LESSON 9

Color, Wavelength, and the Wider Electromagnetic Spectrum


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What property of light enables us to distinguish between the colors on these cards?

INTRODUCTION

In the previous lesson, you discovered that white light could be split to produce a visible spectrum of different colors. What is it about light that makes it appear to be different colors? What property of light allows your eyes to distinguish between red and blue or between yellow and orange? In this lesson, you will use one of the models for light from Lesson 7—the wave model—to help explain what your eyes detect when you see color. You also will discuss and investigate the existence and behavior of "invisible light." This "invisible light" is the part of the electromagnetic spectrum that exists outside the range of your vision.

OBJECTIVES FOR THIS LESSON

Model light waves of different colors.

Discuss evidence for an invisible spectrum.

Investigate the behavior of infrared.

Getting Started

1. Can you use a piece of beaded chain to make waves? As you and your partner experiment with the chain, think about these questions:

   What do you have to do to the chain to make waves?

   What does the wave transmit down the chain?

2. In a class discussion, share your approach to making waves and any observations you may have.

MATERIALS FOR LESSON 9

For you

1 copy of Student Sheet 9.2: Constructing the Spectrum
1 pair of scissors

For you and your lab partner

1 piece of beaded chain
1 meterstick
Glue

Inquiry 9.1
Measuring Different Wavelengths

PROCEDURE

1. You are going to examine and measure the waves you make with your chain. To do this, you will need to freeze the motion of the chain on a flat surface. Work with class members to determine which method of making waves best allows you to freeze the motion of the chain.

2. Use the method the class selects to make waves. Stop shaking the chain abruptly. In your science notebook, draw the pattern formed by the chain. Do not move your chain.

3. Read "Measuring a Wave." Measure the wavelength (in mm) of the wave shown in the diagram in "Measuring a Wave." Record your measurement in your notebook.

4. Now measure and record the wavelength of the wave you made with the chain (see Figure 9.1). Your wave may not be the exact shape of the wave shown in the diagram. You may find it useful to measure a few wavelengths on your chain and take their average (mean) wavelength.

5. Shake the chain faster than you did in Step 2. Abruptly stop shaking it. Draw the pattern formed by the chain. Do not move the chain. In your notebook, answer the following questions:

   A. What is the difference between the two wave patterns?

   B. What is the wavelength of the new wave?

   C. What happened to the wavelength of the chain when you shook the chain faster?

6. Shake the chain again, starting slowly and then speeding up. Record what happens to the frequency of waves in the chain. (Remember: Frequency is the number of waves that pass a certain point every second.)

   D. What is the relationship between the wavelength of your waves and their frequency?

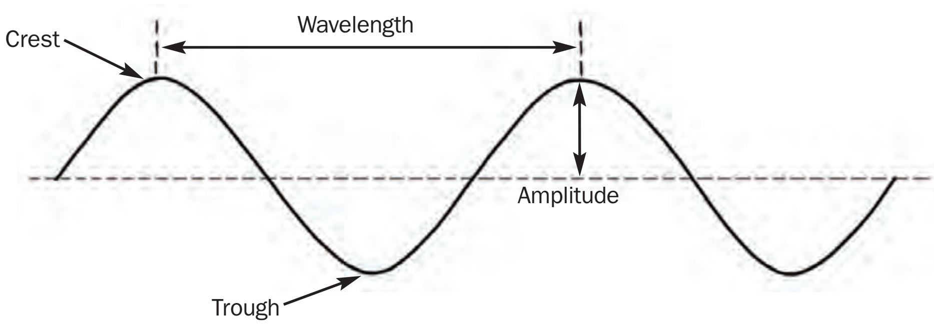
   E. Which wavelengths of your chain carry the most energy?

Figure 9.1 *What is the wavelength of the wave you made with the chain?*

MEASURING A WAVE

Waves can vary in length and height. The distance between the crests (or the troughs) of two adjacent waves is the wavelength of the wave. The distance from the midpoint of the wave to its crest is the amplitude of the wave.

The number of waves that pass a certain point during a specific time—usually a second—is called the frequency of the wave and is measured in Hertz (Hz). With light rays, the speed of the light—the rate at which the waves move along—depends on what substance (or material) the light waves are traveling through. Light travels slightly slower in air than in a vacuum, and its exact speed through air depends on the density of the air. However, because light travels at a constant speed through a vacuum or any one material, frequency and wavelength are related to one another. Remember, the shorter the wavelength, the higher the frequency.



The distance between two crests, or two troughs, of adjacent waves is called the wavelength. The distance from the midpoint of the wave to its crest is the amplitude of the wave.

Inquiry 9.2
Constructing the Spectrum

PROCEDURE

1. Read "Color and Wavelength."

COLOR AND WAVELENGTH

You have been modeling light waves using your chain. But what does this have to do with color? Our eyes can detect different wavelengths of light. Our eyes and brain perceive these different wavelengths as color. We cannot see all the wavelengths of electromagnetic radiation—some are invisible. We see only those wavelengths that range from about 400 to 800 nanometers (a nanometer is one billionth of a meter (1×10^{-9} m), so these wavelengths are very tiny).

2. In this inquiry you will construct a model of the visible spectrum by identifying some waves and drawing other waves in the order they appear in the visible spectrum. Remember that red light has the longest wavelength and violet has the shortest in the visible spectrum.

   A. On the first page of Student Sheet 9.2: Constructing the Spectrum are drawings of waves that represent red, green, and blue light. Identify each of these waves. Cut them out and attach each to the appropriate row in Table 1 (on the second page of the student sheet).

   B. Use a pencil to draw the waves for orange, yellow, indigo, and violet in the appropriate rows of Table 1.

3. Read "Infrared and Ultraviolet" to learn about waves that are shorter and waves that are longer than those of visible light.

INFRARED AND ULTRAVIOLET

The spectrum of visible light is part of a much larger spectrum of waves called the electromagnetic spectrum. The electromagnetic spectrum contains wavelengths that are much longer and wavelengths that are much shorter than those of visible light. Most wavelengths of electromagnetic waves are invisible to the human eye. For example, infrared is invisible electromagnetic radiation, with wavelengths a little longer than red light. Ultraviolet is invisible electromagnetic radiation, with wavelengths slightly shorter than violet light.

   C. Identify the wave in Table 1 that represents ultraviolet and the wave that represents infrared. Correctly label these waves on the table.

4. Read more about the invisible electromagnetic spectrum in "The Hidden Spectrum."

Inquiry 9.3
Looking Outside the Visible Spectrum

PROCEDURE

1. Your teacher will show you an everyday device that produces invisible infrared. Work with your group to devise a series of simple experiments to compare the behavior of the infrared produced by this device with the behavior of visible light. Record your ideas in your notebook.

2. Discuss your ideas with the class. When the class has agreed on a series of simple experiments, design a table in your notebook to record the results of these experiments and compare the behavior of infrared to the behavior of visible light.

3. Your teacher will ask you to either try some of the experiments at home or have different groups of students demonstrate them in class. Record in your table the results of any experiments that are conducted.

4. Discuss the results of the experiments with other students. *Do you think that infrared behaves like visible light?*

Is this dog an expert on using the invisible electromagnetic spectrum?

REFLECTING ON WHAT YOU'VE DONE

1. Draw a wave in your notebook. Label the following features on the wave: wavelength, amplitude, trough, and crest.

2. Answer the following questions in your notebook:

   A. In the wave model for light, what feature of the wave determines how your eyes sense the color of a particular wave of light?

   B. In the visible spectrum, your eyes detect the longest wavelength as what color?

   C. In the visible spectrum, your eyes detect the shortest wavelength as what color?

   D. Which type of electromagnetic radiation lies directly below the red end of the visible spectrum?

   E. Which type of electromagnetic radiation lies directly above the violet end of the visible spectrum?

3. Discuss your answers to these questions with the class.

The Hidden Spectrum

INFRARED PROCESSING AND ANALYSIS CENTER, CALTECH

In 1800, William Herschel discovered infrared light. He thought he had discovered heat rays. It took almost 50 years for scientists to determine that the invisible infrared had characteristics similar to those of visible light.

In 1800, the famous astronomer William Herschel (1738–1822) began to study sunspots. To protect his eyes, he added special filters to his telescope. He pointed the telescope at the Sun and was able to see sunspots very clearly.

But after a few minutes, he ran into a problem. His telescope got too hot to use. Why was this happening? Was there a link between the temperature of his telescope and light? He decided to conduct some experiments to try to answer these questions.

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William Herschel used this prism to split sunlight. He used thermometers to measure the increases in temperature produced by different colors. He also discovered that beyond the red end of the visible spectrum was an invisible form of radiation that produced an even greater increase in temperature.

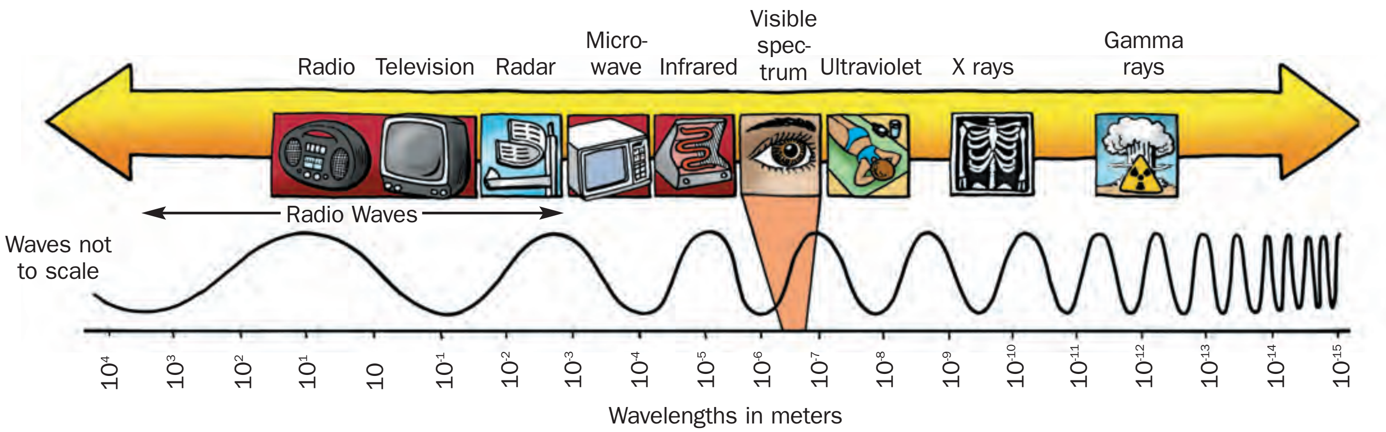
In one experiment, Herschel tried to find out which color in white light produced the most heat when it hit a surface. He used a prism to split white light into its different colors. He put a thermometer in each line of colored light and measured the increase in temperature produced by each color. He discovered that red light produced the most heat. He then put a thermometer just outside the red end of the spectrum. Here no light was visible, but to his surprise the thermometer got even hotter. He had discovered an invisible form of light. Herschel incorrectly thought he had discovered heat rays. This invisible light was later called infrared. Were there other types of invisible light? The search was on!

Widening the Search

Johann Wilhelm Ritter (1776–1810), a German scientist, heard about Herschel's discovery. He decided to use a light-sensitive chemical to search for other types of invisible light. He used the chemical to test for light at the violet end of the visible spectrum. He found another invisible form of light and named it ultraviolet.

Soon the idea of a whole range, or spectrum, of radiation began to grow. Scientists realized that visible light made up only a tiny part of a much wider electromagnetic spectrum. The idea of an electromagnetic spectrum fit neatly with the emerging idea that light was a form of wave energy. Different colors and types of light belonged to the same electromagnetic spectrum. They simply had different wavelengths.

Many types of electromagnetic waves have been identified. Wavelengths can be as long as tens of kilometers (radio waves) and as short as 0.000000000000001 millimeters—10^{-15} meters—(gamma rays). ☐



The different wavelengths of the electromagnetic spectrum have a variety of names and uses.

Tuning In

Have you ever tried tuning a radio? Have you wondered about those numbers on a digital display or scale? And what's all this about AM and FM?

The numbers refer to the frequency of the electromagnetic waves—radio waves—you are tuning into. AM and FM refer to groups or bands of radio frequencies. AM frequencies are around 1 million waves per second or 1 megahertz (MHz). Waves in the FM band are about 100 times shorter, with a frequency of 100 MHz. Remember, the shorter the wave, the higher the frequency (the number of waves that pass a certain point every second).

Which frequency do you tune into most frequently?

VIEWING THE WORLD AND BEYOND IN INFRARED

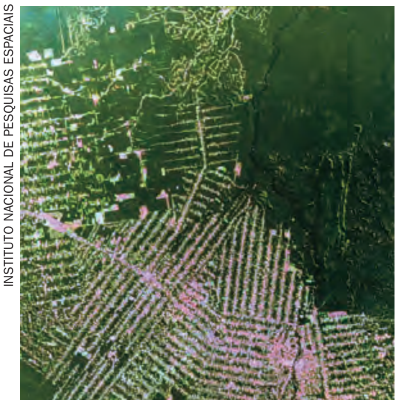
This infrared image uses color to show where infrared is given off. The red areas show parts of the face giving off the most infrared. This image shows a hot face but cool sunglasses!

INFRARED PROCESSING AND ANALYSIS CENTER, CALTECH/JET PROPULSION LABORATORY

Infrared may be invisible, but it can still be detected. Hot objects give off infrared. Hold your hands near a heater and they will soon warm up. When the infrared released by the heater strikes our hands, the infrared is transformed back into heat. By using special film or special electronic cameras, you can view the world in infrared. One such device could be looking at your school right now. In orbit around Earth are satellites designed to view Earth in infrared. The images they collect can provide information on the condition of crops, pollution, or the temperature of the oceans.

Weather satellites take images in infrared. Meteorologists use these images to record the temperature of air masses moving across the planet. These images also can record the temperature of the clouds inside giant storms.

Infrared detectors in space also look away from Earth. Many regions of the universe cannot be seen with optical telescopes. These regions are hidden by clouds of gas



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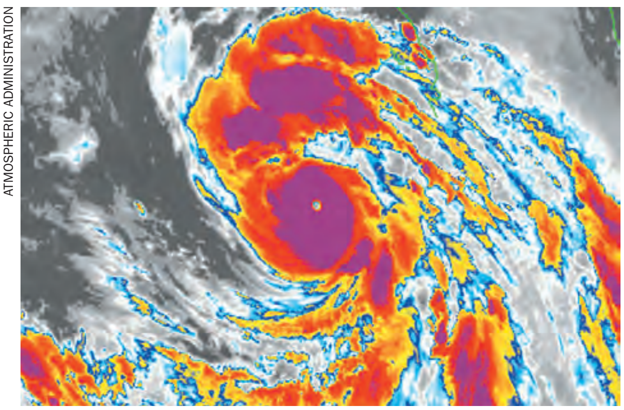
This infrared image shows the Amazon Basin in South America. It can be used to identify areas where the rainforest has been cut down.



NATIONAL CLIMATE DATA CENTER/NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

In this infrared image of hurricane Linda, the purple areas in the center of the storm show the warmest air and clouds.

VISUALS UNLIMITED

Rainforest destruction, such as that caused by this fire, can be monitored using Earth-orbiting satellites. Some of these satellites look at Earth using infrared detectors.

and dust. However, infrared can pass through these clouds. So it is possible to see through these clouds by using orbiting infrared observatories such as the Infrared Astronomical Satellite (known as IRAS). IRAS gives astronomers a different perspective on the universe. With it, they can look into the center of our own galaxy. Infrared can be used to detect objects much cooler than stars. Astronomers also use infrared to look for planetary systems other than our own solar system.

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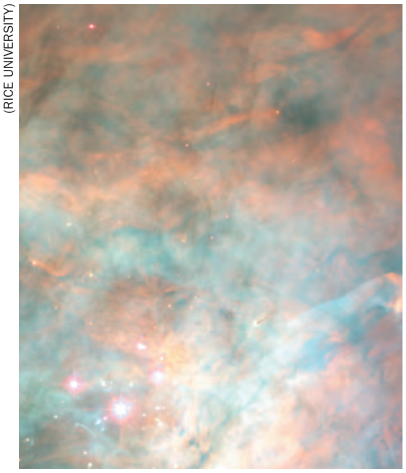

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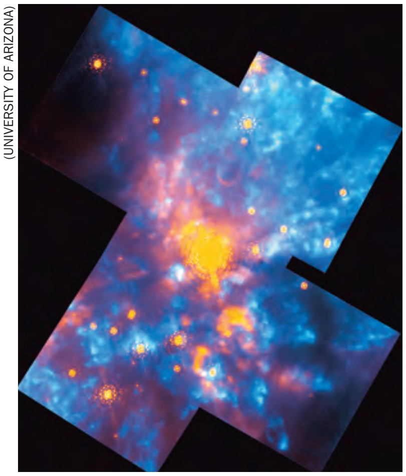

Visible light photos of the Orion Nebula look like a glowing cloud containing a few stars (as on the left). The picture on the right was taken using infrared wavelengths from part of the Orion Nebula and reveals much more information about its structure. Infrared allows astronomers to see through the clouds of dust and gas that usually obscure this view.

Using Infrared Closer to Home

Back here on Earth, seeing in infrared gives us a new view of our world—even a new view of ourselves. Look at the human face in infrared. You can see the different temperatures of skin. The human face begins to look quite different.

Looking at objects in infrared provides engineers with useful information. For example, they can use infrared detectors to discover how buildings lose heat. This helps them design buildings that are more energy efficient. They also can use the detectors to check electrical systems for overheating that could cause fires. Computer makers use infrared sensors to look for hot spots on circuit boards. Automakers use these sensors to check that car engines are running properly. Railroads use infrared sensors to spot overheated wheels on railroad cars.

By making the invisible visible, infrared photography and detection allow people to see a world that previously was hidden from view. ☐

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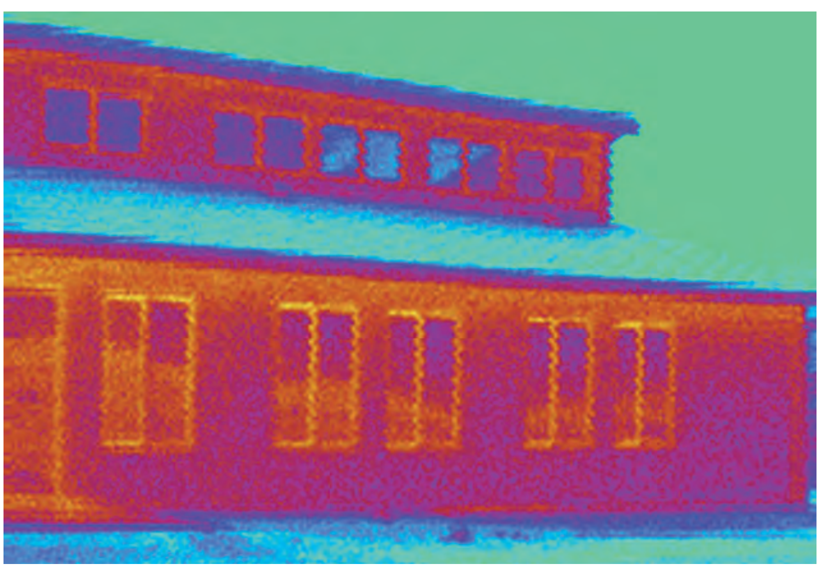

An infrared photograph shows that this house has a well-insulated roof (blue-green areas), but loses much of its heat through its walls and windows (orange areas).

QUESTION

What is another use of infrared? Use the Internet or an encyclopedia to research one additional use of infrared in detail.

STOCKBYTE/PICTUREQUEST

Is this boy endangering his body's largest organ?

Put on your hat, and don't forget the sunscreen. Yes, it's one of those hot summer days, ideal for having fun in or on the water. But spending the morning tubing on a river or swimming at the local pool could cause you to severely burn the largest organ in your body!

No, it's not your liver; it's your skin. The cells that make up the skin all work together to perform a specific function. The skin's job is to separate the inside of your body from the outside world, and the skin does its job well. Outside the body, there are many harmful things. One of these is electromagnetic radiation. Visible light is fairly harmless, but some types of invisible electromagnetic radiation can be very damaging. For example, ultraviolet radiation (UV) causes sunburn.

The Sun produces lots of UV of a variety of different wavelengths. Luckily, most UV is absorbed high in the atmosphere and never reaches Earth's surface. The layer of the atmosphere that absorbs UV is called the ozone layer (see "Ozone and the Ozone Layer" sidebar).

Tanning is the skin's natural reaction to UV. When skin tans, it produces a brown substance called melanin. Cells deep in the skin produce melanin, which acts as a protective barrier by absorbing harmful radiation. In light-skinned people, these cells are less active. People with darker skins produce more melanin than people with lighter skin. In fact, the darkness of people's skins is mainly an indicator of the amount of melanin they produce. Different skin colors are probably the result of adaptation to different levels of UV at different parts of the globe.

Sunburn is the body's reaction to damage caused by UV. Overexposure to UV can kill cells or damage parts of cells, including DNA. The body reacts as it would to an ordinary burn or other skin damage—but slower. A few hours after exposure to the Sun, the skin becomes red, inflamed, and painful. This is why it is easy to get sunburned and not know it until even the following day!

A minor sunburn often heals after a few days. (A bad sunburn, like any burn, can kill.) But repeatedly burning one part of the skin can cause skin cancer. That's why it is important to protect your skin from UV. One way is simply to cover up—wear a wide-brimmed hat and long-sleeved shirt and long pants.

Another way to get some protection from UV is to use a sunscreen. Sunscreens work in two ways. Some sunscreens look white; they simply reflect UV. Others absorb the UV. They work just like our natural skin protector, melanin. If you look at a bottle of sunscreen, you'll notice it is labeled with a Sun Protection Factor (SPF). The higher the SPF, the more effective the sunscreen.

So the next time you are out in the Sun, slip on a hat and slap on the sunscreen! Your skin will thank you. □

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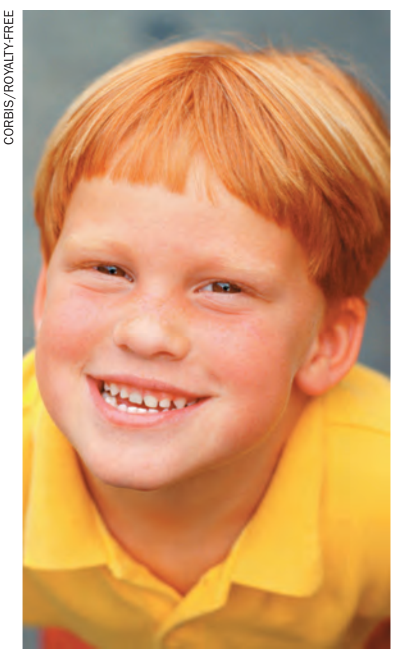
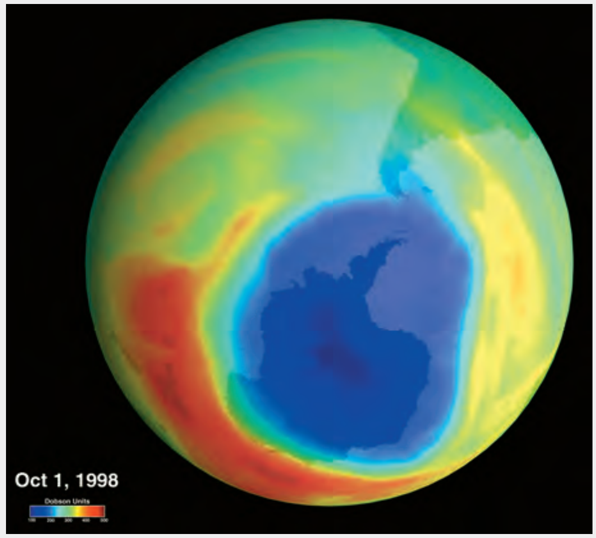


Dark skin provides better protection from UV. Different skin colors offer different levels of protection.

Ozone and the Ozone Layer

The ozone layer of Earth's atmosphere protects us from most of the Sun's UV radiation. Ozone—a type of oxygen—is able to absorb UV. A layer of ozone about 24 kilometers (15 miles) up in the atmosphere shields Earth. The amount of ozone present high in the atmosphere varies naturally over time. However, in the last 30 years scientists have found that human activity is slowly destroying the ozone layer. Pollution, such as some chemicals used in old aerosol cans, refrigerators, and air conditioners, gets into the ozone layer and reacts with and destroys ozone. Scientists have observed big "holes" appearing in the ozone layer where the levels of ozone are very low. The largest of these holes is in the Southern Hemisphere. Scientists also have observed declining levels of ozone in the ozone layer over the whole globe.



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION/GODDARD SPACE FLIGHT CENTER: TOTAL OZONE MAPPING SPECTROMETER

We are protected from some UV by the ozone layer. However, pollution has reduced the amount of ozone in the ozone layer making it less effective. Now a large hole (shown here in blue) has appeared in the layer over part of the Southern Hemisphere.

NATIONAL CANCER INSTITUTE

This is a melanoma. It is one form of skin cancer. Melanomas can be caused by overexposure to UV.

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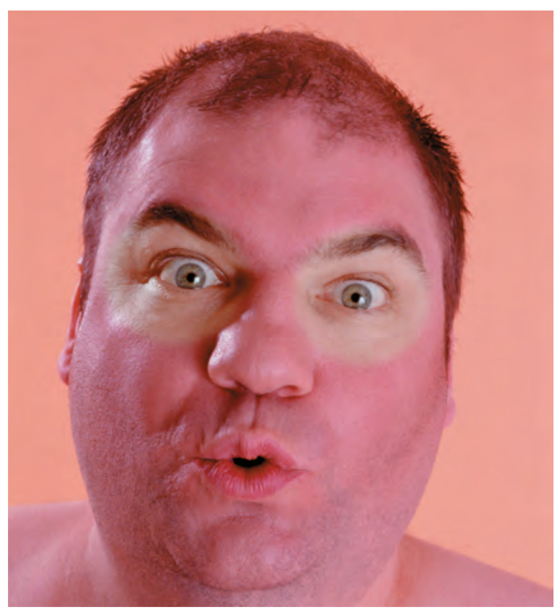

Ouch! Sunburn can damage the skin. Tanning indicates the skin has been overexposed to UV. A bad sunburn like that shown here can be very painful, and a very bad sunburn can be life threatening.