traveling along side, without going through the stuff, the first beam is said to be *delayed*. Much of this was explained by great minds hundreds of years ago.

What's really neat is when the light hits the matter, but not directly head-on. If it comes into contact (figuratively speaking) with the surface of the matter at an angle, the slowing down property, the index of refraction, makes the light beam appear to bend or change direction when it enters the stuff. This property of matter, being able to bend light, is almost always useful. We can make prisms and see the wonderful colors of the rainbow without having to stand outside in the rain. We can make lenses of various shapes to focus light onto digital cameras and take really cool pictures. We can use other lenses to help us see clearly when our eyes are somehow not able to do it for themselves.

The speed of light through stuff

Numbers are very useful for describing the stuff. Remember the vacuum with the index of refraction of unity (that's 1)? Water, a very common substance that is colorless, odorless, and tasteless has an index of refraction equal to 1.33.

[**WARNING! WARNING! EQUATION APPROACHING!**]

The speed (v) of light in a substance is

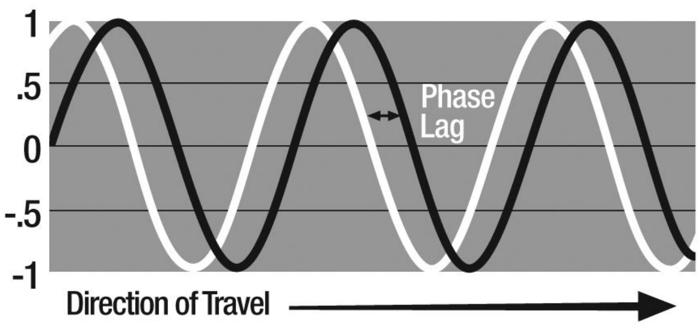
$$v = \frac{c}{n},$$

where c is the speed of light in a vacuum and n is the index of refraction of the substance. Water slows down the speed of light by 25%. We simply divide the speed of light c by the index of refraction n to find the speed of light in the stuff. 186,000 ÷ 1.33 is 140,000, a reduction in speed by 25%. Water, with its index of refraction of 1.33, bends a ray of light.

When it sounds just right—and most trained musicians are *very good* at knowing when this happens—the speed of the wave is such that the frequency is just right. Let's follow the very front of the wave as it travels along the string. The wave will travel along the string to the end and then, when it reaches the end where it is fastened, the wave will reflect back and travel toward the other end. There it reflects again, back and forth, back and forth. The travel time is perfectly suited to doing this 440 times per second. The string will be vibrating at just the right frequency.

It's very important that the front of the wave going one way meets the front of the wave coming the other way. All along the string, one wave is moving up the string when another is moving down the string. If both waves are in the "left" position or the "right" position when they meet, everybody is happy. If one wave is moving "left" when it meets the other moving "right," they are said to be out of phase. The wave won't sound very good. If you have never played a violin yourself, borrow one from your boss and try to play it.[6]

Phase is measured by how far the front of the wave lags behind another (reference) wave. Because waves keep repeating themselves, because waves keep repeating themselves, they go around like riding a bicycle in a circle. You can keep going and never stop, but you end up at the same place.

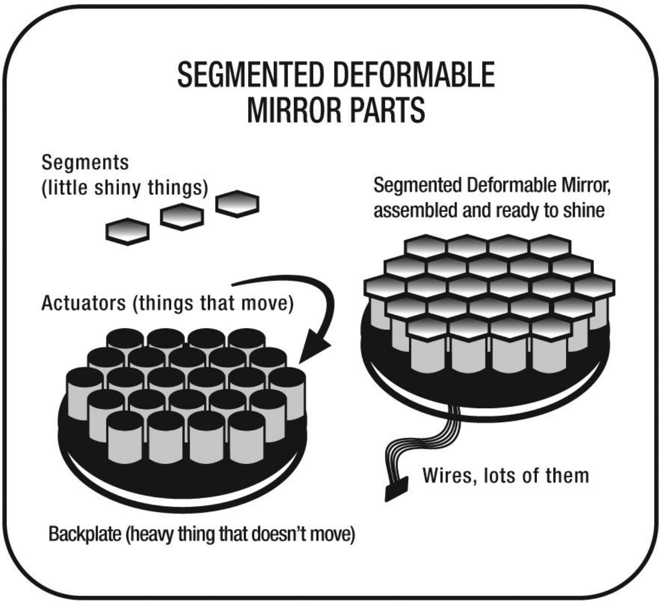


When two waves (even with the same amplitude and wavelength) start at different times, there is a phase lag between them.

[6] You will be not only out of phase, but probably out of a job, too.

Segmented mirrors

The history of high-tech deformable mirrors is filled with excellent designs, a lot of innovation, and a lot of scrap. The first mirrors that were tried were really not individual deformable mirrors, but an array of small mirrors, each one capable of independent motion. The *segmented mirror* had the little segments arranged closely together to make the whole thing look like a continuous mirror. It was unfortunate that even the best ones that could be used for image-forming applications in observatories were pretty much worthless for high-energy laser beams. The gaps between the segments, even though they were thinner than a human hair,[6] allowed high-energy laser radiation to get behind the segments and vaporize just about everything. Segmented mirrors were not used for high-energy lasers after that.



The innards of a segmented deformable mirror.

[6] This analogy is used because everyone knows how thin a human hair is. Some are even getting thinner as you read this. Remember the guys in the wedding photo in Chapter 2.