

The universe and photons

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Abstract

In this essay, we show that the photon can be the most fundamental element of the universe. Many results, based on well-established physical theories, support this assumption.

1 Introduction

What is the most fundamental “brick” of the universe? A string, as suggested by the string theory in [7], a loop, as developed in the loop quantum gravity in [19], or something else. Is it possible that the most fundamental element in the universe is the particle introduced by Albert Einstein in [4]: the photon?

A photon is an elementary particle, the quantum of the electromagnetic interaction and the basic unit of all forms of electromagnetic radiation. This is a particle without mass or electric charge whose energy is given by the formula:

$$E = h \cdot \nu \tag{1}$$

where h is the Planck constant and ν the frequency of the photon. For being the most fundamental elements in the universe, photons must account for the origin of fermionic matter and the fundamental interactions of the universe.

The paper is organized as follows. In section 2, we wonder if photons can emerge from the Big Bang. The section 3 is dedicated to fermionic matter. The section 4 deals with the fundamental interactions. The wave-particle duality is discussed in section 5. Finally, a conclusion is given in section 6.

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2 Photons and the Big Bang

In this section, we wonder if photons can emerge from the initial singularity called the Big Bang, an event which led to the formation of the universe. The Penrose-Hawking singularity theorems require the existence of gravitational singularities [11, 12]. A spacetime with a gravitational singularity is defined to be one that contains geodesics that cannot be extended in a smooth manner, what is also called “path incompleteness”. The end of such a geodesic is considered to be the gravitational singularity. In particular, the black holes which are areas of a spacetime with a gravitational field so intense that its escape velocity is equal to or exceeds the speed of light, contain a gravitational singularity. Stephen Hawking has shown in [10, 11] that a black body radiation, emitted from just beyond the event horizon, can get out of a black hole and can lead to black hole evaporation. The Hawking radiation is due to quantum fluctuations that are a temporary change in the amount of energy in a point in space. Due to the Heisenberg uncertainty principle:

$$\Delta E \cdot \Delta t \geq \frac{\hbar}{2} \quad (2)$$

where ΔE and Δt are the uncertainties in energy and time and \hbar the reduced Planck constant, the conservation of energy can appear to be violated, but only for small times. Quantum fluctuations exist and they are for instance responsible for the Casimir effect. So, it is possible to “remove” a gravitational singularity with emission of photons having a black body spectrum. Nevertheless, the initial singularity is different from a conventional black hole because all timelike geodesics have no extensions into the past. If the photon is the most fundamental element in the universe, then it is possible to extend the result of Stephen Hawking to the initial singularity, considering the boundary of the Planck epoch as a kind of “horizon” where photons are emitted with maximum frequency and black body spectrum. Actually, we know that there exists a black body radiation filling the universe. This is the cosmic microwave background (CMB) radiation discovered in 1964 by American astronomers [18].

3 Photons and the fermionic matter

What is the origin of fermionic matter in the universe? Is it possible that fermionic matter came from photons, due to:

- the Einstein’s mass-energy equivalence:

$$E = \gamma m_0 c^2 \quad (3)$$

with $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$, v the velocity, m_0 the rest mass and c the speed of light in the vacuum. By using (1), we have:

$$m_0 = h \frac{\nu}{\gamma c^2}; \quad (4)$$

– the physical conditions around the Big Bang?

We know that photons are emitted during a molecular, atomic or nuclear transition to a lower energy level, with various energy from infrared light to gamma rays. Moreover, the electron is able to move into an excited state with an absorption of a photon with an appropriate energy. So, fermionic matter can absorb or emit photons and this is a first information [5].

The main argument in favor of photons is a reaction called “pair production in two-photon collisions” that refers to the production of an elementary particle and its antiparticle from photons [6]. There exists an inverse process to pair production, called pair annihilation. This is a branch of physics called “two-photon physics”. For instance, the electron e^- positron e^+ pair production is given by the “collision” of two photons γ :

$$\gamma + \gamma \rightarrow e^- + e^+ \quad (5)$$

at high energy [13, 15]. Let us recall that a photon is its own antiparticle. It is also possible to have a proton p antiproton \bar{p} pair production [1]:

$$\gamma + \gamma \rightarrow p + \bar{p} \quad (6)$$

and more generally, a baryon-antibaryon pair production in two-photon “collisions” at high energy [3]. We also have a neutrino ν antineutrino $\bar{\nu}$ pair production by a photon:

$$\gamma \rightarrow \nu + \bar{\nu} \quad (7)$$

in a dense matter [16]. If the photon is the most fundamental element in the universe, then it is possible to obtain all fermion-antifermion pairs starting from photons [2, 14]. Nevertheless, there are practical problems with pair production because two photons cannot really collide and light is quantized when interacting with matter. The experiments that take place in particle accelerators involve the use of matter, such as electrons, positrons and protons. They produce virtual particles which exist for a limited time and space due to the Feynman diagrams. We need pair production of real particles for the production of fermionic matter. We may wonder if some physical conditions around the Planck epoch can start pair production with photons only, avoiding the chicken or the egg causality dilemma between matter and light. It is possible to obtain pair production reactions of real

particles with photons only, by using thermodynamic processes at very high temperature [22, Chapter 4]. This implies physical conditions that no longer exist in the universe. Different temperatures correspond to different stable pair production reactions [22, p. 156]. When the temperature reaches a certain threshold, there are only photons, and no fermionic matter. This high temperature is provided by gravitational confinement around the Planck epoch.

Even if pair production reactions lead to the same quantity of matter and antimatter, the Sakharov conditions for the baryogenesis ensure that it is possible to produce matter and antimatter at different rates [20]. Then, pair production can be favored with respect to pair annihilation.

4 Photons and the fundamental interactions

The aim of this section is to define a framework such that photons and physical conditions around the Big Bang lead to the fundamental interactions.

The result is established for the electromagnetic force whose gauge boson is the photon, and the weak force whose gauge bosons are W^+ , W^- and Z^0 bosons. Indeed, if the temperature is high enough, the bosons W^+ , W^- and Z^0 become photons. This is the theory of the electroweak interaction before the electroweak symmetry breaking. Higgs bosons explain the mass of the gauge bosons W^+ , W^- and Z^0 after the electroweak symmetry breaking [8].

Concerning the strong force whose gauge bosons are the eight gluons and if the photon is the most fundamental element in the universe, then gluons become photons when the temperature reaches a threshold higher than the electroweak symmetry breaking threshold. This has been explained in [22, Chapter 7] and studied for quark-gluon plasmas [21]. For a very high temperature, quarks could behave like free particles. Then, gluons are freed from the grip of quarks and become photons.

But, what about gravitation? The General Relativity is the most fundamental theory of space and time that links the spacetime geometry with energy and momentum [9]. Gravitation is different from the other interactions because it does not really exist in a given spacetime. It is given by the Riemann curvature tensor of the spacetime. What exists? It is a background spacetime whose metric changes with energy and momentum. So, gravitation cannot emerge from photons when they are considered as particles in a given spacetime. The propagation of photons in vacuum, when they are considered as waves, provides a limit on the possibility of motion for matter and is a kind of “universal clock” for time. Indeed, the notion of time comes from the possibility of motion for matter relative to the possibility of motion for photons in vacuum which is the speed of light c [17]. Moreover, photons are also a kind of “universal rule” for measuring the cosmic distance scale

with the redshift and the luminosity. Space and time are measured relative to photons. At the Planck epoch, we suppose that there are only photons. Thus, time does not exist and all energy is provided by photons that generate themselves a gravitational confinement.

5 Photons and the wave-particle duality

Wave-particle duality is the concept that matter and light exhibit the behaviors of both waves and particles. The metaphor of the cylinder is an example of an object that shares two apparently irreconcilable properties. At first sight, it is incongruous to assert that an object has the properties of a circle and the properties of a rectangle on a map. Let us consider a cylinder. A projection on the axis of the cylinder gives a circle, and a projection perpendicular to this axis gives a rectangle (see Figure 1). We have an object having both properties, but it is neither one nor the other.

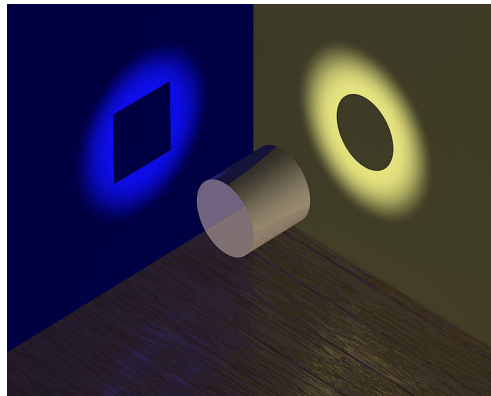


Figure 1: The metaphor of the cylinder

“Waves” and “particles” are mathematical ways of seeing things and not things in themselves. There is a difference between mathematical theories about photons and the physical reality of photons.

If the photon is the most fundamental element in the universe, then it explains the wave-particle duality of matter and it implies that the universe is both continuous and discrete at the most fundamental level. Indeed, photons are themselves both continuous, as waves, and discrete, as particles. They are an important link between the General Relativity and the Quantum Mechanics [5, 9], and this paper suggests that this link is the fundamental one. This theory provides a solution to the problem of quantum gravity, but an unexpected solution. If the photon is the

most fundamental element in the universe then the universe is both continuous and discrete at the most fundamental level, due to the wave-particle duality. Continuous physical theories could not be completely associated with discrete ones although there are links between them, exactly as geometry and algebra in Mathematics. Thus, the continuous/discrete duality of the universe may be preserved until the Big Bang into the wave-particle duality of photons.

6 Conclusion

This article raises the question of whether the photon is the most fundamental element in the universe. Many results are consistent with this assumption. This requires a change in philosophical perspective because the universe can be both discrete and continuous at the most fundamental level.

I leave the final word to Albert Einstein¹:

All the fifty years of conscious brooding have brought me no closer to the answer to the question, "What are light quanta?" Of course today every rascal thinks he knows the answer, but he is deluding himself.

¹Letter to Michele Besso, 1951

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