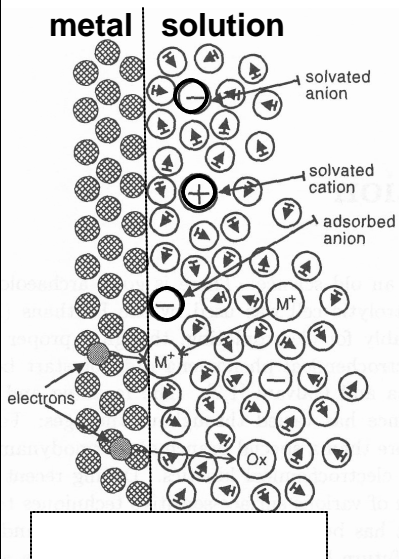


Systems and Applications

Metal-solution Interface



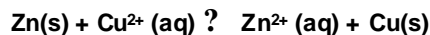
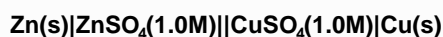
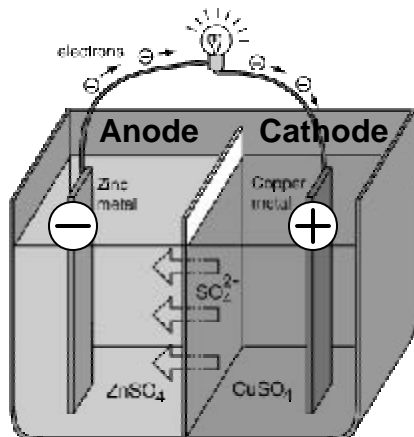
Metal: Role of the surface structure?
(single crystal surfaces, rough surfaces...)

Solvent molecules (dipoles):
How important is solvent structure?

Charged species: anions and cations
- the role of solvation phenomena
(charge-dipole interactions)

Anions less strongly solvated than cations,
specifically adsorbed anion (here: atop)

Galvanic Cell



Spontaneous chemical reaction drives electrical current

Electrode reactions:

heterogeneous chemical processes

Any two different metals (compounds):
different tendency to lose electrons
(tabulated)

Zn more readily loses electrons than Cu
Place Zn and Cu in solution of their salts
? electrons flow through external wire

Anode: $\text{Zn(s)} \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$
oxidation, loss of electrons

Cathode: $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu(s)}$
reduction, gain of electrons

Line notation for galvanic cells:



- single vertical line: change in state or phase
- within half cell: list reactants before products
- concentration of aqueous solutions in parentheses
- double vertical line: junction between half cells, interface
- line notation corresponds to the direction in which electrons flow:
from left to right, cathode (reduction) is right hand compartment
- device applications: two-electrode systems
diagnostics: three-electrode systems
Why do we need different configurations?

Definitions:

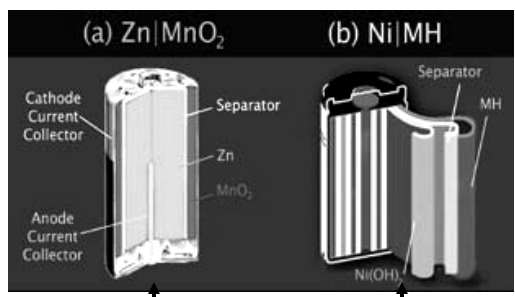
- oxidation, loss of electrons: Anode
 - reduction, gain of electrons: Cathode
- } determined by the direction of electron flow

- positive electrode: ⊕
 - negative electrode: ⊖
- } spontaneous or non-spontaneous?

Spontaneous flow of electrons: anode ⊖; cathode ⊕
(galvanic cell)

Forced flow of electrons: anode ⊕; cathode ⊖
(electrolytic cell)

Batteries

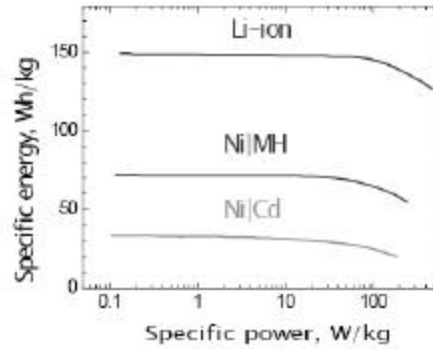
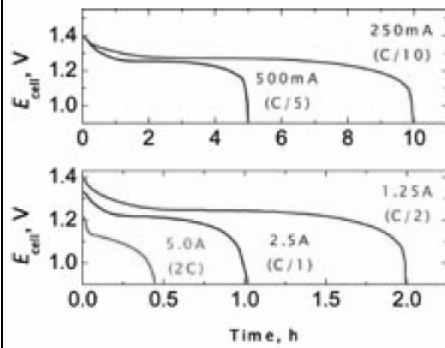


- energy conversion devices
- invented by Alessandro Volta in 1800 - started off "electrochemistry"
- two different metals (e.g. Zn and Cu), separated by aqueous solution
- consist of stacked galvanic cells
- ubiquitous devices (in portable electronics, hybrid electric vehicles)

most common primary battery
(Zn anode, MnO₂ cathode)

popular rechargeable System
(Ni(OH)₂ cathode, MH anode)

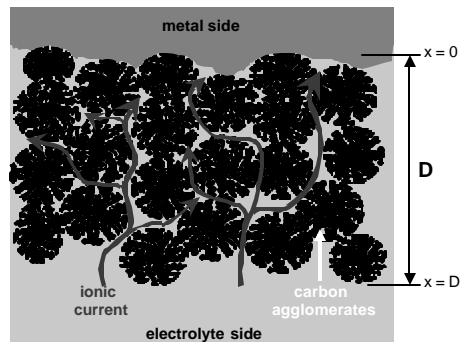
Discharge curves of AA Ni|MH battery Ragone-plot: specific energy vs. specific power



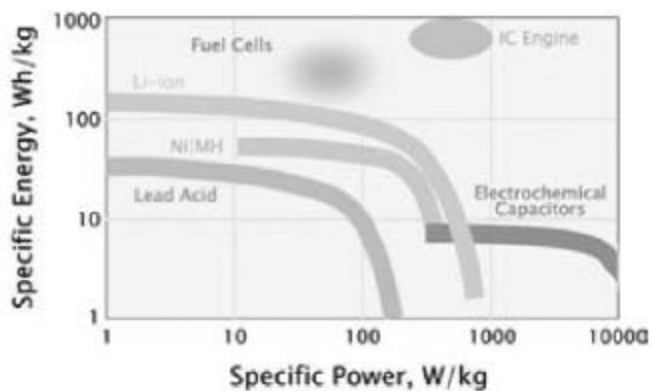
Important in evaluating energy conversion and storage devices

Electrochemical Capacitors

- energy storage devices
- storage of electrostatic energy
 - formation of electrochemical double layer
 - extremely small "plate" separation
- need different type of electrodes that inhibit charge transfer
- high surface area carbon materials (up to 2000 m²/g) provide high capacitances
- capacities of up to 200 F/g
- high power densities
- reversibility
- back-up power for fuel cell vehicles



Ragone-plot: specific energy vs. specific power



Corrosion

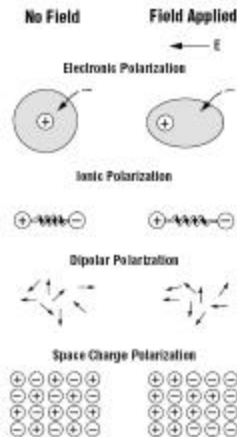
- degradation of materials due to interactions with environment
- affects metals, polymers, ceramics, etc.
- tendency of metal to return to low-energy oxide state
 - attain thermodynamic equilibrium state
- annual direct cost in USA: 3.1% of GNP, i.e. US\$ 276 billion!
- corroding surface: like a short-circuited battery
- use protective coatings



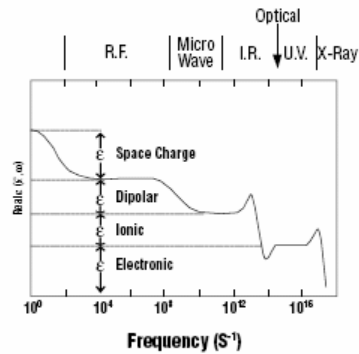
Science of Dielectrics

- one of the oldest branches in physics – fundamental importance
- response of dielectric media to applied field due to polarization of charges
- transistor technology

Mechanisms of polarization

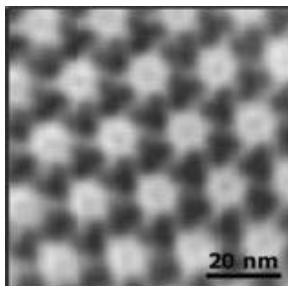


Contributions to frequency-dependent dielectric constant



Electrodeposition

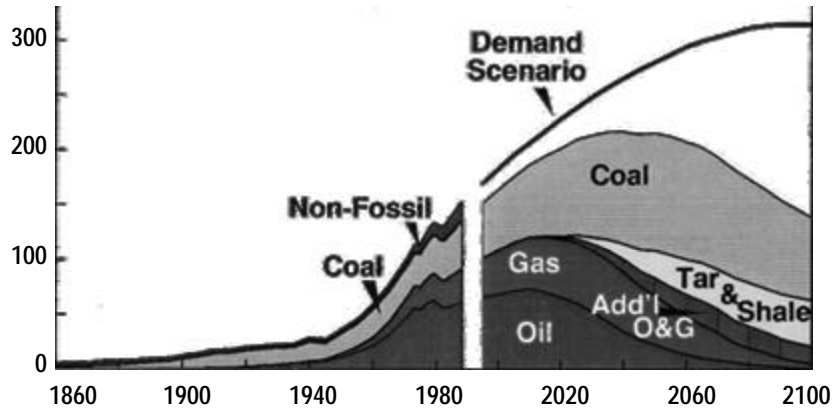
- growth of electrodeposited metals
- strongly linked with development of surface characterization methods (scanning tunneling microscopy, x-ray diffraction techniques)
- protective and decorative coatings, electronics industry
- key method in fabrication of computer chips and magnetic data storage systems
- fabricating arbitrary 3D geometries, development of nanotechnology
 - write materials onto a surface
- electrochemical printing (localized electrodeposition beneath mastering print head)
- works at low temperature, compatible with proteins (nanobiotechnology)



Structure grown through protein mask

World Energy

Millions of Barrels per Day (Oil Equivalent)

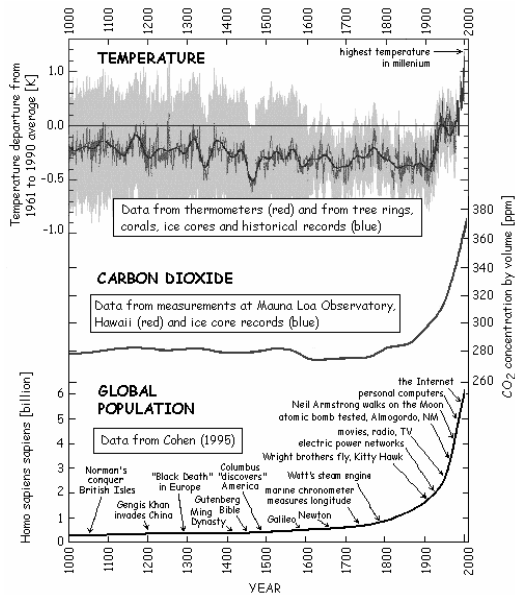


Source: John F. Bookout (President of Shell USA) "Two Centuries of Fossil Fuel Energy" International Geological Congress, Washington DC; July 10, 1985. Episodes, vol 12, 257-262 (1989).

Global warming over the past millennium

Very rapidly we have entered uncharted territory — what some call the *anthropocene* climate regime. Over the 20th century, human population quadrupled and energy consumption increased sixteenfold. Near the end of the last century, we crossed a critical threshold, and global warming from the fossil fuel greenhouse became a major, and increasingly dominant, factor in climate change. Global mean surface temperature is higher today than it's been for at least a millennium.

Slide from Marty Hoffert NYU



Fuel Cells and Energy Conversion

Current energy use:

- largely based on fossil fuels
- dwindling resources (3-fold increase in oil price in recent years)
- adverse environmental impact (air pollution, global warming)
- dependence on instable geographic regions

Is there an energy crisis?

Need for a new energy infrastructure – humanity's No. 1 problem!

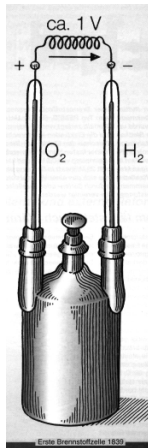
- has to be solved within ~ 50 years
- sustainable infrastructure: decentralized, renewable, clean
- Hydrogen as a fuel?

⇒ fuel cells are a key enabling technology of a hydrogen economy

- high thermodynamic efficiencies (no Carnot limitation)
- versatility (stationar, portable, automotive applications)
- high energy density

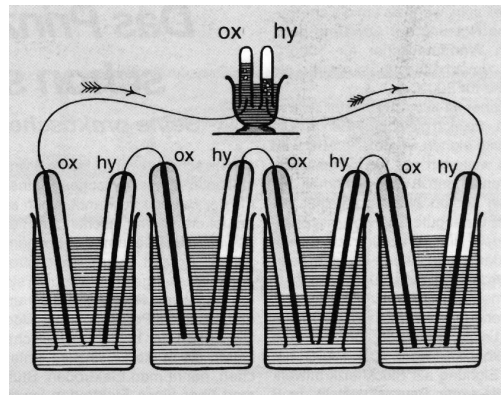
Issues with cost, materials and operating conditions

History: Discovery of Fuel Cells

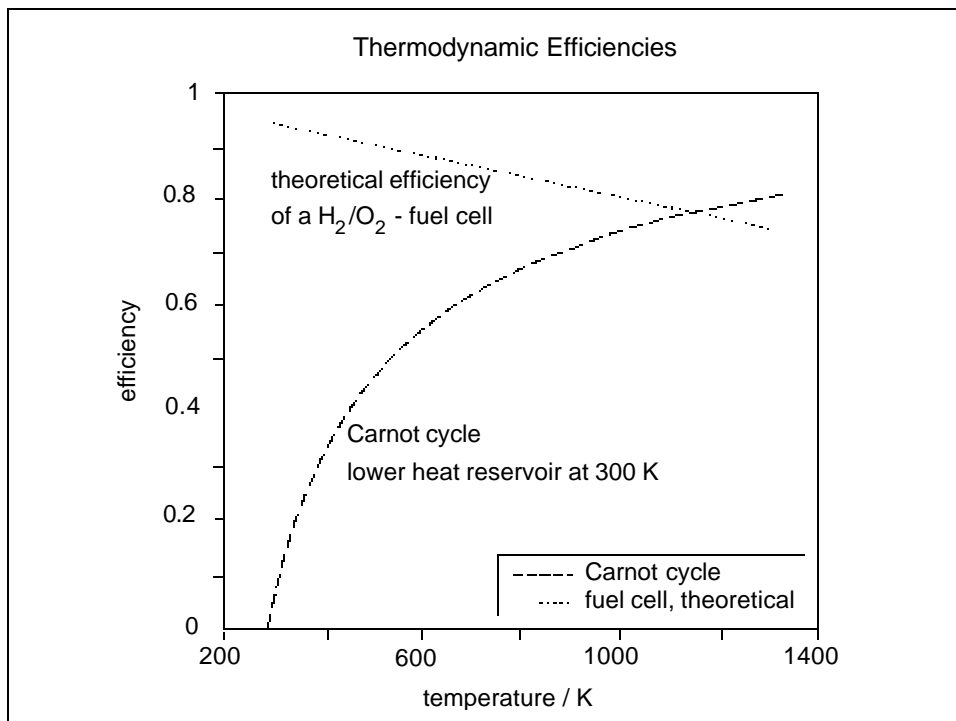
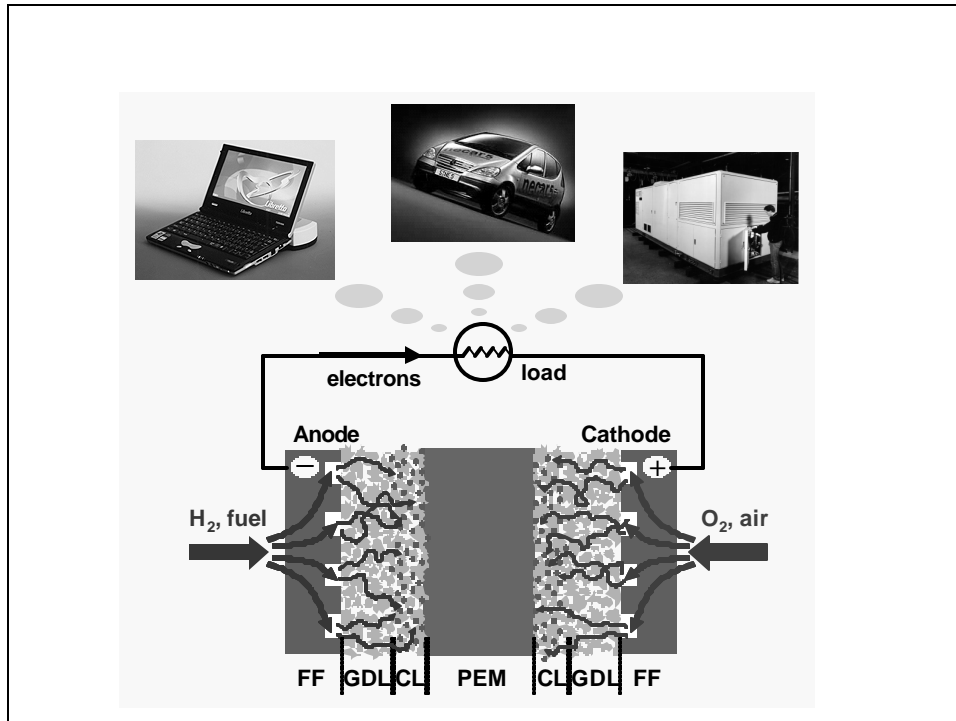


Groves fuel cell, 1839 and

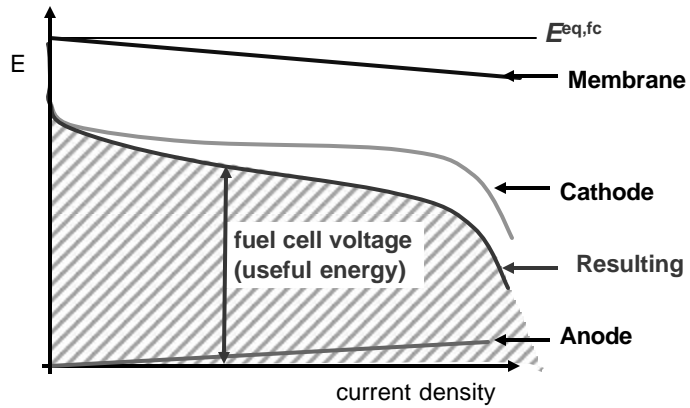
his "gas chain" from 1842



Sir William Grove

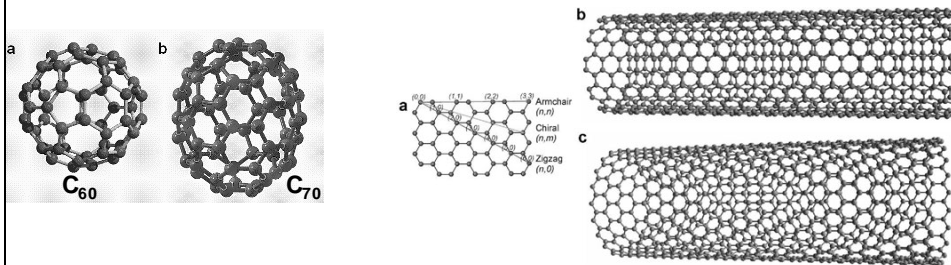


Relation between current and cell voltage



Carbon Nanomaterials

- fullerenes (C_{60}), nanotubes, mesoporous carbon structures
- utilization in energy conversion
- high surface area catalyst supports
- high photochemical and electrochemical activity
- metallic or semiconductor properties



Other Applications

- ❑ **High temperature materials**
(oxide ceramics for Solid Oxide Fuel Cells, high temperature corrosion, protective films)
- ❑ **Organic electrochemistry**
(attachment of monolayers of molecules to electrode surfaces and characterization, provide energy for driving reactions in form of electrode potential, voltammetric studies of protein films, develop films for biosensors)
- ❑ **Sensors – measurable change in output to input stimulus**
(electrochemical glucose sensors routinely used nowadays, gas sensors, etc.)