Photons and Polarization

Edward G. Lake

Independent Researcher

April 8, 2019

detect@outlook.com

***Abstract**: Light consists of photons, not waves, and yet virtually every article and textbook about light polarization describes and uses illustrations of light as consisting of waves. This article is an attempt to analyze, illustrate and explain how light photons can be visualized, how they work, and how they can be polarized.*

Key words: Light; particle; wave; photon; polarize.

Light consists of particles known as photons. As Richard Feynman said and wrote, "We know that light is made of particles because we can take a very sensitive instrument that makes clicks when light shines on it, and if the light gets dimmer, the clicks remain just as loud—there are just fewer of them. Thus light is something like raindrops—each little lump of light is called a photon—and if the light is all one color, all the 'raindrops' are the same size."**[1]** Feynman then added:

> 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.
>
> You might say that it's just the photomultiplier that detects light as particles, but no, every instrument that has been designed to be sensitive enough to detect weak light has always ended up discovering the same thing: light is made of particles.**[2]**

Since light definitely consists of photons, why would colleges and universities teach students about "light behaving like waves"? The answer seems to be that it is very difficult to visualize an oscillating particle that always travels at the speed of light. Other particles, specifically electrons, protons and neutrons, form into visible objects you can hold in your hand. Such particles have mass and there is no known way to cause them travel at the speed of light, even inside a particle accelerator like the Large Hedron Collider (LHC) in Switzerland. Inside the LHC, protons can be made to travel at 99.9999991% of the speed of light, but not *at* the speed of light. Photons, in contrast, have no mass and only exist while traveling at the speed of light. Turn on any light bulb and you have caused countless photons to travel away from the bulb at the speed of light.

It seems absurd to explain light in terms of waves when light is known to consist of photons. While the mathematics may work, the reality is hidden. And the reality may hold all sorts of important information that is just being ignored.

I. Wavelengths

How can a "particle" have a wavelength? Even though light does not travel as waves, virtually every physics student knows how to measure a wavelength of light.

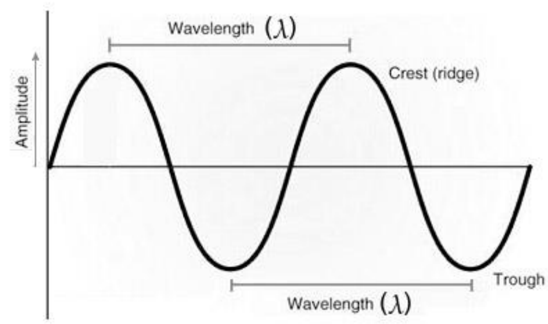

Figure 1

Figure 1 shows that wavelengths of light are measured from crest to crest, or from trough to trough. You just need to imagine a two-dimensional side view of a light wave.

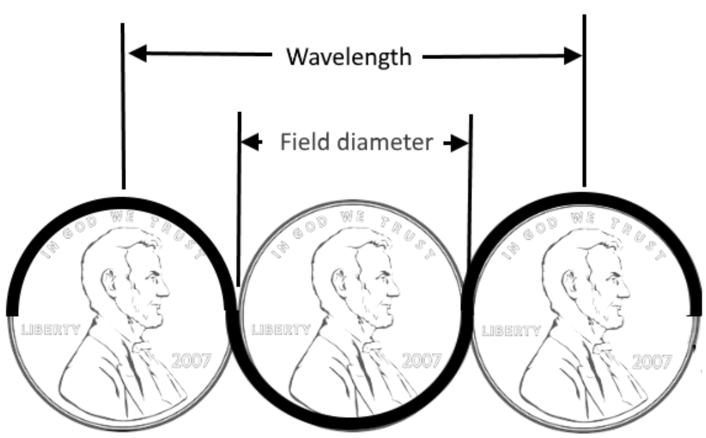

Figure 2

At the sub-atomic level, Nature tends to create objects as spherical or disk shaped. What is the equivalent of Figure 1 if we view light photons as disks? The answer is Figure 2 above.

Different sized disks/photons would provide waves of different wavelengths and different energies. If the photon fields are all of the same size, there is no difference in amplitude. Changes in amplitude involves adding more photons. That is part of what the photomultiplier tests cited by Richard Feynman demonstrated. When you lower the intensity of a light source, each click of the photomultiplier represents a single photon. The loudness of the individual clicks remains the same if the source remains the same. Amplitude is adjusted by adjusting the ***number*** of photons that are being emitted.

One problem with Figure 2, however, is that the "trough" seems to contain another photon. That is because it is the equivalent of Figure 1, which shows a trough where there is no trough. Figure 1 does not represent an electromagnetic wave because there is no such thing as an electromagnetic wave. It may represent waves of water, or of sound, but light waves are electromagnetic, and that makes them very different from water or sound waves.

II. Electromagnetic waves

Figure 3 below shows how electromagnetic waves, including waves of visible light, are typically illustrated in scientific papers and college textbooks. The illustration shows that the "waves" are actually oscillating energy fields. And there are **two** such fields, each oscillating at right angles to the other. In the illustration, the electric field oscillates up and down vertically while the magnetic field oscillates side to side horizontally.

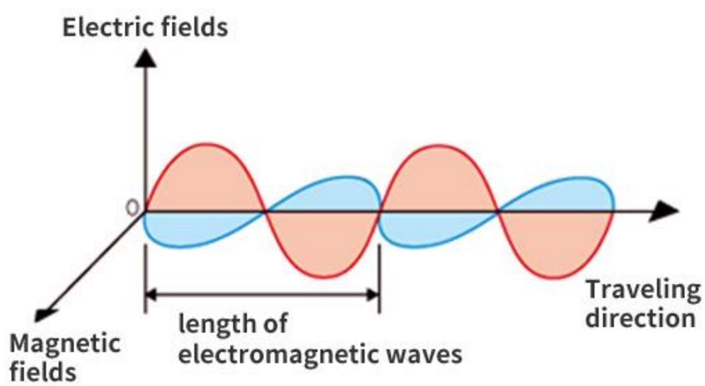

Figure 3

In Figure 3 we also see that the "trough" is not a trough, it is where a different wave moves in a different direction. Comparing electromagnetic waves to water waves is not only misleading, it confuses a critical point about electromagnetic waves. When such waves are again viewed as photons, as was done in Figure 2, it is only necessary to turn the center disk on its side. This is shown in Figure 4 below.

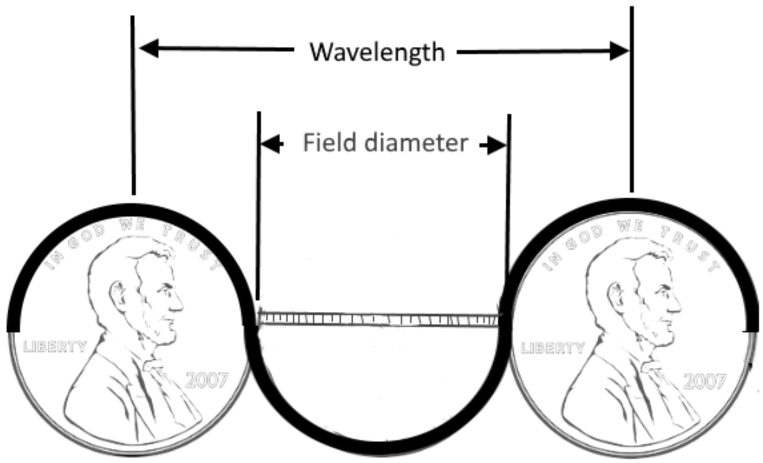

Figure 4

There are other problems with Figure 3 and the way electromagnetic waves are generally depicted in textbooks and scientific papers. Figure 5 below shows a different way of depicting a photon. It makes a photon equivalent to one wavelength. But that is vastly misleading.

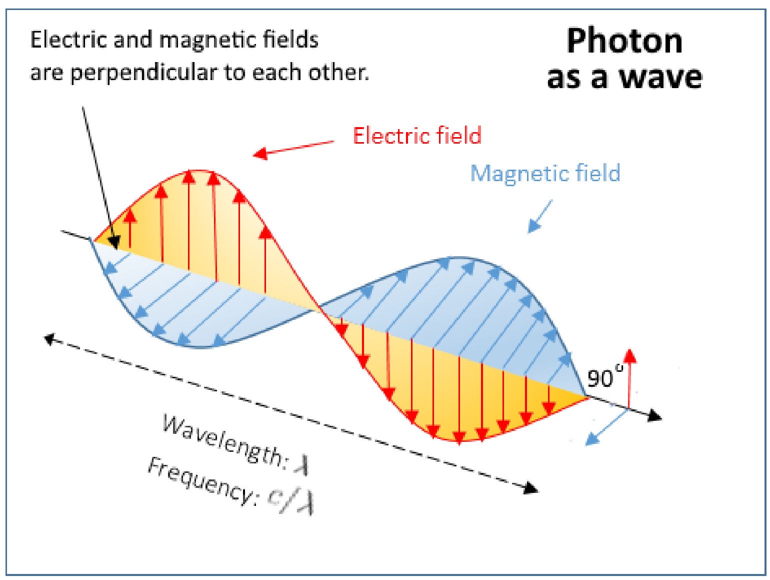

Figure 5

A key problem with photons or waves being depicted this way is that the fields start from nothing. The energy in the fields appears from nowhere and spreads upward and to one side. The fields then retract and cease to exist once again. Then, again starting from nothing, the fields expand downward and to the other side. Then the fields retract to nothing once again before restarting the entire process over again.

How can fields of electric and magnetic energy cease to exist and then reappear? If the fields are energy, isn't the energy vanishing and then reappearing? How does the initial energy for the initial wave appear from nowhere? And isn't the energy destroyed when it disappears?

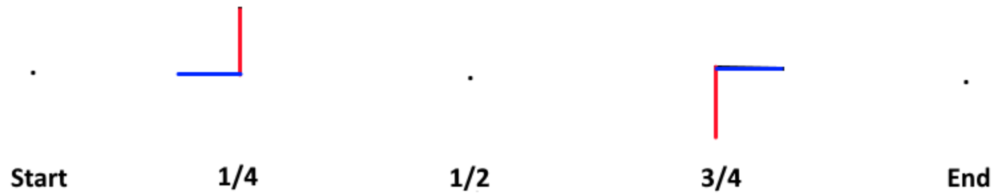

Figure 6

Figure 6 shows how the waves in Figure 3 and 5 would appear when viewed head-on. Waves first expand one way, then the opposite way, and yet the wave moves straight ahead.

III. Visualizing a photon and its fields

If you take what is now known about light photons and re-imagine Figures 3 and 5, you get what is shown in Figure 7 below.

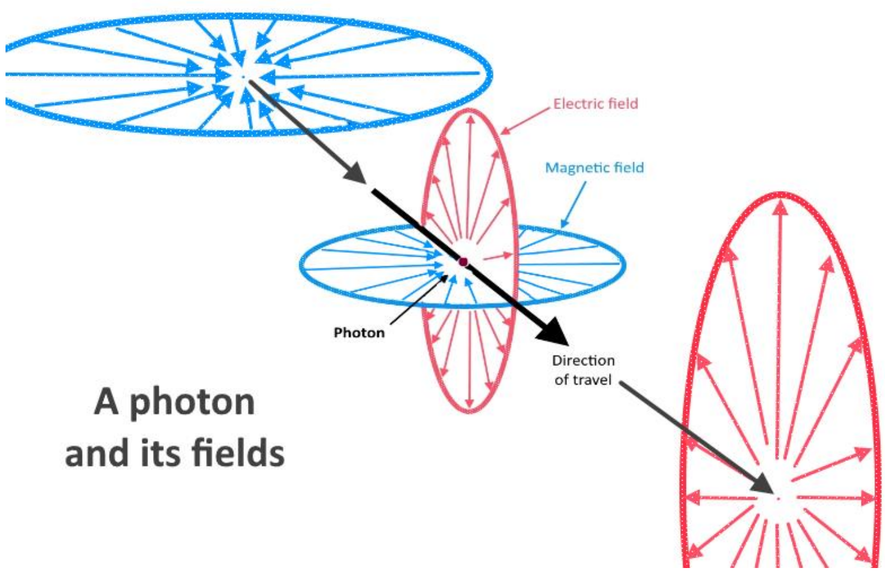

Figure 7

And Figure 8 below shows how a photon's fields would appear when viewed head-on.

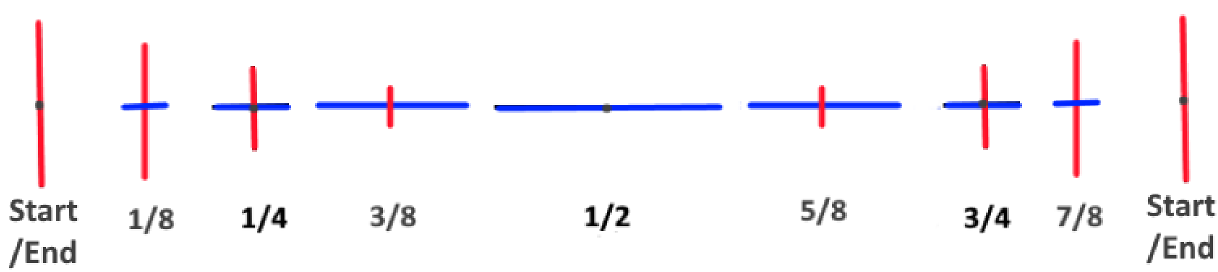

Figure 8

Figure 8 makes the photon's "wave-like" characteristics clear. The electric field at the Start/End contracts toward the photon in the center as the magnetic field expands outward from the photon in the center. This means that the fields never totally disappear the way waves in Figures 3, 5 and 6 appear to. The fields extend away from and back to an energy source, i.e., to the actual photon in the center. The wavelength is one repetition of the cycle. In Figure 8 the cycle begins when the electric field is fully extended, a.k.a, at the "crest." So, the wavelength is from crest to crest. If measured from trough to trough, you just have to begin at the ½ way mark in Figure 8.

Figure 4 can now be understood to actually look like Figure 9 below.

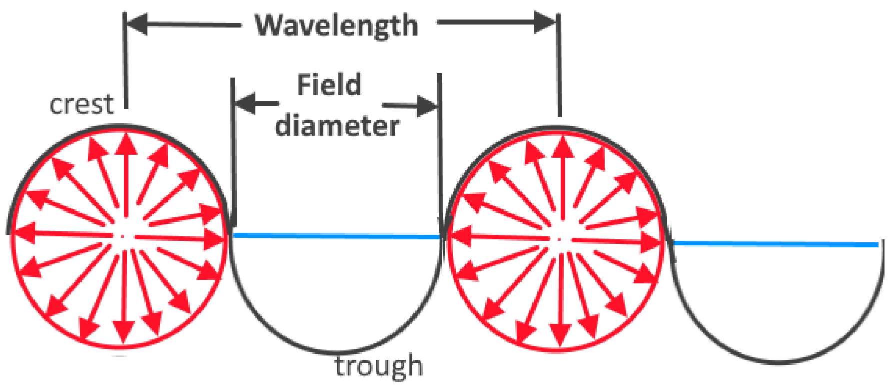

Figure 9

The next question we have to ask is: What is the size of a photon?

A photon is assumed to be about the size of an electron, which is a tiny fraction of the size of an atom. "The diameter of an electron is less than 1/1000 the diameter of a proton. A proton has a diameter of approximately 1/25,000,000,000,000 inch (0.000000000001 mm)."[3] When comparing photons to light waves, however, the size of a photon is generally considered to be the size of its fields. That is a big part of the confusion over what photons look like.

A sodium atom that is 0.38 nanometers in diameter will supposedly emit a yellow light wave that has a wavelength of 580 nanometers, which is 1,526 times the size of the sodium atom. That 580 nanometer wave can then be absorbed and re-emitted by a silver atom in a mirror, even though the silver atom is just 0.33 nanometers in diameter, or 1,758 times smaller than the wave.

That means that if Figure 9 is assumed to be a model of a wave of sodium light, the wavelength shown is 580 nanometers, and the field surrounding the photon is one half that, or 290 nanometers. And if the photon at its center is the size of an electron, that means the actual photon generates electric and magnetic fields that are millions of times larger than the photon itself.

It also means that when a traveling photon strikes and is absorbed by an atom, the fields surrounding the photon collapse down to sub-atomic size. It is much like a train going into a tunnel. Inside the tunnel, all the sounds the train makes and all of the light the train emits go no further than the walls of the tunnel. Inside an atom, the electromagnetic energy of the photons fields is effectively captured and absorbed by the atom. If the atom cannot contain the energy of the photon, it emits a new photon at the speed of light in some random direction.

If the photon strikes glass, water, clear plastic or some other transparent material, the light will be slowed as it passes through the material, but it is not wholly absorbed. Instead, most of the photons simply pass through the material and out the other side – like a train through a tunnel.

If the transparent material is of the right type, however, the photons exiting the material will have their electric and magnetic fields aligned differently from the photons that entered the material. The fields of the exiting photons will be polarized. Polarization provides us with additional information about how photons work.

IV. Polarization

Figure 10 below shows a typical illustration of polarization using light waves.

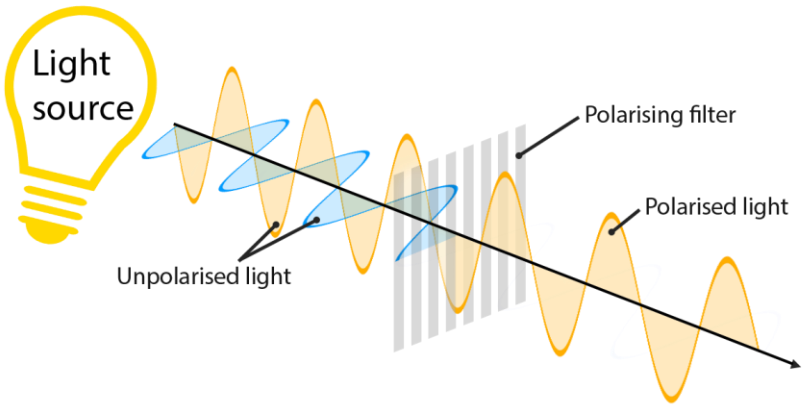

Figure 10[5]

The light source (in this case a light bulb) emits countless waves (or photons) randomly in all directions. While the electric fields and magnetic fields still oscillate perpendicular to the direction of travel, and the electric fields are still at a 90 degree angle to the magnetic fields, the fields are randomly oriented, with no up or down. The light is "unpolarized." In Figure 10, those unpolarized light waves travel outward in a straight line from the light source. When some of the waves hit a polarizing filter, the filter stops and absorbs all waves except those which oscillate in the same general direction as the openings in the filter.

There are many problems with Figure 10, the most obvious of which may be that it appears to confuse unpolarized light with electric and magnetic waves. The polarizing filter appears to stop the magnetic waves and allows only the electric waves to pass. This is definitely **<u>not</u>** how light polarization works. Electric fields cannot be separated from magnetic fields in light waves or photons. Both fields are part of <u>one</u> packet of energy.

But the illustration does pose an interesting question: If electric fields oscillate at 90 degree angles from magnetic fields, how can **<u>any</u>** wave (or photon) fit through a "Polarizing filter?"

More importantly, perhaps, is the known fact that the light source shown in Figure 10 is emitting countless photons oriented in countless angles as a portion of the photons travel in the direction of the polarizing filter.

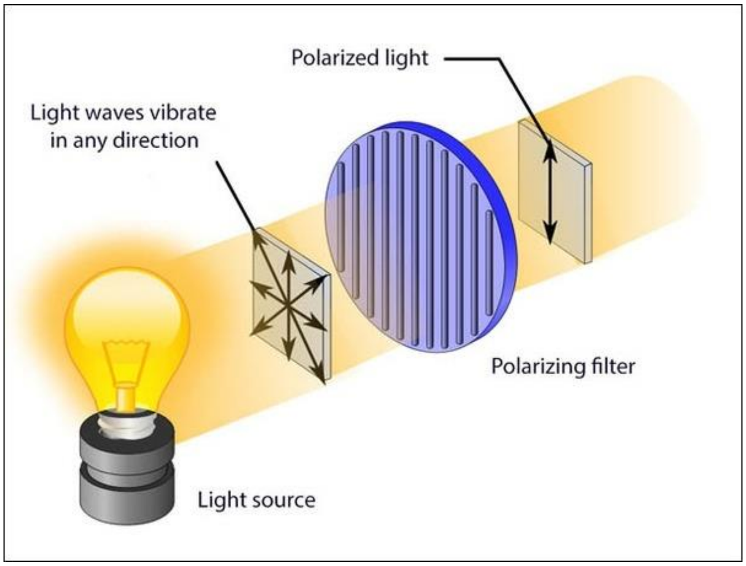

Figure 11

Figure 11 above is another typical illustration of how polarization works. It is better than Figure 10 in that it explains that "Light waves vibrate in any direction." But it still ignores the fact that electric and magnetic waves vibrate in two directions that are perpendicular to one another. That means that, when light waves travel through a polarizing filter, one of these waves is going to go through at right angles, no matter which way the openings in the filter are oriented. You cannot separate the magnetic field from the electric field, and they are always oriented at 90 degree angles from one another

Another known fact that is ignored in Figure 11 and virtually all similar illustrations is that, regardless of the angle at which the light waves vibrate, somehow ***the filter allows 50 percent of the waves through and absorbs the other 50 percent***.

And perhaps the most egregious error in Figures 10 and 11 is the fact that, in reality, the waves or photons that get through the polarizing filter *must be at right angles to the grid*. In other words, waves and photons must be horizontal to get through a vertical filter.

Typical descriptions of polarization, like those shown in Figures 10 and 11, imagine that polarizing filters have slits like a picket fence or a comb. In reality, a polarizing filter has no openings. It is solid plastic. But how does a solid sheet of plastic polarize light?

Polarizing filters are typically created by aligning the magnetic fields in the molecules of some kind of transparent plastic polymer. This can be done by stretching the material. The imagined slits in the filter are thus aligned with the direction the material was stretched. So, if you stretch the plastic by pulling it upward, the magnetic fields of the plastic molecules will be aligned vertically. If you stretch the plastic by pulling it sideways, the magnetic fields of the molecules will be aligned horizontally. There are no openings between molecules, so there are no slits.

Before the plastic is stretched and before the molecules are aligned, light passes through the plastic just as it does through clear glass. But then the plastic is stretched vertically and the magnetic fields of the molecules are aligned vertically. Of course, that also means the electric fields of the molecules are aligned horizontally.

It's also important to understand that, in this context, "vertical" can now be defined as the alignment direction of the magnetic fields in the polarizer. "Horizontal" is 90 degrees away from the alignment direction of the magnetic fields. The actual orientation of the polarizer relative to the center of the earth or some other object is irrelevant.

The result is a grid of aligned electromagnetic fields like that shown in Figure 12 below.

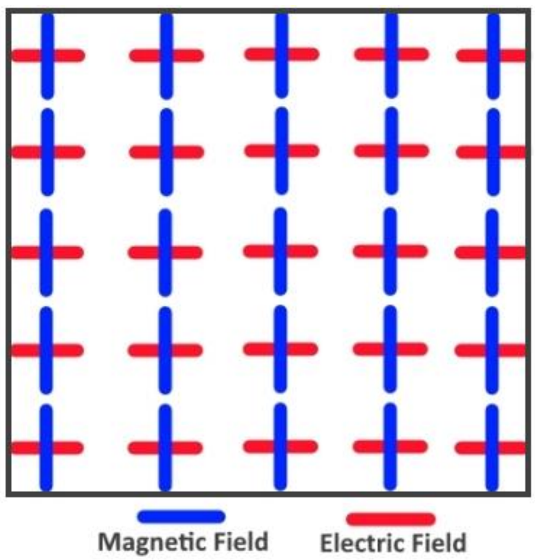

Figure 12

Photons which have their fields aligned at right angles to those in the grid will pass through the grid. Photons that have their fields aligned the same way as the fields in the grid will be absorbed by the atoms in the plastic molecules in the grid. If the photon's magnetic field is not perfectly aligned with the horizontal magnetic fields in the filter grid, it becomes a matter of probability as to whether the photon will pass or not.

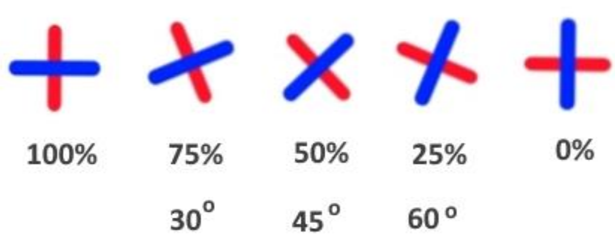

Figure 13

In Figure 13 above, the photon on the left has a 100% probability of passing through a good polarizing filter (i.e., Figure 12) because its fields are aligned the opposite way from the fields in the filter shown in Figure 12. The fully aligned photon on the right has a 0% probability of passing through the filter. The probability changes as the orientation of the photon changes. 30 degrees off of vertical means there is a 75% chance of passing through the filter, 45 degrees equals 50% and 60 degrees equals 25%.

While this is all true, one key point has not been made: When a photon that is 30 degrees off of vertical finishes passing through the filter, it is no longer 30 degrees off of vertical when it emerges from the filter and continues on. While passing through the filter it was re-oriented to be perfectly vertical relative to the filter. If a thousand randomly oriented photons hit a vertical filter, 50 percent should get through the filter, and all of the photons in that 50 percent should have their electric fields oriented vertically.

V. Multiple Polarizing Filters.

Thus far, this paper has only discussed a single filter as shown in Figure 10 and 11. We now know that 50% of the emitted light that reaches the filter gets through a single filter, and that light is polarized so that the fields oscillate uniformly. The molecular magnetic fields are vertically aligned in the filter and thus the only light photons that pass through the filter are the photons which have **magnetic** fields that are horizontal or can be re-oriented to be horizontal. The result is that 50% of the light gets through the filter if the polarization filter is perfect and the emitted light is perfectly random in orientation. The light photons that move beyond the filter have their **electric** fields completely vertically polarized and their **magnetic** fields completely horizontally polarized. This can be confirmed by placing a second polarizing filter oriented the same way between the emitter and a detector, as shown in Figure 14 below.

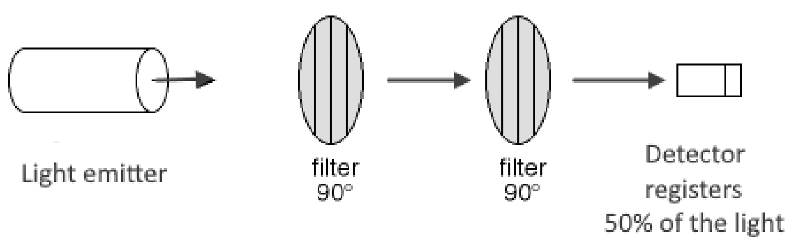

Figure 14

In Figure 14 we know that 50 percent of the randomly oriented photons from the light emitter get through the first filter just as in Figures 10 and 11. This time, however, the light then passes through a duplicate filter that is oriented the same way. Because the photons that passed through the first filter have their electric fields all perfectly oriented in the vertical direction, the second filter has virtually no effect on the light photons, and the detector registers that 50 percent of the emitted light passed through both filters. The results are virtually the same as if the second filter was not there.

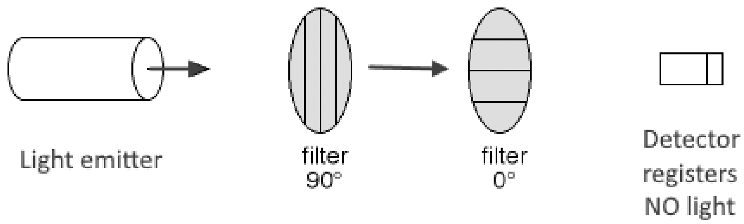

Figure 15

In Figure 15 the second filter is turned horizontal, and as a result all the photons that passed through the first filter have their electric fields vertically oriented and are all absorbed by the second filter which also has its electric field oriented vertically. No light gets to the detector.

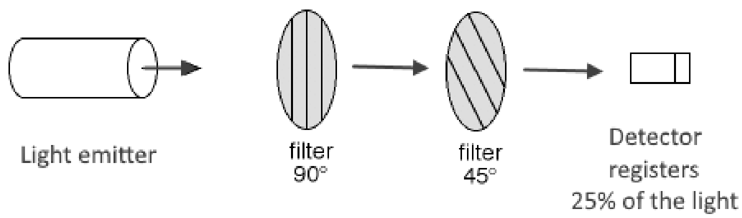

Figure 16

In Figure 16 the second filter is turned at a 45 degree angle to the first filter, and as a result 50% of the photons that passed through the first filter are blocked by the second filter. This means that 25% of the light that was originally emitted gets to the detector.

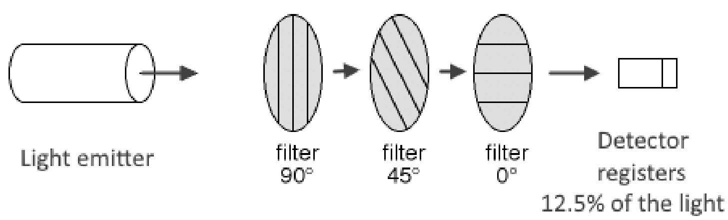

Figure 17

In Figure 17 a third filter is added between the first and second filter as was shown in Figure 15. In this situation, 50 percent of the light is blocked by the first filter and 50% gets through, as before. The center filter is turned at 45 degrees relative to the first filter, so it blocks 50% of the light that it receives and lets 50% through. That means that, as in Figure 15, about 25% of the original photons get through the second filter. The third and last filter is turned at 45 degrees relative to the center filter, so it blocks 50 percent of the light it receives and lets 50% through. As a result, 12.5% of the light that was emitted gets to the detector.

This last experiment also confirms that light photons are reoriented by the filters. If they weren't, adding the center filter in Figure 17 would get the same results as in Figure 15 where the center filter was not there. No light would get to the detector. It is only because the photons are re-oriented by polarizing filters that light can get through the three filters in Figure 17. This experiment is routinely performed in many college physics classes and on many YouTube videos. So, there can be no doubt that the oscillation direction of light photons is re-oriented by polarizers.

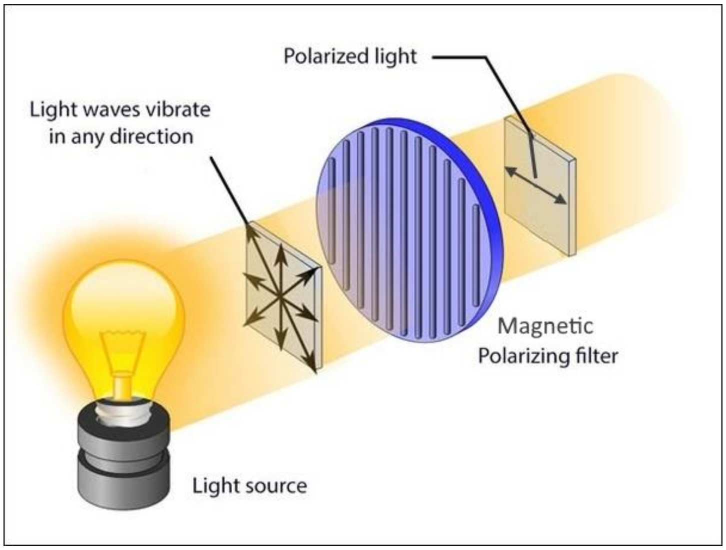

Figure 18

And there is also no doubt that when you view waves or photons going through a polarizing filter, the waves and photons that get through the filter will have their electric and magnetic fields oriented at right angles to the fields in the filter. So, Figure 11 really should look like Figure 18 above. The illustration is also a good one because it shows neither waves nor photons.

VI. Conclusion

Polarization is something that cannot be done with water and sound waves, so there is little reason to discuss similarities between water or sound waves and imaginary light waves. Light consists of photons, not waves. The photon's oscillating fields just simulate wave-like properties.

Polarized light can be produced any place where the terms "vertical" and "horizontal" have some meaning. When light photon is emitted from a star or a light bulb, the photon moves at the speed of light away from its originating source. The photons are unaligned, meaning their electric and magnetic fields can point in any direction that is perpendicular to the direction of travel.

Photons are also polarized when they hit a smooth horizontal surface at a shallow angle. The photons that have their magnetic fields oriented less than 45 degrees off of horizontal will be absorbed by the surface, while those photons with magnetic fields that are more than 45 degrees off of horizontal will be deflected and polarized to be horizontal.

To polarize light means to align the oscillations of the photon's electromagnetic fields with some external electromagnetic fields. The best known way to polarize light is to send the photon through a Polaroid material. "Invented by the American physicist Edwin Land, a sheet of Polaroid consists of long-chain hydrocarbon molecules aligned in one direction through a heat-treatment process. The molecules preferentially absorb any light with an electric field parallel to the alignment direction. The light emerging from a Polaroid is linearly polarized with its electric field perpendicular to the alignment direction. Polaroid is used in many applications, including sunglasses and camera filters, to remove reflected and scattered light."[5]

With all this information available and fully verified, the next task seems to be to explore what refraction, diffraction and interference mean when talking about photons instead of waves. But that would be the subject of another paper.

VII. References

[1] Richard P. Feynman, *QED: The Strange Theory of Light and Matter*, Princeton University Press (1985), page 14

[2] *Ibid*, page 15

[3] World Book Encyclopedia per https://hypertextbook.com/facts/2000/DannyDonohue.shtml

[4] https://www.universetoday.com/15585/diameter-of-the-solar-system/

[5] https://www.britannica.com/science/light/Unpolarized-light#ref929213