Your Name: ______________________________

Teammates: ____

Physics 8, Fall 2021, Worksheet #27.

`http://positron.hep.upenn.edu/p8/files/ws27.pdf`

Upload PDF (smartphone scan or tablet edit) to Canvas shortly after class on Wed, Dec 8, 2021.

Problems marked with (*) must include your own drawing or graph representing the problem and at least one complete sentence describing your reasoning.

Discuss each problem with your teammates, then write up your own solution. Be sure to compare final results with your teammates, as a way to catch mistakes. It can also be very interesting when you and a teammate use different methods to arrive at a result! Do not hesitate to ask for help from other students, from Melina, or from Bill.

Today's two problems are intended to illustrate for you how the physics of beams is used in practice. Both problems are adapted from Onouye/Kane chapter 8, and are similar in spirit to beam questions that you will consider if you take Prof Farley's structures course in your senior year.

If you finish these problems quickly, you can earn some extra credit by doing more parts of the (quite lengthy) hands-on beam activity (with meter sticks, etc) from last week's ws25. Or you can just keep working on the exam problems.

1. (Counts double.) The formula for the maximum vertical deflection (i.e. the deflection at mid-span) of a simply supported beam under uniform load w (vertical force per unit length) is $\Delta_{\max} = (5wL^4)/(384EI)$, where L is the length of the beam, E is Young's modulus, and I is the second moment of area (a.k.a. "area moment of inertia"). Typically the maximum allowable deflection of a beam of length L is $\frac{L}{360}$, to prevent plaster ceilings from cracking under excessive deflection, etc. (a) Using the $L/360$ rule, what is the maximum allowed vertical deflection, $\Delta_{\max}$, of a beam of length $L = 4.5$ m? (b) If the beam is designed to carry a load of 100 kg/m, what is w in N/m? (I chose these numbers to correspond to 50 pounds per square foot at a spacing between beams ("joists") of 16 inches.) (c) If the beam is made from southern pine timber having Young's modulus $E = 1.1 \times 10^{10}$ N/m^2, what minimum value of I (second moment of area) is required? (d) If the beam has a rectangular cross-section of width $b = 0.038$ m (1.5 inches), what minimum vertical depth h is required to obtain this value of I? Remember $I = bh^3/12$ for a rectangular cross-section. (e) Would a 2×10 wooden beam (cross section 1.5 in $\times$ 9.5 in) suffice for the required depth you calculated? (Note: in real life, deflection is one of several criteria that a beam must satisfy; other criteria include maximum bending stress, maximum shearing stress, and lateral stability, as discussed in O/K chapter 8.)

2. (Counts double.) In problem 1, we went step-by-step through a beam design whose only criterion was allowable deflection (which is a "stiffness" criterion). Now let's try a beam-design problem in which we evaluate allowable bending stress (which is a "strength" criterion), as in O/K §8.2. Imagine a set of floor joists, of length $L = 4.5$ m, spaced at 0.40 m intervals, designed to support a uniform load of 2400 N/m^2. (I chose these numbers to correspond roughly to 50 pounds per square foot load, 16 inch joist spacing, 15-foot span.) (a) What is the load, in N/m, carried by each floor joist? (Multiply load per unit area by joist spacing to get load per unit length of each joist.) (b) Considering each floor joist to be a simply-supported beam, draw the usual load, shear (V), and bending moment (M) diagrams for one floor joist. (c) From your bending-moment diagram, what is the maximum bending moment that the beam (joist) must resist? For the given loading and support conditions, this maximum should occur at mid-span. The answer should be in newton-meters. (d) Our floor joists will be made of southern pine timber having allowable bending stress $F_b = 10700$ kN/m^2 (that's 1.07×10^7 N/m^2, which is about 1550 psi in US customary units). Given that $S_{\text{required}} = M_{\text{max}}/F_b$, what is the required section modulus S for this floor-joist design? Your answer should be in m^3, but a meter is quite large compared to the transverse dimensions of a floor joist, so you will get a number that is a small fraction of a cubic meter. (e) For a rectangular beam, the second moment of area is $I = bh^3/12$, and the distance from neutral axis to extreme fibers is $c = h/2$. So the section modulus for a rectangular beam is $S = I/c = bh^2/6$. If $b = 0.038$ m (that's 1.5 inches, the width of "2 × 6," '2 × 8," "2 × 10," "2 × 12" etc. dimensional lumber that you would buy at Home Depot), what minimum value of h is required, to get the necessary minimum section modulus? (f) Convert your answer for part (e) to inches. Would you need a "2 × 6" ($h = 5.5$ in), a "2 × 8" ($h = 7.5$ in), a "2 × 10" ($h = 9.5$ in), or a 2 × 12 ($h = 11.5$ in) for each floor joist? (g) Remember that for identical conditions in problem 1, the "$L/360$" deflection rule required us to use "2 × 10" floor joists. Which design criterion (allowable bending stress vs. allowable deflection) turned out to be more stringent in this case? (Quote from my copy of the ARCH 435 notes, quoting Prof. Farley's lecture: "Sizing of a beam will almost always be dependent on the deflection equation; rarely shear or bending.")

3XC*. If you finish the above problems quickly, you can earn some extra credit by doing more parts of the (quite lengthy) hands-on beam activity (with meter sticks, etc) from last week's ws25. If you do this, just very briefly spell out what you did in whatever way you find convenient.

Here (and continuing onto the next page) are some questions that you might consider answering anonymously in your course evaluation. (You can also feel free to write to me directly, if you wish, so that I can follow up on your suggestions.)

I'll preface these with a comment. My whole approach to teaching rests on three key ideas. One is that the only way to learn something is by **doing** it, not just by watching someone else do it.[1] The second is that effective teaching usually resembles coaching: that transforms my role from being "the sage on the stage" to being "the guide on the side."[2] The third is that college teaching is constrained by two scarce resources: the hours we can spend together in a classroom, and the total number of hours that I can reasonably ask you to spend each week on my course. A big part of my job is to make the limited time that we have as worthwhile and as effective as possible for your learning. Toward that end . . . .

What are the pros and cons of the round-table format, vs a traditional auditorium lecture format? I enjoy this format, as it gives me more opportunity to work with you individually and to get to know most of you. (This is our first year in this format.)

Would standing up to present your group's solution to one problem each day (or maybe each week) have a positive or a negative effect on your experience in this course? (Some SAIL-format physics courses do this. I'm not convinced that it's the best use of time.)

Do you like the hands-on activities? I would like to add many more of them in future years.

Would you enjoy a project-based component of the course? For example, the USC "Physics for Architects" course has students design and assemble a scaled-down hirise about half a meter tall. They then compete to see whose design can withstand the most intense earthquake, simulated using a "shake table" that oscillates horizontally.

If we add a lot more project-based or hands-on time to the course, how should we manage the time? Should some problem-solving be done at home? Should we add a Friday meeting time, in addition to MW? Should we cut back on something?

What grading/assessment scheme would best motivate you and future students to learn as much physics as you can, at a pace that is manageable? Would you want weekly online quizzes (different people getting different questions)? Quizzes in class every other week? Traditional midterm exams? No exams whatsoever?

Comment on the seating system. (The SAIL-course experts feel that both "seating" and "assessment" are important to get right.) It seemed to me like a pretty good balance that you were always in same group of 3 ± 1 students, but your group shared a table with a

[1] When I teach physics majors, I show them this quote from Prof Mary Boas (*Mathematical Methods in the Physical Sciences*): "One point about your study of this material cannot be emphasized too strongly: To use mathematics effectively in applications, you need not just knowledge but *skill.* Skill can be obtained only through practice. You can obtain a certain superficial *knowledge* of mathematics by listening to lectures, but you cannot obtain *skill* this way. How many students have I heard say, 'It looks so easy when you do it,' or 'I understand it but I can't do the problems!' Such statements show lack of practice . . . ."

[2] I'm paraphrasing Prof Eric Mazur here.

randomly chosen other group each day. To my mind, this system maintained camaraderie while letting you get to know nearly all of your classmates.

Is the total weekly time commitment appropriate? How would you change either the total time or the balance of how the time is spent? What is the appropriate number of total hours per week (in class plus at home) for a 1 CU Physical World Sector course?

Comment on the meeting time. I intend to use MW 1:45-3:15pm in future years, if possible. Note that ARCH majors spend all afternoon TR in studio.

Are video lectures helpful? If so, should they complement textbook chapters, or should they completely replace textbook chapters, with the textbook there only if needed for reference? If not, what do you propose instead? (In past years, students read chapters carefully, then participated in lecture, to the degree possible in an auditorium.)

Would you prefer to do some problem-solving at home? Maybe with an optional zoom-breakout recitation?

Would it be helpful if some or all of the semester consisted of a menu of modules that your workgroup could complete, with different groups potentially choosing different modules from the menu?

A propos modules, would it be helpful if I put together a short "calculus boot camp" module (feel free to suggest a better name!) that covers just enough calculus to make you more comfortable with our use of calculus in this course? I feel that it is my job here to help you to learn useful things, so if you would find this helpful, I would be happy to do it.

If you have an opinion on whether or not we should continue to offer this course, or what its niche should be, I think it could be helpful for you to put that opinion into your course evaluation, where it may carry more weight than if you tell me directly. [If you're in ARCH, you might also consider making your opinion (pro or con) known to the incoming chair of the undergrad ARCH program.] An alternatve would be for ARCH majors simply to take PHYS 150 (1.5 CU, 6 contact hours/week with lab), and for others to seek out other Physical World Sector options. A downside of offering this course is that its enrollment is smaller than a section of PHYS 150 or PHYS 101, and it is thus in some sense more costly. An upside is that ARCH majors have a dedicated physics course (two of them, in fact) tailored to your interests, your learning style, and your studio schedule, which neatly fits into the College sector requirements. For ARCH majors, my main goal is to leave you in excellent shape to take a structures course later, such as ARCH 435. For others, my main goal is to exercise your math brain (a valuable life skill, I feel) in a way that makes physics feel like a source of worthwhile insights into the everyday world, not just a set of abstract equations. And I want to leave all of you confident that you really can "do physics," whether or not it was a favorite subject in high school.

It has been my pleasure to serve as your "coach" in your study of physics this semester. Best wishes to every one of you for a happy, safe, and healthy new year.