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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)
Course Syllabus

- Introduction *(historical overview, applications of NLO)*
- Nonlinear Susceptibilities *(χ(2) and χ(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 χ(2) processes, phase matching, second harmonic generation, sum and difference frequency generation, optical parametric processes, cascading nonlinearities)*
- Quantum Mechanical Treatment of Nonlinear Susceptibilities
- χ(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) \[ \vec{P} = \chi \varepsilon_0 \vec{E} \]

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

\[ P = \varepsilon_0 (\chi \vec{E} + \chi_2 \vec{E}^2 + \chi_3 \vec{E}^3 + \cdots) \]

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

\[ n = n_0 + n_2 I \]

\[ \alpha = \alpha_0 + \beta I \]
1961: NLO was born!

Peter Franken (1929-1999)

**Figure 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 Å. The arrow at 3472 Å indicates the small but dense image produced by the second harmonic. The image of the primary beam at 6943 Å is very large due to halation.
Have you seen SHG?: Green Laser Pointer
1961: NLO was born!

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)
Two-photon microscopy

Two-photon polymerization

Fluorene 3

80nm, 200fs

760nm, 200fs

Two-photon fluorescence

Water immersion objective

Dental acrylic

Skull

Artificial CSF

Pial arteries

Cortical capillary beds

Diving venules and arterioles

Diving pial veins

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

Two-photon absorption theory (1931, doctoral dissertation)

\[ \alpha = \alpha_0 + \beta I \]

Theoretical Foundations

Nicholas Bloembergen
1962,

Nobel Prize in Physics, 1981

(July 2011) in Hawaii!

\[ \begin{align*}
\frac{du_s}{dz} &= \kappa u_p u_e \sin(\phi) \\
\frac{du_e}{dz} &= \kappa u_p u_e \sin(\phi) \\
\frac{du_p}{dz} &= -\kappa u_s u_e \sin(\phi)
\end{align*} \]
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

- Kerr Effect - 1875:
  \[ \Delta n = \lambda K E^2 \]

- Pockels Effect - 1893:
  \[ \Delta n = r \cdot n^3 E \]
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*