

PHYS 212

Review 3

Exam 3
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Exam 3 Overview

18) RL Circuits

19) LC Circuits

20) AC Circuits

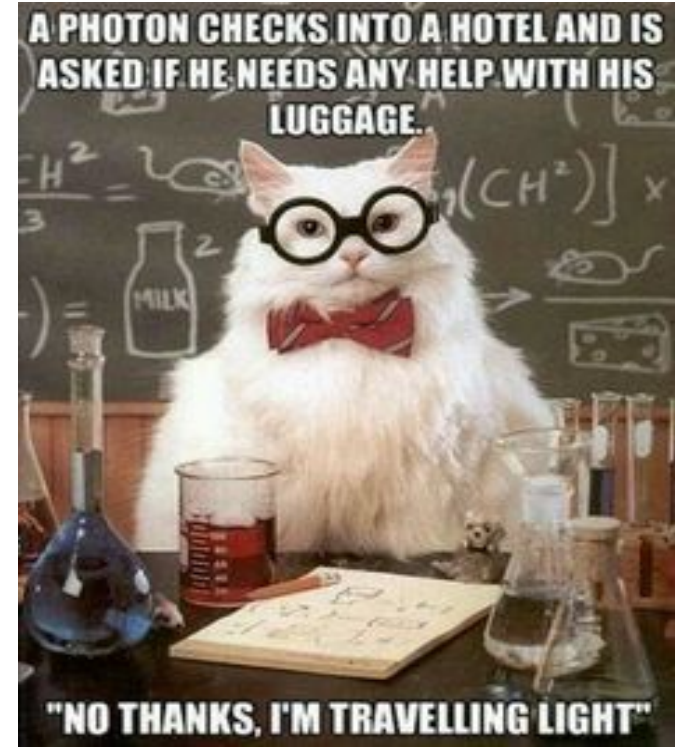
21) AC Power and Resonance

22) Maxwell's Displacement Current

23) EM Waves

24) Polarization

25) Refraction



RL Circuits

Inductors behave “oppositely” to capacitors (i.e. at $t=0$ and $t=\infty$ when charging up)

Inductors in circuits add in series and in parallel like resistors

$$L \equiv \frac{\Phi_B}{I}$$

Inductance: L = magnetic flux / current

Time constant: $\tau = L / R$

$$\tau = \frac{L}{R} \quad V = L \frac{dI}{dt}$$

Charging and Discharging Equations

$$I(t) = I(\infty) \left(1 - e^{-t/\tau} \right) \quad I(t) = I(0) e^{-t/\tau}$$

RL Circuits cont.

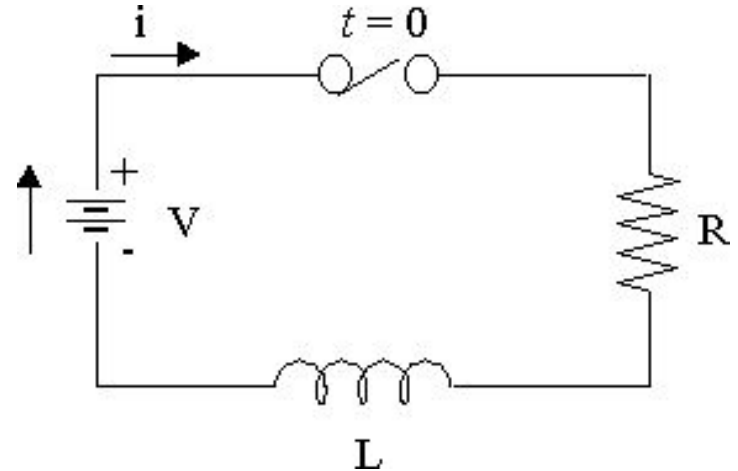
Charging

$t = 0 \rightarrow$ inductor acts like an open circuit

- $I = 0$ A, but there is a voltage

$t = \infty \rightarrow$ inductor acts like a wire (short circuit)

- $V = 0$ V, but there is a current



Discharging

$t = 0 \rightarrow$ inductor acts like a current source (I at $t = 0$ is the same as I at $t = \infty$ found when charging up)

$t = \infty \rightarrow$ inductor acts like a wire (no more current in the circuit)

LC Circuits

Inductors and capacitors are storage devices so their energies are constantly oscillating between one another (given an initial voltage/current)

Total Potential Energy: $U_{\text{total}} = U_{\text{inductor}} + U_{\text{capacitor}} = 0.5LI^2 + 0.5CV^2$

Resonance only occurs at the natural frequency: ω_0

Natural Frequency

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

$$U = \frac{1}{2}LI^2 \quad U = \frac{1}{2}CV^2$$

AC Circuits (RLC)

Resistor is in phase with the current

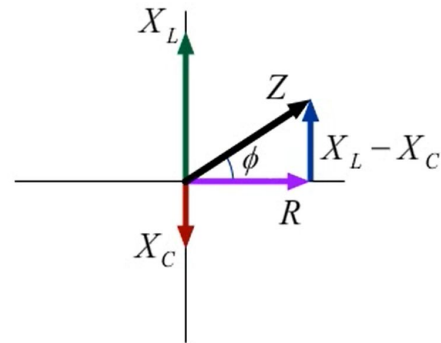
Inductor leads current by 90 degrees

Capacitor lags current by 90 degrees

Steps for AC Circuit Problems:

- 1) Find the reactances first (X_L and X_C)
- 2) Then find impedance (Z)
- 3) Now you can solve for I_m
- 4) Solve for phase of the generator
 - a) If phase is positive → generator voltage leads current
 - b) If phase is negative → generator voltage lags current

Impedance Phasor Diagram



$$\tan \phi = \frac{X_L - X_C}{R}$$

Phase

$$I_m = \frac{\mathcal{E}_m}{Z}$$

Maximum Current

Inductor Reactance $X_L = \omega L$

Capacitor Reactance $X_C = \frac{1}{\omega C}$

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

Average Power and Resonance

Resonance occurs when $\omega = \omega_0$

This makes $X_L = X_C$ thus $Z = R \Rightarrow$ this is when I_m is at its maximum value

$$\langle P_{\text{Generator}} \rangle = \mathcal{E}_{\text{rms}} I_{\text{rms}} \cos \phi$$

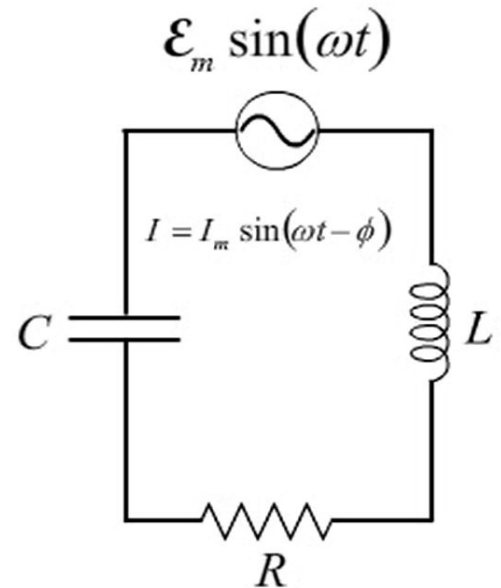
Root Mean Square (rms)

$$\mathcal{E}_{\text{rms}} = \frac{\mathcal{E}_m}{\sqrt{2}} \quad \text{Voltage}$$

$$I_{\text{rms}} = \frac{I_m}{\sqrt{2}} \quad \text{Current}$$

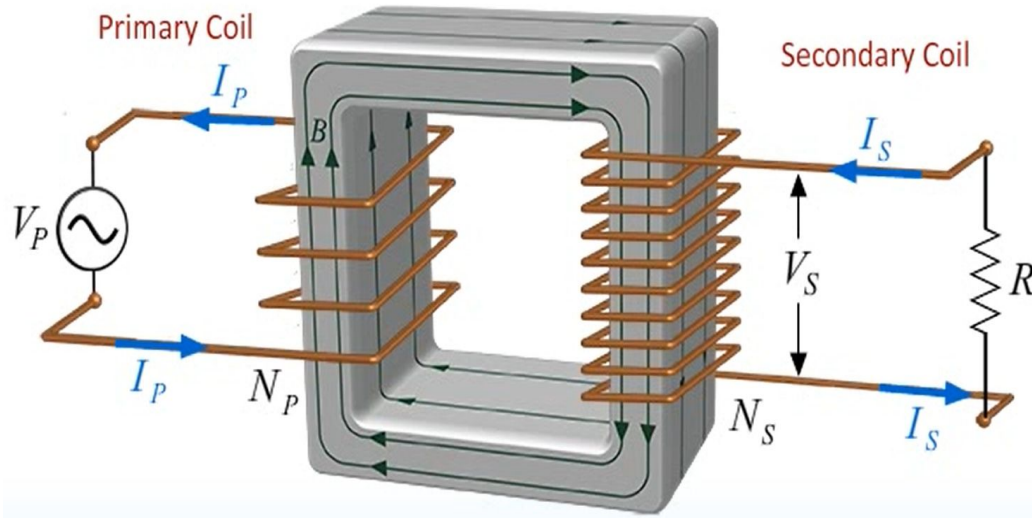
Natural Frequency

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



Transformers

Transformers are used to convert from high voltages to low voltages and vice versa



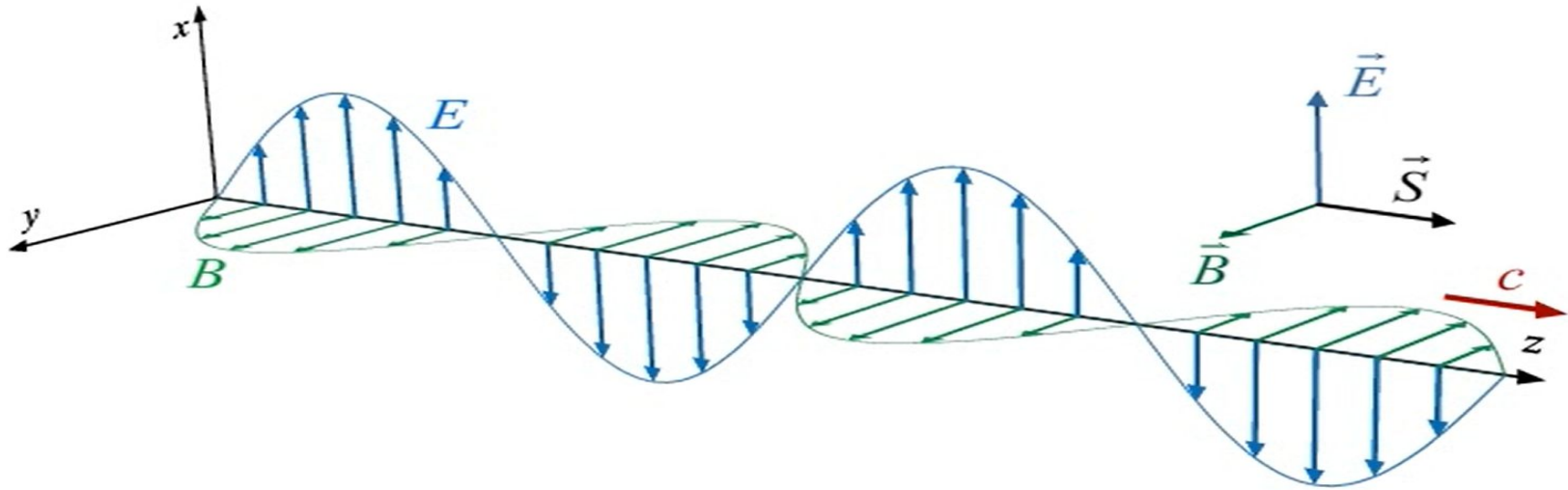
Voltage Relation

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

Current Relation

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

EM Wave Image (Remember this image!)



EM Wave Properties

$$E_x = E_o \cos(kz - \omega t)$$

E and B have the same waveform: If E is $\sin(kz - \omega t)$ then B is also $\sin(kz - \omega t)$

Magnitude of B is smaller: $B_o = E_o / c$ where c is the speed of light (3×10^8 m/s)

The “x, y, or z” variable inside the argument tells you the direction of propagation
 $\cos(kz - \omega t)$ travels in +z-direction, $\cos(kz + \omega t)$ travels in -z-direction

Wave parameters: $\omega = 2\pi f$, $v = \lambda f = \omega / k$ ($v = c$ for EM waves in free-space)

Poynting vector (S) points in the same direction the wave is traveling

$$\mathbf{S} = (\mathbf{E} \times \mathbf{B}) / \mu_o$$

Power = $\mathbf{S} \times \mathbf{A}$ (units: W) , **Intensity = Power / Area = $\mathbf{S}$** (units: W/m²)

Doppler Shift

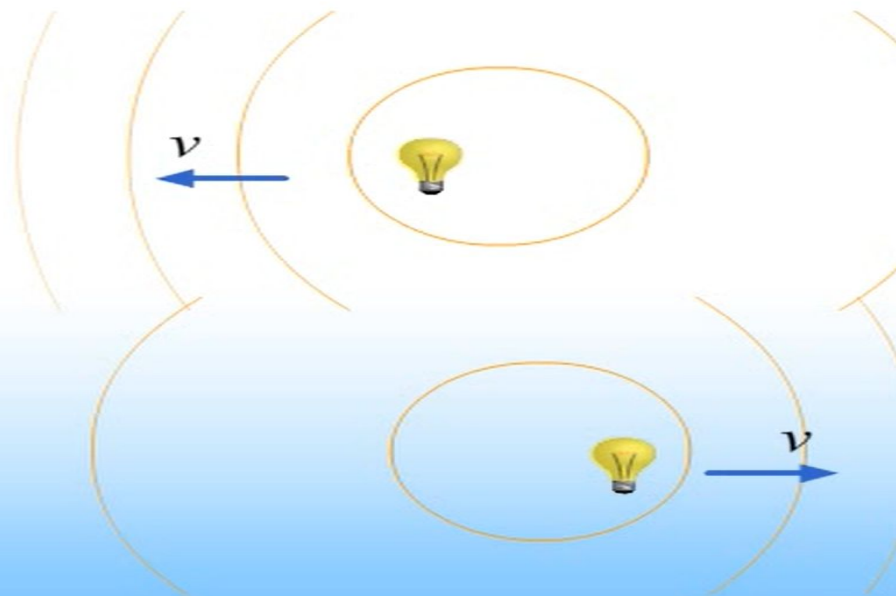
$$f' = f \sqrt{\frac{1 \pm \beta}{1 \mp \beta}} \xrightarrow{\beta \ll 1} f' \approx f(1 \pm \beta)$$

where $\beta \equiv \frac{v}{c}$

Decreasing Separation

$$f' = f \sqrt{\frac{1 + \beta}{1 - \beta}}$$

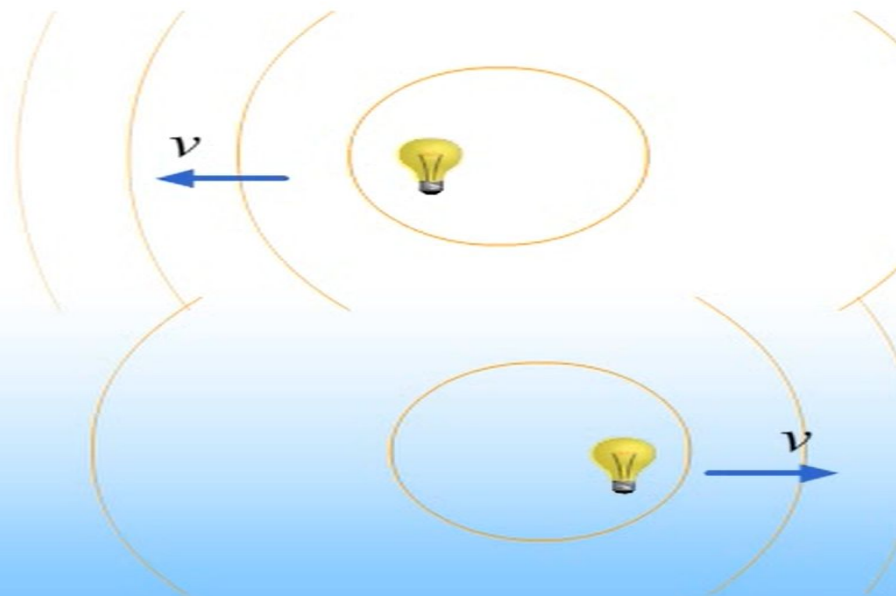
$$(f' > f)$$



Increasing Separation

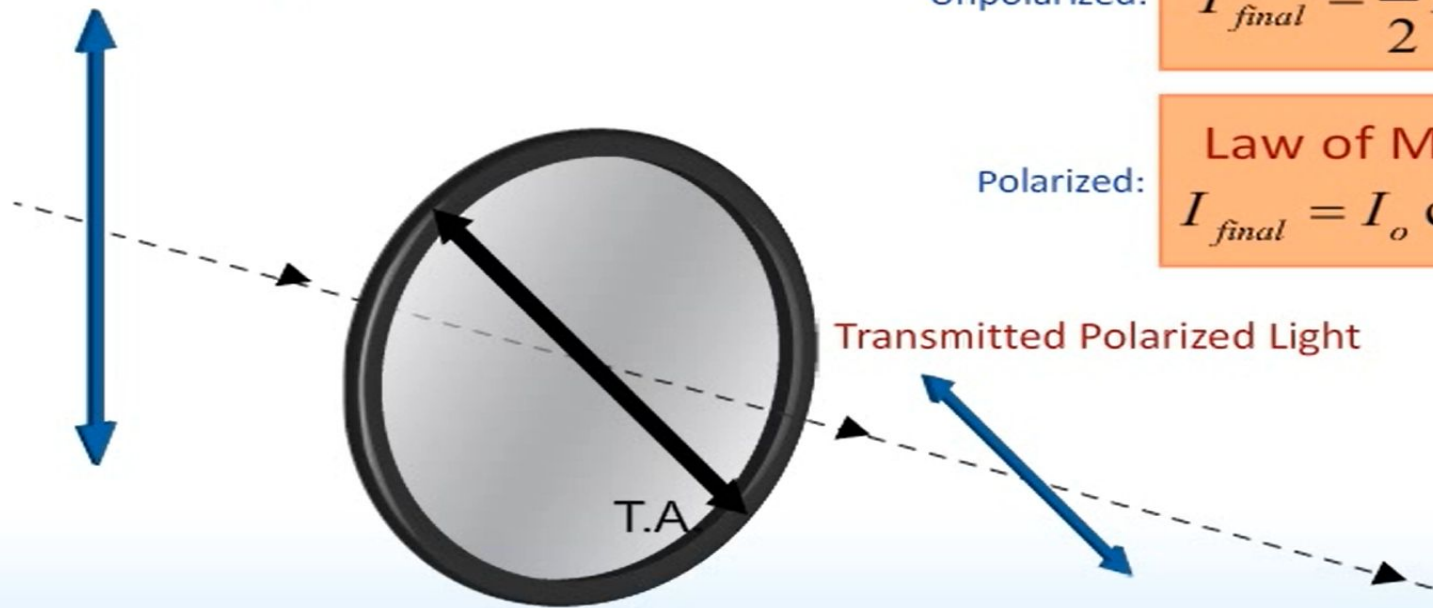
$$f' = f \sqrt{\frac{1 - \beta}{1 + \beta}}$$

$$(f' < f)$$



Linear Polarization

Incident Polarized Light



Incident Light

Unpolarized:

$$I_{final} = \frac{1}{2} I_o$$

Polarized:

Law of Malus

$$I_{final} = I_o \cos^2 \theta$$

Circular Polarization

Circular Polarization

Right-handed (RCP):

$$\phi_x - \phi_y = \frac{\pi}{2} \xrightarrow{\text{Examples}} \begin{cases} E_x = E_o \cos(kz - \omega t) \\ E_y = E_o \sin(kz - \omega t) \end{cases}$$

The diagram illustrates Right-handed Circular Polarization (RCP) in a 3D coordinate system with x, y, and z axes. The electric field vector $\mathbf{E}$ is shown as a helix along the z-axis. At the plane $z=0$, the x-component is $E_x = E_o \cos(kz)$ and the y-component is $E_y = E_o \sin(kz)$. Blue arrows represent the instantaneous direction of the electric field at various points along the helix. A red arrow labeled $\mathbf{C}$ indicates the direction of wave propagation along the positive z-axis. The helix appears to rotate in a right-handed sense as the wave travels away from the viewer.

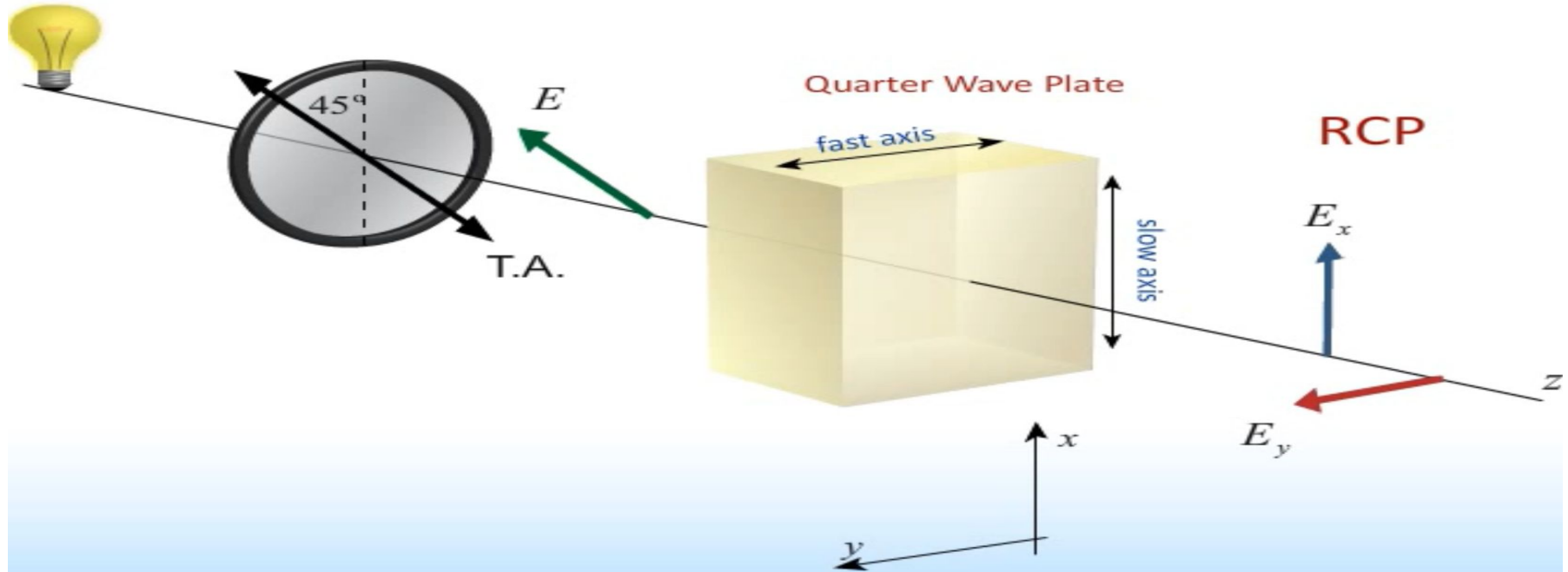
Left-handed (LCP):

$$\phi_x - \phi_y = -\frac{\pi}{2} \xrightarrow{\text{Examples}} \begin{cases} E_x = E_o \sin(kz - \omega t) \\ E_y = E_o \cos(kz - \omega t) \end{cases}$$

The diagram illustrates Left-handed Circular Polarization (LCP) in a 3D coordinate system with x, y, and z axes. The electric field vector $\mathbf{E}$ is shown as a helix along the z-axis. At the plane $z=0$, the x-component is $E_x = E_o \sin(kz)$ and the y-component is $E_y = E_o \cos(kz)$. Blue arrows represent the instantaneous direction of the electric field at various points along the helix. A red arrow labeled $\mathbf{C}$ indicates the direction of wave propagation along the positive z-axis. The helix appears to rotate in a left-handed sense as the wave travels away from the viewer.

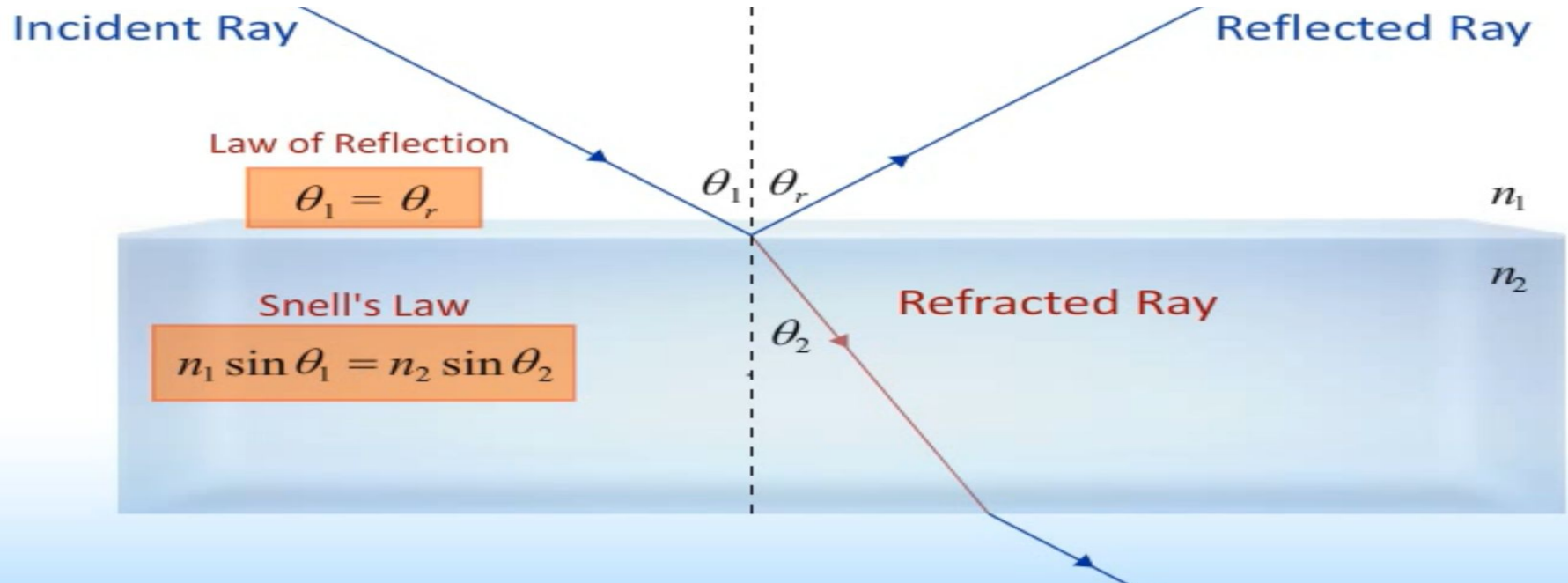
Circular Polarization cont.

- Produced by passing linear polarized light through a quarter wave plate (**only if the light isn't 100% vertically or horizontally linearly polarized beforehand**)
- If **Slow-Axis X Fast-Axis = Direction of Wave** $\rightarrow$ RCP , otherwise LCP



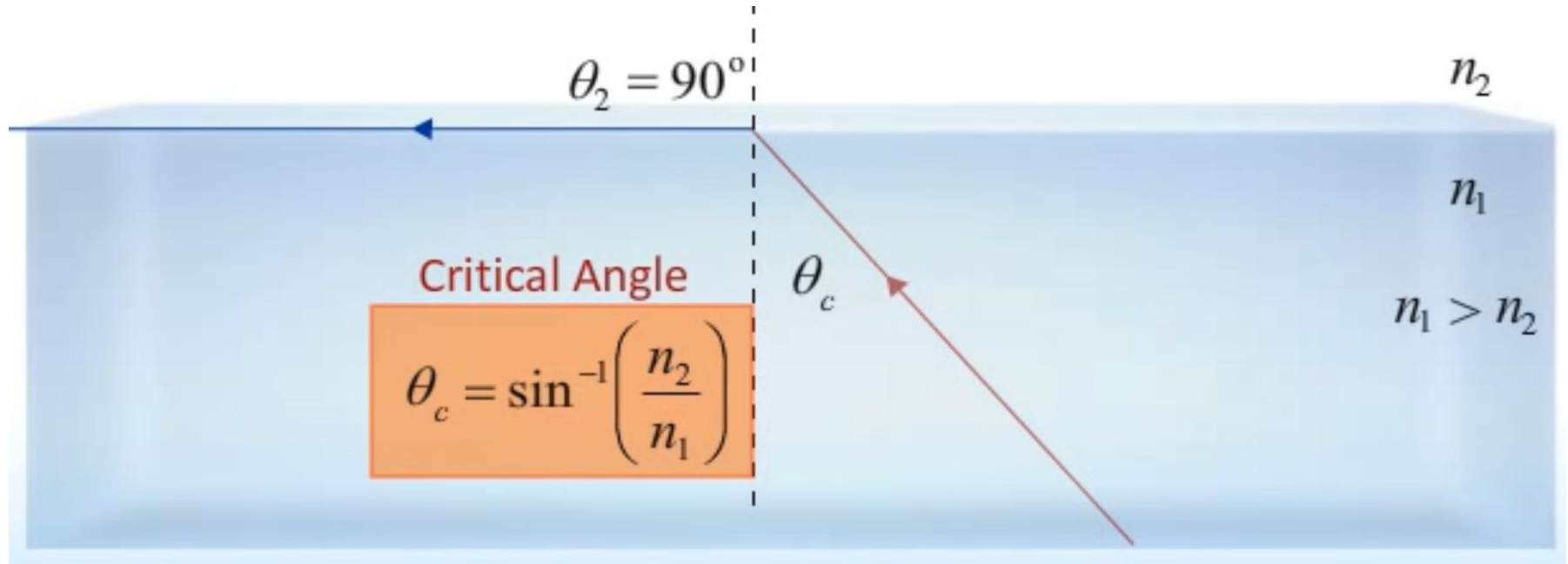
Reflection and Refraction

- **Law of Reflection** - the incident angle is equal to the reflected angle wrt the normal
- **Index of Refraction** - $n = c/v$ is material specific: for vacuum/air $n = 1$
- **Snell's Law** - used to find the angle of the refracted ray wrt the normal



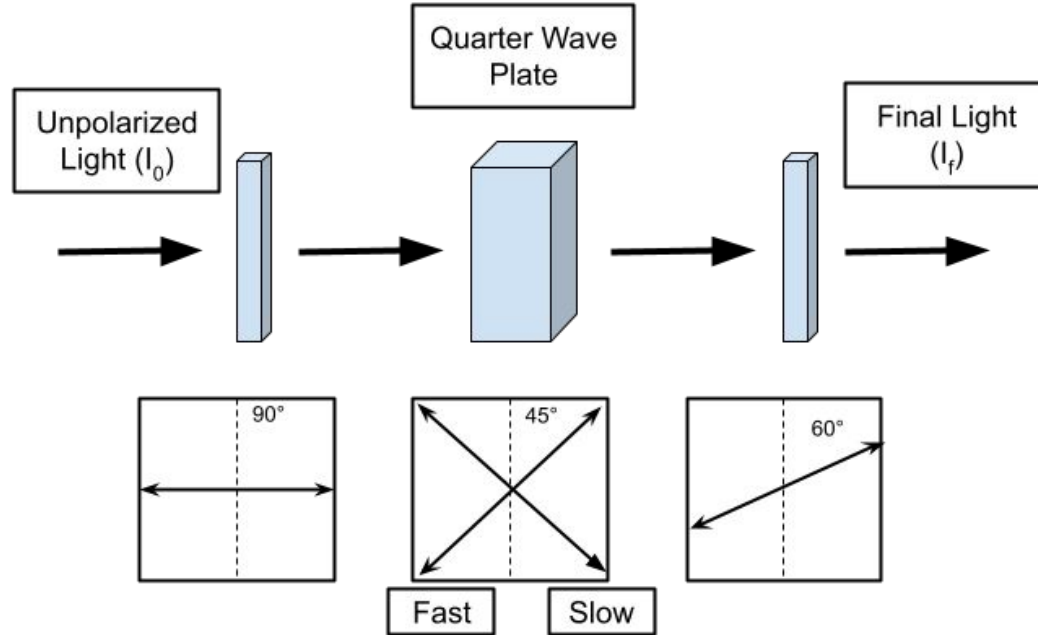
Reflection and Refraction cont.

Total Internal Reflection - only happens when rays are at the critical angle or at angles larger than the critical angle



Question Time!

Question 1

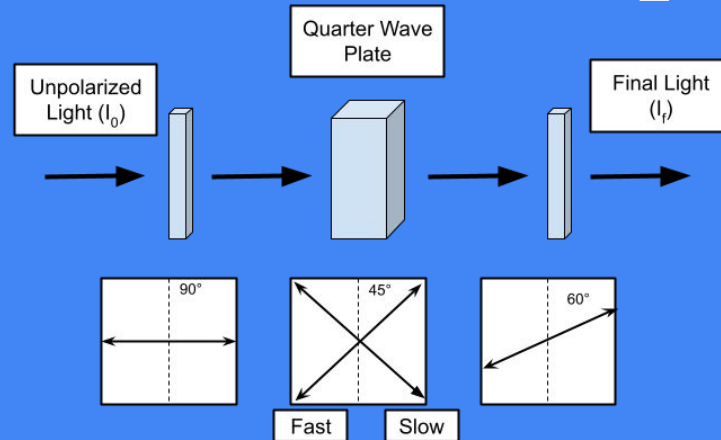


Find the Final Intensity:

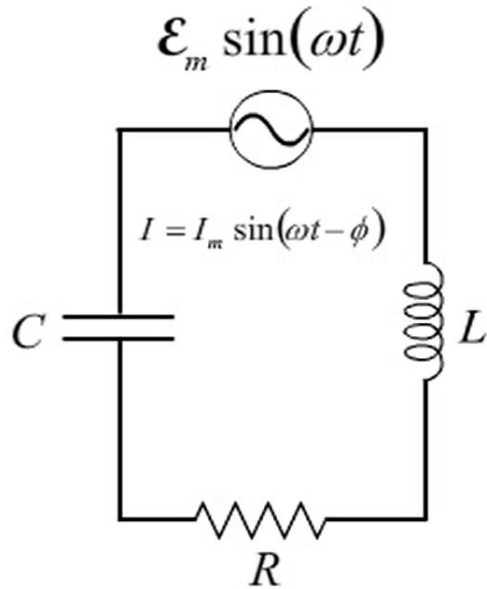
- a. $(0.5)I_0\cos^2(45)$
- b. $(0.5)I_0\cos^2(15)$
- c. $(0.25)I_0$
- d. $(0.5)I_0$
- e. $(0.5)I_0\cos^2(60)$

Answer: C

First Polarizer cuts intensity by 0.5
QWP creates circular polarization
Circularly polarized light is cut in half when incident to a polarizer



Question 2



$$\omega = 886 \text{ rad/s}$$

If the power from the resistor is at a maximum at t_1 , how much longer will it be before the power from the resistor is at a maximum again?

- a. 0.00113 seconds
- b. 0.00056 seconds
- c. 0.0071 seconds
- d. 0.0035 seconds

Answer: D

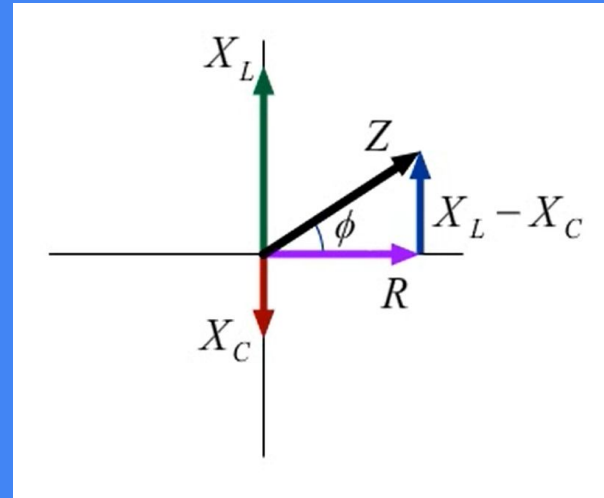
$P = IV$ or V^2/R

Voltage is maximized on x-axis

Phasor needs to make half a rotation

$2\pi(\text{rad/rotation})/886(\text{rad/s})=0.0071 \text{ s}$

Half a rotation = 0.0035 seconds



Sign into queue for worksheet!

