

Physics

Section 2

Light

[Lexile](#)

Light is [electromagnetic radiation](#) in the wavelength range extending from about 0.4 micron to about 0.7 micron (1 micron equals one-millionth of a meter); or, perhaps more properly, the visual response to electromagnetic radiation in this range. By extension, the term is frequently applied to adjacent wavelength ranges that the eye cannot detect: [ultraviolet light](#) (also known as black **light**) and infrared **light** (see [infrared radiation](#)). In addition to wavelength, [frequency](#) (expressed in hertz) and wave number (in inverse units of length) are also used to specify and designate the character and quality of the radiation. Associated with wavelength or frequency is the visual response of [color](#). The term *monochromatic* is applied to the idealized situation in which the **light** in a beam is all of one wavelength.

Characterization of Light

Light is characterized not only by wavelength, essentially a temporal quality, but also by state and degree of polarization (see [polarized light](#)), a geometric or directional quality, and by intensity, essentially a physical quality. The visual response to intensity is brightness. In the human visual system, at least, there is no counterpart response to the state and degree of polarization, but ample evidence exists that certain arthropods—bees in particular—are sensitive to the state of polarization of sky **light**. There is some speculation that certain migrating birds may also respond to this quality of **light**.

Light is further characterized by its degree of coherence (see [coherent light](#)). Coherence, closely related to the degree of polarization and to the degree of monochromaticity, refers to the ability of a beam of **light** to interfere (see [interference](#)) with itself. Coherence is therefore an interferometric property of **light**. By the use of a Michelson [interferometer](#), most **light** sources can be made to produce interference fringes. These are clearest when the length of the two arms of the interferometer are equal. As one arm is lengthened, however, the contrast of the fringes is seen to decrease until they are no longer visible. Unfiltered **light** from an incandescent source will barely produce fringes under any circumstances. **Light** from a mercury arc lamp will produce fringes over a range of one or two centimeters. On the other hand,

light from a continuous-wave gas laser has produced fringes at a distance of more than 100 m (328 ft).

Light is moving energy that travels at a speed of 300,000 km/sec (186,000 mi/sec). It can be regarded both as a particulate flow and as a wave phenomenon. These two apparently diametrically opposed views have been brought together in a theory that combines the best features of each. The particulate unit is the [photon](#), which has associated with it a central frequency or wavelength that determines (or is determined by) the amount of energy it contains. In a so-called monochromatic beam, the photons are all of the same energy and therefore have the same frequency. They can be made to interfere, which indicates a high degree of coherence as well as a more or less uniform state of polarization. If the distribution of the energy in the photons is more random, however, the beam will be less coherent and will have a lower degree of polarization.

It is also convenient to think of **light** as propagating as wave fronts (see [Huygens's principle](#)). These waves, like the crest of an ocean wave, are surfaces on which the phase relationship is constant. Unlike an ocean wave, a wave front or surface of constant phase is unobservable and undetectable. **Light** may be considered as energy being transported in a train of wave fronts. The direction of propagation (except for anisotropic media) is in a direction perpendicular to the wave front. Rays can be conceived as trajectories of photons.

Light Production

Light, like any other electromagnetic radiation, results from either an accelerating electric charge or a nuclear [fusion](#) or [fission](#) reaction. In nuclear reactions a photon is created in the same manner as other elemental partial products of the reaction. With the exception of sunlight and starlight, however, **light** usually is the result of changes in the electronic structure of atoms and molecules as they absorb and reemit energy.

The incandescent electric **light** has as its **light** source the heat that results from the ohmic resistance of the filament to the electric current. A red-hot poker absorbs heat directly from the fire resulting from the liberation of chemical energy. As the material in the filament or poker heats up, the atoms and molecules gain kinetic energy, which is realized by an increase in the

number of collisions among the particles. Boiling off of some of the material is one mechanism that can be used to maintain an equilibrium temperature. Another mechanism is for the electrons associated with the various atoms in the metal to move to higher [energy levels](#). When they drop back to lower energy levels they emit a photon, keeping the temperature of the material more or less constant despite the fact that energy is continually supplied. The excess energy is emitted as **light**.

Thermal production of **light** is essentially random and is idealized as [blackbody radiation](#). The **light** produced contains a mixture of wavelengths skewed around a central maximum λ_m , which is related to the temperature T of the material in degrees Kelvin. This relation, $\lambda_m T = \text{constant}$, is known as the Wien displacement law (see [Wien, Wilhelm Jan](#)). The spectrum produced by the **light** from such a source is continuous. Although there is a dominant wavelength, this **light** is not monochromatic. It is generally unpolarized and has a relatively short coherence length.

Another type of **light** source is energized plasma, such as a flame, or the gas in a discharge tube, such as a neon bulb. Although **light** is produced by a mechanism similar to thermal emission, the atoms are in a gaseous phase and less random. The energy levels reached by the electrons depend more on the electronic structure of the atoms themselves, and therefore the photons emitted tend to be clustered around specific wavelengths. The spectrum produced by such a source is not at all continuous but consists of lines or bands that are characteristic of the atoms or molecules in the gas. Highly monochromatic **light** can be obtained from this type of source, particularly if the **light** is filtered. The **light** has a much longer coherence length but is generally unpolarized.

A third type of source is the [laser](#). Two principles are involved in laser operation. First, the lasing material is composed of atoms, or mixtures of atoms, that have a peculiar energy level structure. As they absorb energy, their electrons move up to higher energy levels, tending to accumulate at certain metastable levels. This is called *population inversion*. There they remain until stimulated by a photon of the proper frequency. Then the electrons drop to a lower energy level, emitting a photon of the same frequency and traveling in the same direction as the incident. Because a single photon may stimulate the release of a large number of additional

photons, the total number of photons is increased, thus increasing the intensity of the **light** within the medium. The process is referred to as *gain*.

The second principle is the geometry of the laser itself. The laser can be regarded as a hollow tube, much like an organ pipe, which is tuned to the wavelength of the emitted photons. The process can be visualized as a wave front being reflected back and forth between the two ends of the laser, picking up more photons with each reflection. The portion of the **light** that is permitted to escape from the cavity is highly monochromatic, with a long coherence length. In some circumstances the laser output is highly polarized.

Dualistic Nature of Light

The historical development of a theory of **light**, at least from the 17th century on, involved two apparently contradictory descriptions. One concept was the corpuscular theory, which envisioned **light** as a stream, or flow, of small particles. René [Descartes](#) modified this concept. He viewed **light** more as a pressure than as a flow—not as motion but as a tendency to motion. And since **light** was not motion it was not limited by a finite velocity. In other words, a beam of **light** required no time of transit. Pierre [Fermat](#) held a different view. He believed not only that **light** propagated at a finite velocity, but also that its particles described trajectories or rays. Christiaan [Huygens](#), on the other hand, was a believer that **light** was a wave phenomenon. **Light** propagated at a finite velocity in the form of a moving disturbance, just as a water wave moves as a ripple on a smooth pond.

As a ray of **light** passes across a surface from one medium to another (for example, from air to glass), its direction is changed—a phenomenon known as [refraction](#). The law of refraction, discovered first empirically by Willebrord [Snell](#), then subsequently derived formally by Descartes and Fermat, states that $\sin r = K \sin i$, where i is called the angle of incidence, the angle between the incident ray and the normal (perpendicular) to the refracting surface. The angle of refraction, r , is the angle between the refracted ray and the surface normal.

Fermat and Descartes agreed on the form of the refraction law, but they disagreed violently on the meaning of the constant K . Fermat saw K as being proportional to the reciprocal of the velocity of propagation. Descartes, even though he believed that the velocity of propagation was infinite, concluded,

on a different level of logic, that K was proportional to a velocity. The distinction is important because whether **light** speeds up or slows down as it passes into a denser medium determines the meaning of K .

Two opposing points of view evolved. Descartes and Fermat were both proponents of a corpuscular theory; Huygens believed in a wave theory. He also obtained a proof of the refraction law in terms of the existence of wave fronts, a construction now called Huygens's principle.

If **light** is a wave phenomenon, then a medium is required. Sound waves travel through the air but not through a vacuum; ripples require a watery medium. At first it was thought that air would be the medium that would support the propagation of **light**. The simple experiment of shining **light** through an evacuated jar, however, showed clearly that this theory was not correct. Theorists chose to hypothesize the existence of a medium called the [ether](#).

Experimental evidence to support the wave theory of **light** was particularly strong. [Diffraction](#), the ability of **light** to bend around a sharp edge, certainly gave credence to the idea that **light** was a form of wave motion. Further support came with the discovery of polarization, which indicated that the undulations of a **light** wave were transverse to the direction of propagation and were not longitudinal, as were sound and water waves. Thus, if **light** was to be a wave phenomenon, the ether was required, and if so, then certain effects should be observed when a massive body passed through the ether. To detect such effects, telescope tubes were filled with water to determine the effect on starlight. No effect was observed. Experiments to detect an ether "drag" also failed.

On the other hand, James [Bradley](#) discovered stellar aberration in 1729 when he found that he had to aim his telescope a little in the direction of the Earth's motion ahead of the theoretical position of a star. This effect could be compared to a person in a rainstorm tilting the umbrella forward as he or she walks into the rain. Bradley's discovery supported a corpuscular theory, or at least it did not support the idea of an ether drag.

It was postulated, however, that if ether exists, then another observable phenomenon, ether "drift," must also exist. If both the Earth and **light** are moving through the ether, then the velocity of **light** observed on the Earth

would depend on the direction of observation. The ether was regarded as stationary; the Earth and other planets, the Sun and the stars, and **light** moved through it. By measuring the apparent velocity of **light** in various directions, one could determine the absolute velocity and direction of the motion of the Earth.

In the late 19th century A. A. [Michelson](#) and E. W. Morley (1838–1923) attempted to measure the absolute motion of the Earth through the ether (see [Michelson-Morley experiment](#)). No ether drift was observed. The conclusion was the inconceivable notion that the velocity of **light** was constant and independent of the motion of the observer. This paradox led to Einstein's special theory of [relativity](#), a cosmological theory of major significance.

Apparent Variations in the Speed of Light

As just stated, it has become one of the fundamentals of modern physics that the velocity of **light**—300,000 km/sec (186,000 mi/sec)—is invariant. This theory underlies current understanding of the [space-time continuum](#). Although this velocity does not change, however, it can be affected by the relative motion of objects with respect to an observer in a manner similar to the way in which sound waves are affected by relative motion. That is, sound coming from an object moving away from a person appears lower in pitch because the sound wave are relatively longer for that person (see [Doppler effect](#)). Similarly, as objects in space move away from an observer, the **light** from them appears to lengthen and become redder (see [red shift](#)). This effect, along with corresponding blue shifts as objects in space move toward the observer, are phenomena familiar in astronomy, where distance scales are vast enough for these shifts to be readily observed.

The velocity of **light** also varies with the density of the medium through which the **light** is passing. This is not observable in ordinary experience—**light** is either transmitted or it is not, without any notable slowing—but the slowing can be dramatic in scientific experiments where **light** is subjected to extreme densities. For example, two separate experiments reported at the turn of the 21st century described how scientific researchers have brought **light** to a virtual "stop." in effect, by using quantum-interference effects on optical pulses of **light** passing through an

otherwise opaque medium. That is, the information about this **light** was stored and then released.

O. N. Stavroudis

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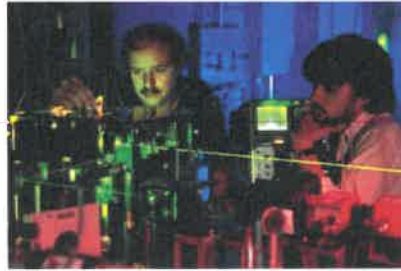
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Name: _____

Date: _____

Light

- Which of the following is true of visible light?
 - Its waves are used for radio broadcasts.
 - It is also called X-ray.
 - It is the largest portion of the electromagnetic spectrum.
 - Its waves hit an object and are either absorbed or reflected.
- If an object reflects red light and absorbs all the other colors, what color does the object appear to be?
 - white
 - black
 - red
 - all colors except red
- Compared to visible light, the wavelength of ultraviolet light is
 - longer.
 - shorter.
 - the same.
 - brighter.
- Light does not pass through an object at all that is _____.
 - opaque
 - translucent
 - shiny
 - transparent
- Light shines clear through objects that are _____.
 - opaque
 - translucent
 - shiny
 - transparent
- Which is the best description of the nature of light?
 - Light always behaves like waves.
 - Light always behaves like particles.
 - Light sometimes behaves like waves and at other times like particles.
 - Light never behaves like either waves or particles.
- When light strikes a convex lens, the light beams
 - diverge or spread out.
 - become wiggly lines.
 - converge or become focused into one beam.
- Unlike sound waves, light waves _____.
 - carry energy
 - must travel through matter
 - travel as compression waves
 - travel as transverse waves
- White light can be separated into different colors by using a _____.
 - mirror
 - convex
 - concave lens
 - prism
- What is the difference between a lens and a mirror?
 - A mirror refracts light.
 - A mirror bends light inward.
 - A mirror reflects light while a lens refracts light.

11. The lens that is thicker in the middle than at the edges is _____.

- a. convex
- b. concave
- c. light-reflecting
- d. corrective

12. When light passes from one material to another, you may observe _____.

- a. spectrum
- b. rays
- c. refraction
- d. wavelength

Name: _____

Date: _____

Refraction of Light

1. When you see a straw in a glass of water it looks bent, why is this?
 - a. diffraction
 - b. reflection
 - c. refraction
 - d. polarization
2. Light travels through all transparent media at the same speed.
 - a. True
 - b. False

3. What is refraction? Include a real world example as part of your explanation.

4. How light propagates through a material is given by the ratio of the speed of light in vacuum to the speed of light in that material. What is this ratio called?
 - a. reflection ratio
 - b. ratio of bending
 - c. light speed index
 - d. refractive index
5. The imaginary line perpendicular to the boundary of two materials or to a reflective surface is called the _____.
 - a. normal
 - b. phase line
 - c. refractive path
 - d. reflection path
6. When a light ray traveling along the normal hits the boundary of two materials, it changes its _____ but not its _____.
7. When a ray of light passes from air, a less dense medium, to glass, a more dense medium, the ray of light will bend _____ the normal.
 - a. towards
 - b. away from
8. What occurs when the angle of incidence of a light ray is greater than the critical angle?
 - a. critical refraction
 - b. total internal reflection
 - c. total external reflection
 - d. dispersion

9. The refractive index of water will change with its temperature due to the change in density of its molecules.
- a. True
 - b. False
10. Some fiber optic cables are made with various materials arranged in such a way that the refractive index of the cable changes gradually. These are called _____ fibers.
-

Name: _____

Date: _____

Motion Vocabulary

Instructions: Match each motion term with its definition. Write the letter of the term that matches the definition on the line.

- A. inertia
- B. average speed
- C. force
- D. terminal speed
- E. velocity
- F. friction
- G. mechanical equilibrium
- H. acceleration
- I. speed
- J. free-fall

1. _____ downward movement of an object when only influenced by the force of gravity
2. _____ the distance something travels divided by the time it travels
3. _____ when a free-falling object no longer accelerates
4. _____ total distance an object travels divided by the time it takes to travel that distance
5. _____ the rate at which an object changes direction and/or speed over time
6. _____ an object experiences this when all the net forces acting upon equal zero
7. _____ how fast an object moves and the direction it moves
8. _____ an influence that causes an object to undergo an acceleration
9. _____ the tendency of an object to resist a change in motion
10. _____ a force that opposes motion

