SCIENCE OVERVIEW

Sunlight is the source of life-sustaining energy on Earth. Its effects range from allowing temperatures on our planet to remain hospitable for life to providing energy for photosynthesis. In addition to light that can be seen with the human eye—visible light—there are other forms of energy emitted by the Sun. In this lesson, we discuss one of these other forms—infrared radiation.

The Electromagnetic Spectrum

Weather forecasters often show temperature maps of the United States based on the temperature measurements in different parts of the country that day. The maps are created by assigning each temperature a color, and then filling the map with colors corresponding to the temperatures measured at each location. A map created this way shows the temperature field of the United States on that particular day. The temperature field covering the United States, in this sense, is a description of the temperatures at every location across the country.

In a similar fashion, the Universe can be thought of as being permeated by an electric field. All electrically charged particles (such as electrons) have a region of space around them where they influence the behavior of other charged particles wandering there. This region can be described as an electric field around the particle. Just as temperatures in different parts of the country create the temperature field of the United States, the electric charges in the Universe can be thought of as creating an electric field permeating the whole Universe. Magnetic objects behave in a similar fashion: every magnetic object creates a magnetic field around it, and their collective magnetic field permeates the Universe.

Most things in the Universe tend to move around, and electric charges are rarely an exception. If the velocity of an electric charge changes (that is, it accelerates or decelerates), it creates a disturbance in the electric and magnetic fields permeating the Universe. These disturbances move across the Universe as waves in the "fabric" of the electric and magnetic fields. The waves also carry energy from the disturbance with them, in a similar way that the energy of the wind striking a flag is carried across the fabric by the waving of the flag. The waves carrying the energy of the disturbance across the Universe are characterized by their wavelength, which measures the distance between two consecutive wave crests.

A familiar example of this kind of wave is visible light. Different colors of visible light have slightly different wavelengths, and there are waves which have much higher and shorter wavelengths than the light that humans can see. Together, the waves of all different wavelengths are called electromagnetic radiation, and the whole array of different kinds of light, arranged according to their wavelength, is called the electromagnetic spectrum (See Figure 2.) Electromagnetic radiation travels at the speed of light (300,000 km/s or 186,000 miles/s in a vacuum such as space).

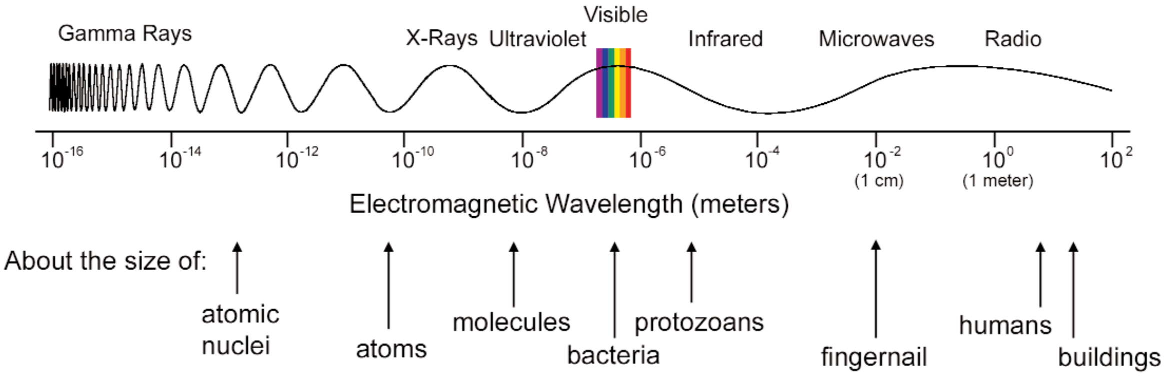

Figure 2. The electromagnetic spectrum. In the picture, different parts of the spectrum are shown as one continuous wave. In reality, a given electromagnetic wave has one particular wavelength. The continuous wave in picture above is used to better illustrate the difference between wavelengths from one part of the spectrum to another.

The complete electromagnetic spectrum includes:

- Radio waves (including microwaves): Used for transmitting radio and television.
- Infrared: Seen by many animals (not humans), also used in night vision goggles.
- Visible light: The portion of the spectrum that humans can see.
- Ultraviolet: Causes sunburns.
- X-rays: Used in hospitals to make internal images of the human body.
- Gamma rays: Used in radiation treatments of cancer.

Light travels at different speeds through different materials. When light moves from one substance to another (for example, when a beam of light passes through air and into water, or vice versa), it changes its speed, and therefore its direction if it enters the substance at an angle. This effect (called refraction) is noticeable if a stick is placed halfway under water; light from the submerged part of the stick changes direction as it reaches the surface, and our eyes perceive the refracted light as the illusion of a bent stick. The same effect happens when visible light passes through a prism. In this case the different colors of light are bent (refracted) onto different paths according to their wavelength. A beam of light can consist of just one color, so that only one color of light enters the prism and the same color exits, bent onto a new path; or, a beam of light can consist of a mixture of colors, so that the mixture of colors enters the prism and each color exits the prism bent onto a path of its own. Shorter wavelengths (blue and violet) are refracted, or bent, more than longer wavelengths (red), resulting in the familiar rainbow pattern of colors. Radiation that is not visible also is refracted according to wavelength. Beyond the red end of visible light is the infrared, and beyond the blue is the ultraviolet part of the electromagnetic spectrum.

Sunlight, as it emerges from the Sun, consists of all types of electromagnetic radiation. The Earth's atmosphere reflects away or absorbs much of the electromagnetic spectrum, so that only part of the radiation reaches the surface. Most radio waves come through the atmosphere unimpeded, visible light passes through without much difficulty, while only some infrared radiation, very little of the ultraviolet rays, and none of the X-rays and gamma rays reach the surface. This is very fortunate for life on Earth because some kinds of radiation (such as ultraviolet light, X-rays, and gamma rays) can break apart molecules in living things. Most forms of life could not survive unprotected on the Earth's surface if the atmosphere did not almost completely shield us from these harmful forms of radiation.

Infrared Radiation

Infrared radiation comes from warm objects—the warmer the object, the more infrared radiation it emits. If the temperature of the object becomes very high, it will emit visible light in addition to infrared radiation. For example, the filament in an ordinary light bulb glows with both kinds of radiation when its temperature rises to more than 2500º C (4500 °F). One way to think about this is to say that infrared radiation comes from warm objects while infrared as well as visible light comes from hot objects. Even hotter objects (for example, stars) will emit infrared, visible, as well as even more energetic forms of light such as ultraviolet or X-rays. Remember that most of the objects we see with our eyes are visible to us because they reflect the light from a hot source—the Sun during the day, a light bulb at night—and they are not hot enough to emit visible light themselves. Humans, with body temperatures around 37˚C (99˚F), emit infrared radiation but no visible light—we see each other because we reflect the light from a light source. If we could see infrared light, we would be able to see each other even in the middle of the night. Some animals, such as rattlesnakes, can detect infrared light. This allows the snake to find warm-blooded animals, such as small rodents, by detecting the infrared radiation that they emit.

Infrared radiation is used in many modern applications. The most familiar instance of everyday use of infrared radiation may be television remote controls. Other examples include security and surveillance cameras, and instruments used to observe the insides of a human body without having to do surgery. Firefighters use infrared cameras to locate people and animals hidden by smoke in burning buildings and to find hot spots in forest fires. Engineers use infrared-based scanners to find heat leaks in buildings and to test for problems in mechanical and electrical systems. Infrared satellites are used in investigating global climate properties, weather phenomena, and vegetation patterns, and even to discover ancient roads in archaeological studies. Astronomers use infrared imaging to study a variety of objects, such as newly formed stars and the most distant galaxies in the Universe. Infrared radiation is very useful for studying planets in the Solar System. Planets reflect away much of the sunlight they receive, but they absorb part of it. The light heats up the surface of the planets to warm (but not hot) temperatures, and the surfaces emit infrared light (as all warm objects do). Using this emitted infrared radiation to make observations of the planets provides invaluable clues to their properties which may be difficult to determine otherwise. Since much of the infrared radiation arriving from astronomical objects is blocked by Earth's atmosphere, infrared telescopes have been launched to make their observations from space.

Considering the many ways in which infrared radiation is important in our lives, it is remarkable to realize that its existence was not discovered until a little over two centuries ago by Sir William Herschel.

Sir Frederick William Herschel

Sir Frederick William Herschel (1738-1822) was born in Hanover, Germany, and became well known both as a musician and as an astronomer. He moved to England in 1757 and, with his sister Caroline, constructed telescopes to survey the night sky. Their work resulted in several catalogs of double stars and nebulae. Herschel is famous for his discovery of the planet Uranus in 1781, the first new planet found since ancient times.

The Herschel Experiment

Sir William Herschel made another important contribution to science in the year 1800. In his astronomical work, Herschel noticed that when he used filters of different colors to observe sunlight, the filters seemed to let through different amounts of heat. He thought that the colors themselves might be of varying temperatures and devised an experiment to investigate his hypothesis.

Herschel directed sunlight through a glass prism to create a spectrum and then measured the temperature of a thermometer illuminated by each color in turn. He noticed that the temperature increased from the blue to the red end of the visible spectrum. After noticing this pattern, Herschel decided to measure the temperature just beyond the red portion of the spectrum in a region that did not appear to have any sunlight falling on it. To his surprise, he found that this region had the highest temperature of all. He realized that there must be another type of light beyond the red, light that we cannot see. He probably could not have been expected to discover ultraviolet light beyond the blue end of his spectrum, as most (but not all) materials that transmit visible light are very effective in absorbing ultraviolet light, and thus his prism would not have provided the ultraviolet portion of the Sun's spectrum.

Herschel performed additional experiments on the rays he had discovered beyond the red portion of the spectrum. He found that they were reflected, refracted, absorbed, and transmitted in a manner similar to visible light. He called this new kind of light "calorific rays," derived from the Latin word for "heat." Today, this form of light is known as infrared radiation. The word "infra" is derived from the Latin word for "below"—it describes where you find the infrared radiation on the electromagnetic spectrum when compared with visible light.

Herschel's experiment is important because it was the first time someone demonstrated that there are types of light we cannot see with our eyes. As we now know, there are many other types of radiation that we cannot see, and the visible colors are only a small part of the entire range of the electromagnetic spectrum.

The Herschel Experiment as an Example of Scientific Discovery

Herschel's experiment is a good demonstration of how scientific progress takes place. Herschel started out with a question based on his research and experience: he noticed that different color filters seemed to pass different amounts of heat and wanted to find out if this was really the case. He devised a hypothesis based on this observation—that the colors themselves could be of varying temperatures. He designed an experiment to test the hypothesis—measuring the temperatures of the different parts of the visible spectrum. After noticing that the temperatures of the different colors appeared to indeed be different, he was able to confirm his hypothesis. It is now known that he was measuring the intensity of sunlight at different wavelengths rather than any inherent property of different colors of visible light, but when this distinction is made clear, the hypothesis still remains valid.

Herschel did not stop there, and this shows an important aspect of the scientific process. Sometimes experiments designed to investigate a specific question can produce unexpected results and lead to even more important discoveries. When Herschel noticed that the temperatures increased toward the red end of the visible spectrum, he continued the experiment to measure the temperatures beyond the visible part of the spectrum, and discovered the existence of infrared radiation. He had not originally designed the experiment to determine whether there was radiation beyond the visible part of the spectrum, but once the experiment hinted that this might be the case, he was able to come up with a new, modified question and augment his experiment to test the new hypothesis. This versatility and ability to modify one's perspective, questions, and experiment in the middle of the process, while still maintaining the integrity of the experiment, are important characteristics of a good scientist.

Infrared Radiation and the MESSENGER Mission

Infrared radiation is of great importance in the design of the MESSENGER spacecraft and in the operation of its scientific instruments. One of the instruments on MESSENGER, the Mercury Atmospheric and Surface Composition Spectrometer (MASCS), includes a visible-infrared spectrometer, which measures the amount of energy at different wavelengths in the visible and infrared parts of the electromagnetic spectrum. Just as rocks and minerals have specific colors in visible

light (e.g., turquoise is blue), they have unique "colors" at infrared wavelengths, providing an enhanced opportunity for MESSENGER to learn what Mercury's surface is made of. This will help us understand the geologic history of Mercury, as well as provide clues to solving one of the biggest mysteries Mercury poses—why is the planet so dense?

Although it is useful to the scientific goals of the mission, infrared radiation is also a great concern for MESSENGER. The amount of infrared radiation (as well as visible light) that the spacecraft receives from the Sun during its orbit around Mercury will be up to 11 times higher than it would receive in Earth orbit. When one considers the fact that Earth's atmosphere typically passes through only about half of all solar radiation, the amount of sunlight MESSENGER will be exposed to can be 22 times as high as what objects experience on the surface of Earth. In addition, the surface of Mercury that faces the Sun heats up and emits infrared radiation.

This poses a great engineering challenge to the mission design team: How can the spacecraft and its sensitive instruments be protected against extremely high temperatures while remaining in Mercury orbit and exposed to Mercury itself, as required to complete its mission? To protect against direct sunlight, the spacecraft will have a sunshade that is at all times pointed toward the Sun so that the instruments are always shaded. The spacecraft's orbit around Mercury has been designed so that its closest approach to the planet is away from the most sun-baked region of the surface and so that it flies quickly over the sunlit areas. This is achieved by an orbit where the periapsis (the closest point to the surface of Mercury and also the part of the orbit where the spacecraft's speed is at its highest) is at a high latitude and the apoapsis (the farthest point of the orbit and also the part of the orbit where the spacecraft's speed is at its lowest) is far away from the surface of Mercury. In this manner, infrared radiation received by the spacecraft can be kept at safe levels.

With these safeguards, MESSENGER's instruments will be in a thermal environment that is roughly comparable to room temperature: During the orbital part of the mission, the temperature on the instrument deck of MESSENGER is expected to vary from a few degrees below 0°C (32°F) to 33°C (91°F).