Science of Invisibility

Subject Area(s) Physical science, Chemistry

Associated Unit

Lesson Title **Science of invisibility**

Header

Image 1
ADA Description: This image shows Harry Potter wearing invisibility cloak
Caption: None
Image file: invisibility-face.jpg
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http://drinkthis.typepad.com/tesla/2009/11/history-in-the-making.html

Grade Level 11 (9-12)

Lesson # 1 of 1

Lesson Dependency None

Time Required 50 minutes

Summary
Through this lesson the physics of invisibility that depends on an understanding of properties of light is introduced to the students as a field of cutting-edge research that scientists are challenging with. After being introduced to the challenging question of making objects invisible which looks more as a science fiction, the students consider the knowledge required to generate ideas and explore the different technologies of invisibility and their possible applications outside of magical quests and sci-fi infiltration missions.

Engineering Connection
It is essential for engineers to understand the properties of light and physics behind them. Considering the laws of optics, scientists and engineers are challenging to create new materials that bend visible light around an object and make it invisible or creating optical technology call

optical camouflage to make objects vanishing from sights or improving laser technologies that has a lot of application in medical science, engineering and other aspects of human life.

Engineering Category = #_

Choose the category that best describes this lesson's amount/depth of engineering content:

1. Relating science and/or math concept(s) to engineering
2. Engineering analysis or partial design
3. Engineering design process

Keywords

Light, optics, invisibility, camouflage, metamaterial, nanotechnology, nanoscience

Educational Standards

Texas, Science: (C) know that scientific theories are based on natural and physical phenomena and are capable of being tested by multiple independent researchers. Unlike hypotheses, scientific theories are well-established and highly-reliable explanations, but may be subject to change as new areas of science and new technologies are developed

Texas, Science: (B) communicate and apply scientific information extracted from various sources such as current events, news reports, published journal articles, and marketing materials

Learning Objectives

After this lesson, students should be able to:

- Explain what happens when light hit an object in general
- Explain why we see objects in different colors
- Distinguish the wave length of visible light
- Define the refractive index of a material
- Explain reflection and refraction of light
- Explain Snell's law
- List different real world invisibility technology
- Explain the optical camouflage technology
- Describe how scientists are using nanoscience to make objects invisible
- Define metamaterials and how it works when a light beam hit it
- Explain the weaknesses of each invisibility technology that is so far available
- List some potential application of invisibility

Introduction / Motivation

Imagine that you can slip on a ring and vanish or wearing Harry Potter cloak and disappear from sights or drink a magic potion and dissolved to the background. This sort of thing tends to fly unquestioned on the grounds of Hogwarts or in the umber-hulk-infested depths of the Underdark. But what about in the real world, where even the "Predator" aliens' clunky sci-fi camouflage looks far-fetched? Well, science has some good news for you: Invisibility cloaks are a reality. The technology is far from perfect, but we've already reached the point where you even get to choose from few different invisibility technologies.

In science fiction, invisibility is used for anything from hiding a spaceship to escaping from a bad guy. Scientists are challenging to make these dreams real by designing a device that gives the power of invisibility. But generation of scientists had dismissed it and they said that it was impossible because it violated the laws of optics but they were wrong and now invisibility is possible and recent science researchers have achieved it.

What exactly an invisibility device needs to do?

To create a real invisibility device, it has to do three things:

1. Make invisible from any angle
2. It has to be compact and practical
3. It has to be reversible so that we can switch between being visible and invisible

Turning an object into invisible is not easy but certainly what makes the design a success is manipulating how things interact with light. So let's review the properties of light.

Light is why we see and is made of many different colors and things scatter or absorb these colors when they hit by a light beam. That's why leaves are green. They absorb all the colors of light except green. If we can control how objects scatter or absorb light, we can control how to perceive reality.

Lesson Background & Concepts for Teachers

Light is electromagnetic radiation that has properties of waves. The electromagnetic spectrum can be divided into several bands based on the wavelength of the light waves. As we have discussed before, visible light represents a narrow group of wavelengths between about 380 nm (1 nm = 10^{-9} m) and 730 nm.

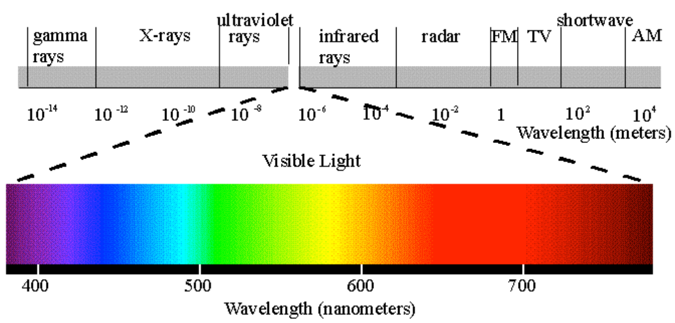

Image 2

ADA Description: This image shows visible light spectrum

Caption: None

Image file: light.bmp

Source/Rights: Copyright ©

Our eyes interpret these wavelengths as different colors. If only a single wavelength or limited range of wavelengths are present and enter our eyes, they are interpreted as a certain color. If a single wavelength is present we say that we have *monochromatic light*. If all wavelengths of visible light are present, our eyes interpret this as white light. If no wavelengths in the visible range are present, we interpret this as dark.

Interaction of Light with Matter

Velocity of Light and Refractive Index

The energy of light is related to its frequency and velocity as follows:

$$E = h\nu = hC/\lambda$$

Where

E = energy
h = Planck's constant, 6.62517×10^{-27} erg·sec
ν = frequency
C = velocity of light = 2.99793×10^{10} cm/sec
λ = wavelength

The velocity of light, C, in a vacuum is 2.99793×10^{10}cm/sec. Light cannot travel faster than this, but if it travels through a substance, its velocity will decrease. Note that from the equation given above

$$C = \nu\lambda$$

The frequency of vibration, ν, remains constant when the light passes through a substance. Thus, if the velocity, C, is reduced on passage through a substance, the wavelength, λ, must also decrease.

We here define *refractive index*, n, of a material or substance as the ratio of the speed of light in a vacuum, C, to the speed of light in a material through which it passes, C_m.

$$n = C/C_m$$

Reflection and Refraction of Light

When light strikes an interface between two substances with different refractive indices, two things occur. An incident ray of light striking the interface at an angle, i, measured between a line perpendicular to the interface and the propagation direction of the incident ray, will be reflected off the interface at the same angle, i. In other words the angle of reflection is equal to the angle of incidence.

Image 3
ADA Description: This image shows reflection and refraction of light
Caption: None
Image file: snellslaw.bmp
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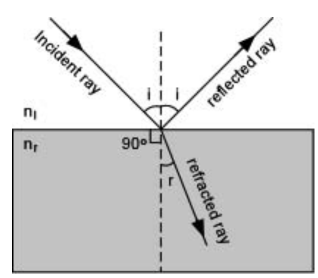
http://www.tulane.edu/~sanelson/geol211/proplight.htm



If the second substance is transparent to light, then a ray of light will enter the substance with different refractive index, and will be refracted, or bent, at an angle r, the angle of refraction. The angle of refraction is dependent on the angle of incidence and the refractive index of the materials on either side of the interface according to *Snell's Law*:

$$n_i \sin (i) = n_r \sin (r)$$

Note that if the angle of incidence is 0^o (i.e. the light enters perpendicular to the interface) that some of the light will be reflected directly back, and the refracted ray will continue along the same path.

We have some general idea about what an invisible device need to do and considering the properties of light and optics law mentioned above, we are going to discover how we can turning an object into invisible by manipulating how things interact with light.

Optical Camouflage: Real-world Invisibility Applications

Image 4

ADA Description: This image shows invisibility cloak by optical camouflage technology

Caption: None

Image file: comouflage1.jpg

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In fact invisibility can be something as simple as just tricking the eyes.On one hand, there's the *optical camouflage* technology developed by scientists at the University of Tokyo. This approach works on the same principles of the blue screen used by TV forecasters and Hollywood filmmakers. If you want people to see through you, then why not just film what's behind you and project it onto your body.

A camera behind an object takes images from their background. These pictures are projected to a box of mirrors called combiner and then onto the cloak and then onto the cloak. Look through the combiner and you see a composite image of the original projection and light reflecting from the cloak.

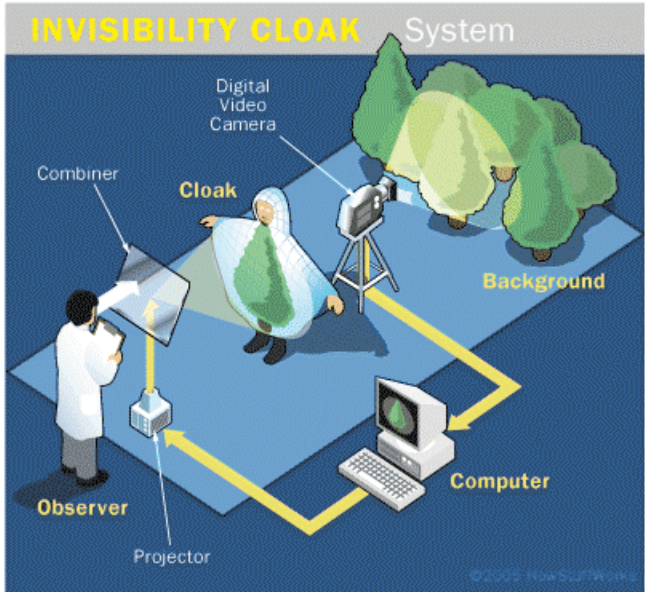

Image 5

ADA Description: This image shows invisibility cloak by optical camouflage technology

Caption: None

Image file: invisibility-cloak-system.bmp

This method is impressive but still has a lot of practical disadvantages. We have to have cameras everywhere and a camera behind you to photograph the background. You have to look through special eye piece or wear special goggles. To make it really more effective we have to put hundreds of high resolution micro-lenses into the fabric of the cloak so they are not conspicuous. But there is still a second problem. The cloak is invisible if only it seen through a set of combiner. If the cloak is made of LED lights it could play the background on the surface of the fabric, then the cloak would be invisible through any angle, but almost… So we are interested in one hundred percent invisibility and indistinguishable. If you become invisible fifty percent, the people can still trace you and this is not desirable.

So, optical camouflage is a promising start and clever elusion.

Making individual atoms invisible

If we want to make object completely disappear in the thin air, we need to make that object completely transparent. In "H. G. WELLS" book the invisible man, the main character of the book does exactly the same.

Light travels in air in a straight line, but when it hits any thing else transparent like water it bends. That's why a straw is broken in a glass of water. The amount that something transparent bends light depends on its reflective index. So if we want to make an object invisible we need to make the reflective index of that object and of thin air the same.(Here it's better to ask students to do the "make beaker invisible" activity to understand the concept better).

A group of scientists at London by using the same concept were able to make one individual atom invisible for a very short time (one millionth of a second). Professor Chris Phillips, a solid state physicist in Imperial College London, with his colleagues was the first group who discovered the amazing secret of controlling how materials in the atomistic size react with light. When an atom is hit by light beam, its electrons get excited and jump to the higher state of energy. Electrons then crash back to lower state of energy and emit light. Professor Phillips had tried to use quantum physics to stop electrons from moving so that they can not absorb light and you can not see them.

By now, Prof Phillips team can use this method just for vanishing nano-scale objects that have special structures with identical atoms and use just one frequency of light to disappear that because all the atoms are identical. But imagine for larger objects like human's body that has different types of atoms. So you need thousands of different laser beams to disappear thousands of different types of atoms in the body. That is the problem but still the potential of this technology is enormous.

Metamaterials: Bending Light Waves

Normally when light beam hits objects, some part would be absorbed and some parts get reflected to our eyes and then we are able to see that object. But what if the incident light be bent around the object and does not reflect back to our eyes. Then it changes the appearance of that object and it would be vanished. It seems that it violates the laws of optics and it is impossible. Because based on laws of optics, light can not wrap around an object and reformed at the other end. But Professor David Smith and his team at Duke University created such an impossible. They made an amazing material of complex copper circuits called *metamaterials* which is beyond anything in the nature. Metamaterials don't occur naturally. In order to create the minute structures required to redirect electromagnetic waves, scientists employ nanotechnology.

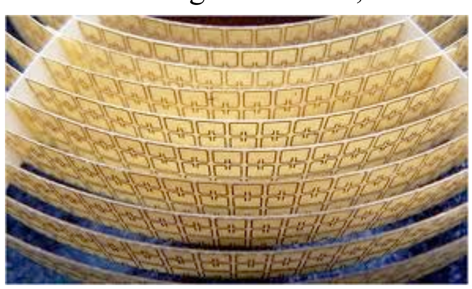

Image 6

ADA Description: This image shows how metamaterial structure

Caption: None

Image file: metamaterial.jpg

Source/Rights: Copyright © the picture is from the following web http://bbs.stardestroyer.net/viewtopic.php?f=5&t=125532&start=25http://drinkthis.typepad.com/tesla/2009/11/history-in-the-making.html

Metamateri … icrowaves, the colored ve… is the coil of metamateri… ave's movement is similar to river water flowing around a smooth rock. Anything in the middle appears to vanish. Metamaterials offer a more compelling vision of invisibility technology, without the need for multiple projectors and cameras.

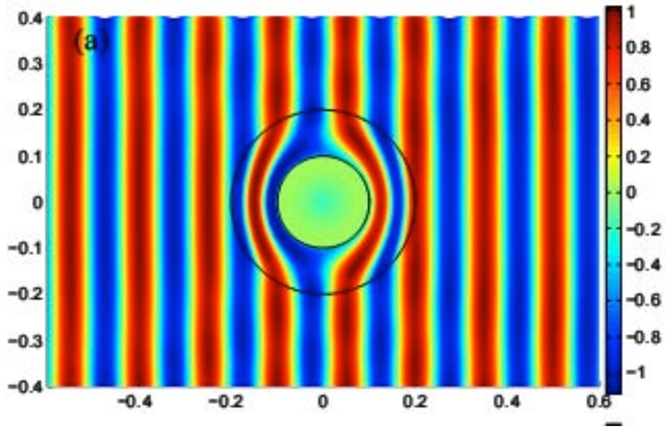

Image 7
ADA Description: This image shows how metamaterial bend light
Caption: None
Image file: INVfield.bmp
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If it is possible to bend microwaves around an object, it should be possible to bend visible light around the objects, too. Both are types of electromagnetic radiation. But there is a problem. Microwaves have a large wavelength, about three inches long. To bend them a metamaterial need only to be a third of that size. Visible light has a wavelength between 400 to 700 nanometers. So to bend them, the circuit has to be scaled down million times. But if you do that you hit a problem. If they make the circuit in nanoscale it would not be cloak any more. So making this nanoscale circuit act as a cloak is a big challenge that scientists are facing now. Obviously humans don't see in the microwave spectrum, but the technology demonstrated that energy waves could be routed around an object. Smith's metamaterials proved the method. “It's not yet clear that you're going to get the invisibility that everyone thinks about with Harry Potter's cloak or the Star Trek cloaking device," said David Smith, who led the experiments at Duke University.

Several research groups have already created metamaterials for visible light at nanoscale. They are confident that in a near future they are able to scale it up. Then this metamaterial can be used to make a human body invisible. If we can shape the metamaterial like a cylinder large enough to stand in, then it can make the human body appear invisible and we would have simple invisibility cloak that bends light. But we can go even further and have a cloak like a jump suit that can cover every inch of our body.

But still some more problems exist. Visible light doesn’t have a single frequency. It’s a composite of different electromagnetic waves, each with their own frequency which we see as different colors. So we need to have our invisibility suit with at least three layers of metamaterials, one layer for each color.

Potential applications:

Cloaking devices are keenly awaited and coveted by the military, which believes they will usher in a new age of stealth technology by hiding planes and other vehicles from radar. More advanced versions could ultimately be good enough to make objects or people invisible to onlookers.

A prototype was built and demonstrated in America by a team of US and British scientists only five months after proving it was theoretically possible to pull off the most famous of optical illusions, without breaking the laws of physics. The test involved firing a beam of microwaves at the object, the same radiation used for radar.

At present, although the angular lines of stealth bombers make them hard to spot on radar screens, they can leave a "shadow" that gives away their position. The military hopes that cloaking devices could render them almost completely invisible.

Image 8
ADA Description: This image shows aircrafts
Caption: None
Image file: aircraft.jpg
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Radar waves are about 3cm long and to cloak objects from them, metamaterials need to be designed with features a few millimetres across. Visible light waves are far shorter - less than one thousandth of a millimetre - meaning a cloaking device would need metamaterials with much finer features to bend light properly.

While invisible to radar, today's bulky stealth aircraft are easily spotted with the naked eye. But military technicians are said to be developing adaptive camouflage that changes color to match its surroundings. The idea is that sensors all over an aircraft receive visual information about their surroundings, and then output corresponding images to chameleon-like panels made of "electro-chromic polymers". Whatever is above the plane is projected onto its underside, making it virtually invisible from the ground.

As another example of real world optical camouflage technology think that pilots landing a plane could use this technology to make cockpit floors transparent. This would enable them to see the runway and the landing gear simply by glancing down at the floor (which would display the view from the outside of the fuselage). Similarly, drivers wouldn't have to deal with mirrors and blind spots. Instead, they could just "look through" the entire rear of the vehicle. The technology even boasts potential applications in the medical field, as surgeons could use optical camouflage to see through their hands and instruments for an unobstructed view of the underlying tissue.

Associated Activities

Make it invisible!

Lesson Closure

Assessment

Assessment on science of invisibility

Lesson Extension Activities

Additional Multimedia Support

References

http://science.howstuffworks.com/invisibility-cloak.htm

http://www.tulane.edu/~sanelson/geol211/proplight.htm

Attachments

Other

Redirect URL

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