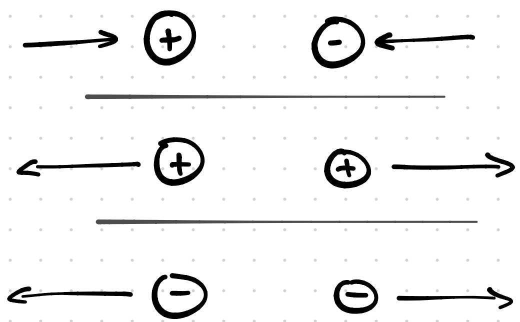
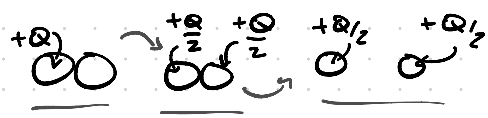
302L S20

Review

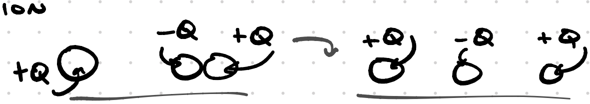
ELECTRIC CHARGE



- CONSERVED: NEITHER CREATED NOR DESTROYED
- QUANTIZED: $e \simeq 1.6 \cdot 10^{-19}$ C
- CHARGING BY:
  - FRICTION
  - CONDUCTION

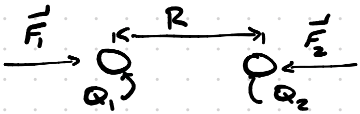


  - INDUCTION



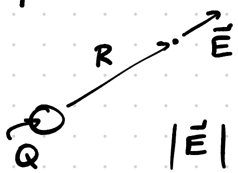
- ELECTROSTATIC ATTRACTION OF NEUTRAL OBJECTS:

- Coulomb's Law:



$$|\vec{F}_1| = |\vec{F}_2| = \frac{k Q_1 Q_2}{R^2} \qquad \left[k = \frac{1}{4\pi\varepsilon_0}\right]$$

- Electric Field:
  - Electric field due to a point charge:



$$|\vec{E}| = \frac{kQ}{R^2}$$

Direction of $\vec{E}$? "What would a proton do?"

- Electric field due to multiple point charges:

  Superposition principle: $\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \cdots$

Why do we care about $\vec{E}$ field?

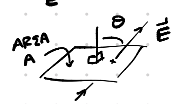
- Force $\vec{F}$ on a charged particle of charge Q?

  $\vec{F} = Q\vec{E}$ where $\vec{E}$ is the electric field due to all the other charges.

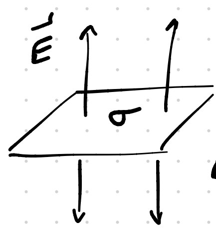
- Gauss' Law: $\Phi_E = Q_{enc}/\varepsilon_0$

  (Φ_E: electric flux thru closed surface; Q_{enc}: charge enclosed by surface)

  $\Phi_E = EA\cos\theta$



- Gauss' law helped to find $\vec{E}$ field of continuous charge distributions:



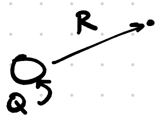
E.g. ∞-plane

$$E = \frac{\sigma}{2\varepsilon_0}$$

- CONDUCTORS
  - CHARGE CARRIERS MOVE FREELY
  - IN EQUILIBRIUM:
    - $\vec{E} = 0$ EVERYWHERE INSIDE
    - ALL CHARGE IS @ SURFACE.
    - @ SURFACE, $\vec{E}$ POINTS $\perp$ TO SURFACE & $|\vec{E}| = \frac{\sigma}{\varepsilon_0}$

- ELECTRIC POTENTIAL
  - ALTERNATIVE TO $\vec{E}$ FOR DESCRIBING INTERACTIONS BETWEEN CHARGES.
  - ELECTRIC POTENTIAL DUE TO POINT CHARGE:

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



  - ELECTRIC POTENTIAL DUE TO MANY CHARGES:

SUPERPOSITION PRINCIPLE: $V = V_1 + V_2 + \ldots$

WHY DO WE CARE ABOUT ELECTRIC POTENTIAL?

  - POTENTIAL ENERGY OF POINT CHARGE DUE TO ELECTRIC POTENTIAL OF ALL OTHER CHARGES:

$$U = QV$$

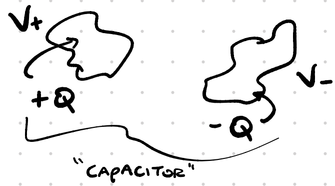
  - ENERGY CONSERVATION: $E = KE + U$ FIXED IN TIME!

(TOTAL ENERGY → E; KINETIC ENERGY $(\frac{1}{2}mv^2)$ → KE; POTENTIAL ENERGY → U)

- WHAT DOES ELECTRIC POTENTIAL TELL US ABOUT FORCES ON CHARGES?
    - (+) CHARGES SEEK **LOW** ELECTRIC POTENTIAL
    - (−) " " **HIGH** " "
- ELECTRIC POTENTIAL IS **CONSTANT** EVERYWHERE ON A CONDUCTOR.

- CAPACITANCE:

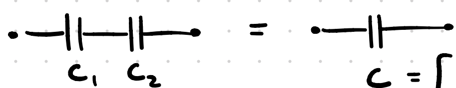
THE ELEC. POT. V BETWEEN TWO CONDUCTORS IS PROP. TO. THE CHARGE $\pm Q$ ON THEM:



$$V \equiv V_+ - V_- = \frac{Q}{C}$$

C: "CAPACITANCE", DEPENDS ON GEOMETRY OF CONDUCTORS

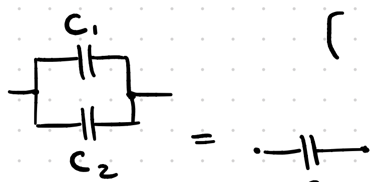
- CAN FORM NEW CAPACITORS BY CONNECTING THEM:
    - IN SERIES:



$$C = \left[\frac{1}{C_1} + \frac{1}{C_2}\right]^{-1}$$

$$\left[\begin{matrix} C < C_1, \\ C < C_2 \end{matrix}\right]$$

- IN PARALLEL:

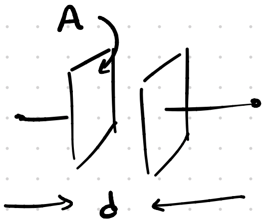


$$C = C_1 + C_2$$

$$\left[\begin{matrix} C > C_1, \\ C > C_2 \end{matrix}\right]$$

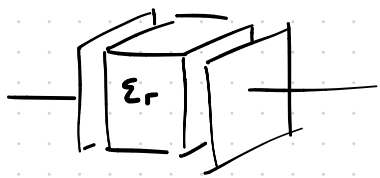
- CAPACITORS STORE **ENERGY** $E = \frac{1}{2} QV$

- PARALLEL PLATE CAPACITOR



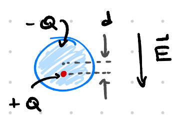
$$C = \frac{\varepsilon_0 A}{d} \quad [\, d \ll \sqrt{A} \,]$$

- DIELECTRICS
  - INSULATORS: CHARGES BOUND TO ATOMS.
  - INCREASE THE CAPACITANCE BY SCREENING THE CHARGE ON THE PLATES:



$$C = \varepsilon_r \frac{\varepsilon_0 A}{d}$$

"RELATIVE PERMITTIVITY" OR "DIELECTRIC CONSTANT".
DEPENDS OF "POLARIZABILITY" (α) OF THE DIELECTRIC MATERIAL:

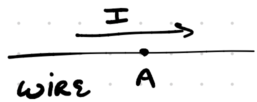


"DIPOLE MOMENT" (p)
$\underbrace{Qd}_{} = \alpha E$

- BATTERIES
  - CHEMICAL FORCE DRIVES CHARGE TRANSFER BETWEEN TWO ELECTRODES [E.G. Zn + Cu]
  - CHEMICAL FORCE CHARACTERIZED BY AN "EMF", WHICH IS ELEC. POT. DIFFERENCE REQUIRED TO OPPOSE CHEM. FORCE.
  - WHEN CURRENT CONDUCTING BETWEEN ELECTRODES IS LOW, BATTERY ACTS AS SOURCE OF CONSTANT VOLTAGE. $V = \text{emf}$

• Electric Current

- Flow of charge



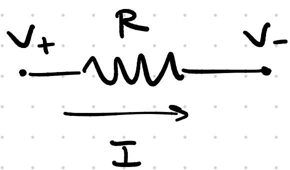
E.G. wire

Current @ A: amount of positive charge ΔQ moving past A along arrow's direction over time Δt

$$I = \frac{\Delta Q}{\Delta t}$$

• Resistors

- Obstruct flow of charge

- 

Voltage drop across resistor carrying current:

$$V \equiv V_+ - V_- = IR$$

("Ohm's law")

"Resistance", depends on geometry of resistor & its resistivity

What is a short?

Open circuit?

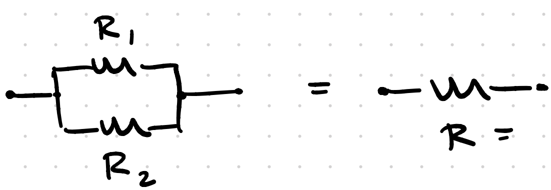
Series

- 

$$R = R_1 + R_2$$

$$[R > R_1,\ R > R_2]$$

Parallel

- 

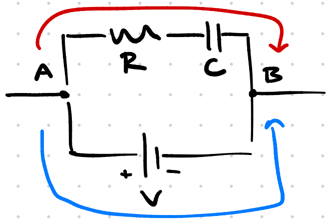
$$R = \left[\frac{1}{R_1} + \frac{1}{R_2}\right]^{-1}$$

$$[R < R_1,\ R < R_2]$$

- Resistors consume power: $P = IV$

KIRCHOFF'S CIRCUIT LAWS:

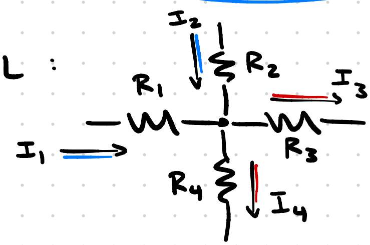
- KVL:



$$\sum V_{A \to B} = \sum V_{A \to B}$$

E.G. $V = V_R + V_C$

- KCL:

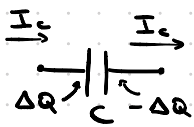


$$\sum I_{IN} = \sum I_{OUT}$$

E.G. $I_1 + I_2 = I_3 + I_4$

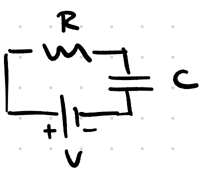
R.C. CIRCUITS

- CAPACITOR CHARGED BY CURRENT:

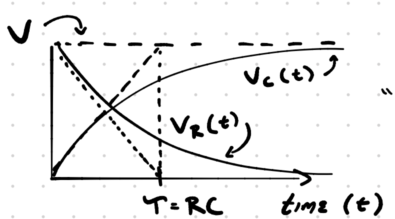


$$\frac{\Delta Q}{\Delta t} = I_c$$

- RC SERIES:



RESISTOR PREVENTS INSTANTANEOUS INCREASE IN CAPACITOR CHARGE:

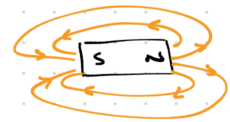


"EXPONENTIAL CHARGING"

- WHAT ABOUT EXPONENTIAL DISCHARGING?
- CHARGING OF RC PARALLEL CIRCUIT?

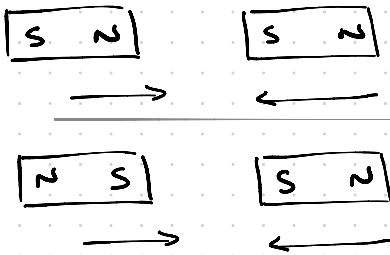
MAGNETISM

$\vec{B}$ FIELD OF MAGNET:



- MAGNETS:
  [I.E. MAGNETIC DIPOLES]

ATTRACT

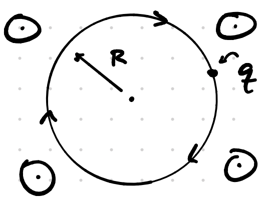


REPEL

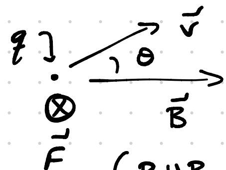
E.G. PAPERCLIP

ATTRACTS IRON BY INDUCTION.

- EXERTS FORCE ON MOVING CHARGES



$R = \frac{mv}{qB}$



$F = qvB\sin\theta$

(RHR #1)

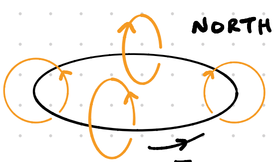
- AUDIOSPEAKER / ELECTRIC MOTOR

- CURRENTS GENERATE MAGNETIC FIELDS:

$\vec{B}$ (RHR #2)

$B = \frac{\mu_0}{2\pi} \times \frac{I}{R}$

NORTH POLE

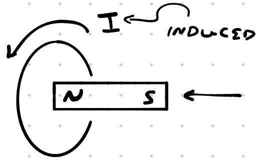


SOUTH POLE

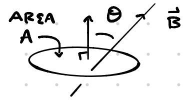
"ELECTROMAGNET"

ELECTROMAGNETIC INDUCTION

- CHANGING $\vec{B}$ FIELDS PRODUCE $\vec{E}$ FIELDS:



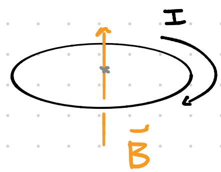
MAGNETIC FLUX

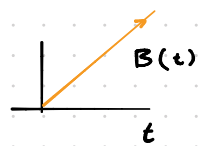


- FARADAY'S LAW:

$$\mathcal{E}mf = N\frac{\Delta\Phi}{\Delta t} \qquad \Phi = BA\cos\theta$$

- LENS' LAW: INDUCED CURRENT GENERATES $\vec{B}$ FIELD WHICH OPPOSES Φ THAT INDUCED CURRENT.

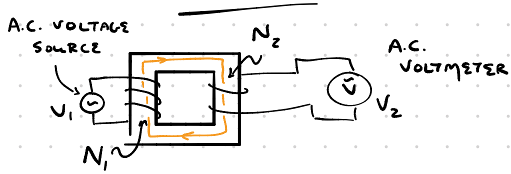




- GENERATORS:
  - CONVERT MOTION INTO ELECTRICITY

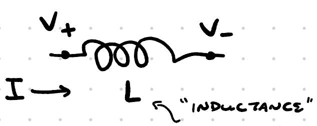
$$\mathcal{E}mf = 2\pi f NBA\cos[2\pi f t]$$

TRANSFORMERS



$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

- INDUCTORS

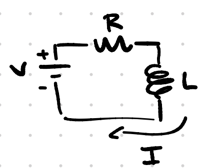


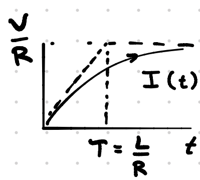
$$V \equiv V_+ - V_- = L\frac{\Delta I}{\Delta t}$$

RL CIRCUIT:

INDUCTOR PREVENTS INSTANTANEOUS CHANGES IN CURRENT:

E.G.

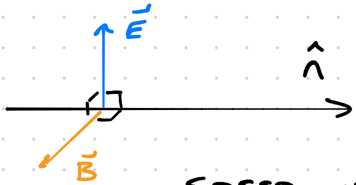




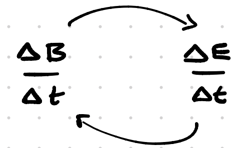
ELECTROMAGNETIC WAVES

FARADAY : CHANGING $\vec{B} \rightarrow \vec{E}$

MAXWELL'S HYPOTH : " $\vec{E} \rightarrow \vec{B}$



E.M. WAVE :



SELF-SUSTAINING CYCLE

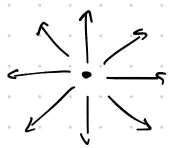
SPEED IN VACUUM:

$$c \simeq 3 \times 10^8 \ \frac{m}{s}$$

$B = \frac{E}{c}$, $f\lambda = c$ ← MONOCHROMATIC WAVES

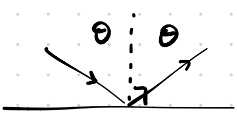
Ray optics

- POINT SOURCES

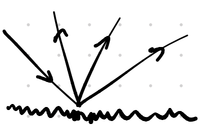


- PINHOLE CAMERAS / IMAGE FORMATION / VISION

- REFLECTION



SPECULAR



DIFFUSE

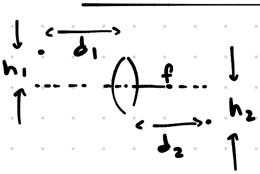
- REFRACTION

- SPEED OF LIGHT DEPENDS ON

DISPERSION → λ & MEDIUM:

$$v = \frac{c}{n}$$ ← INDEX OF REFRACTION

LENSES / MIRRORS



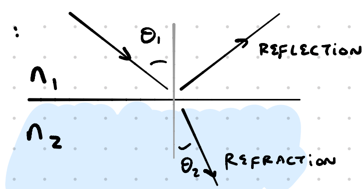
$$\frac{1}{d_1} + \frac{1}{d_2} = \frac{1}{f}$$

$$\frac{h_2}{h_1} = -\frac{d_2}{d_1}$$

SNELL'S LAW :

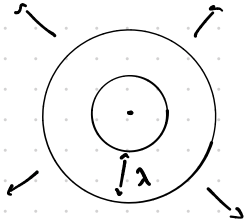
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

T.I.R. : $\theta_1 > \theta_c = \arcsin\frac{n_2}{n_1}$



WAVE OPTICS

- POINT SOURCES



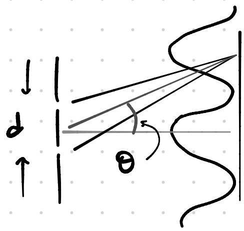
- AMPLITUDE VS. INTENSITY

$$I = A^2$$

- SUPERPOSITION PRINCIPLE: AMPLITUDES ADD.
- HUYGEN'S PRINCIPLE: EVERY POINT ON A WAVEFRONT IS A SOURCE OF SPHERICAL WAVES

TWO-SLIT INTERFERENCE:

BANDS OF CONSTRUCTIVE & DESTRUCTIVE INTERFERENCE



MAXIMA

$$d \sin\theta = 0, \pm\lambda, \pm 2\lambda, \ldots$$

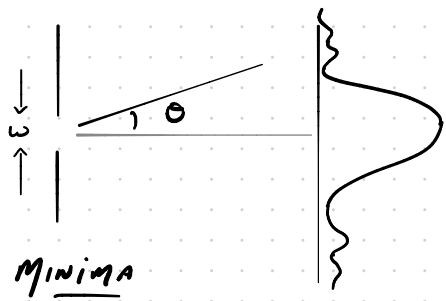
Δr "PATH LENGTH DIFFERENCE"

MINIMA

$$d \sin\theta = \pm\frac{\lambda}{2}, \pm 3\frac{\lambda}{2}, \pm 5\frac{\lambda}{2}, \ldots$$

- DIFFRACTION GRATING? # SLITS LARGE

SINGLE-SLIT DIFFRACTION

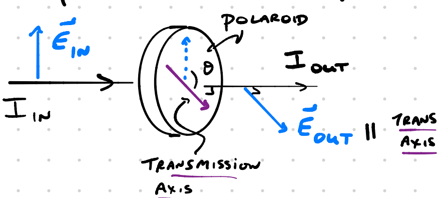


MINIMA

$$\sin\theta = \pm\frac{\lambda}{\omega}, \pm 2\frac{\lambda}{\omega}, \pm 3\frac{\lambda}{\omega}, \ldots$$

POLARIZATION

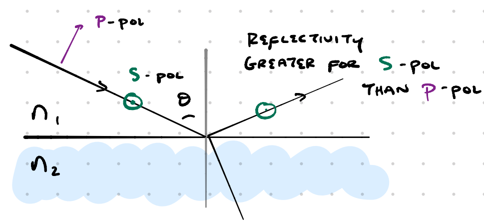
- POLARIZATION BY ABSORPTION:



$$I_{OUT} = I_{IN} \cos^2\theta$$

(MALUS' LAW)

- POLARIZATION BY REFLECTION:



BREWSTER'S ANGLE:

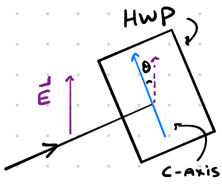
@ $\theta = \theta_B \equiv \arctan\frac{n_2}{n_1}$, P-POL REFLECTIVITY = 0

BIREFRINGENCE:

- DEPENDENCE OF INDEX OF REFRACTION ON POLARIZATION
- DOUBLE REFRACTION:

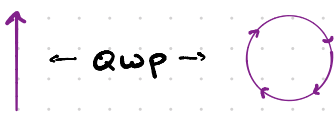
- WAVEPLATES:

HALF-WAVE PLATE: $\frac{\Delta x}{\lambda_0} \times \Delta n = \frac{1}{2}$



ROTATES POLARIZATION BY 2θ.

QUARTER WAVE PLATE: $\frac{\Delta x}{\lambda_0} \cdot \Delta n = \frac{1}{4}$



CONVERTS LINEAR POL. TO CIRCULAR, & VICE VERSA.

- OPTICAL ACTIVITY: DEPENDENCE OF INDEX OF REFRACTION ON HANDED-NESS (RIGHT OR LEFT) OF CIRCULAR POLARIZATION [I.E. "CIRCULAR BIREFRINGENCE"]
  - OPTICALLY ACTIVE MATERIALS ARE CHIRAL [$\not\!$ MIRROR SYMMETRIC] & ROTATE LINEARLY POL. LIGHT]
- DEXTRO- VS. LEVO- ROTARY.