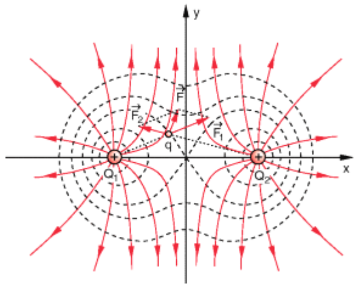
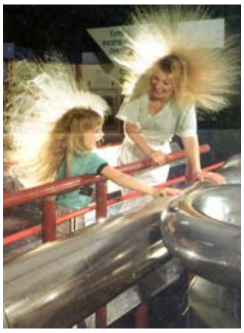
Kapitel 1: Elektrostatik

- Elektrische Ladungen und Kraft (Coulomb-Gesetz)
- Das elektrische Feld und elektrostatisches Potential
- Dipole
- Die Energie des elektrischen Feldes
- Leiter und Dielektrika im elektrischen Feld
- Die atomaren Grundlagen von Ladungen und elektrischen Momenten
- Weitere Beispiele in Natur und Technik

$$\boldsymbol{F} = f \cdot \frac{Q_1 \cdot Q_2}{r^2} \hat{\boldsymbol{r}}$$





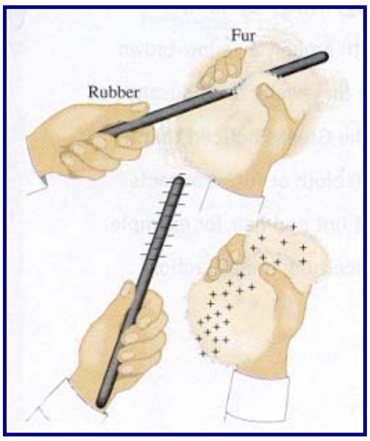
Triboelectric sequence

(Reibungselektrizität)

- Rabbit Fur (very positive)
- **Glass**
- **Human Hair**
- Wool
- **Cat Fur**
- Lead
- **Silk**
- Human skin, Aluminum
- Paper
- Cotton
- Wood
- Amber (Bernstein)
- Rubber (hard)
- Copper, Brass
- Styrene (Styrofoam)
- **Polyethylene (like scotch tape)**
- **Polypropylene Vinyl (PVC)**
- Silicon, Teflon (very negative)

\+

The ***items on top*** are less attractive to electrons and become positively charged



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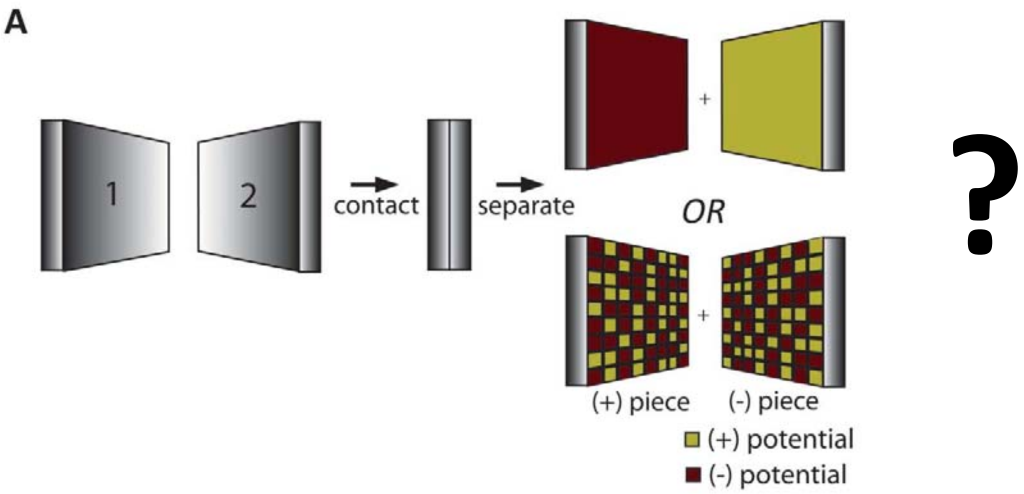
the ***items on the bottom*** are more attractive to electrons and become negatively charged.

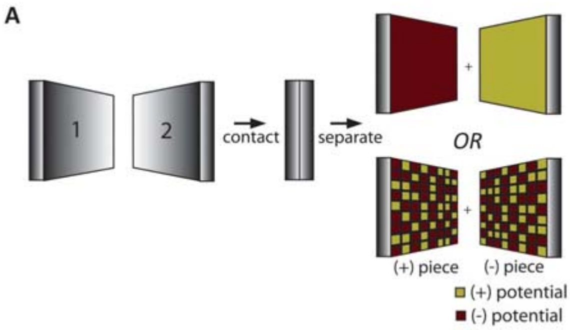
Triboelektrizität

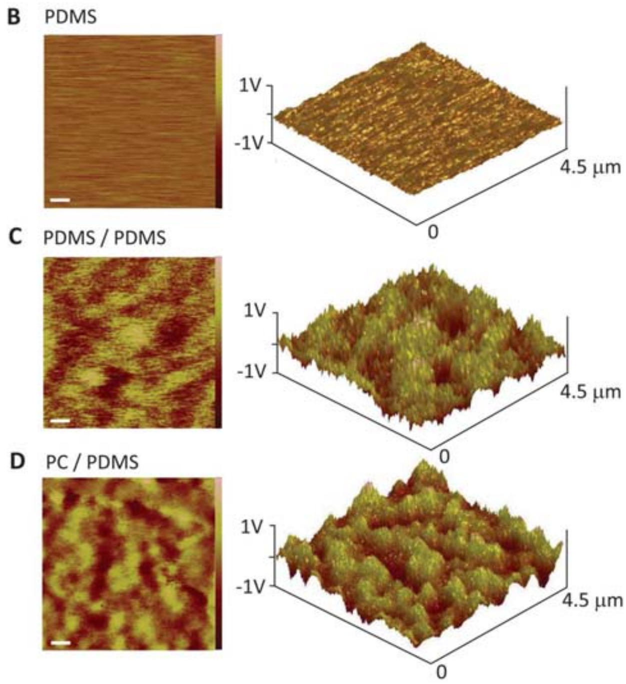


"When dielectric materials are brought into contact and then separated, they develop static electricity. For centuries, it has been assumed that such contact charging derives from the spatially homogeneous material properties (along the material's surface) and that within a given pair of materials, one charges uniformly positively and the other negatively. "

The Mosaic of Surface Charge in Contact Electrification
Grzybowski et al., 308, 333, Science (2011)

Triboelektrizität





"We demonstrate that this picture of contact charging is incorrect. Whereas each contact-electrified piece develops a net charge of either positive or negative polarity, each surface supports a random "mosaic" of oppositely charged regions of nanoscopic dimensions. "

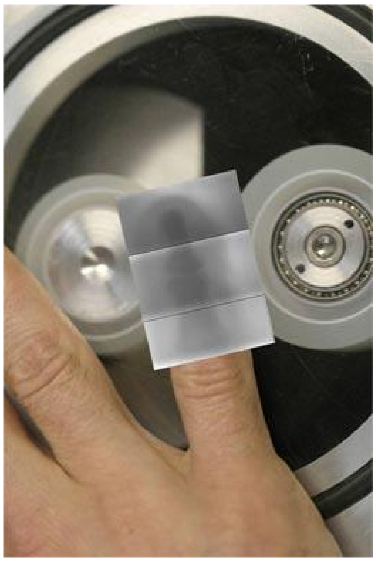
The Mosaic of Surface Charge in Contact Electrification
Grzybowski et al., 308, 333, Science (2011)

Triboelektrizität

Correlation between nanosecond X-ray flashes and stick–slip friction in peeling tape
Putterman, et al., Nature 455, 1089–1092 (2008).

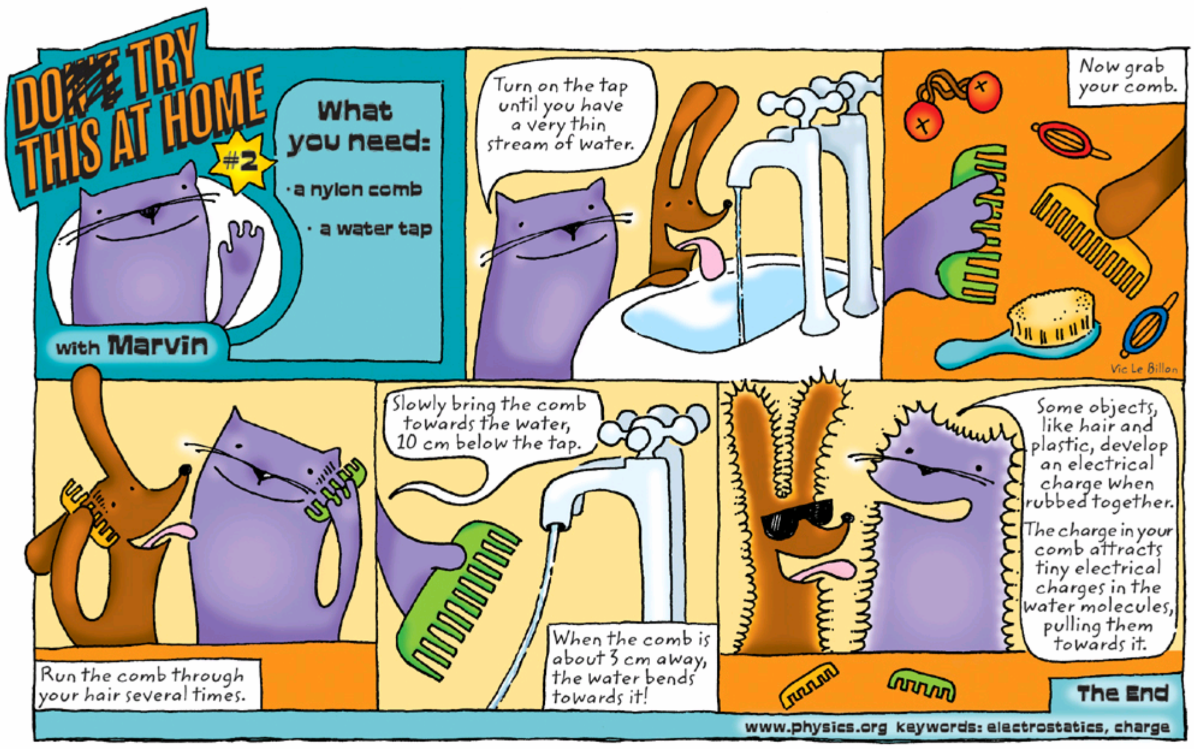
video

While being unpeeled, sticky tape emits light … and x-rays. The light emission occurs due to charge separation (taking place due to friction) and charge recombination.

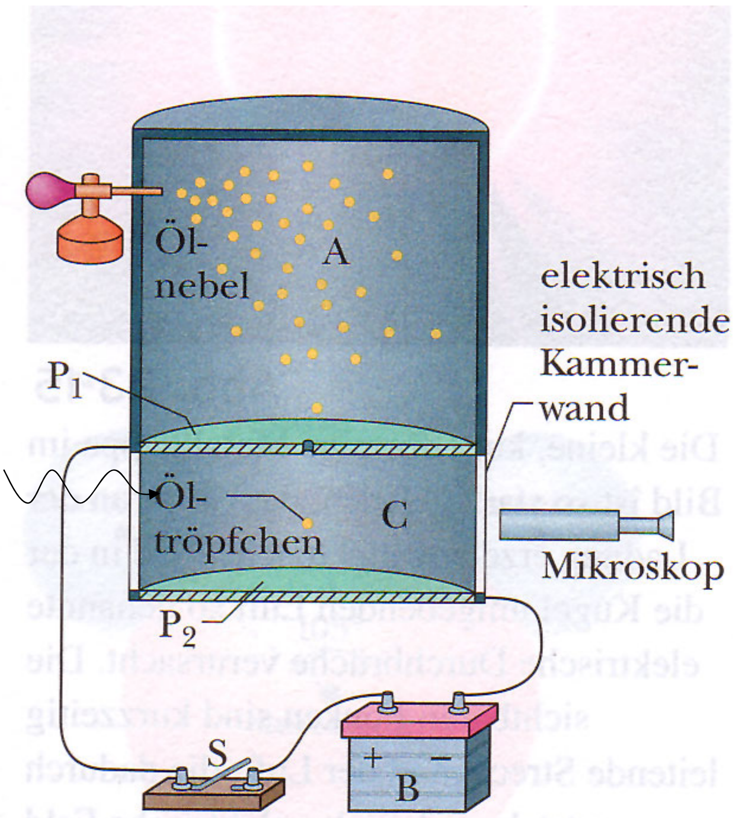


X-ray image (superimposed) of a human finger taken using X-rays emitted during sticky tape peeling. Estimate: 1 electron in 10'000 generates x-ray upon recombination.

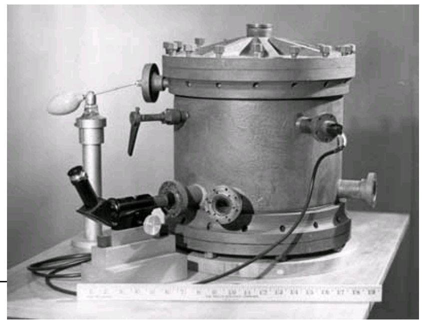
Home experiment…



Milikan's Experiment



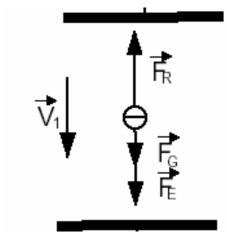
Robert Millikan
USA, 1868-1953
Nobel: 1923
Phys. Rev. II (2), 109 (1913)



Milikan's Experiment

Robert Millikan
USA, 1868-1953
Nobel: 1923
Phys. Rev. II (2), 109 (1913)

Tröpfchen sinken

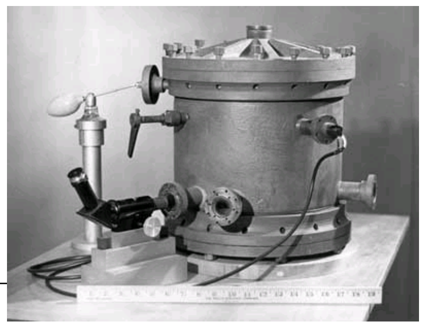


Kräfte

Gewichtskraft $F_g = m \cdot g = \frac{4}{3}\pi r^3 \cdot \rho_O \cdot g$

Auftriebskraft $F_A = \frac{4}{3}\pi r^3 \cdot \rho_L \cdot g$

Reibungkraft $F_R = 6\pi\eta r v$



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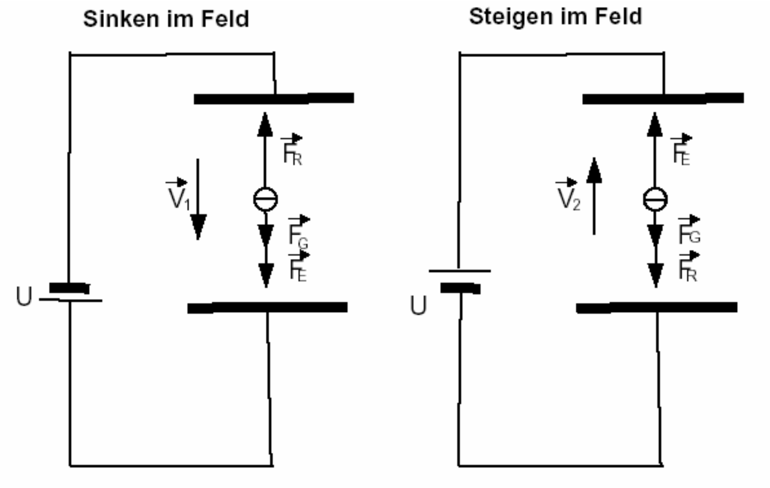


Kräfte

Gewichtskraft $F_g = m \cdot g = \frac{4}{3}\pi r^3 \cdot \rho_O \cdot g$

Auftriebskraft $F_A = \frac{4}{3}\pi r^3 \cdot \rho_L \cdot g$

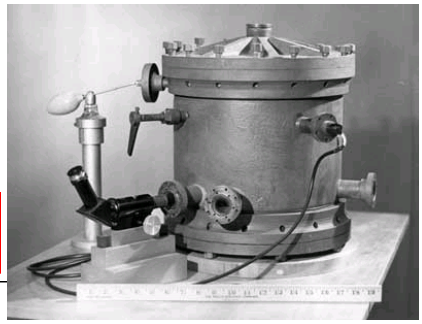
Reibungkraft $F_R = 6\pi\eta r v$

Elek. Kraft $F_E = q \cdot E = \frac{qU}{d}$

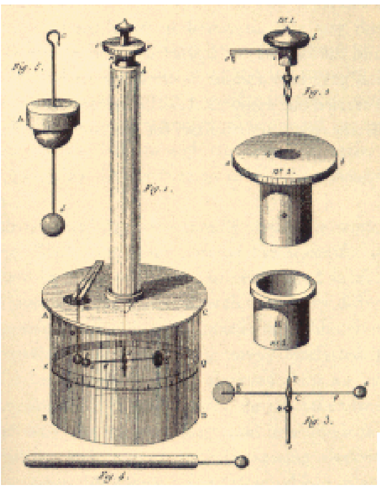
Im Schwebezustand:

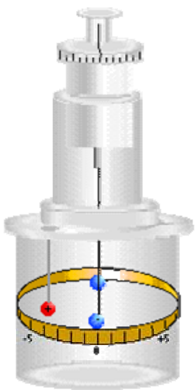
F_G-F_A = F_E

⇨ Elementar Ladung e
q=N·e



Coulomb's law: torsion balance





Charles-A. de Coulomb
France, 1736-1806

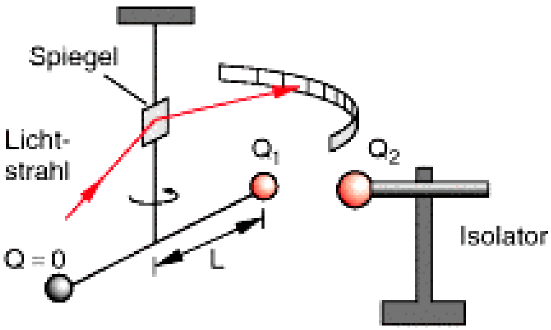
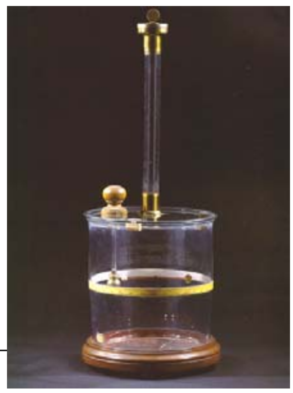


Abb. 1.3. Coulombsche Drehwaage



Feldlinien

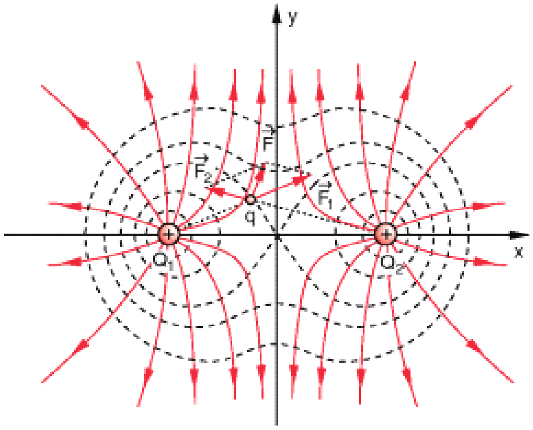


Abb. 1.9. Elektrische Feldlinien. Kraft $F(r)$ auf eine Ladung q und Äquipotentiallinien zweier räumlich getrennter gleicher Ladungen. Die Figur ist rotationssymmetrisch um die x-Achse

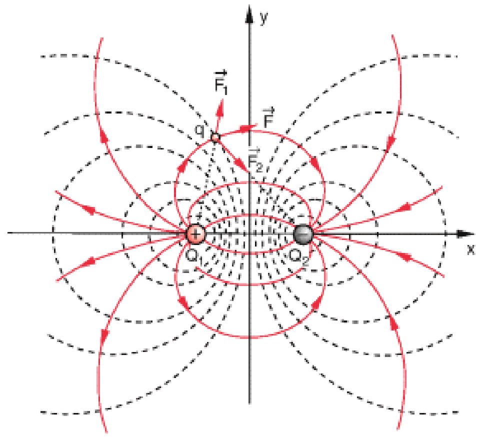


Abb. 1.10. Elektrische Feldlinien und Äquipotentiallinien zweier entgegengesetzt gleicher Ladungen Q_1 und $Q_2 = -Q_1$ (elektrischer Dipol). Die Figur ist rotationssymmetrisch um die x-Achse

Feldlinien

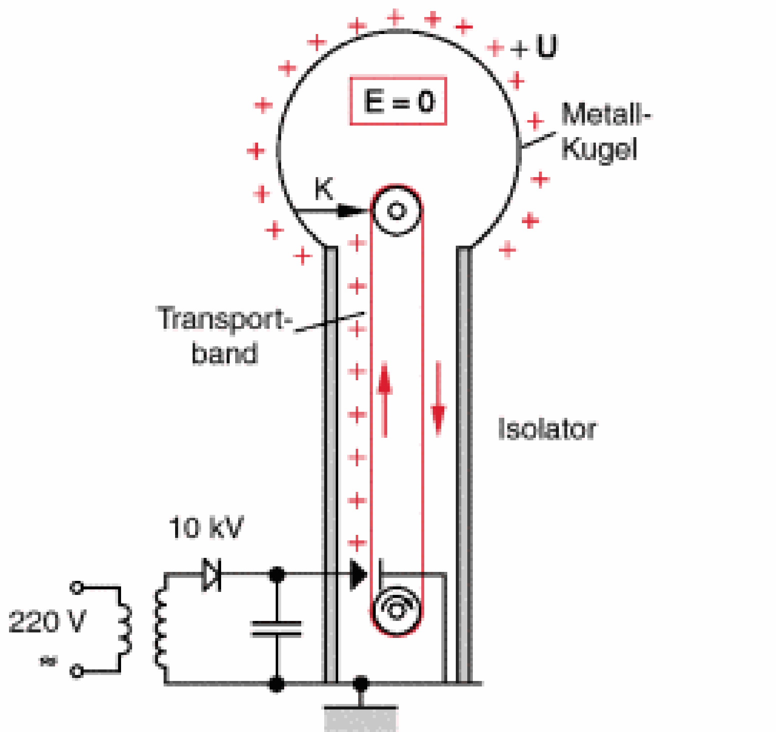


Abb. 1.33. Prinzipschema des Van-de-Graaff-Generators

Feldlinien

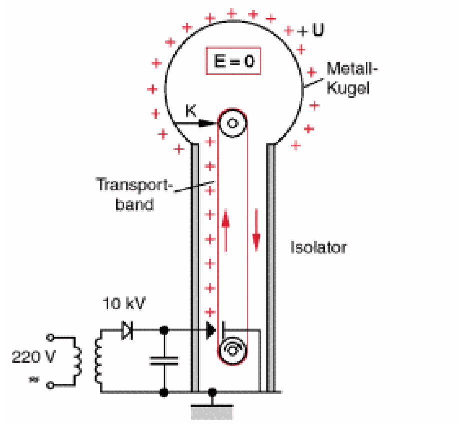
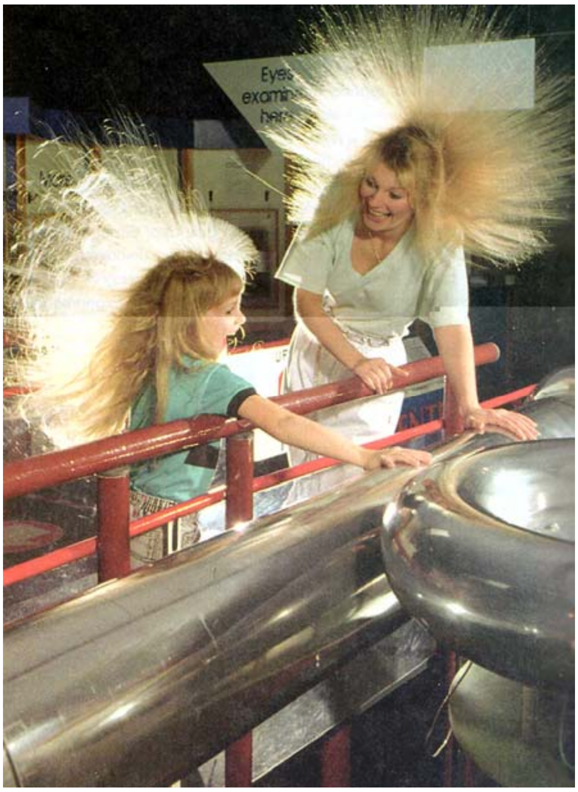
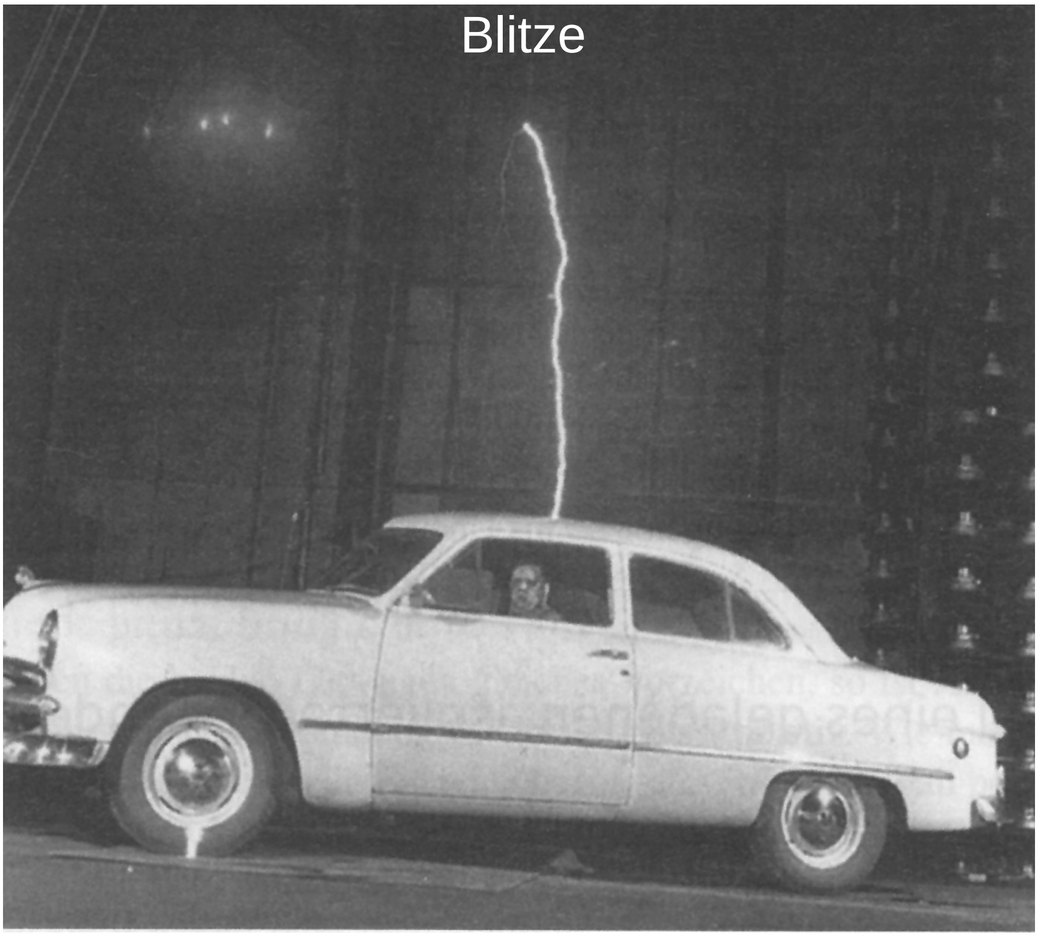
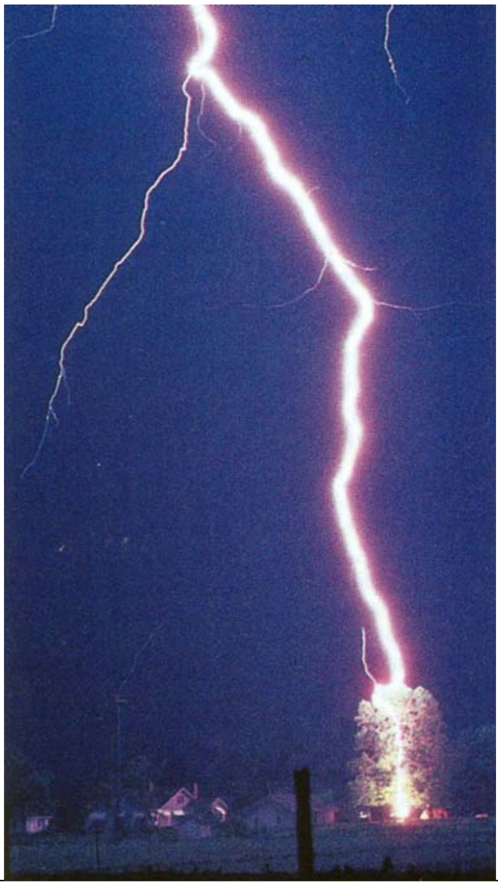


Abb. 1.33. Prinzipschema des Van-de-Graaff-Generators



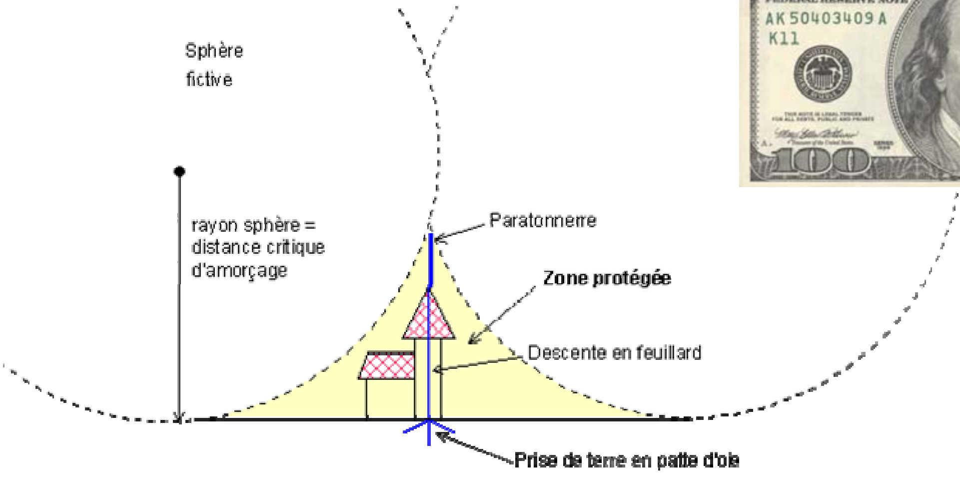


Blitze



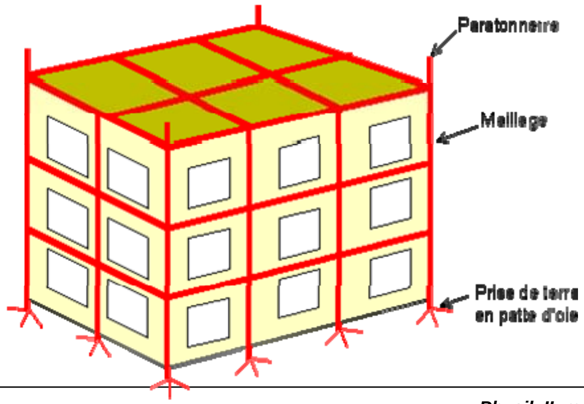
St-Elme Feuer

'ST. ELMO'S FIRE' ON MASTS OF SHIP AT SEA.

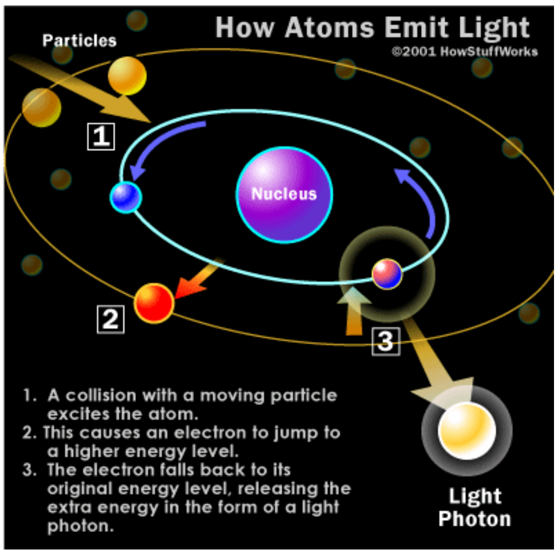


Benjamin Franklin
USA, 1706-1790

Spitzeneffekt Anwendung:
e.g.: Blitzableiter

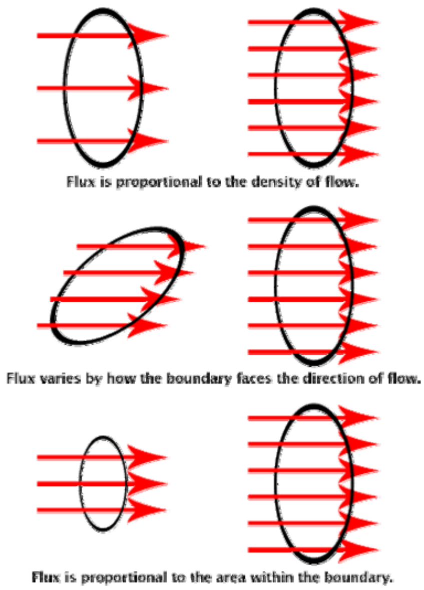


Leuchtrohr

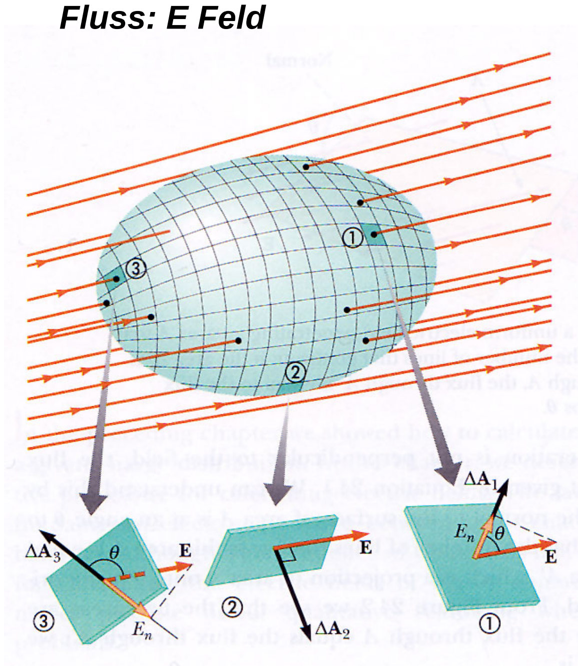


Gauss' law

Fluss: mechanik



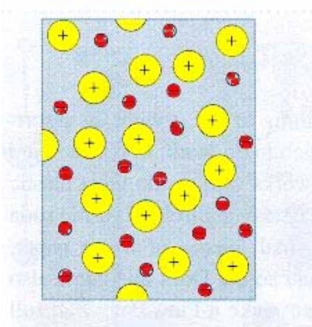
Fluss: E Feld



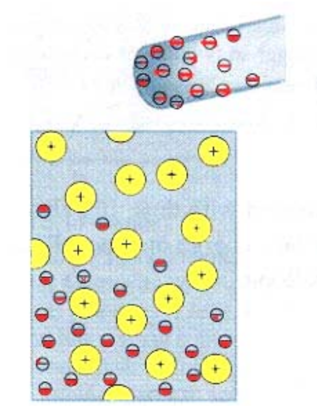
<0 **=0** **>0**

Karl F. Gauss
German, 1777-1855

Attracting Uncharged Metallic Objects

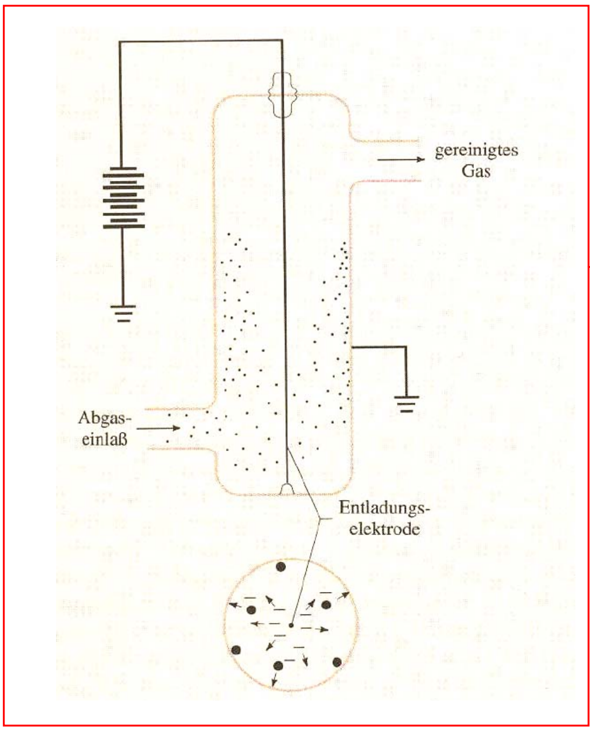


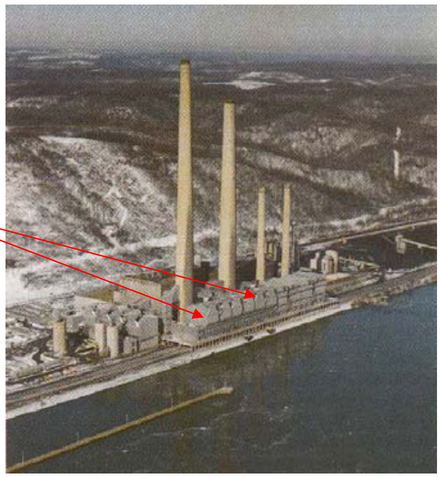
Electrons are free to move in metals.



Nuclei remain in place; electrons move to bottom.

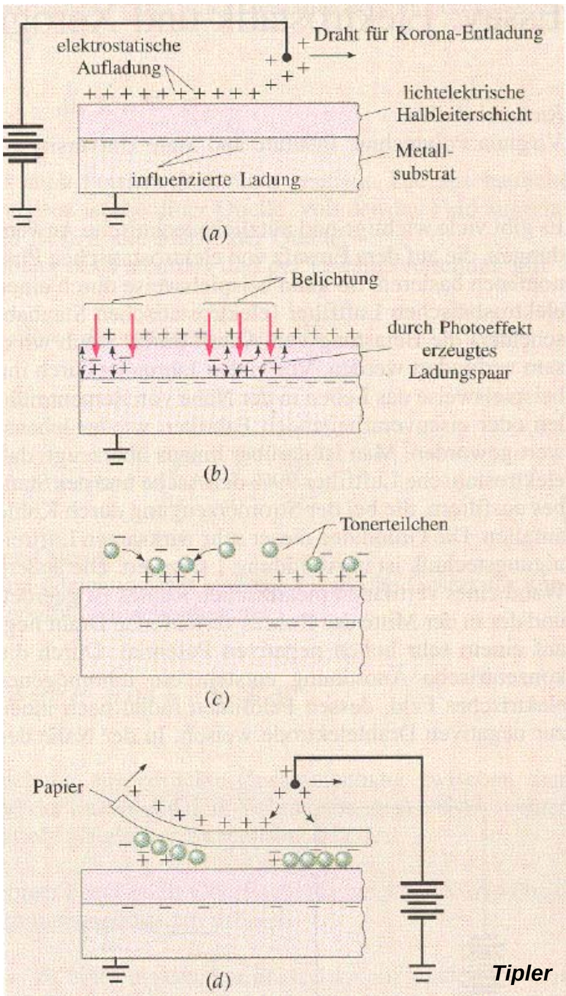
Anwendungen





Entladung in einem Elektrostatischen Abgasfilter

Tipler



Tipler

(a) Aufladen

(b) Belichten

(c) Entwicklung

(d) Übertragung auf Papier

Chester Carlson
USA, 1906-1968
(patent: 1942)

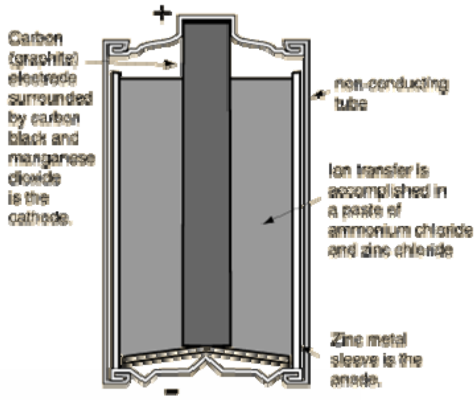
batteries

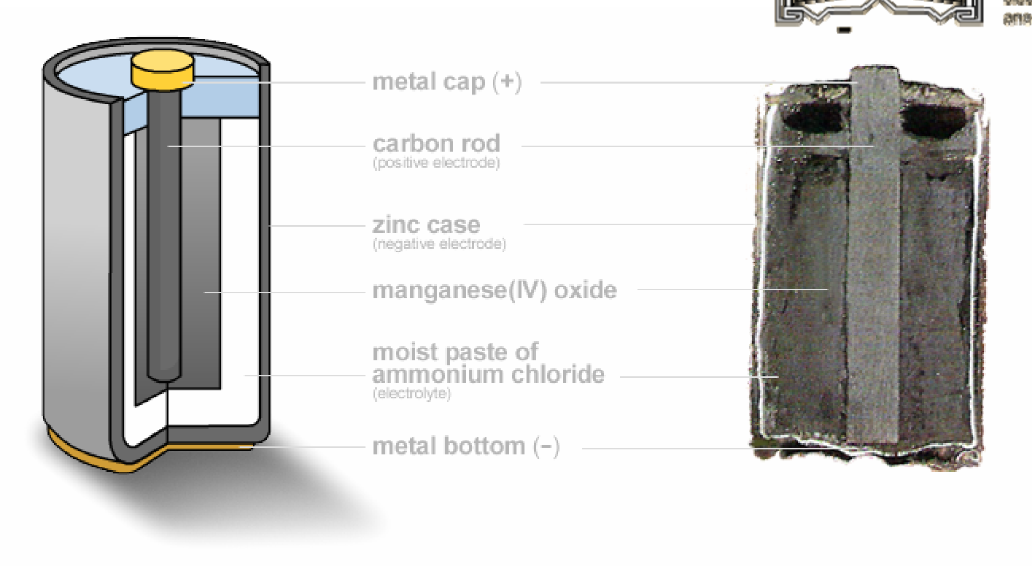
Carbon-zinc Batteries

anode (-)
$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

cathode (+)
$2NH_4^+(aq) + 2MnO_2(s) + 2e^-$
$\rightarrow Mn_2O_3(s) + H_2O(l) + 2NH_3(aq)$

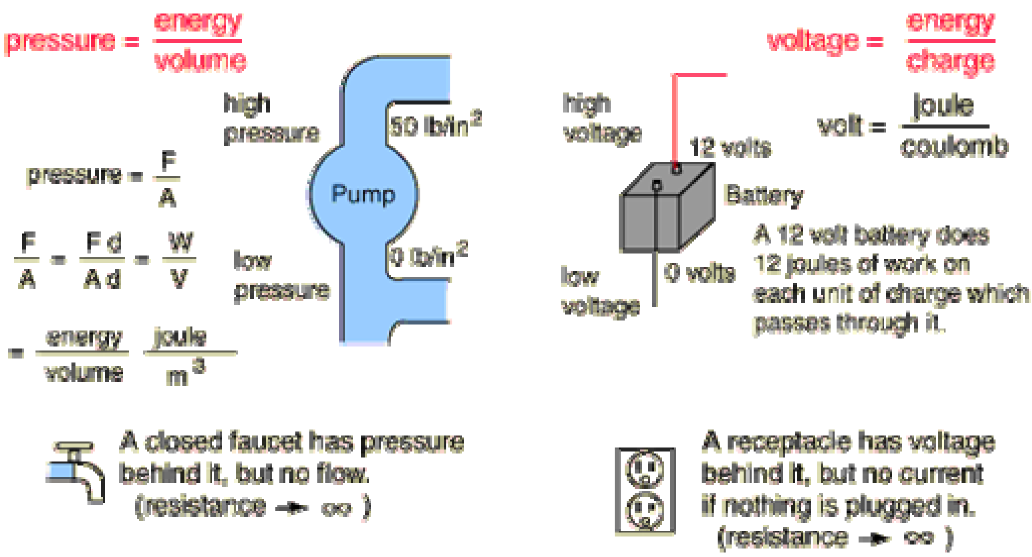
+ other reactions in paste (gas, must be absorbed)





Battery

- A battery is analogous to a pump in a water circuit. A pump takes in water at low pressure and does work on it, ejecting it at high pressure. A battery takes in charge at low voltage, does work on it and ejects it at high voltage.



Kondensator Prinzip

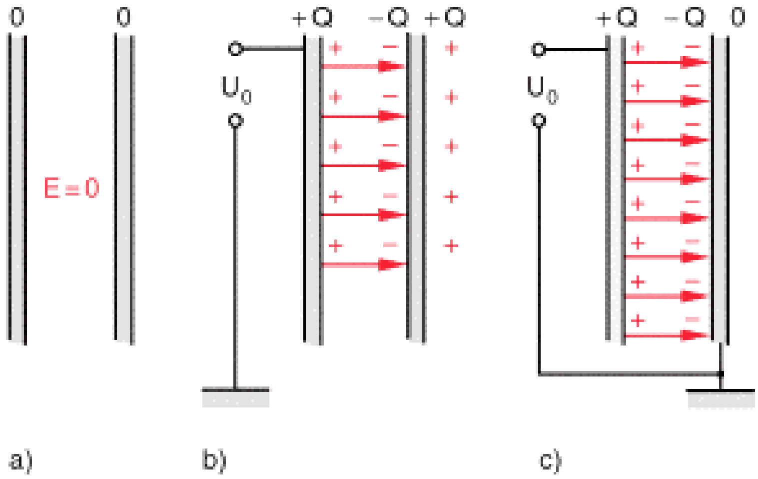
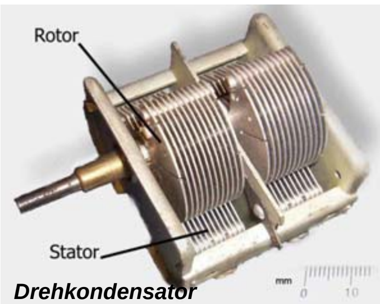


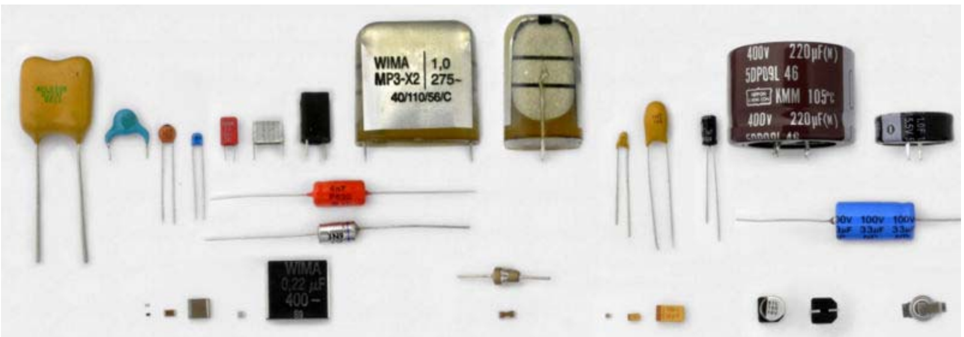
Abb. 1.35a–c. Zum Prinzip des Kondensators: (a) ungelade-

Kondensatoren



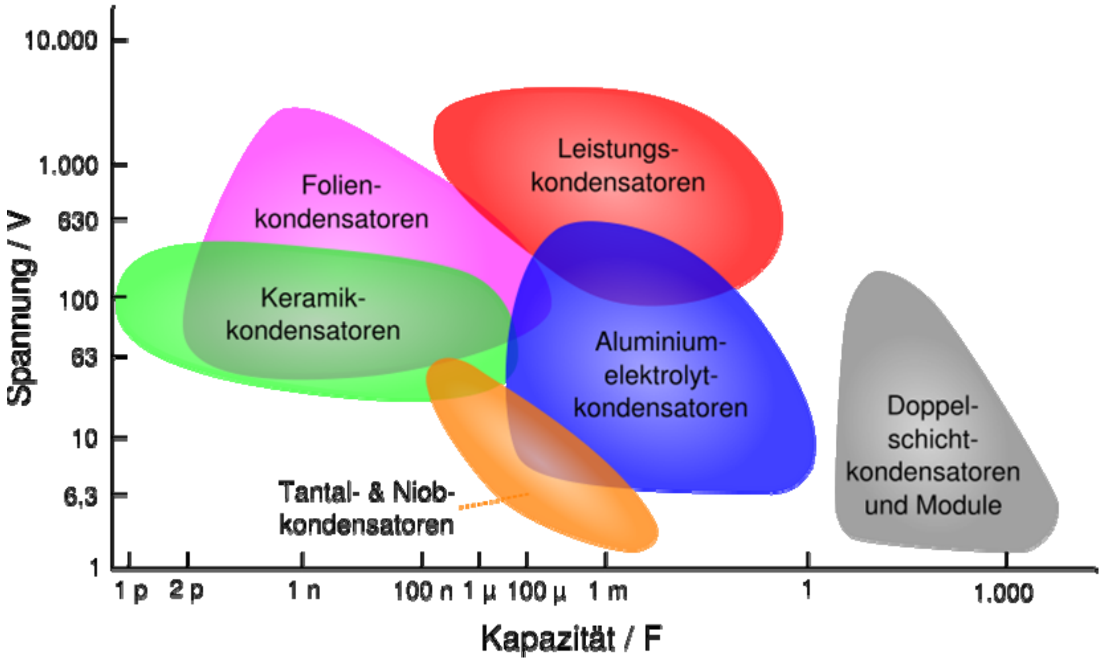
Drehkondensator

Papierkondensator



Obere Reihe, radiale Anschlüsse (v.l.): Glimmer, Keramik-Y, Keramik-Scheibe, Keramik-Mehrschicht, Folie gewickelt und vergossen, geschichteter Folienkondensator, gewickeltes und vergossenes Polystyrol, gewickelter X-Metallpapierkondensator, dito hochkant (man sieht die großflächige Kontaktierung der Stirnseiten), zwei Tantal-, zwei Aluminiumelektrolytkondensatoren, Doppelschichtkondensator
Mittlere Reihe, axiale Anschlüsse: gewickelter Polypropylen-, Polystyol-Folienkondensator, Keramik-Durchführungskondensator, bipolarer Elektrolytkondensator.
Untere Reihe, SMD-Bauformen: zwei SiO2-, zwei Keramikkondensatoren, zwei Folienkondensatoren, Durchführungskondensator sowie die entsprechenden Elektrolytkondensatoren.

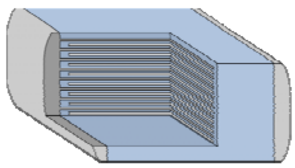
Kondensatoren



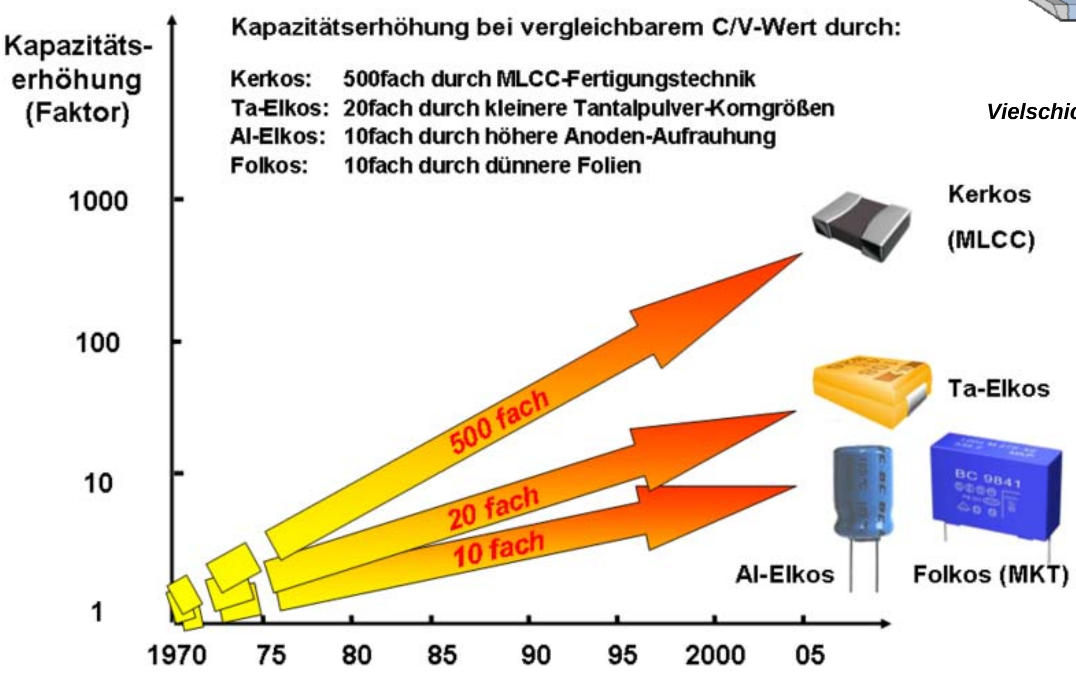
Spannungsfestigkeit und Kapazität verschiedener Kondensator-Technologien

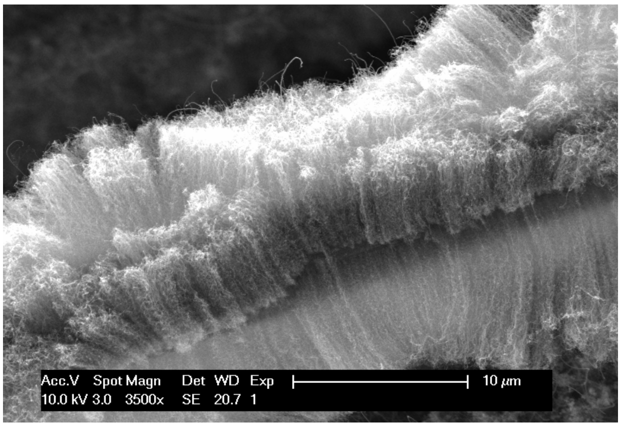
wiki

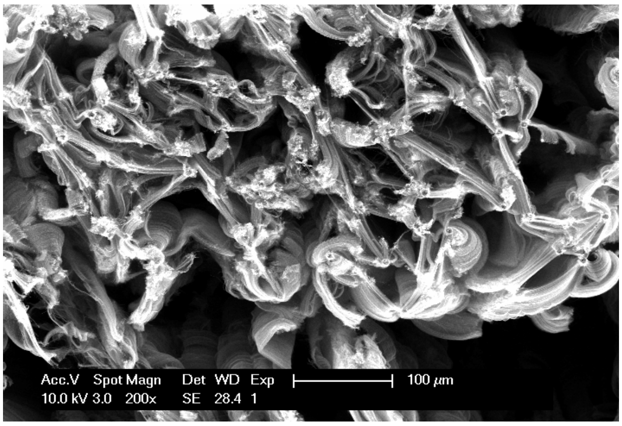
Kondensatoren

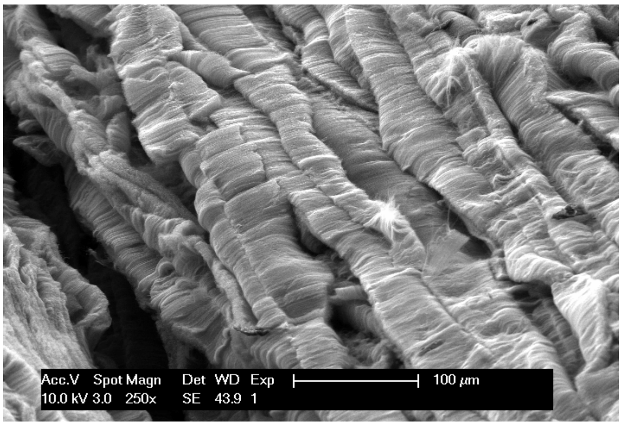


Vielschichtkondensator







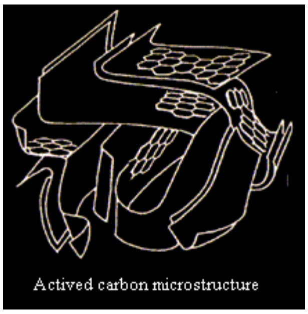


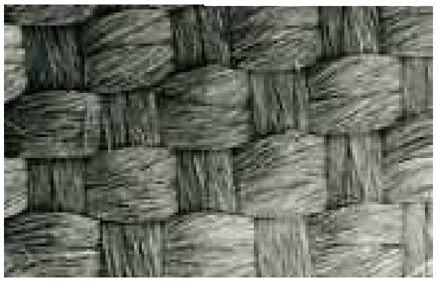
M. Perrin et al.,

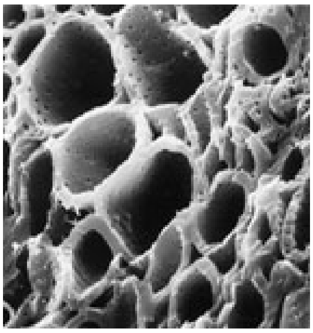
super-condensateurs

1-100 Farads ⇨ **voitures hybrides**

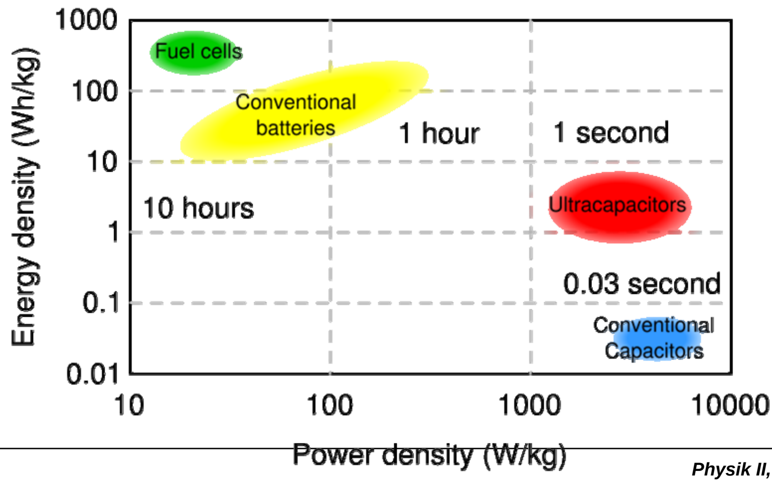
Supercapacitor







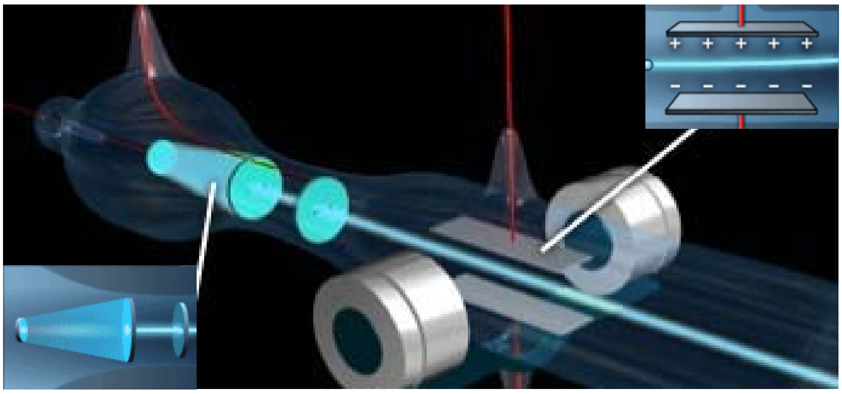
> 1000 m^2/g

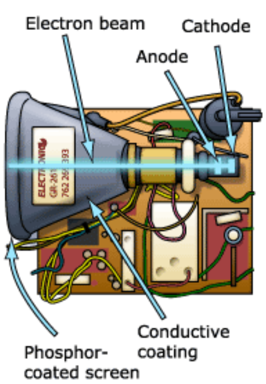


typische Werte: 1-10 Farad

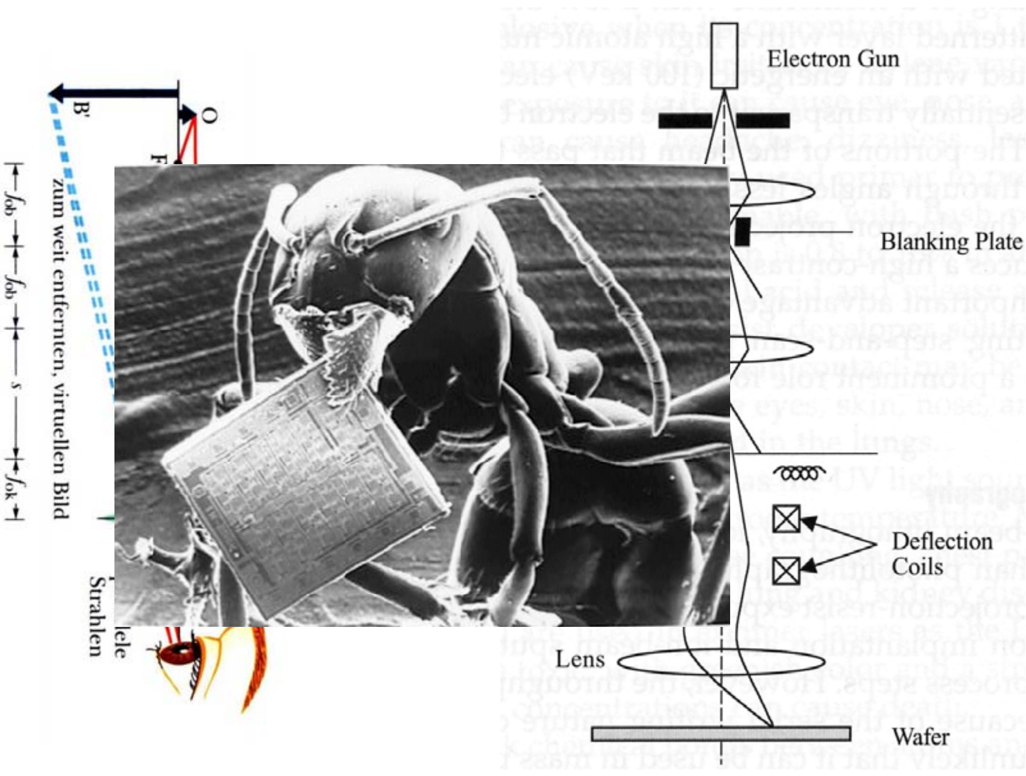
Elektron Rohr

(Kathodenstrahloszillograph)



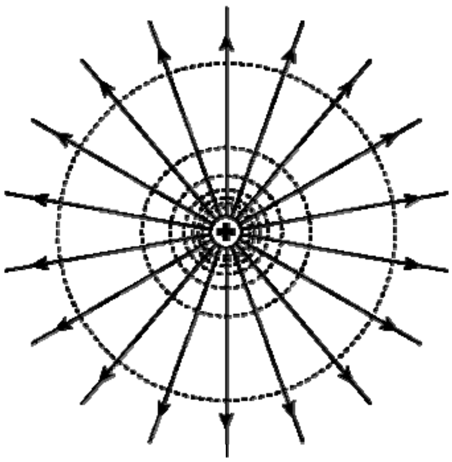


Elektronmikroskop

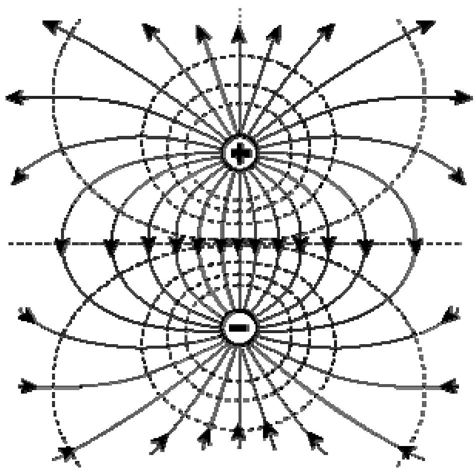


Feld und Aequipotential Linien

Ladung

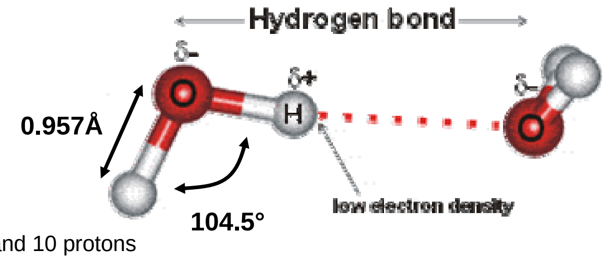


Dipol



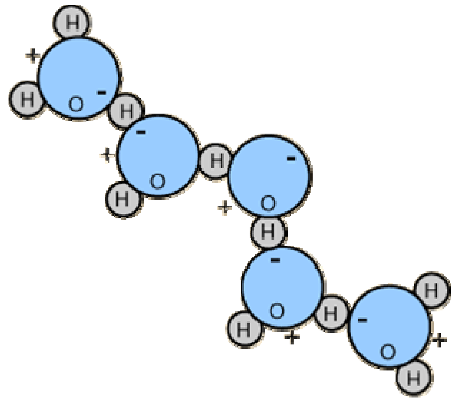
Wasser Moleküle

- dipole moment: p = **1.83 Debye** = $6.11 \cdot 10^{-30}$ C·m

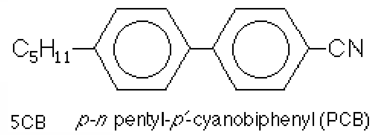


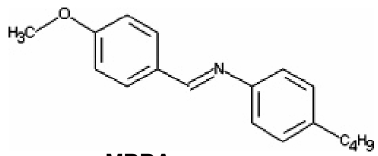
system seen as 10 e and 10 protons
⇨ effective charge separation (d=p/10e)
d ~ 3.8pm = 0.0038nm

(*1st Bohr radius: 0.05nm, charge separation small*)

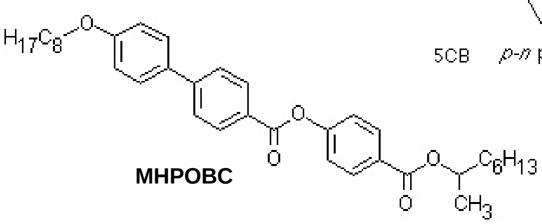


Flüssigkrystall





MBBA

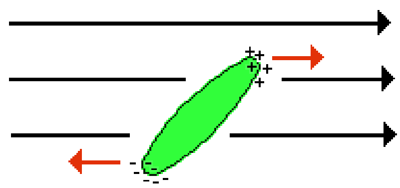


MHPOBC

interaction between rings:
short range intermolecular forces,
Nematic structure

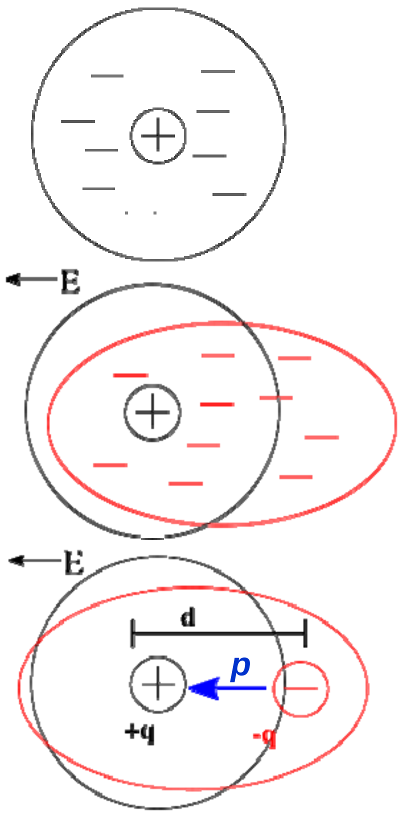
C chains: strong influence transition temperature between phases & elastic properties

terminal groups: affect dielectric constant, polarizability

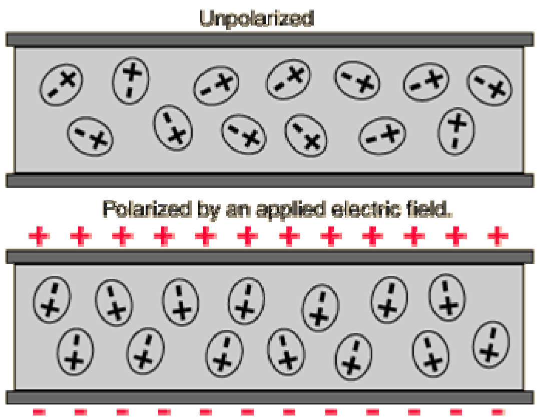


NB: permanent and/or induced dipoles

Verschiebungspolarisation

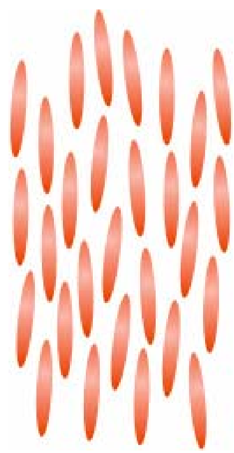


Orientierungspolarisation

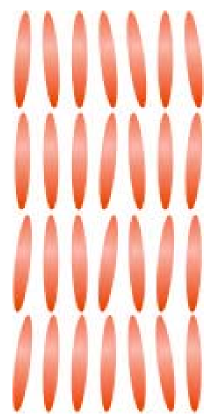


Flüssigkrystall

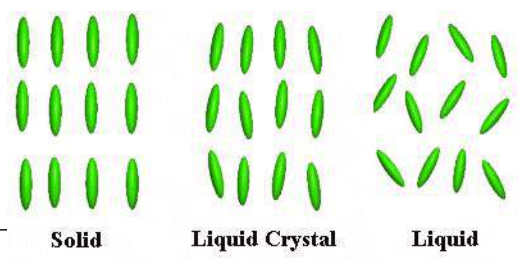
Isotropic
(no ordering)



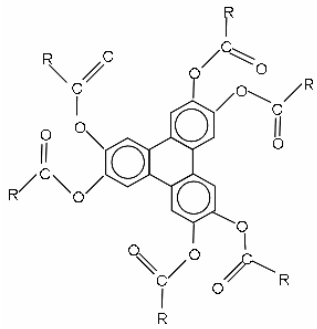
Nematic
(order in orientation)

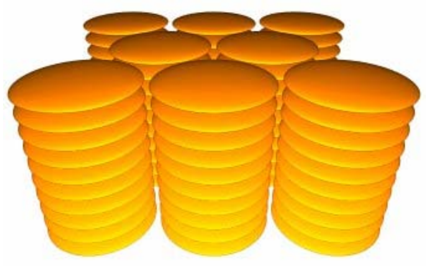


Smectic
(order in position)

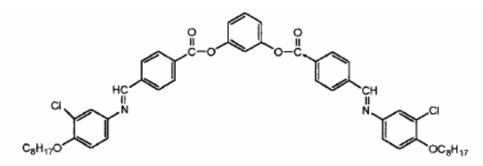


Flüssigkrystall



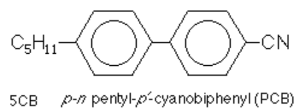


discotic structure



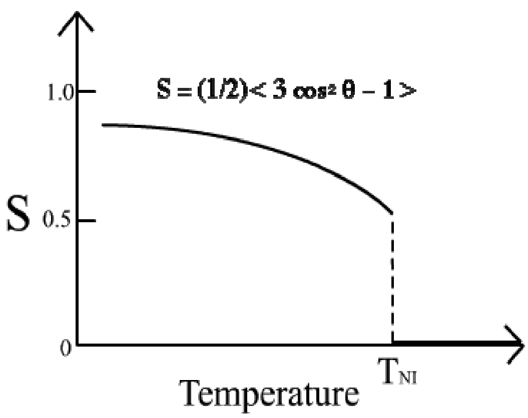
Banana shaped

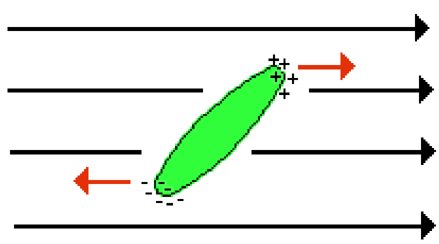
Flüssigkrystall



random

ordered

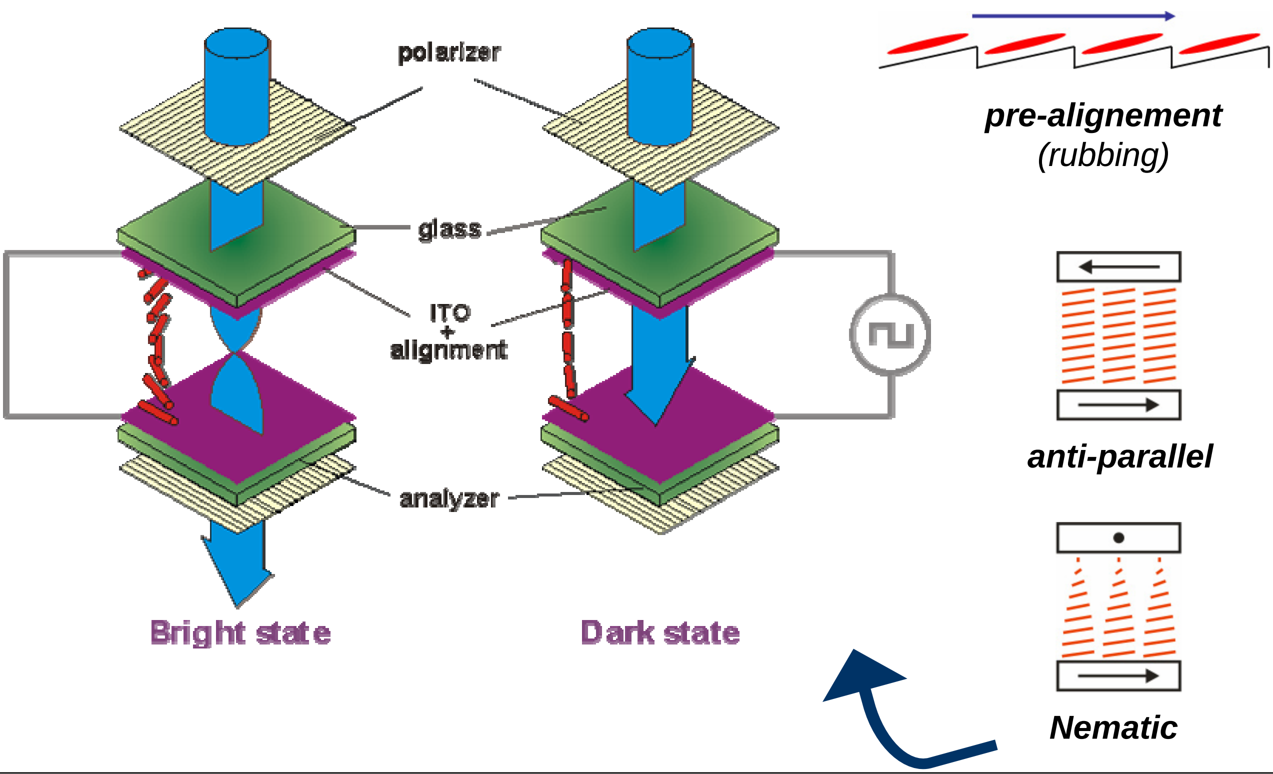




Feld

Flüssigkrystallbildschirm

liquid crystal displays



Dielektrika im elektrischen Feld

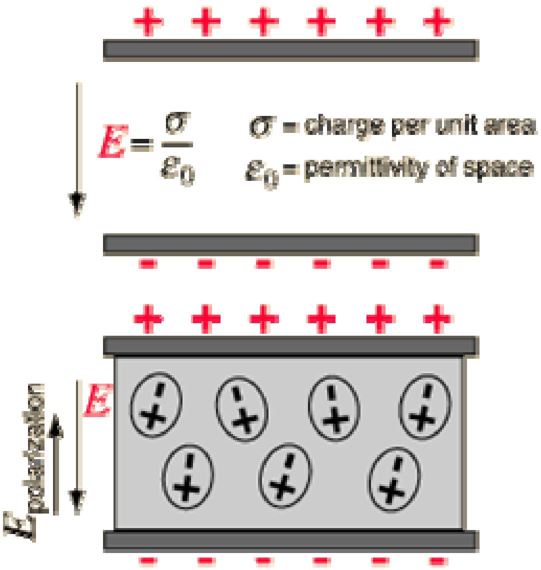
Tabelle 1.1. Relative statische Dielektrizitätszahl ε_r einiger Stoffe bei 20 °C

Stoff	ε_r
Quarzglas	3,75
Pyrexglas	4,3
Porzellan	6–7
Kupferoxyd CuO_2	18
Keramiken	
TiO_2	≈ 80
$CaTiO_3$	≈ 160
$(SrBi)TiO_3$	≈1000
Flüssigkeiten	
Wasser	81
Ethylalkohol	25,8
Benzol	2,3
Nitrobenzol	37
Gase	
Luft	1,000576
H_2	1,000264
SO_2	1,0099

Kondensator

$$C = \frac{\varepsilon_0 A}{d}$$

$$C = \frac{\varepsilon \varepsilon_0 A}{d}$$



$$E_{effective} = E - E_{polarization} = \frac{\sigma}{\varepsilon \varepsilon_0}$$