Lec #13: Electricity and Magnetism

LAST: Thermal Energy. III.

- Thermodynamic Efficiency
- Heat Engines
- Examples of Electromagnetic Induction

TODAY: Electricity & Magnetism

- Electric and Magnetic Forces and Fields
- Electromagnetic Induction
- Electric Circuits

NO CLASS UNTIL 11 MARCH

MidTerm Due 5 PM 11 March

Examples of Electromagnetic Induction

- Electrical Current --> Magnetic field
  - compass needle deflection
  - electromagnet
  - planetary magnetic fields (where is the current?)
- Changing Magnetic field --> Current
  - generator
  - motor
- Lenz's Law
  - "Will of Landru" demo
  - jumping rings

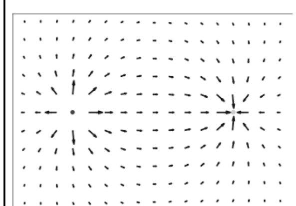
Electric Force

- force (vector) depends on product of charge, net sign, and separation of charges

$$\mathbf{F}_E = (q_1\, q_2) / \mathbf{r}^2$$

- electron charge -1.6×10^{-19} Coulomb (C)
  - (protons are $+1.6 \times 10^{-19}$)
  - charge is always conserved
  - force "neutralizes" charge separations

Electric Field

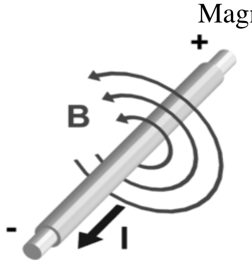


$\mathbf{F}_E = q\,\mathbf{E}$; $\mathbf{E} = q/\mathbf{r}^2$

(vector field)

- field "lines" show direction a *positive charge* will accelerate
- potential energy due to position (like gravitational field)
- note: electrons move much more freely than ions
- field lines originate and terminate on charges
- no medium is required

Magnetic Field



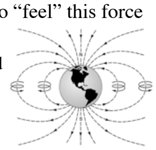
- lines describe direction a magnet would point at any location
- north and south attract; NN or SS repel
- no magnetic "monopoles"; field closes on itself
- surrounds electric current
- no medium is required
- charges also "feel" this force

$\mathbf{F}_B = q\,(\mathbf{v} \times \mathbf{B})$

perpendicular to both velocity and magnetic field

does no work; it only changes direction

1 Tesla = 1 Nt/(C-m/J) = 10^4 Gauss



Basic Electricity

- Voltage = Potential (Energy) Difference
  - 1 Volt = 1 Joule / Coulomb
  - work required to move one coulomb of charge across the potential difference, or...
  - work released by one coulomb of charge moving across the potential difference
- Conduction Current
  - defined as "positive" in direction positive charges would move, but
  - kinetic energy almost all in electrons
  - 1 Ampere = 1 Coulomb / sec

Basic Electricity (continued)

- complete circuit with a potential difference is required to have an electric current
  - analogy with gravity: blocks don't fall sideways, and no work is done moving them horizontally
- Resistance to current flow
  - energy lost to heating of conductor
  - resistivity is property of material (low for conductors, high for insulators)
  - resistance also due to length and diameter of wire
  - 1 Ohm = 1 Coulomb^2 / (Joule-sec)

TABLE 27.1 Resistivities and Temperature Coefficients of Resistivity for Various Materials

Material	Resistivity[a] ($\Omega \cdot m$)	Temperature Coefficient $\alpha[(°C)^{-1}]$
Silver	1.59×10^{-8}	3.8×10^{-3}
Copper	1.7×10^{-8}	3.9×10^{-3}
Gold	2.44×10^{-8}	3.4×10^{-3}
Aluminum	2.82×10^{-8}	3.9×10^{-3}
Tungsten	5.6×10^{-8}	4.5×10^{-3}
Iron	10×10^{-8}	5.0×10^{-3}
Platinum	11×10^{-8}	3.92×10^{-3}
Lead	22×10^{-8}	3.9×10^{-3}
Nichrome[b]	1.50×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}
Silicon	640	-75×10^{-3}
Glass	$10^{10}-10^{14}$	
Hard rubber	$\sim 10^{13}$	
Sulfur	10^{15}	
Quartz (fused)	75×10^{16}	

[a] All values at 20°C.

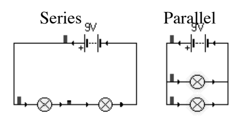
[b] A nickel-chromium alloy commonly used in heating elements.

Ohm's Law

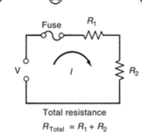
$$V = R \times I$$

- Voltage = Resistance x Current
- or Volts = Amps x Ohms
- *empirical* relationship, never strictly true, but very close for conductors
- low R --> high I
- high R --> low I

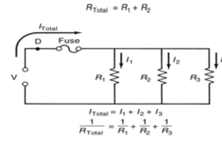
Electric Circuits



- basic elements:
  - potential difference (voltage)
  - conducting path (wires)
  - resistance (load)
- Series
  - same *current* flows through all resistors
  - different voltage across each



- Parallel
  - same *voltage* across all resistors
  - different current across each



Series and Parallel Example
(6 Volt battery, 2 Ohm and 3 Ohm resistors)

- Series:
  - $V_1 + V_2 = 6$ Volt
  - $I_1 = I_2 = 1.2$ Amp
  - Net resistance: $R_{net} = R_1 + R_2 = 5$ Ohm
- Parallel:
  - $V_1 = V_2 = 6$ Volt
  - $I_1 + I_2 = 5$ Amp
  - Net resistance: $1/R_{net} = 1/R_1 + 1/R_2 = 1.2$ Ohm

Power in Electrical Circuit

$$P = V \times I = I^2 \times R$$

- Power measured in Watt = Joule/sec
- Depends on current squared!
- low R --> high I; high R --> low I
- Power dissipated as either...
  - mechanical energy or
  - heat

How Do We Get a Potential Difference?

- Natural charge separations (DC)
  - lightning
  - height above ground
  - clouds
- <u>Batteries</u> (DC)
  - chemical (potential) energy -> electrical
- <u>Fuel Cells</u> (DC)
  - chemical (potential) energy -> electrical
- <u>Capacitors</u> (DC)
- <u>Motors</u> (AC or DC)
  - mechanical energy -> electrical energy

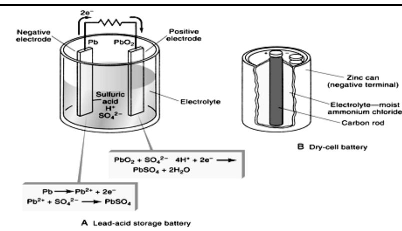


Table 10.1 BATTERY CHARACTERISTICS

Battery Type	Energy Density (W-h/kg)	Range, City (km)	Notes
Lead-Acid	30–50	110–150	Reliable, low cost, heavy
Nickel-cadmium	55	180–200	Established technology, expensive
Sodium-sulfur	80–140	300	Good storage, high temperature operation (350°C)
Lithium	150	450	Inexpensive, R & D needed
Zinc-air	180–200	400	Expensive, low life cycle
Nickel metal hydride	60	180–200	Popular, lightweight

Source: Data from "Replacing the Battery in Portable Electronics," by Christopher K. Dyer, July 1999, p. 92.

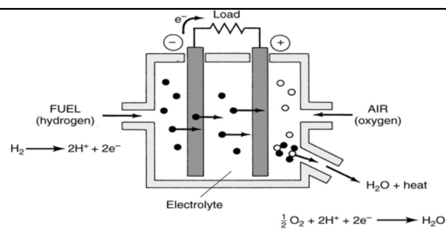
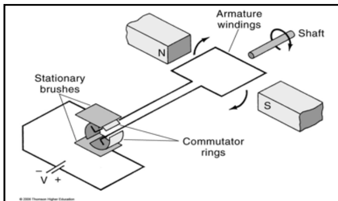
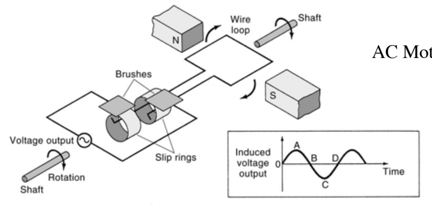


Table 10.3 TYPES OF FUEL CELLS

Type of Cell	Efficiency	Operating Temp.	Unit size
PEM	40–50%	80°C	50 kW
Phosphoric acid	40–50%	200°C	200 kW
Molten Carbonate	60+%	650°C	2000 kW
Solid-oxide ceramic	40–50%	1000°C	100 kW
Alkaline	70%	60°C	2–5 kW



DC Motor/Generator



AC Motor/Generator

AC v. DC

	AC	DC
Source	Generator	Generator Battery Fuel Cell Natural
Use	Resistive Heating Motor	Resistive Heating Motor Electronics

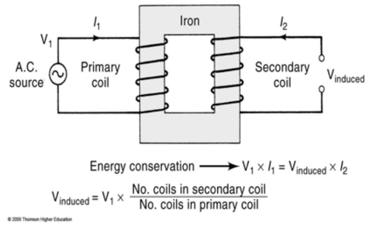
Is one "better" than the other?

Why do we have/use both types?

Transforming Voltage (AC v. DC)

- 12,000 W @ 120 V, 1Ω Resistance
  - Ohm's Law: $V=IR$, $P=VI=I^2R$
  - 12000 = 120 x I --> current 100 Amp
  - 12000 = I^2 x (1) --> loss in line 10,000 W (83%!)
- 12000 W @ 12000 V, 1Ω Resistance
  - 12000 = 12000 x I --> current 1 Amp
  - 12000 = I^2 x (1) --> loss in line 1 W !!
- Changing voltage is easy with AC; not so easy (but not impossible) with DC
- Change voltage with a "Transformer"

Transformers



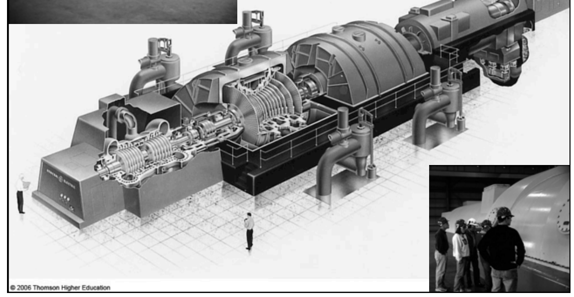
if N_s is large, V_s is large

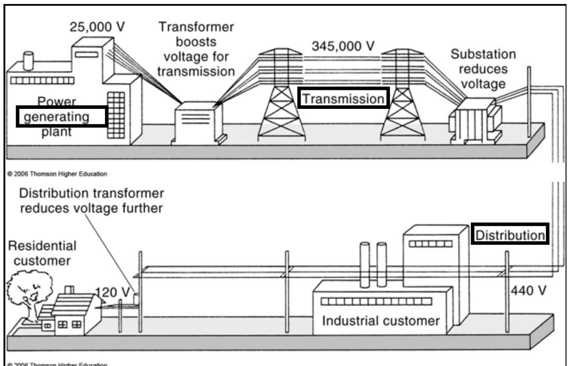
can “step up” or “step down” voltage by increasing or decreasing the number of coils

some energy is lost, but much less than would be loss through transmission at low voltage

multiple transformers are used

<-- Electrical Generator at SCEG
<-- Williams Coal Burning Facility





Some Electricity Fundamentals

- No current will flow unless
  - potential difference exists
  - conducting path exists (“circuit”)
- Can’t **store** energy in circuit (energy of motion)
- We get useful energy **out** through
  - resistive heating
  - motors (mechanical energy)
  - electronics
- Current follows *every available path*, not just “path of least resistance”, but fraction through each path depends on resistance.