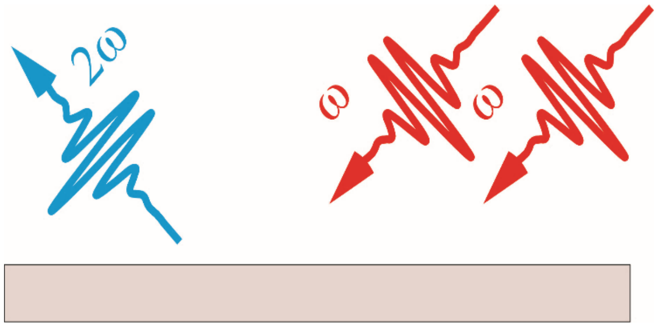
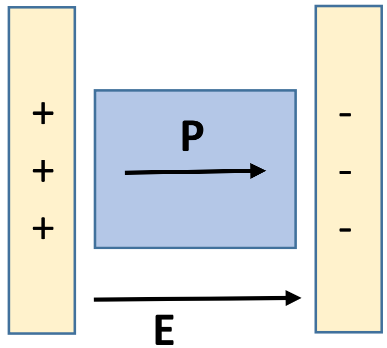
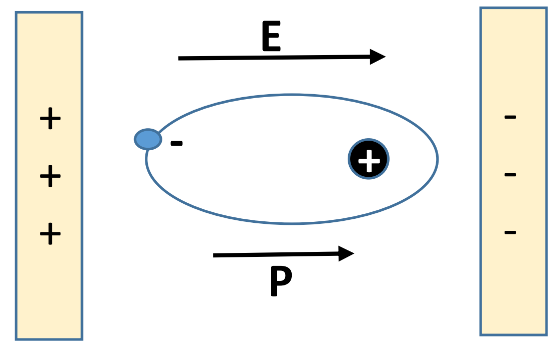
# Second Harmonic Generation (SHG)




**Kishan Sinha**
Xu Group
Department of Physics and Astronomy
University of Nebraska-Lincoln

# A dielectric subjected to an electric field

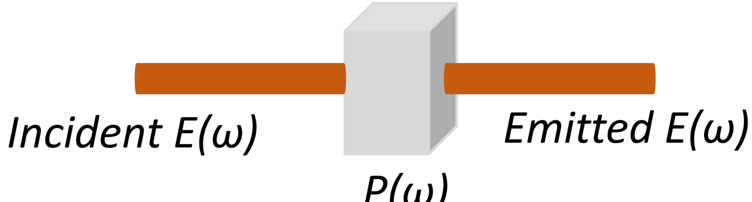



**Assumption of linearity:** $$\boldsymbol{P} = \varepsilon_o \chi \boldsymbol{E}$$

**In case of oscillating fields:** $$\boldsymbol{P}(\omega) = \varepsilon_o \chi(\omega) \boldsymbol{E}(\omega)$$

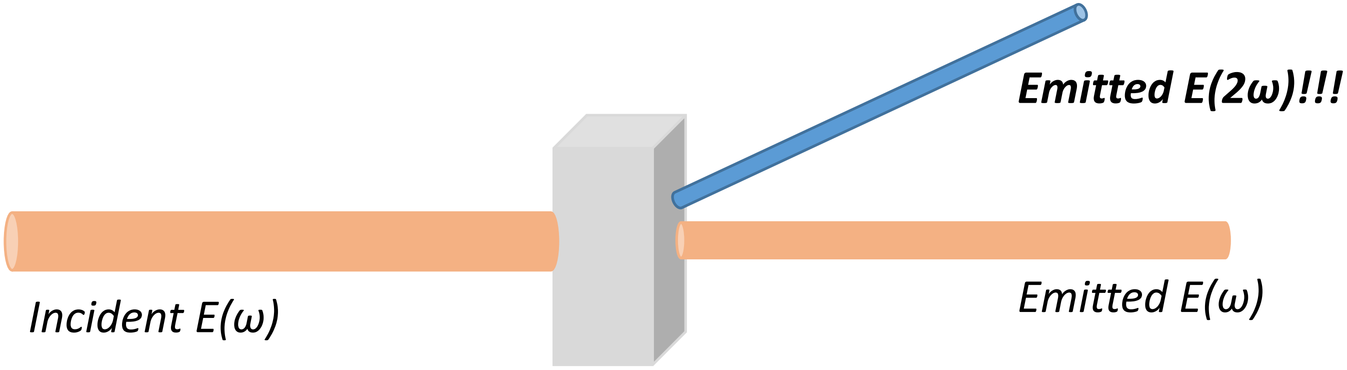
Polarization changes linearly
with the applied field



# 1960s: Advent of LASERS

LASER: coherent and high intensity light sources

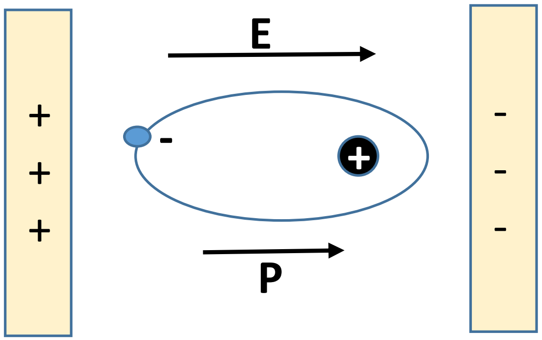
Atoms could be subjected to much intense electric fields




**Linearity:** ~~$\boldsymbol{P}(\omega) = \varepsilon_0 \chi \boldsymbol{E}(\omega)$~~ **Breaks down when the field is strong**

# What's going on?

**Ignored the electric field inside the atom**




Typical field inside an atom
1 V per Angstrom
**$10^{10}$ V/m or $10^{17}$ W/m$^2$**

Compare this with a typical laser
**$10^{9}$ W/m$^2$**

**Applied field can be treated as a perturbation**

**Taylor expansion**

$$\boldsymbol{P}(E) = C + \varepsilon_o \chi^{(1)} \boldsymbol{E} + \frac{1}{2} \varepsilon_o \chi^{(2)} \boldsymbol{E}^2 + \ \ldots$$

$\boldsymbol{P}$ and $\boldsymbol{E}$ are vectors:

$$\boldsymbol{P_k(E)} = C + \varepsilon_o \chi_{ik}^{(1)} E_i + \varepsilon_o \chi_{ijk}^{(2)} E_i E_j + \varepsilon_o \chi_{ijlk}^{(3)} E_i E_j E_l + \ \ldots$$

Constant DC term

1st order Radiation at ω

2nd order perturbation

**2nd order perturbation**

$$\boldsymbol{E} = \ E_i \, e^{-i\omega t}$$

$$P_k(E) = \ \varepsilon_o \chi_{ijk}^{(2)} \quad \left( E_i E_j e^{-i2\omega t} + \ E_i^* E_j^* e^{i2\omega t} + \ E_i^* E_j + E_j^* E_i \right)$$

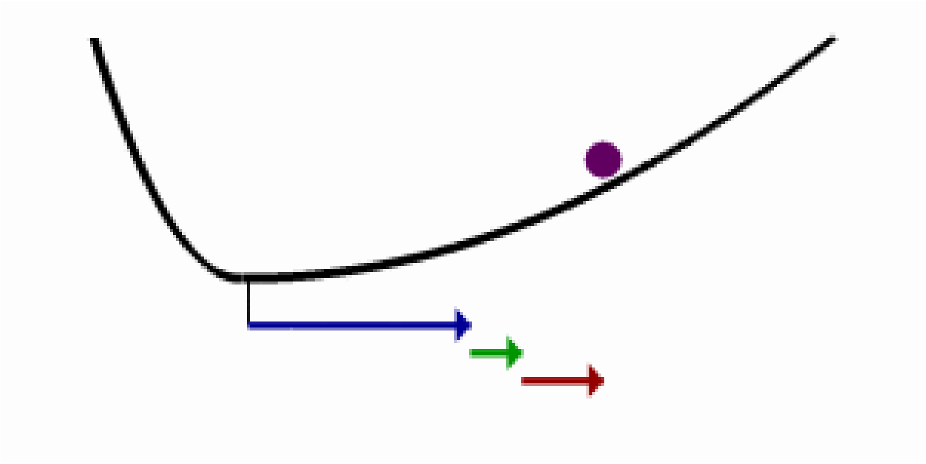
Cos $(2\omega)$

**Second Harmonic Generation (SHG)**

Oscillation at frequency $2\omega$

Radiation emitted at $2\omega$

# Second Harmonic Generation (SHG)



**Electron in an anharmonic potential subjected to E**

⇓

Motion of the electron can be Fourier decomposed

⇓

Term with 2ω frequency is SHG

**NOT all of crystals exhibit SHG**

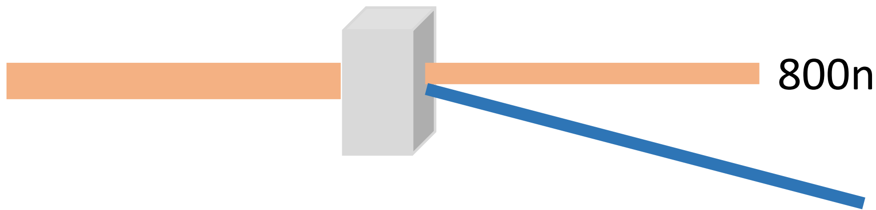
| |
|---|
| **Crystal MUST be non-centrosymmetric** |

Absolute requirement

# Applications of SHG

**1. Frequency doubling in LASERS**

Used to obtain short-wavelength laser from longer one.




**2. SHG Microscopy**

Certain bio-materials such as collagen are non-centrosymmetric and capable of SHG.

Tissues are first excited with a laser of frequency (ω) and then measure radiation with twice the frequency (2ω). This light is used to create an image.

**Resolution is on par with *Confocal microscopy*.**

**2. Surface characterization**

SHG discriminates signals from surface and bulk, hence, used as a surface specific technique. Used to study monolayers of adsorbed materials on a surface, characterize nanoparticles, etc.

# Thank you!