Wizards of Wright

Lesson: Advanced Optics – Rochester Cloak

Use WOW! Lesson Intro to begin.

Background Info for Wizards:	This lesson will introduce students to geometric, or ray optics, and their applications to cloaking technology. Students will build a cloaking device! The lesson will include a review of electromagnetic waves, discuss reflection, refraction, and diffraction and teach them about optics and lenses (e.g. concave vs convex, focal length). In physics, electromagnetic radiation (EM radiation or EMR) refers to the waves of the electromagnetic field, transmitting through space, carrying electromagnetic radiant energy. It includes radio waves, microwaves, infrared, (visible) light, ultraviolet, X-rays, and gamma rays.
Materials:	Each group needs: 2: 50 mm f/l double convex lenses 2: 150 mm f/l double convex lenses 4: lens holders 4: bench supports 1: screen holder 1: laser pointer 1: meter stick 1: large blank notecard For example: 
Lesson Time: 45-60 minutes	Introduction:10-15 minutes Student Activity: 30 minutes Conclusion: 5-10 minutes

Learning Targets:	Students will learn about optics, lenses, and their applications in cloaking technology. Students will calculate the distance between lenses needed to create cloaking effect.
Introduction for Students: 10-15 minutes	**Using Slide 2 of the PowerPoint:** The **Electromagnetic Spectrum** is the range of all the types of electromagnetic waves arranged according to frequency and wavelength. Light waves are separated into 7 regions: Radio (longest), microwave, Infrared, visible, ultraviolet, x-ray, and gamma rays (shortest). Wavelength and frequency are inversely proportional. As wavelength decreases and frequency increases energy increases. **Using Slide 3 of the PowerPoint:** What are **Ray optics**? Wave motion can be visualized in terms of water waves—such as those created on a quiet pond by a bobbing cork (**a**). The successive high points (crests) and low points (troughs) occur as a train of circular waves moving radially outward from the bobbing cork. Each of the circular waves represents a wave front. A wave front is defined as a collection of points that connect identical wave displacements, or identical positions above or below the normal surface of the quiet pond **(b)**. Ray optics considers only the direction and power of the EM wave. We don't consider how the electric nor the magnetic portions are behaving, only the direction of propagation is relevant. This allows us to consider the EM waves as rays and simplifies the problem of considering wave behavior. Circular wave fronts are shown with radial lines drawn perpendicular to them along several directions. **(b)** Each of the rays describes the motion of a restricted part of the wave front along a particular direction. Geometrically then, a ray is a line perpendicular to a series of successive wave fronts specifying the direction of energy flow in the wave **(b)**. Figure **C** shows plane wave fronts of light bent by a lens into circular (spherical in three dimensions) wave fronts that then converge onto a **focal point F**. The same diagram shows the light rays corresponding to these wave fronts, bent by the lens to pass through the same focal point F. Figure **C** shows clearly the connection between actual waves and the rays used to represent them. In the study of geometrical optics, we find it acceptable to represent the interaction of light waves with plane and spherical surfaces—with mirrors and lenses—in terms of light rays.

	Using Slide 4 of the PowerPoint: **Reflection, refraction, and diffraction** are all behaviors associated with the bending of the path of a light wave. - Diffraction is the process by which a beam of light or other system of waves is spread out as a result of passing through a narrow aperture or across an edge, typically accompanied by interference between the wave forms produced. - Dispersion is the property by which light is spread out according to its color as it passes through an object such as a prism. - It is related to refraction, as each wavelength of light bends a different amount as it passes through the media. This is how a rainbow is formed! **Using Slide 5 of the PowerPoint:** We will be focusing today on **reflection and refraction**. With the useful geometric construct of a light ray we can illustrate **propagation/transmission, reflection, and refraction** of light in clear, uncomplicated drawings. Each ray indicates the geometrical path along which the light moves as it leaves the source. *** Use sheet F with the rectangular block to demonstrate this on single beam mode. Set the block with the short end horizontal and the long vertical. Tilt until you can clearly see the refracted beam. **Reflection** is the abrupt change in the direction of propagation of a wave that strikes the boundary between two different media. At least some part of the incoming wave is reflected and remains in the same medium. Assume the incoming light ray makes an angle θ_i with the normal of a plane tangent to the boundary. Then the reflected ray makes an angle θ_r with this normal and lies in the same plane as the incident ray and the normal. **Law of reflection:** $\theta_i = \theta_r$ **Refraction** is the change in direction of propagation of a wave when the wave passes from one medium into another and changes its speed. Light waves are refracted when crossing the boundary from one transparent medium into another because the speed of light is different in different media. Assume that light waves encounter the plane surface of a piece of glass after traveling initially through air as shown in the figure. What happens to the waves as they pass into the glass and continue to travel through the glass? The speed of light in glass or water is less than the speed of light in a vacuum or air. The speed of light in a given substance is $v = c/n$, where n is the index of refraction of the substance. **Typical values for the index of refraction of glass are between 1.5 and 1.6, so the speed of light in glass is approximately two-thirds the speed of light in**

	air. The distance between wave fronts will, therefore, be shorter in the glass than in air, since the waves travel a smaller distance per period T. We can see that the rays will bend as the wave passes from air to glass. The bending occurs because the wave fronts do not travel as far in one cycle in the glass as they do in air. The wave front halfway into the glass travels a smaller distance in glass than it does in air, causing it to bend in the middle. Thus, the ray, which is perpendicular to the wave front, also bends. The amount of bending depends on the angle of incidence and on the indices of refraction of glass and air, which determine the change in speed. The relationship between the index of refraction and the angles of incidence and refraction is described by **Snell's Law of the Law of Refraction**. If the beam is passing through air into a transparent substance, Snell's Law can be used to calculate the unknown index of the media assuming the index of air is about equal to 1. $n_i \sin\theta_i = n_t \sin\theta_t$. **Using Slide 6 of the PowerPoint:** *Types of lenses and how they work -* ***show with the ray box in 3 ray mode and diagram F using lens 1 (convex) and lens 5 (concave) A lens is made up of a transparent refracting medium, generally of some type of glass or plastic, with spherically shaped surfaces on the front and back. The lens can be used to manipulate light rays. A ray incident on the lens refracts at the front surface (according to Snell's law) propagates through the lens, and refracts again at the rear surface. A **convex lens (lens 1)** can be made of any optically transparent material that is **thicker in the middle**. This shape causes the light to refract **or bend towards the normal perpendicular** to the surface of the lens at any point. All rays entering perpendicular to the axis of the lens will refract and **meet at a single point, or focal point**. The distance between that point and the center of the lens is the **focal length (*fl*).** Thinner lenses will have a longer *fl*, this is because a thicker lens will bend the light more. A **concave lens (lens 5)** is made of an optically transparent material that is thinner in the middle. They cause parallel rays passing through them to spread as they leave the lens. The refraction of the light causes it to diverge as if it is coming from focal point located to the left of the lens, giving rise to negative a focal length. **Using Slide 7 of the PowerPoint:** *Lens use: The eye* *** Use Sheet A

	Consider your eye. Our eye contains a lens that focuses light onto the sensors in the back of our eye. There is a sensor in the back of your eye that translates optical information. The eye flips the image inside your head, then the brain reprocesses it right side up. Vision problems can stem from abnormalities in the shape of that lens. Let's explore: 1= normal 2=near sighted, focus point too far in front of sensor 3=far sighted, focus point behind sensor As you can see the shape of the lens alters the focal point. The addition of a corrective lens can fix this! Show: 3 + 4 2 + 5 ** facts for wizard? To add to handout?? Extra eye facts: • Humans have a very broad range of light sensitivity, but we can't see well in extremely dark, or very bright situations. Likewise, different animals have developed specialized light sensitivity to adapt to their environment, think nocturnal animals. • Sometimes the iris in your eye can't adjust fast enough when moving from a very brightly lit area, to a dark room, and vice versa. If you close your eyes. Those brightly colored patterns are what is referred to in the digital world as "noise". There is not enough light information for the eye to process, so the brain tends to make up the missing information. 3D depth perception comes from the combined optics of our 2 eyes. VR cameras utilize a similar process. • We never see anything in real-time. We always see everything a fraction of a second slower than what is really there. 2 reasons: A, the time it takes for light photons to travel from the object, then bounced back to the eye. B, the time it takes for the eye to pass through the optic nerve, and then processed by the brain/sensor. We are very much used to this process from birth, which is why it doesn't seem different to us, and our brain has developed a way of predicting much of this information, once we are used to our surroundings. Often the eye sees more than the brain can process, which is why sometimes you will miss objects that are right in front of you, or barely hidden. It takes an incredibly calm mind to accurately process the visual information in a room, rather than jump to conclusions of what you think is there. • Humans have a nearly 180-degree field of view, with clarity dropping off greatly in our periphery. Obviously our blind spot is behind us. Because of the positioning of the eyes, certain animals can have a nearly 360-degree field of view, but with unique blind spots in the very front, and back of the

head. This is why birds often have to turn their heads to one side or the other to get a better look at an object

Using Slide 8 of the PowerPoint:
A Camera:
The average camera lens functions mechanically much like the human eye. A camera lens operates in much the same fashion, focusing the light on a sensor in the back of the camera :
**** Use Sheet B with lens 1

The aperture is another important design parameter for a lens, related directly to how much light the lens gathers. The aperture of a camera opens and closes to let more or less light in, exactly like your iris lets more or less light into the eye.
Extra Camera Facts:

- Lenses are classified by their field of view, which you designate by using "mm". The lower the "mm" number, the wider the field of view. A higher number "mm" will result in a narrow field of view. A camera lens that is 15mm would be great for taking a wide shot of landscape, but would suffer in clarity compared to a 180mm lens taking a portrait of a person.

- The size of a lens determines its light gathering power and, consequently, the brightness of the image it forms.

- The aperture is another important design parameter for a lens, related directly to how much light the lens gathers.

These diagrams and lenses will be up here for you to experiment with at the end of the period.

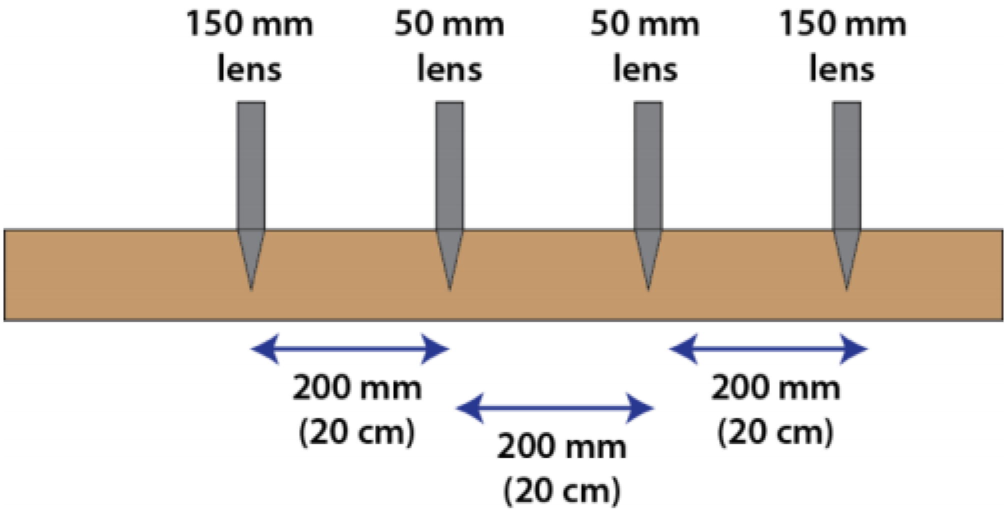
Using Slide 9 of the PowerPoint:
Moving forward:

The concept of invisibility is rooted deep in human history. Greek, Celtic, and Norse mythology all reference the power of invisibility. H.G. Well's story "The Invisible Man" tells the tale of a scientist obsessed with the idea. The character later manages to change the refractive index of his body to match that of air, rendering himself invisible. The fantasy of invisibility also emerges, albeit in a less scientific fashion, in tales such as Harry Potter and Lord of the Rings. Although these situations are beyond reality, scientists around the world are working on cloaking technology.

There are currently two different types of cloaking technology being developed.

The use of ray optics seeks to prevent the light from interacting with the object at all. The weaknesses of this method are the uniaxial nature of the device as well as

	background distortion. If you move out of the exact line of sight the object becomes visible or the background becomes so distorted that the presence of the cloak becomes apparent. **Using Slide 10 of the PowerPoint:** In special cases in which the incoming light rays are parallel with a lens' vertical axis, paraxial ray optics cloaking can be implemented. This typically requires the background to be relatively close to the lens. Paraxial ray optics cloaking, however, has proven to be the most successful ray optics methods to date. The Rochester Cloak you will be building is an example of this method. The Rochester Cloak is the first perfect paraxial ray optics cloak and was invented by Professor John Howell and his doctoral student Joseph Choi at the University of Rochester. It uses a series of convex lenses to redirect light in such a way that it never comes in contact with an object in the cloaked region. Therefore, the viewer only sees the background! The Rochester Cloak uses two pairs of lenses with two different focal lengths. Convex, or converging, lenses are key to the operation of this device. The lenses are set up in tandem with the thicker two in the middle. The thin lens will be referred to as f_1 and the thicker f_2. It is important for the spacing between the lenses to be very precise, as the device depends entirely on the focal lengths to bend light around the cloaked region. Use the provided formulas to calculate the distance between the lenses and follow the instructions to build an invisibility cloak!
Student Activity: 30 minutes	See attached handout: Building a Rochester Cloak
Conclusion: 5-10 minutes	The Rochester cloak creates a donut-shaped volume of invisibility around the central axis of the lens. This area is completely avoided by light waves, therefore any object placed in this region would not obstruct light from the background. Invisibility has countless possibilities from medical, communications, and military applications. This technology could even be extended to cloaking not only EM waves, but sound waves and even dampening the waves produced by earthquakes! The surface of this realm of research had only been scratched and needs future scientists like you to take it to the next level.



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