

HLTH 204 Radiographic Physics and Protection

Module I - Radiation Physics

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Fri August 15, 22, 29 2-4 CSC T1

- how x-rays are produced

- accelerate electrons using high voltage
- smash into target

electric and magnetic forces produce & control beams

circuitry to create high voltage DC
electricity and magnetism

production of x-rays in target

- interaction of x-rays with matter
attenuation, imaging, shielding

i.e. today

week 2 - electricity and magnetism

3 - x-ray machines: circuits, tube design & operation

4 - x-rays: electromagnetic radiation, x-ray production
and interactions

Text chapters 5-13 inclusive

Electricity and Magnetism

1. Two types of electrical charge: +, -

- charge measured in Coulombs

- charge on electron = 1.6×10^{-19} C (-ve)
" " proton = 1.6×10^{-19} C (+ve)

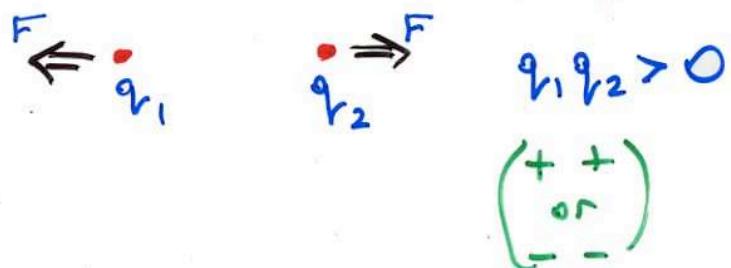
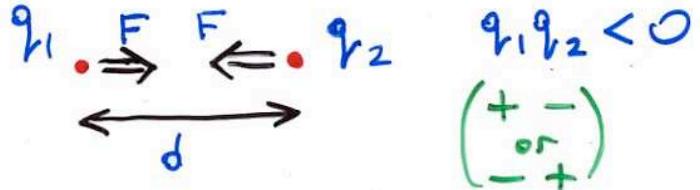
so 1 C = charge on $\approx 6 \times 10^{18}$ electrons

2. Like charges repel, unlike charges attract

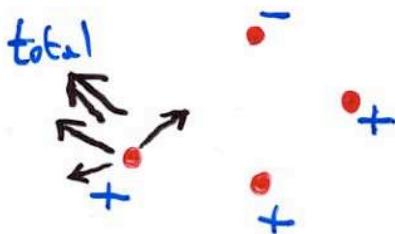
- strength of force depends on how much charge and distance between them

$$F = \frac{kq_1 q_2}{d^2}$$

Coulomb's law

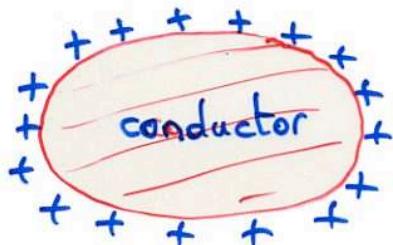


3. Many charges: add forces to get net effect



Electrostatics

Charges on a conductor accumulate on its surface and concentrate at regions of high curvature:



(deficit of electrons)

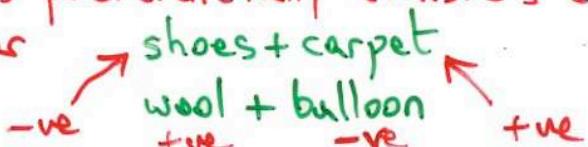


(excess of electrons)

Charge bodies by:

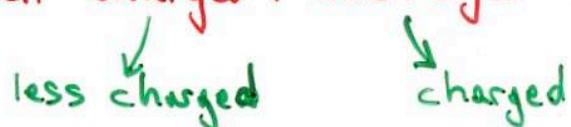
1. Friction

- rubbing unlike materials preferentially transfers e⁻ from one to the other

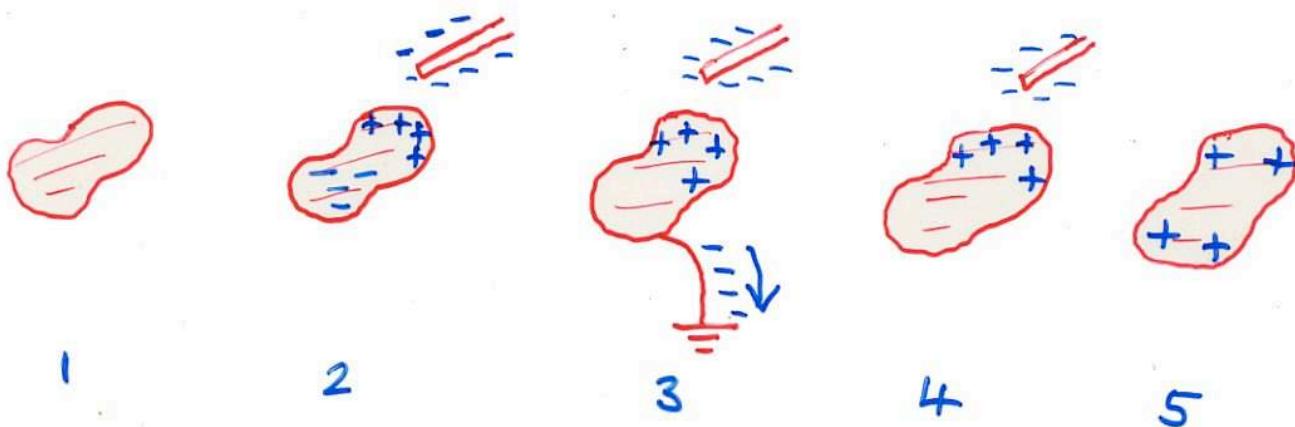


2. contact

- share charges between charged & uncharged conductors

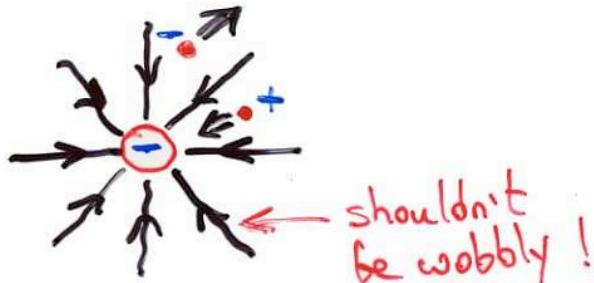
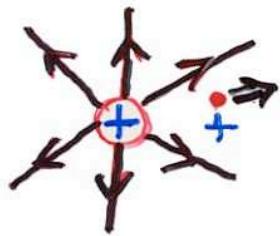


3. induction



Electric Field

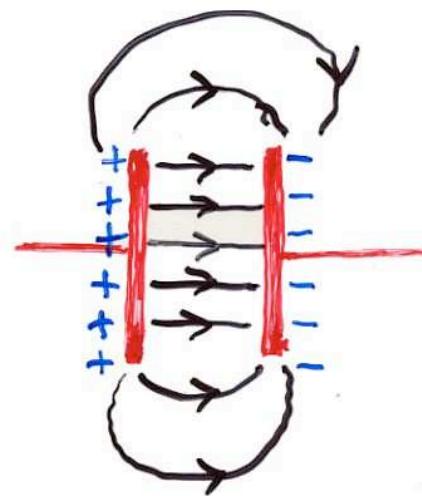
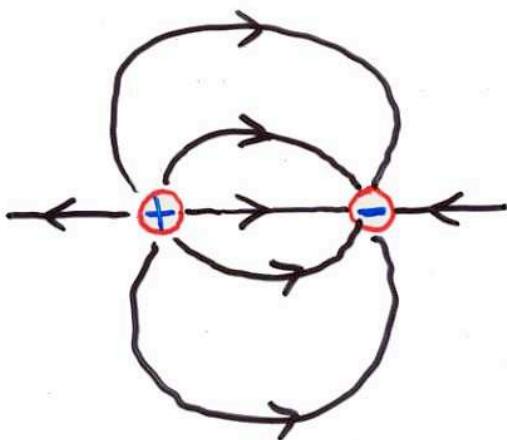
- created by charges
- traces direction of force exerted on a +ve "test" charge



- relative strength indicated by closeness of field lines

$$F = q_r E$$

(N) (C) (N/C)



parallel plates
⇒ uniform field between them

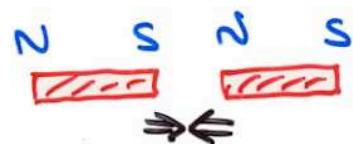
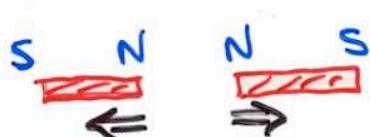
Magnetism & magnetic fields

- weird: have magnetic dipoles - little magnets - instead of charges

- * Magnets have a north and south pole

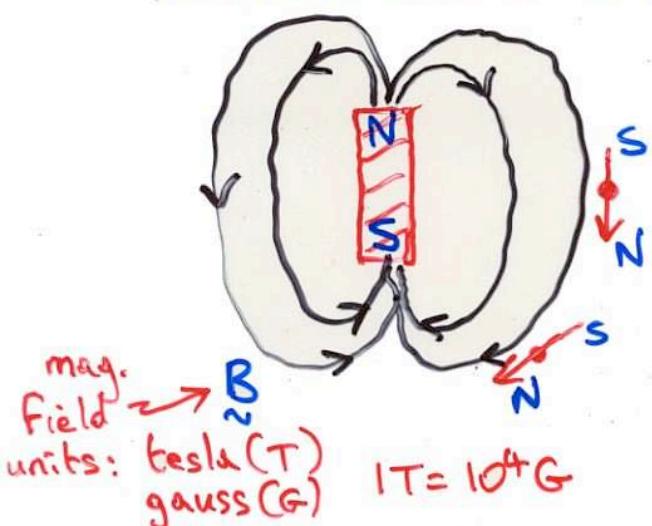


- * like poles repel, unlike poles attract

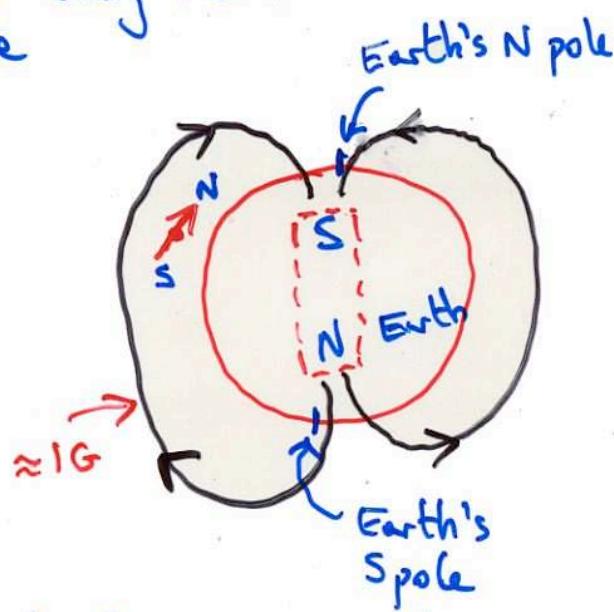


- * magnetic field: direction indicates how a small magnet would line up along field.

- lines run from N to S pole



units: tesla (T)
gauss (G) $1\text{T} = 10^4\text{G}$



Earth's N pole

Earth's
South pole

- * magnetic materials

response to B

examples

Ferromagnetic

strong (can be
magnetised)

Fe, Ni, Co

paramagnetic

weak

Al, H₂O

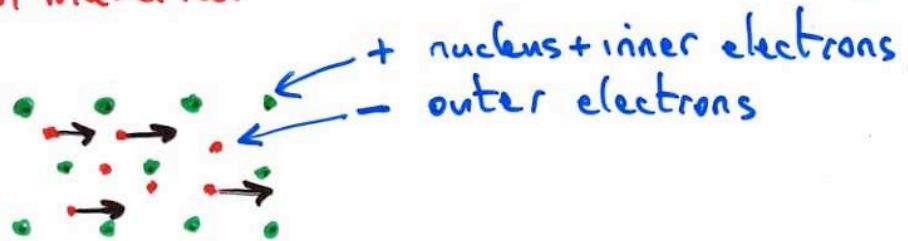
nonmagnetic

none

wood, glass, rubber,
plastics

Electrical properties of materials depend on the mobility of electrons

- protons bound in nuclei
- outer electrons may be able to drift depending on bonding in material



conductors e⁻ move freely eg/ copper, silver

insulators e⁻ fixed eg/ wood, plastic, glass

semiconductors depends on conditions
(conducting or insulator) eg/ silicon, germanium,
diodes

superconductor zero resistance at
low T (e⁻ move
completely unimpeded) certain metal
alloys

Electrostatics - charges at rest

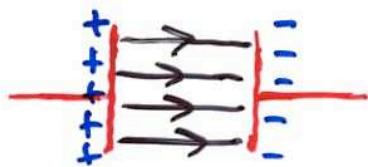
Electricity or electrodynamics - moving charges

currents
magnetic fields

Potential difference (voltage, emf)

- energy needed to get unit charge from A to B in an electric field

1 volt = 1 Joule for each Coulomb of charge
($1V = 1J/C$)



$1.5V \Rightarrow$ takes 1.5 J to move 1 C from -ve plate to +ve plate

An e^- "falling" from -ve plate to +ve plate gains

$$1.5 \times 1.6 \times 10^{-19} \text{ J} = \cancel{1.5 \text{ eV}}$$

\uparrow \nwarrow charge on an e^-
 J/C (C)

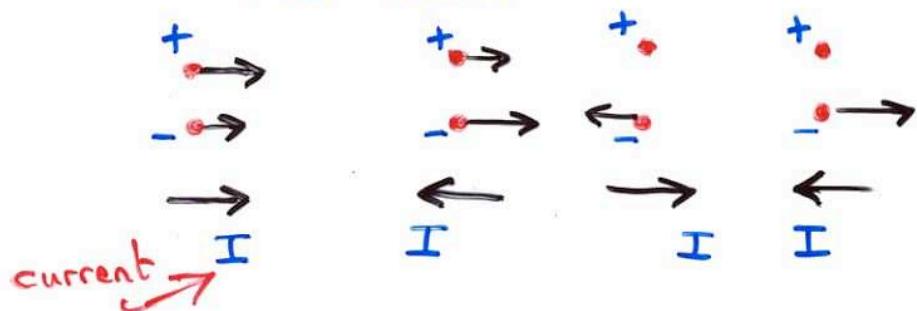
Energy unit: eV (electron-volt) = energy equivalent to an e^- crossing a potl. diff. of 1 V
 $= 1.6 \times 10^{-19} \text{ J}$

e.g. e^- travelling from cathode to anode w/ 1000 V across the pair has kinetic energy of 1000 eV (1 keV) before striking the anode

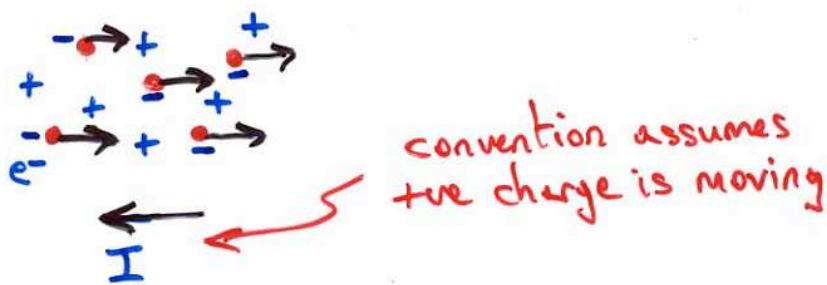
1 keV \approx x-ray photon energy

Current, Voltage and Resistance

current: drift of +ve and -ve charges with respect to each other.



* in circuits, e⁻ drift through the wire while +ve ions are fixed in a lattice:



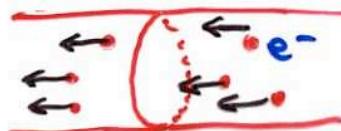
* current = total charge flowing past a point per unit time

Ampere = Coulomb/second
(A) (C/s)

mA = milliAmpere
= 10^{-3} A

X-ray filament 2-5 A
" tube 50-800 mA
e⁻ beam

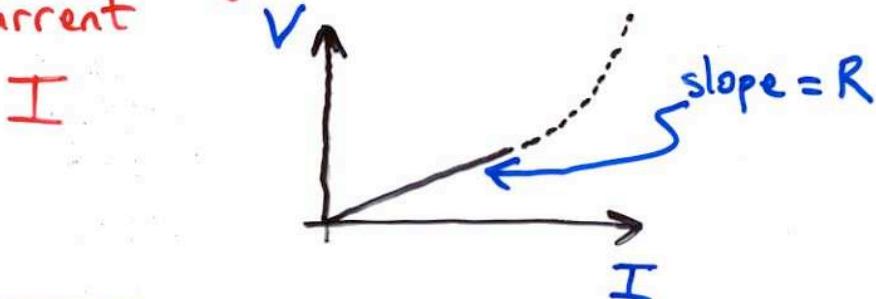
$$1 \text{ A current in wire} = 1 \text{ C/s} \\ = 6 \times 10^{18} \text{ e}^-/\text{s} !$$



drift speed typically
 $\sim 1 \text{ mm/s}$
(response to electric force)

Resistance of a material determines current that will flow in response to a potential difference.

- potl difference \Rightarrow electric field in material
 V \Rightarrow force on electrons
 \Rightarrow drift with speed depending on ease of motion through material
 \Rightarrow current



* Ohm's law

$$R = \frac{V}{I}$$

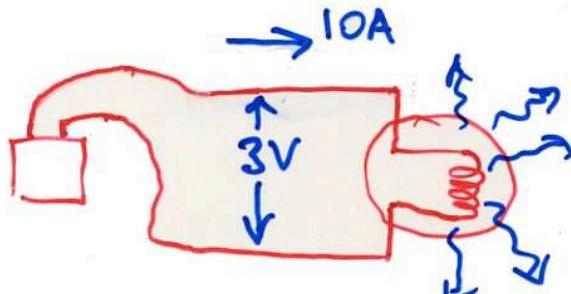
units: Ohm, $\Omega = \frac{J\cdot S}{C^2}$

$$V = IR, I = V/R$$



Power = rate of total energy gained
= energy/charge \times charges/sec

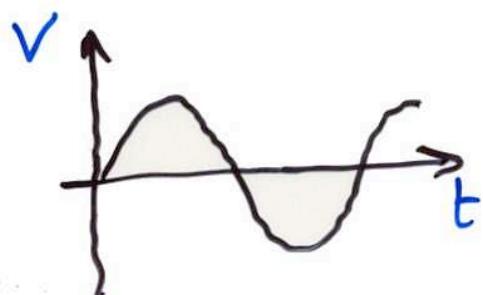
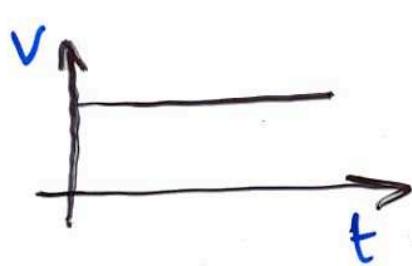
$$P = VI$$



$$\begin{aligned} P &= 3V \times 10A \\ &= 30 \underbrace{\frac{J}{C} \times \frac{C}{S}}_{J/S = W} \\ &= 30 \text{ watts} \end{aligned}$$

Direct current: V, I constant
DC

Alternating current: V, I vary sinusoidally
AC



$\overrightarrow{e^-}$
uniform drift

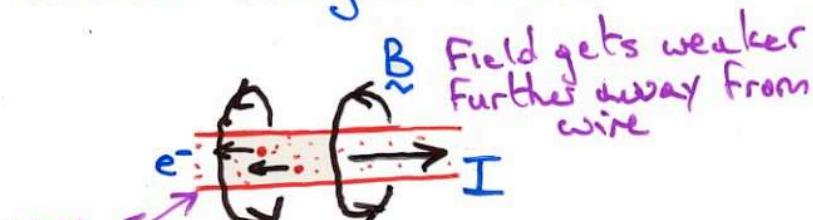
$\overleftarrow{\overrightarrow{e^-}}$
oscillatory drift

Electromagnetism

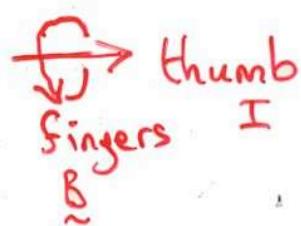
- relationship between currents and magnetic fields

- * currents \Rightarrow magnetic fields (e.g. electromagnets)
- * moving charges experience magnetic forces (e.g. control electron beams)
- * changing magnetic fields \Rightarrow potential differences (emfs)
voltage conversion by transformers

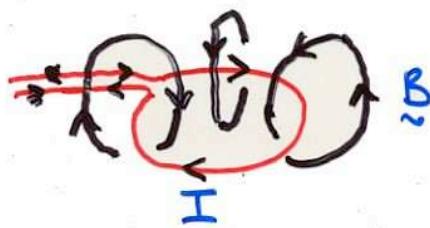
1. Current \Rightarrow magnetic field



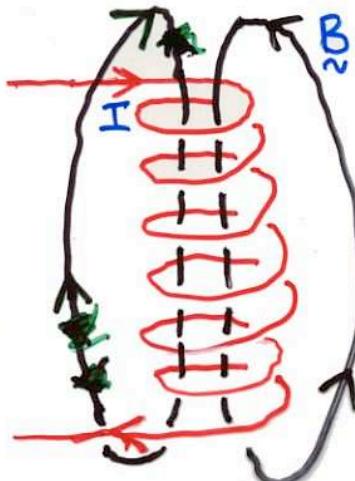
right-hand rule



- straight wire \Rightarrow circular field lines



- loop of wire \Rightarrow toroidal field, strong in centre of loop

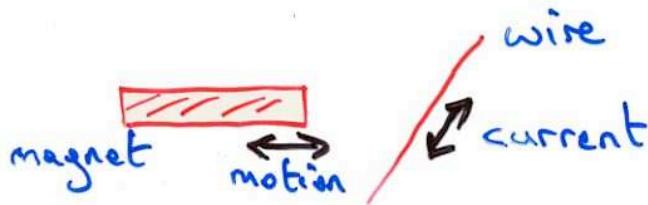


add turns
 \Rightarrow strong, uniform field
in centre of coil

- add a ferromagnetic core
(Fe/Ni/Co) to concentrate
central field lines

Electromagnetic induction

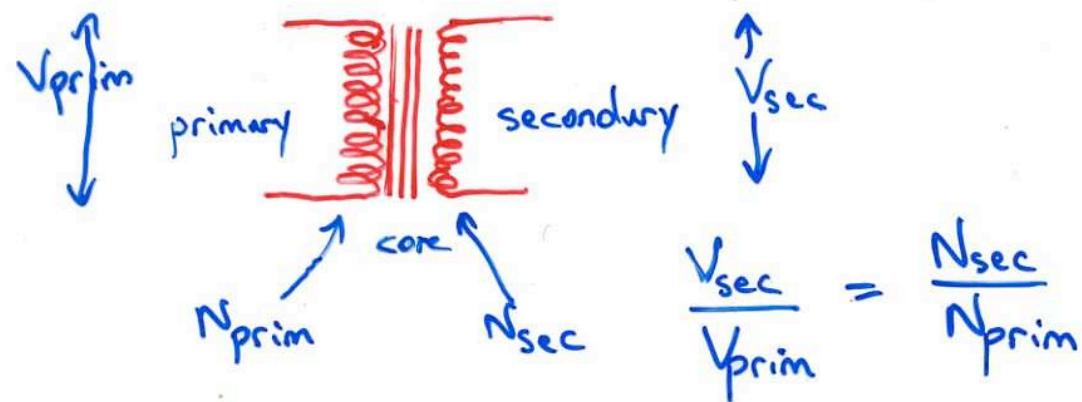
- change in magnetic field induces a current in a conductor (because creates an induced voltage, or emf)
electromotive force
- effect is larger for stronger fields, and for faster changes.



Transformers

- use induction to convert voltages.

- * two coils "magnetically linked" by a ferromagnetic core
 - use AC input voltage to drive AC current in the primary coil \Rightarrow creates varying B
 - the other, secondary coil "feels" the varying B and ~~an~~ an output voltage is created across it.



Electric generators

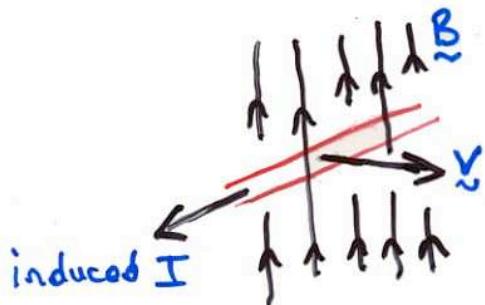
- convert mechanical energy to electrical energy

* pull a conductor across magnetic field lines

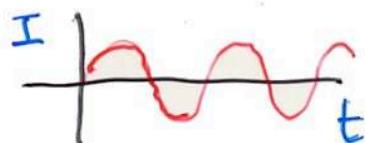
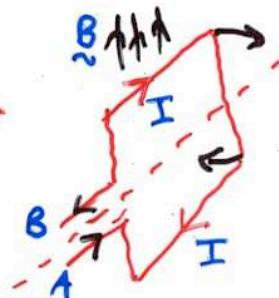
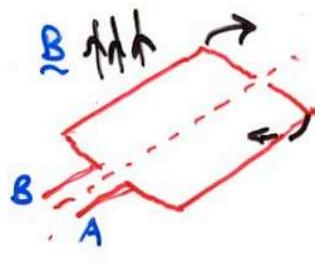
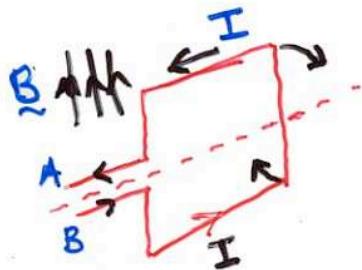
⇒ induced current in wire

(electrons drift in response to magnetic forces)

⇒ current



motion \parallel to B has no effect



⇒ AC current

Electric motors

- convert electrical to mechanical energy

- apply current to loop ⇒ magnetic forces cause it to rotate

- several coils used to maintain duty cycle

- AC vs DC?

Induction motor - use fixed electromagnets to spin up a rotor using forces on induced currents in the rotor.

step-up transformer: $N_{sec} > N_{prim}$ e.g. high voltages
to X-ray tube

step-down transformer: $N_{sec} < N_{prim}$ e.g. high current
to filament

NB: $V_{sec} I_{sec} \leq V_{prim} I_{prim}$
(power) \uparrow = for high efficiency

e.g.

$$? = 200V \times \frac{250,000}{500} = 200V \times 500 \\ = 100,000 \text{ V}$$

$$I_{prim} = 10 \text{ A}$$

$$I_{sec} = \frac{200}{100,000} \times 10 \text{ A} = \frac{1}{50} \text{ A} = 20 \text{ mA}$$