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. Here is a quick look at a tungsten filament lamp. For a more complete understanding of photons, see the pdf file of the white paper, **Light and Matter: The Dangerous Romance**.

How a Tungsten Lamp Works

You have been told that an incandescent light bulb turns electricity into light by sending an electric current through a thin, coiled wire, usually tungsten, and the heat becomes light.

The filaments resistance is high. So the metal does heats. In it incandesces. As the heat climbs and the filament gets hotter and hotter, the filament glows.

Quickly the filament gets so hot in Kelvin temperature (how a lamp's color is rated) that the filament turns the electricity into visible white light. The "collisions heat up" the metal's atoms which in turn "generate the heat used to emit light." The gas surrounding the filament also helps generate this light, because it adds to the heat.

For understand photochemical and photomechanical damage, this is way too simplistic.

How a Tungsten Lamp Really Works

A dense, tightly-bound molecular material that resists free electrons by definition has a high melting temperature. Tungsten is a good, economical choice. As a thin, coiled wire it has resistance and area. The coiling puts more atoms in less area.

Crowd an electrical current into this filament. Electricity is a stream of electrons. Those electrons excite the atoms in the tungsten.

The orbits of the tungsten 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.

Not only is there the electrical flow forcing through the wire. But atoms are so active, electricity jumps from coil ridge to coil ridge. Extra electrons are everywhere on the outside of atoms trying to get in to the positive center of the nuclei.

The outer rings of the atoms are the most agitation. They 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. Its 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. This is why in studying light, the math provides a positive and a negative number. The electron turns into a "positron".

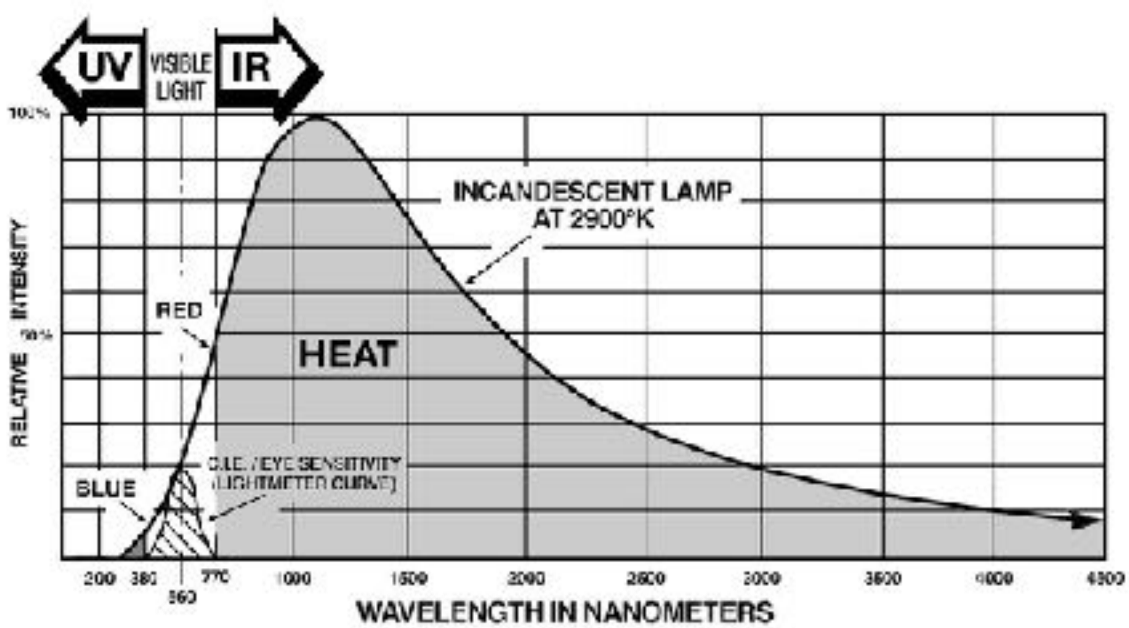
A neighboring negatively-charged electron within the orbit ring matches the positron's orbit. But the positron wants out. It is surrounded by too much negativity. As it swings away, the electron follows, attaches itself to the positive particle and together the pair rotate as if joining hands.

The 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 tungsten atom's outer rings. So most of the photons are infrared. Big orbits. Big wavelengths. The filament heats. It makes Incandescent or "burning" light.

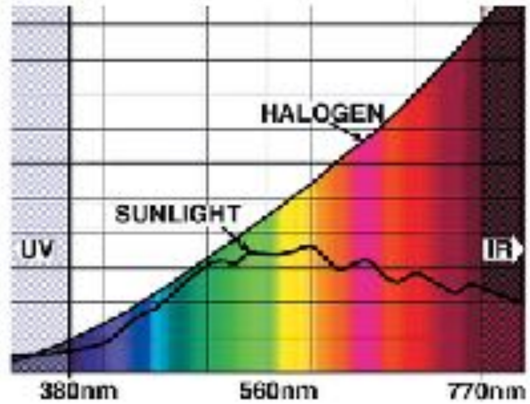
It is not so much that the electricity is making the filament hotter. Instead the incoming electricity has so excited and crowded the tightly-locked atoms of the tungsten that more and more electron shells are shedding electrons as photons.

The filament glows and grows. The coils inhibits the electricity from jumping from atom to atom, but forces the resistance making light. The electrons brush and jostle and push and spin into positrons. These outer orbits make an electron and positron with a wider spacing matching the orbits which is the motion of the wavelengths of infrared.



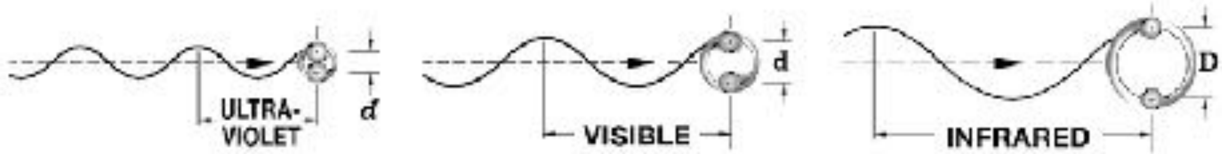
As the rush of electrons overwhelms the tungsten, more and more electrons get crowded further and further inside the atoms. The actively producing photons are not just the outer rings. But rings are spinning out photons that are ever closer to the nucleus.

The wavelengths get shorter. Eventually the rings closer to the atom are producing visible light. If the system can be driven hard enough without breaking the filament, the tungsten will produce a small amount of ultraviolet. The UV is the tightest spinning photon and comes from the orbits even closer to the nucleus.



The filament is pouring out an incredible volume of heat. It is converting much of the electricity into infrared photons. But the activity has become so crowded, that visible light is produced as well.

Again, the orbital ring that causes the electron to buffer backward to become a positron and then grab a negatively charged electron forming the photon as a pairing determines the wavelength. Other types of lamps use this knowledge to create specific wavelengths. It is not heat. It is getting deep enough to the orbits that produce visible light.

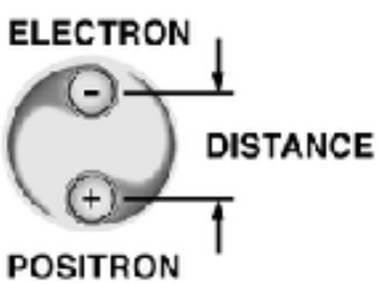


The lamp is biased towards red light. But driven hard enough, all the colors of visible light are generated. The blue light in volume is less than the red light. But all the colors of visible light are present.

The massive amount of infrared is simply the product of the most active photon pairing. It is the nature of the outer rings of an atom to be less stable and be easier to influence. Tungsten will not create much visible light unless it has so many electrons shoving deeply into its atoms to reach the orbits that make visible light. The heat grows, because reaching those visible-generating rings needs more and more electrons. Most of them get converted by the outer rings that generate infrared.

Light Equals Photons Equals Particles

A photon is a particle made up of an electron and a positron. It is not a packet of energy. It is not a wave. It has a wavelike motion. But it is a particle. Every instrument designed to detect light at the most sensitive level responds to a thing hitting it.



This is light. If the electron and positron are paired and made in the outer rings of the atom, the wavelength is relatively large. The light s infrared.

If the photon pair is spun out of an orbit closer to the nucleus, the wavelength is in the visible light range. The rotation of the orbit determined the spin distance between the two particles.

If the photon is closer to the nucleus, it is ever harder to make the photon pairing out of a tungsten atom. But the photon is closely coupled. This is ultraviolet. It is the same electron and positron, just with less distance between them with more rotations over the same forward motion and time.

Today you will still hear that light is a wave, an energy packet or a particle without mass. The genius physicist, Dr. Richard Feynman, made it very clear to his students. He told them over and over again that light is a particle.

“I want to emphasize that light comes in this form - **particles**. It is very important to know that light behaves like particles, especially for those of you who have gone to school, where you were probably told something about light behaving like waves. I’m telling you the way it does behave - like particles…light is made of particles.” (Feynman, *QED*, 1985, pg 15.)

The first proof that light is made of particles was Einstein’s 1919 Solar Eclipse experiments. Observatories around the world confirmed Einstein’s prediction that a star’s light would be bent by the massive gravity of the sun. The observer on earth would see a change in the apparent location of the star during the eclipse. The known location would be hidden b y the sun. But the observer would see the star, because the sun’s gravity bent the light.

Therefore, light had to be things. The particles were influenced by gravity. Waves would not be bent.

Einstein not only stated light would be influenced by the gravity, but he predicted the general relativity showing his concept that gravity pulled objects together and warped space. Later particle theory would be formed and further identify the photon as a two-particle system acting as a single particle. The light bent, because the light had mass, meaning it was a thing and not a wave or energy packet.

Wave theory and packet energy is still taught. But the demonstration of the atomic bomb alerted the science community to the unquestionable fact of light being matter. In splitting the atom, the energy are particles. One of the particle types are photons including rays from the very center rings close to the nucleus and released wen the nucleus in annihilated.

If you are having trouble with this concept, read the pdf Light and Matter: the Dangerous Romance *and other sections on this website. See “what is light?” There are numerous references. Also check out the pdf for further reading as the last pdf on the list.*

Extending Lamp Life Using Gas

A dense, tightly-bound molecular material that resists free electrons by definition is a material with “a high melting point”. Tungsten is resistive. But it will melt. And it will evaporate when driven hard enough. Shoving electrons as electricity in the tungsten atom and forcing it to convert a stream of electrons into photon pairs stresses the the atom.

Deep electron rings make visible light. A tungsten molecule can get so excited that it changes its status from a solid into a gas. To try to keep the filament from breaking, inert gas atoms are added inside the glass bulb.

In an ordinary light bulb, the bulb can be a vacuum (no gas) if it is low wattage. Or it can have nitrogen or argon added inside the bulb. The gas is inert. It will not chemically combine. It leaves the tungsten as pure tungsten rather than allowing the metal to become a salt or oxidize. So the gas is not chemically keeping the tungsten together. It is mechanical.

The inert gas physically holds the tungsten at the filament. It isn't perfect. A tungsten molecule can still get through the gas. Remember that all atomic structures are hundreds of times more volume as space than matter. But it lets the filament be driven harder making more visible light.

Brighter Using Halogen Gas

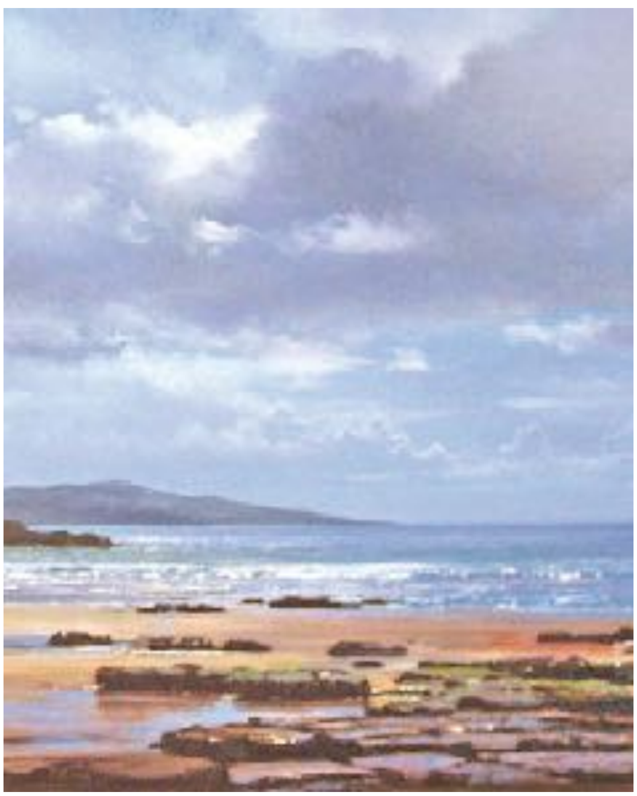
Halogen molecules are large gas structures that will crowd around the filament. The molecules are so big that the orbits physically rub against the tungsten encouraging the tungsten to stay in place. Driving more and more electrons into the tungsten, some of the tungsten molecules will try to evaporate as escapees. But the halogen guards the exit path. The room is too tight. The tungsten can't shoulder past the standing line of gas. The halogen's presence encourage the tungsten's atoms to stay attached as a filament.

With a halogen lamp, instead of filling the whole area of the bulb, a small envelope usually made of clear quartz surrounds the filament. This encapsulation has a second function. In design, the photons coming off of the outer rings of the tungsten find no trouble blowing through the halogen molecules. The molecules may be big gas molecules. But the orbits of the halogen's atoms are mismatch to the photons spin. Light ignores the gas.

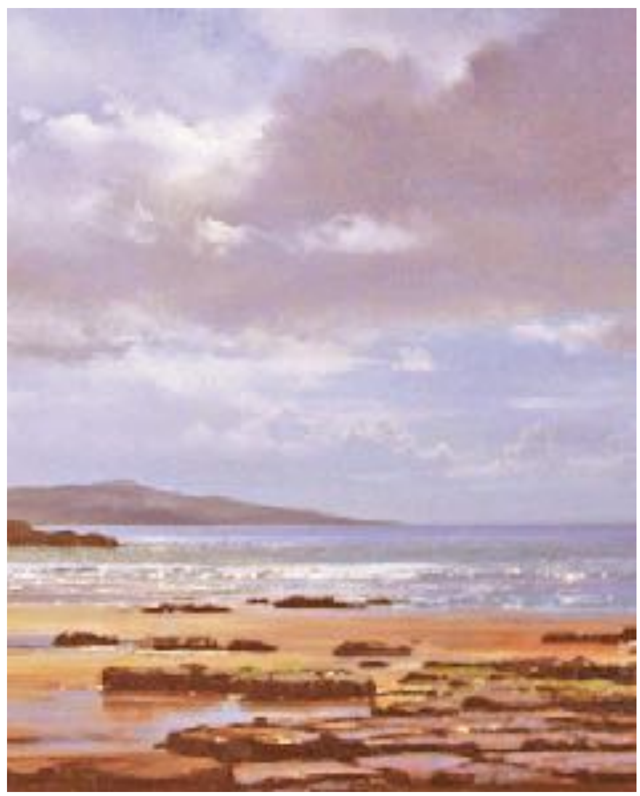
But the quarts does absorb a few of the big infrared photons as they exit. The quartz get hot. It is never incandescing like the filament. But it absorbs enough infrared to radiate infrared out as its atoms are overly crowded.

This provides advantages. The filament can be worked at even a higher intensity with better color. It makes more visible light. The halogen keeps the filament from coming apart.

Indirect "Artist" Sunlight



Halogen Lighting



When a tungsten atom does break free as evaporation, the quartz cools slower than the filament. The atom is attracted to the cooler filament and will deposit there instead of the glass. Of course, eventually too many tungsten atoms are disconnected, evaporate earlier and earlier as the filament is driven and can end up somewhere else including as a gray spot on the envelope. This is photomechanical damage.

The other form of mechanical damage is for the filament to break. The rush of electrons grow the outer atomic rings of the outer parts of the wire. But the atoms buried within are les agitated. The size differences sheer the filament.

Everyone has seen lamp failure when electricity is first applied. The filament flexes larger and the weakened tungsten pops apart. The light can even make a sound as the tungsten sheers.

Brighter Using Halogen Gas Optics

To complete the discussion, infrared photons can be redirected with a mirror back onto the filament. Now the filament's outer atomic rings are not just shuffling and responding to electrons. But infrared photons are bouncing into the atoms making the rings gimbal or twist to reflect off and not absorb the photon pair.

This extra agitation makes the filament even more active. It gets the electron flow deeper into the atoms. The rings that make visible light are reached more quickly. The lamp produces more visible light. The light is whiter.

Optics can also filter photons. Instead of reflection, the lamp is designed with a "reflector" that has a coating which will let infrared light pass through, but will redirect visible light. Thre is less heat in the beam.

Photons Back into Electricity

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.

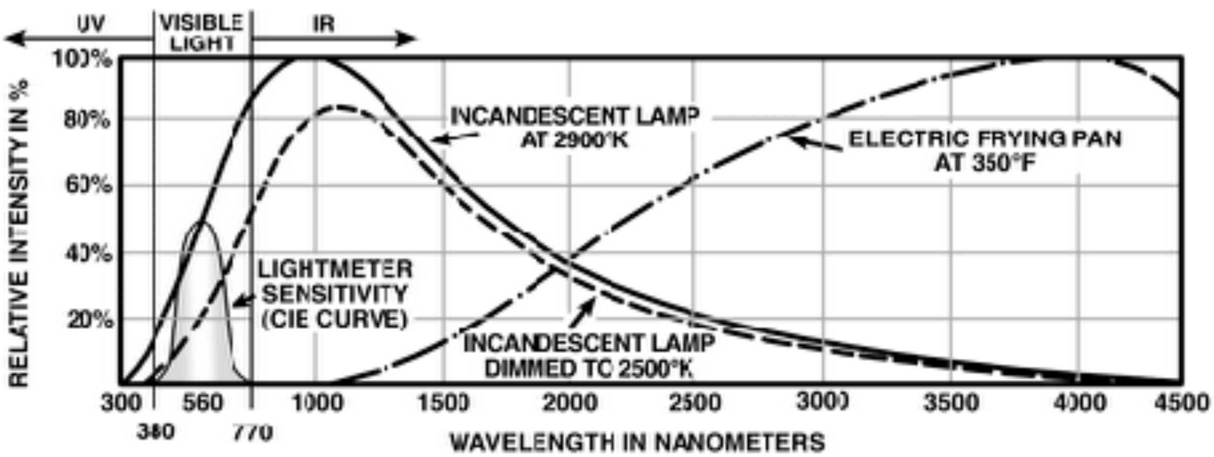
The electron when it comes apart is directed one way in the material and flows. The positron is spun back into an electron and usually flows the other direction. Enough photons broken apart and there is electricity that can do work. Usually, because it is a circuit, only half the photon is registered,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

Practical Lamp Physics

In application, controlling the electrical inrush upon startup extends lamp life. A “soft” start ramps up the voltage. The few seconds of exciting the filament with a glow before overly crowding the inner orbits protects the lamp from sheer failure.



Since visible light comes from electron rings closer to the nucleus, the more white visible light a filament lamp produces, the shorter its lamp life. The filament producing more visible light is always driven harder. So dropping the flow of electrons extends lamp life.

But it means less blue light in the content as a warmer color. The filament produces less blue light. Compare the two curves at 380 nm.

As for halogen lamps, they can be driven harder and will produce more visible light. The filament is protected from some of the stresses. The quartz envelope encourages the tungsten that does escape to redeposit back onto the filament. Since oils and containments can change the properties of the quartz, do not handle the lamp with your fingers.

Because there can be confusion, all filament lamps work the same way. The physics is the same. The first lamps Edison made using carbon stimulated photons out of electricity in the exact same manner as a modern filament lamp.

Quality control, manufacturing methods and automation have changed. The knowledge of the science has changed. Edison did not know what a photon was.

But how the lamp makes light has not.

And that brings in an important point. Filament lamps convert electricity into visible photons directly. *Useable light comes directly from the filament.*

Other lamps have to go through a process to covert photons into more useable photons. Other lamps may be more energy efficient (if you ignore the energy costs in making the lamp); but they use chemicals, usually metallic salts, to fluoresce or convert unacceptable light into better visible light. Sometimes converting is a big advantage. Sometimes it is a terrible disadvantage.

Filaments have a simplicity that works superiorly in certain applications. Fiber optic lighting is one of those applications. Useable light direct from a filament is an inexpensive, reliable design. That direct output provides optical control.

Additional Information You Might Need
Lighting Definitions

Let's be clear about some terms. A lamp is a light emitter. Every light bulb is a "lamp".

A "light bulb" is the common word for anything that looks like a round glass enclosure surrounding a light emitter, in this case, a filament. Light bulbs look like Edison's invention.

Technically, light bulbs are lamps. And light bulbs do not have to be filament lamps. There are LED and fluorescent lamps that are "light bulbs", because they look like a filament lamp in a glass bulb.

There are popular "Edison" light bulbs today which look like something out of the 1890's. But they do not work at all like Edison's invention (1879). They use light emitting diodes. In some applications these LEDs are great lamps.

But no matter the surroundings, all filament lamps work the same way.

They can be enclosed in bulbs, teardrop shapes, flames, very round globes, tiny grain-size bulbs, long tubes and come in a large variety of sizes and diameters. They can be very simple as a filament in a thin glass shell in a vacuum. They can be technically advanced as a filament in a quartz envelope with dichroic mirror reflectors. They can be with the filament oriented or coiled in different directions.

They can use different materials for filaments. They can come in a variety of bases. A screw base makes positive contact and is very intuitive to use. But the electrical contact connected into the socket come in all sorts of forms.

A basic light bulb can also be environmentally green. That is suppose to be a contradiction. But the materials to make a light bulb are minimal. When burned out, the waste of the lamp is small and inert.

Energy saving lamps consume a great deal more energy in manufacturing, shipping and waste disposal. Therefore, light bulbs in applications that are used for short durations spread out over years are better for the planet. There are tungsten lamps in operation that are 40-years-old, because they are rarely turned on and run under voltage. A closet, a basement, a garage with windows, a storage shed rarely visited, a service corridor used once a year…if you need light every once in awhile, a regular light bulb is a very green choice.

Finally, because lamps come in so many types, sizes, wattages and styles, the lighting industry along with the American National Standards Institute long ago assigned codes.

A typical light bulb is an "A19" meaning it is shape A at 2-⅜" diameter (or 19 x ⅛-inch increments) with an "E" base (screw base) at 60W 120V or 60 watts operating on 120 volts.

Lamps are described by shape, diameter size, reflector shape, wattage and socket type. You can find the descriptions through any search. You can specify by code.

But this shorthand should be printed on the lamp itself.

Reflector lamps can have an even simpler basic three letter code. A MR16 150W 21V GX5 (miniature reflector with 2-inch diameter using 150 watts at 21 volts with a bi-pin base) is an EKE lamp regardless of who manufacturers the lamp.

Talk “lamp” short hand.

Use the codes. It makes it easier to buy the right lamp.