"And There Was Light"

First published in *Lapidary Journal*, December 1991

The phenomena of light has puzzled thinkers for millennia—and scientists are still trying to figure it out.

Light. It surrounds us, reveals our world to us, and creates colors. It gives us rainbows and the romance of moonlight and candlelight, television and laser light shows. It triggers photosynthesis in plants and the production of vitamin D in our skin. It warms the earth and, focused on solar cells, it supplies a clean source of power. Most importantly to gemologists and mineralogists, light is responsible for much of the beauty of gemstones. Yet we take light for granted until a thunderstorm leaves us groping in the dark for candles and matches hidden at the back of the kitchen drawer.

The nature of light has puzzled people almost as long as there have been people to puzzle. The Greeks were perhaps the first to try to think it out and explain it, although they were primarily interested in the phenomenon of sight.

The Greeks were great ones for thinking. They thought that by careful reasoning the "truth" could be divined. So they weren't much for experiments. Experiments were too much like manual labor, which educated Greeks thought beneath them. Because they did not actually try out any of their well-argued theories, they never knew how wide of the mark they were.

For example, Pythagoras, philosopher and mathematician, theorized that objects gave off particles that resembled them; an apple gave off apple-like particles, for example. When these struck the eye, we experienced sight. (Pythagoras was the closest of the early Greeks to being right.) Another Greek said just the opposite, that our eyes sent out particles (like Superman's x-ray vision) and we perceived an object when it was struck by these particles. Aristotle believed that there was a fire-like substance in the air that transmitted particle activity from the object to the eye. However, by AD 1000, it was accepted that light emitted from a source reflected off an object and entered the eye creating sight.

But what was this crazy thing called light? It wasn't until the 17th century that scientists, philosophers and mathematicians began to make some inroads into answering that question.

The Greeks knew about reflection and refraction. In the 17th century, a Dutch astronomer, Willebrord van Roijen Snell, worked out the mathematical relationship (called Snell's Law) between an incident ray (the one striking a surface) and the refracted ray (the one that enters a substance). This gave us refractive index, the measure of the extent to which the light is bent when it enters a dense material. And that's when things got complicated.

In 1678, Dutch scientist, Christiaan Huygens, using Snell's Law, developed a theory that light traveled in waves. The wave theory explained refraction and reflection very well, but there was a snag. Waves are a type of action, the result of disturbing some kind of medium. To exist, waves must travel through something--water, oil, air. Because light traveled from the sun to the earth, scientists assumed there must be something in between through which the light waves moved. So they hypothesized a "luminiferous ether" that filled space between the sun and the earth.

Huygens was a well-known and a well-respected scientist. But over in England was someone even more well known and well respected: Sir Isaac Newton. Newton, when he wasn't sitting under apple trees and getting bonked on the head with falling fruit, was very interested in light. He discovered that white light was a combination of seven pure hues: red, orange, yellow, green, blue, indigo, and violet. (Today, most color charts limit the spectral hues to six and leave out the indigo.)

In 1704, Newton developed the corpuscular, or particle, theory of light. These particles of light, said the discoverer of gravity, travel in straight lines, not waves. While the wave theory would explain the prismatic colors of light as the result of the bending of light rays, particle theory said that the different colors were caused by particles of different sizes. Because of Newton's standing in the scientific community, the particle theory of light was widely embraced and became virtually unassailable.

But even Newton himself wasn't entirely comfortable with the particle theory. There were some effects of light that the existence of light particles did not explain. One of these phenomena was the "fringes" of light seen at the edges of some shadows. Newton said they might be caused by light being alternately attracted and repelled by the objects near which it passed. As a result, the light was "bent several times backwards and forwards, with a motion like that of an eel." Although it wasn't necessarily the best answer, Newton, mistakenly, did not believe that these fringes had anything to do with the basic nature of light. This odd phenomenon was more important than Newton suspected, however. It would eventually undo the particle theory for these "fringes" were actually caused by diffraction, a characteristic of waves.

When waves pass the edge of an object they are bent slightly. If they pass through a narrow opening, the waves fan out, sometimes quite a bit. No one tried to explain this odd little phenomenon until 1801, when an English physician named Thomas Young did some experimenting of his own. (In addition to dabbling in light, Young also helped decipher the Rosetta stone.)

Waves are composed of *crests*, their highest points, and *troughs*, their lowest points. When the crests of two different waves coincide with each other, the wave is intensified. When a crest coincides with a trough, the waves cancel each other out. Young set out to discover whether or not light, in some circumstances could cancel itself out.

Shine a light through a pinhole poked in one piece of cardboard. Focus it on another white cardboard set a short distance away. The light spreads out evenly over the surface. Now poke two pinholes, close together, in a third piece of cardboard. Set that between the other two cardboards. You would expect to see two points of light on the farthest cardboard.

As Young discovered, you would be wrong. What you see is a checkerboard of dark and light. As the waves of light pass through the two pinholes, diffraction occurs and the waves fan out. As they overlap, some waves are intensified creating spots of light. Others cancel each other out, creating spots of shadow. (You can see the same effect if you stand in shallow water on a sunny day. The overlapping of the waves as they spread out around your ankles will create a light/dark pattern on the lake bottom or a pool step.)

Young's principle of interference had proven that light was composed of waves. He had disproven Newton's corpuscular theory. Newton would probably have approved Young's work, though no doubt it would have sent him back to his own drawing board. But Newton's supporters were less than charitable. Young, after all, was a physician, not a physicist. What could he know about light? The British scientific community attacked Young and his theory viciously.

But the particle theory was on its way out. Across the English Channel in France, in 1819, Augustin Jean Fresnel, a mathematician proved Young was right. He also showed that light waves traveled differently than other kinds of waves. Up until this time, there was only one kind of wave action known, the kind we are all familiar with.

If two people hold the ends of a rope and one snaps the rope, a wave travels from one end to the other. The wave moves only in one plane (up and down) and travels from one person to the other. Light waves, however, spread out in all directions. Imagine a straight rope moving through a series of blown-up balloons. The rope shows the direction in which the light is traveling. The surface of the balloons represents the leading edge of all the countless light waves moving away from the light's path of travel.

Okay. So light was once again composed of waves moving through the ether of space to the atmosphere of Earth. At least it was until 1881 when A.A. Michelson and Edward Williams Morley decided to get a very precise measurement of the speed of light. They decided to use the displacement of the luminiferous ether caused by the Earth moving through it to get their measurements. In the process of pinning down the speed of light to 186,000 miles per second, they discovered there was no ether. They were shocked. What were the waves of light moving through?

Fortunately, about 10 years earlier, James Clerk Maxwell, Scottish mathematical physicist, had made a major discovery. He had shown that electricity and magnetism were always found together and, in fact, were two aspects of the same force: electromagnetism. Electromagnetic force travels in waves, wrote Maxwell, and the two components, the electric field and the magnetic field, vibrate at right angles to each other.

To calculate the speed of his electromagnetic waves, Maxwell passed them through a vacuum. Not only did he find that these waves traveled through a vacuum, they traveled at just about the speed of light. He realized that the coincidence was too great; there could not be two forms of energy that traveled so swiftly. Therefore, he wrote, light is actually a type of electromagnetic energy. And, he added, it was only one of other forms of electromagnetic radiation with wavelengths both longer and shorter than visible light.

A bold statement as none of the other kinds of electromagnetic radiation were known at that time. But he was right. Electromagnetic radiation comes in a variety of wavelengths from the almost impossibly short wavelengths of cosmic and gamma rays to radio waves which can be measured in feet or even miles. Visible light falls in the middle of the electromagnetic spectrum and is measured in nanometers or one billionth of a meter.

No matter what the wavelength, though, electromagnetic energy travels at 186,000 miles per second, the "speed of light." (Richard Feynman, eccentric physicist at the California Institute of Technology, used to refer to all forms of electromagnetic radiation as "light.") The difference in energy wallop is in the difference in the wavelength: shorter wavelengths pack more punch than longer wavelengths.

So now physicists had to live with waves that traveled without a medium at unchanging speed of 186,000 miles per second. They made their uneasy peace with that idea. For a while anyway.

Then physicist Max Planck, in 1900, began to look into the phenomenon of "black body radiation." This is the tendency of heated objects to give off light. Iron, for example, when heated turns first red, than orange, then white. Although there are no further visible changes after it turns white, if the metal is heated to a higher temperature it begins to give off ultraviolet radiation.

During his investigations, Planck made a discovery that shocked him and the rest of the scientific world. For he discovered that the light from these bodies was emitted as small, discrete packages of energy which he called quanta. It seemed that the particle theory of light was raising its head again. Planck was so upset by this that he spent a great deal of his career trying to disprove his own discovery. He tried to integrate the two theories by proposing that quanta traveled in waves, but even he wasn't satisfied with this explanation.

But in 1905, Albert Einstein came along and stated unequivocally that light was made up of quanta pure and simple. That was how it was emitted, how it traveled, and how it was absorbed. He also gave these small packages of energy a new name: photons (from the Greek word *phos* or *photos* meaning light).

Although Einstein believed that light was made up of particles, he did not try to replace the wave theory. He said that light behaved as both. This led to the popular saying among physicists that on Mondays, Wednesdays, and Fridays they believed in the wave theory, on Tuesdays, Thursdays, and Saturdays they believed in the particle theory, and on Sundays they prayed for enlightenment.

Einstein also theorized that light interacted with matter when photons collided with electrons in an atom. Niels Bohr took this idea farther.

Bohr explained that electrons circled an atom's nucleus in fairly fixed orbits. When an electron was exposed to electromagnetic energy (heat, light, x-ray and so on) it absorbed the energy and was boosted to a higher orbit. When it fell back to its original orbit, or ground state, it gave off photons--which could be visible light, ultraviolet, heat or whatever. This was the quantum theory.

Today the field of quantum mechanics (which Einstein called "voodoo") takes Bohr's quantum theory one step farther. It treats the electrons in an atom not as if they were particles, but as packages of electromagnetic waves. (This prompted someone to coin the term wavicle, which, perhaps fortunately, never caught on.)

And that is where matters stand today. Visible light is a kind of electromagnetic energy that we can perceive with our eyes, and which travels in small packages called photons that have the characteristics of both waves and particles.

In the study of the properties of gemstones, both characteristics of light come into play. The wave theory explains phenomena such as refraction, reflection, interference, diffraction, which affect brilliance, dispersion and some forms of phenomena. The particle theory explains many of the causes of color in gemstones, one of the first things anyone notices about a gemstone.

For more information on light and light theory, read *Light* by Richard Morris; *Seeing the Light: Optics in Nature, Photography, Color, Vision, and Holography* by David Falk, Dieter Brill, and David Stork; and *The Beauty of Light* by Ben Bova.