Physics 100: **Solutions** to Homework Assignment #10

Was Due on Friday, April 27th at the Beginning of Class

Section 1. **Warm-up! Fill-in-the-Blanks (1 pt each)**

1. Light, radio waves, microwaves, x-rays, and gamma rays are all electromagnetic waves. The only real difference between all of these waves is their wavelength/freq..
2. Electromagnetic waves are generated by oscillating electric charges.
3. The speed of all electromagnetic waves in a vacuum is $3 \times 10^8\ m/s$.
4. If an object appears *green* when illuminated with sunlight, then we know that it reflects green light while it absorbs the other colors.
5. Our eyes only sense visible light. Red has a longer wavelength than blue light. We sense infrared light as heat.
6. Electromagnetic waves tend to bend toward places where they travel more slowly. This is known as refraction.
7. Air molecules scatter blue light more than red light. That is why the sky is blue.
8. Like all waves, electromagnetic waves reflect off of things with the same angle as they hit them.
9. The wavelength of light in glass is smaller than the wavelength of the same light in air.
10. If light hits a surface at an oblique angle, more of the light is reflected than if it had hit the surface closer to normal (i.e. 90° to the surface).

Section 2. **Short Answer Questions (2 pts. each)**

11. Explain why sunsets are red and the sky is blue.

Answer: Shown below in Figure 1 is a diagram depicting the Earth and its atmosphere, 5 incoming Sun rays, and two people at positions A and B. The Sun rays are represented by four colors: yellow, red, green and blue (cyan, really), which add to 'white.' The thickness of the individual components represents their intensity. As we discussed in class, the air molecules basically cause light to 'bounce' off of them (Raleigh Scatter). We also learned that they the molecules interact more with shorter wavelength light, meaning that blue light will be scattered (bounced around in all directions) more than red light will.

If you are Person A, you are seeing the Sun either set or rise, and if you are Person B, you are experiencing high noon. Let us consider Person A first. The light that reaches Person A from the Sun has traveled through a lot of atmosphere and all the while, little bits of it were being scattered out of the beam into random directions. It doesn't take long to scatter the blue light out of the beam. It takes a bit longer to scatter out all the green light. By the time the light reaches Person A, all of the blue and green are gone, leaving some yellow and most of the red[1]. Therefore, Person A sees the Sun's light as being red, explaining the reddish tinge to the sky during sunset and sunrise.

Person B, on the other hand, is seeing light that doesn't travel very far in the atmosphere. It travels far enough so that a lot of blue light and a little green light are scattered out of the ray, so that the light from the Sun that Person B sees is more yellowish (hence the yellow color of the Sun, even though it's peak emission is in the green!). But as he looks into the sky, he sees all of that blue light scattered from all of those different Sun rays that hit the Earth– making the sky look blue.

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[1] This is a bit of an exaggeration, as there will be some blue and green light left- just not much!

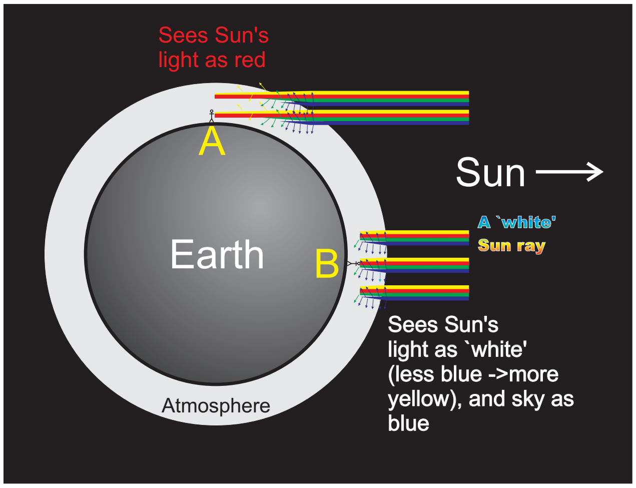


Figure 1: A cartoon showing how the Sun's light interacts with the atmosphere. See Problem 11

12. Some colors that we see correspond to certain wavelengths of light and therefore exist in the rainbow. Others, like brown do not. Explain.

    Answer: Colors like brown do not exist in the rainbow because they're a product of our brains interpretation of multiple colors that do exist in the rainbow. Just as we think of all the rainbows colors as being 'white' light, we interpret different combinations of rainbow colors as being entirely new colors.

13. When the electromagnetic waves from something are reflected from a plane mirror, where does its image appear to exist, relative to its original location?

    Answer: The image appears to be behind the plane mirror, the same distance that the object making the image is in front of it. See Figure 2.

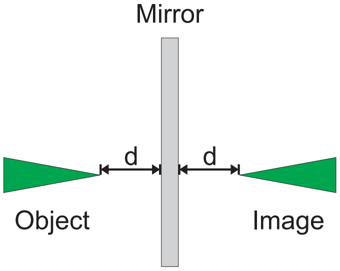


Figure 2: The image of an object is created behind a plane mirror the same distance away from the surface as the object is. See Problem 13

14. Is it more correct to say that a mirror reflects left and right or that it reflects front and back? Explain.

    Answer: It is more correct to say that the mirror reflects (inverts) front and back. See Figure 3

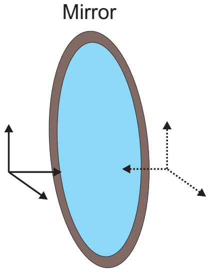


Figure 3: The image of an object is flipped front-to-back, not left-to-right or up-to-down. See Problem 14

15. Draw a diagram that explains why things in water seem to be closer to the surface than they really are. *This is important to keep in mind when you are deciding if a stream or river is shallow enough to wade through!*.

    Answer: See Figure 4. Light from the fish refracts as it leaves the water– bending towards the water as it leaves (it moves more slowly in water). The two blue rays represent this. One of the blue rays enters your left eye, the other your right eye. Because of refraction, they two rays appear to have diverged from a point shallower and a bit further away than they really did. All the rays leaving from the differen parts of the fish do this, with the net result that the fish appears to be shallower and a bit farther away than it really is. When crossing rivers and tide pools remember: they always *look* shallower than they are!

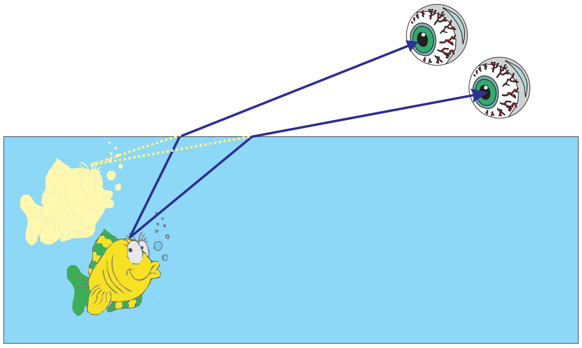


Figure 4: The image of a fish underwater appears shallower than it really is. See Problem 15

16. **(A)** Explain how an optical fiber works.
    (B) How is this similar to the ocean sound channel?

    Answer:

    (A) Consider four light rays originating in water and hitting the surface at different angles, as shown in Figure 5. As the angle becomes more and more oblique, the refracted ray bends more and more towards the water, where the light travels more slowly. Rays `a` and textsfb illustrate this. As the obliquity is increased further, the ray actually comes out parallel to the surface of the water, as Ray `c` shows. If the angle is more oblique than that, the ray actually reflects back into the water, as shown by Ray `d`. This is called *Total Internal Reflection*.

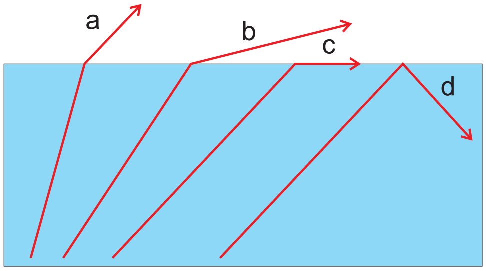


Figure 5: Four rays originating in water and hitting the surface at different angles. See Problem 16

The most common type of optical fiber works using total internal reflection, and a schematic is shown in Figure 6, below. Light is put in on one end of the fiber, undergoing some refraction. When that light hits the side of the fiber, it is oblique enough so that it undergoes total internal reflection. The angle it's reflected at is the same as it came in with so when it hits the fiber again, it again undergoes total internal reflection. In this manner, the light is 'trapped' within the fiber and transported to the opposite end. Gentle bending of the fiber won't lose too much light, so it is possible to use optical fiber to actually transmit light in cables like electricity is transmitted. Important to note is that not all light is trapped– light that comes into the fiber with really oblique angles doesn't internally reflect, but goes through the fiber.

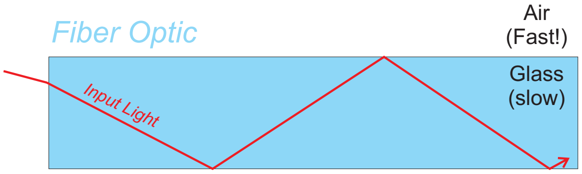


Figure 6: A schematic of a typical optical fiber. See Problem 16

Another type of optical fiber is shown in Figure 7. This fiber is specially designed so that the speed of light varies as you go out from the center of the fiber: the speed of light in the center of the fiber is slow, while the speed of light at the edges is fast. This is called a graded index fiber and is more difficult to make than the common optical fiber depicted in Figure 6. The idea of operation is based on normal refraction: within the fiber, the light tends to bend back to where it travels the slowest– the center of the fiber. In that way, the light is 'trapped' and can be piped around.

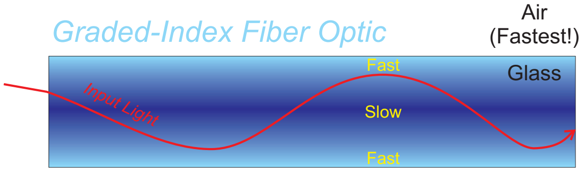


Figure 7: A schematic of a graded index fiber. See Problem 16

(B) An optical fiber is very similar to the ocean sound channel, which is shown below in Figure 10. It's uses exactly the same physics as the graded index fiber, and is very analogous to the standard optical fiber.

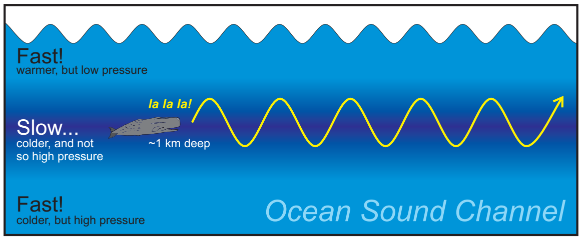


Figure 8: A schematic of a graded index fiber. See Problem 16

17. If the speed of light in glass, plastic, and air were the same, would eyeglasses work?

    Answer: No. If the speed of light in air was the same as the speed of light in the material used to make glasses (i.e. plastic and glass), then the light rays hitting the glasses wouldn't bend at all (light bends to where it travels the slowest– if it doesn't travel more slowly in glass/plastic than air, it won't bend towards anything). If it eyeglasses didn't bend light, they wouldn't do anything.

18. Do Exercise 8 in Chapter 28 of your textbook (*Conceptual Physics, 10th Edition*, p. 554).

    Answer: Shown below in Figure **??** is the schematic of how a car's rear-view mirror is made and adjusted for daytime-use. The mirror actually has a piece of glass or plastic glued to the front of it so that its front surface is not parallel to the mirror. When light hits the glass/plastic surface, most of it is transmitted, but some is reflected (as shown by the thin dotted line in Figure **??**. During the day, the mirror is adjusted so that light from behind is reflected right into the drivers eyes, while the weak reflected part goes somewhere else.

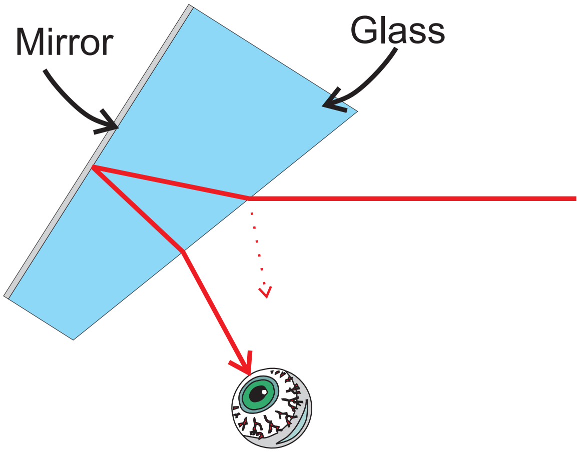


Figure 9: How a car's rear-view mirror is adjusted for daytime use. The dotted line represents reflected light. See Problem 18

During the night, the mirror is adjusted up so that the weakly reflected part is what goes into the driver's eyes while the strongly reflected part is shot upwards to the ceiling of the car, as shown in Figure **??**. In this way, the driver is not blinded by the headlights of cars behind her.

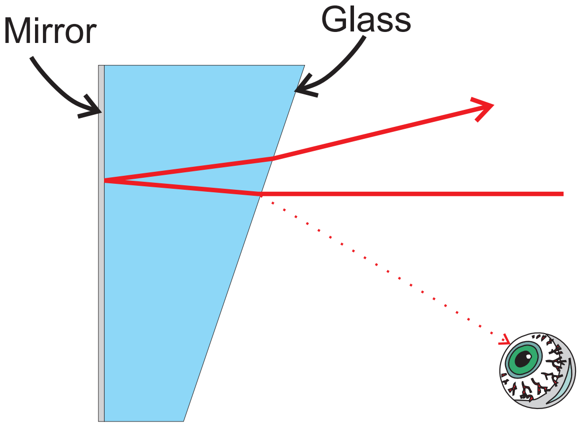


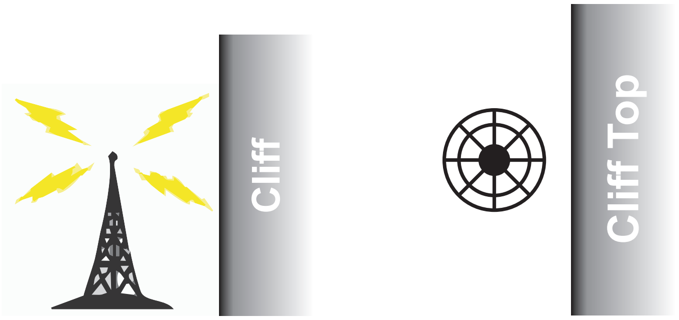
Figure 10: How a car's rear-view mirror is adjusted for nighttime use. The dotted line represents reflected light. See Problem 18

19. **(A)** Explain why the speed of light in warm air is faster than in cold air.
(B) Is this the same reason why the speed of sound is faster in warm air than in cold air? Why/why not?

Answer:

> **(A)** The speed of light in warm air is faster than in cold air because warm air is less dense than cold air. To test this, blow up a balloon and then put it in the freezer. As the air in the balloon cools, the balloon shrinks– the same amount air takes up less space, so it is more dense. Then let the balloon warm up to room temperature and maybe even put it in a pot of hot water. As the air inside the balloon warms up, the balloon expands– the same amount of air takes up more space, so it is more dense.
>
> Now remember that what slows light down is how it interacts with the atoms of whatever it's traveling in. If there are fewer atoms per volume to interact with, it interacts less on the whole and so isn't slowed down as much. Therefore, since warm air has fewer atoms per unit volume than cold air, it travels faster in warm air.
> **(B)** This is not the same reason that the speed of sound is faster in warm air than in cold air. The speed of sound in air is determined by how fast the air molecules are moving. Hot air molecules have more kinetic energy (and therefore speed) than cold air molecules.

20. Consider an AM radio tower, sitting next to a large, flat cliff, as shown in Figure 11. Radio waves can reflect off of the cliff, just as light waves reflect off of mirrors. This can lead to 'dead zones'– places around the tower (even nearby!) that have very weak signals. Explain how this happens. *Hint: First imagine what the reflection does– think of a bathroom mirror. Then refer to the 2-source interference section of the course web site:*
http://smcweb.smccd.net/accounts/bramalln/new_material/supplimentary_material_framesets.html.



(a) An AM Radio tower is located next to a cliff: SIDE VIEW.

(b) An AM Radio tower is located next to a cliff: TOP VIEW.

Figure 11: The diagram of an AM Radio Tower near a cliff. See Problem 20

Answer:

The radio waves from the tower will bounce off the cliff– it will essentially act like a plane mirror for the radio waves. As we know, a plane mirror creates an image of an object a distance behind it equal to the distance that the object is in front of it. This is shown in Figure 12.

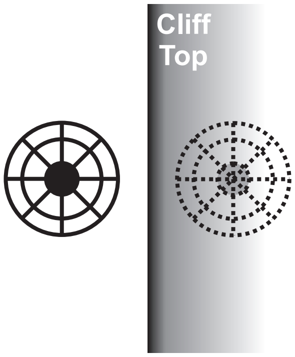


Figure 12: The cliff acts like a plane mirror for the radio waves. Therefore, a radio tower image is created. See Problem 20

This image will act like a second source of radio waves– just as your reflection in a mirror acts as a second source of light (which is why you can see your image). Thus we may think of the radio tower and its image as two sources emitting the same frequency of radio waves, which we know will interfere with each other[2]. This is shown in Figure 13. The yellow dots represent all the places where the two waves constructively interfere (crest on crest *or* trough on trough) while the black dots represent all the places where the two waves destructively interfere (crest on trough). you can see that there are lines radiating from the radio tower of both constructive interference and destructive interference. Where it's constructive interference, you will get string signal. Where it's destructive interference, you will get a weak signal (a dead spot). Note that I've just drawn the top-view interference pattern. The same thing happens on the different side-views too, so you

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[2] See the page I set up for you if you don't know this:
http://smcweb.smccd.net/accounts/bramalln/new_material/supplimentary_material_framesets.html.

end up with a very complicated 3D interference pattern.

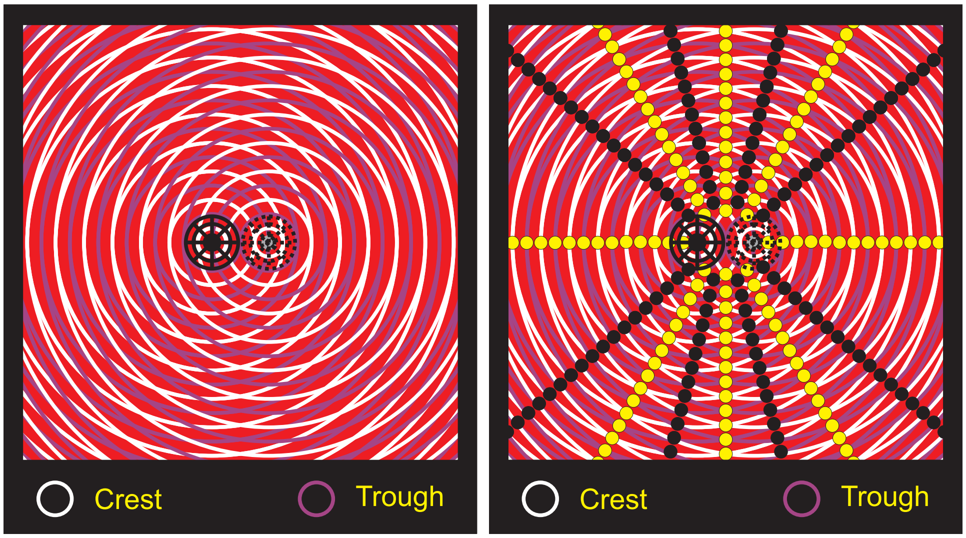

Figure 13: The tower and its image both act like sources of radio waves with the same frequency. Therefore, they act like a two source interference problem. See Problem 20

21. Explain why the Moon, during a lunar eclipse, has a dark red/orange color as shown below in Figure 14. *The next total lunar eclipse will occur in just a few months on August 28, 2007 at 10:37:22.3 UT (3:37 AM).*

Figure 14: During a lunar eclipse the Moon appears red such as it did during the eclipse of Oct. 27, 2004. Photo by Doug Murray, 2004.

Answer: When a lunar eclipse is occurring, the Moon is in the shadow of the Earth, so that sunlight cannot hit it directly. See Figure 15. The sunlight that hits the atmosphere of the Earth refracts, bending it towards the Moon (the light travels slower in the atmosphere of the Earth!). Now, as this light travels through the atmosphere, all of the non-redish light is scattered away, as described in Problem 11. Therefore, the only light that makes it out of the atmosphere in a ray is the redish component. Since the atmosphere refracts the redish part of the Sun's light onto the Moon, the Moon appears redish.

Here's an Interesting link (NPR's All Things Considered): here[3]

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[3] http://www.npr.org/templates/story/story.php?storyId=7703394

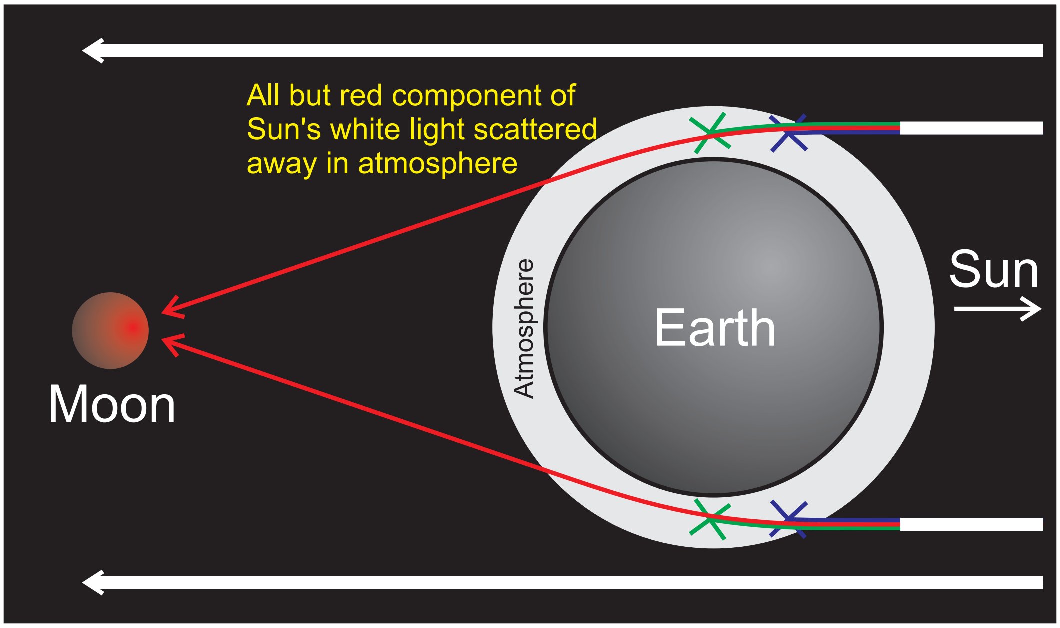

Figure 15: The atmosphere of the Earth bends the (1) bends the Sun's light towards the Moon and (2) scatters all of the non-redish light away so that the Moon is illuminated by redish light during an eclipse.