

What is light?

WHAT NEWTON DID NOT KNOW

What is light? It's a question that has intrigued mankind since time immemorial. Scientists, philosophers, and mystics of all times have observed light phenomena and constructed different physical models to describe light.

Light is made up of particles | The ancient Greeks already developed two conflicting theories to explain light. According to Empedocles, the eye projects a ray that “feels” the object. Pythagoras, on the other hand, postulated that light is made up of particles emitted by the object.

Roughly one and a half milleniums later, in 1665, Isaac Newton put forward his corpuscular theory. This theory, too, states that light is composed of particles, or “corpuscles.” While this fully accounts for some light phenomena, it only partially explains others. What Newton could not have fore-

seen: the theory of light would be revised many times before today's accepted concept of light finally emerged.

Light is made up of waves | A few years after the appearance of the corpuscular theory of light, the Dutch astronomer, mathematician, and physicist Christiaan Huygens proposed a new way of seeing things. In his research, Huygens was occupied with a variety of topics, including waves. He studied their form and behavior by looking at water waves and, from this, developed his wave theory of light and laws of refraction. Huygens concluded that light must also be a type of wave.

This viewpoint was elaborated by Scottish physicist James Clerk Maxwell and German physicist Heinrich Rudolf Hertz. Maxwell formulated the fundamental equations of electrodynamics in 1871. Hertz succeeded in demonstrating the existence of electromagnetic waves in 1888. Since then, we know that light is an electromagnetic wave like radio waves and x-rays.

Wave-particle duality | At the beginning of the 20th century, German physicist Max Planck postulated that energy in the form of electromagnetic waves can only be emitted in discrete amounts called quanta. Not long after this, Albert Einstein introduced the concept of light quanta. A light quantum is also called a photon.

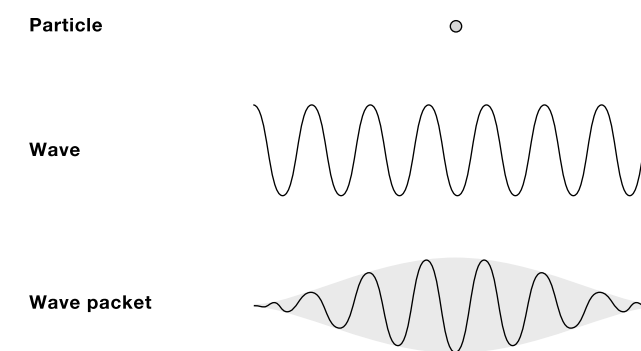
Einstein used this definition to explain the photoelectric effect. The photoelectric effect is the phenomenon by which electrons are ejected from a steel plate when irradiated by light. In this instance, light exhibits a characteristic property of particles: the photon must possess a precisely defined amount of energy to cause the ejection of an electron from the steel plate. In other instances, however, light continued

1 Water waves inspired Huygens to form his wave theory of light.

to exhibit characteristic properties of waves, for example, in diffraction and interference patterns. Out of this apparent discrepancy emerged the concept of wave-particle duality. For calculations examining individual photons, the formulas of quantum mechanics were used. In cases where light appeared as a beam of many photons, scientists would have to rely on the wave equations.

Wave packets | Today's model of light seeks to resolve the wave-particle paradox. The model describes a photon as a wave train, or a “wave packet.” Wave packets are electromagnetic waves that are spatially contained instead of extending to infinity. Their oscillation amplitude begins at zero, becomes increasingly larger, and then diminishes again.

A wave packet contains a specific amount of energy as described in quantum mechanics, but at the same time also has wavelike properties. Many wave trains together form a beam of light, but they can also be regarded individually.



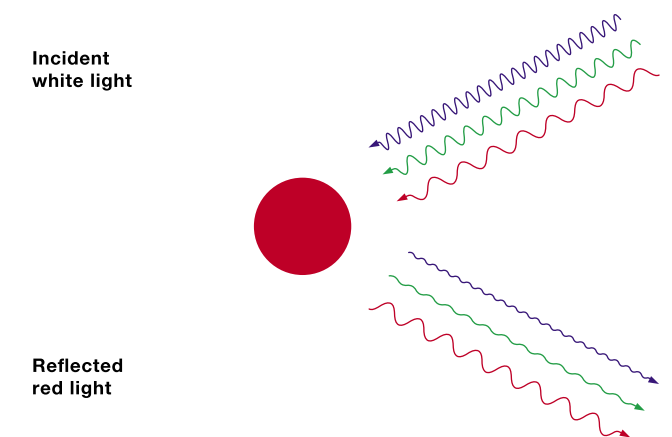
Light models: today, photons are depicted as wave packets.

The measure of all things Light is fast – very fast. It shoots from place to place in the air at around 300,000 kilometers per second. That's equivalent to roughly 7.5 times around the earth. By the time one second has elapsed, it has reached the moon. About 500 seconds is what it takes for it to reach the sun. The speed of light is the highest speed possible.

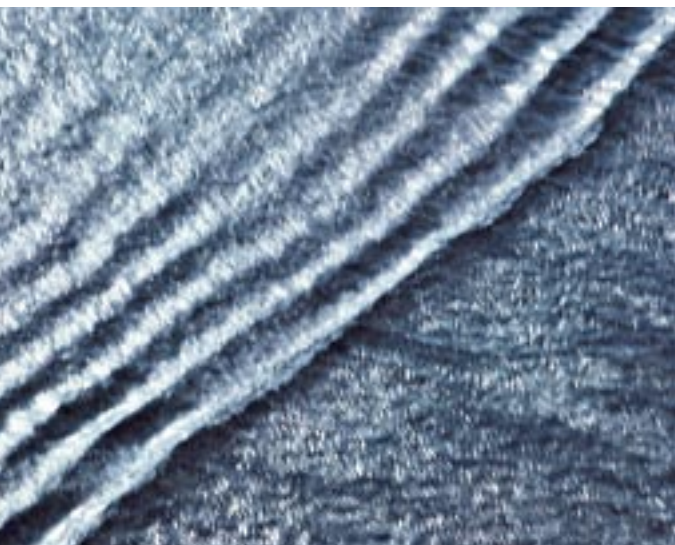
LIGHT PHENOMENA IN EVERYDAY LIFE

Even if you've never really stopped to wonder what light is, you are familiar with its basic properties as revealed in ordinary life. Some light phenomena do not seem very remarkable at all. Your reflection in a mirror, for instance. Other phenomena such as a rainbow or a spectacular sunset never fail to inspire and enthrall.

Reflection | Every time you look at your reflection in the mirror, admire the glistening waves of the sea, or observe the red color of a tomato, you are experiencing the phenomenon of reflected light. Objects that do not emit light are only visible because they reflect light. The tomato is red because it reflects the red components of white sunlight more strongly than it does other colors.



A red object reflects the red components of light more strongly.



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Diamonds are a girl's best friend Refraction and reflection – without these phenomena, cut diamonds would neither glisten nor sparkle. If that were true, women would probably lose all interest in the lustrous and alluring gems.



- 1 Patches of fog scatter the light from a car's headlights.
- 2 Refraction: the spoon in the tea glass appears to be bent.
- 3 Interference: iridescent colors are produced when light is diffracted.
- 4 The dark asphalt absorbs sunlight and heats up as a result.

Refraction | Many optical devices use the laws of refraction to deflect light rays: a magnifying glass, a pair of glasses, or the lenses used in cameras and telescopes are only some of the many examples you can find.

Light is refracted when it passes from one medium into another medium that is optically denser or thinner – for instance, from the air into a pool of water. The propagation velocity of light is lower in water than in the air, because water has a greater optical density. This is why the light ray changes direction when it enters the water. Observed from the outside, the light ray seems to change course or bend.

Different effects can be observed when light is deflected: things that are small become magnified; light is broken down into its component colors. A photographer zooms in on an object. In a sleight of hand, a magician makes a coin in a glass of water disappear by changing the angle at which the audience views.



When light is reflected, the angle of incidence is equal to the angle of reflection. This can be grasped intuitively: the spot of light reflected by a mirror onto a wall moves whenever the mirror is moved. This is because the different position of the mirror changes the angle of the incoming, or incident, light and, with it, its angle of reflection. This is also why you have to adjust the rearview mirror of the car if the person driving before you was taller or shorter.

Scattering | Blue summer skies, white clouds, and red sunsets all have one thing in common: they are created by scattering. Scattering is a process in which particles absorb light and then immediately give it off again. Both wavelength and direction of oscillation (polarization) play a role in this process. After interacting with the particles, the light takes a different trajectory: it is "scattered." Scattering can be seen in the light produced by a car's headlights in the fog.

Diffraction and interference | Diffraction and interference patterns are created when light rays overlap. For example, when light is projected onto a screen through a slit, you see alternate bands of light and dark instead of the uniform distribution of light that you would expect. Bands of different colors appear on the surface of a thin film, even though the substance is clear – like on soap bubbles. If you look at a candle flame or car headlight through a thin curtain or stretched silk scarf, you will see a pattern of bright, rainbow-colored spots. In all of these instances, light reveals its wavelike properties.

Similarly, the lustrous colors of iridescent butterflies, hummingbirds, and peacock feathers are not the result of any special pigments. The feathers or scales have such a finely structured surface that it diffracts the light. For the casual observer, the wings or plumage appear to shimmer in a host of beautiful colors.



Interference between your index finger and middle finger To see what an interference pattern looks like, all you need is your hand and a bright source of light such as a light bulb. Bring your index finger and middle finger close together so that they almost touch, and hold them in front of your eye. Now look at the light through the slit between your fingers. Instead of a uniform area of light, you will see light and dark bands. The bands run parallel to your fingers and are arranged symmetrically. That's the interference pattern!

Absorption | Absorption is a process in which light rays are taken up by another medium. The energy of the light is usually converted to heat in the process. Varying amounts of light and different wavelengths are absorbed depending on the construction and color of the material. Everyone knows that dark clothing is warmer than light-colored clothing. A person wearing a black suit in the middle of summer is more likely to break into a sweat than someone wearing a white suit. The cause: black objects absorb all colors of visible light, while white objects reflect the light almost completely.

Emission | Emission is the opposite of absorption. It describes the basic phenomenon in which light is given off – for example, when energy transitions occur in atoms. The result is the radiant, luminous, shimmering light that accompanies us throughout the day and comes from innumerable light sources illuminating the world.

