Scientific Facts for You

All light sources make photons in specific ways. How each type of luminaire physically works determines how useful it is in any application. The physics controls the output. That spectral output in visible light impacts the presentation and preservation (damage rate).

Fast facts are brief articles designed to arm you with information.

How a Fluorescent Lamp Works

A fluorescent lamp is a tube with an electrode at each end. The tube contains a small amount of mercury along with an inert gas like argon to help suspend the mercury and spread it along the tube. The tube is under a very low pressure.

Inside the tube, the walls of the tube are coated with phosphor. These phosphors convert ultraviolet light into visible light. The better the phosphors, usually the better the color rendition of the lamp. But the more phosphors, the more expensive the lamp is to make and the more energy it consumes to get through the coating of the phosphors.

You have heard that electricity is forced to jump the gap between the electrodes. This arc or man-made lightning runs through the suspended argon that is mixed with the mercury. The argon is inert. But the electrons “collide” with the mercury and the mercury produces ultraviolet light.

The UV light is absorbed and re-emitted. Phosphor is often described as a substance that gives off light when exposed to light. The phosphors coating the inside of the tube convert the UV into visible light. Since the phosphor coating is not too thin, much of the UV light is changed into visible light. And since the phosphor coating is not too thick, most of the visible light escapes from the wall of the tube.

Energy Savings Verses Light Quality

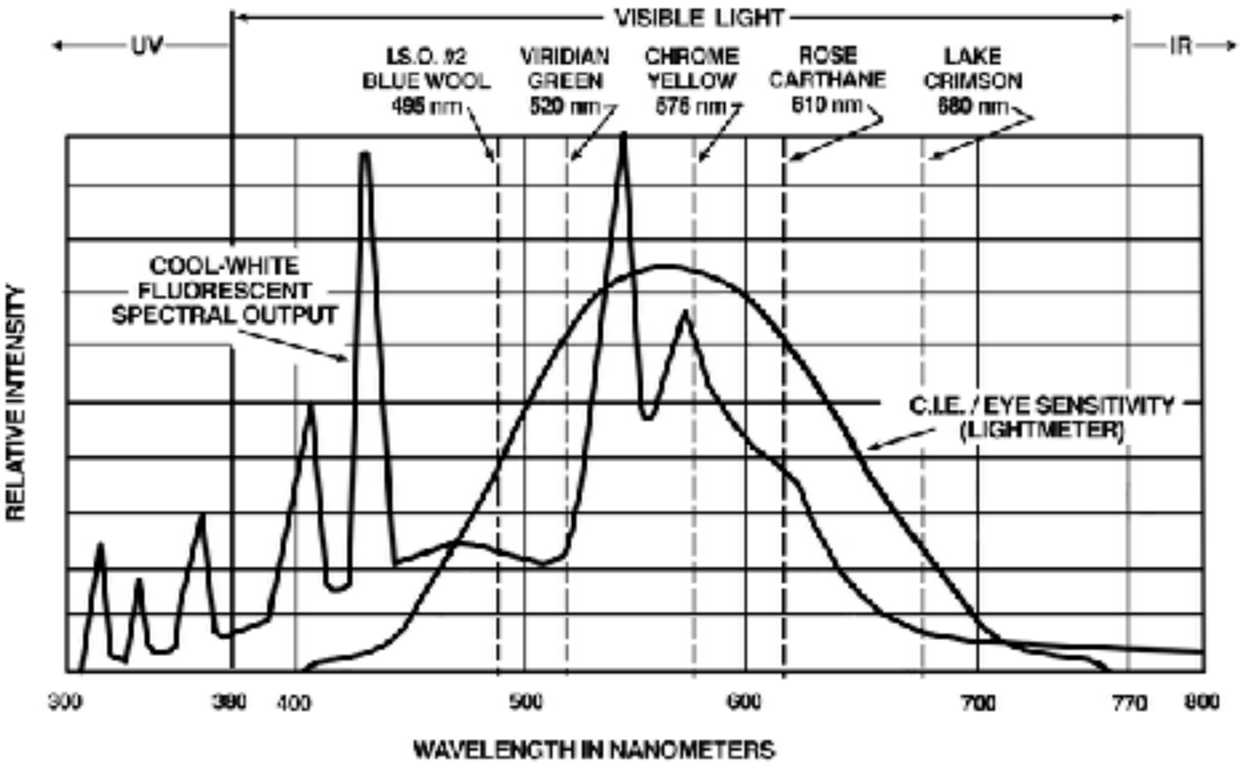
The thickness of the phosphors are critical. Thin phosphors bleed more ultraviolet light. A just right coating shuffles the UV produced by the mercury into visible light. Too thick of a coating and the visible light created by the phosphor cannot make it through the coating to other side and shine out of the tube.

Different phosphors spit out different visible wavelengths. So the performance for fluorescent lamps greatly vary depending upon not just how thick the phosphors are, but what phosphors are used in the coating. Larger surface areas produce more light. But consume more electricity.

A fluorescent lamp with the best phosphors at a coating thickness that is optimal will produce a visible light spectrum that has wavelengths of every color. But the phosphors always have an output that is in the same wavelength family. The phosphors overlap.

Phosphors are blended to convert to the widest distribution of blue, green and red . Since colors are generated between the peaks, all the colors exist in the light source. The problem is that some colors are 1/3rd or a 1/4th intensity.

The spikes of color tend to overwhelm colors outside the spikes. Visually the presentation shifts. The complexity of color is lost.



The above shows excellent performance for a fluorescent lamp. This is the output for a “Cool white” lamp. Notice that the reds from around 600 nm to 770 nm are under represented. So the white light looks slightly blue compared to the standard of artist’s sunlight.

A warm white lamp will have very much the same peaks and valleys in the distribution. But the spikes will move and more red phosphor is added. The same amount of UV bleeds through the phosphors as pure ultraviolet light.

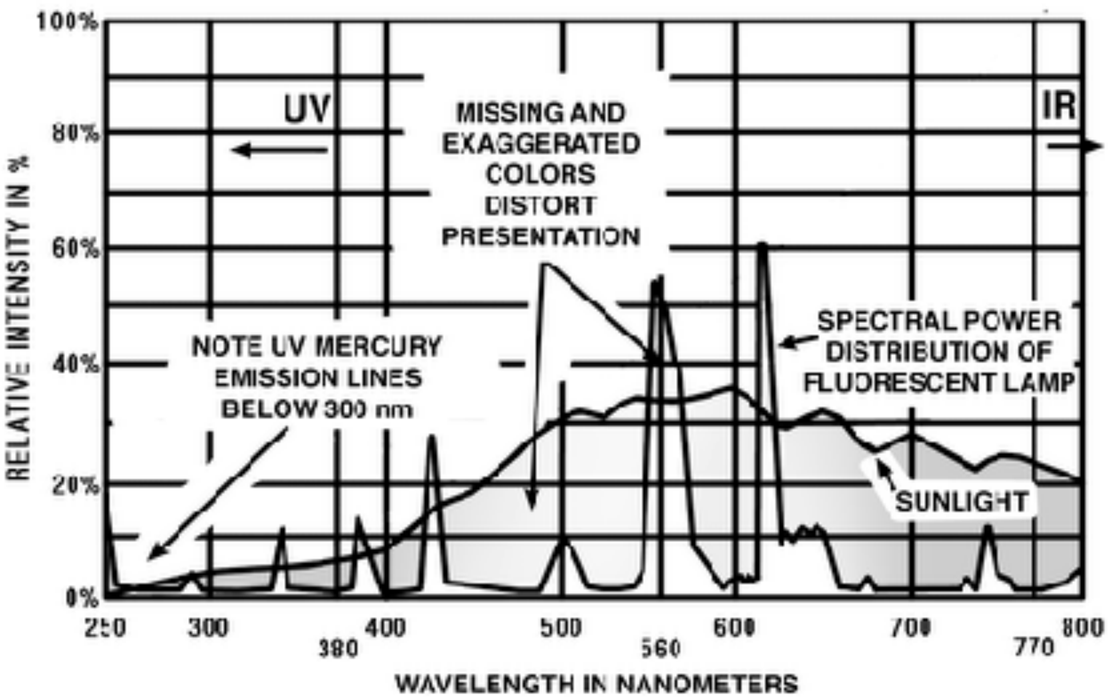
Fluorescent Lamps Are Changing

Today’s trends are dramatically impacting the performance of fluorescent lamps. FIRST, the concern over viruses and bacteria has encouraged lamp manufacturers to cut the amount of phosphors or to intensionally leave a gap without phosphor at the lamp’s ends. This means the UV content goes up. Less of the UV is converted into visible light.

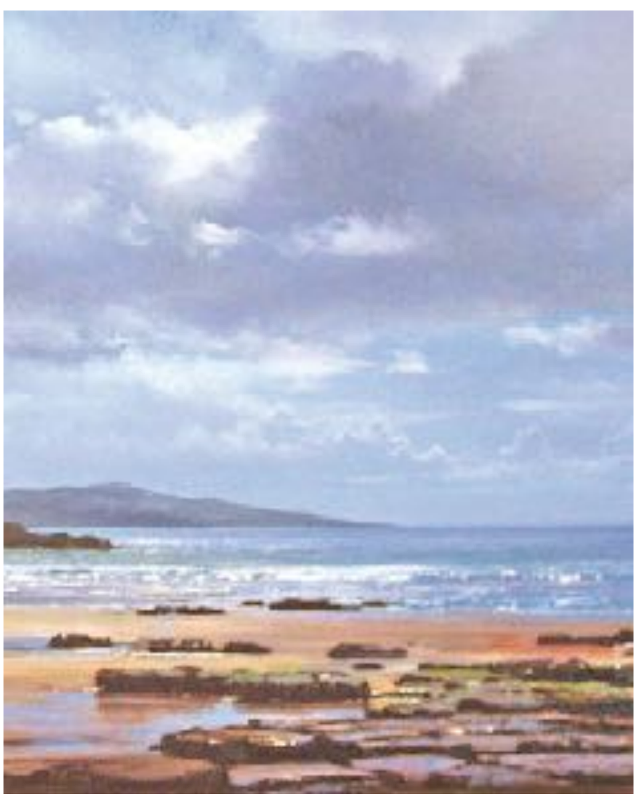
Ultraviolet light will sanitize and kill germs. But UV light is not good for humans or objects. It can be very harmful if the quantity is too high or the exposure is over long periods of time.

SECOND, the goal to improve energy efficiency has many newer fluorescent lamps becoming more and more tri-stimulus. The lamp fakes colors using a “white” that is more red, green and blue. An RGB blend of phosphors can show thousands of colors like the lamp above or like your computer monitor. But the human eye is incredible complex. The brain processes the data it reads in light with exacting detail. We see billions of colors.

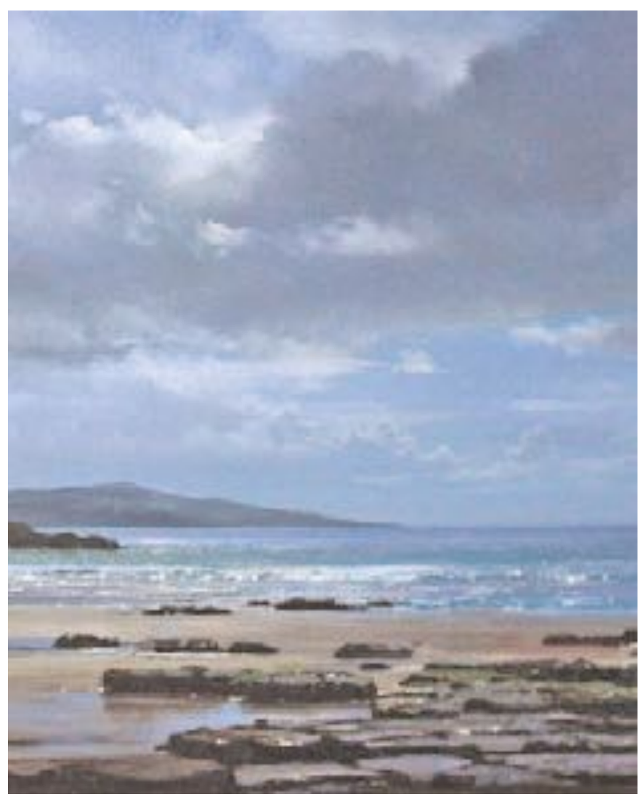
A pure chrome yellow is bombastic under balanced light. Under a good quality fluorescent light, it looks like a basic yellow. A crimson lake is a fiery, deep red under artist's sunlight or NoUVIR fiber optic lighting. A fluorescent lamp will turn crimson lake dark and even a little brown. The red wavelengths are not intense enough in the lamp's output.



Indirect "Artist" Sunlight



Fluorescent Lighting

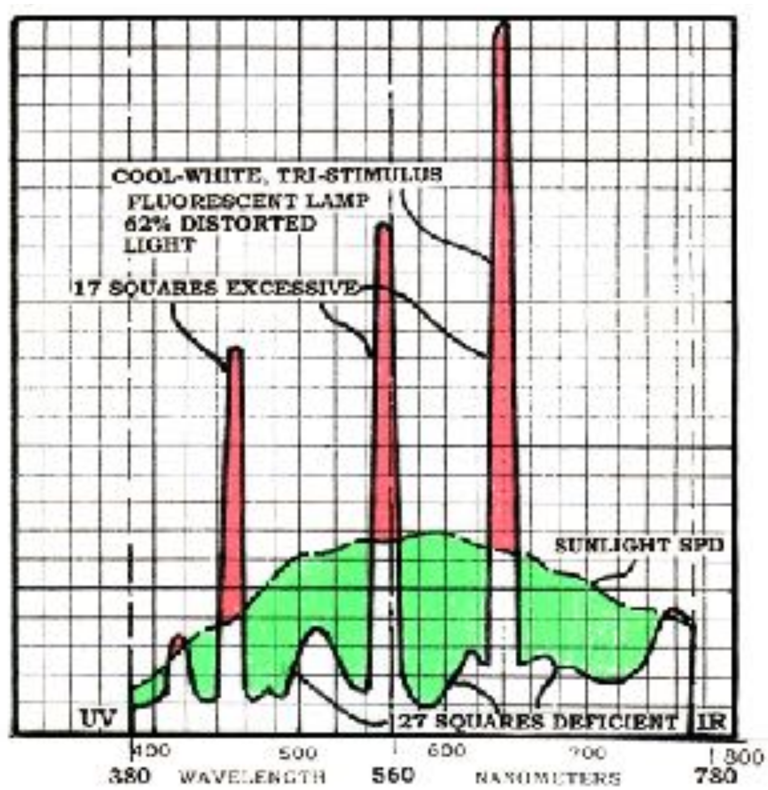


A more typical spectral output for today's average fluorescent lamp is with more peaks and valleys that indicate the color barely exists. The phosphors have been more carefully picked for peak performance of outputting a very tight distribution of wavelengths.

Notice how the composition of the seascape changes. The day looks gray. The sea does not sparkle. The sand and rocks all look wet instead of colorful.

The energy consumption has dropped. The output in footcandles measured by a light meter is impressive. Light meters read at a peak right at 560 nm where a phosphor is producing the most light for that band of color. But the beauty is masked. Look how much color you miss.

And it is getting worse.



Here is the spectral output of a "green" fluorescent lamp. It has become even more RGB. Again, notice the peak at 560 nm where a light meter reads. But though the light meter states there are a lot of footcandles, the reality is that most of the photons of the other colors are missing. If the seascape lost color above, think how it would look under this lamp. The mathematics shows a 62% distortion.

You can see. You can read. But artwork, food, carpeting, makeup…everything looses color.

Energy saving is tied to more than the phosphors. The fluorescent tube's gap is hard to jump. So different electrodes and different electronic packages including the saturation start ballast are used to operate the lamp. These different ways to start and run the lamp impact energy efficiency.

Some fluorescent lamps conserve more energy if they are allowed to stay on instead of being repeatedly cycled on and off. The start up consumes more energy than continuous operation. Therefore, motion sensors can waste energy.

THIRD trend is to cut back on the mercury. Fluorescents need mercury to generate the UV. It is a small amount. And it has been recovered and recycled in large buildings since the 1970's, because mercury is a valuable metal.

But like most metals, it is toxic. Recycling costs at the homeowner level is threatening fluorescent lamps. How do you dispose of the lamps? There is a great deal of pressure from LED manufacturers to degrade and ban the fluorescents. LEDs have yet to meet the energy efficiencies fluorescents continuously demonstrate in the field. But LEDs have some waste issues as well.

How a Fluorescent Lamp Really Works

We have digressed. The description of how a fluorescent lamp works fails to really explain how the photons are made. In a fluorescent lamp there is no “colliding” with the mercury gas to generate a photon. The property of loosing a photon out of an inner shell is inherent in the nature of mercury.

Mercury as an atom has the loose outer orbits as do most atoms. In chemistry these are the valence electrons in the outermost shell. From other discussions, we know these generate infrared photons.

But within the atomic structure of mercury is a ring nearer the nucleus with looser and less stable orbits. These shells have orbits that spin out ultraviolet photons.

A crowd of electricity runs through the gas inside the tube. Electricity is a stream of electrons. Those electrons excite the atoms in the mercury.

The orbits of the mercury atoms grow. They get excited. The speed of the electrons are the same, but the shuffling and size of the orbits gets more erratic and avoiding other electrons is more difficult especially with the inrush of more and more unattached electrons that is the electricity flowing between the electrodes.

Extra electrons are everywhere on the outside of the atom trying to get into the positive center of the nucleus. The atoms are excited. The outer rings of the atoms are assaulted first. They scramble. They gimbal. They get messy in their paths. The electrons so crowd, they start bumping into each other.

Suddenly one electron physically kisses another and slides sideways in an effort to avoid another electron. The rotation turns. And the near encounter is enough that the electron flips backwards as its pole is destabilized.

The electron still spins. It is still an electron. But it is spinning backwards. This changes the electron’s charge from negative to positive.

It has become a “positron”. It is anti-electron. Or it is “anti-matter” compared to its original state as an electron. A neighboring negatively-charged electron within the orbit ring matches the positron’s orbit.

But the positron wants out. It is surrounded by too much negativity. As it swings away, the electron follows, attaches itself to the positive particle and together the pair rotate as if joining hands.

An infrared photon is born. It races away at the speed of light. It is made of an electron and a positron. Its wavelength is the original electron orbit translated into spin around each other. The distance between the electron and the positron is the wavelength.

Most of the action and agitation is from the atom’s outer rings. So most of the photons are infrared. Big orbits. Big wavelengths.

These photons speed into the phosphor coating as they rocket out of the mercury gas. But the atoms of the phosphors are not matched. The orbits fail to capture most of the photons. The infrared photons escape. The lamp produces IR.

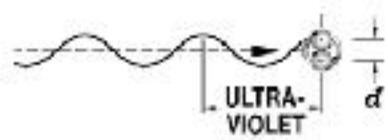
The incoming electricity continues to excite and crowd the mercury structure. More and more outer orbiting electron shells are shedding entering electrons as infrared photons. But buried within the mercury is a set of orbital rings that are unstable in their orbits.

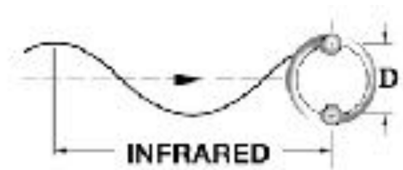
These electrons are close to the nucleus. They have the tight orbits that spin into ultraviolet. Usually these are the hardest electrons to displace. But not for mercury. The metal as vapor is constructed to spin out ultraviolet.

The electron rings that would normally start creating visible light are more tightly linked in the orbits. They are able to negotiate around the infiltrating electrons and keep stable. They excite. But the entering electrons do not get close enough to create an opposite spin. These rings have ideal spacing. They are able to flex and gimbal to keep from shedding off a pair as a photon. So the electrons from the electricity shove deeper inside the mercury's atom.

Closer to the nucleus, the electrons are so tight that the extra electron makes the orbital paths greatly swing and undulate away to avoid the new comer and each other. The rings get over active. The electrons from the electrical jump across the gas "collide" with the electrons in orbit.

The rotation around the nucleus translates into a tight, small diameter motion. It comes out as a UV wavelength. The electron and positron pair are a short couple.





The mercury is now not just pouring out an incredible volume of infrared. But the inrush of electrons is also throwing out a lot of photons in the ultraviolet. It is converting the electricity into UV.

That UV is useful. But tightly bound. The electron and positron are close together in distance as they spin around each other more often covering the same length of travel. It will penetrate deep into other atoms in molecules, because the rotation size is smaller and it is easier to fit through spaces.

But the phosphor is picked to mismatch the ultraviolet's spin. The UV gets pulled in, absorbed and broken apart. The electron of the photon is added to the ring. The positron is buffeted and rubbed physically. The positron's spin rolls over on its axis again and it turns back into an electron.

The phosphor is not chemically stable with the extra electrons. So a ring further out jostles the orbits of its original electrons to spit out a pair from a different part of the atom. The ring has the spin orbit of visible light. This characteristic is why the lamp is coated in phosphor.

The photon paring of an electron and positron are ejected. The phosphor has converted UV into visible light. The coating produces rays of visible light.

Visible light is also trapped inside the tube. But for the most part, light comes from all the area of the tube and exits. The fluorescent lamp has converted UV into visible light.

Phosphors are blended to make warm and cool white colors. The phosphors do not throw out the smooth output of a filament. But they do convert more electricity via the UV into visible light.

These are specific materials. Fluorescing is unusual in nature. But certain materials do it. This is why the phosphors are referred to as rare earths.

It has to do with how the electron rings move internally. The photon pairing is always over a probability curve with a spread over a specific set of color in blues or greens or oranges or reds. Different phosphors output bias towards certain color bands. These phosphors are combined to get better presentation.

A fluorescent lamp with a lot of the right choices in phosphors will blend into a curve that has all the colors present. The peaks will shift in the data depending upon if the lamp is a warm white or cool white lamp. But every color is present. There are just colors that are underrepresented.

However, in the effort to get more light per watt, the phosphors can become more specific and more a blending with of a specific RGB without the visible light between the peak colors. These lamps have poorer color rendering abilities.

The Facts to Remember

The key to glean from the physics is that the phosphors are producing colors in the same subset of wavelengths.

If those wavelengths match the colors of a painting, costume or other object, the color will be reflected. The object will "look" okay. But the light really is not a smooth blend of visible light. It is a fake white light. It is a simulation made by phosphors.

If those wavelengths mismatch by a little bit just being slightly off, the color will be shifted to the color produced by the phosphor. The object will reflect a slightly false color. The color is there.

But it is tinted by the bias of the phosphor's tendency to produce particular wavelengths instead of a full spectrum. There is a favorite wavelength or orbit from among the subset color. For example, the blues view as a more singular blue.

If the color mismatches, the photon will be absorbed. This accelerates damage by releasing electrons into the object that can break up its larger molecules into smaller molecules. At the chemistry level you have added electrons. And the color will not reflect as data, but appear gray. The artwork, costume or object will become duller with deader color.

The mercury's outer rings produce IR (around 70% of its output). The mercury also produces UV. The ultraviolet light drives the phosphors. But it is a coating.

Some of the UV is never captured by the phosphor. It escapes. On top of that, the coating is usually thin or can be intentionally not coated for a germ-killing feature at each end of the tube. This UV does not get converted. It bleeds through.

So fluorescent lamps have UV content (about 5% to 7%). Ultraviolet light can be very destructive to artifacts. And it is not that good for humans. Therefore, these lamps should be filtered for UV using an acrylic lens.

Fluorescent Lamps and Fiber Optics

A fluorescent lamp is a tube. It might be straight, curved into a U-shape or twisted into the spiral of an ice cream cone shape. But it has a lot of surface. Therefore, fluorescents are hard to focus tightly enough to get light into fiber. So why cover fluorescent lamps?

Fluorescent lamps filtered for UV content are one of, if not, the most energy efficient ways to light areas. In field testing, quality fluorescent lamps still outperform LED lights for energy savings. These lamps are everywhere including in museums. But they contain UV and IR. And their color rendering can be okay to very poor depending upon the phosphors used in the lamp.

Photons Back into Electricity

Remember photons are particles. The light is an electron and a positron. Certain materials can be identified and made rich in electrons (meaning the outer shells respond to new electrons and try to stabilize by spitting out the intruder) or depleted in electrons (meaning the outer shells of the atoms are looking for more electrons to add to have more stable orbits at rest.) To simplify, put such materials in layers, and they are sensitive to photons. The materials as “cells” will break apart photons.

The electron when it comes apart is directed one way in the material and flows. The positron is spun back into an electron and usually flows the other direction. Enough photons broken apart and there is electricity that can do work. Usually, because it is a circuit, only half the photon is registered, like in a light meter.

This is how photocells work. But note that the one layer is full of electrons. Solar panels wear out over time. The materials suffer from photochemical and photomechanical damage.

The point is to understand a photon can be generated by forcing electrons into the orbits of atoms. A photon can be broken apart by mismatching an electron orbit in an atom. The photon is absorbed. But it does not disappear. The light becomes electrons.