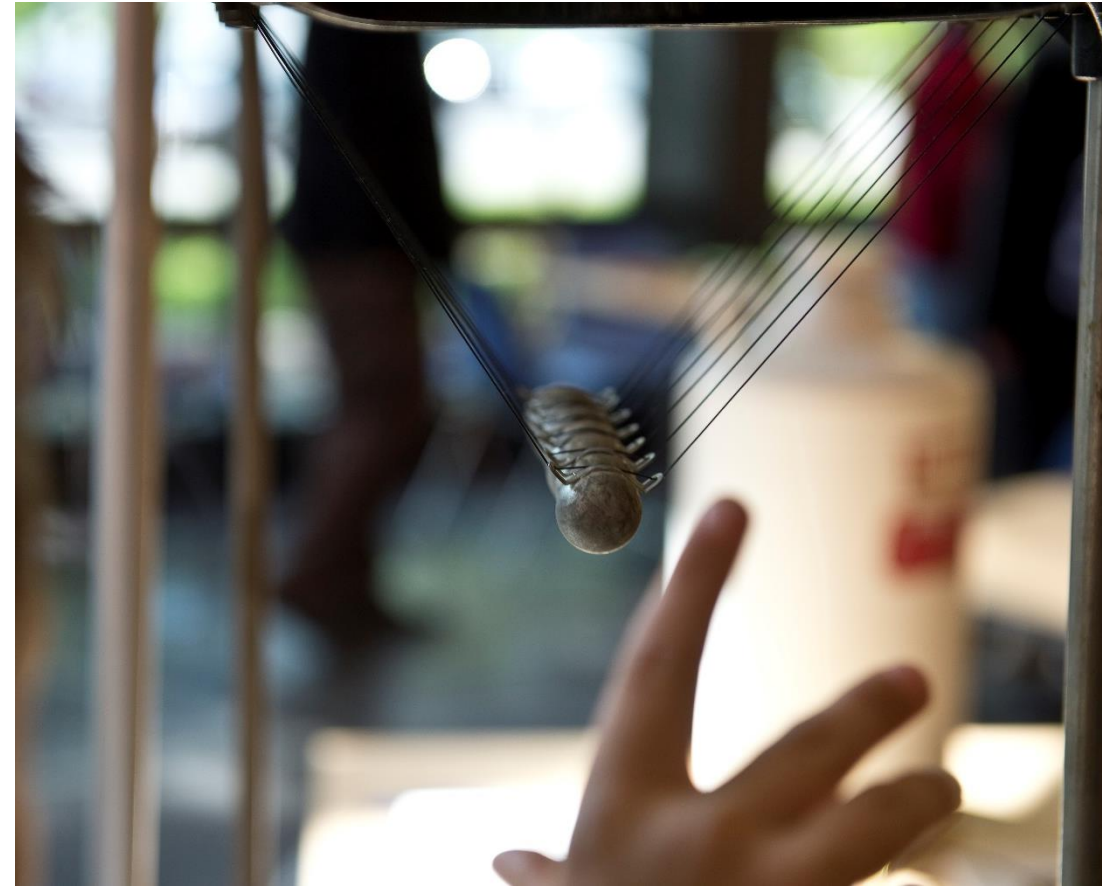


# BIOLOGICAL PHYSICS

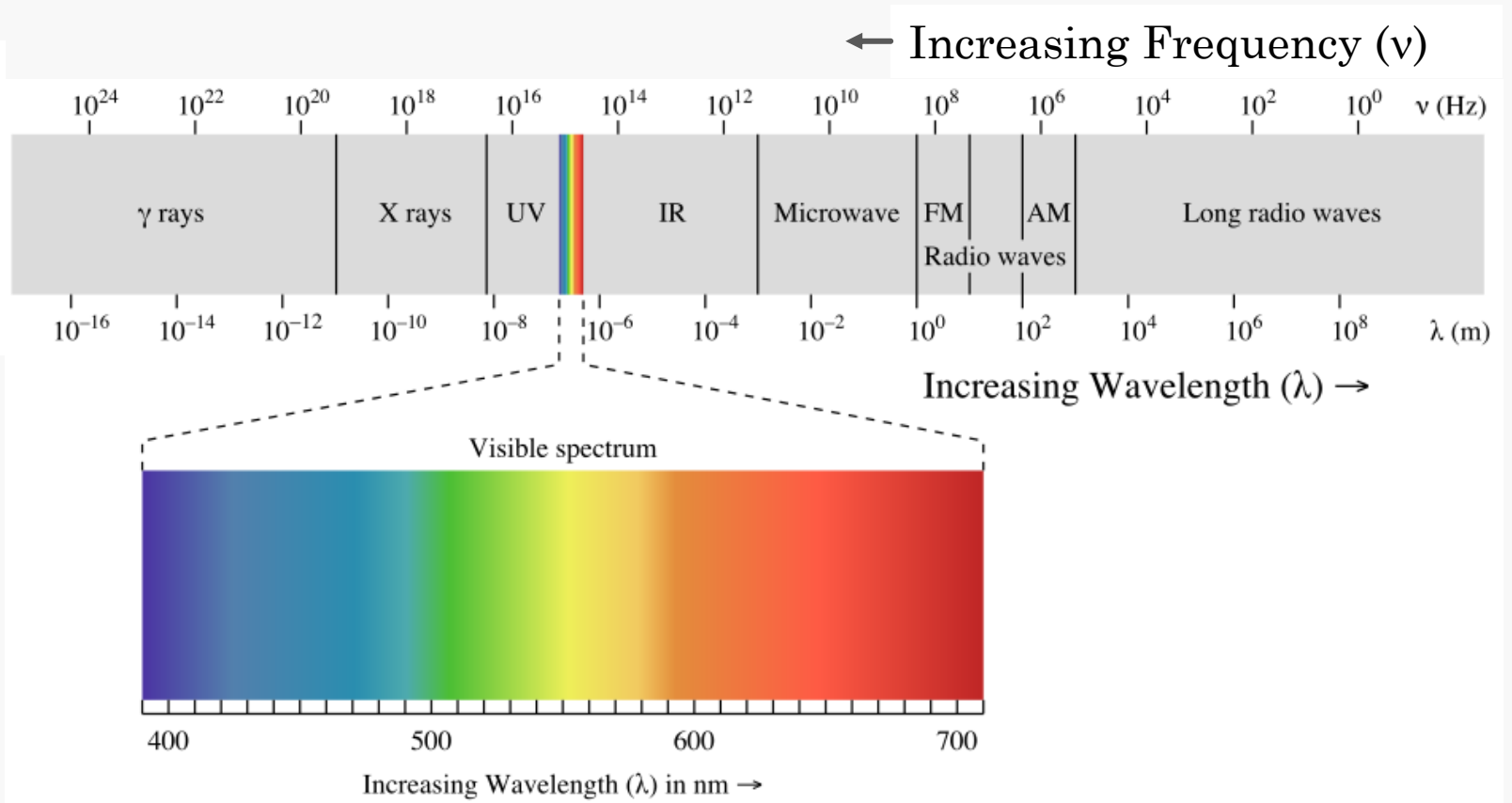
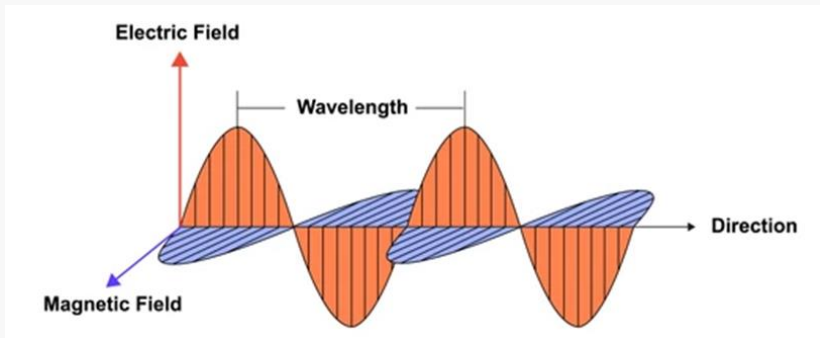
## CHAPTER 5 –INTRODUCTION TO LIGHT AND SPECTROSCOPY

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# Electromagnetic Spectrum

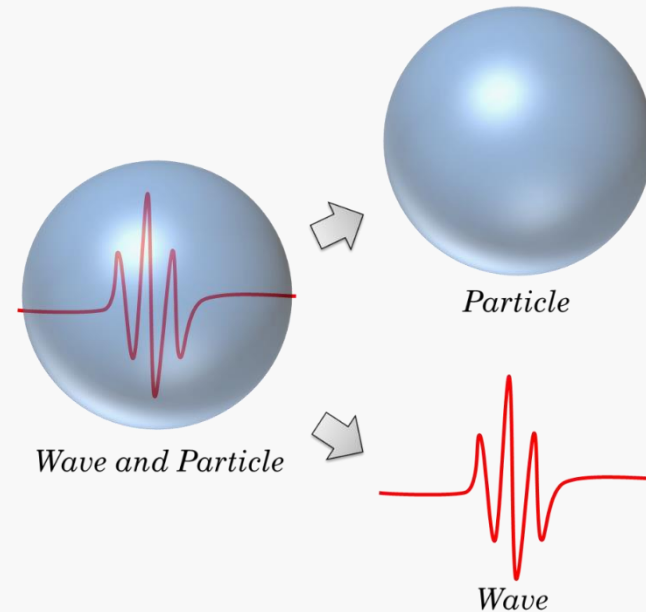
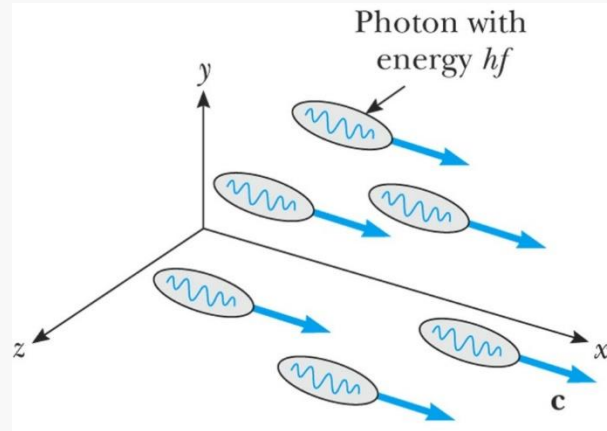
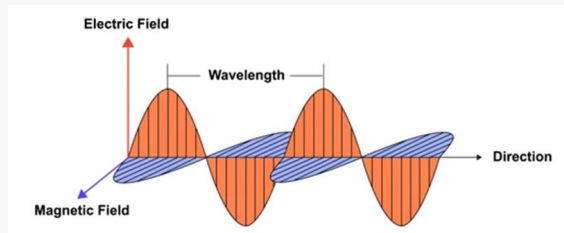
- Light is part of EM spectrum.
- Photon is a massless particle and travel like wave with speed  $c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \approx 3 \times 10^8 \text{ m/s}.$



- $\gamma$ -ray: nuclear
- X-ray: core-level electron
- UV: valence electrons
- Vis: valence electrons
- IR: molecular vibrations

# Photons: The Dual Nature of Light

- **Photon** is the smallest quantity (quantum), also known as quanta.
- **Wave-Particle Duality:** Photons exhibit a unique ability to behave like both waves and particles depending on the experimental setup.
- **Energy of a Photon:**  $E = hf = \frac{hc}{\lambda}$  (*Planck Hypothesis*).



Albert Einstein

# Particle Nature of Photon

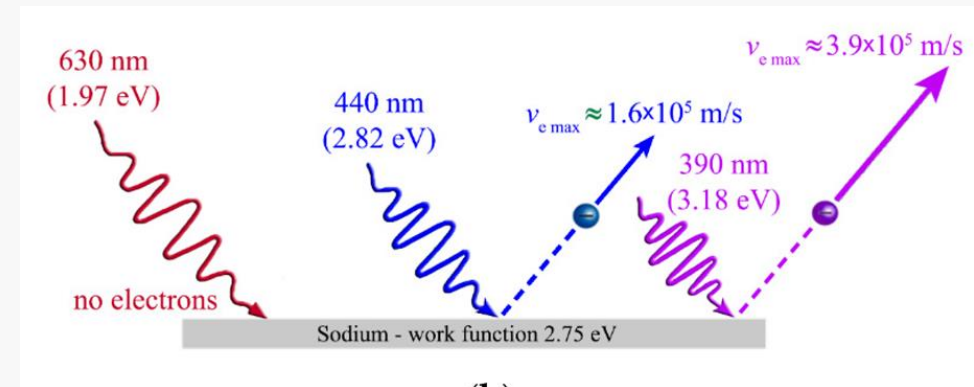
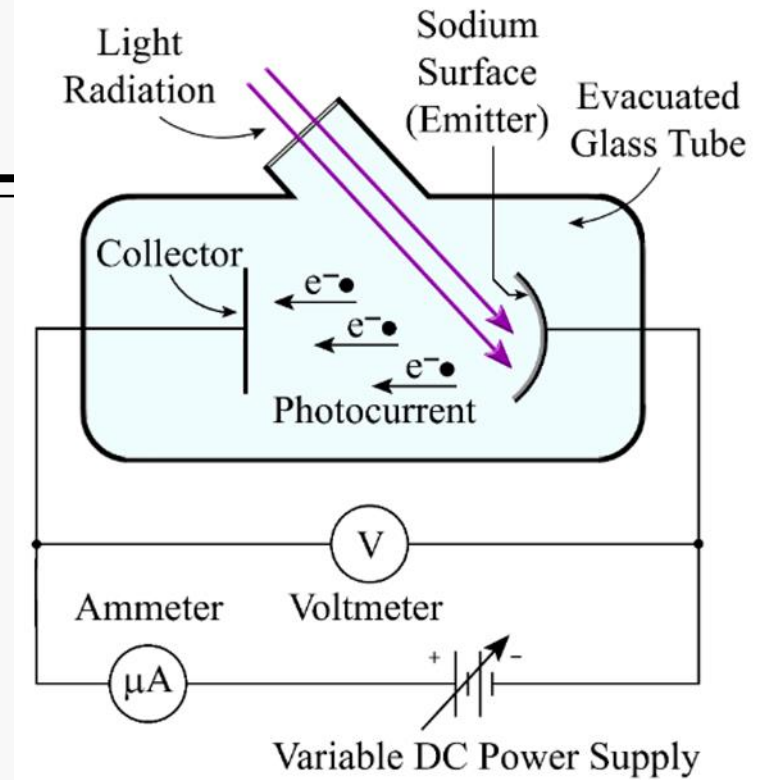
**Photoelectric effect experiment** is an evidence of particle nature of light in which electrons are emitted from metal surface when UV light shines on metal surface.

- i. Electron energy is independent of intensity radiation (larger amplitude waves).
- ii. Energy of electron depend on the wavelength of light but not on amplitude of the wave.

Albert Einstein proposed that energy of light is quantized. And the kinetic energy of electron can be expressed as:

$$K_e = hf - \phi$$

Where  $K_e$  is the kinetic energy of an escaping electron, and  $\phi$  is work function of material.



# Particles

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In special relativity predict that for particles:

➤ **Energy**  $E = \gamma m_0 c^2 = K.E + m_0 c^2 = \sqrt{p^2 c^2 + m_0^2 c^4}$

➤ **Momentum**  $p = \frac{\sqrt{E^2 - m_0^2 c^4}}{c}$

➤ **Wavelength**  $\lambda = \frac{h}{p} = \frac{hc}{\sqrt{E^2 - m_0^2 c^4}}$  (In 1924, Louis de Broglie published his speculation)

➤ **Velocity**

$$v = \frac{pc^2}{E} = c \sqrt{1 - \frac{m_0^2 c^4}{E^2}}$$

# Photons

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In case of photon, rest mass is zero :

- *Momentum*  $p = \frac{E}{c}$
- *Wave Vector*  $k = \frac{2\pi}{\lambda} \Rightarrow p = \hbar k$  where  $\hbar = \frac{h}{2\pi}$
- *Wavelength*  $\lambda = \frac{h}{p} = \frac{hc}{E}$
- *Velocity*  $v = \frac{pc^2}{E} = c$

# Duality of Photon

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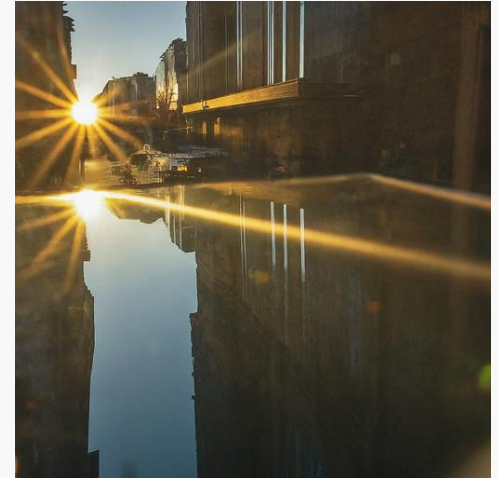
**Particle like model:** Can describe phenomena like reflection. Light is conceptualized as a stream of tiny particles called photons. Each photon carries a specific amount of energy.

## Wave Model:

- Light propagates as an electromagnetic wave.
- Waves carry energy without transporting matter.
- Essential for explaining interference and diffraction.
- When light moves between mediums, wavelength changes, frequency remains constant.
- Wave speed in a medium is independent of intensity.

**Wavelength and wavenumber:** inverse of the wavelength ( $1/\lambda$ ) is called wavenumber ( $\nu$ ), which is expressed in  $cm^{-1}$  (number of cycles per unit length)

$$\nu \text{ (or } \bar{\nu}) = \frac{10^7}{\lambda \text{ (in nm)}}$$



# Geometrical Optics

**cycle time or period ( $\tau$ ):** The time to complete one cycle.

$$\tau = \frac{\lambda}{v}$$

**frequency:** Number of cycles pass a point in a second.

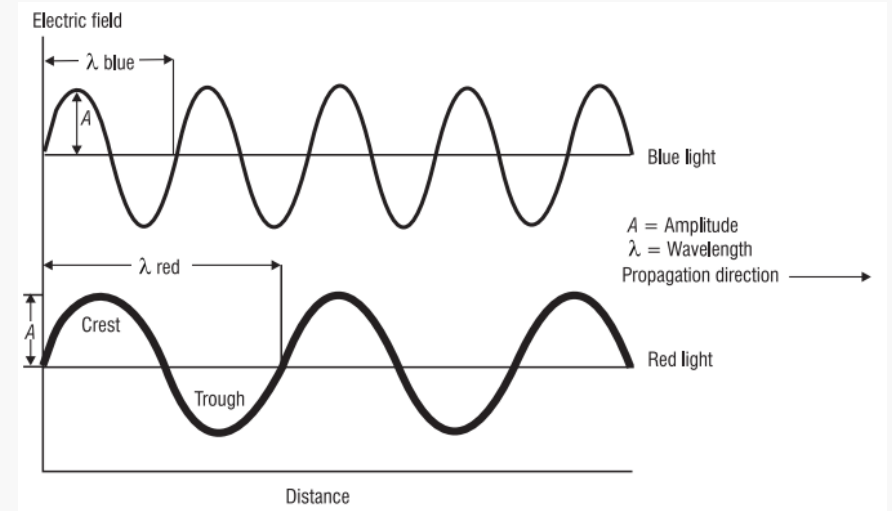
$$f = \frac{1}{\tau} = \frac{v}{\lambda}$$

In geometric optics, the wavelength ( $\lambda$ ) of light is negligible compared to the size of the components in the optical system (lenses, mirrors, etc.).

$$\lim_{\lambda \rightarrow 0} \text{Physical Optics} = (\text{geometrical optics})$$

EM waves share six properties with all forms of wave motions:

Polarization, Superposition, Reflection, Refraction, Diffraction, and Interference.



## Example 5-1

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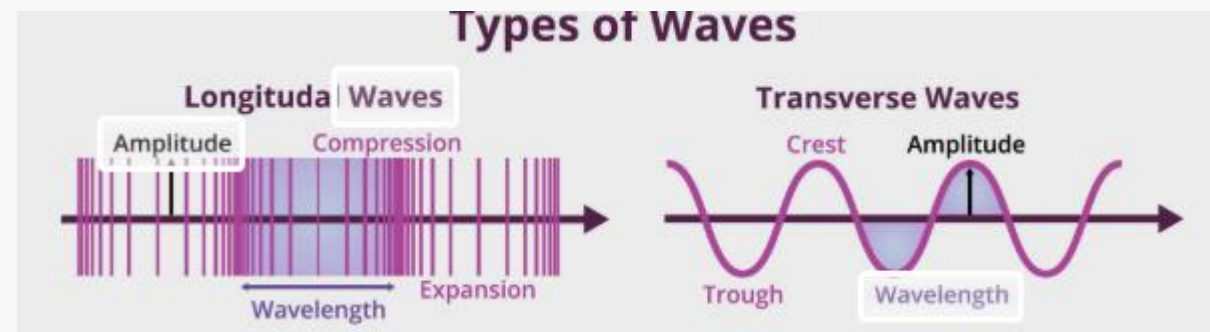
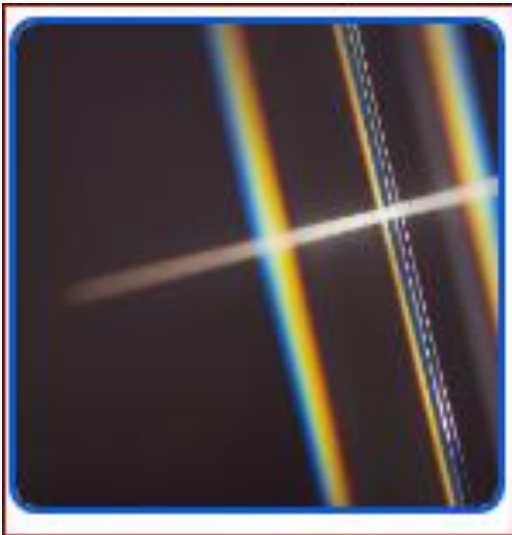
Determine the frequency, energy, and wavenumber of a blue light, wavelength of 500 nm.

# Light and Polarization

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- Polarization arises from the direction of the E-field vector with respect to the direction of light's propagation.
- Because light is transverse wave (electric field vibrating perpendicular to its propagation motion), it is polarizable.
- In the other hand, sound wave (longitudinal), vibrate along its propagation direction and thus is not polarizable.

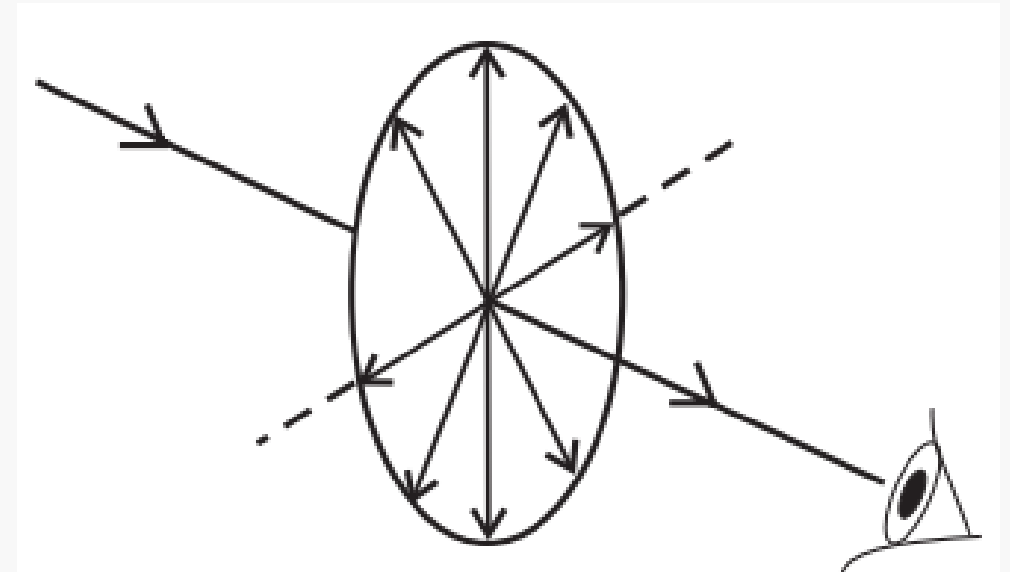


# Unpolarized Light

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- An ordinary light source consists of a very large number of randomly oriented atomic emitters. Each excited atom radiates a polarized wave-train for roughly  $10^{-8}$ s.
- Because of rapid change, the resultant polarization is indiscernible, this wave is referred as **natural light**. This is known as *unpolarized*, no preferred orientation.
- **Randomly polarization** is probably a better way of representation than unpolarized light. For example, of unpolarized light source are incandescent bulbs, arc lamps, and sun.



# Linear Polarization

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Let's consider two orthogonal optical disturbances

$$\vec{E}_x(z, t) = \hat{i} E_{0x} \cos(kz - \omega t)$$

$$\vec{E}_y(z, t) = \hat{j} E_{0y} \cos(kz - \omega t + \varepsilon)$$

Where  $\varepsilon$  is the relative phase difference between the waves, both are traveling in the z-direction.

The resultant of optical disturbance is.

$$\vec{E}(z, t) = \vec{E}_x(z, t) + \vec{E}_y(z, t)$$

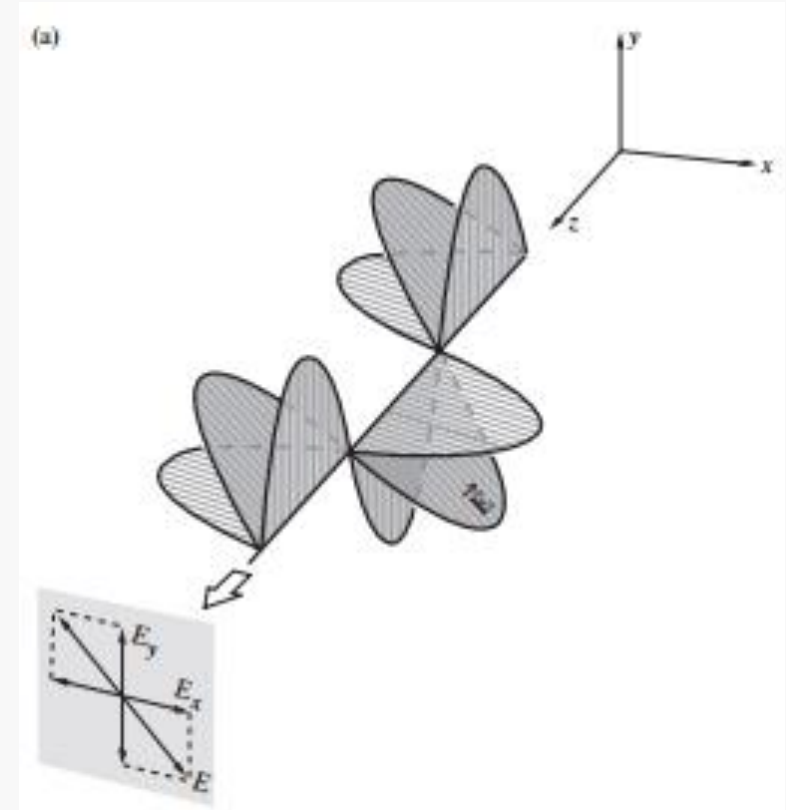
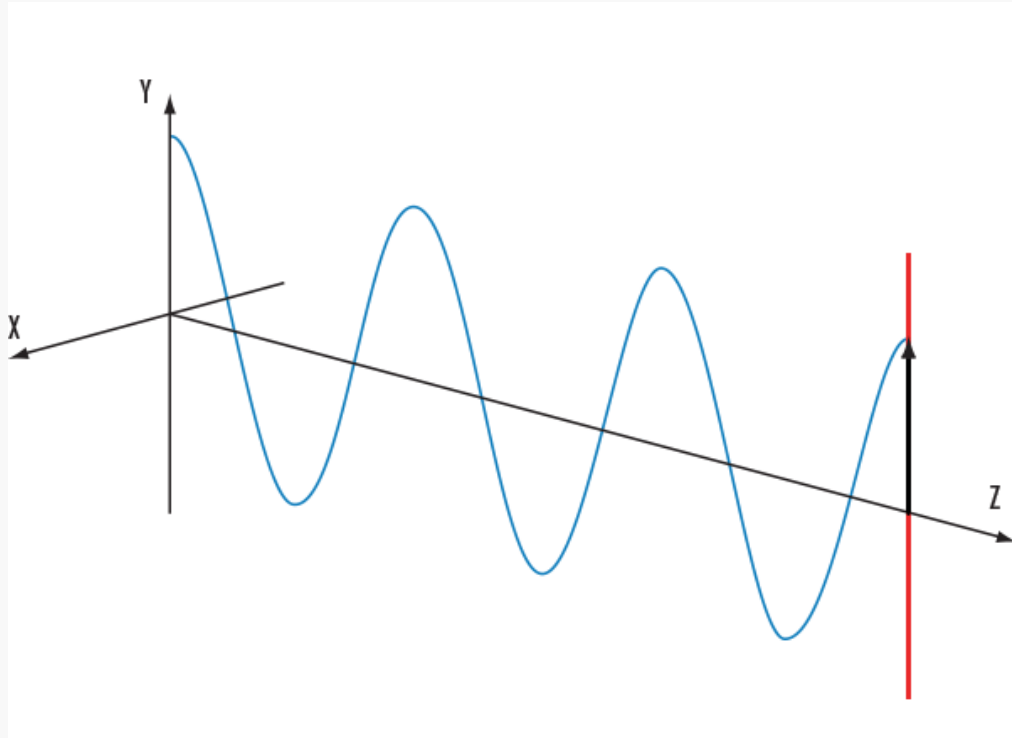
If  $\varepsilon$  is zero or an integral multiple of  $\pm 2\pi$ , the waves are in-phase, and becomes

$$\vec{E} = \left( \hat{i} \vec{E}_x(z, t) + \hat{j} \vec{E}_y(z, t) \right) \cos(kz - \omega t)$$

# Linear Polarization

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# Circular Polarization

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When both constituent waves have equal amplitudes (i.e.,  $E_{0x} = E_{0y} = E_0$ ), and their relative phase difference  $\varepsilon = -\frac{\pi}{2} + 2m\pi$ , where  $m = 0, \pm 1, \pm 2, \dots$ , it is said circular polarization. In other words, for any value of  $m$  (increasing or decreasing)

$$\begin{aligned}\vec{E}_x(z, t) &= \hat{i} E_{0x} \cos(kz - \omega t) \\ \vec{E}_y(z, t) &= \hat{j} E_{0y} \cos\left(kz - \omega t - \frac{\pi}{2}\right) = \hat{j} E_{0y} \left[ \cos(kz - \omega t) \cos\frac{\pi}{2} + \sin(kz - \omega t) \sin\frac{\pi}{2} \right] \\ \vec{E}_y(z, t) &= \hat{j} E_{0y} \sin(kz - \omega t)\end{aligned}$$

Wave becomes:

$$\vec{E} = E_0(\hat{i} \cos(kz - \omega t) + \hat{j} \sin(kz - \omega t))$$

Notice that now the scalar amplitude of  $\vec{E}$  is constant, and

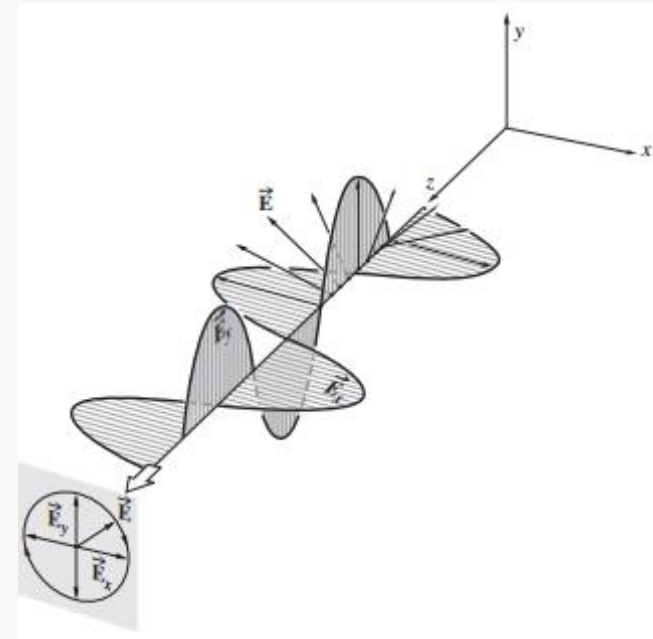
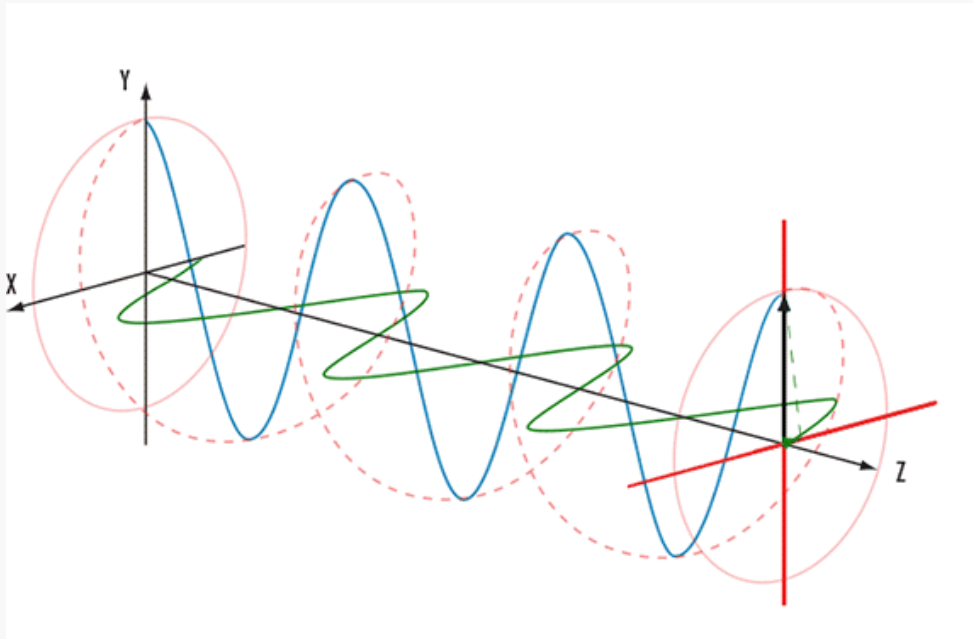
$$\sqrt{\vec{E} \cdot \vec{E}} = E_0$$

$\vec{E}$  is rotating **clockwise** at angular frequency of  $\omega$ . Such a wave is **right-circularly polarized** and generally it is referred as **right-circular light**.

# Circular Polarization

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- In other word, if  $\varepsilon = \frac{\pi}{2} + 2m\pi$ , where  $m = 0, \pm 1, \pm 2, \dots$ , then  $\vec{E}$  rotates **counterclockwise** at angular frequency of  $\omega$ . Such a wave is **left-circularly polarized** and generally it is referred as **left-circular light**.



# Elliptical Polarization

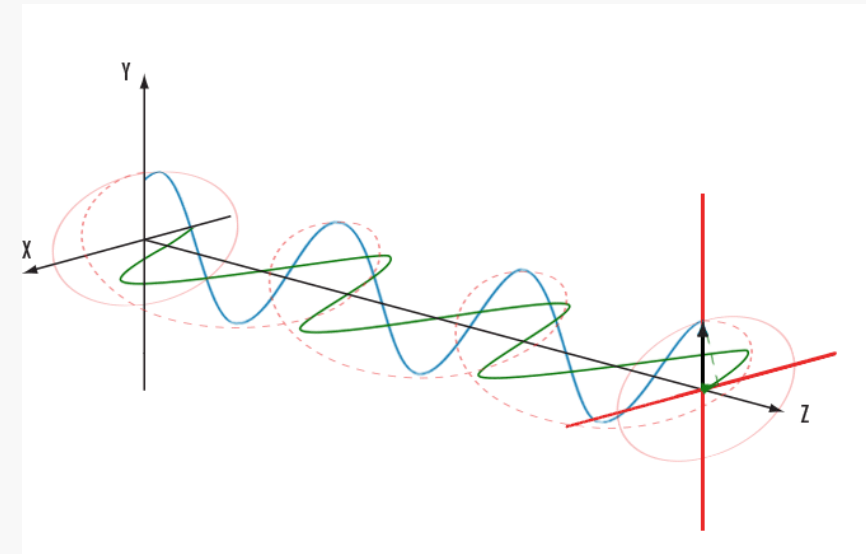
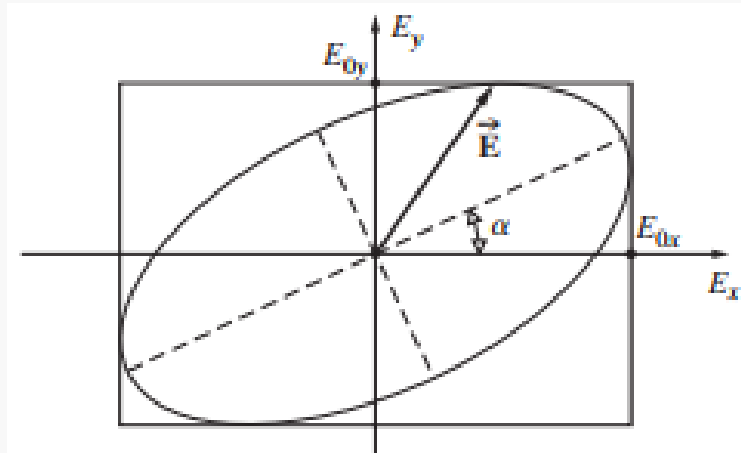
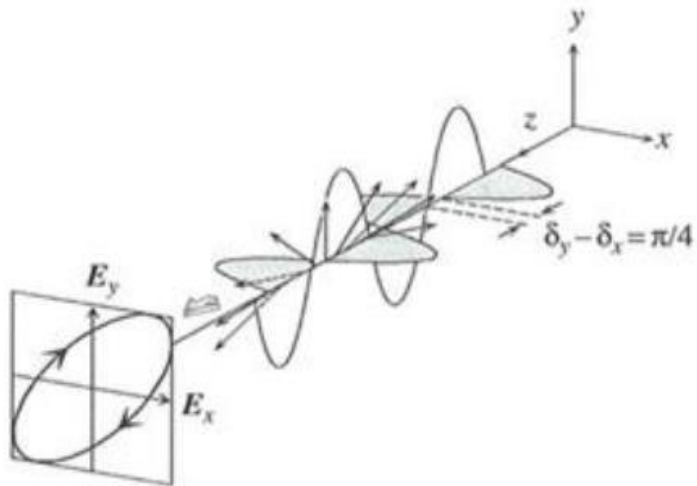
As far as the mathematical description is concerned, both linear and circular light may be considered to be special cases of **elliptically polarized** light or, more simply, **elliptical light**.

➤ We have learned that Two components

$$\vec{E}_x = E_0 \sin(kz - \omega t) \text{ and } \vec{E}_y = E_0 \sin(kz - \omega t + \phi)$$

➤  $\phi = 0, \pm\pi$  corresponds to linear polarization and  $\phi = \pm\frac{\pi}{2}$  corresponds to circular polarization.

➤ What about the other values of  $\phi$ , It is called **Elliptical Polarization** where the two components of  $\vec{E}$  field have the different phase  $\phi$  where  $\phi \neq 0, \pm\frac{\pi}{2}, \pm\pi, \dots$

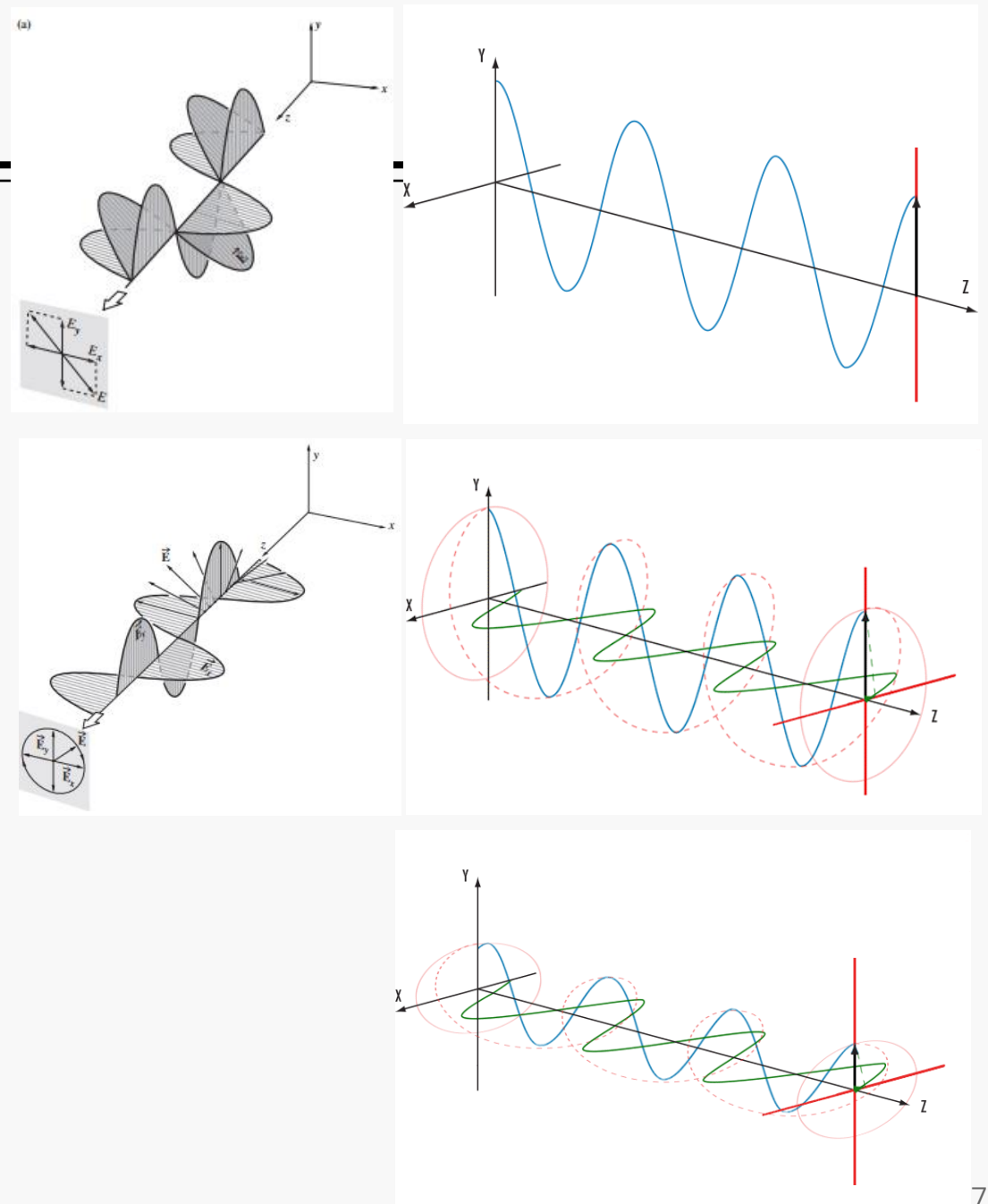


# Recapitulate of Last Class

Both linear and circular light can be considered to be special cases of **elliptically polarized** light. We have learned that Two components

$$\vec{E}_x = E_0 \sin(kz - \omega t) \text{ and } \vec{E}_y = E_0 \sin(kz - \omega t + \phi)$$

- $\phi = 0, \pm\pi$  corresponds to linear polarization
- $\phi = \pm\frac{\pi}{2}$  corresponds to circular polarization.
- What about the other values of  $\phi$ , It is called **Elliptical Polarization** where the two components of  $\vec{E}$  field have the different phase  $\phi$  where  $\phi \neq 0, \pm\frac{\pi}{2}, \pm\pi, \dots$



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*Thank you very much for your attention*