**PHYS5130: Ultrafast Science and Spectroscopy**

**Instructor:** Bill Rice, email: wrice2@uwyo.edu; Office: PS116

**Pre-requisites:** PHYS4350 (or equivalent) and PHYS4420 (or equivalent)

**Lecture location and time:** T, Th. 9:35—10:50 am, A&S 209

**Text:** *Ultrashort Laser Pulse Phenomena*, 2nd Edition by Diels and Rudolph (2006) with significant amounts of supplementary material from other books, articles, and course notes.

**Other Important and Useful (but not required) Texts:**

- *Lasers* by A. Siegman (1986)
- *Laser Spectroscopy 1* (Basic Principles) and *Laser Spectroscopy 2* (Experimental Techniques) by W. Demtröder (2014 and 2015)
- *Quantum Electronics* by A. Yariv. 3rd ed. (1989)
- *Photon-Atom Interactions* by M. Weissbluth (1989)
- *Nonlinear Optics* by R. W. Boyd. 3rd ed. (2007)

**Course Content**

This graduate course introduces major themes, topics, and techniques in modern ultrafast science. Topics covered include:

- Light-matter interaction
- Principles of cavities, coherence, population inversion, and lasers
- Laser dynamics, Q-switching, active and passive mode-locking
- Pulse description and characterization
- Generation and propagation of ultrashort pulses
- Ultrafast processes in chemistry and physics
- Frequency generation: terahertz, high-harmonics, parametric processes
- Linear and nonlinear pulse shaping processes: optical solitons, pulse compression
- Laser amplifiers, free-electron lasers, optical parametric amplifiers, and oscillators

**General Outline of the Course**

The first weeks of this course will focus on learning and understanding how light and matter interact, followed by a discussion of population inversion, lasing, and how ultrafast pulses are generated, characterized (mathematical descriptions, *e.g.*), and measured. After this framework is established, we will explore the applications and uses of ultrafast pulses, focusing on processes in atoms/molecules, semiconductors, and metals and then expanding into frequency generation in condensed matter and atomic gases (terahertz pulses, high-harmonic generation, and parametric processes). Last, some time will be spent on addressing experimental implementation, such as pump-probe techniques, laser amplifiers, and free-electron lasers.

**Grading**

Homework will be accepted up to 24 hours late without penalty; after that, full points will exponentially decrease with a two-day time constant: full points = 100*exp[-(days late)/2 days]. The tentative distribution: Homework (20%), Oral Presentations (20%; 5% for presentation 1 and 15% for presentation 2), Exam 1 (20%), Paper (15%), and Final exam (25%)

**Class Presentations**

You are required to give two oral presentations during the semester. The first presentation will be ten minutes long and will cover a recent (*i.e.*, published in the last three years) *refereed* article on either a new ultrafast technique (generation, detection, characterization, *etc*.) or measurement/theory (*e.g.*, pump-probe study on XYZ or new multi-temperature model of a ABC system). For this first presentation, you will be allotted ten minutes of speaking time and up to eight slides. In addition, you can present at least half of the talk on a whiteboard/chalkboard. Note that this exercise will be excellent preparation for presentations you will make at national meetings (*e.g*, the *American Physical Society* or the *Materials Research Society*). For example, *APS* March Meeting speakers are limited to a whopping ten minutes, with two minutes for questions making concise presentation not an option but a **necessity**. Presenting effective, impactful ideas about important topics in a short amount of time is a tremendous challenge that is relevant to nearly all modern-day careers.

The second presentation will be over three articles (including the first one that you presented earlier in the semester) that are all (closely) related. For example, it could be a series of articles disputing some interpretation of a phenomenon or a collection showing how a technique has been developed and improved. This presentation will be 20 minutes long with up to 20 slides. Additionally, you will write a short (not to exceed five pages, including references) paper on your chosen article collection. The presentations will take place on the last week of the semester with the paper being turned in on finals week.

**Academic Honesty**

Academic honesty develops trust and respect between faculty and students, ensures fair and effective grading, and creates an environment that fosters learning. Although you are encouraged to study together with other students, any assignments, exams, and lab submissions must be your own work unless you have been directed by your instructor to work together. Academic dishonesty is defined in University Regulation 802, Revision 2 as "an *act attempted or performed which misrepresents one's involvement in an academic task in any way, or permits another student to misrepresent the latter's involvement in an academic task by assisting the misrepresentation."* There is a well-defined procedure to judge such cases, and serious penalties may be assessed.

**Special accommodations**

If you have a disability and require accommodations, please let the instructor know as soon as possible. You will need to register with, and provide documentation of your disability to, University Disability Support Services (Room 330 Knight Hall; 766-6189; TTY:766-3073; udss@uwyo.edu).

**Expectations**

Consider reading "A&S Students and Teachers—Working Together" found at www.uwyo.edu/as/_files/current/Students%20and%20Teachers%20Working%20Together.pdf . This useful set of guidelines was written by a faculty and student committee. It is a concise attempt to inform students of instructor expectations as well as what students may expect of teachers and advisors.

***What I expect from you:***

- To attend and participate in each class meeting. It is your responsibility to obtain and understand the material presented, even if you are not in attendance due to illness or a University-sponsored activity.

- To make a good effort and to be prompt in completing assignments.

- To spend about 10 hours per week on this course. If you are spending more time than this, please see me so that we can ensure you spend your time efficiently.

***What you should expect from me:***

- To cover the material outlined.

- To administer feedback questionnaires, to better gauge your needs.

- To expeditiously grade and return your work.

Spring 2016 **Tentative** Class Schedule

| Week | Notes |
|---|---|
| Jan. 25th – Jan. 29th | Review of Quantum Mechanics and Electromagnetism. |
| Feb. 1st – 5th | Polarization, photon angular momentum, Jones' matrices, absorption, dispersion, atomic transitions, and susceptibility. |
| Feb. 8th – 12th | Einstein coefficients, oscillator strength, Rabi frequency, Bloch eqns., relaxation processes, coherence, and coherent and squeezed states. *Homework #1 is due Feb. 11th*. |

| | |
|---|---|
| Feb. 15th – 19th | Cavity modes, population inversion, and lasing. |
| Feb. 22nd – 26th | Pulse descriptions and characterization, chirp, auto- and cross-correlations. *Homework #2 is due Feb. 25th.* |
| Feb. 29th – Mar. 4th | Pulse generation, active mode-locking, passive mode-locking, soliton formation. |
| Mar. 7th – Mar. 11th | Interferometers (Fabry-Perot, Gires-Tournois, etc.), group-velocity dispersion, pulse compression, shaping, and picking. *Homework #3 is due Mar. 10th.* |
| Mar. 14th – 18th | *Spring Break* |
| Mar. 21st – 25th | Harmonic generation, parametric processes, OPOs and OPAs. *Homework #4 is due Mar. 24th.* |
| Mar. 28th – Apr. 1st | Terahertz/far-infrared generation and detection. |
| Apr. 4th – 8th | **Mid-Term Exam on April 5th.** Parametric processes. |
| Apr. 11th – 15th | Applications: measurements in atomic and molecular systems. Attosecond pulse generation. *Homework #5 is due Apr. 12th.* |
| Apr. 18th – 22nd | Applications: ultrafast measurements in condensed matter systems. |
| Apr. 25th – 29th | Special techniques and methods: free-electron lasers and strong-field, ultrafast pulses. *Homework #6 is due Apr. 26th.* |
| May 2nd – 6th | Oral presentations of final projects. |
| May 9th – 13th | **Final Exam** |