Particles in displays

Particles 2007
Particle-based device technologies
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Particles in displays?

- Prints with pigments “reflect” light.
  - The “readability” is high.
  - But the image is static.
- Displays “emit” light.
  - The images are dynamic.
  - But the “readability” is poor.

Beyond “readability”

- Persistent images, lower power
- Liquid coating rather than vacuum coating
  - Flexibility
  - Less expensive
  - Light weight
  - Fancy form factors
- Passive addressing?

The Electronic Book

- How do you make an electronic book?
- Put together electronic pages.

The Electronic Book

- How do you make an electronic book?
- How do you make an electronic page?
- Put together electronic pages.
- Put together electronic pixels.

The Electronic Book

- How do you make an electronic book?
- How do you make an electronic page?
- How do you make an electronic pixel?
- Put together electronic pages.
- Put together electronic pixels.
- Make a dot that switches colors.

The Electronic Book

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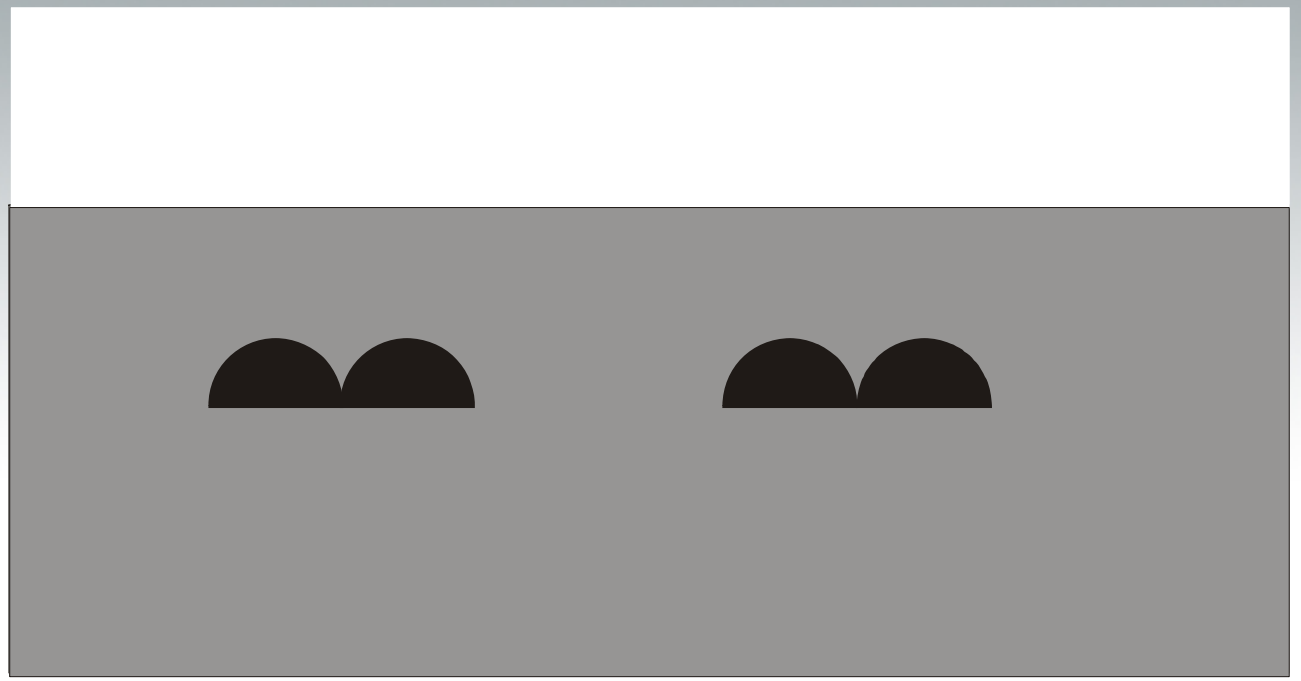
- How do you make an electronic book?
- How do you make an electronic page?
- How do you make an electronic pixel?
- How do you make a dot that switches?
- Put together electronic pages.
- Put together electronic pixels.
- Make a dot that switches colors.
- Encapsulate an ink that switches.

To create a display – start with a print



and invent ways to make it change:

Liquid ink-based printing technology

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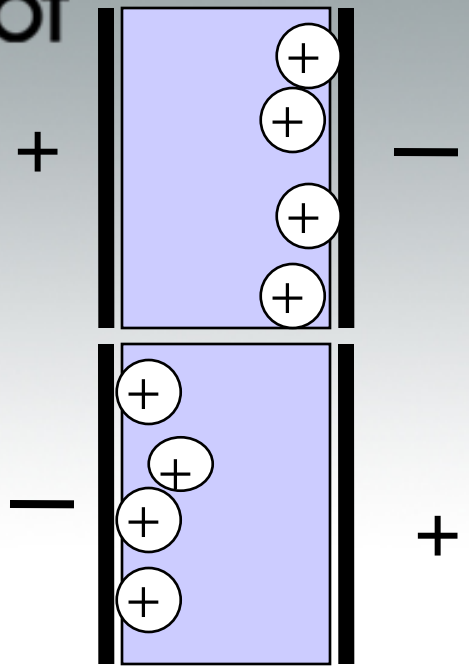
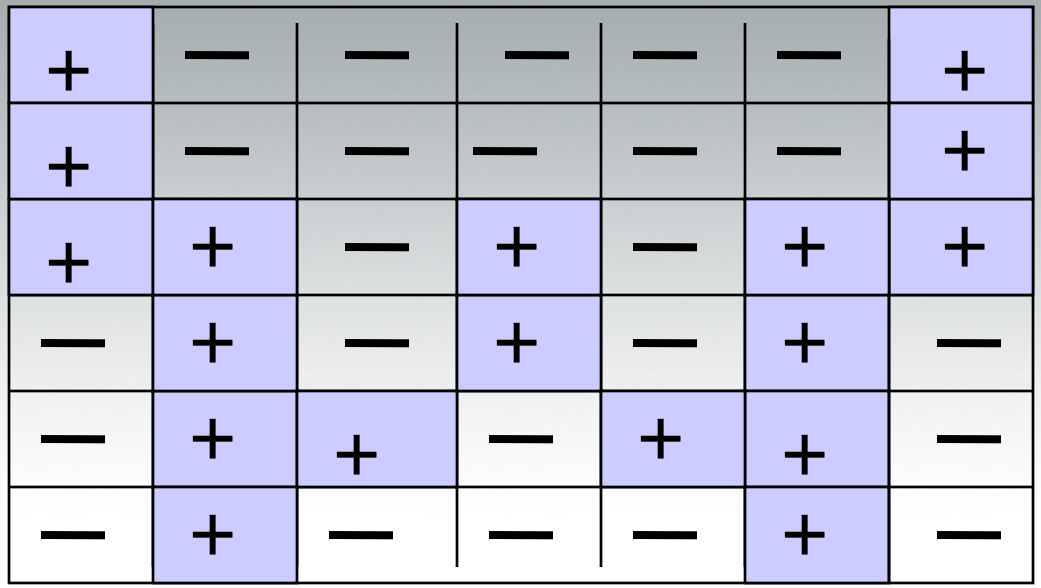
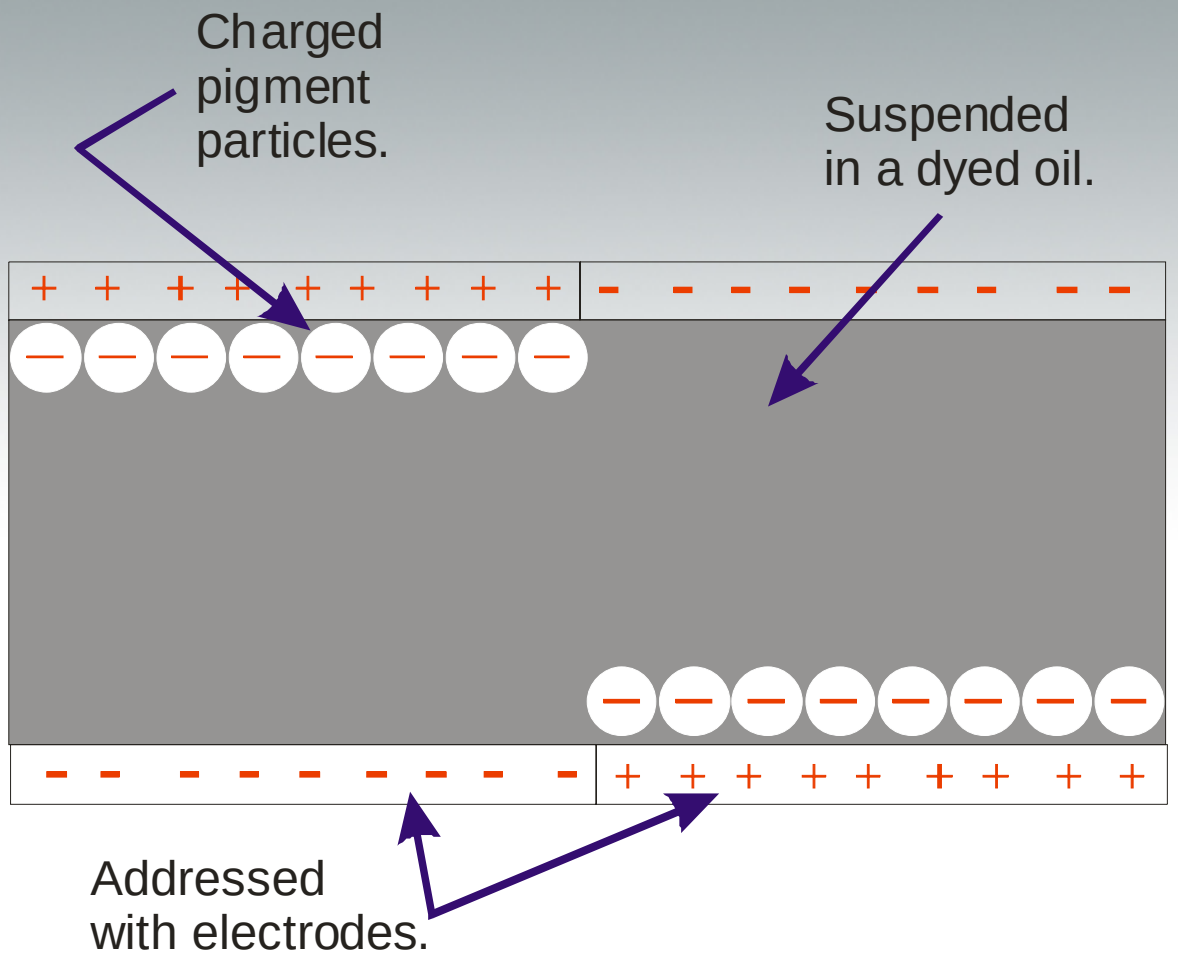




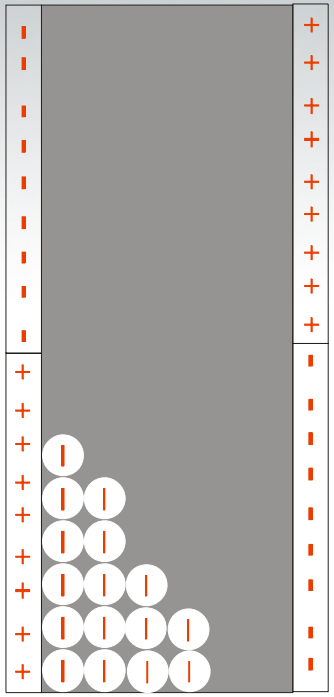
- An electrostatic image is written on a charged photoconductive surface with a scanning laser beam.
- Where addressed, charged pigment moves to the developer surface.
- The particles are transferred from the developer roll to paper and dried.

Electrophoretic displays

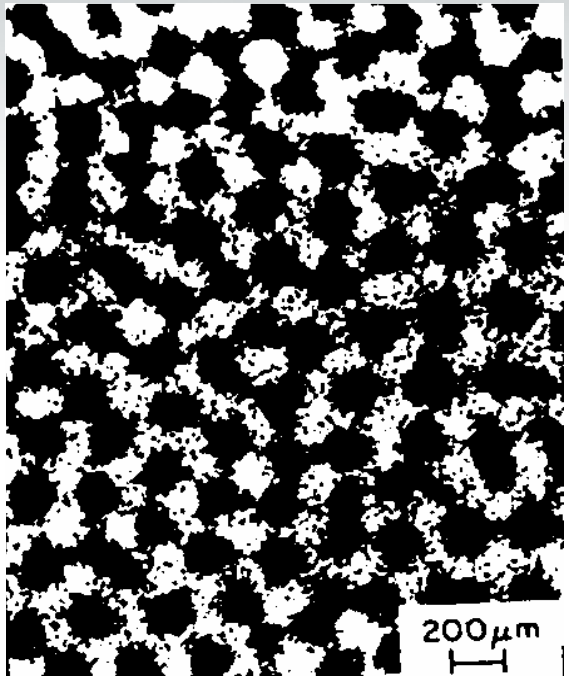


Why ink pixels are needed

Sedimentation:



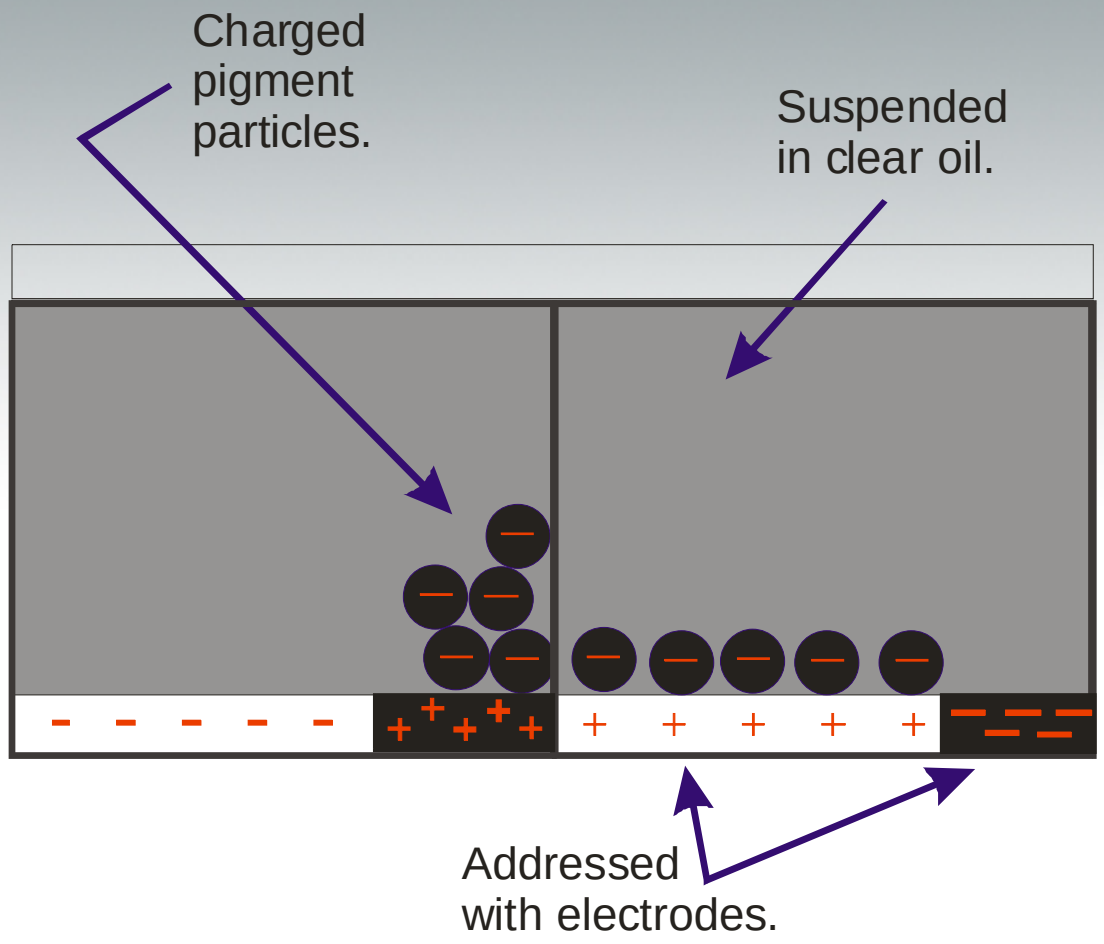
Electrohydrodynamics:



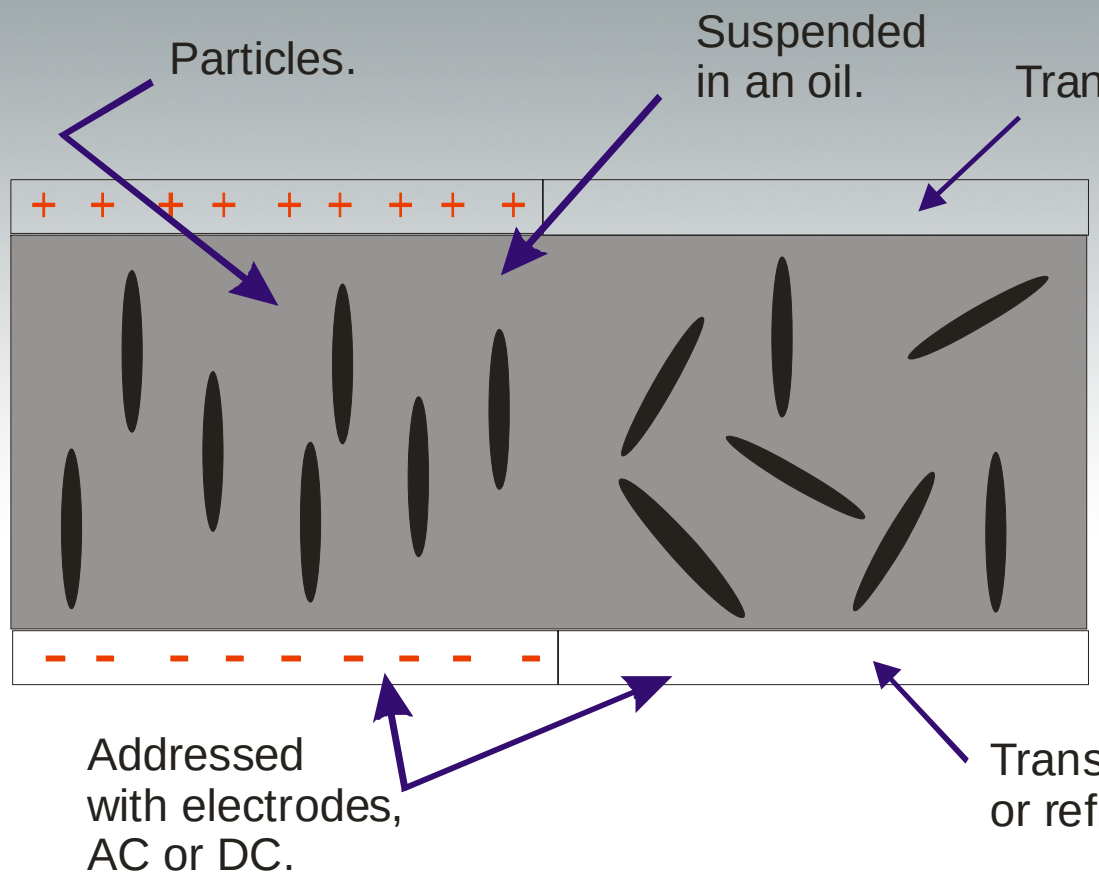
Shutter mode

Electrophoresis in shutter mode

Polymer Vision International – Reflective TFTs



Suspended particle displays*



*Invented by E.H. Land in 1934

The same effect can be obtained with small, polarizabile particles chaining in an electric field.

The charging of particles in oil:

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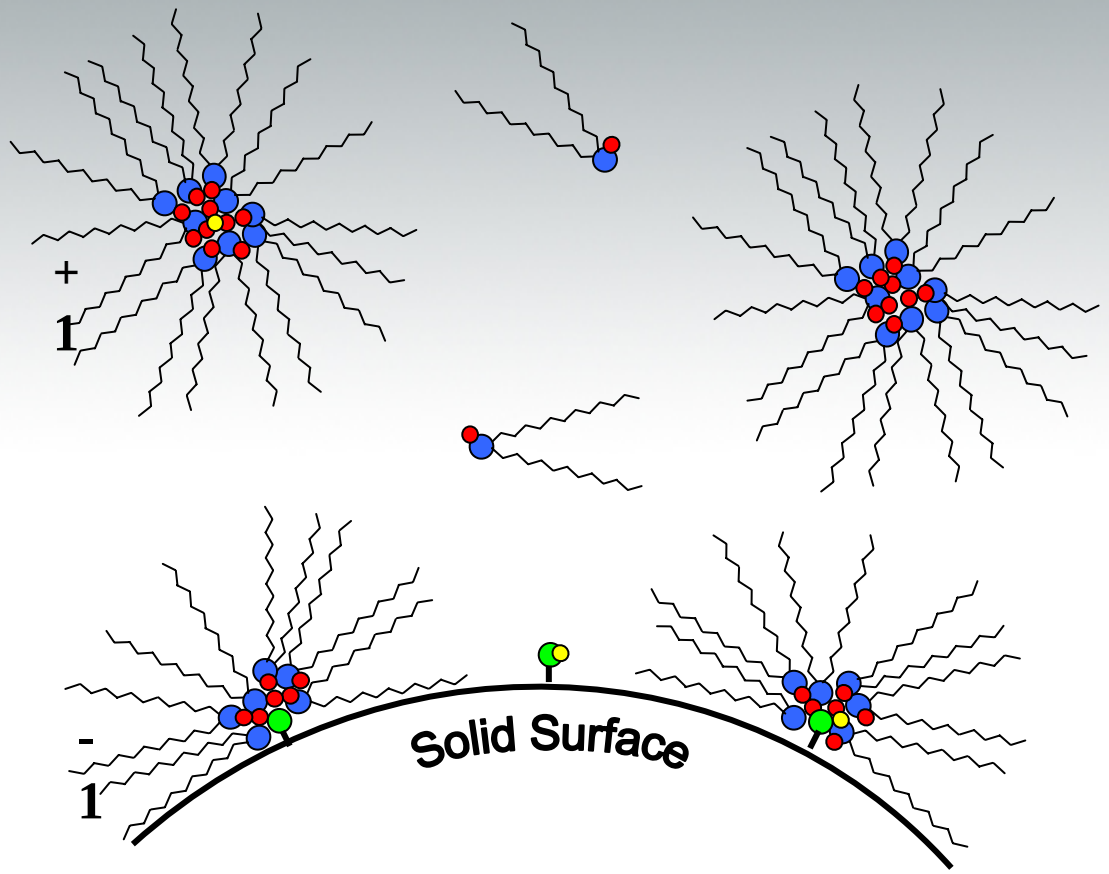
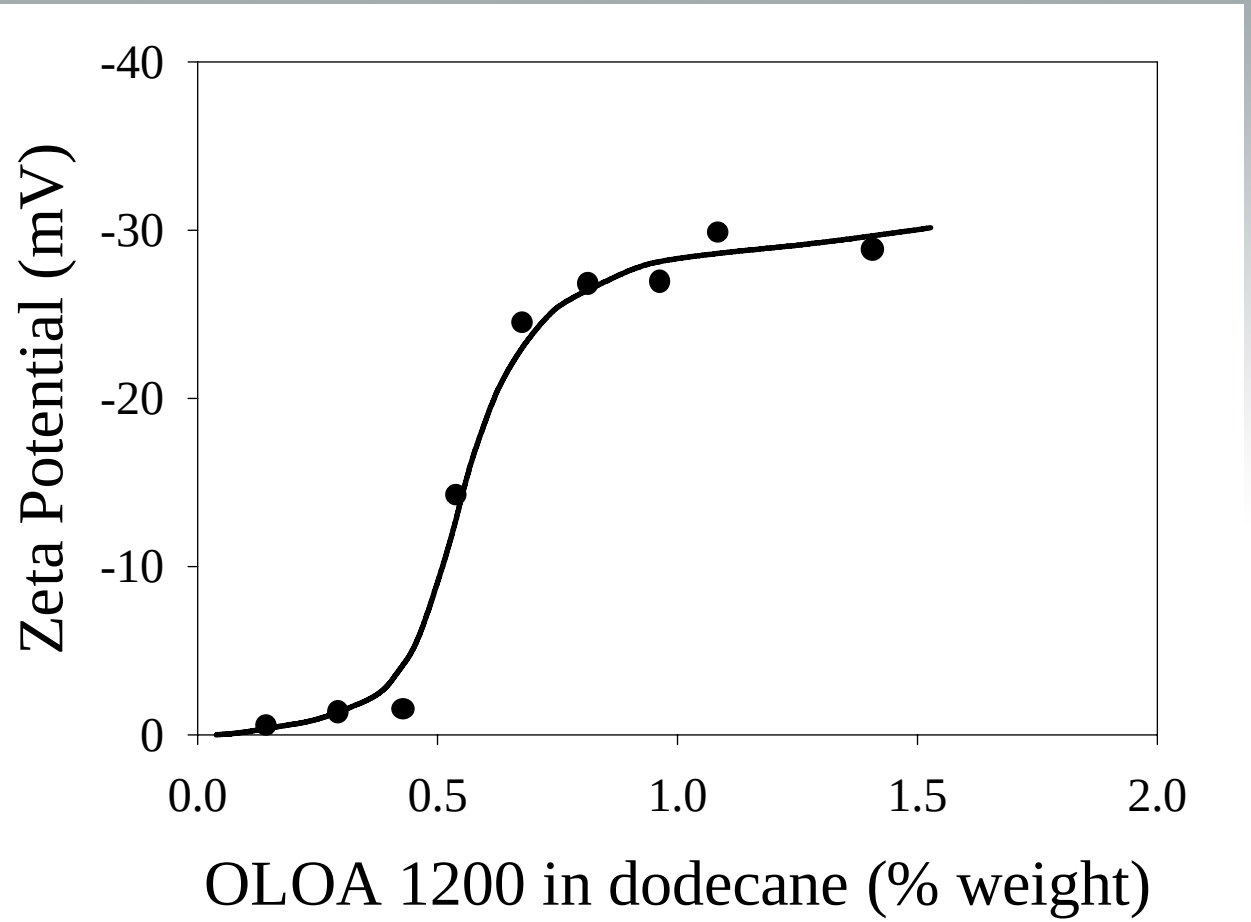


To make particles move, not ions, requires minimal free ions, therefore need nonaqueous dispersions.

If only charged particles move, and no charges were injected at the electrodes, the image forms capacitively.

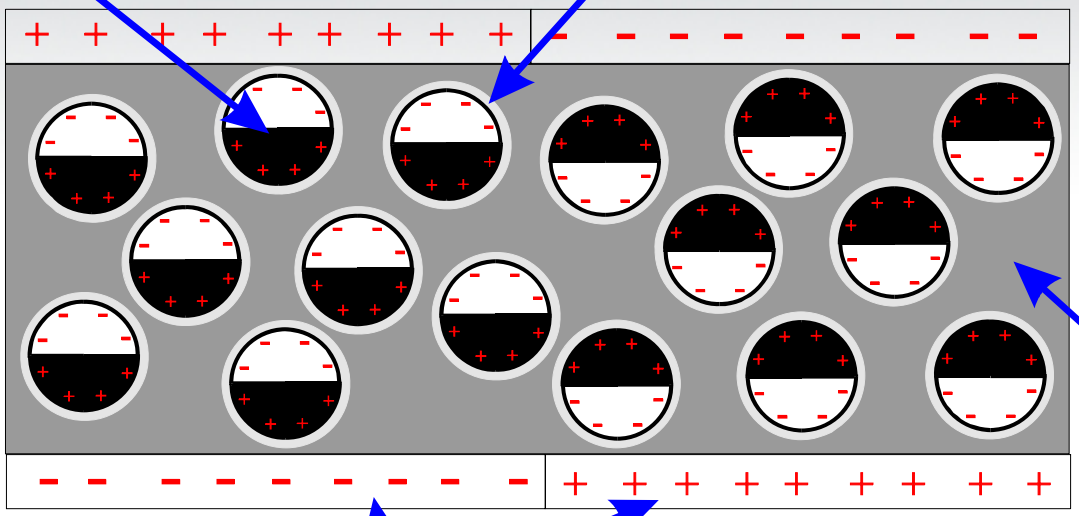
No net current and image stability!

Electric charges on carbon black in oil



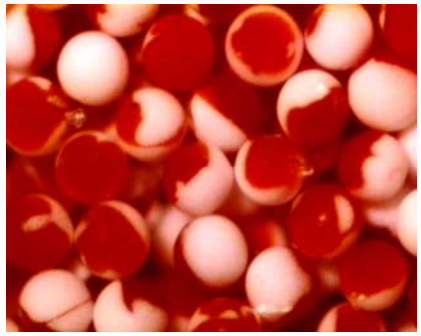
Imaging by particle rotation

The Gyricon display

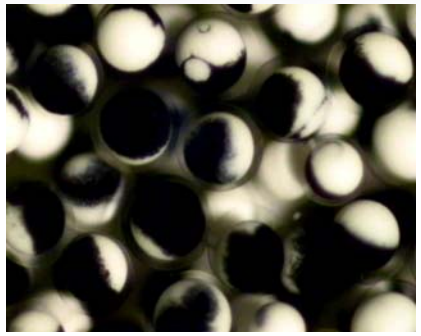


Gyricon Display

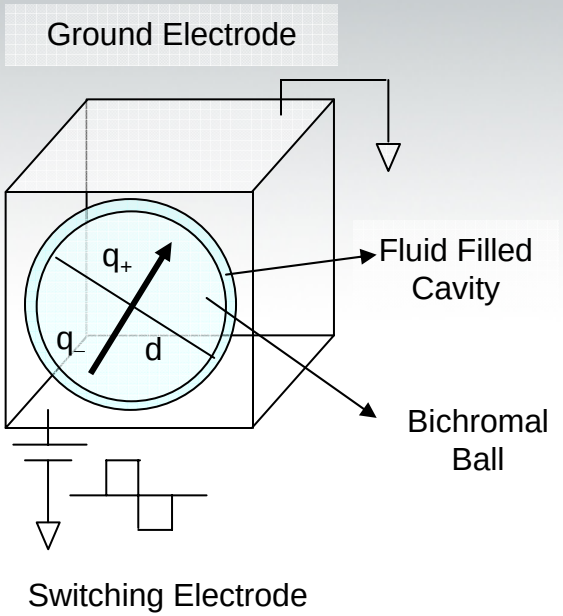
- Capable of gray levels by partial rotation.
- If the charge is unbalanced, a Coulomb force translates the ball.
- The torque varies as the ball rotates.



Red and white bichromal balls

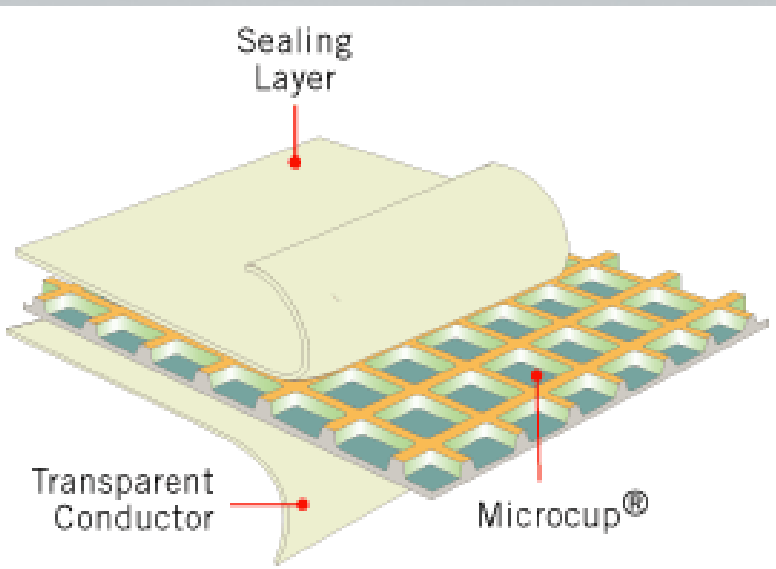


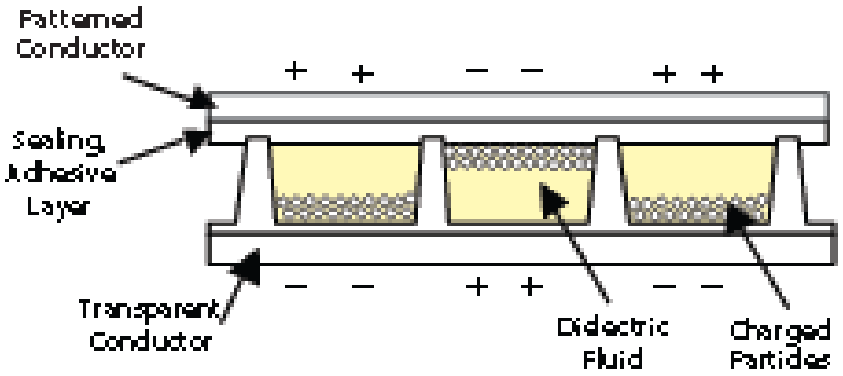
Black and white bichromal balls



SiPix Corporation

The Microcup® technology





Bright white particles are suspended in a dyed solution enclosed in a Microcup®.

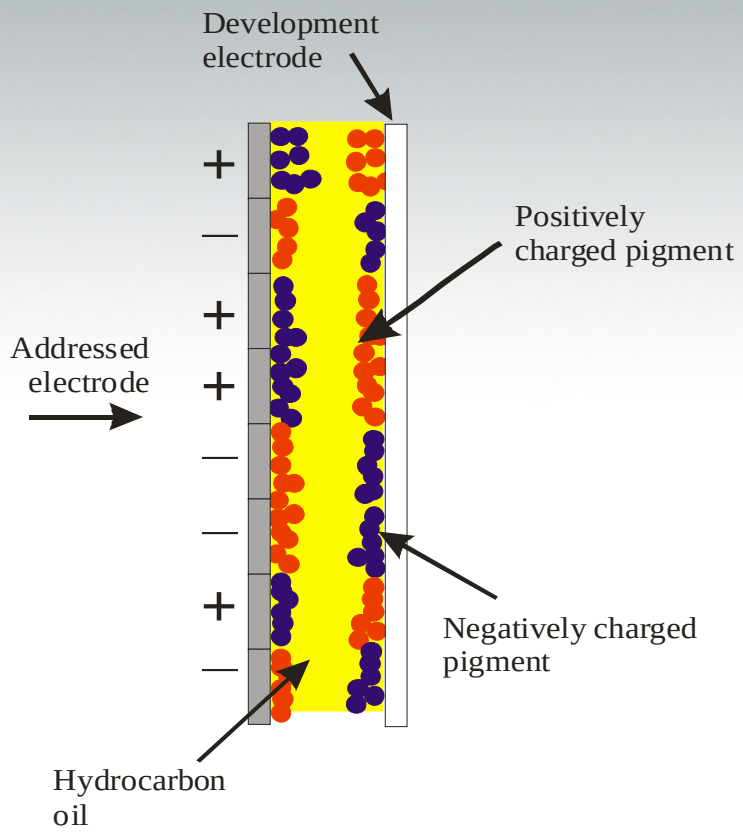
The search for lower voltage and higher speeds

- Switching time goes as square of thickness:

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

- The necessary thickness is determined by the optical density.

Imaging with oppositely charged pigments



Typical charge control agents

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- CCA1:

  Soluble tail: Polyhydroxystearic acid

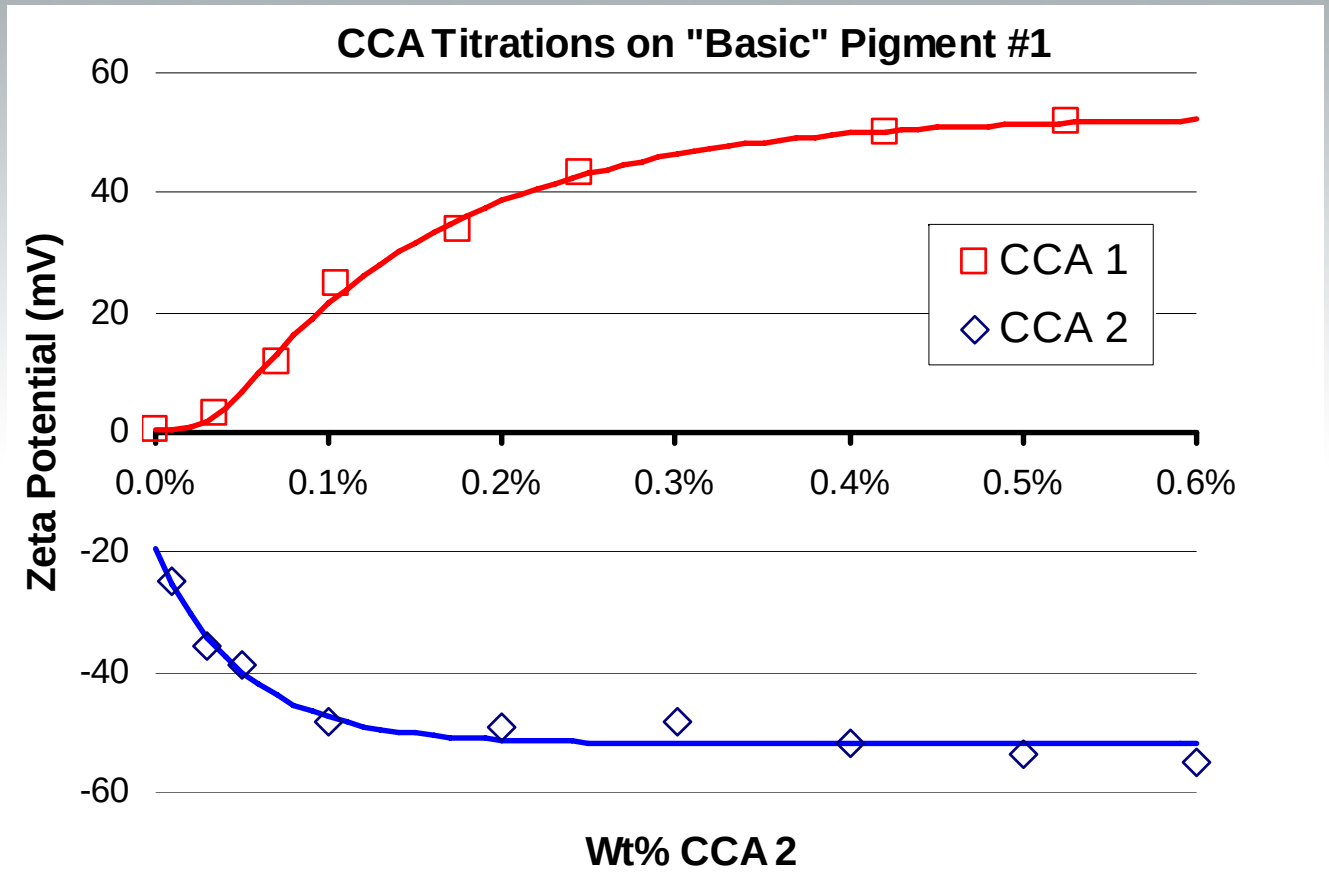
  Head group: Quaternary ammonium - methyl sulfate

- CCA2:

  Soluble tail: C13 Hydrocarbon chains

  Head group: Sodium sulfosuccinate

Charging of a surface modified pigment



Charge titration with “mixed” micelles

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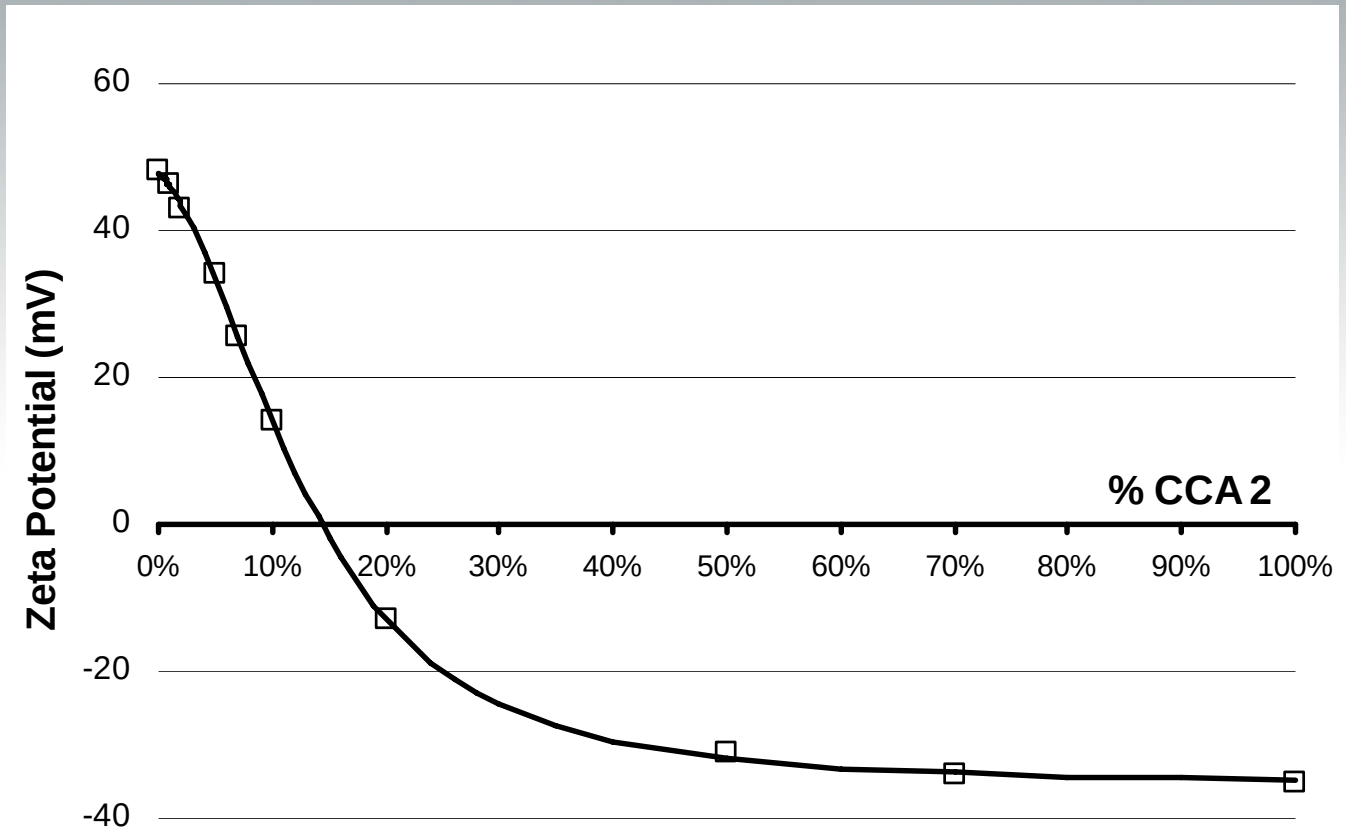
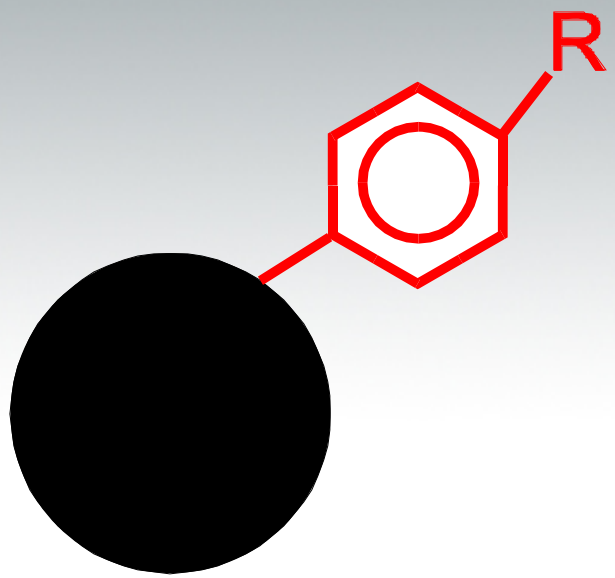
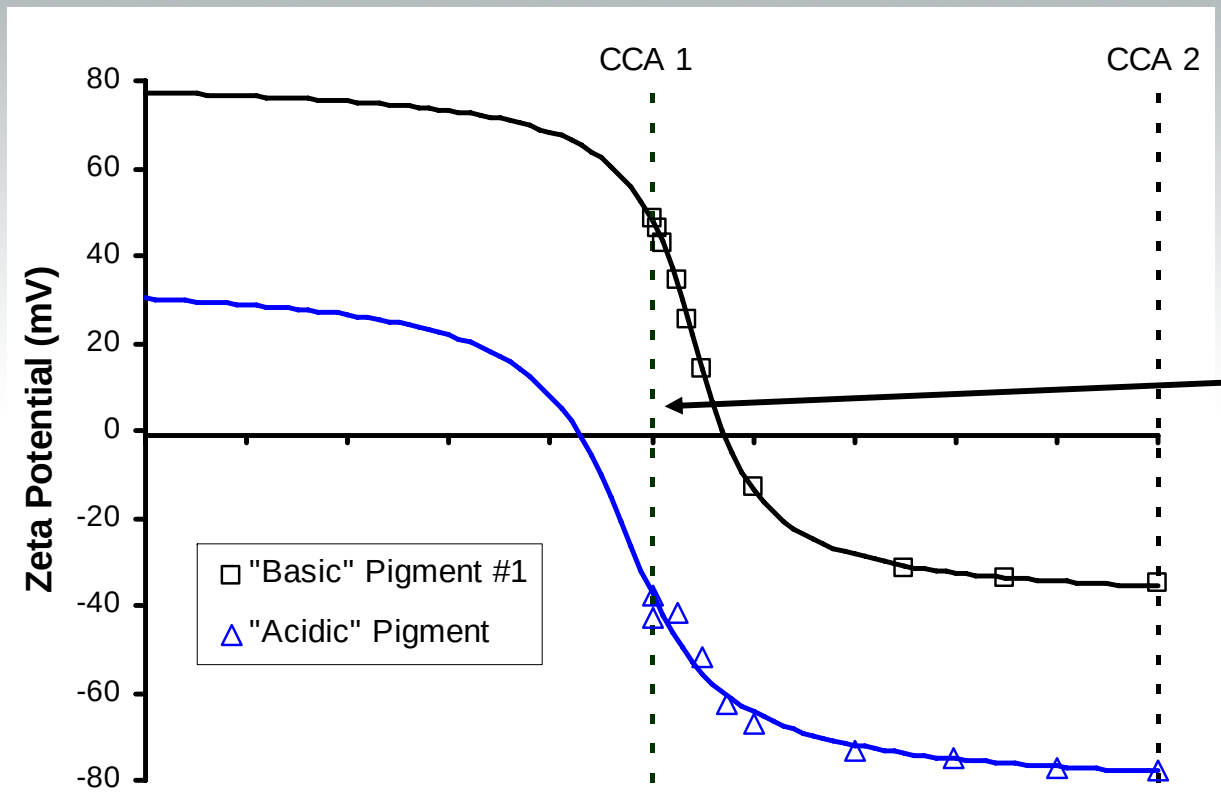


Cabot's modified pigments



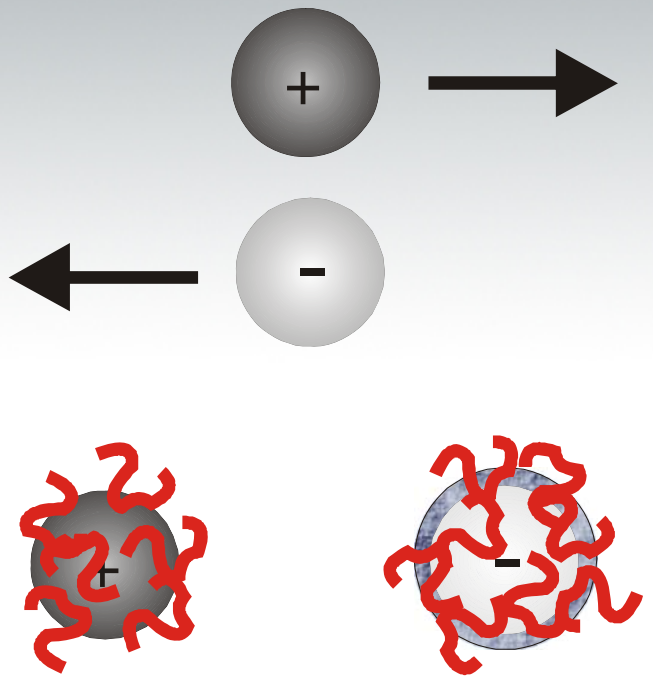
Covalently attached chargeable sites.

Titration of an “acidic” and a “basic” pigment



Note the concentration for oppositely charged particles.

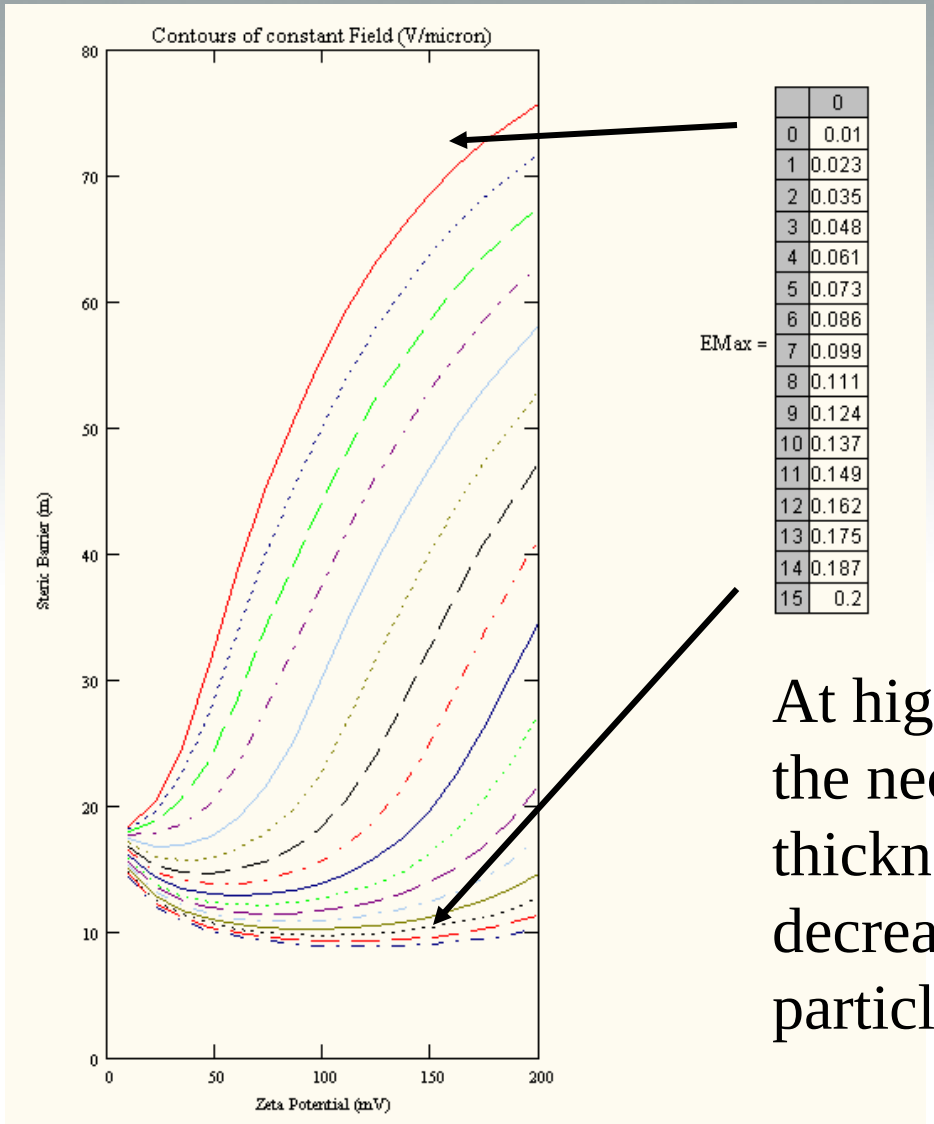
Stability of oppositely charged particles



- Calculate the force between particles as a function of distance.
- Determine the distance between particles that just equals the applied electric field.
- Calculate the energy of particles at that distance.
- Calculated how much closer the particles can come before the energy increases by kT.
- Half of that distance is the minimum steric barrier.

Requirements on steric barrier

For low electric field, the necessary thickness increases with particle charge.



At high field, the necessary thickness decreases with particle charge.

E Ink Corporation

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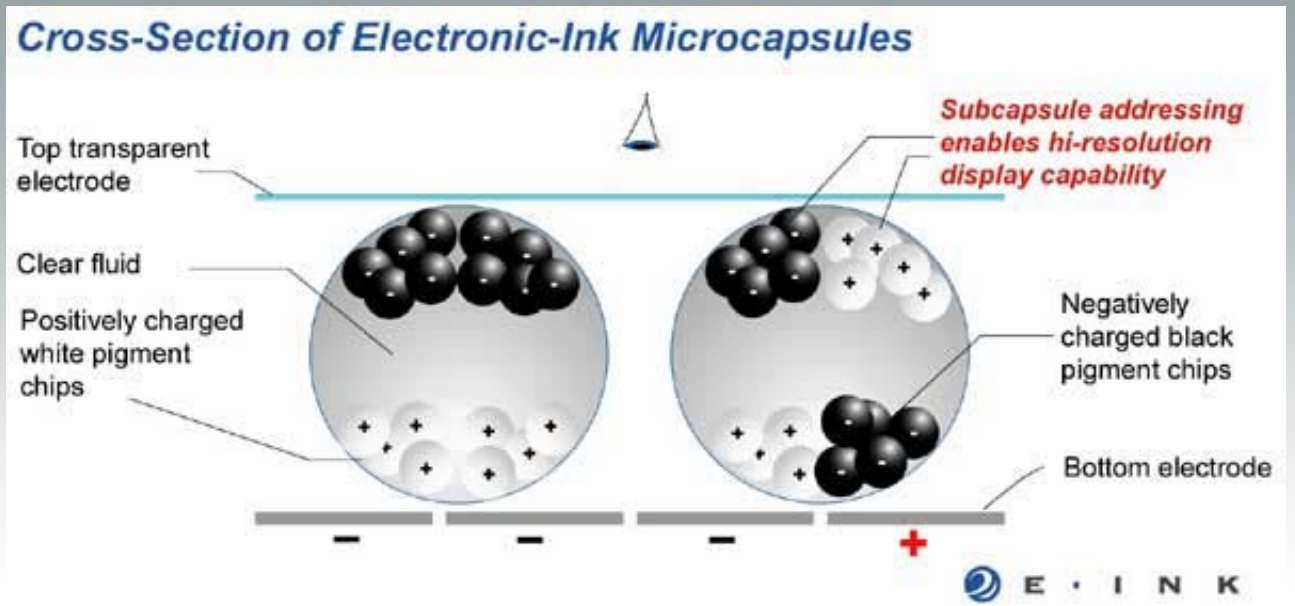
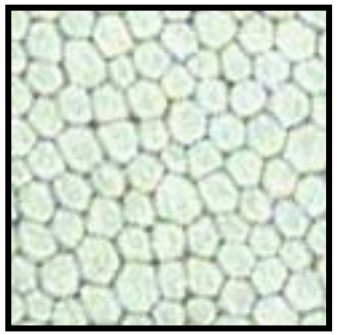
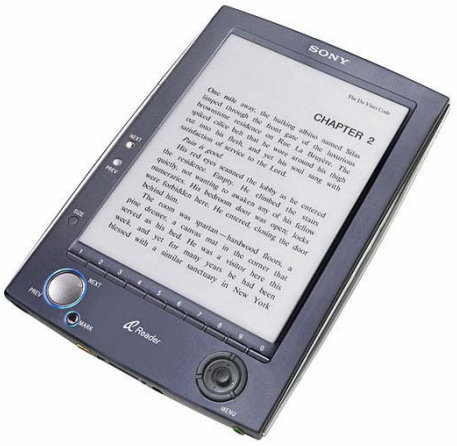


Dark State



Light State



- Sony Reader utilizing E Ink Imaging Film TM
- *Photos courtesy of Sony Corporation*

creating what matters

Scaling laws for an ideal system

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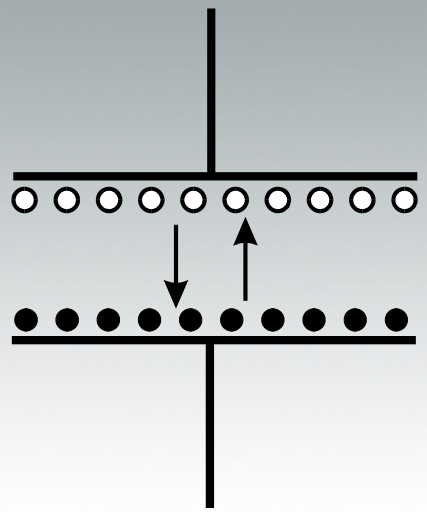
Assume: the charged particles just neutralize the applied voltage.



M is the mass of particles/area.

The charge and zeta potential of the particles are:

$$q = \frac{DV_0}{n_0 L_s^2} \qquad \zeta = \frac{q}{4\pi Da}$$

The switching time doesn't depend on size:

$$t = \frac{3\eta L_s^2}{2D\zeta V_0}$$

The voltage is: $V_0 = \frac{3\zeta M}{\rho}\frac{L_s}{a^2}$

Bigger is better!

Particle Morphologies

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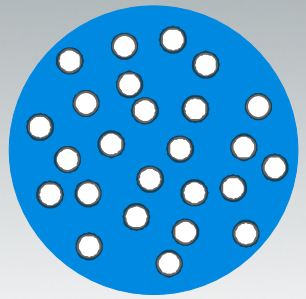
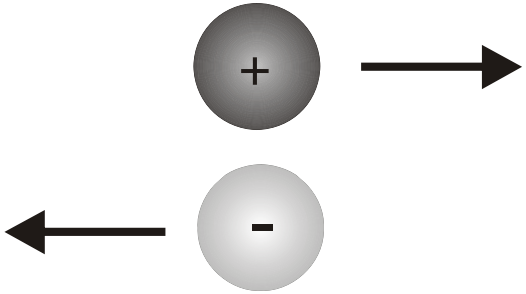
Not:

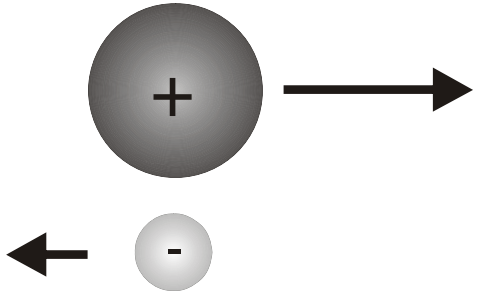
But:



Not:



But:



Passive addressing: Thresholds

- 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)

Xeroxgraphy – Dry printing

Dry toner particles exchange charge (tribocharge) with large, generally magnetic carrier bead.

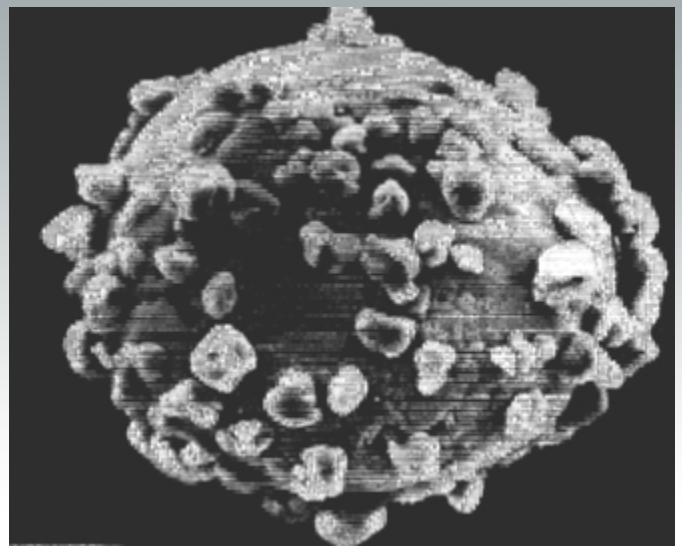


Photo courtesy Xerox
A developer bead coated with small toner particles

An image is formed when the toner particles are pulled off and attach to the electrostatic image on a photoreceptor.

Bridgestone's Quick Response Liquid Powder® Display

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- The "Liquid Powder" is a dry dispersion of two types of particles.
- The particles are about 10 microns, pigmented polymer beads, spherical, smooth, and chemically treated.
- The powder flows freely. The different colors have different sign charged.
- The image forms quickly with the separation of dry powder in the electric field.

Bridgestone's Quick Response Liquid Powder Displays (QR-LPD®)

Caveat emptor

- An “adequate” print resolution is about 1200 dots/inch.
- Or pixels of about 20 microns (for black and white). Smaller for cyan/magenta/yellow.
- Or about 10,000 pixels across a page!
- Well beyond current electronic displays!
- Progress will be limited by the electronic addressing.

Particles in displays

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- Dielectrophoresis - particle alignment or chaining
- Segmented structures
- Particle rotation
- Electrophoresis to a viewing surface
  - Particle and dye
  - Dual particle
- Electrophoresis in shutter mode
- Passive addressing
- Dry powder flow

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