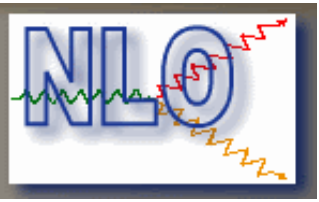
Fall 2015

PHYC/ECE 568

University of New Mexico

Nonlinear Optics

Course Homepage



Instructor: [Mansoor Sheik-Bahae](#)

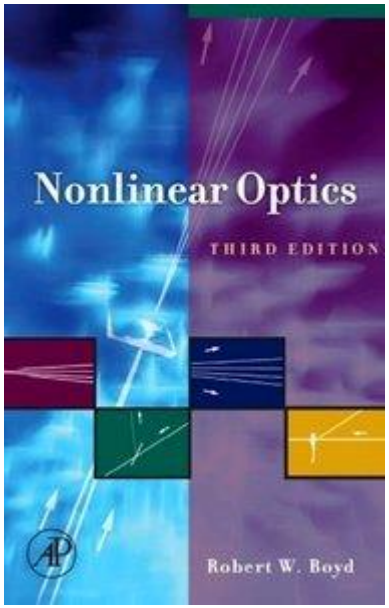
Office: Physics & Astronomy Rm. 1109 (North Wing)

Phone: 277-2080, Fax: 277-1520

e-mail: msb@unm.edu

Office Hours: Thu, 2-3 pm or by appointment

Textbook



The final grade is weighted as follows:

Midterm Exam: 45%

Final Project (paper + presentation): 40%

Homework: 15%

http://www.optics.unm.edu/sbahae/physics568/index.htm

TA: Junwei Meng (Tiger)

OPTICAL SCIENCE & ENGINEERING

University of New Mexico

Course Syllabus

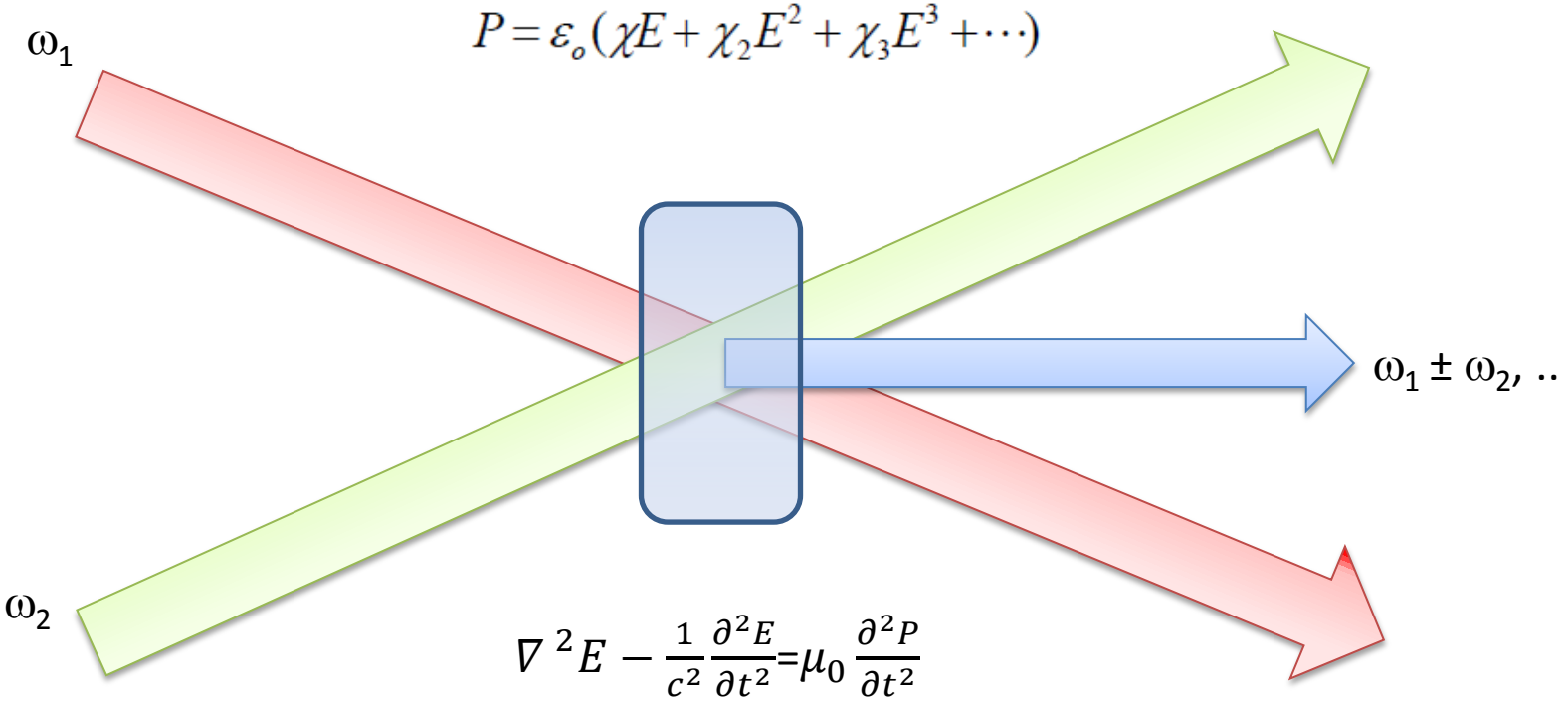
- Introduction (*historical overview, applications of NLO*)
- Nonlinear Susceptibilities ($\chi^{(2)}$ *and* $\chi^{(3)}$ *processes, nonlinear refraction and absorption)*
- Classical Anharmonic Oscillator Model
- Properties of Nonlinear Susceptibilities (*symmetries, Kramers-Kronig dispersion relations)*
- Wave Propagation in NLO Media (*coupled amplitude equations for* $\chi^{(2)}$ *processes, phase matching, second harmonic generation, sum and difference frequency generation, optical parametric processes, cascading nonlinearities)*
- Quantum Mechanical Treatment of Nonlinear Susceptibilities
- $\chi^{(3)}$ Processes (*electronic, vibrational and rotational effects, optical Kerr effect, self-focusing, wave-mixing, bistability, phase-conjugation, beam coupling, solitons)*
- Photo-Refractive Nonlinearities
- Stimulated Light Scattering (*stimulated Raman, Brillouin, and Rayleigh scattering)*
- Recent advances in ultrafast NLO (high-harmonic generation, atto-physics, terahertz)

What is Nonlinear Optics?

Two light beams cross without any interaction (linear optics) $\vec{P} = \chi \varepsilon_o \vec{E}$

Light beams interact with each other, or themselves (nonlinear optics)

$$P = \varepsilon_o(\chi E + \chi_2 E^2 + \chi_3 E^3 + \cdots)$$



$$\nabla^2 E - \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} = \mu_0 \frac{\partial^2 P}{\partial t^2}$$

Primary Manifestations:

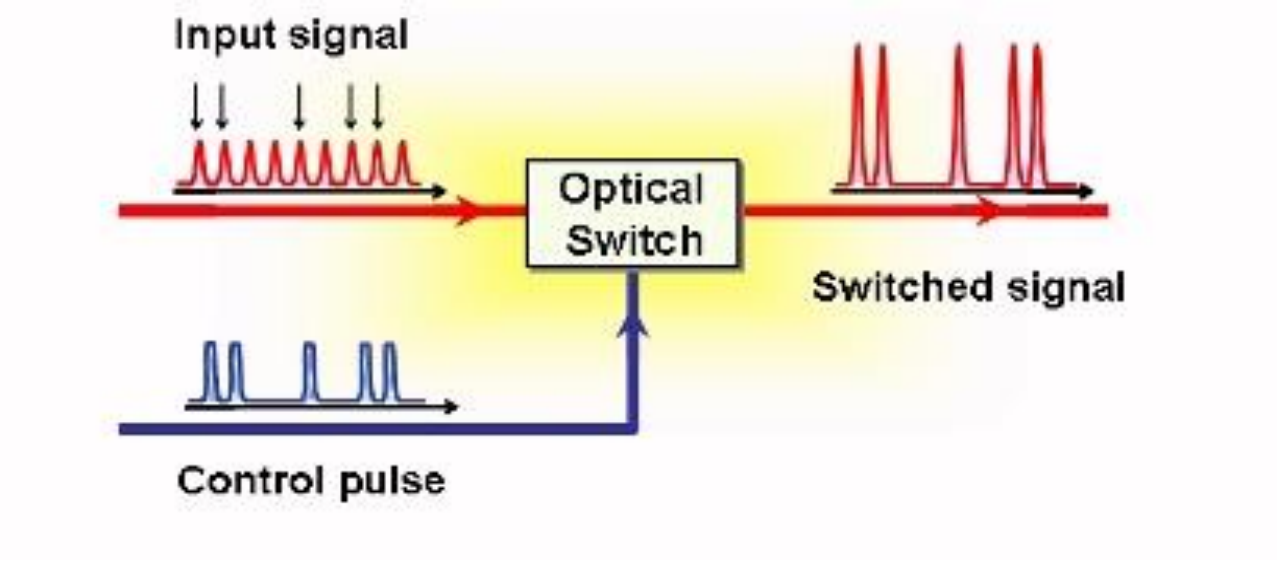
- sum, difference, harmonic frequency generation (new frequencies)
- modulating refractive index and absorption coefficient (e.g. $n = n_0 + n_2 I$)

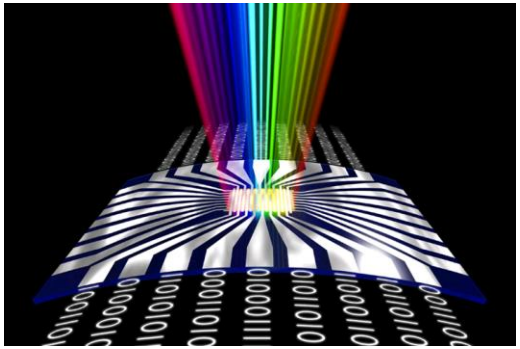
$$\alpha = \alpha_0 + \beta I$$

Controlling Light with Light

$$n = n_0 + n_2 I$$

$$\alpha = \alpha_0 + \beta I$$



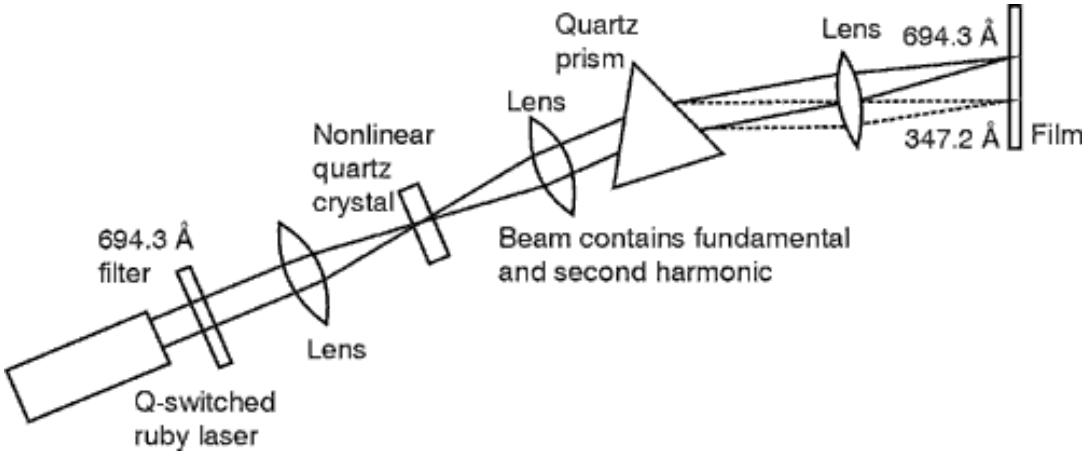


Optical Computers !

54th Anniversary of Nonlinear Optics

1961: NLO was born!

University of Michigan



Peter Franken (1929-1999)

VOLUME 7, NUMBER 4 PHYSICAL REVIEW LETTERS AUGUST 15, 1961

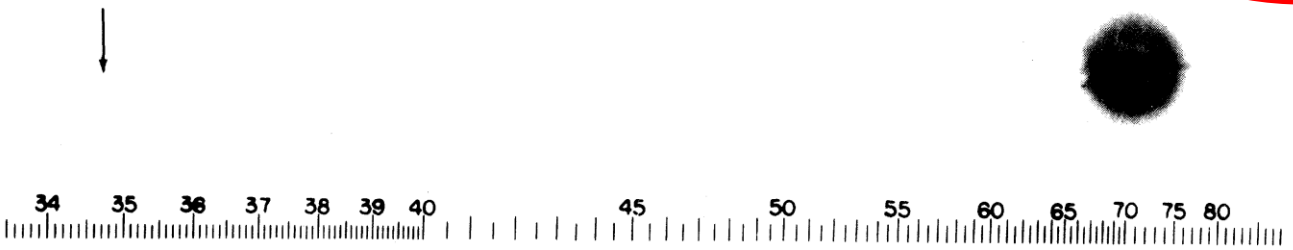


FIG. 1. A direct reproduction of the first plate in which there was an indication of second harmonic. The wavelength scale is in units of 100 A. The arrow at 3472 A indicates the small but dense image produced by the second harmonic. The image of the primary beam at 6943 A is very large due to halation.

52nd Anniversary of Nonlinear Optics

Have you seen SHG?: Green Laser Pointer

52nd Anniversary of Nonlinear Optics

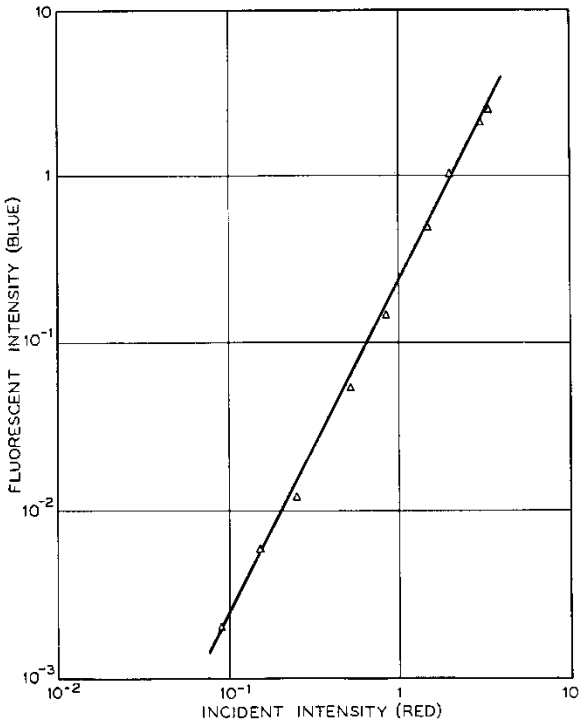
1961: NLO was born!

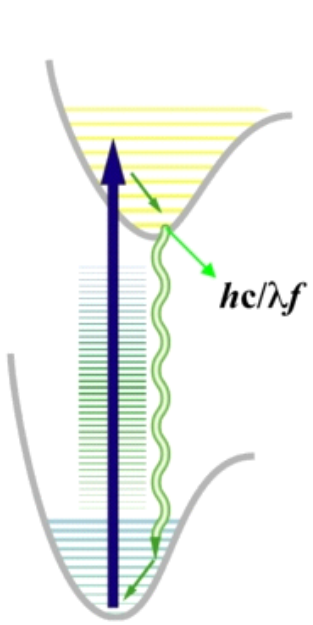
VOLUME 7, NUMBER 6 PHYSICAL REVIEW LETTERS SEPTEMBER 15, 1961

TWO-PHOTON EXCITATION IN $CaF_2:Eu^{2+}$

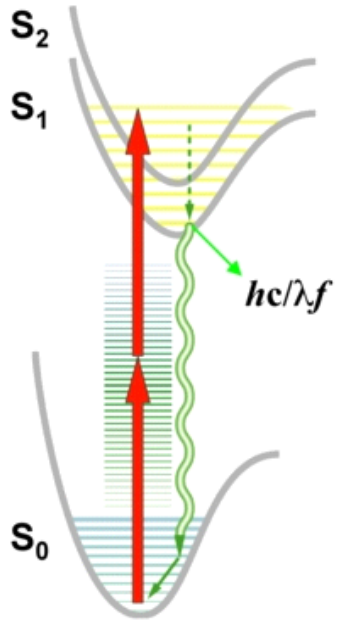
W. Kaiser and C. G. B. Garrett
Bell Telephone Laboratories, Murray Hill, New Jersey
(Received August 28, 1961)

VOLUME 7, NUMBER 6 PHYSICAL REVIEW LETTERS

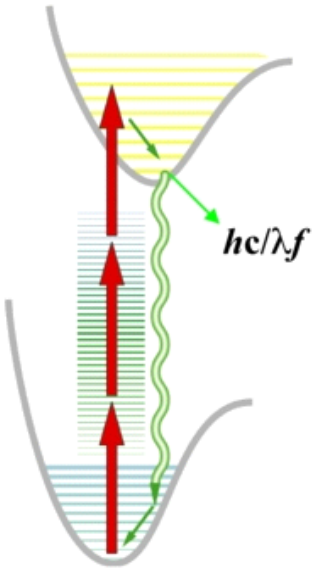




Linear (one-photon) fluorescence

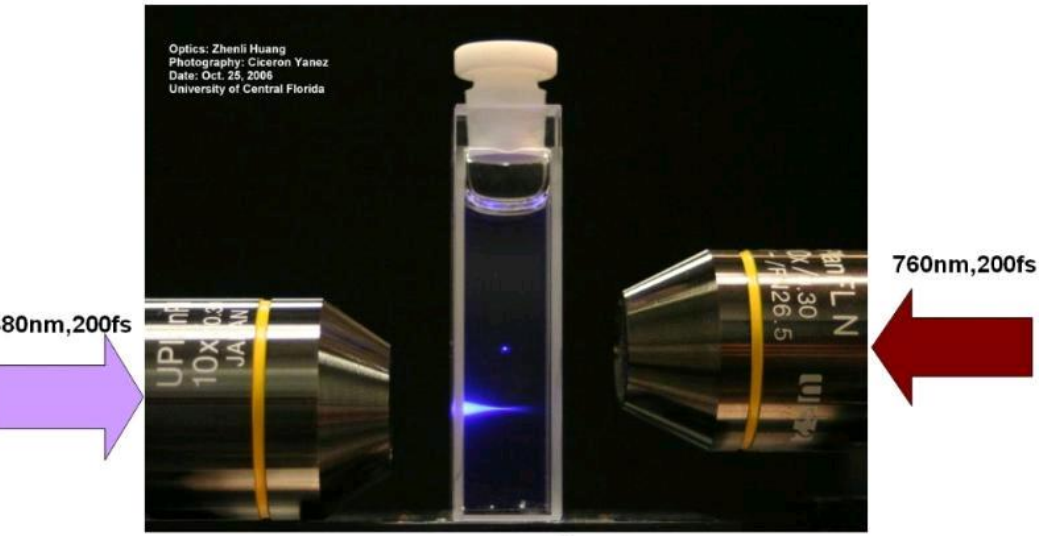


Two-photon fluorescence (TPF)

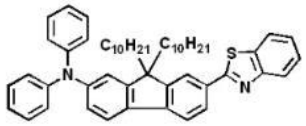


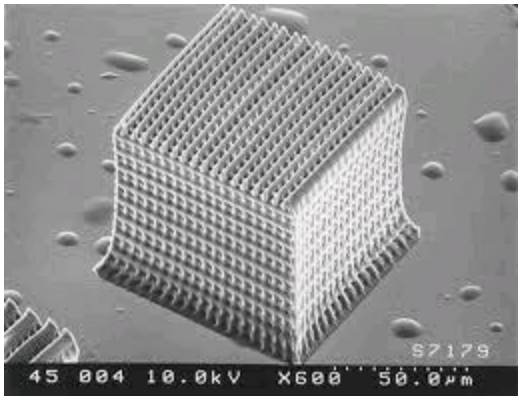
Three-photon fluorescence (3PF)

Two-photon microscopy

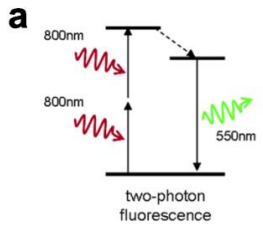


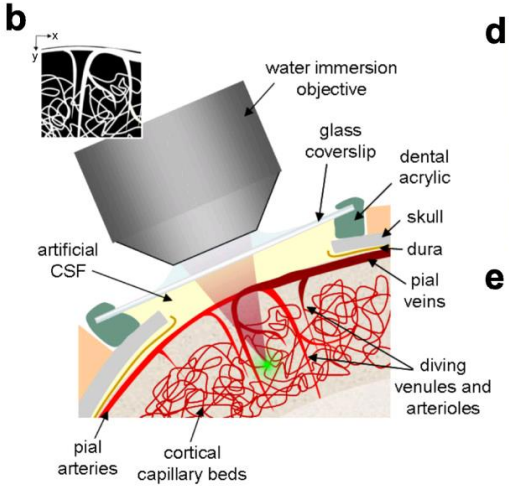
Fluorene 3

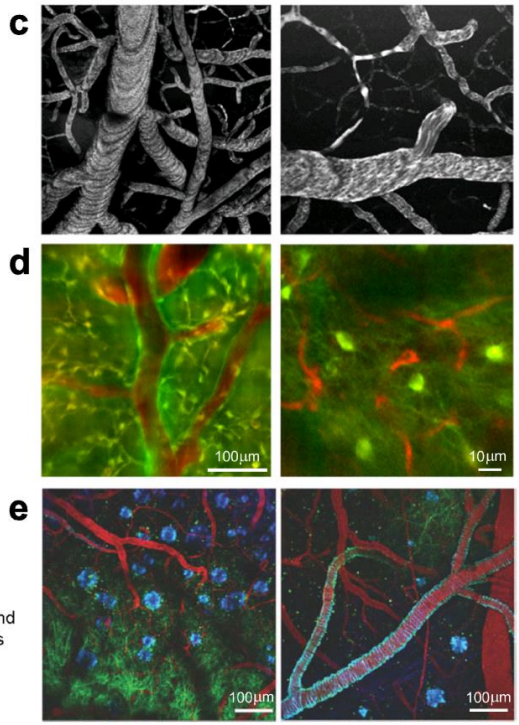




Two-photon polymerization



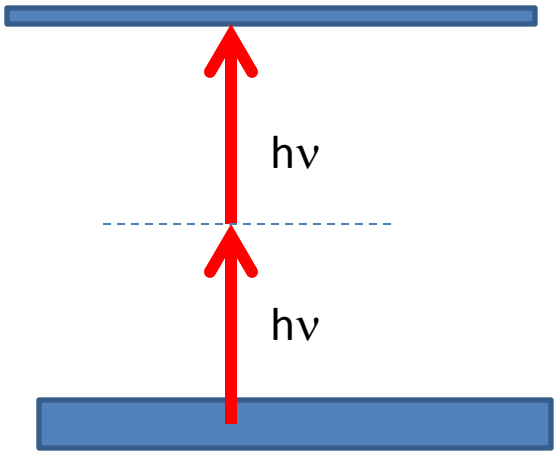




Theoretical Foundations

Maria Goeppert-Mayer (June 28, 1906 – February 20, 1972)

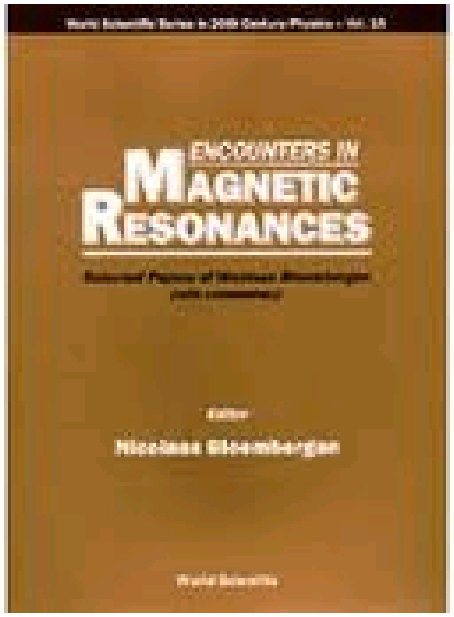
Two-photon absorption theory (1931, doctoral dissertation)



$$\alpha = \alpha_0 + \beta I$$

Awarded the Nobel Prize in Physics in 1963, shared with J. Hans D. Jensen and Eugene Paul Wigner.

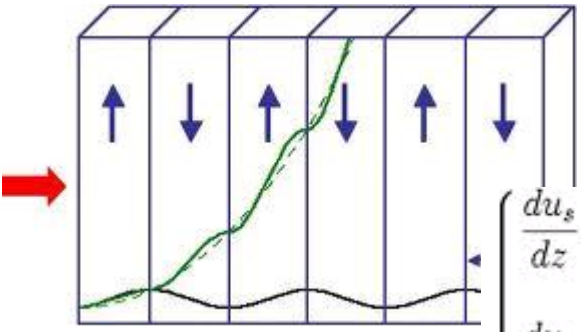
Theoretical Foundations



Nicholas Bloembergen

1962,..

Nobel Prize in Physics, 1981



$$\frac{du_s}{dz} = \kappa u_p u_c sin(\phi)$$

$$\frac{du_c}{dz} = \kappa u_p u_s sin(\phi)$$

$$\frac{du_p}{dz} = -\kappa u_s u_c sin(\phi)$$

(July 2011) in Hawaii!

OPTICAL SCIENCE & ENGINEERING
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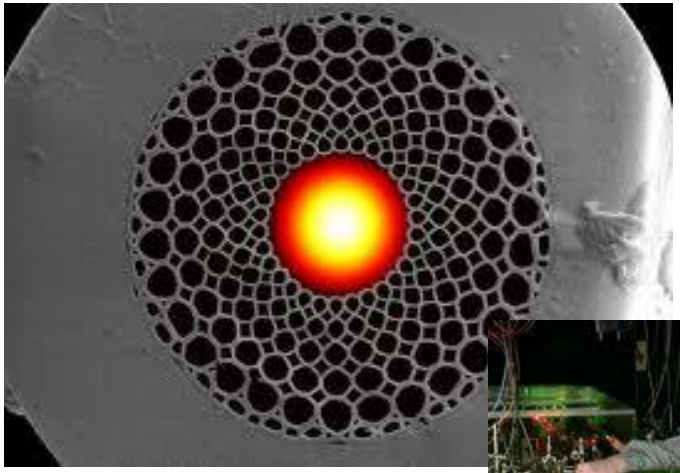
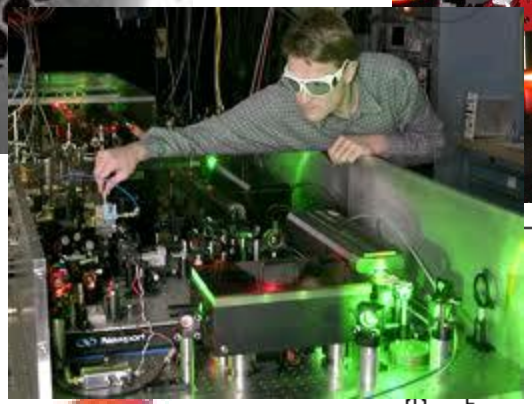
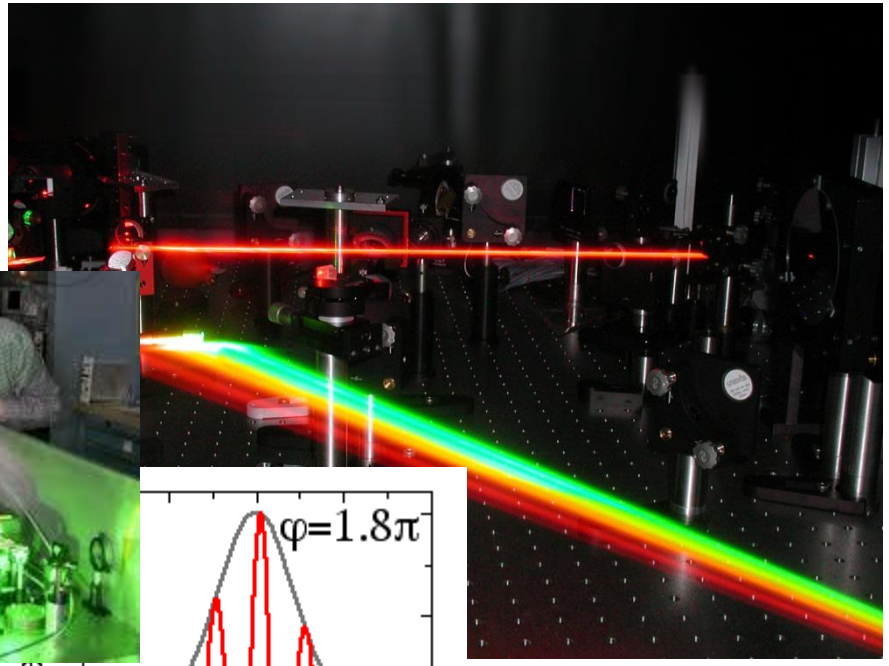
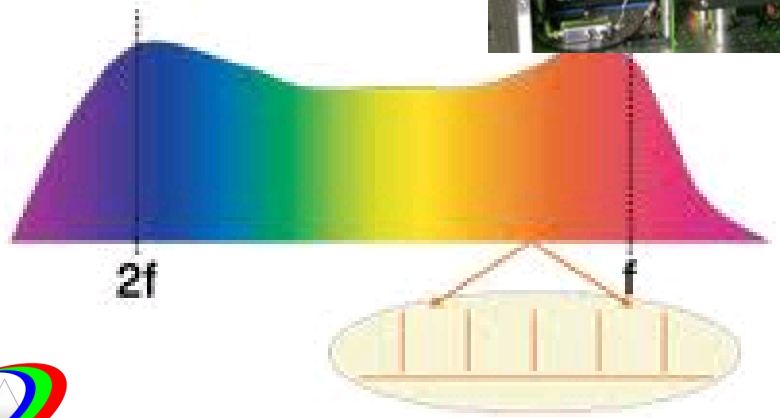
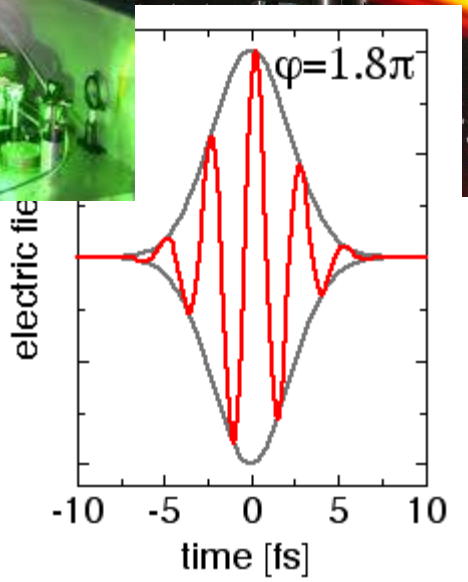
Femtosecond Lasers, Frequency Combs and Optical Clocks



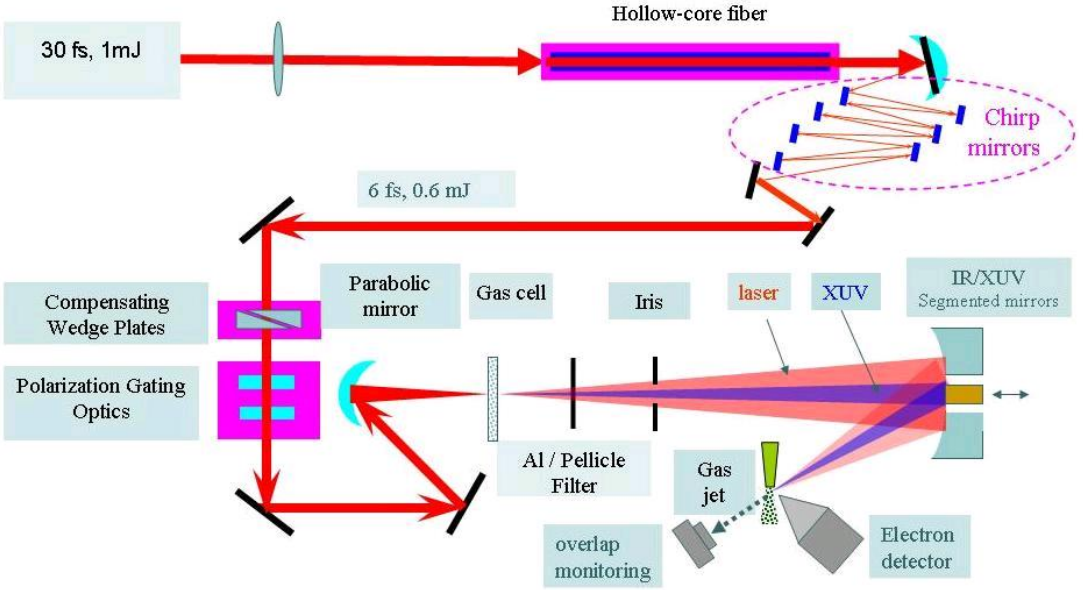


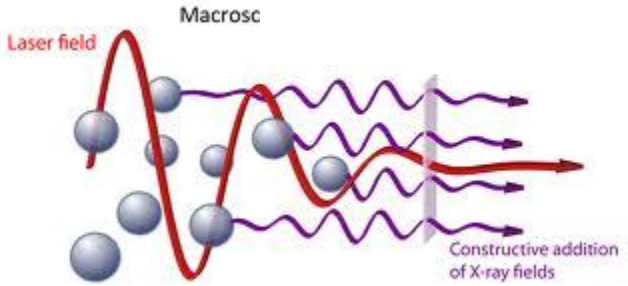


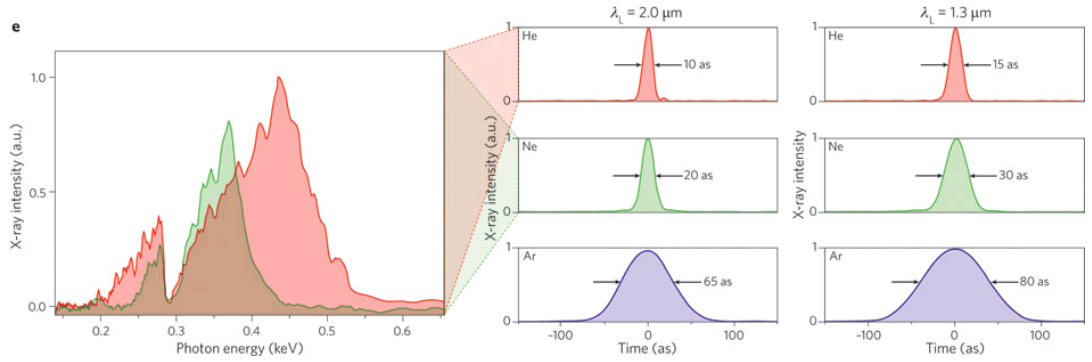




Extreme Nonlinear Optics (X-ray bursts, attosecond pulses, and laser fusion)





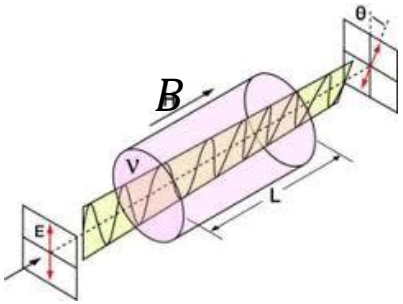


Other historical perspectives

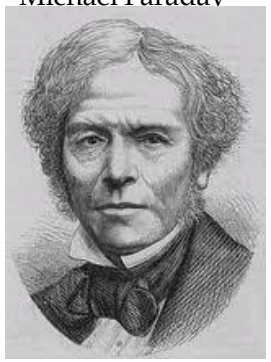
- Faraday Effect (magneto-optic) - 1845:

$$\theta = V \times B \times L$$

V *is the Verdet constant*

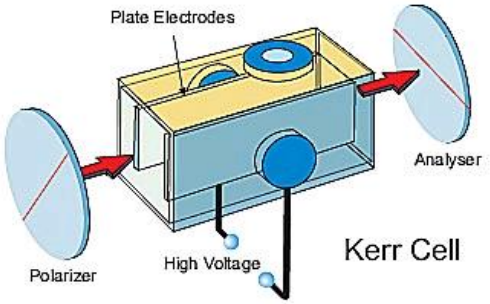


Michael Faraday

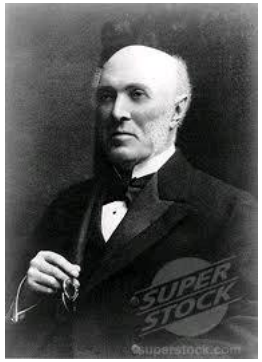


- Kerr Effect- 1875:

$$\Delta n = \lambda K E^2,$$

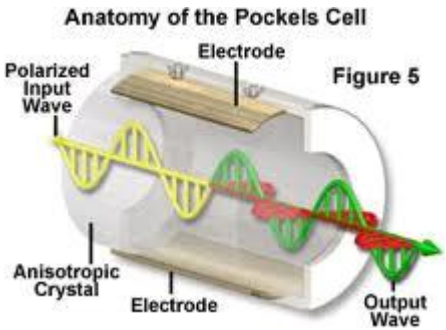


John Kerr

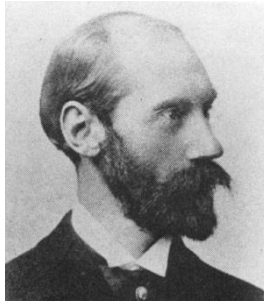


- Pockels Effect- 1893:

$$\Delta n = r \cdot n^3 E$$

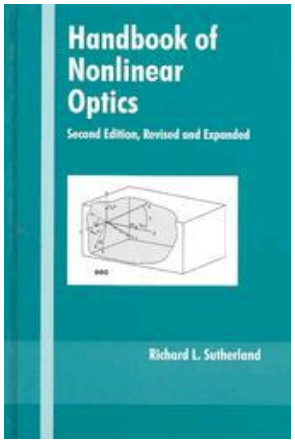


Friedrich Pockels

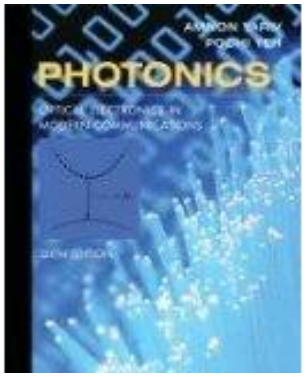


Other References

Handbook of Nonlinear Optics
Richard Sutherland



Photonics: Optical Electronics in Modern Communications
Amnon Yariv and Pochi Yeh



Fundamentals of Nonlinear Optics
Peter Bowers