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ORIGINAL PAPER

Considerations about photons and antiphotons

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Abstract: Photons and antiphotons, because they are uncharged, are considered the same particle. But this criterion would lead to the same conclusion for neutrinos and antineutrinos. These elementary particles have nevertheless an opposite leptonic number. They are different elementary particles. Special relativity makes a completely symmetric description of elementary matter and antimatter, but it seems that the only exception are photons. If photons and antiphotons are the same particle, there will be no phenomenon of electromagnetic attraction. We analyze the differences between elementary particles and antiparticles under external interactions. We make the conjecture that the main form of electromagnetic radiation of matter is by the emission of photons, while for antimatter it is the emission of antiphotons. With this conjecture in mind, we make a design of a telescope for focusing antiphotons. The nearest objects to be detected will be antimatter galaxies. The complete validity of this conjecture might depend on an experimental basis but it opens a discussion about possible differences between photons and antiphotons.

Keywords: Photons; Antiphotons; Particles and antiparticles; Spinning particles; Gravitational lensing

1. Introduction

In previous works [1, 2], we have developed a classical and quantum mechanical formalism for describing elementary spinning particles, which shows, among other things, that a relativistic theory makes a completely symmetric description of spinning matter between elementary particles and antiparticles. Antiparticles arise, from the mechanical point of view, as objects of the same mass as the corresponding particle, but with negative energy and linear momentum pointing in the opposite direction to the velocity of the centre of mass. A further requirement that energy has to be a definite positive observable leads to consider that antiparticles have positive energy, the linear momentum is pointing in the direction of the centre of mass velocity and under interaction all interacting charges, electric, color, weak charges, etc., have opposite values to those of the corresponding particle. This is today's assumption.

Of all known elementary particles, their antiparticles have been identified as different objects. There is only one exception: the photon. It is usually argued that because photons are uncharged they are their own antiparticle. Photons and antiphotons are usually considered the same particle. However, this is in contradiction with the fact that neutrinos and antineutrinos, which are also uncharged, have opposite leptonic number, as far as the weak interaction is concerned. In this work, we shall see that photons and antiphotons can have opposite mechanical properties and therefore their behavior with some optical devices could be different. In particular with mirrors, so that conventional reflecting telescopes, which focus beams of photons, would not focus beams of antiphotons.

The symmetry between matter and antimatter seems to be in contradiction with the observed astronomical objects. When looking to a galaxy, we do not know if it is made of matter or antimatter and it is argued that in the universe there is an asymmetry between both forms of matter, which is contradictory with the symmetric prediction of special relativity. This is one of the unsolved problems of particle physics and cosmology. Recent measurements of the hyperfine structure of the antihydrogen atom confirm the symmetric prediction of quantum electrodynamics [3].

We are going to conjecture that our galaxy, and even our local group of galaxies, is made from matter. These local clusters of matter are separated from local clusters of antimatter. The main form of electromagnetic radiation of matter is by the emission of photons. The second conjecture is that if the main form of electromagnetic radiation of antimatter is by the emission of antiphotons and, as we will

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show, they have a different optical behavior with mirrors, we cannot detect the antimatter galaxies with our conventional reflecting telescopes.

This paper is organized as follows: In Sect. 2, we make a short description how special relativity predicts the properties of both particles and antiparticles. In Sect. 3, we see the differences between elementary particles and antiparticles from the dynamical point of view, and how two different interpretations are possible. One arrives to the usual interpretation that antiparticles have opposite charges if the energy is required to be a definite positive observable. In Sect. 4, we show that if the electromagnetic interaction between two charged particles is mediated by the interchange of a virtual photon the phenomenon of electromagnetic attraction cannot take place. Electromagnetic attraction requires the interchange of a virtual antiphoton. In Sect. 5, we describe how photons and antiphotons interact with the same external medium. When we consider the interaction with the conducting surface of a mirror, if the interacting force is opposite for antiphotons, this will lead to consider that antiphotons are not reflected by the same mirror which reflects photons. This different optical behavior with mirrors will lead us to consider the design of a telescope for focusing antiphotons. This is contained in Sect. 6. If this conjecture works, the nearest objects to be detected in the visible spectrum will be antimatter galaxies. Dark matter problems and some gravitational lensing could be related to these unseeing forms of antimatter galaxies.

2. Elementary particles and antiparticles

The standard model of particle physics states that the elementary particles of Nature are the following:

- *Fermions of spin 1/2* They are the six quarks (u, d, s, c, t and b), the three charged leptons (electron e, muon μ and tau τ) and their corresponding uncharged three neutrinos (ν_e, ν_μ and ν_τ).
- *Bosons of spin 1* They are the particles which mediate in the different interactions: gluons in the strong interaction, photons for the electromagnetic interaction and the massive $W^\pm$ and Z^0 for the weak interaction.

Of all of them, their antiparticles have been found and they are different particles. There is only one exception, the photon, which is 'usually considered the same particle.' The three antineutrinos and the anti(Z^0) although they are also uncharged are different particles because they have opposite leptonic number. It can be argued that the existence of the neutral spin 0 mesons, which are their own antiparticles, justifies that photons and antiphotons, being neutral, are also their own antiparticles. But the neutral mesons are not elementary particles because they are bound states of a quark–antiquark pair. The very existence of the neutral mesons justifies that the quarks and antiquarks have opposite electric charge and opposite baryonic number.

Special relativity establishes for a massive object a relationship between the energy H and linear momentum $\mathbf{p}$, $\mathbf{p} = H\mathbf{v}/c^2$, where $\mathbf{v}$ is the velocity of the centre of mass of the material object. In addition to this, there is an invariant property of the elementary particle, called its mass m, which satisfies the relation:

$$H^2 - p^2c^2 = m^2c^4.$$

Taking into account the relation between H and $\mathbf{p}$, we get that $H = \pm\gamma(v)mc^2$ and $\mathbf{p} = \pm\gamma(v)m\mathbf{v}$, where $\gamma(v) = (1 - v^2/c^2)^{-1/2}$. The object which has a positive energy $H = \gamma(v)mc^2 > 0$ and linear momentum along its centre of mass velocity $\mathbf{p} = \gamma(v)m\mathbf{v}$ is called matter, while the object of negative energy $H = -\gamma(v)mc^2 < 0$ and linear momentum $\mathbf{p} = -\gamma(v)m\mathbf{v}$, opposite to its centre of mass velocity, is called antimatter.

For massless objects like photons, the same thing happens, but now $H^2 - p^2c^2 = 0$ and thus $H = \pm pc$ and also $\mathbf{p} = H\mathbf{v}/c^2 = \pm p\mathbf{v}/c$, where $\mathbf{v}$ is the velocity of the photon. It implies that special relativity makes a completely symmetric description of matter and antimatter. For antiphotons, the energy is negative and its linear momentum has the opposite direction to the velocity.

3. Differences between elementary particles and antiparticles

In this section, we show that antiparticles can have two possible interpretations which both lead to the same dynamical behavior when interacting with external fields.

According to the above description, we see that the energy of the antiparticle is negative and its linear momentum points in the opposite direction to its centre of mass velocity. We shall see now that particles and antiparticles must have the same mass and the same interacting charges. The other interpretation is that both objects have the same mass, their energy is definite positive, but the interacting charges are opposite. It is the further requirement that energy must be a definite positive observable which will lead to this usual second interpretation.

The most general Lagrangian of an interacting particle is written as

$$L = L_0 + L_I,$$

where L_0 represents the free Lagrangian and L_I is the interaction Lagrangian.

The mechanical properties of the elementary particle come from the free Lagrangian L_0. These properties are the mass m, the mechanical energy H, the linear momentum $\mathbf{p}$ and the spin $\mathbf{s}$, [2]. The interacting properties, like the different charges, are contained in the interaction Lagrangian L_I.

We have seen that the relativistic formalism predicts the existence of two kinds of elementary particles of the same positive mass m, but the magnitude H can be either positive or negative. For the mechanical linear momentum $\mathbf{p}$, the two possibilities are: one in the direction of the centre of mass velocity $\mathbf{v}$ and another in the opposite direction, respectively. The first object is called particle, while it is called antiparticle in the second case. The difference is that if the free Lagrangian for the first object is L_0, the free Lagrangian for the second is $-L_0$.

The part L_I, and under an electromagnetic interaction, takes the general form,

$$L_I = -e\phi(t,\mathbf{r}) + e\mathbf{A}(t,\mathbf{r})\cdot\mathbf{v},$$

where the constant e represents the electric charge of the particle and $\mathbf{v}$ the velocity of the charge. The functions $\phi(t,\mathbf{r})$ and $\mathbf{A}(t,\mathbf{r})$ are, respectively, the external scalar and vector potentials defined at the charge position $\mathbf{r}$. For the antiparticle

$$L_I^* = -e^*\phi(t,\mathbf{r}) + e^*\mathbf{A}(t,\mathbf{r})\cdot\mathbf{v},$$

where e^* is the charge of the antiparticle and under the same external potentials.

For the particle, from $L_p = L_0 + L_I$, we get the dynamical equations

$$\frac{\mathrm{d}\mathbf{p}}{\mathrm{d}t} = \frac{\mathrm{d}}{\mathrm{d}t}(\gamma(v)m\mathbf{v}) = e(\mathbf{E} + \mathbf{v}\times\mathbf{B}), \tag{1}$$

while for the antiparticle, from $L_a = -L_0 + L_I^*$, we arrive to

$$\frac{\mathrm{d}\mathbf{p}^*}{\mathrm{d}t} = \frac{\mathrm{d}}{\mathrm{d}t}(-\gamma(v)m\mathbf{v}) = e^*(\mathbf{E} + \mathbf{v}\times\mathbf{B})$$

or

$$\frac{\mathrm{d}}{\mathrm{d}t}(\gamma(v)m\mathbf{v}) = -e^*(\mathbf{E} + \mathbf{v}\times\mathbf{B}), \tag{2}$$

where $\mathbf{E} = -\nabla\phi - \partial\mathbf{A}/\partial t$ and $\mathbf{B} = \nabla\times\mathbf{A}$. Under the same external electromagnetic field, the experience shows that the acceleration of the centre of mass of the particle is opposite to the acceleration of the antiparticle, so that the r.h.s. of (2) has to be opposite to the r.h.s. of (1) and thus $e^* = e$, and both objects have the same electric charge. This last equation for the antiparticle (2) will be rewritten as

$$\frac{\mathrm{d}}{\mathrm{d}t}(\gamma(v)m\mathbf{v}) = -e(\mathbf{E} + \mathbf{u}\times\mathbf{B}).$$

We can consider that the mechanical linear momentum is always in the direction of the velocity, which implies that the mechanical energy H should be definite positive, and the two kinds of particles, of the same positive mass, will be different by the different sign of their charges, and they will be described by the Lagrangians

$$L_p = L_0 - e\phi(t,\mathbf{r}) + e\mathbf{A}(t,\mathbf{r})\cdot\mathbf{v},$$

for the particle and

$$L_a = L_0 + e\phi(t,\mathbf{r}) - e\mathbf{A}(t,\mathbf{r})\cdot\mathbf{v},$$

for the antiparticle, respectively. This corresponds simply to a change of e by $-e$, and where the free common part L_0 is that free Lagrangian which leads to a positive $H > 0$ and $\mathbf{p} = H\mathbf{v}/c^2$.

Because the dynamical equations derived from L_a and from $-L_a$ are exactly the same, we can have two possible equivalent interpretations of the concept of antiparticle. One is that both elementary objects have the same mass and charge but their mechanical properties H and $\mathbf{p}$ are opposite. The usual interpretation is that they have opposite charges, which brings us to adopt that the sign of the energy must necessarily be positive and that the linear momentum has the direction of the velocity of the centre of mass.

The requirement of the positive definiteness of the energy could be related to the arrow of time. As far as time translations are concerned, from the active point of view, only translations to the future are allowed, so that the energy, considered as the generator of time translations, can only have a single sign. The other generators of the other transformations of the Poincaré group can have both signs, because from the active point of view transformations and their inverses are allowed. This means that from the group theory point of view we have not a complete time translation group, but rather a semigroup. In Quantum Field Theory, the requirement of positive definiteness of energy is necessary for the achievement of the Spin–Statistics theorem [4]. What we are going to consider from now on is that particles and antiparticles are positive energy objects.

The above analysis for the electromagnetic interaction can be extended to any other interaction, and therefore, all quantum numbers of the antiparticle, included in the interaction Lagrangian L_I, have to take the opposite signs when compared to those of the particle, and under the assumption of positive definiteness of the energy.

In the case of photons, because they do not have electric charge we can think that they are their own antiparticle. This is the usual interpretation. But the same conclusion will be reached for neutrinos, because they are uncharged and they could be their own antiparticles. However, the antineutrinos interact weakly and have opposite leptonic number and are, therefore, different than the neutrinos. They have a no vanishing $L_I \neq 0$, which depends on the interacting properties. The conservation of the leptonic number requires they have opposite values of this quantum number.

Photons interact with matter, crystalline media and mirrors, and transfer energy, linear momentum and angular momentum, although we do not know how is the detailed structure of this local interaction, when the photons are considered as particles. Therefore, for photons, necessarily $L_I \neq 0$, and thus for antiphotons the interaction Lagrangian is $-L_I \neq 0$.

3.1. The Lagrangian of the photon

In [1] and [5], we have found the relativistic description of classical spinning photons and antiphotons. They are particles of six degrees of freedom, three $\mathbf{r}$, represent the location of the particle which moves with velocity $\mathbf{v}$, and $v = c$, and the other three $\boldsymbol{\alpha}$, its orientation in space, described as an orthonormal set of unit vectors which rotate with angular velocity $\boldsymbol{\omega}$. The relativistic Lagrangian of a free photon is given by

$$L_0 = \frac{\epsilon\hbar}{c}\,\mathbf{v}\cdot\boldsymbol{\omega}, \tag{3}$$

where $\epsilon = \pm 1$ is the helicity. The conjugate momentum of the orientation variables is the spin $\mathbf{s} = \partial L_0/\partial\boldsymbol{\omega} = \epsilon\hbar\,\mathbf{v}/c$. The value of the spin $\hbar$, is Poincaré invariant and is not transversal. It takes only the values $\pm\hbar$ and points forward or backward with the direction of the motion. The conjugate momentum of the position is the linear momentum $\mathbf{p} = \partial L_0/\partial\mathbf{v} = \epsilon\hbar\boldsymbol{\omega}/c$. Since L_0 does not depend explicitly on $\mathbf{r}$ and $\boldsymbol{\alpha}$, both momenta $\mathbf{p}$ and $\mathbf{s}$ are constants of the motion for the free particle. The free photon (and antiphoton) moves at a constant velocity $\mathbf{v}$ and with constant angular velocity $\boldsymbol{\omega}$. The Hamiltonian is

$$H = \mathbf{p}\cdot\mathbf{v} + \mathbf{s}\cdot\boldsymbol{\omega} - L_0 = \mathbf{s}\cdot\boldsymbol{\omega} = \mathbf{p}\cdot\mathbf{v}. \tag{4}$$

and because $\mathbf{p} = H\mathbf{v}/c^2$, the velocity and angular velocity are parallel or antiparallel vectors. Since $H^2 - p^2c^2 = 0$, the photon and antiphoton are massless particles. All four vectors $\mathbf{s}$, $\mathbf{p}$, $\mathbf{v}$ and $\boldsymbol{\omega}$ are collinear. The energy of a free photon and antiphoton is $H = \pm\hbar\omega = \pm h\nu$, positive for photons and negative for antiphotons, being ν the frequency of its rotational motion. Spinning photons rotate along the direction of motion. From Eq. (4), we see that the spin and angular velocity are parallel vectors for photons, while they are antiparallel for antiphotons. Similarly, for photons, the linear momentum and velocity are parallel vectors, while they are antiparallel for antiphotons. The Lagrangian for a free antiphoton is $-L_0$.

The important feature of this discussion is that, special relativity makes a prediction of the existence of both spinning photons and antiphotons, which are described as different objects.

4. Attraction and repulsion

Today we know that in electrodynamics and chromodynamics, the interaction mechanism between elementary particles (fermions of spin 1/2) is the interchange of virtual bosons of spin 1 (photons, gluons, massive bosons $W^{\pm}$, Z^0). In the electromagnetic case, if the interchange is mediated exclusively by photons, the phenomenon of attraction will not take place. Let us assume, as is depicted in Fig. 1, that a negative electron and a positive positron, both of positive mechanical energy H and linear momentum in the direction of the velocity of its centre of mass interact by the interchange of a virtual photon, which is emitted by the electron in 1 and being absorbed by the positron in 2. Due to the interchange of linear momentum and energy, the electron gets a linear momentum $\mathbf{p}'_1 = \mathbf{p}_1 - \mathbf{k}$, while the positron ends with a linear momentum $\mathbf{p}'_2 = \mathbf{p}_2 + \mathbf{k}$, and if analyzed from the centre of mass of one of the particles, the two particles repel each other. This process will be the same if the virtual photon is emitted by the positron.

Because we know experimentally that particles of opposite electric charge attract to each other, the mechanism should be that of Fig. 2, with the interchange of a virtual antiphoton, emitted from 1 by the electron, with linear momentum $\mathbf{k}$, in the opposite direction to its

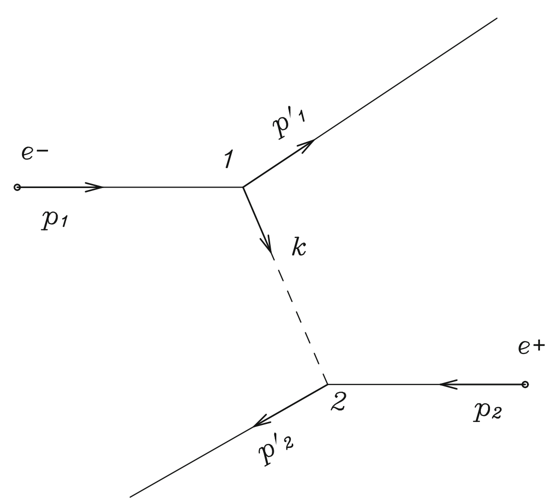

Fig. 1 Interaction of an electron and a positron by the interchange of a virtual photon. Both particles separate from each other

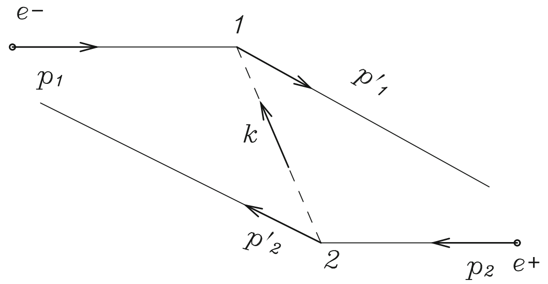

Fig. 2 Interaction of an electron and a positron by the interchange of a virtual antiphoton. Both particles attract to each other

velocity, being absorbed at 2 by the positron. Now we get again $\mathbf{p}'_1 = \mathbf{p}_1 - \mathbf{k}$, and the result is that the electron and the positron approach to each other. The same interpretation will be obtained if the emission of the virtual antiphoton is produced by the positron. There exists electromagnetic attraction and repulsion. Electromagnetic attraction must be carried out by means of antiphotons and therefore they are necessarily different particles than photons.

5. Photon and antiphoton interactions

Photons can be described as particles carrying energy, linear momentum and spin and a beam of photons can be interpreted as an electromagnetic wave, carrying energy, linear momentum and angular momentum. We are going to analyze the behavior of photons (an antiphotons) in two different media. One is the motion of photons in a transparent homogeneous and no conducting medium and the other is the interaction with a conducting medium like a mirror. In the first case, we shall consider that a beam of monochromatic photons can be described as an electromagnetic polarized plane wave while in the second case they will be considered as particles.

5.1. Electromagnetic wave analysis

Let us consider a monochromatic beam of photons, circularly polarized. From the electromagnetic point of view, this is represented by the plane wave of Fig. 3, travelling along the direction of the beam. In the plane wave, we have the electric $\mathbf{E}$ and magnetic $\mathbf{B}$ fields as depicted in the figure, rotating leftwards or rightwards according to the beam polarization. All photons of the beam have their spins in the same direction, pointing forward or backward. Poynting vector $\mathbf{S} \simeq \mathbf{E} \times \mathbf{B}$ is along OZ axis and thus the linear momentum density of the electromagnetic wave is pointing forward.

If what we have is a monochromatic beam of antiphotons, circularly polarized, traveling along OZ axis, the

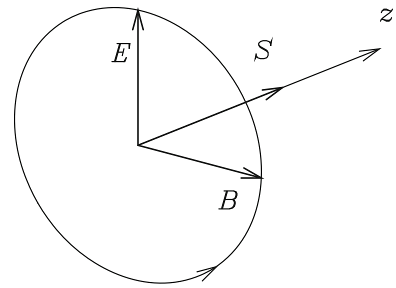

Fig. 3 Electric and magnetic fields of the electromagnetic plane wave corresponding to a beam of circularly polarized monochromatic photons. Poynting vector $\mathbf{S}$ is along the direction of the motion of the wave

corresponding electromagnetic wave will be that of Fig. 4 where the relative orientation of the fields is opposite. Now Poynting vector $\mathbf{S} \simeq \mathbf{E} \times \mathbf{B}$ is oriented in the opposite direction to the motion of the beam, as it corresponds to a wave where the linear momentum density is in the opposite direction to the velocity of the beam of antiphotons.

In a transparent, homogeneous and no conducting medium of permittivity ϵ and permeability μ, both waves satisfy Maxwell's equations. If the wave goes from one medium to another of different values of ϵ and μ with a smooth separation surface between them, Fresnel's formulae lead to Snell's and reflection laws for both waves, as can be shown by applying the usual method of electromagnetic optics, like the one in the well-known reference [6].

This means that photons and antiphotons, from the electromagnetic point of view, behave in the same way in no conducting transparent media, so that a refracting telescope behaves in the same way for photons and antiphotons. But, what about in conducting media like reflecting telescopes?

5.2. Particle analysis: reflection and refraction of photons and antiphotons

We know that mirrors reflect photons. Let us consider an aluminum foil of 140 nm of thickness. It reflects photons in

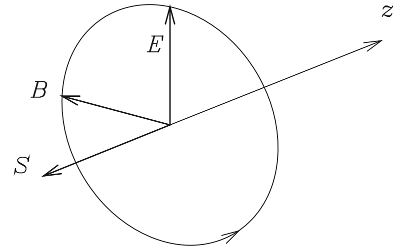

Fig. 4 Electromagnetic plane wave corresponding to a beam of circularly polarized monochromatic antiphotons. Poynting vector $\mathbf{S}$ is along the opposite direction to the motion of the wave

a wide range of wavelengths. This is the typical average thickness of the reflecting surface of the principal mirror of a professional telescope, once has been aluminized. The law of reflection for beams of photons implies that, when a photon interacts with the conducting media, it gets a linear momentum transfer of $\Delta p = -2p_\perp$, twice the perpendicular component of its linear momentum and reflects with the reflection angle of the same value as the incidence angle (see Fig. 5). Its final linear momentum is $\mathbf{p}' = \mathbf{p} + \Delta\mathbf{p}$. From the particle point of view that process could be described by the Lagrangian $L = L_0 + L_I$, where L_0 is the free Lagrangian of the photon (3) and in L_I is contained the local action of the thin conducting surface on the photon which produces the momentum transfer $\Delta\mathbf{p}$. We do not know how is the exact form of L_I, but because the photon interacts with the thin conducting surface, is clear that $L_I \neq 0$.

From the above analysis, if what we have is a beam of antiphotons, and under the requirement that the energy is a positive definite observable, the Lagrangian which describes that process is $L_a = L_0 - L_I$, so that when analyzing the interaction with the conducting surface the linear momentum transfer will be the opposite to the case of the photon.

Let us consider that a positive energy antiphoton approaches that surface with the same angle of incidence (see Fig. 6) and the same linear momentum $\mathbf{p}$. The interaction produces the transfer of a linear momentum $-\Delta\mathbf{p}$, and the final momentum is $\mathbf{p}' = \mathbf{p} - \Delta\mathbf{p}$, forms a different angle with the normal direction than the incidence angle and the antiphoton crosses the conducting foil with an angle of refraction α', different than the incidence angle. A mirror which reflects photons does not reflect antiphotons.

We know experimentally that photons at mirrors are reflected in this way. Can we consider that antiphotons behave in the same way? In the case of photons and antiphotons, they interact with matter, and thus $L_I \neq 0$, and therefore, they will experience the opposite force when interacting with mirrors.

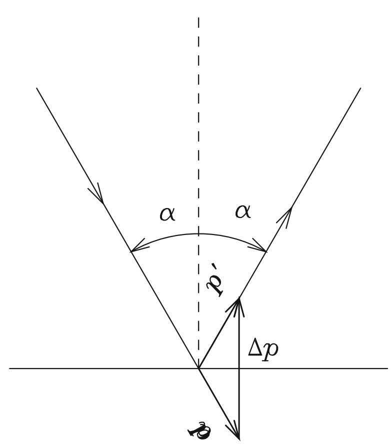

Fig. 5 Modification of the trajectory of a photon with the transfer from the conducting surface of a linear momentum $\Delta\mathbf{p} = -2p_\perp$

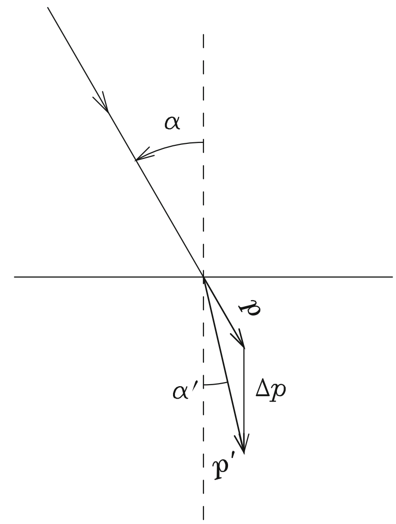

Fig. 6 Modification of the trajectory of an antiphoton, considered as a positive energy particle, with the transfer of opposite linear momentum $-\Delta p = 2p_\perp$, when interacting with the same thin conducting surface. It is not reflected but it rather crosses the surface with a different angle than the incidence angle

Let α be the incidence angle for the antiphoton, and thus, they satisfy

$$\cos\alpha = \frac{p_\perp}{p}, \quad \tan\alpha' = \frac{p\sin\alpha}{3p_\perp}, \quad \tan\alpha' = \frac{1}{3}\tan\alpha. \tag{5}$$

5.3. Spherical mirrors

In Fig. 7, we see the ray of a photon which is reflected by a spherical mirror of radius R and crosses the optical axis at point F, at a distance x from the centre O. Clearly

$$2x\cos\alpha = R, \quad x = \frac{R}{2\cos\alpha} = \frac{R}{2}\left(1 + \frac{\alpha^2}{2} + \frac{5\alpha^4}{24} + \cdots\right)$$

If the rays are parallel to the optical axis and the angle α is small, the focus of the spherical mirror is at a distance $x \approx R/2$ of the centre of the sphere.

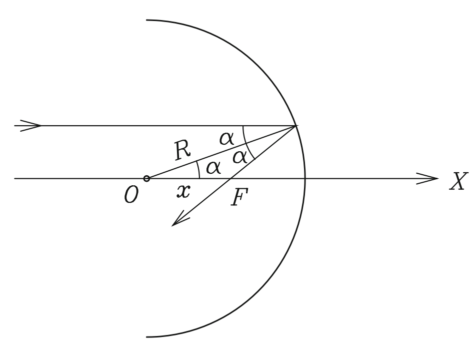

Fig. 7 A photon impinges on a concave spherical mirror and is reflected passing through the point F at a distance x from the centre O

Similarly, an antiphoton impinges on a convex spherical mirror at the point A, with an incidence angle α with the normal to the surface, and is refracted through an angle α' with the normal, passing through the point F of the optical axis (see Fig. 8).

If we call

$$AF = l, \quad OF = a, \quad \alpha' + \beta + (\pi - \alpha) = \pi, \quad \Rightarrow \quad \beta = \alpha - \alpha',$$

it implies that

$$a = l\cos\beta - R\cos\alpha, \quad R\sin\alpha = l\sin\beta,$$

and thus

$$a = R\left(\frac{\sin\alpha\cos(\alpha-\alpha')}{\sin(\alpha-\alpha')} - \cos\alpha\right),$$

and after the expansion of $\cos(\alpha-\alpha')$ and $\sin(\alpha-\alpha')$ in terms of single arguments, we arrive to

$$a = R\left(\sin\alpha\left(\frac{1+\tan\alpha\tan\alpha'}{\tan\alpha - \tan\alpha'}\right) - \cos\alpha\right).$$

Since the law of refraction (5) for antiphotons is $\tan\alpha' = \frac{1}{3}\tan\alpha$, we get

$$a = R\left(\sin\alpha\left(\frac{3+\tan^2\alpha}{2\tan\alpha}\right) - \cos\alpha\right) = \frac{R}{2\cos\alpha}$$
$$= \frac{R}{2}\left(1 + \frac{\alpha^2}{2} + \frac{5\alpha^4}{24} + \cdots\right).$$

If the angle α is small, the focus for antiphotons is at a distance $x = a + R \approx 3R/2$ from the mirror vertex. A convex spherical mirror will concentrate at that focal point antiphotons coming from a distant source.

6. A telescope for antiphotons

If, according to the analysis of Sect. 5.3, a convex aluminized spherical mirror of radius R reflects photons and allows antiphotons to cross the layer according to the refraction law (5) $\tan\alpha = 3\tan\alpha'$, the focal point is approximately at a distance $3R/2$ of the vertex of the mirror. However, this is not an accurate focal point for antiphotons of a greater incidence angle.

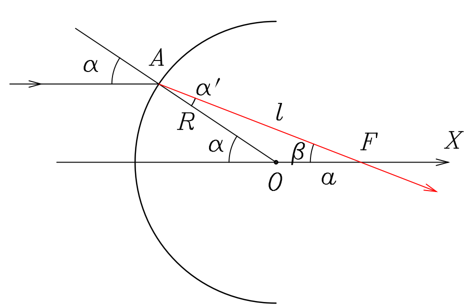

Fig. 8 An antiphoton impinges on a convex spherical mirror and is refracted passing through the point F of the optical axis OX

We are going to determine the shape of the mirror such that a beam of antiphotons parallel to the optical axis would focus at a single point F, the focus of the mirror.

In Fig. 9, an antiphoton ray parallel to the optical axis OY of the mirror reaches a point P, under un angle of incidence α with the normal to the surface. It diffracts with an angle α' passing through the focus located at the point F.

Let $y(x)$ be the shape of the mirror. In the figure, we have

$$\tan\alpha = -y'(x), \quad \tan\alpha' = -\frac{1}{3}y'(x)$$

The straight line PF has the slope of angle γ such that

$$\tan\gamma = \cot(\alpha-\alpha') = \frac{1+\tan\alpha\tan\alpha'}{\tan\alpha-\tan\alpha'} = \frac{3+\tan^2\alpha}{2\tan\alpha} = \frac{3+y'^2}{-2y'}.$$

If $Y(X)$ is the straight line coming from point P of coordinates (x, y), of slope γ, the equation is

$$Y - y = \tan\gamma(X - x).$$

The focus is the point $Y(0)$, which corresponds to $Y(0) = y - x\tan\gamma$. This point has to be independent of the coordinate x of the incidence point P of the vertical ray, and therefore equating to zero the derivative with respect to x of this expression, we get the differential equation satisfied by the form of the mirror.

$$(2y + 2xy')y'' + 3y'^2 + 3 = 0.$$

The highest-order derivative is

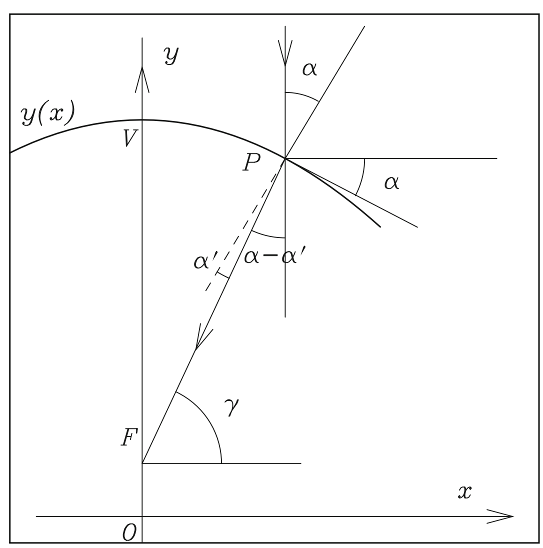

Fig. 9 A vertical ray arrives at the point P of the mirror, under an angle α with the normal and is diffracted through an angle α', passing through the focus located at the point F

$$y'' = -\frac{3}{2}\left(\frac{1+y'^2}{y+xy'}\right), \quad y(0) = 3/2, \quad y'(0) = 0,$$

and the particular solution with the above boundary values will give us the form of the mirror with a focus at the origin O. With these boundary conditions, the curvature of the mirror at the vertex V is

$$\kappa(x) = \frac{y''}{(1+y'^2)^{3/2}}, \quad \kappa(0) = -1.$$

This is consistent with the fact that the osculatory circle at V has a radius of curvature 1, and according to the previous analysis on spherical mirrors, the focus will be at a distance 3/2 from the vertex V.

No analytical solution has been found and the numerical integration of the above differential equation is depicted in red in Fig. 10. We have also depicted the osculatory circle (blue) at the vertex V of radius 1.

The two straight lines parallel to the OY axis represent the lateral edges of the telescope tube of 1.5 m of total length with a mirror of 40 cm of diameter and 1 m of curvature radius.

When we perform the numerical integration in Cartesian coordinates, y'' is singular when $y + xy' = 0$, which in the figure corresponds to the point of coordinates (0.6801,1.2017) and slope $y' = -1.767$, and the numerical integration stops.

A close view of the mirror (Fig. 11) shows no appreciable difference between the calculated shape of the mirror and a spherical mirror of 1 m of curvature radius, for a telescope of these dimensions.

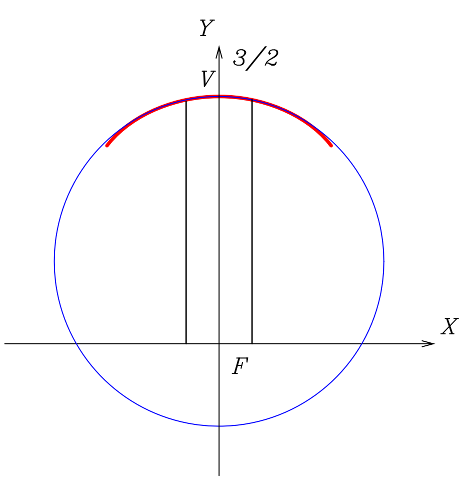

Fig. 10 Shape of the mirror (red) which concentrates antiphotons at the origin coming from above parallel to the OY axis. The outer blue circle corresponds to the osculatory circle at the vertex V

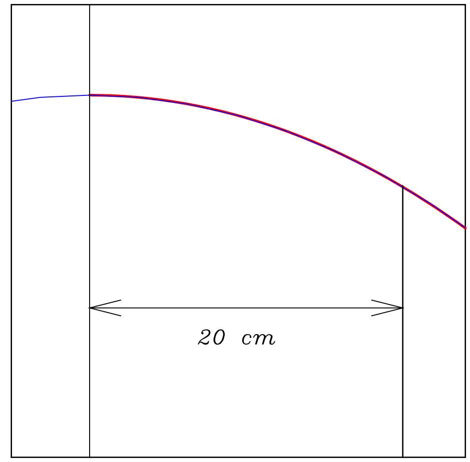

Fig. 11 Close view of the mirror, where the two lines are the shape of the mirror (red) and the osculatory circle at the vertex of radius 1 m (blue). For a telescope of 1.5 m of length and a mirror of 40 cm of diameter and 1 m of curvature radius, we cannot see any difference, and with these dimensions a spherical mirror will probably do the job

7. Conclusions

Special relativity predicts that photons and antiphotons are different particles. The existence of the electromagnetic attraction and repulsion means that both phenomena cannot be mediated by the same particle. Attraction requires interchange of antiphotons while repulsion represents the interchange of photons. The electromagnetic analysis of Sect. 5.1 of photonic and antiphotonic waves shows that they behave in the same way in no conducting transparent media. The particle analysis of Sect. 5.2 strengths that they have a different behavior when interacting with conducting media like mirrors. But this has to be verified experimentally.

We do not know if dark matter is formed by clusters of galaxies of antimatter. Our conjecture is that if antimatter galaxies exist and radiate antiphotons, and these have a different behavior than photons when interacting with mirrors they cannot be seen with the usual reflecting telescopes.

The symmetry between matter and antimatter suggests that if antimatter galaxies emit antiphotons the emission spectrum will be similar to the photonic spectrum of matter galaxies. If all photons and antiphotons are positive energy particles, they will transfer positive energy to the detectors. One possibility is to compare pictures of distant galaxies taken with refracting and reflecting telescopes. An antimatter galaxy will appear in the refracting telescope image but not in the reflecting one.

What has been clear is that with the proposed telescope no photons will be detected, and therefore, only antiphotons will arrive to the detector located at the focus. What is being left is to check if this conjecture is right or wrong. This is a challenge for experimentalists and astronomers.

If unseen antimatter galaxies are responsible for some gravitational lensing effects, one possibility is pointing this telescope to those areas of high-intensity lensing. The binary quasar or massive dark lens Q2345+007 [7] could be one of these goals. The expectation is that if antimatter galaxies are responsible for these gravitational effects, they will be detected in the visible spectrum in those regions. If, luckily, antimatter galaxies are detected as gravitational lenses, the next job is to explore everywhere in the universe to obtain the antimatter distribution.

If this conjecture works, similarly as a beam of accelerated electrons radiate photons, a beam of accelerated positrons should be a source of antiphotons. Although the Sun is made from matter, the inner interactions also produce antiparticles, mainly positrons, and a faint antiphotonic radiation from these antiparticles could be expected. We do not know how is the spectrum of this radiation. If it is in the range of the visible spectrum, pointing this telescope to the Sun will elucidate this conjecture.

Another consideration for future research is that if photons and antiphotons are different particles there should exist some device, involving conducting media, which will be able to distinguish them. This proposed telescope could be one of these devices.

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