$$B\prime = \frac{mv}{qR}$$

$$\frac{1}{2}mv^2 = eV \qquad \text{or} \qquad v = \sqrt{\frac{2eV}{m}}$$

$$\frac{E}{B} = \sqrt{\frac{2eV}{m}} \qquad \text{so} \qquad \frac{e}{m} = \frac{E^2}{2VB^2}$$

Physics 1C Equations Page 1

Fundamental Constants

$c =$ speed of light $= 3.00 \times 10^8$ ms^{-1}

$k =$ Coulomb's constant $= 8.9876 \times 10^9$ Nm$^2 C^{-2}$

$\epsilon_o =$ permittivity of free space $= 8.85 \times 10^{-12}$ N^{-1}C$^2 m^{-2}$ (m/F)

$\mu_o =$ permeability of free space $= 4\pi \times 10^{-7}$ H/m

Chapter 27

$\vec{F} = q\vec{v} \times \vec{B} =$ magnetic force on charged particle

$\vec{F} = I\vec{l} \times \vec{B}$ magnetic force on a conductor

$||F|| = ||q||vBsin(\phi) =$ magnitude of Magnetic Force

$\otimes =$ into page

$\odot =$ out of page

$\tau = IBAsin(\phi) =$ magnitude of magnetic torque

$\vec{\tau} = \vec{\mu} \times \vec{B} =$ magnetic torque

$\vec{\mu} = IA =$ magnetic dipole moment

$U = -\vec{\mu} \cdot \vec{B} = -\mu Bcos(\phi) =$ potential energy of magnetic moment

Chapter 28

Magnetic Fields

$\vec{B} = \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\hat{r}}{r^2} =$ magnetic field due to a point charge with constant velocity

$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l}\times\hat{r}}{r^2} =$ magnetic field due to an infinitesimal current element (Biot Savart)

$B = \frac{\mu_0 I}{2\pi r}$ magnetic field near a long straight current carrying conductor

$\frac{F}{L} = \frac{\mu_0 II'}{2\pi r}$ force between two long straight parallel current carrying conductors

$\oint \vec{B}\cdot d\vec{A} = 0$ magnetic flux through any closed surface

B fields

$B = \frac{\mu_0 I}{2\pi r}$ magnetic field distance r from conductor

$B = \mu_0 nI$ Inside a solenoid, closely wound with n turns per unit length

$B = 0$ outside a solenoid

Chapter 29 Part A

Faraday Induction

$\Phi_B = \int \vec{B} \cdot d\vec{A} = \int B \, dA \, cos(\phi)$

$\mathcal{E} = \frac{-d\Phi_B}{dt}$

Motional EMF

$\mathcal{E} = vBL$ where v is conductor speed, L is length and B is the magnitude of the uniform magnetic field

$\mathcal{E} = \oint(\vec{v} \times \vec{B}) \cdot d\vec{l}$

Chapter 29 Part B

Lenz's Law

The direction of any magnetic induction effect is such as to oppose the cause of the effect.

induced Electric Fields

$\mathcal{E} = \oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$

Displacement Current

$i_D = \epsilon\frac{d\Phi_E}{dt}$ displacement current

Maxwell's equations

$\oint \vec{E} \cdot d\vec{a} = \frac{Q_{encl}}{\epsilon_0}$

$\oint \vec{B}\cdot d\vec{A} = 0$ magnetic flux through any closed surface

$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$ Faraday's Law

$\oint \vec{B} \cdot d\vec{l} = \mu_0(i_C + \epsilon_0\frac{d\Phi_E}{dt})_{encl}$ Ampere's Law including Displacement Current

Magnetic force per unit length between two long, straight, parallel, current-carrying conductors

Magnetic constant

Current in first conductor

$$\frac{F}{L} = \frac{\mu_0 I I'}{2\pi r}$$

Current in second conductor

Distance between conductors

Magnetic field on axis of a circular current-carrying loop

Magnetic constant

Current

$$B_x = \frac{\mu_0 I a^2}{2(x^2 + a^2)^{3/2}}$$

Radius of loop

Distance along axis from center of loop to field point

Magnetic field at center of N circular current-carrying loops

Magnetic constant

Number of loops

Current

$$B_x = \frac{\mu_0 N I}{2a}$$

Radius of loop

Ampere's law:

$$\overbrace{\oint}^{\text{Line integral around a closed path}} \underbrace{\vec{B} \cdot d\vec{l}}_{\text{Scalar product of magnetic field and vector segment of path}} = \mu_0 I_{\text{encl}}$$

Magnetic constant

Net current enclosed by path

Faraday's law:

The induced emf in a closed loop ...

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

... equals the negative of the time rate of change of magnetic flux through the loop.

Motional emf, conductor length and velocity perpendicular to uniform $\vec{B}$

$$\mathcal{E} = vBL$$

Conductor speed

Conductor length

Magnitude of uniform magnetic field

Line integral over all elements of **closed conducting loop**

Motional emf, general case

$$\mathcal{E} = \oint (\vec{v} \times \vec{B}) \cdot d\vec{l}$$

Length vector of conductor element

Velocity of conductor element

Magnetic field at position of element

Line integral of electric field around path

Faraday's law for a stationary integration path:

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

Negative of the time rate of change of magnetic flux through path

Displacement current through an area

$$i_D = \epsilon \frac{d\Phi_E}{dt}$$

Time rate of change of electric flux through area

Permittivity of material in area

Flux of electric field through a closed surface

Gauss's law for $\vec{E}$:

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{encl}}}{\epsilon_0}$$

Charge enclosed by surface

Electric constant

Flux of magnetic field through any closed surface ...

Gauss's law for $\vec{B}$:

$$\oint \vec{B} \cdot d\vec{A} = 0$$

... equals zero.

Line integral of electric field around path

Faraday's law for a stationary integration path:

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

Negative of the time rate of change of magnetic flux through path

Magnetic force on a moving charged particle

Particle's charge

$$\vec{F} = q\vec{v} \times \vec{B}$$

Magnetic field

Particle's velocity

Magnitude of magnetic field $\vec{B}$

Component of $\vec{B}$ perpendicular to surface

Magnetic flux through a surface

$$\Phi_B = \int B\cos\phi \, dA = \int B_{\perp} \, dA = \int \vec{B} \cdot d\vec{A}$$

Angle between $\vec{B}$ and normal to surface

Element of surface area

Vector element of surface area

Gauss's law for magnetism:

The total magnetic flux through *any* **closed surface** ...

$$\oint \vec{B} \cdot d\vec{A} = 0$$

... equals zero.

Radius of a circular orbit in a magnetic field

Particle's mass

Particle's speed

$$R = \frac{mv}{|q|B}$$

Magnetic-field magnitude

Particle's charge

Magnetic force on a straight wire segment

Current

$$\vec{F} = I\vec{l} \times \vec{B}$$

Magnetic field

Vector length of segment (points in current direction)

Magnetic force on an infinitesimal wire segment

Current

$$d\vec{F} = I \, d\vec{l} \times \vec{B}$$

Magnetic field

Vector length of segment (points in current direction)

Vector magnetic torque on a current loop

Magnetic dipole moment

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

Magnetic field

$$\mu = IA$$

Potential energy for a magnetic dipole in a magnetic field

Magnetic dipole moment

$$U = -\vec{\mu} \cdot \vec{B} = -\mu B \cos\phi$$

Angle between $\vec{\mu}$ and $\vec{B}$

Magnetic field

Hall effect:

Concentration of mobile charge carriers

Current density

$$nq = \frac{-J_x B_y}{E_z}$$

Magnetic field

Charge per carrier

Electrostatic field in conductor

Magnetic field due to a point charge with constant velocity

Magnetic constant

Charge

Velocity

Unit vector from point charge toward where field is measured

$$\vec{B} = \frac{\mu_0}{4\pi} \frac{q\vec{v} \times \hat{r}}{r^2}$$

Distance from point charge to where field is measured

Magnetic field due to an infinitesimal current element

Magnetic constant

Current

Vector length of element (points in current direction)

Unit vector from element toward where field is measured

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I \, d\vec{l} \times \hat{r}}{r^2}$$

Distance from element to where field is measured

Magnetic field near a long, straight, current-carrying conductor

Magnetic constant

Current

$$B = \frac{\mu_0 I}{2\pi r}$$

Distance from conductor

Physics 1C Equations Page 2

Chapter 30 Part A

Mutually Induced EMFS

$\mathcal{E}_1 = -M\frac{di_2}{dt}$ Induced EMF in coil 1

$\mathcal{E}_2 = -M\frac{di_1}{dt}$ Induced EMF in coil 2

Mutual Inductance

$M_{21} = \frac{N_2\Phi_{B2}}{i_1}$

a change in current i_1 in coil 1 induces an emf in coil 2 proportional to rate of change of i_1

$M = \frac{N_2\Phi_{B2}}{i_1} = \frac{N_1\Phi_{B1}}{i_2}$

Self Inductance

$\mathcal{E} = -L\frac{di}{dt}$

The self induced emf in a circuit is proportional to the inductance of the circuit multipled by the rate of change of current in the circuit.

$L = \frac{N\Phi_B}{i}$

The self inductance of a coil is defined to be the number of turns in the coil, multiplied by the flux due to current through each turn, divided by the current in the coil

Chapter 30 Part B

Magnetic Field Energy

$U_L = \frac{1}{2}LI(t)^2$

An inductor with inductance L carrying current I has an energy U associated with the inductor's magnetic field. The magnetic energy desnity u (energy per unit volume) is proportional to the square of the magnetic field magnitude

$u = \frac{B^2}{2\mu_0}$
(in a vacuum)
$U_C = \frac{1}{2}\frac{Q^2}{C}$

$V = IR$ Always True in General
$P = IV$
$P = I^2R$

LC circuits

$\omega = \sqrt{\frac{1}{LC}}$
A circuit that contains inductance L and capacitance C undergoes electrical oscillations with angular frequency ω that depends on L and C

$\omega' = \sqrt{\frac{1}{LC} - \frac{r^2}{4L^2}}$
A circuit containing inductance, resistance and capacitance undergoes oscillations that are damped with frequency ω'

Chapter 31

AC current

$i = Icos(\omega t)$

$I_{rms} = \frac{I}{\sqrt{2}}$

$V_{rms} = \frac{V}{\sqrt{2}}$

AC Circuits

$V_R = V_Rcos(\omega t)$
Amplitude of Voltage across a resistor

$V_L = IX_L$
Amplitude of Voltage across an inductor where $X_L = \omega L$
L leads current by 90 deg = $(\phi + 90\,\text{deg})$
$V_C = IX_C$
Amplitude of Voltage across a capacitor where $X_C = \frac{1}{\omega C}$

C lags current by 90 deg = $(\phi - 90\,\text{deg})$

Impedance and the LRC series circuit

$V = IZ$

In a general AC circuit, the voltage and current amplitudes are related by the circuit impedance Z. In an LRC series, the values of these and the angular frequency ω determine Z and the phase angle of the voltage relative to the current.

$Z = \sqrt{R^2 + [\omega L - \frac{1}{\omega C}]^2}$

$tan(\phi) = \frac{\omega L - \frac{1}{\omega C}}{R}$

Ampere's law for a stationary integration path:

Line integral of magnetic field around path; Electric constant; Time rate of change of electric flux through path

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \left(i_C + \epsilon_0 \frac{d\Phi_E}{dt} \right)_{\text{encl}}$$

Magnetic constant; Conduction current through path; Displacement current through path

Mutually induced emfs:

Induced emf in coil 2; Rate of change of current in coil 1; Induced emf in coil 1; Rate of change of current in coil 2

$$\mathcal{E}_2 = -M \frac{di_1}{dt} \quad \text{and} \quad \mathcal{E}_1 = -M \frac{di_2}{dt}$$

Mutual inductance of coils 1 and 2

Turns in coil 2; Magnetic flux through each turn of coil 2; Turns in coil 1; Magnetic flux through each turn of coil 1

Mutual inductance of coils 1 and 2

$$M = \frac{N_2 \Phi_{B2}}{i_1} = \frac{N_1 \Phi_{B1}}{i_2}$$

Current in coil 1 (causes flux through coil 2); Current in coil 2 (causes flux through coil 1)

Number of turns in coil

Self-inductance (or **inductance**) of a coil

$$L = \frac{N \Phi_B}{i}$$

Flux due to current through each turn of coil; Current in coil

Inductance of circuit

Self-induced emf in a circuit

$$\mathcal{E} = -L \frac{di}{dt}$$

Rate of change of current in circuit

Inductance

Energy stored in an inductor

$$U = L \int_0^I i \, di = \tfrac{1}{2} L I^2$$

Final current

Integral from initial (zero) value of instantaneous current to final value

Magnetic energy density in vacuum

$$u = \frac{B^2}{2\mu_0}$$

Magnetic-field magnitude; Magnetic constant

Magnetic energy density in a material

$$u = \frac{B^2}{2\mu}$$

Magnetic-field magnitude; Permeability of material

Time constant for an *R*-*L* circuit

$$\tau = \frac{L}{R}$$

Inductance; Resistance

Angular frequency of oscillation in an *L*-*C* circuit

$$\omega = \sqrt{\frac{1}{LC}}$$

Capacitance; Inductance

$$i = \frac{\varepsilon}{R}\left(1 - e^{-(R/L)t}\right) \quad \text{(current in an } R - L \text{ circuit with emf)}$$

Mass-Spring System

Kinetic energy $= \frac{1}{2} m v_x^2$

Potential energy $= \frac{1}{2} k x^2$

$\frac{1}{2} m v_x^2 + \frac{1}{2} k x^2 = \frac{1}{2} k A^2$

$v_x = \pm \sqrt{k/m}\sqrt{A^2 - x^2}$

$v_x = dx/dt$

$\omega = \sqrt{\frac{k}{m}}$

$x = A\cos(\omega t + \phi)$

Inductor-Capacitor Circuit

Magnetic energy $= \frac{1}{2} L i^2$

Electrical energy $= q^2/2C$

$\frac{1}{2} L i^2 + q^2/2C = Q^2/2C$

$i = \pm \sqrt{1/LC}\sqrt{Q^2 - q^2}$

$i = dq/dt$

$\omega = \sqrt{\frac{1}{LC}}$

$q = Q\cos(\omega t + \phi)$

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Chapter 32

Maxwell's equations

$\oint \vec{E} \cdot d\vec{a} = \frac{Q_{encl}}{\epsilon_0}$

$\oint \vec{B} \cdot d\vec{A} = 0$ magnetic flux through any closed surface

$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$ Faraday's Law

$\oint \vec{B} \cdot d\vec{l} = \mu_0(i_C + \epsilon_0 \frac{d\Phi_E}{dt})_{encl}$ Ampere's Law including Displacement Current

Field Magnitudes

$E = cB$ Electric Field Magnitude in terms of Magnetic Field Magnitude

$B = \epsilon_0\mu_0 cE$ Electromagnetic wave in a vacuum

Speed of light

$c = \frac{1}{\sqrt{\epsilon_0\mu_0}}$

Sinusoidal Electromagnetic Waves

$\overrightarrow{E}(x,t) = \hat{j}E_{max}cos(kx - \omega t)$ For a wave traveling in the + x direction

If the wave is traveling in - x direction, replace $kx - \omega t$ by $kx + \omega t$.

If wave is traveling in y or z direction, use the right hand rule to find the direction of the $E_{max}cos(kx - \omega t)$ vector.

Chapter 32 Part B

Sinusoidal Electromagnetic Waves

$\overrightarrow{B}(x,t) = \hat{k}B_{max}cos(kx - \omega t)$ For a wave traveling in the + x direction

If the wave is traveling in - x direction, replace $kx - \omega t$ by $kx + \omega t$.

If wave is traveling in y or z direction, use the right hand rule to find the direction of the $B_{max}cos(kx - \omega t)$ vector.
$E_{max} = cB_{max}$

Poynting Vector

$\overrightarrow{S} = \frac{1}{\mu_0}\overrightarrow{E} \times \overrightarrow{B}$

$I = S_{av} = \frac{E_{max}B_{max}}{2\mu_0} = \frac{E_{max}^2}{2\mu_0 c} = \frac{1}{2}\sqrt{\frac{\epsilon_0}{\mu_0}}E_{max}^2 = \frac{1}{2}\epsilon_0 cE_{max}^2$

Radiation Pressure

$\frac{1}{A}\frac{dp}{dt} = \frac{S}{c} = \frac{EB}{\mu_0 c}$ flow rate of electromagnetic momentum

$p_{rad} = \frac{I}{c}$ for a perfect absorber

$p_{rad} = \frac{2I}{c}$ for a perfect reflector

Chapter 37

Time dilation

$\Delta t = \frac{\Delta t_0}{\sqrt{1 - \frac{u^2}{c^2}}}$

Length contraction

$l = l_0\sqrt{1 - \frac{u^2}{c^2}}$

Lorentz Transformations

For observers where the relative velocity difference is along the x axis

$x' = \frac{x - ut}{\sqrt{1 - \frac{u^2}{c^2}}}$

$y' = y$

$z' = z$

$t' = \frac{t - \frac{ux}{c^2}}{\sqrt{1 - \frac{u^2}{c^2}}}$

For observers where the relative velocity difference is along the x axis

$v_x' = \frac{v_x - u}{1 - \frac{uv_x}{c^2}}$

$v_x = \frac{v_x' + u}{1 + \frac{uv_x'}{c^2}}$

Angular frequency of underdamped oscillations in an *L-R-C* series circuit

$$\omega' = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$

Resistance

Inductance

Inductance

Capacitance

Sinusoidal alternating current:

Instantaneous current

Angular frequency

$$i = I\cos\omega t$$

Time

Current amplitude (maximum current)

Rectified average value of a sinusoidal current

$$I_{\text{rav}} = \frac{2}{\pi}I = 0.637I$$

Current amplitude

Root-mean-square (rms) value of a sinusoidal current

$$I_{\text{rms}} = \frac{I}{\sqrt{2}}$$

Current amplitude

Root-mean-square (rms) value of a sinusoidal voltage

$$V_{\text{rms}} = \frac{V}{\sqrt{2}}$$

Voltage amplitude (maximum value)

Amplitude of voltage across a resistor, ac circuit

$$V_R = IR$$

Current amplitude

Resistance

Amplitude of voltage across an inductor, ac circuit

$$V_L = IX_L$$

Current amplitude

Inductive reactance

Amplitude of voltage across a capacitor, ac circuit

$$V_C = IX_C$$

Current amplitude

Capacitive reactance

Circuit Element	Amplitude Relationship	Circuit Quantity	Phase of v
Resistor	$V_R = IR$	R	In phase with i
Inductor	$V_L = IX_L$	$X_L = \omega L$	Leads i by 90°
Capacitor	$V_C = IX_C$	$X_C = 1/\omega C$	Lags i by 90°

Amplitude of voltage across an ac circuit

$$V = IZ$$

Current amplitude

Impedance of circuit

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Resistance Inductance Capacitance

Impedance of an *L-R-C* series circuit

$$Z = \sqrt{R^2 + [\omega L - (1/\omega C)]^2}$$

Angular frequency

Inductance

Phase angle of voltage with respect to current in an *L-R-C* series circuit

$$\tan\phi = \frac{\omega L - 1/\omega C}{R}$$

Capacitance

Resistance

Phase angle of voltage with respect to current

Average power into a general ac circuit

$$P_{\text{av}} = \tfrac{1}{2}VI\cos\phi = V_{\text{rms}}I_{\text{rms}}\cos\phi$$

Voltage amplitude

Current amplitude

rms voltage

rms current

Resonance angular frequency of an *L-R-C* series circuit

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

Inductance

Capacitance