Make Your Own Interferometer (for about €0.0001)

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You've probably heard that light seems sometimes like a particle, sometimes like a wave. Well, building an interferometer is a striking way to see some of the wave aspects of light. Just looking around normally, you can see various objects. The table looks smooth, and it has sharp corners. It seems that there's an unlimited amount of detail available; if you keep zooming in you'll see more and more detail. In fact, that's not true, there's a definite limit to how much detail you can see, and it's because of the wave nature of light. An interferometer (the clue's in the name) is a simple device that lets you see the wave nature of light by "interfering" two waves with one another. When the peaks and troughs of the two waves come together they add up, giving a pattern that we can see with our eyes.

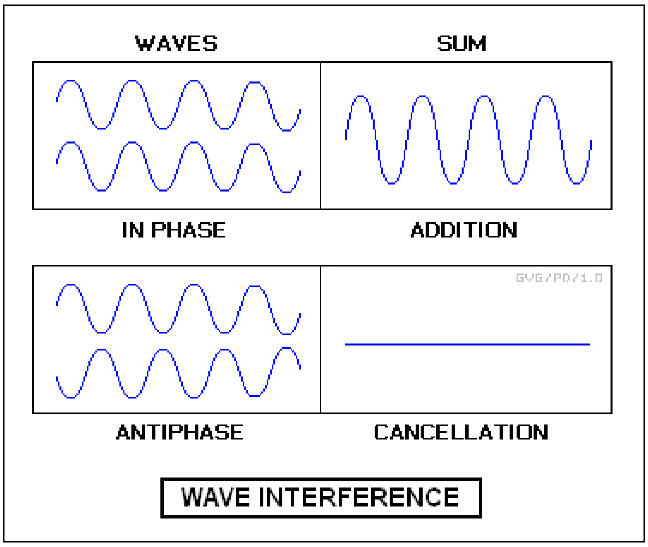

Figure 1: Here we see the way that light waves add when they come together. If the peaks line up we get a bigger wave, if the peaks and the troughs align they cancel each other out.

All we need to make an interferometer is some set up that lets light from a source in by more than one path, then the waves travelling in different directions can interfere. In astronomy we do this but connecting up lots of huge telescopes, often separated by miles, then bringing the light from each one together and letting it interfere. For your experiment you'll do the very same thing only using a bit of tinfoil and a needle. We'll begin with one hole, equivalent to what happens to light when it comes into a telescope, and then work up to two.

Cut a piece of tinfoil 10cm square, and get a sewing needle. Find a smooth surface, like a formica countertop or a piece of glass, and put the foil on the surface. (The smooth surface helps to make small, round pinholes.) Now lightly "spin" the needle into the foil. You'll need a little practice to find the right pressure; we're aiming to make a very small hole, perhaps 0.1mm in diameter, much smaller than the thickness of the needle itself. Make several holes of varying sizes to figure out which one works best. Mount the tinfoil on a little card slide to hold it straight. Now look through the various pinholes by holding them close to your eye. You'll instantly notice that everything gets a lot darker. The reason is obvious, your normal pupil is around 6mm in diameter, but these pinholes are only 0.1mm. The pinhole lets through about three thousand times less light.

Things also appear fuzzier when viewed through the pinhole. Why is that? The basic answer is that there's a limited amount of information you can stuff through a small hole. If the hole is very small compared to the wavelength of light (which is the distance between successive "crests and troughs" of the light; for light we can see, it's 550 nanometers, or 0.00055mm - the difference between different colours is the wavelength of the light), then only a diffuse overall glow can make it through. As the hole gets bigger, more and more detailed images can get through. By looking at a small light source we see a distinctive pattern called the *Airy disk*, named after a British scientist.

The general term for this modification of light as it passes an edge or a small hole is *diffraction*. When the light passes through a small hole it spreads out on the other side and that give us the pattern that we see in the figure below. You should be able to see this by looking at a small light source, like a penlight, through your foil. This is **exactly** what we observe when we look at a distant star through a telescope, just on a smaller scale.

Now comes the magic. Start making pairs of pinholes, closely spaced. Ideally you want each pair to be equally sized and a little smaller than 0.1mm in diameter. Perhaps try varying the spacing from, say, 0.3 mm to 1.5 mm.

When you look at the light through the double pinhole, you will see an amazing set of lines or "fringes" that cross the Airy disk. (If the fringes don't appear, the star needs to be smaller/farther away, or the spacing is too large, or the pinholes themselves are too large.) Try rotating the foil; what happens?

What is happening here? The thing you'd expect to see would be two spots, or perhaps a single spot twice as bright as with the single pinhole. What's happening is that the light from the two holes interferes and gives us the fringe pattern, as shown in the diagram below. The first man to do this, Thomas Young, did his experiment in the 1790's and it is one of the most famous results in all of physics.

As a next step (providing that at least some of the preceding has worked/made literally any sense) is to look at what happens when you add more pinholes. What happens when you put three, equally spaced, in a row? Or a triangle pattern? How about adding another penlight, as if there were two stars (a binary system)? In fact this method is **exactly** the same as how scientist find the separation between pairs of stars, only using fancier telescopes.

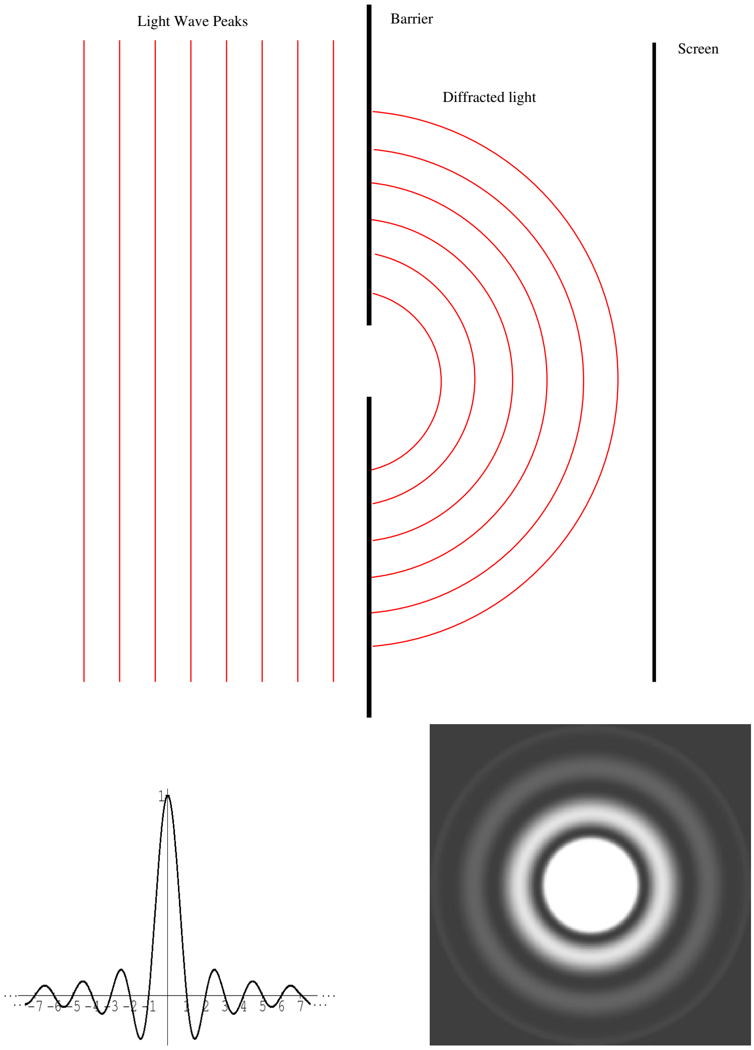

Figure 2: In the top picture we see the diffraction of light. When light passes through a small whole the waves bend and spread out on the other side to fill the space. The pattern on the bottom right is what we see on the screen behind from light coming through a circular hole, on the lower left is a cut through this image.

As I mentioned at the start, our best notion of light at the moment really is particles. We call these particles of light *photons*. Individual photons can be counted; they exist. Yet the dark fringes represent regions for which, with one pinhole, there is light, and with two, no light. Opening up another hole has prevented the particles from reaching the dark fringe! How do the particles know what to do? How do they know whether or not there's a second pinhole open? There is a full theory describes all these phenomena, in fact it is by far the most accurate theory of anything that we've ever worked out, giving us prediction that match every experiment we've tried. So the theory is good,

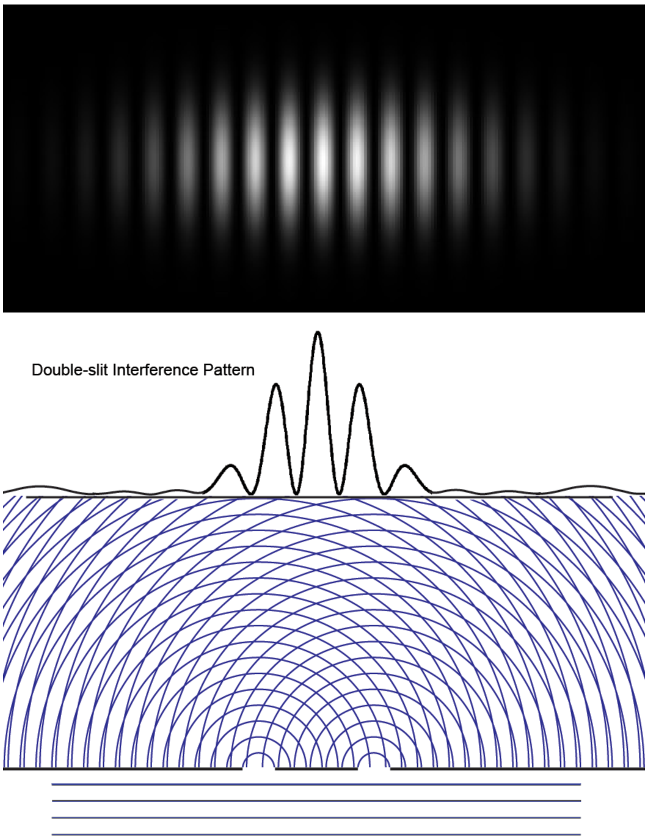

Figure 3: This is how our diffraction and interference works for two slits. The image on top shows the light and dark fringes that we get.

it's just a little tricky to interpret. Crazily enough other particles you may have heard about, like electrons and protons, also do this interference trick; in fact it's a general rule that everything does in the right circumstances! If you're interested in finding out more about this kind of quantum magic there's a superb non-technical book by Richard Feynman, who won the Nobel Prize for his work on this subject, called *QED; The Strange Theory of Light and Matter*. Some of the ideas are subtle, and might take more time than others to catch on to, but the book is straightforward and designed to be read by anyone. The same man was a wonderful lecturer and at the following link you'll find a great talk by him on the same topic: `https://www.youtube.com/watch?v=eLQ2atfqk2c`.

Quick Build Instructions

- Get a piece of tinfoil. Put some small holes of various sizes in it but placing it on a hard surface and carefully pushing a pin through it. The holes should be around 0.1mm. Be sure the holes aren't too close together to begin with.
- Glue or staple the foil onto a piece of card to keep it from bending.

- Look through the holes at a small penlight the other side of the room.
- Find the hole size that gives you the clearest Airy disk (Fig 2.)
- Now try to repeat the process but this time with two equally sized holes separated by around 0.5mm. This should give you the fringe pattern in Fig. 3