Topics in Physics: Problem Set #7

Topics: electromagnetism, light, diffraction, geometric optics

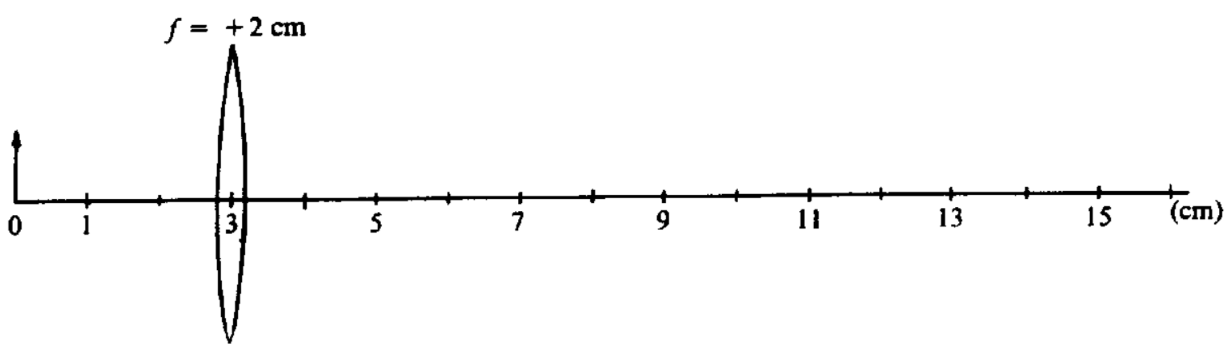
General TA instructions

- Give students the estimated time for each section, and plan to spend about 50% of the estimated time going through answers.
- Try not to go over time for the earlier sections, since many of the more interesting activities are at the end of the assignment.
- Ask for student volunteers to explain their answers and discuss discrepancies.
- Be stingy with hints, but if a student seems legitimately stuck or won't finish the section in time, try to walk them through how to solve the problem without giving them the answer. You could also have them discuss with any students who have finished the section.

Practice Problems (approx. 60 min)

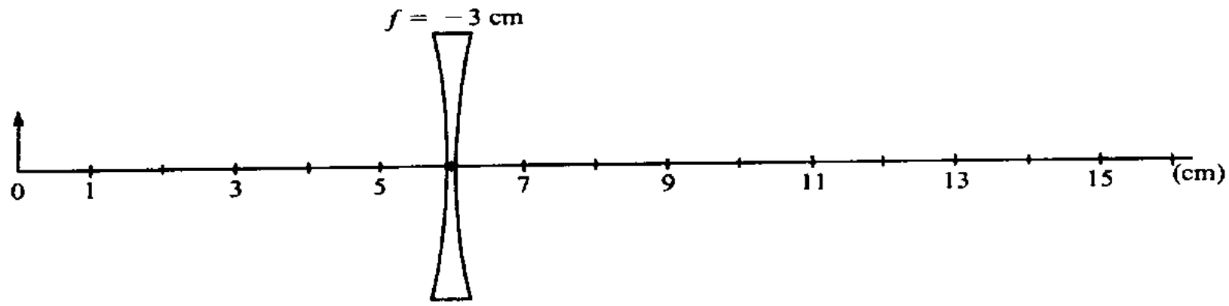
You should try to do these problems individually. None of them should take very long to solve; if you get stuck, ask a TA for help!

1. If you are underwater in a still pool, what range of angles are you able to see upwards out of?
2. An object is placed 3 centimeters to the left of a convex (converging) lens of focal length $f = 2$ centimeters, as shown below.



   (a) Sketch a ray diagram on the scenario to construct the image.
   (b) Determine the ratio of image size to object size.

3. The converging lens is removed and a concave (diverging) lens of focal length $f = -3$ centimeters is placed as shown below.



(a) Sketch a ray diagram of the figure above to construct the image.

(b) Calculate the distance of this image from the lens.

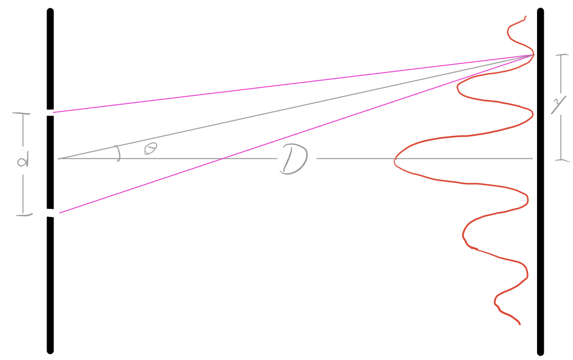
4. Get a red laser pointer from the supplies, and use one of the 500mm^{-1} or 1000mm^{-1} diffraction gratings to determine its wavelength.

Challenge Problems (approx. 75 min)

You may work in small groups to solve these problems, but each student should submit and understand their own answer. These problems are challenging but not impossible to solve. If you get stuck, ask another student or a TA how to approach the problem, and if you are helping another student, try to explain so they understand how to solve the problem (don't just give them the answer). Show all your work and walk the reader through the solution; you may get feedback on both the approach and the clarity of your solutions.

Problem 1: deriving double-slit diffraction

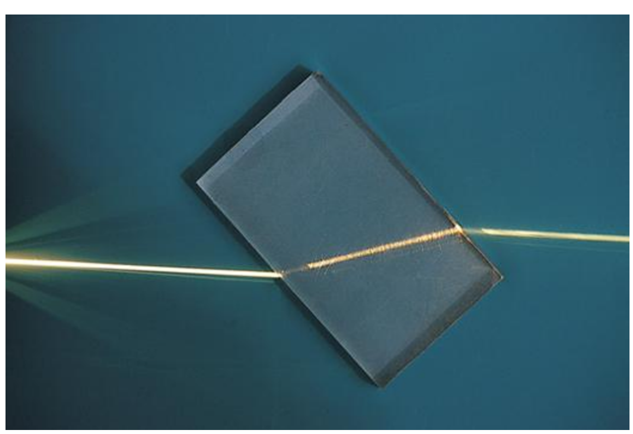
The double-slit experiment is one of the most important experiments in modern physics. In 1801, Thomas Young first performed the experiment on a beam of light, but it would later be used to show in 1927 that electrons – and in fact all particles – have a wave-like nature. In this problem you'll derive an expression which determines where the fringes are located on a distant screen. You won't be given much guidance on this derivation, but it is similar to some of the ones we did in lecture.



Refer to the figure above. A double-slit with slit separation d is a distance $D \gg d$ away from a screen. Light with wavelength λ is incident on the setup and creates a fringe pattern on the screen. Denote the vertical displacement from the center fringe as y. Determine expressions for the location of maximum intensity fringes $y_{\max}$ and for the location of minimum intensity fringes $y_{\min}$, assuming in both cases that $D \gg y$. Both of your expressions should involve only λ, D, d, and n, where $n \in \mathbb{Z}$.

Problem 2: refraction action

Prove that a beam entering a planar transparent block, as shown below, emerges parallel to its initial direction. Derive an expression for the lateral displacement of the beam.



Problem 3: electric generators

An electric generator works exactly as the inverse of an electric motor. Suppose you have a generator which consists of 100 turns of wire formed into a rectangular loop 50.0 cm by 30.0 cm, placed entirely in a uniform magnetic field with magnitude $\|\vec{B}\| = 3.5\text{T}$. What is the maximum value of the voltage produced when the loop is spun at 1000 rev/min about an axis perpendicular to $\vec{B}$?

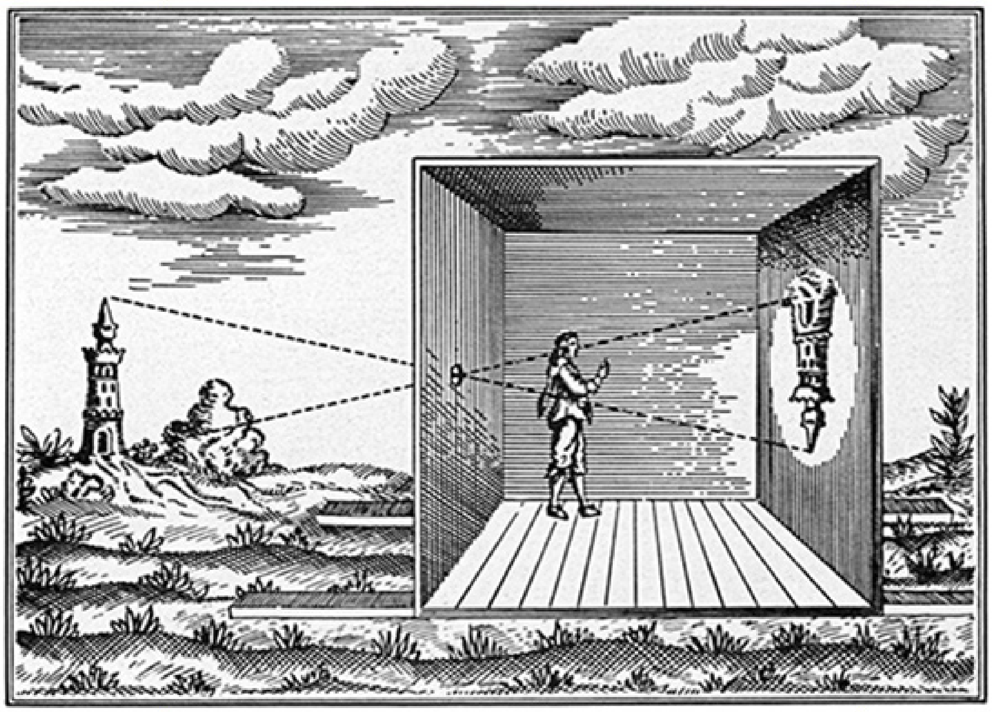
Problem 4: mirror mirror on the horizontal wall...

Why does your reflection in a mirror look flipped horizontally but not vertically?

Activity: room-scale camera obscura (approx. 45 min)

A camera obscura, also referred to as pinhole image, is the natural optical phenomenon that occurs when an image of a scene at the other side of a screen is projected through a small hole in that screen as a reversed and inverted image. The surroundings of the projected image have to be relatively dark for the image to be clear, so many historical camera obscura experiments were performed in dark rooms.

The camera obscura was used as a means to study eclipses, without the risk of damaging the eyes by looking into the sun directly. As a drawing aid, the camera obscura allowed tracing the projected image to produce a highly accurate representation, especially appreciated as an easy way to achieve a proper graphical perspective.



In this activity, you'll make room-scale camera obscura! The procedure is very simple. Find a room with a window that has a large blank wall opposite of it. Using masking tape and the large roll of black paper, black out all of the windows in the room. Finally, use a knife or pair of scissors to cut a small circular hole (about 1 inch diameter, but this isn't critical) in the paper. Ideally, the room (1) has a large flat surface to project on, (2) has an interesting view, and (3) is easily made dark (e.g. connected to any other rooms by closable doors). Take some pictures when you're done!