


PHY 712 Electrodynamics
9-9:50 AM MWF Olin 105

Plan for Lecture 39:

Special Topics in Electrodynamics:

- **Optical properties of materials**
- **Brief introduction to non-linear optics**

Ref. Robert W. Boyd, Nonlinear Optics
(material from that text used in lecture notes)



→ Evaluation form
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22	Wed: 03/14/2018	Chap. 9	Harmonic radiation	#14	03/19/2018
23	Fri: 03/16/2018	Chap. 9	Harmonic radiation	#15	03/21/2018
24	Mon: 03/19/2018	Chap. 9 & 10	Interference and Scattering	#16	03/23/2018
25	Wed: 03/21/2018	Chap. 11	Special relativity	#17	03/26/2018
26	Fri: 03/23/2018	Chap. 11	Special relativity	#18	03/28/2018
27	Mon: 03/26/2018	Chap. 11	Special relativity		
28	Wed: 03/28/2018	Chap. 14	Radiation from accelerated particles		
	Fri: 03/30/2018		No class <i>Good Friday</i>		
29	Mon: 04/02/2018	Chap. 14	Synchrotron radiation	#19	04/06/2018
30	Wed: 04/04/2018	Chap. 14	Synchrotron radiation	#20	04/09/2018
31	Fri: 04/06/2018	Chap. 15	Radiation from collisions of charged particles		
32	Mon: 04/09/2018	Chap. 13	Cherenkov radiation		
33	Wed: 04/11/2018		Review		
34	Fri: 04/13/2018		Review		
35	Mon: 04/16/2018		Special topic: Superconductivity		
36	Wed: 04/18/2018		Special topic: Superconductivity		
37	Fri: 04/20/2018		Special topic: Optical properties of materials		
38	Mon: 04/23/2018		Special topic: Optical properties of materials		
39	Wed: 04/25/2018		Special topic: Optical properties of materials		
	Fri: 04/27/2018		Presentations I		
	Mon: 04/30/2018		Presentations II		
	Wed: 05/02/2018		Presentations III		

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Presentations I -- Friday April 27, 2018

	Presenter name	Presentation title
9:00-9:23 AM	Matthew Weidrip	Magnetrons
9:25-9:47 AM	Yan Li	General Introduction to Lithium-ion Batteries

Presentations II -- Monday April 30, 2018

	Presenter name	Presentation title
9:00-9:23 AM	Nouf Alharbi	Jackson 7-2
9:25-9:47 AM	Ellie Alipour	

Presentations III -- Wednesday May 02, 2018

	Presenter name	Presentation title
9:00-9:23 AM	Haardik Pandey	Magnetohydrodynamic
9:25-9:47 AM	Kevin Roebuck	Jackson 14.15 - Radiation by a charge moving in a circular path

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Sun	Mon	Tue	May Wed	Thu	Fri	Sat
		1	2	Take home exam	4	5
6	7	8	9	10	Exam due	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

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Events

Colloquium: "Physics Honors Presentations - Part I April 25, 2018 at 4pm" WFU senior physics students will present highlights of their honors theses. George P. Williams, Jr. Lecture Hall, (Olin 101) Wednesday, April 25, 2018, at 4:00 PM. There will be a...

Colloquium: "Physics Honors Presentations - Part II and Ceremonies and Awards" May 2, 2018 at 5:30pm WFU senior physics students will present highlights of their honors theses. STE and Physics Awards Ceremonies will follow. George P. Williams, Jr. Lecture Hall, (Olin 101) Wednesday, May 2, 2018, ...

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Up to now, we have considered electrodynamics as a linear phenomenon. Maxwell's equations are linear equations. However, for some light-matter interactions, light alters the properties of the material and causes nonlinear effects.

Linear response (cgs Gaussian units)

$$\mathbf{P} = \chi^1 \mathbf{E} \quad \mathbf{D} = \mathbf{E} + 4\pi \mathbf{P} = (1 + 4\pi \chi^1) \mathbf{E}$$

Nonlinear response

$$\begin{aligned} \tilde{\mathbf{P}}(t) &= \chi^{(1)} \tilde{\mathbf{E}}(t) + \chi^{(2)} \tilde{\mathbf{E}}^2(t) + \chi^{(3)} \tilde{\mathbf{E}}^3(t) + \dots \\ &\equiv \tilde{\mathbf{P}}^{(1)}(t) + \tilde{\mathbf{P}}^{(2)}(t) + \tilde{\mathbf{P}}^{(3)}(t) + \dots \end{aligned}$$

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Nonlinear response to time harmonic field:

$$\tilde{E}(t) = Ee^{-i\omega t} + \text{c.c.}$$

$$\tilde{P}^{(2)}(t) = \chi^{(2)} \tilde{E}^2(t)$$

$$\tilde{P}^{(2)}(t) = 2\chi^{(2)} EE^* + (\chi^{(2)} E^2 e^{-2i\omega t} + \text{c.c.})$$

↑
↑
 optical rectification second harmonic generation

Example Nd:YAG (Nd:Y₃Al₅O₁₂) laser has $\lambda=1060$ nm; a nonlinear crystal can output $\lambda/2=530$ nm.

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FIGURE 1.2.1 (a) Geometry of second-harmonic generation. (b) Energy-level diagram describing second-harmonic generation.

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Drude-like model of nonlinear response of electron of mass m :

FIGURE 1.4.1 Potential energy function for a noncentrosymmetric medium.

$$\ddot{\tilde{x}} + 2\gamma\dot{\tilde{x}} + \omega_0^2\tilde{x} + a\tilde{x}^2 = -e\tilde{E}(t)/m.$$

Perturbation theory expansion:

$$\tilde{x} = \tilde{x}^{(1)} + \tilde{x}^{(2)} + \tilde{x}^{(3)} + \dots$$

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Drude-like model -- continued

$$\ddot{\tilde{x}} + 2\gamma\dot{\tilde{x}} + \omega_0^2\tilde{x} + a\tilde{x}^2 = -e\tilde{E}(t)/m.$$

$$\ddot{\tilde{x}}^{(1)} + 2\gamma\dot{\tilde{x}}^{(1)} + \omega_0^2\tilde{x}^{(1)} = -e\tilde{E}(t)/m,$$

$$\ddot{\tilde{x}}^{(2)} + 2\gamma\dot{\tilde{x}}^{(2)} + \omega_0^2\tilde{x}^{(2)} + a[\tilde{x}^{(1)}]^2 = 0,$$

$$\ddot{\tilde{x}}^{(3)} + 2\gamma\dot{\tilde{x}}^{(3)} + \omega_0^2\tilde{x}^{(3)} + 2a\tilde{x}^{(1)}\tilde{x}^{(2)} = 0.$$

For $\tilde{E}(t) = Ee^{-i\omega t}$

$$\tilde{x}^{(1)}(t) = \frac{-eE/m}{\omega_0^2 - \omega^2 - 2i\omega\gamma} e^{-i\omega t}$$

$$\tilde{x}^{(2)}(t) = \frac{-a(eE/m)^2}{(\omega_0^2 - \omega^2 - 2i\omega\gamma)^2 (\omega_0^2 - (2\omega)^2 - 2i(2\omega)\gamma)} e^{-2i\omega t}$$

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Drude-like model -- continued

Solving for susceptibility:

$$\tilde{P}^{(l)}(t) = \chi^{(l)}(\tilde{E}(t))^l = -Ne\tilde{x}^{(l)}(t)$$

$$\chi^{(1)}(\omega) = \frac{Ne^2/m}{\omega_0^2 - \omega^2 - 2i\omega\gamma}$$

$$\chi^{(2)}(2\omega) = \frac{Nae^3/m^2}{(\omega_0^2 - (2\omega)^2 - 2i(2\omega)\gamma)(\omega_0^2 - \omega^2 - 2i\omega\gamma)^2}$$

Note that this analysis assumes that the crystal is asymmetric.

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Examples of nonlinear crystals

Crystals 2017, 7, 93; doi:10.3390/cryst7030093 S17 of S17

$\beta\text{-BaB}_2\text{O}_7$ 98-673 K

LiB_3O_5 98-650 K

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