Science Overview

Radiation comes across as something mysterious. We cannot feel it, hear it, smell it, and apart from visible light, even see it, but it can be useful in our lives or cause us harm. On Earth, in our daily routine, radiation is not a great concern (barring exceptional circumstances, such as a nuclear power plant accident). However, once we travel into space, radiation can be a significant problem, because the atmosphere—the air that we breathe—which normally blocks out most of the harmful cosmic radiation arriving on Earth, is no longer present to protect us. Without the shielding atmosphere, cosmic radiation could reach the Earth's surface unimpeded. Some scientists claim that under such conditions, life might never have evolved here.

What Is Electromagnetic Radiation?

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.

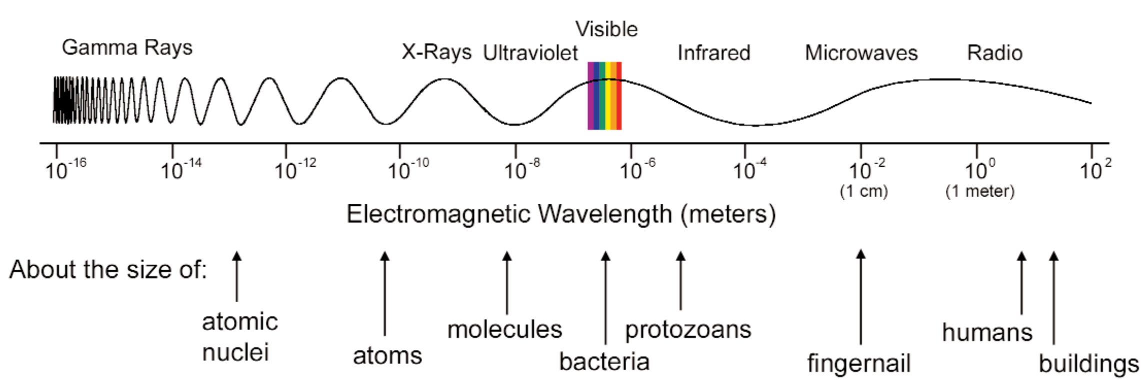

Figure 2. The electromagnetic spectrum. In the picture, different parts of the spectrum are shown as one continuous wave. In reality, a given electromagnetic wave has one particular wavelength. The continuous wave in the picture above is used to better illustrate the difference between wavelengths from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

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).

The complete electromagnetic spectrum includes, from low to high energy:

- ▼ Radio: Used for transmitting radio and television (includes microwaves).
- ▼ 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 (UV): Causes sunburns.
- ▼ X-rays: Used in hospitals to make internal images of the human body.
- ▼ Gamma rays: Used in the radiation treatment of cancer.

The effect of radiation on matter depends on how much energy it carries. For example, radio waves have low energy and are fairly harmless. On the other hand, high-energy radiation, as discussed more fully below, can be harmful to matter, particularly living organisms.

The lower-energy parts of the electromagnetic spectrum (ultraviolet to radio waves) are not as dangerous as high-energy radiation but can still be harmful. For example, sunburn is caused by too much exposure to the Sun's ultraviolet radiation, and it is possible that low-frequency radio and microwave radiation from cell phones could be a health concern, though the current data suggests that it is not a significant concern. Note that there is a popular misconception that cell phones (as well as microwave ovens) can cause cancer; this is wrong. The energy of the microwaves and low-frequency radio waves emitted by the cell phones is not sufficient to create the effects by which radiation can cause cancer.

What Is Radiation?

Electromagnetic radiation is one of many different kinds of radiation that exist in nature. Radiation in general can be defined as the process of emitting energy. There are two basic carriers of this energy:

- Particles: E.g., high-energy protons, neutrons, electrons, atoms, and ions (which are atoms that have lost or gained electrons, resulting in an electric charge).
- Waves: E.g., light and sound.

That is, the energy can be carried from one place to another in the form of particles or waves. A form of radiation with which all of us are familiar is sunlight.

What Is Ionizing Radiation?

An especially damaging form of radiation is "ionizing radiation," which can create electrically-charged ions in the material it strikes. This ionization process can break apart atoms and molecules, causing severe damage in living organisms, either by affecting living tissue directly (e.g., causing radiation sickness and possibly cancers), or by prompting changes in the DNA (i.e., causing mutations—hereditary mutations are extremely rare, however). The most significant forms of ionizing radiation are:

- X-rays and gamma rays: High-energy parts of electromagnetic spectrum.
- Alpha particles: Atomic nuclei consisting of two protons and two neutrons.
- Beta particles: Fast-moving electrons ejected from the nuclei of atoms.
- Cosmic radiation: Energetic particles arriving at Earth from outer space.
- Neutrons: Produced mainly in nuclear power plants.

As the list indicates, ionizing radiation can be either waves (X-rays, gamma rays) or particles (alpha and beta particles, neutrons and cosmic radiation).

In newspapers and public discussions, ionizing radiation often is just called "radiation." This may cause us to forget that both low-energy and high-energy forms of radiation are processes of transmitting energy, and that they have a very different impact on the materials they encounter. In addition, sometimes even radioactive elements are called "radiation" in the media, further confusing the situation. When seeing or hearing the term "radiation," it is always good to determine exactly what is being discussed.

Atomic Sources of Radiation

Radiation is created by changes in the state of an atom. For example, the disturbances in the electric and magnetic fields permeating the Universe arise from the vibration of atoms (at high temperatures) or excitation of electrons (at lower temperatures). Gamma rays are produced when the nucleus of the atom changes state.

Much ionizing radiation comes from radioactive elements, when “unstable” or “radioactive” atoms change to a completely new atom. During this spontaneous change to a more stable form (radioactive decay), some of the excess energy of the atom is released as radiation. One way to describe the radioactivity of an element is its half-life, which is the time it takes for half of the atoms of a radioactive substance to decay. Half-lives can range from less than a millionth of a second to millions of years.

Cosmic radiation comes from many sources, both inside and outside the Solar System, and even from outside the Milky Way galaxy. Many, but not all, of the processes that create cosmic rays are at least roughly understood.

How Do We Measure Radiation?

While we cannot see ionizing radiation or directly feel whether an item is radioactive, we can use a variety of instruments that detect and measure radiation levels accurately. The basic unit used to measure exposure to ionizing radiation is a sievert (Sv). It measures the biological effect of absorbed radiation (referred to as an "effective dose"). Most often, radiation exposure is expressed in millisieverts (mSv), one thousandth of a sievert, or in microsieverts (mSv), one millionth of a sievert. An older, non-Standard-Internationale (SI) but still often-used unit of exposure is a rem. One sievert is one hundred times larger than one rem; that is, 1 Sv = 100 rem.

Where Does Ionizing Radiation Come From?

On the surface of Earth, there are several natural sources of ionizing radiation. The most important of these is radon, a gas formed by the radioactive decay of naturally occurring uranium in rock, soil, and water. Once formed, some radon gas seeps through the ground into the air we breathe, while some remains below the surface and dissolves in underground deposits of water. These kinds of radiation from natural sources are commonly referred to as "background radiation." Naturally-occurring background radiation levels are typically between 1.5 and 3.5 mSv per year, though levels more than ten times higher have been measured in parts of Brazil, China, Europe, India, Iran and Sudan.

Ionizing radiation is also produced in a variety of human activities. A familiar example is a nuclear power plant, where radiation is created as a by-product of electricity generation. In other facilities, large doses of radiation are used to kill cancerous cells in our bodies or harmful bacteria in food, and to sterilize medical equipment.

It is a common misconception that most harmful radiation to humans comes from human activities. Typically, about 88% of the ionizing radiation exposure to humans comes from natural sources; most of the remaining 12% comes from medical procedures. In the United States, the average person is exposed to approximately 3.6 mSv of whole body exposure per year from all sources.

Once we go up into space and leave the protection of the Earth's atmosphere behind, radiation becomes a significant problem. Of most concern to both humans and equipment are different types of particle radiation from sources such as:

- ▼ Trapped particle radiation regions near the Earth (the Van Allen belts).
- ▼ Solar energetic particles, which are high-energy particles emitted by the Sun.
- ▼ Galactic cosmic rays, which are high-energy particles created outside the Solar System by stellar flares, nova and supernova explosions, and quasars.

How Does Radiation Cause Damage to Humans?

We are exposed to different forms of radiation every day. Radiation only becomes a problem if we are exposed to too much of it. A familiar example is ultraviolet radiation from the Sun here on Earth; overexposure to it may cause eye and skin damage, and in the worst case, lead to cataracts, glaucoma, or skin cancer.

Ionizing radiation can be very harmful, which is why it is useful in killing cancer cells as long as it is carefully directed so that its effect on healthy tissue is minimal. Large doses of ionizing radiation on healthy tissue can result in cancer after a delay of a few years. At very high levels, high-energy radiation can cause sickness and death within weeks of exposure. By creating changes in the DNA, ionizing radiation can also cause genetic mutations that could affect future generations, but in fact a person exposed to levels of radiation sufficiently high to cause mutations is more likely to die from the radiation exposure than pass the mutations to his/her offspring.

The level of damage caused by radiation depends on many factors such as the dose, the type of radiation, the part of the body exposed, and the age of the exposed person. Embryos are particularly sensitive to radiation damage. For the health concerns raised by different doses of ionizing radiation, see the table on Student Worksheet 2.

There is a common misconception that people exposed to high-energy radiation (especially radioactive material) become radioactive themselves. However, in reality, ionizing radiation usually does not cause the exposed body to become radioactive beyond its natural level; it just causes damage to the living tissue. The exception to this is a very high dose of high-energy neutron radiation, which can cause the material it strikes to become radioactive. However, this is a very rare occurrence for living things, and only tends to happen to nuclear power plant generators and other related equipment over long periods of time.

The level of exposure to radiation during nuclear bomb blasts and nuclear power plant accidents also depends on the distance. For example, most people killed in Hiroshima died from the immediate blast and not from radiation, and people farther away experienced a short-term dose of about 200 mSv. During the 1986 Chernobyl nuclear power plant accident in the former Soviet Union (present Ukraine), most fatalities came from the fire fighters and workers inside the power plant (their doses were well over the 10,000 mSv level), while people downwind were exposed to smaller doses that are expected eventually to cause a total of about 24,000 deaths from cancer.

The most effective ways to protect against radiation are to limit exposure time, increase the distance from the source, or use shielding. The effectiveness of shielding material depends largely on the density of the material—dense materials generally are more capable of blocking all kinds of radiation than low-density materials.

Much ionizing space radiation is stopped by Earth's atmosphere, as well as by Earth's magnetic fields. Once above the thick atmosphere, though, astronauts are exposed to much higher radiation levels. The research into understanding the effect of space radiation on people is still in its early stages. For example, an experiment aboard the International Space Station (ISS) Expedition Two in 2001 used a test dummy called Fred, which was designed to mimic some of the characteristics of a real human even though it was built of artificial materials. Fred was placed on the station for four months to measure the radiation dose rate on human tissue. The results from these kind of experiments will help us achieve a much better understanding of the effects of space radiation on humans.

MESSENGER and High-Energy Radiation

Much of the radiation that spacecraft encounter in space is actually beneficial for the mission. For example, the instruments aboard the MESSENGER mission to Mercury will be making observations in various parts of the electromagnetic spectrum, from gamma rays to radio waves; they will also make observations of the high-energy particle radiation near Mercury. This will help us get a better understanding of the space environment near the planet. High-energy radiation is also used to help determine whether water ice exists in permanently shadowed craters near the planet's poles.

Just as for people on Earth, radiation becomes a concern only if the spacecraft is exposed to too much of it. Fortunately, spacecraft can be specially built to survive much higher doses of radiation than humans can handle. It is not possible to specially build humans this way!

Based on the properties of high-energy radiation in different parts of the Solar System, ionizing radiation levels encountered by the MESSENGER spacecraft are expected to be 3-10 times higher than what a spacecraft near Earth or in interplanetary missions away from the Sun usually experience. Therefore, high-energy radiation is a concern for the mission. On the other hand, the levels are thought to be about 30 times less than what a spacecraft encounters near Jupiter, which has a particularly harsh radiation environment.

Of greatest concern for the MESSENGER mission are solar energetic particles, which are created in solar flares; big explosions in the Sun's atmosphere. Their amount is controlled by an 11-year solar activity cycle, which goes from about four years of solar activity minimum to roughly seven years of solar activity maximum. The current cycle (number 23), began in early 1997, and reached maximum in late 2000. The cycle's progression can be followed by observing changes in the number of sunspots visible on the Sun's surface (see Figure 1).

MESSENGER's journey to Mercury will take place during solar activity minimum years, when the typical dose is only 1% of that during the maximum years. However, during the time that the spacecraft will orbit the planet (2011-2012), Sun's activity will be near maximum. Therefore, MESSENGER will experience large changes in the radiation environment during its operation.

Possible radiation effects on the MESSENGER spacecraft are: Damage to the electronics including computer memory, decreased power production by the solar cells, and interference with the onboard instruments. These dangers can be reduced by effective shielding. The overall spacecraft structure offers some protection, and critical electronic components are radiation-hardened. Redundancy and the use of radiation-resistant materials also reduce the probability of major problems.