Of the full range of solar radiation, only two distinct portions pass easily through the atmosphere. One is the wide range of long radio waves; the other, a tiny fraction we can see with our eyes: visible light.

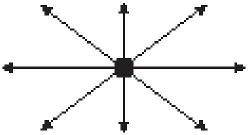
EARTH'S ATMOSPHERE

With its unique proportion and mixture of gases, water, dust, and airborne particles, the atmosphere makes life possible, weather interesting, and its optical properties fascinating. The atmosphere is abundant enough to be held by gravity and allow us to breathe with ease; viscous enough to transport moisture and swirl about on the surface; and conductive enough to absorb heat and transmit electricity. Our atmosphere is thin enough to be transparent to visible light, yet thick enough to filter life-harming ultraviolet radiation, bending and splitting that which enters into its colored components.

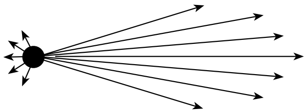
The atmosphere is pulled toward the center of the Earth by gravity. The pressure of the gases, however, resists such a pull and pushes outward toward space. The result is a slender sphere of air surrounding the globe, densest at the surface, tapering off to where individual molecules of gas do not even meet one another. Fifty percent of its mass is below three-and-a-half miles above the surface; 90 percent of it is within about ten miles; and 99.9 percent of it is below twenty-nine miles. Yet even at a height of 350 miles, air exists, although its density there is about one-trillionth of that at sea level. Beyond that, atmospheric gases give way to the magnetic fields and radiation belts of outer space.

As visible light streams through the inhomogenous atmosphere, encountering air molecules in varying densities, dust of all kinds and sizes, and water in all its phases and forms, the light may be absorbed as heat, never to be seen again; or it may be bent, split, attenuated, concentrated, deflected, or otherwise diverted along its entire pathway to our eyes. Four different processes contribute to these outcomes, alone or in combination: *scattering, diffraction, refraction, and reflection*. The first three also separate light into its component wavelengths in a neat feat called dispersion. Whenever they get their cumulative act together with the ever-diverse, ever-changing weather, the resultant light show can be astonishing.

SCATTERING BEHAVIOR



Air molecules scatter light of shorter wavelengths more efficiently than longer wavelengths, and in a symmetrical pattern.



Tiny water droplets scatter light more strongly forward than in other directions, and without any preference to wavelengths.

1. SCATTERING

In the vacuum of space, where nothing interferes with the solar radiation, the surroundings are black. At about sixteen miles from the Earth, the radiation's encounter with tiny particles of dust and gas molecules begins to diffuse a portion of the energy in all directions. These particles, which may be thought of as very tiny reflectors, scatter the radiation in all directions; the amount of light and the directions in which it is scattered depends on the size of the particles.

Air molecules, which are much smaller than the wavelengths of light (about 1/1000 the size), scatter light in a symmetrical pattern. As much light is scattered straight ahead (0°) as is sent straight back toward the Sun (180°). The least amount of light is scattered at 90° to the direction of travel. This interaction is called Rayleigh scattering, named after the English physicist Lord Rayleigh, who was first able to calculate the intensities of light scattered in all directions by clean air. He also found that air scatters approximately ten times as much blue light as red light. This explains the overwhelmingly blue appearance of the clear sky overhead, as well as the yellow to orange to red tints of skylight at sunrise and sunset, when light travels through a comparatively longer cross section of the atmosphere and most of the blue light has been completely scattered away.

Because light waves from the Sun oscillate in all directions, scattering in any particular direction (other than 0° and 180°) "filters out" those waves vibrating in all other directions and produces polarized light, whose waves propagate in only one direction. Light scattered at 90° (the plane of maximum polarization) results in the minimum brightness in the sky.

As the size of the scattering particles increases, so does the intensity of the light scattered in the forward direction. Mist and fog droplets, which are comparable in size to the wavelengths of light, scatter light more strongly forward and backward, and with more or less equal intensity according to wavelength, resulting in the whiteness of their appearances.

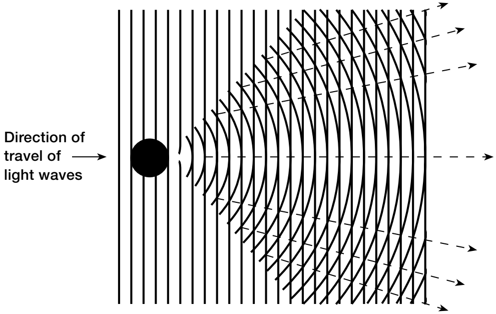
2. DIFFRACTION

Scattering is caused by particles smaller than the wavelengths of visible light. Similar to scattering, diffraction also changes the direction and distribution of light, but it occurs when the diameter of the particles is approximately the same size or greater than the wavelength of light. At this ratio, light's wavelength—and its behavior as a wave—determines its ultimate distribution. If the crests of two waves moving in different directions reach a point at the same time, their effects add together and reinforce each other in a condition known as constructive interference. If the crest of one wave reaches a point at the same time as the trough of another wave, they cancel each other out, in a condition known as destructive interference.

3. REFRACTION

As light waves pass from one medium to another of a different density, both their speed and direction change; this effect is called refraction. Light may refract through a single medium, as when it passes through varying densities of air layers, or through two or more substances, as when it passes from air into water or ice, which usually results in dispersion. Refraction is the commonly observed effect when a stick thrust into a pond appears bent and shorter in the water.

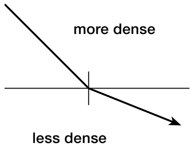
DIFFRACTION BEHAVIOR
When waves encounter an obstruction, new circular waves are generated about the obstruction, much like the waves of a boat's wake passing a pier post. When light strikes a cloud droplet, which is about fifty times the wavelengths of visible light, the new circular waves originating on both sides of the droplet combine with the original straight waves, causing light to travel out at an angle to the original direction. (For clarity, just a portion of the circular waves is shown here.) Wave crests combine in constructive interference along the dashed lines to produce bands of maximum light intensity; between them, destructive interference results in darker areas.

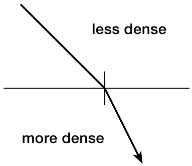


REFRACTION BEHAVIOR
The degree of refraction is measured as an angle between the bent ray and an imaginary line perpendicular to the boundary between the different densities, called the normal.

Passing from denser to less dense refracts light away from the normal (cooler air to warmer air).

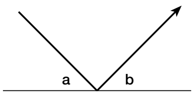
Passing from less dense to more dense refracts light toward the normal (air to water or ice).

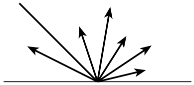




REFLECTION BEHAVIOR
In regular reflection, the angle of incidence (a) is always equal to the angle of reflection (b).

In diffuse reflection, light is reflected in many different directions without respect to the angle of incidence.





The amount of bending depends on the densities of the substances and the wavelengths of the light involved: the greater the difference in densities and the shorter the wavelengths, the greater the refraction. The shorter wavelengths of violet and blue light are slowed more and consequently bend more than the longer wavelengths of red and orange light.

4. REFLECTION

For reflection to occur, at least a portion of the light that strikes an object or surface is turned back. When the surface is smooth compared to the wavelength of light, as it is with a mirror—and the surfaces of water droplets and ice crystals—regular, or specular, reflection occurs. The angle of reflection equals the angle at which the light first struck the surface, called the angle of incidence. When the reflecting surface has large irregularities compared to the wavelength of light, diffuse reflection occurs, and the reflected light is sent out in many directions with no simple relationship to the angle of incidence. Diffuse reflectors include ordinary white paper, clouds, and almost all terrestrial surfaces, except for perfectly calm water.

SUBSUN When light reflects off the top surfaces of horizontally oriented ice crystal plates, the Sun is brilliantly reflected in the subsun. This image can only be viewed from an airplane or high mountain, since it forms as far below the horizon as the Sun is above it. This series of images, taken at one-second intervals late in the afternoon of February 24, 2006, shows the apparent movement of the subsun as the aircraft flies from left to right past the face of the north peak of Three Fingers Mountain in Washington's Central Cascades.