

Tutorial Instructor's Guide

Wave properties of light

Equipment:

- A shallow pan for water. The best is a jelly-roll pan (cookie sheet with one-inch-tall sides), but I think all we have around is plastic dishpans, which are minimally acceptable. One per table.
- A bucket of water. One for the room, with a way to refill it.
- Paper towels aplenty.
- A wooden dowel a bit shorter than the width of the pan, so that it fits into it. The dowel will be rolled back and forth or tapped to make periodic waves in the water. One per table.
- Wooden blocks or sponges cut into rectangles. The sponges or blocks need to sit calmly on the bottom of the pan, not bob around. Enough for each table to make a little wall in their pan of water, with a variable-width gap in the middle of the wall for waves to go through.
- Prepared photographs of periodic waves in water: each sheet has six photos on it, with a variety of wavelengths and hole sizes, and is in a sheet protector. One per table.
- Enlargements of the diagram for part II.B, showing the wavefronts for the case in which the distance between two slits is 3λ . (The enlargement shows the wavefronts even though the diagram in part II.B does not; this helps force students to work together on the enlargement instead of individually in their workbook.) One per table per section (these are “used up”).

This tutorial helps students understand two-source interference of light in terms of two-source interference of water waves. The analogy is very close.

Each tutorial should begin with each table having their own pan of water, already set up with a dowel and a wall of sponges/blocks. Withhold the sheet of photographs and the diagram of waves from two slits until later.

Note: Starting especially on the second page, this tutorial builds strongly on last week's tutorial (*Two-Source Interference*). Students who weren't fully engaged last week (or weren't there) are likely to suffer. If they're doing *Multiple-Slit Interference* next week, it's only going to get worse.

There are no explicit checkpoints in this tutorial. The idea is that by now, students should have developed some decent judgment about when to consult a TA, and TAs should be getting better at actively monitoring students all along. However, anyone who's more comfortable with explicit checkpoints is welcome to insert them.

I. In this part students observe how straight wavefronts in water are affected by passing through a gap in a barrier.

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A. In this part, students observe real water waves in real water.

The setup for each table is as follows: Pour maybe one inch of water into the dishpan. Place a dowel in the dishpan so that it's parallel with the short side of the dishpan. Use blocks to make a wall across the dishpan, close to the dowel but leaving enough room to rock the dowel back and forth. The blocks need to sit securely on the bottom, not bob about. Use an arrangement of blocks that allows students to vary the width of a gap in the center of the wall without creating new gaps elsewhere (that is, overlap the blocks). Leave as much space as possible on the non-dowel side of the wall, since that's where students will observe effects.

Students should start with a wide slit, and rock or tap the dowel to create straight wavefronts at a constant rate. They should be able to see straight wavefronts on the other side of the gap. This is not the easiest observation in the world to make; the dishpans are kind of small for the purpose, the lighting is bad, students slosh the water too much and don't know what they're looking for. Help them focus.

1. As students reduce the width of the gap to a slit, they should notice that the wavefront is overall more curved, approaching a semicircular shape for a narrow slit. For very narrow slits, the amplitude of the transmitted wavefronts is small, so it can be harder to see what's going on, but you can still see it.
2. Again, students don't think they can see what they need to see, but actually they pretty much can. The spacing of the wavefronts is about the same before and after the slit, no matter what the width of the slit. Students should be able to say that since the waves are in the same medium (water) on both sides, the waves have the same speed on both sides; since they move at the same constant rate wherever they are, they maintain the same spacing throughout.

B. In this part, students observe photographs of water waves in a ripple tank.

1. Students should be able to observe that the wavefronts are more curved overall for smaller slits, and that the wavelength (spacing between wavefronts) is the same before and after each slit.
2. Students **and TAs** tend to pick the smallest slit as being the one that "acts most like a point source," because... it's the smallest. Duh. They then propose that the way to make a slit act more like a point source is to make it smaller. These answers are not really wrong (for the photographs shown), but neither do they identify what it means for a slit to "act like a point source." The questions in part 3 below are important follow-ups.
3. The answers sought here are that one slit can "act more like a point source" than another even when the two slits are the same size *if* the waves going through one of the slits have a longer wavelength. That is, it's not the size of the slit that

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determines its point-source-like behavior; it's the size of the slit relative to the wavelength of the waves going through it.

A good criterion for identifying which slit acts most like a point source is to look at the waves that come out of the slit, not the slit itself. In particular, you should look for the one that *generates the most uniformly semicircular wavefronts*. Students **and TAs** have trouble with this. They all want to think about the "inputs," rather than observing the output, which is really much more direct.

You can make a slit more point-source-like either by making the slit smaller *or* the wavelength larger. A good follow-up question is, *How can you make the wavelength larger?* Two ways are to tap the dowel less frequently, or to change the medium to make the wave speed faster. It's good to make students relate the mathematical quantities (wavelength, frequency) to the physical setup.

4. By now students should be able to state that to make the slit affect the wavefronts even less, they could either widen the slit *or* decrease the wavelength.

II. In this part students generate a two-source interference diagram much like last week's (but for a different slit spacing).

- A. They're semicircles. This is just to get students oriented.
- B. In this part, students should use the enlargement to draw nodal lines and lines of maximum constructive interference, just like last week. Depending on how secure they are with last week's material, they may spend a lot of time on this. If students need help, TAs should send them right back to the *Two-Source Interference* tutorial. In extreme cases students may need to just redo (or do) pages 2 and 3 of that tutorial. These students are going to be behind, but that's life; they really cannot do this week's material without having a pretty good grip on two-source interference.

Some students **and TAs** worry about the fact that a couple of the lines cross the X-X' line outside the right and left boundaries of the "tank." It's no big deal one way or the other if they want to imagine a wider tank or not.

III. In this part students interpret two-source interference of *light* in terms of what they've learned about two-source interference of water waves.

- A. This question is meant to recall the tutorial called *A model for light*. If light traveled in straight lines through slits, like it did in that tutorial, you'd only see two lit strips (with sharp edges), not the five that are shown here.
- B. 1. Most students do fine making this part of the analogy. Some students **and TAs** incorrectly associate the dark regions on the screen with the locations on

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the X-X' line where *two troughs* meet, as though the intensity of the light were determined by the “height” of the wave (whatever is meant by height) rather than its deviation from equilibrium. People who think this way are usually already using the diagram from part II.B, which is good. Have them show you a point they're talking about, where two troughs meet at the X-X' line. As them: *What would be happening here a short time later?* (The waves would expand outward, so there would be two crests there later.) *How fast is that happening?* (At the speed of light! And the wavelength is darned small for light, too. So the light [actually, the electric field] is flickering there, much too rapidly for our eyes to detect, and it would look lit there.) Usually that's enough for people to recognize that that's not the location of the dark spots – that the dark spots are the places where crests and troughs cancel.

2. Students **and TAs** tend to give poor answers to this question, the most popular being “Amplitude.” Okay, in some sense that's not terrible, but it doesn't distinguish light from water at all (and, less importantly, amplitudes are absolute values and can't cancel). Some students just don't know what's “waving” in a light wave. Try asking, *In a light wave, what is it that's going up and down?* Ask the lecturers whether students should know this from them.
 3. Students sometimes do nutty things like measure the source separation with a ruler, measure the wavelength with a ruler, and divide. This is because they don't yet know that it's useful to express source separation in terms of wavelength, and they think the instruction to do so is just an exercise. It's fine to tell them to just count rather than measuring.
- C. Students do fine on this too. Some have minor difficulties with whether to ‘cap’ ΔD and $\Delta\phi$ or not, as last week.
- D. *This is probably the most important question in the tutorial.* When we've asked this on pretests, students **and TAs** have very frequently sketched very wrong answers to part 3, including (for example) stripes only on one side of the screen, or showing the same overall pattern but stating that it's half as bright. People who answer this way are *really* not thinking about how an interference pattern is produced. People who get this right should be applauded, told what a hard question it is, and asked to consider some of the common wrong answers and what someone might be thinking who said that. People who get this wrong should be asked to look explicitly at the diagram for part II.B (with the semicircular wavefronts) and asked, *How would this diagram change if you covered up one of the slits?* That usually gets people on the right track, but it's still nontrivial.

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- E. Students usually do all right with these exercises. They should be able to sketch diagrams sort of like the one for part II.B in each case (and that's what they should do if they get stuck).
- F. This exercise is a lot like one you might find at the end of a textbook chapter. Doing it with actual conceptual understanding, however, is a lot harder than plugging and chugging, and students **and TAs** are likely to struggle with it even though they're now well equipped. Here's how to do it:
- First, you have to recognize that for point B, $\Delta D = \lambda$.
 - Then, you can draw a diagram like the one in part III, showing the 1.2 m to the screen and the 3.6 mm from C to B. These are two sides of a right triangle, and the third side is $(1.2 \text{ m} + \Delta D)$, which is equal to $(1.2 \text{ m} + \lambda)$. You might be tempted to use the Pythagorean theorem and solve for λ , and that's a good thought, but the differences are too small to show up on your calculator.
 - Instead, use trig. $(\text{Spacing between maxima/distance to screen}) = (3.6 \text{ mm} / 1.2 \text{ m}) = \sin \theta$, where θ is the angle between the lines from the slits to point B and from the slits to point C.
 - Now draw another triangle that also has θ in it: the one whose hypotenuse is the distance between the slits, and whose short side is ΔD . Note that $\tan \theta = \Delta D / (\text{slit spacing}) = \lambda / 0.2 \text{ mm}$.
 - Finally, we're well within the small-angle approximation, so $\sin \theta = \tan \theta$, and you're done.

This is hard, but it's good for TAs, and it's good prep for next week if you're doing *Multiple-slit Interference*.