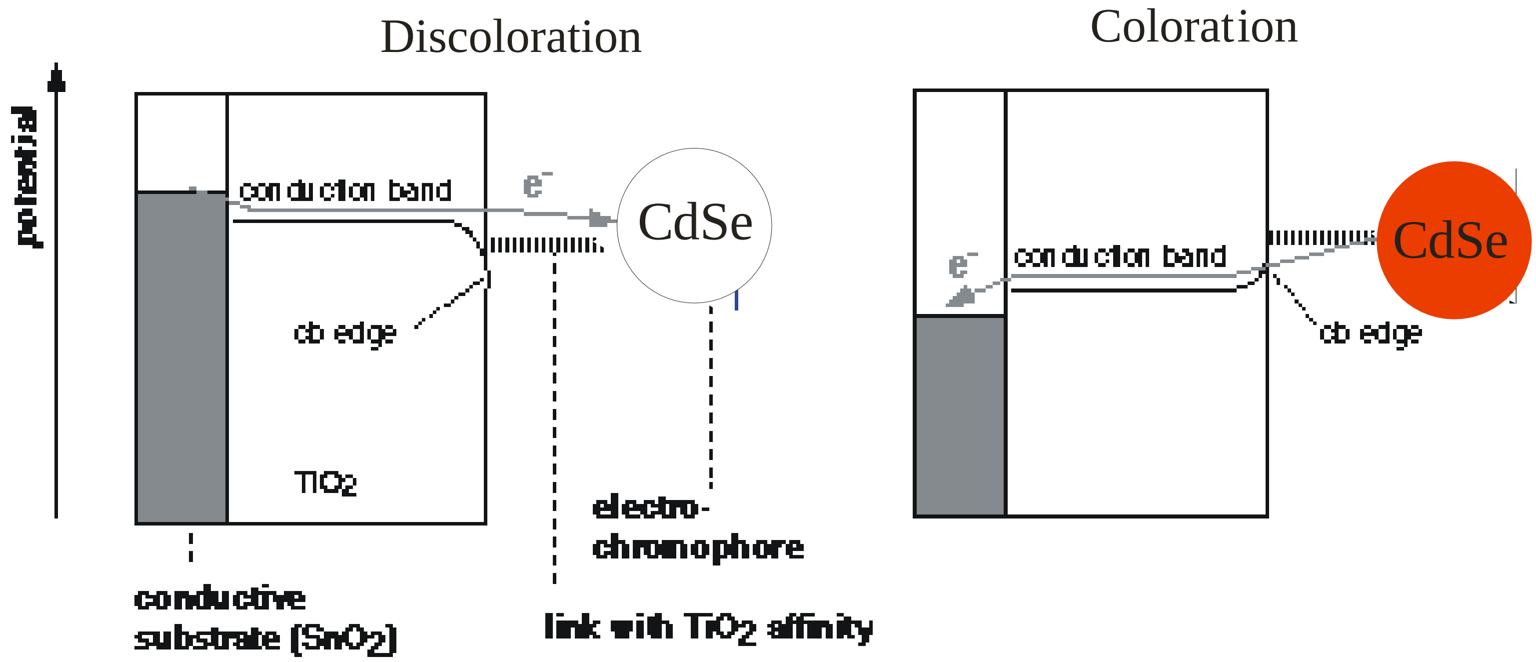
Colloidal CdSe quantum dots dispersed in hexane. Quantum confinement effects allow quantum-dot color to be tuned with particle size. (Fluorescence shown.)

Moungi Bawendi
http://web.mit.edu/chemistry/nanocluster/

Q-dot optics also depend on interparticle distance

- Large Q-dots quench smaller Q-dots
- Q-dots can be coated with a dielectric and charged
- Q-dots could be tethered to each other or to an electrode.

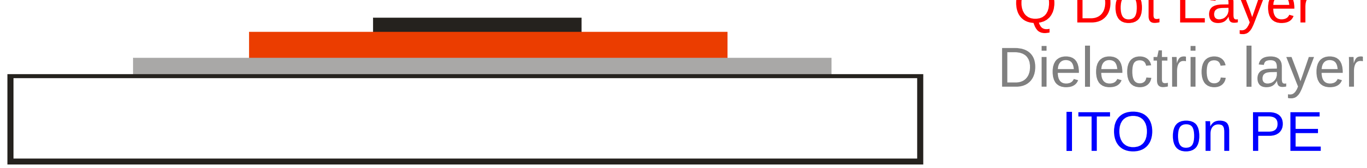
Electron injection into quantum dots



n.b. One electron per particle makes these 10^3 to 10^4 more sensitive than molecular electrochromics.

http://dcwww.epfl.ch/lpi/electr.html

Quantum dot electrochromic display



Cabot – We make fine particles by the ton.

www.cabot-corp.com