# What is Light?

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**Abstract**

A basic discussion of light and electromagnetic radiation.

We are able to measure a wide range of properties and parameters which we attribute to light. Historically this information has led to confusion about exactly what light is. We measure a wave-like behavior in many experiments, and we use waves of electromagnetic radiation for literally thousands of different purposes. However we can also see particle-like behavior in certain circumstances.

Among the properties we detect when studying light is the appearance of spin angular momentum. This angular momentum (spin) of light is measured to be the value ħ under many circumstances, if we assume that light is comprised of photons which obey Planck's rule E=hv. This spin angular momentum cannot logically be attributed to the spin angular momentum of the fermions (½ ħ) with which light reacts.

Some who have studied light in depth for years insist light or electromagnetic radiation is just a wave. However other scientists, who have also studied light carefully, insist light's behavior demands light come in discrete quanta, which we call photons. Strong arguments persist for both perspectives. Many physicists simply attribute the mysteries of light to another mystery called "wave/particle duality".

Herein we will address the properties of light and provide an explanation for those properties, as well as propose a simple model which unifies the seemingly contradictory wave-like and particle-like reaction data we have on the behavior of light.

**Properties of Light**

Maxwell's equations disclose a host of properties and behavior for light. And they do such a good approximation that they have served us well since 1865 when Maxwell published. Huygens-Fresnel's diffraction integral also shows us properties and behavior of light when diffracted. The Huygens-Fresnel's diffraction integral serves optical engineers well because it quite accurately predicts the behavior of light. These two bits of information are compelling enough to convince some that light and electromagnetic radiation are only comprised of waves.

However, the photo electric effect, and Compton scattering provide some additional information which we cannot ignore in our quest to fully understand the nature of light. Regarding Compton scattering, we quote from Wikipedia, "The effect is important because it demonstrates that light cannot be explained purely as a wave phenomenon. Thomson scattering, the classical theory of an electromagnetic wave scattered by charged particles, cannot explain low intensity shifts in wavelength (classically, light of sufficient intensity for the electric field to accelerate a charged particle to a relativistic speed will cause radiation-pressure recoil and an associated Doppler shift of the scattered light,… but the effect would become arbitrarily small at sufficiently low light intensities regardless of wavelength). Light must behave as if it consists of particles, if we are to explain low-intensity Compton scattering. Compton's experiment convinced physicists that light can behave as a stream of particle-like objects (quanta), whose energy is proportional to the light wave's frequency."

So with this seemingly contradictory information it is quite easy to see how there are differing opinions regarding the nature of light.

In order to sort out this dilemma, let us consider a more total picture of what we know of light and of particles. One phenomenon which also initially seems to add some confusion to the scenario, but eventually helps us better understand, is the wave-like behavior of electrons in electron double-slit experiments. Here we have objects which are clearly particles, acting like waves.

For many years, I must admit, I held the opinion, and actively defended the position, that electromagnetic radiation was not quantized, but was just a wave in space. However, eventually, and with much study and effort, I now feel the overwhelming evidence in nature demands a bit of a different perspective.

If we use the information above, and imagine that space has a set of rules, a controlling set of properties, which govern the behavior of energy as it propagates through space, and we imagine that these rules are definable and universal, then we can develop a model for light which dispels the confusion surrounding this "wave-particle" duality. We can then see more precisely how it is that both particles of matter and light are made of waves.

## Properties of Space

Maxwell's equations disclose to us some of the properties of space and the way space reacts to energy (in the form of waves) propagating through space. These equations are an accurate macro view of a substantial portion of the important properties of space with regards to the behavior of light. But they simply do not tell the whole story. Maxwell's equations do not explain the spin angular momentum of light and fermions, and do not explain why electrons can behave as waves. To get the rest of the information we need to look at the behavior of the micro world of particles. In this micro, subatomic particle domain, E=hv, Planck's rule is paramount for our understanding of more of this puzzle. To understand light we have to discuss the properties of space, in some detail, simply because light waves propagate through space, and the properties of space determine exactly how these waves can move. In this context we will then postulate that elementary fermionic particles are comprised of confined waves of energy, propagating in confinement within the particle, at the same velocity that the waves in light propagate.

There are at least two interpretations for the application of Planck's rule. In one case we can assume that Planck's rule, E=hv, only applies to fermions, and that light waves are not inherently quantized by this rule, but just appear quantized to us, because all of the fermionic emitters and absorbers are quantized by this rule. Another case for the interpretation of the application of Planck's rule is to assume that the properties of space are universal, and therefore the same for all energy waves propagating through space, so that E=hv would apply to all waves. Quantization would then be an inherent behavior of energy propagating in space. This author believes the second interpretation listed above to be the more appropriate representation of what we observe in nature. There are compelling reasons for taking such a position regarding the nature of space, light, and matter. If we follow this postulate we are able to answer many otherwise unanswered questions, and sort out solutions to puzzles we would simply not be able to solve using the first interpretation listed above.

## Planck's Rule

Let us follow a line of reasoning which indicates that Planck's rule applies to all energy propagating through space. Then if matter is comprised of confined waves of energy, as postulated above, Planck's rule would apply equally to particles of matter, and to the quantization of light. So that *E=hv* would be a universal rule. Therefore this rule would be attributable to, and caused by, the universal properties of space.

In order for Planck's rule to be such a universal property there must be a cause, a property of space, which makes this rule work. It is not a new perspective to postulate that there is a quantization of action defined by *E=hv*, Planck, Einstein, as well as many others, have already suggested quite profoundly that this quantization of action must exist. Here we are just adopting the view that such a quantization of action is a universal property of space. Making this assumption has some significant benefit in solving several of the puzzles of the physical universe.

Now we need to better define the term "quantization of action". Let us start with a couple of the properties we have discussed. The spin angular momentum of light, and Planck's rule. We can see from Maxwell's equations that light, on the macro scale, is comprised of what we detect to be waves, with properties remarkably similar to those of transverse waves in an elastic solid.

If light is comprised of discrete quanta or "photons" then the transverse spin angular momentum of each photon is measured as being the value ħ (*the reduced Planck's constant* $\frac{h}{2\pi}$). Then if we treat the photon as a rotational transverse wave, which makes one rotation on one wavelength, we have a starting model to examine.

The measured longitudinal momentum of one of these photons is $p = \frac{E}{c}$. Where *p* represents longitudinal momentum, *E* represents the energy of the photon, and *c* of course represents the forward propagation speed of light. In order for us to measure a spin angular momentum of ħ for these photons we have to assign an "action radius" *r* to this rotational wave with the dimensional value of the measured wavelength $\lambda = \frac{h\,c}{E}$ divided by 2π $\left(r = \frac{h\,c}{2\pi\,E}\right)$. This yields $\hbar = p\,r$.

Now we have a simple model of a single wavelength "photon" with energy E, momentum p, and (left or right) spin angular momentum ħ.

This model displays several important properties for such a photon but does not yet explain a cause for the quantization of action.

If this wave is confined, in a helical rotational form, which displays a longitudinal momentum of p, then there must be a force of confinement which acts against that momentum causing the spin of this wave. From the information listed above can calculate what amount of force would need to be present for this confinement. The transverse force $F_c$ required for such confinement of this wave, with its momentum, would be calculated using a basic centripetal force calculation.

Since centripetal force is momentum *p* multiplied by velocity (*v* or in this case *c*), over the radius, we can state that:

$$F_c = \frac{p\,v}{r} = \frac{p\,c}{r}$$

We have now calculated a force which could confine the wave of a photon in the manner we have described. If our assumptions to this point are correct then this force would be the explicit cause for Planck's rule. Now we will explore a bit to see if this force has any basis in our existing body of physics knowledge.

First let us inspect the relative strength of this force compared to other known forces. Probably the easiest force to use is the force of electric charge.

In order to compare the strength of this force $F_c$ to the force $F_e$ (of two electric charges separated by the distance *r*), we can use the following steps:

$$F_e = \frac{e^2}{4\pi\,\varepsilon_0\,r^2}$$

Then for the relationship between $F_e$ and $F_c$ we find:

$$\frac{F_e}{F_c} = \alpha$$

Where α represents the fine structure constant.

Since the nuclear strong force is 1/α stronger than the force of electric charge $F_e$, we can see that this force of confinement $F_c$ for the photon would have to be exactly the same strength as the strong nuclear force in order to confine the photon wave in the manner we have described and give it a spin of ħ.

**Cause of the Confinement Force**

We are able to calculate this confinement force $F_c$ from first principles as well. Let us illustrate how this can be done:

$$F_c = \frac{2\,\hbar\,c}{2\,r^2}$$

Which simplifies to:

$$F_c = \frac{\hbar\,c}{r^2}$$

As it turns out the more accurate simplified form of this equation is:

$$F_c = \frac{S\,\hbar\,c}{r^2}$$

Where S represents the spin number of the particle (1 or ½).

**Indications of the Confinement Force $F_c$**

1. If a single wave of monochromatic light has spin angular momentum then there must be a force which causes the spin.
2. If there is spin in a single wave of monochromatic light, then there is a transverse helical confinement (quantization) of the wave which results from that spin.
3. If photons exist as discrete light quanta then some form of confinement is required to cause them to be quantized.
4. The relationship $E=mc^2$ is clearly understandable if matter is made of confined waves of energy. If fermions are comprised of propagating energy as light is, then they are confined waves of energy. As confined waves of energy they would require a confinement force.
5. If Planck's rule is a universal property of space which regulates the behavior of energy propagation through space (wave action), and applies to particles of matter, then it is reasonable to assume that this quantization of action is caused by a force $F_c$ which is ever-present when these waves of energy propagate through space, and would also apply to light energy propagating through space.
6. If we follow this line of reasoning suggesting the force $F_c$ exists, we can see how it is that fermions can be formed from these waves of energy which propagate through space. We then have a cause for Planck's constant, and a way to tie many of the physical constants together, and show cause for the fine structure constant as well.

7. This force $F_c$ is exactly the force which would be needed to confine the energy wave of a fermion to form a spin ½ particle. The quantization of a photon in this manner yields a solution which also allows quantization of matter.

Following the discussion above, the confinement force required for photons and fermions is precisely the same magnitude as the strong nuclear force. So we are not proposing that there is a new force, only that the force we had identified as the "strong nuclear force" has a much broader manifestation then we had previously imagined. It is probably more accurate therefore to call this force the "confinement force" instead of the "strong nuclear force".

Regrettably, in a short article, there is not space to cover all of the ways that this force helps to solve many of the puzzles and mysteries of physics. So we will leave that discussion for later review.

## Photon Behavior

A photon model, such as the one described, inherently has a set of attributes due to its structure and the nature of these waves in space.

Diffraction behavior is well worth discussion. Starting with a Photon with lower energy (longer wavelength $\lambda = \frac{h\,c}{E}$). This lower energy photon also has a larger radius $\left(r = \frac{h\,c}{2\pi\,E}\right)$. With a longer structure (wavelength), and a larger transverse extent. One reason that the low energy (visible light) photon is diffracted less in certain environments, is that the confinement force $F_c$ is so much less in a lower energy photon. This low energy photon structure is therefore a less rigid form than a higher energy photon. And the wavelength of the photon, and its radius, are so much longer than the wavelength or radius of the particles, or atoms, or even molecules it encounters. The incident objects to have less influence on the photon's overall trajectory. The smaller (more energetic) a photon is, the "stiffer" it is, and the more easily these objects (due to their size) can have a large influence on its trajectory. We can see the results of this phenomenon with a simple optical prism. Due to this, the photon would follow a path much like the path a simple wave would follow. This mode of reaction is related to the size and stiffness of the photon and the objects with which it interacts. However, when the rigidity of the photon is equal to or greater than the rigidity of an electron, we will see an entirely different behavior. Reflection (scattering) of the photon will become the prevailing reaction and we will see very little diffraction. However we can see that the diffraction of an EM wave is dependent on the size of the wave related to the size of the "objects" in the environment with which the wave (photon) interacts. Contrary to the case with visible light and a prism, low frequency radio waves will follow the curvature of the earth much more readily than higher radio frequency waves. In that situation, low frequency waves diffract more than high frequency waves. Again, diffraction is the interaction between the photon and the objects in its environment. In many circumstances the photon will just behave like a simple wave. But there are a few slight differences which are detectible in experiment.

**Conclusion**

Given the overwhelming evidence from experiment, and the results of implementing the force $F_c$ in our formulae and definitions, it is reasonable to conclude that photons exist, and that light and electromagnetic radiation is quantized in the form of photons.

So this premise suggests that light is in the form of quantized rotational waves of energy.

For visible light and lower energy EM radiation, these quanta have such a small amount of energy that they must come in very large numbers for us to normally be able to detect them. It simply takes a lot of them at very low energies to have enough energy to significantly move an electron. Which means that in our day to day observations, this low energy radiation will just look like waves of energy. It is only when we take great care that we can see the results of this quantization in the visible spectrum and below. But the evidence is there. The photon is simply a quantized, rotational transverse wave, which allows it to sometimes act like a particle.

So the argument about whether a photon is a wave or a particle is mute, because the photon is a quantized wave, which makes it both a particle and a wave.