



PHYSICS 102N

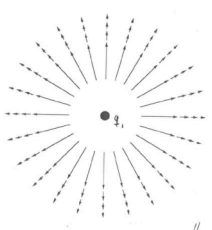
Spring 2009

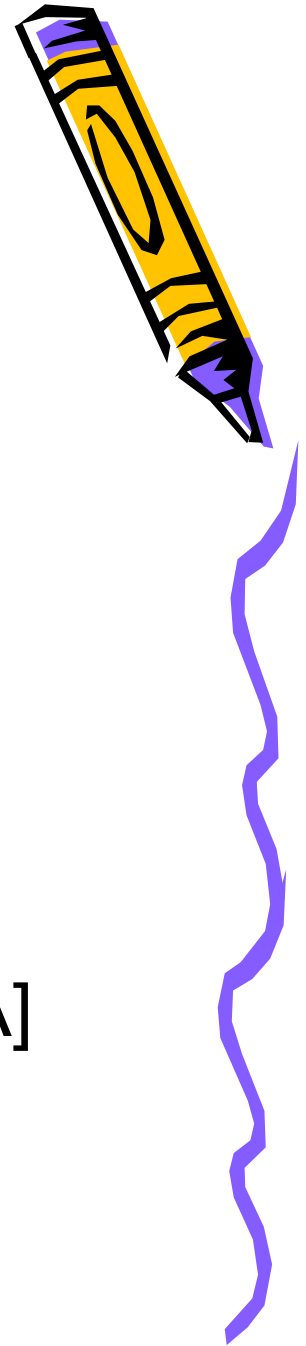
Week 7 - 8

Electromagnetism and Light



Remember PHYS101...?

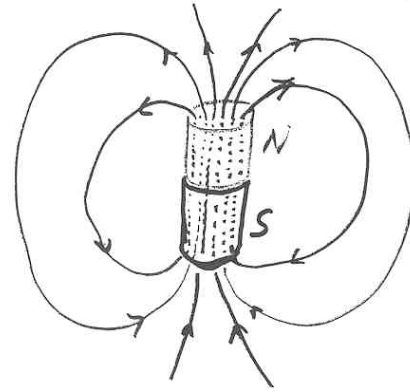
- Electrostatic force (Coulomb): $F = k \frac{Qq}{r^2}$
charges q, Q at distance r
-  Electric field: $\mathbf{E} = \mathbf{F}/q$, $\mathbf{F} = q\mathbf{E}$
- Electric potential V [V], electric potential energy
- Current I [A]; Ohm's Law $\Delta V = RI$ [$V = \Omega A$]
- Power: $P = \Delta V \cdot I$; Circuits (AC/DC)



Remember PHYS101...?



- Magnets and Magnetism
- Magnetic field **B**
(ultimately due to currents)
- **Acts** on moving charges = currents ($F = ILB$)
- Connection to electric field:
 - if charge q moves in stationary **B** - Force $\propto q, v, B$
 - if magnet moves relative to charge - Force $\propto q \Rightarrow$ electric field **E** due to changing magnetic field
 - same if **B** simply changes for other reasons (induced **E** field)

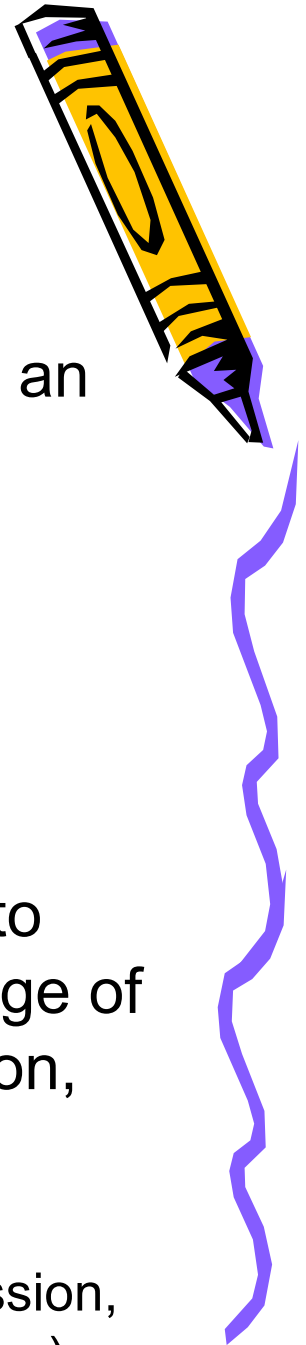


Faraday and Lenz

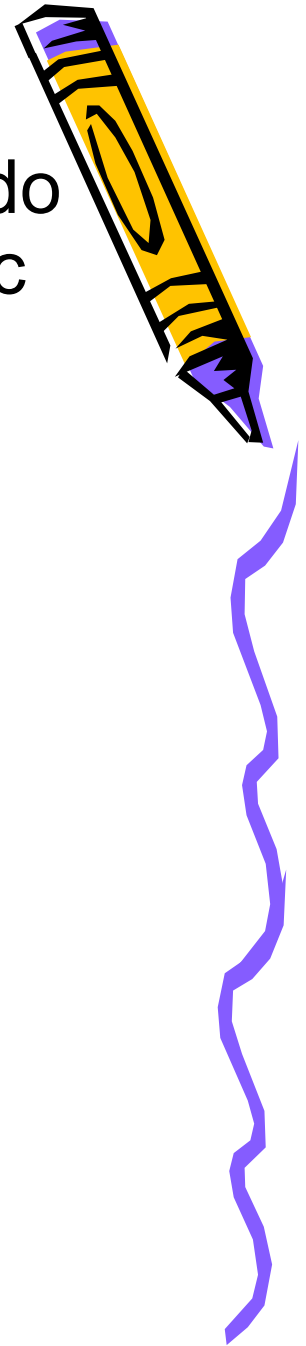
- Faraday: A changing magnetic field will induce an electric field circling it
 - The faster the change of \mathbf{B} , the larger \mathbf{E}
 - \mathbf{E} tends to be perpendicular to \mathbf{B}
- Lenz: The effect of \mathbf{E} will be to counteract the *change* of \mathbf{B}
 - if circuit present, drive current I that will tend to create magnetic field to compensate for change of \mathbf{B} , or that will create force counteracting motion, or move circuit out of increasing \mathbf{B} ...



Applications: Generators, transformers, power transmission, self induction, electric brakes (conventional, regenerating)



- (cont'd): While static magnetic fields cannot do work on moving charges, **changing** magnetic fields **can** do work (through induced **E**) and therefore magnetic fields can **store energy**



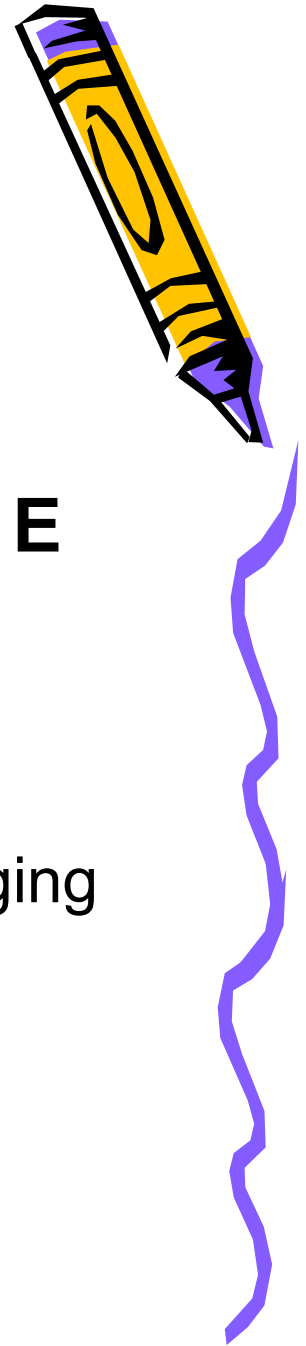
Closing the loop: Maxwell

- Changing **B** -> **E** (Faraday)
- Changing **E** -> **B!!!** Maxwell's Law
 - Proportional to the rate of change of **E**, perpendicular to **E** (circling around it)
 - Usually small effect



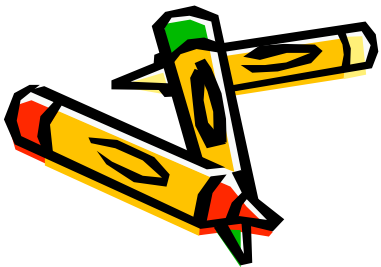
Closing the loop: Maxwell

- Changing **B** \rightarrow **E** (Faraday)
- Change in the changing of **B** \rightarrow changing **E**
- Changing **E** \rightarrow **B!!!** Maxwell's Law
 - Proportional to the rate of change of **E**, perpendicular to **E** (circling around it)
- Changing **B** \rightarrow **E**, Changing **E** \rightarrow **B**, Changing **B** \rightarrow **E**, Changing **E** \rightarrow **B**,
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Changing **B** \rightarrow **E**, Changing **E** \rightarrow **B**, Changing **B** \rightarrow **E**, Changing **E** \rightarrow **B**,...
- Electromagnetic Waves!



Solving the equations of electromagnetic fields...

- ...Maxwell found that they give rise to a solution for oscillating electric and perpendicular magnetic fields (in phase) forming a plane wave with wave velocity - $300,000 \text{ km/s} = c!$
 - “We can scarcely avoid the conclusion that light is an electromagnetic wave” - the wave velocity of light was known before!



Note: EM wave doesn't need a medium - electric and magnetic fields ARE the medium. c is universal constant and turns out to be a property of space and time!



Properties of EM waves

- **E**, **B** and propagation all perpendicular to each other
- $B = E/c$ (magnetic field much smaller)
- Can have 2 directions of polarization - up-down or left-right (direction of oscillation of **E**-field) - Polaroid glasses
- Wave velocity always c in vacuum (and other “dilute” media)

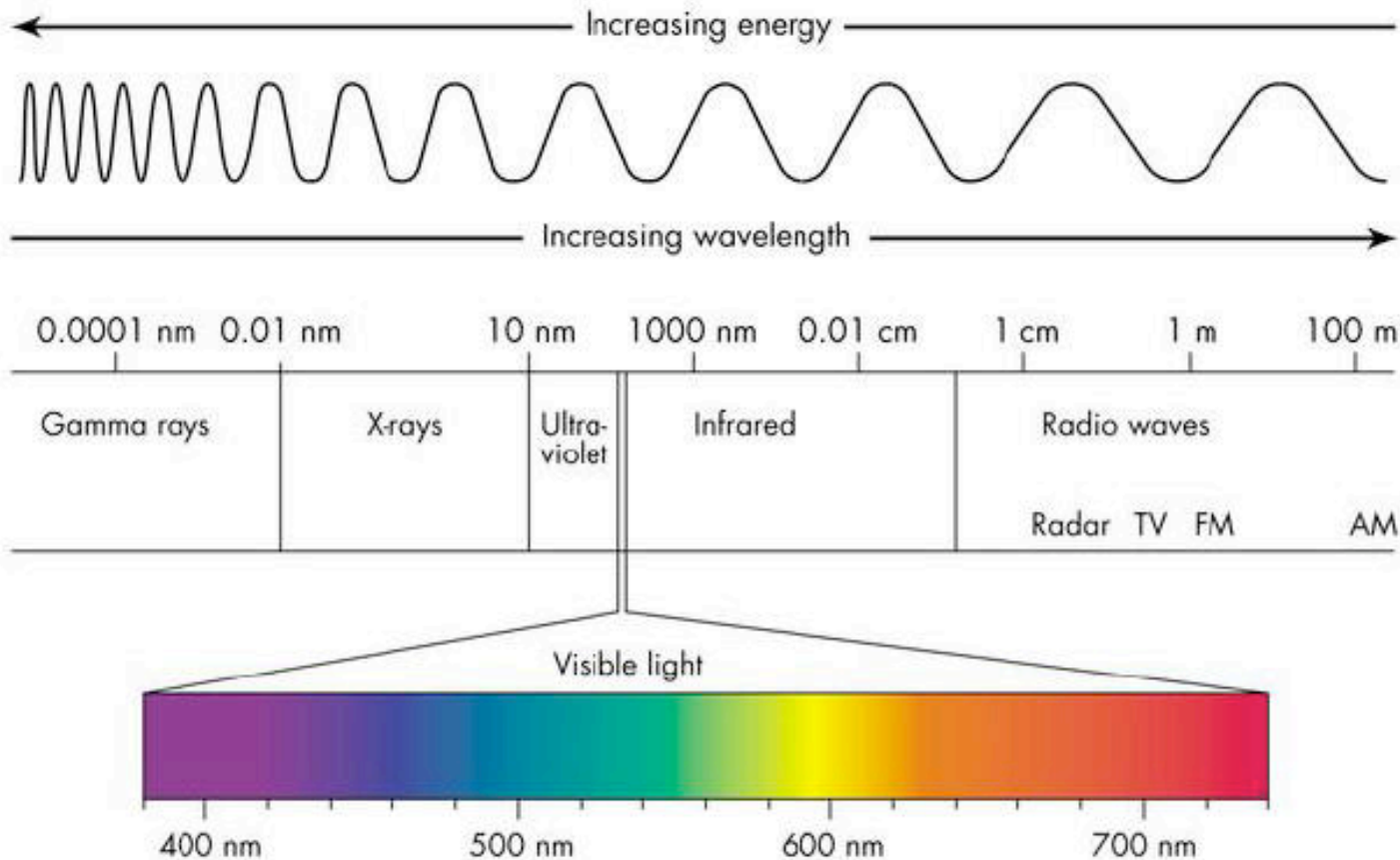


All EM waves are created by **accelerated** electrical charges:
(Changing)² **E** -> changing **B** ->...

Example: Radio antenna, oscillating molecules (IR), electrons in atoms (light-UV-Xrays), protons in nuclei (gamma-rays)...



EM wave spectrum



$$f = c/\lambda \text{ (like all waves)}$$

200 m \rightarrow 1500 kHz; 3 m \rightarrow 100 MHz; 10 mm \rightarrow 30 GHz

10 μ m \rightarrow 30 THz; 600 nm \rightarrow $0.5 \cdot 10^{15}$ Hz, 10^{-13} m \rightarrow $3 \cdot 10^{21}$ Hz



Propagation of Light



- Simple model:
 - In free space, light waves follow straight lines (“rays”).
 - Example: rays from outer edges of sun make angle of $1/2$ degree, sun is 150 Mio km away \rightarrow sun diameter = 1.4 Mio km
 - In medium, 3 possibilities:
 - Reflection: wave reflected; ray “bounces back”
 - Some reflection present at nearly all interfaces; max. for metals because of free electrons
 - Absorption: EM energy transferred to oscillating atoms/molecules; ray is “stopped”
 - max. for resonance frequency; e.g. UV in glass, IR in CO_2 ...
 - shadow (only rays that avoid medium continue)
 - Propagation (often with reduced wave velocity \Leftrightarrow reduced \mathbf{E}):
 - waves absorbed and re-emitted (possibly with phase delay)

