Lec #12: Electricity & Magnetism

TODAY: Basics of Electricity (Chap 10, 11)
- The Electrostatic Force
- Circuits and Ohm's Law
- Batteries and Other Sources of Voltage
- Residential Circuits; AC v. DC

NEXT: Generation, Transmission, & Distribution (Chap 11)
- Motors, Generators, Transformers
- The Electrical Power "Grid"

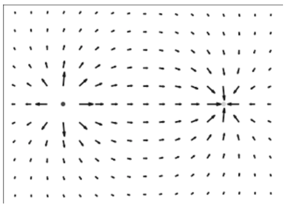
Electric Force

- 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

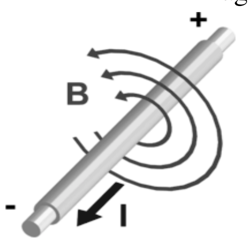


$\mathbf{F}_E = q\,\mathbf{E}$; $\mathbf{E} = q/\mathbf{r}^2$

(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



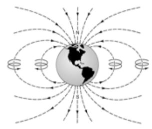
- lines describe direction a magnet would point at any location
- north and south attract; NN or SS repel
- no magnetic "monopoles"; field closes on itself
- surrounds electric current
- no medium is required
- charges also "feel" this force

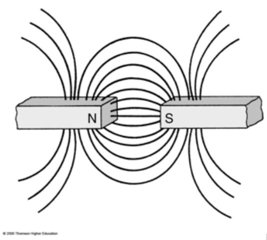
$\mathbf{F}_B = q\,(\mathbf{v} \times \mathbf{B})$

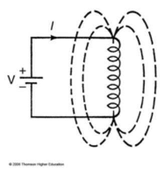
perpendicular to both velocity and magnetic field

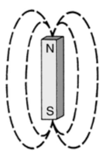
does no work; it only changes direction

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

$$V = R \times I$$

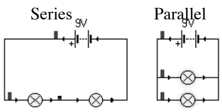
- Voltage = Resistance x Current
- or Volts = Amps x Ohms
- *empirical* relationship, never strictly true, but very close for conductors
- low R --> high I
- high R --> low I

Power in Electrical Circuit

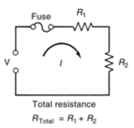
$$P = V \times I = I^2 \times R$$

- 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

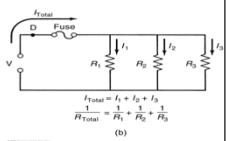
Electric Circuits



- 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

How Do We Get a Potential Difference?

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

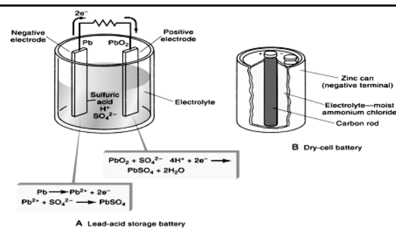


Table 10.1 BATTERY CHARACTERISTICS

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.

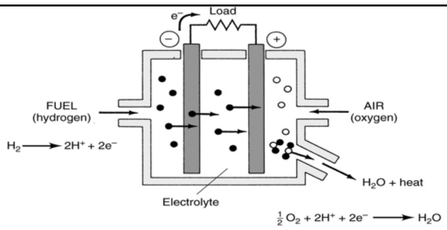


Table 10.3 TYPES OF FUEL CELLS

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

Review: 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.

Residential Circuits

- 120 V_{AC}
  - residential wiring is "alternating current"
  - 120 Volts is an *RMS* average
  - AC circuits also obey Ohm's law
- Power = V x I = 120 x I (Watts) [= I^2 x R]
  - 100 Watt bulb : 5/6 Amp
  - 400 Watt refrigerator = 3.3 Amps
  - 4,000 Watt water heater : 33 Amps!
    (this can't be right! what's wrong here?)

Table 10.2 RESIDENTIAL APPLIANCE USAGE

	Average Wattage	Monthly kWh used
Food Preparation		
Carving knife	100	0.5
Coffeemaker	1000	9
Deep fryer	1500	7
Dishwasher	1200	30
Frying pan	1200	8
Hot plate	1200	8
Mixer	150	1
Microwave oven	1450	15
Range with oven	2000	60
Roaster	1500	5
Toaster	1100	3
Trash compacter	400	4
Waffle iron	1200	2
Waste disposer	400	2
Food Preservation		
Freezer (16 cu ft)	350	100
Freezer (frostless 16 cu ft)	440	150
Refrigerator/freezer (12 cu ft)	235	60
Refrigerator/freezer (frostless 17 cu ft)	450	150
Refrigerator/freezer (frostless 18 cu ft)	550	220
Home Entertainment		
Computer (notebook)	90	6
Radio	10	2
Radio/record player	80	5
Color Television	100	18

Table 10.2 *(Continued)*

Comfort Conditioning		
Air cleaner	50	18
Air conditioner (room)	700	120
Bed covering	170	18
Dehumidifier	670	240
Fan (attic)	370	25
Fan (circulating)	75	12
Heater (portable)	1350	400
Humidifier	175	42
Housewares		
Clock	2	2
Floor polisher	300	1
Sewing machine	75	1
Vacuum cleaner	650	4
Laundry		
Clothes dryer	5000	85
Iron (hand)	1100	5
Washing machine (automatic)	375	10
Water heater	4500	500
Health and Beauty		
Hair dryer	1000	3
Heat lamp (infrared)	250	1
Shaver	15	0.1
Sun lamp	800	1

Source: New York State Electric & Gas Corporation.

Residential Circuits (continued)

- homes have circuit boxes with several separated circuits (each of which can carry 10 to 20 Amps), each with a circuit breaker (switch) or fuse
- main breaker typically 100 to 200 Amps
- outlets in each circuit are wired in parallel
- circuits themselves are in parallel (all have same voltage)
- how/why do we get 240 V?

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