Physics 471 Class Schedule – Winter 2012

	Monday	Tuesday	Wednesday	Thursday	Friday
January	2 **Holiday**	3	4 Lecture 1: Vector Calculus Reading: 0.1; syllabus; "What you should already know" handout	5	6 Lect.2: Maxwell Eqns Reading: 1.1-1.3
	9 Lect.3: Maxwell Eqns, cont. Reading: 1.4-1.5	10 HW 1	11 Lect.4: Materials, Wave eqn Reading: 1.6-1.7	12 HW 2	13 Lect.5: Complex numbers/ Plane waves/Index of refr. Reading: 0.2, complex numbers handout, 2.1-2.2
	16 **Holiday**	17 HW 3	18 Lect.6: Lorentz model Reading: 2.3	19 HW 4	20 Lect.7: Conductors/Poynting/ Irradiance Reading: 2.4-2.6
	23 Lect.8: Refraction/Reflection Reading: 3.1-3.3	24 HW 5	25 Lect.9: Brewster/T.I.R./metal Reading: 3.4-3.6	26 HW 6	27 Lect.10: Double interfaces Reading: 4.1
February	30 Lect.11: Interfaces at angles Reading: 4.2-4.3	31 HW 7	1 Lect.12: Fabry-Perot Reading: 4.4-4.6	2 HW 8	3 Lect.13: Multilayers Reading: 0.3, 4.7-4.8
	6 Lect.14: Light in crystals Reading: 5.1-5.2	7 HW 9	8 Lect.15: Uniaxial crystals Reading: 5.3-5.5	9 HW 10	10 Lect.16: Polarization states Reading: 6.1-6.3 **Begin Exam 1 (Ch 1-5)**
	13 Lect.17: Jones matrices Reading: 6.4-6.6	14 **End Exam 1**	15 Lect.18: Polar. & reflect/transm Reading: 6.7	16 HW 11	17 L19: Group velocity Reading: 7.1-7.2
	20 **Holiday**	21 L20: Fourier Reading: 0.4, 7.3	22 Lect.21: Delta func./Convolution Reading: Delta function handout, Convolution handout	23 HW 12	24 Lect.22: Group delay Reading:7.4-7.5 (skipping 7.6)
March	27 Lect. 23: Guest lecturer Reading: no assignment	28 HW 13	29 Lect.24: Guest lecturer Reading: no assignment	1 HW 14	2 Lect.25: Michelson/ Temporal coherence Reading: 8.1-8.2
	5 Lect.26: Visibility/Fourier Spectr. Reading: 8.3-8.4	6 HW 15	7 Lect.27: Spatial coherence Reading: 8.5	8 HW 16	**9** Lect.28: Rays Reading: 9.1-9.3 **Begin Exam 2 (Ch 6-8)**
	12 Lect. 29: ABCD matr./Imaging Reading: 9.4-9.6	13 **End Exam 2**	14 Lect.30: Complex imaging Reading: 9.7-9.8	15 HW 17	16 Lect.31: Aberrations Reading: 9.A
	19 Lect.32: Diffraction Reading: 10.1-10.3	20 HW 18	21 Lect.33: Fraunhofer approx. Reading: 10.4	23 HW 19	23 Lect.34: Array Thm/Gratings/ Spectrometer Reading: 11.3-11.5
	26 Lect.35: Cylindrical apertures Reading: 10.5 & Bessel functions handout	27 HW 20	28 Lect.36: Diffraction through lens Reading: 11.1-11.2	29 HW 21	30 Lect.37: Gaussian Beams Reading: 11.6-11.7, 11.A
April	2 Lect.38: Interferogram/Hologram Reading: 12.1-12.4	3 HW 22	4 Lect.39: Blackbody Radiation Reading: 13.1-13.3 **Begin Exam 3 (Ch 9-12)**	5	6 Lect.40: Einstein A & B/Lasers Reading: 13.4 **Exam 3 ends Saturday night**
	9 Lect.41: Color Reading: 2.A	10 HW 23	11 Lect. 42: Color, cont. Reading: none HW 24	12 **Reading Day**	13 **Reading Day** **extra-credit papers due**

Homework Assignments are due Tues/Thurs at 11 pm (building close). Each problem is worth 4 pts unless otherwise indicated.

Exam 1 Assignments

1. P0.1; P0.6; P1.1; L1.10 (8 pts)
2. Colton 1; P1.3; P1.4; P1.11
3. P1.9 (8 pts); P0.14; P0.20; Colton 2
4. Colton 3; P2.2; P2.3 (8 pts); P2.4
5. P2.5; P2.6 (I didn't use the specified equations at all; I think there are typos in the book); P2.7; P2.8
6. P2.10; P3.1 (just derive the far right form of the eqns); P3.3 (6 pts); L3.4 (8 pts)
7. P3.12; P3.14 (additionally, make a plot of R_p); P3.15; P4.2; P4.4
8. P4.6; L4.7 (6 pts); P4.8; P4.9
9. P4.10; P4.13 (6 pts); P4.17 (6 pts); P4.18 (6 pts)
10. P5.2; P5.6 (6 pts); L5.7 (6 pts); R28

Exam 2 Assignments

11. L6.3; P6.5 (2 pts); P6.6; L6.9
12. P6.11; P0.24 (2 pts); P0.25 (2 pts); P0.26(b)
13. P0.28 (6 pts); Colton 4; P7.5
14. P7.6; P7.7; P7.8
15. P8.2; P8.3; P8.4 (for your plot, let $\omega_0 = 1$, $\Delta\omega = 0.1$, and have τ go between -100 and +100)
16. P8.7; L8.8 (6 pts); P8.9

Exam 3 Assignments

17. P9.5; P9.8**;** P9.11 (I used Mathematica to solve the four simultaneous eqns); P9.12
18. L9.13; P9.14; P9.15 (6 pts); L9.17
19. P10.1; P10.2 (6 pts); P10.6 (6 pts; don't do the "make suitable approximations…" part. Hint: "on axis" means $\rho = 0$. Also note that $J_0(0) = 1$.); P10.9
20. Colton 5; P11.7 (you can use Eqn 11.28); P11.8; Colton 6 (6 pts)
21. L11.10; Colton 7 (2 pts); P11.5 (6 pts; d is the distance to the screen); Colton 8 (6 pts)
22. Colton 9 (6 pts); P11.15**;** P12.1; Colton 10

Assignments after exam 3

23. P13.4; Colton 11; Colton 12; Colton 13 (6 pts)
24. Colton 14 (6 pts); Colton 15; P2.13 (Use the function $I(\lambda) = I_0 e^{-((\lambda - 500\,\text{nm})/(20\,\text{nm}))^2}$ instead of the given $I(\lambda)$. Hint: you can create a function from a two-column file of numbers in Mathematica like this: `X=Interpolation[Import["C:/xfile.csv"]];`)

Physics 471 – Winter 2012

Instructor: Dr. John S. Colton, john_colton@byu.edu
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Instructor Office Hours: 3-4 pm MWF, Underground Lab under the skylight (right after class)
Research Lab: U130 ESC, Phone: 422-5286
Website: http://www.physics.byu.edu/faculty/colton/courses/phy471-Winter12/
You can navigate there via www.physics.byu.edu → Courses → Class Web Pages → Physics 471

TAs: Grayson Tarbox, grayson.tarbox@gmail.com and Claira Wilson, claira.wilson@gmail.com
TA Office Hours: 4-6 pm Tues (Grayson), 4-6 pm Thurs (Claira), in the "walk-in lab", S415 ESC.

Prerequisites:

- *Required:* The following are strict prerequisites: Physics 123 and Physics 220.
- *Recommended:* I suspect this class will be prohibitively challenging if you have not yet had any Multivariable Calculus (e.g. Math 214 or Math 302). Also, the BYU catalog lists Physics 318 as a "recommended" prerequisite.
- *Helpful:* There will be many homework problems that require solving or plotting things on a computer. I recommend Mathematica for this, as is taught in Physics 230. Additionally, Physics 441 will certainly be helpful, especially at the start of the semester. Some of Physics 442 is also directly related to much of the material that will be covered on the first exam.

Textbooks:

- *Physics of Light and Optics*, by Peatross and Ware. Required textbook. (Called *P&W*, for short.) This is the main textbook for the class, and can be purchased at the bookstore. We will be using the Oct 5, 2011 version, called "2011c edition". Please make sure you have the right edition, because otherwise (for example) the homework problems will not all match up. The textbook is also available for free online at http://optics.byu.edu. Please download a copy if you wish, but do not use the department printers to print the book from the pdf file since the bookstore is already selling the book at cost.
- *Optics*, by Eugene Hecht. Optional textbook. This is the standard text in the field, and the one that I myself used when I was an undergraduate student at BYU. Its strengths and weaknesses make it the perfect complement for *P&W*: *Hecht* has a ton of qualitative descriptions and applications of the various concepts, but is a bit skimpy on the math. *P&W* on the other hand is much more mathematically intense but lacks a lot of real-world examples. I have turned to my own copy of *Hecht* for reference too many times to count since I graduated from BYU. It's now on the 4th edition, but the 2nd and 3rd editions are about as good and will be much cheaper. (I haven't ever seen the 1st edition, so can't vouch for that.) If you have any inkling of doing optics in graduate school or on a professional level, you should buy this book.
- *Electrodynamics*, by David Griffiths. Optional textbook. This is the standard text for Physics 441 and 442, and overlaps the first part of this course quite a bit. Specifically, *Griffiths* chapters 8 and 9 are directly related to *Peatross & Ware* chapters 1-3—and in my opinion *Griffiths* is a clearer treatment.

Learning Outcomes: This course focuses on the physics of light, and its interaction with matter. Specifically, after taking this course, you should be able to:

- Use mathematical and conceptual descriptions of propagation of light in matter, reflection/transmission at boundaries, polarization effects, interference, dispersion, coherence, image formation, diffraction, and quantum aspects of light to analyze and predict optical phenomena.
- Manipulate and measure properties of light in a laboratory setting.
- Apply mathematical tools such as vector calculus, complex numbers, matrices, and Fourier transforms (1D and 2D) to optical problems.

I also hope that as you learn more about the physical laws governing the universe, your appreciation for the order, simplicity and complexity of God's creations will increase. I sincerely believe that one can come to know the Creator better by studying His creations. I have been struck by these two quotes; hopefully they will be as meaningful to you as they are to me.

Brigham Young:

> Man is organized and brought forth as the king of the earth, to understand, to criticize, examine, improve, manufacture, arrange and organize the crude matter and honor and glorify the work of God's hands. This is a wide field for the operation of man, that reaches into eternity; and it is good for mortals to search out the things of this earth.

Steve Turley (former BYU Physics Department chair):

> My faith and scholarship also find a unity when I look beneath the surface in my discipline to discover the Lord's hand in all things (see D&C 59:21). It is His creations I study in physics. With thoughtful meditation, I have found striking parallels between His ways that I see in the scriptures and His ways that I see in the physical world. In the scriptures I see a God who delights in beauty and symmetry, who is a God of order, who develops things by gradual progression, and who establishes underlying principles that can be relied on to infer broad generalizations. I see His physical creations following the same pattern.

Class Identification Number: Each of you will receive a personal identification number for this course, called a "Class ID" (CID). The purpose of this number is to protect your privacy. If you did not receive your CID by e-mail, you can obtain it from the link on the class website. Include this number—and NOT your name—on all work you turn in.

Student Email Addresses: I will periodically send class information via email to your email address that is listed under myBYU/Route-Y. If that is not a current address for you, please update it.

Clickers: We will use "i-clickers" in class. On the reverse side of your clicker is an alphanumeric ID code for your transmitter. You must go to the course website as soon as possible and register your transmitter ID in order to get credit for your in-class quizzes.

Grading: If you hit these grade boundaries, you are guaranteed to get the grade shown. I may make the grading scale easier than this in the end, if it seems appropriate, but I will not make it harder. Because students are not graded relative to each other, it is to your advantage to learn collaboratively!

A	93%	B+	85%	C+	71%	D+	59%
A-	89%	B	79%	C	65%	D	53%
		B-	74%	C-	62%	D-	50%

Grades will be determined by the following weights:

- Clicker quizzes: 4%
- Homework: 36%
- 3 Midterm Exams: 39% (13% each)
- Final Exam: 21%

Your current grade can be viewed through the class web page. Please check your scores regularly to make sure they are recorded correctly.

Clicker quizzes: There will be clicker-based reading quizzes each lecture which should not be too difficult if you have done the reading assignment. You will get 2 points each for a right answer and 1 point for a wrong answer (for participating). There may be additional discussion clicker questions worth 1 point each (no penalty for being wrong). All of the questions from a given class period constitute a single “quiz” which will be recorded in your grades. You will not be allowed to make up missed quizzes **for any reason** (tardy, excused absence, unexcused absence, registered late, forgot/lost clicker, etc.). However, so that you are not penalized unduly for missing class when circumstances necessitate, you will get four free quizzes: I will convert your four quizzes with the most missed points into perfect scores. I will bend the “no make-up quizzes” rule only if circumstances beyond your control have resulted in you missing more than four class periods.

Midterm Exams: Three midterm exams will be given in the Testing Center and will be available for the days indicated on the schedule. Exams will mainly include worked problems similar to homework problems, but may also require you to give some conceptual answers as well.

Final Exam: A comprehensive final exam will be given in the Testing Center during the week of finals.

Homework: This will be a very homework-intensive class, and homework scores will count as a substantial fraction of your overall course grade. The homework problems for this course are from the Peatross & Ware textbook, with the exception of the ones labeled “Colton 1”, “Colton 2”, etc., which are found later in this packet. As can be seen on the schedule, homework will typically be due twice weekly – on Tuesdays and Thursdays by 11 pm (building close). Turn in assignments to the slot labeled “Physics 471” in the boxes near room N375 ESC. Graded assignments will be returned to the open slots next to those boxes, sorted by the first two digits of your class ID.

Late Homework: Points received from homework problems received after the deadline will be counted as “late points” and will count towards partial credit if turned in within one week of the due-date. (No credit will be given for late homework turned in after that point.) You will receive full credit for late points on the four assignments with the most late points. That is, you get four free late assignments, chosen to maximize your points. You will receive half credit for all other late points. When turning in a late assignment, clearly write, “Late submission” at the top. If you turned in a partially completed assignment for your original homework submission, you can turn in the rest of the assignment late. Again, that will be for half credit, and must be done within one week of the original due-date. In that case please write, “Late submission; previously turned in [*list of problems*] on time” at the top.

Collaboration: You are encouraged to collaborate with other students while working on the homework problems, but remember that “collaborate with” means “work together with” and not “copy from”. Just as it is your responsibility to not copy from others, it is similarly your responsibility to make sure that others do not copy from you. If you do collaborate with others, please acknowledge them in your homework assignment. That is a standard practice for professional scientists and I think students should adhere to this practice as well. On each applicable problem, please write “Worked with [*list of names*]” at the top.

Grading: Most HW problems will be graded out of 4 points: 4 points are earned for a well-presented correct solution. 3 points are earned for a solution with only minor errors, or for a correct but unclear solution. 2 points are earned for a very wrong solution which had a substantial amount of effort. 1 point is earned for a wrong solution with little effort put into it. 0 points are earned if the homework problem is not done at all. Half points may be awarded if deemed appropriate. Problems that are worth a different amount of points are indicated on the schedule.

Lab assignments: Some of the homework assignments will include lab assignments so that you can get hands-on experience. These will be set up in a room that is inside the “walk-in” lab, S415 ESC, in the back corner. Most of the lab assignments have video demonstrations of students completing the labs, which you should view before doing the lab yourself: http://optics.byu.edu/labs.aspx.

Additional Guidance: Follow these general rules when writing up an assignment.

- Take **at least 1 page per problem**. Start each problem at the top of a new page.
- Answers should be **boxed** if appropriate, and (if numerical) should be given to **three or four significant digits** with the appropriate **units**. That means you must use more than three significant digits as you are working the problem, so that you don't have rounding errors in your final answer.
- **Staple** your problem set using an actual staple (not a fold), with your problems **in order**.
- **Be neat**. If needed, work the problem out first on scratch paper before making a neat final copy. Neatness is important because it shows you **take pride in your work**.
- **Explain yourself** as you go along, as needed. If the grader has difficulty following your work you will lose points, even if you get the correct answer.
- Think about whether **your answer is reasonable** (e.g. can an electron move at 10^9 m/s?). If you get an unrealistic answer, figure out what you did wrong.
- **Consult your colleagues.** I strongly recommend you talk with one or more of your fellow students before the homework is due, to make sure you got the same answers. If you turn in an incorrect solution without first consulting with others, you really have only yourself to blame when you lose points. And as mentioned previously, remember to **acknowledge your collaborators** by writing e.g. "Worked with John Smith and Jane Doe" at the top of problem 3.

T.A. discretionary points. Each homework assignment will include a standard 3 points to be given at the TA's discretion, used to grade the legibility of your work. If the assignment is reasonably neat and complete, you will get the full 3 points. If it is messy, missing sections, not stapled, etc., then the TA will reduce your points accordingly.

Homework solutions. Homework solutions will be posted in the hallway by the CSR's office, around the corner from where you turn in the homework, typically a day or two after an assignment is due. When you have missed problems, it's a very good idea for you to look at how the problems should have been worked. Solutions will only stay posted for a week or two, so don't miss out. Because many of these problems are re-used from year to year, please do not take photographs of the posted solutions or make your own solutions available to future students.

Extra Credit: There are two types of extra-credit papers you can write during the semester.

1. Book review. This is a book review of an optics-related book that you read during the semester, written in a style similar to book reviews that you find on amazon.com. The book could be on an optics-related topic (e.g. lasers), or on an optics-related person (e.g. a biography of any of the scientists mentioned in the course), or anything else like that. Not a textbook, just a "regular" book. If you want to do this extra-credit assignment, you must get my (Dr. Colton's) approval of the book first. For the review, you must include at least this much this information: (1) title and author of the book, (2) a rating out of five stars, (3) a paragraph description of what the book was about and how it relates to optics, and (4) a paragraph with your personal assessment of the quality of the book. Your review will be graded out of 6 points based on the quality of the writing and helpfulness/completeness of the review, the maximum score being the equivalent of +6 points on one of your midterms. This extra credit item can be done twice during the semester. Send your review(s) to Dr. Colton via email.

2. Physics-related lecture. This is a brief report of a physics-related lecture you attended during the semester. At a minimum you must include this information in your report: (1) name of speaker, (2) time/place of lecture, and (3) some info about what kind of physics was discussed and how it relates to optics, (4) at least one thing you learned that you (hopefully) found interesting. This could be one of the weekly Physics Department colloquia or any other optics-related science lecture that you can find. Prior approval is not needed, just be sure it relates somehow to optics. Your report will be graded out of 2

points, the maximum score being the equivalent of +2 points on one of your midterms. This extra credit item can be done twice during the semester. Send your report(s) to Dr. Colton via email.

BYU Policies:

Prevention of Sexual Harassment: BYU's policy against sexual harassment extends to students. If you encounter sexual harassment or gender-based discrimination, please talk to your instructor, or contact the Equal Opportunity Office at 801-422-5895, or contact the Honor Code Office at 801-422-2847.

Students with Disabilities: BYU is committed to providing reasonable accommodation to qualified persons with disabilities. If you have any disability that may adversely affect your success in this course, please contact the University Accessibility Center at 801-422-2767, room 1520 WSC. Services deemed appropriate will be coordinated with the student and your instructor by that office.

Children in the Classroom: The serious study of physics requires uninterrupted concentration and focus in the classroom. Having small children in class is often a distraction that degrades the educational experience for the entire class. Please make other arrangements for child care rather than bringing children to class with you. If there are extenuating circumstances, please talk with your instructor in advance.

“Colton” HW problems

1. Let $\vec{E} = (7x^2y^3\hat{x} + 2z^4\hat{y})\cos\omega t$.
   a. Find $\rho(x, y, z, t)$.
   b. Find $\dfrac{\partial \vec{B}(x,y,z,t)}{\partial t}$.
   c. Determine if the given **E** is a solution to the wave equation, Eqn 1.43.

2. A certain electromagnetic wave is traveling in the (2, -1, 3) direction, and oscillates in the (1, 2, 0) direction. Note that neither of those vectors has been normalized. The wave’s electric field amplitude is 5 V/m, its wavelength is 13 m, and its speed is obviously 3×10^8 m/s. Write down the proper exponential “wave function” which describes the electric field of the wave.

3. Complex optical constants
   a. Gallium arsenide (GaAs) is a semiconducting material. For photons with energy 2 eV, it has n = 3.86 and κ = 0.20.
      i. What wavelength does that photon energy correspond to?
      ii. What complex susceptibility do those n and κ values correspond to?
   b. According to this website, http://www.kayelaby.npl.co.uk/general_physics/2_6/2_6_5.html, a certain plastic (“aniline resin”) has a complex dielectric constant ε equal to 3.5 + 0.175i at 3 GHz.
      i. What wavelength does that frequency correspond to?
      ii. What n and κ values does that ε correspond to?

4. Convolution of three pulses
   a. Use the results from problem P0.28(c) and a convolution theorem to evaluate the Fourier transform of *h*(*t*) which consists of three Gaussian optical pulses of the form $e^{-t^2/2\tau^2}\sin\omega_0 t$, but each separated by a time t_0. The three Gaussians are centered at $t = -t_0$, $t = 0$, and $t = t_0$. Hint: the three pulse function *h*(*t*) is a convolution of $e^{-t^2/2\tau^2}\sin\omega_0 t$ with three delta functions. Here is a good check for your final answer: if you set $t_0 = 0$, the three pulses are on top of each other, so you should get 3× the answer to problem P0.28(c).
   b. Plot *h*(*t*) and the imaginary part of its Fourier transform for the parameters $\omega_0 = 1$, $\tau = 8$, and $t_0 = 30$.
   c. This *h*(*t*) is “longer” in time than the single pulse in problem P0.28(c). Should its Fourier transform be broader or narrower than the F.T. in that problem? Comment on what you see in the plots.

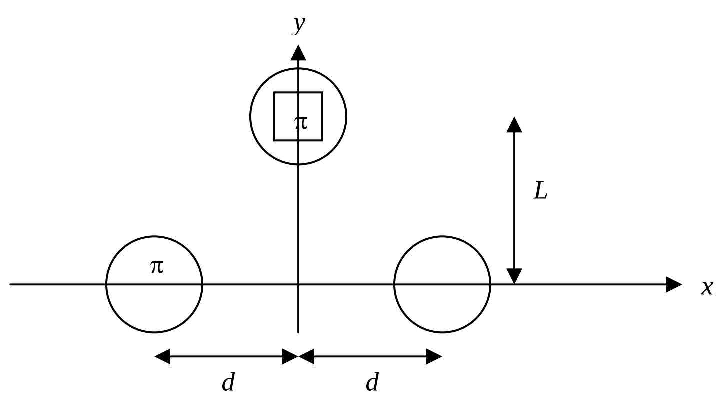
5. Use the convolution theorem to find the (1D) Fourier transform of the aperture functions for 3 slits, 4 slits, and 5 slits. The slits all have width “*a*”, are separated by a distance “*d*” (from center to center), and are symmetric about the origin. You can ignore factors of $\sqrt{2\pi}$ that arise from the convolution theorem. *Hint*: We did this for 2 slits in class. Use the same method. Make plots of your results for some “friendly” choice of parameters.

6. Diffraction Lab 1. Take careful measurements; you will be graded in part on accuracy (based on the TAs’/my own measurements, which may or may not agree with any printing on the apertures). There are two 633 nm lasers set up in the lab: one has its beam expanded (via two lenses), the other does not. Use the expanded beam only for part (a), and don’t touch the lenses. For all of the following parts, make sketches of the diffraction pattern in addition to any quantitative calculations that may be called for. *Hint*: your quantitative measurements may be easiest to make by tracing the diffraction

pattern onto a piece of paper, and then measuring the spots on the paper rather than trying to measure the spots directly on the wall.

a. Poisson spot. (Qualitative only.) Use the glass slide with the glued-on metal ball to look at the Poisson spot. You may not be able to see it for all distances, and it may not be centered perfectly,* but you should be able to see a bright spot within the ball's shadow.
b. Slits. Use the red slide labeled "1 2 3 4 5 6". The numbers correspond to the number of slits at that position. The slits at a given number may or may not be the same width/spacing as the slits at a different number (although it turns out that they are close). For positions 2, 3, 4, and 5: measure the separation of nearby bright peaks and the distance from the center to the first long-range minimum to determine the separation of the slits and the width of the slits, respectively. *Hints*: Use the general principle that the spacing between slits governs the fine structure and the width of the slits governs the overall modulation. Use your results from the "Colton 5" HW problem to guide you; think carefully about the period over which the fine structure should repeat in each case. In general the fine structure will be much easier to see and measure than the overall modulation. You can look at position 1 to qualitatively see what the overall modulation should look like for the rest of the positions.

7. Some more questions about the Jarrell-Ash spectrometer (aka monochromator).
   a. Measure the width of the first mirror. What is the f-number of the spectrometer?
   b. Although "light in" is indicated with an arrow, if you collect light that is emitted from a material by focusing the light down onto the spectrometer slit with a lens, you will actually typically have a *cone* of light focused on the entrance slit. What angle in the plane of the spectrometer should you pick for the incoming light cone?



8. A diffraction screen has apertures as arranged in the diagram above.** All the circles are of radius b, and the square, which is centered in the upper circle, is of side a. Light comes through all the circles and the square, but the letter π indicates those regions where the light coming through is 180° out of phase with light coming through the other regions. Thus the square is 180° out of phase with the rest of the upper circle, and the left circle is 180° out of phase with the right circle. The distances d and L are also given as indicated. (d is perhaps a poor choice of letters; use D for the distance to screen.)
   a. Find the diffraction pattern for the upper aperture alone—that is, the circle-square combination.
   b. Find the diffraction pattern for the lower two apertures alone (omitting the upper square-circle combination)
   c. Find the diffraction pattern for all the apertures together.
   d. Extra mile opportunity: make 3D plots of all of your answers, for the situation where (in some choice of units) $a = 1$, $b = 1$, $d = 3$, $L = 3$, and $k/d = 1$.

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* Probably due to the expanded beam not being exactly a plane wave.

** Note: this was an actual exam problem from when I took Optics here at BYU, on a timed exam in the Testing Center (exam date: April 21, 1994).

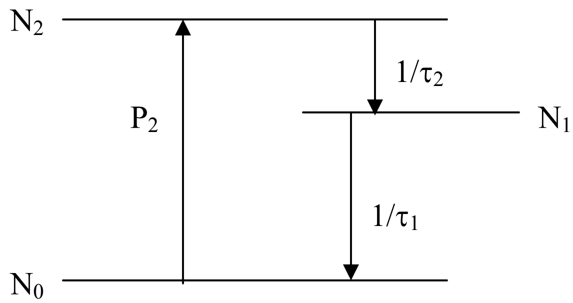
9. Diffraction Lab 2. Continued from Diffraction Lab 1, above.
    a. Grating. Use the grating marked "Fraunhofer slide 5". Use the separation of maxima to determine the distance between slits. Estimate the width of each the central maximum and use that with the formula we've discussed in class to estimate how many slits are illuminated by the laser. Do your answers to the previous two questions make sense with how big the laser beam looks?
    b. Slide marked "Fraunhofer 0.04 0.08 circular apertures". This slide contains three different apertures:
        i. A single circular aperture (it's tiny, hard to see). Use the width of the Airy disk to determine the radius of the circle.
        ii. A rectangular array of circles (on the far side from the single circle). Use the separation of maxima to determine the vertical and horizontal distances between apertures. Use the long-range minima to determine the size of the circles.
        iii. A hexagonal array of circles, located in-between the two previous apertures. Just observe qualitatively what the diffraction pattern looks like. I think it's cool.

10. The simplest possible hologram is when the object beam is a plane wave; the interference would produce a diffraction grating structure.
    a. Show by adding the E-fields of two plane waves that the interference between an object beam (at angle θ_0) and a reference beam (at zero angle) create an intensity grating on a screen that has a fringe period: $\Lambda = \lambda/\sin\theta_0$.
    b. Show that when this grating is illuminated by a beam at zero angle, it produces a diffraction beam into the direction θ_0.

11. For this problem, assume that the emissivity of both the Sun and the Earth is equal to 1.
    a. *P&W* P13.1.
    b. Assume that the Sun's power is radiated in all directions. How much reaches the Earth? Look up the Earth's radius, and the radius of the Earth's orbit. Hint: the sphere of the Earth intercepts the same amount of light that a circular disk facing the Sun would.
    c. Assuming the Earth is in thermodynamic equilibrium, it must radiate out as must power as it absorbs (otherwise it would heat up uncontrollably). Use that fact to get a theoretical value for the average temperature of the Earth. (Assume that the earth is a perfect blackbody absorber as well as radiator.) Compare your answer with the experimentally measured average temperature of the Earth's surface,[*] about 14°C; comment on possible reasons for the discrepancy.

12. From *Hecht.*
    a. A somewhat typical person has a surface area of 1.4 m^2 and an average skin temperature of 33°C. Assume an emissivity of 97%. How much *net* heat power does the person provide in a 20°C room? (Net = power radiated – power absorbed.) Compare your answer to a typical incandescent light bulb.
    b. At what wavelength will the person be radiating the most energy? At what wavelength will the surroundings be radiating the most energy? (Use Wien's displacement law from P13.4.) What do these answers imply about "night vision goggles"?

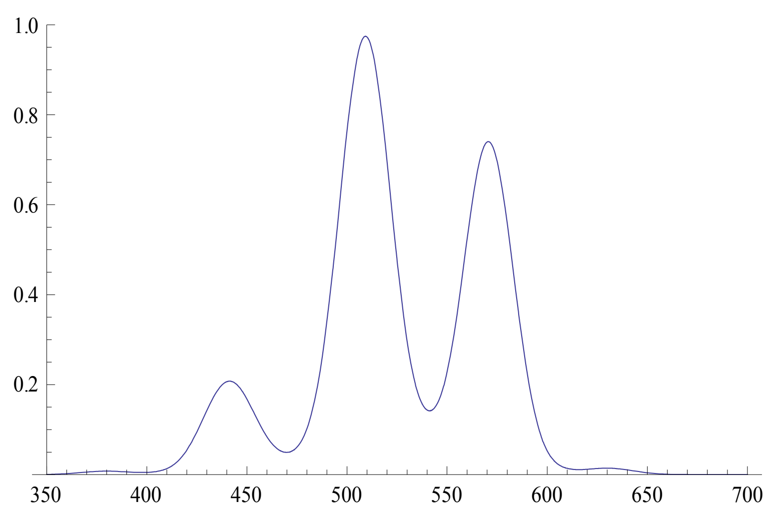
[*] http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf, figure SPM.3



13. Suppose you have a three-level system as indicated above.* In the figure, N_0, N_1, and N_2 refer to how many electrons per cubic meter, exist in those states. In this system, the pump (i.e. caused by electron injections, flashlamps, another laser, etc.) excites atoms from state 0 to state 2 at a rate of P_2 electrons/m^3, per second. The τ's are spontaneous emission lifetimes. To make this problem easier, let's assume state 0 is not depleted to any significant extent for any time (i.e., $dN_0/dt = 0$), and neglect stimulated emission.
    a. What are the rate equations for states 2 and 1?
    b. Assuming the initial concentrations $N_1(t = 0)$ and $N_2(t = 0)$ are both equal to 0, determine the densities $N_2(t)$ and $N_1(t)$ as a function of time.
    c. Suppose τ_2 is 1 μs, τ_1 is 2 μs, and $P_2 = 10^{20}$ cm^{-3}/s. Plot the expressions you obtained for part (b). Over what time interval is the population difference $N_2 - N_1 > 0$?
    d. What are the steady-state populations in states 2 and 1? ("Steady state" = "after a long time".) Can this system lase between states 2 and 1 in steady state?

    Some comments: You should find in part (d) that it cannot lase steadily. This system is a reasonable model for the pulsed N_2 laser, which lases at 337 nm; its major drawback is that the population inversion cannot be maintained indefinitely.

14. A light produces the following spectrum, I vs λ (nm).



    a. Compare this to the colors of the rainbow and make a reasonable guess for what color this light would look to you.

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* Real systems of course have more levels then this, but this is a good model if the transitions that are not shown here have slow enough rates that they essentially do not participate in the process.

b. Do the integrals $X = \int I(\lambda)\bar{x}d\lambda$ and so forth, to obtain X, Y, and Z. Since you don't have an analytic form for the spectrum $I(\lambda)$, I recommend you do each integral by first multiplying $I(\lambda)$ by the color matching functions graphically, then estimating the area under the three resulting curves.*
c. Compute the chromaticity coordinates *x*, *y*, and *z*.
d. Use the chromaticity diagram to determine the hue and saturation. How does the hue compare with your guess in part (a)?
e. Plot the sRGB color triangle on your chromaticity diagram. Estimate (fairly carefully) the relative R, G, and B values you would need to use in order to reproduce this color, assuming it falls within the sRGB gamut (if it doesn't, show why not). I.e. this color would be what percent R, what percent G, and what percent B?

15. Two equally bright lights, A and B, have chromaticities (*x*, *y*) of (0.4, 0.2) and (0.5, 0.4) respectively. They are produced by letting white light shine through two colored filters, which are also called A and B.
    a. Locate A, B, and the white point W on a chromaticity diagram.
    b. Use your diagram to estimate the hue and saturation of A.
    c. Repeat for B.
    d. Now let equal amounts of lights A and B illuminate a white object. Find the chromaticity of the object in this light and estimate the hue and saturation of that color. Show your construction on your diagram; label the resultant point A + B.
    e. If white light is sent through both filters in succession, what is the resulting color? Use simple subtractive color laws for the hues obtained in parts (b) and (c).

* When I did this for e.g. x-bar, I picked several points (~10) across the spectrum and multiplied I(λ) point-by-point by x-bar to obtain the product function I times x-bar. Then I plotted the product function, drew a rectangle of approximately the same area as that product function, and calculated the area of the rectangle to get X. Same thing for Y and Z.