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DE BROGILE WAVES AND PSEUDOTACHYONIC RELATIVITY

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Abstract

Despite their author, de Broglie waves for ordinary (bradyonic) particles are often considered without physical signification, mainly because they are tachyonic. I revisit some of de Broglie's original ideas and discuss the standard approach to the problem, the "wave packet" overlapped to a de Broglie wave.

Using Pseudotachyonic Theory, it's easy to conclude that this tachyonic wave actually exists but may only be detected with the same velocity of its associated particle. Furthermore, in what comes to "dualities", it appears that wave and particle are not two aspects of the same thing but instead two different though intimately correlated entities. These reflections concern the physical nature of de Broglie waves, including particles "internal vibration", and lead to the premises of a new general Field Theory. Including positive as well as negative

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energies, at a fundamental level, this Field Theory will probably allow to unify the theoretical study of all known forces, mainly gravitational and electrostatic interactions.

For now, with respect to gravity, a fundamental triple conclusion is established:

- Two particles attract each other;
- Two antiparticles also attract each other;
- A particle and an antiparticle repel each other.

1 Introduction

In two former articles [1][2], I proposed the model of *pseudotachyonic transformations* derived from an extension of Lorentz transformations to $|v| > c$ and, then, a new conception of an antiparticle as the detection of an homologous tachyonic particle. According to this model, we may never directly detect a tachyonic particle but only its "image", which is an antiparticle. This point of view brought some different ideas about antiparticles, mainly their negative energy and, if massive, their negative mass.

In general – keeping in mind that movement is relative –, anything that moves with tachyonic velocity v may only be detected (and interact) with *associated velocity* $\hat{v}$:

$$\hat{v} = \frac{c^2}{v}.$$

As we'll see, this new approach to old-standing problems naturally concerns de Broglie waves. In this paper, we'll attack the following questions:

1. *Why* do these waves exist?
2. What is their *physical nature*?
3. Do the so-called *wave/particle duality* consist on two manifestations of the same thing or on the manifestation of two connected but different things?
4. How does a (tachyonic) particle physically relate to its (bradyonic) associated antiparticle?

The answer to these questions may reveal crucial facts in the structure of Nature and unsuspected connections between them. Even though the first question isn't often raised, it isn't misplaced because there is always a reason, at least, for things to exist (in fact, I believe that Nature is wiser and the reasons are multiple and connected). We have, since long, learned about de Broglie's symmetry reasoning for the existence of a wave related to a moving particle, dualities and complementary realities, Compton effect, etc., but there's something missing, and this is the fundamental *why*. We must not obliterate this question, even if our theory seems to work well and we feel that we don't really have to bother with it. We may indeed learn a lot from the answer or in the process of finding this answer.

We'll come again to the second question, fundamental in the twenties of the 20th century but put away in a locker since Max Born's probabilistic concept imposed itself as the standard answer to it. Far from presenting solely an "historical interest", this question remains in fact a fundamental one.

Related to it, the answer to the third question seems not to be the first statement (the standard approach in Quantum Mechanics) but instead the last one. Moreover, we'll discover that the link between associated particles appears to be exactly de Broglie waves.

We'll begin discussing the interpretation of de Broglie waves. Afterwards we'll quantitatively study some of these waves proprieties (characteristics and behaviour), mainly concerning the fourth question above. Finally, we'll take a look at the proposed premises for a new general Field Theory, based in pseudotachyonic theory and de Broglie's "internal vibration".

2 De Broglie waves

In a famous 1924 paper [3], Louis de Broglie applied to massive particles the same dualistic wave/particle behaviour established for the light:

> *"Let us consider a moving body whose "mass at rest" is m_0; it moves with regard to a given observer with velocity $v = \beta c$ $(\beta < 1)$. In consequence of the principle of energy inertia, it must contain an internal energy equal to $m_0 c^2$. Moreover, the quantum relation suggests the ascription of this internal energy to a periodical phenomenon whose frequency is $\nu_0 = \frac{1}{h} m_0 c^2$. For the fixed observer, the whole energy is $\frac{m_0 c^2}{\sqrt{1-\beta^2}}$ and the corresponding frequency is $\nu = \frac{1}{h} \cdot \frac{m_0 c^2}{\sqrt{1-\beta^2}}$. (...) Let us suppose that, at time 0, the moving body coincides in space with a wave whose frequency ν has the value given above and which spreads with velocity $\frac{c}{\beta} = \frac{c^2}{v}$. This wave, however, cannot carry energy, according to Einstein's ideas."*

In section III of his article, he enounces this hypothesis as well as "an important Theorem on the Motion of Bodies":

> *"If, at the beginning, the internal phenomenon of the moving body is in phase with the wave, this harmony of phase will always persist."*

And from this theorem he sets the conclusion that:

> *"We are then inclined to admit that any moving body may be accompanied by a wave and that it is impossible to disjoin motion of body and propagation of wave."*

According to this extraordinary idea, we may apply to massive particles the same fundamental quantum equations established for the light, implicit in their dualistic behaviour. De Broglie himself wrote many years later [5]:

> *"I had no doubt whatsoever about the physical reality of waves and particles. (...) I then noticed that the 4-vector defined by the phase gradient of the plane monochromatic wave could be linked to the energy-momentum 4-vector of a particle by introducing h, in accordance with Planck's ideas, and by writing:"*

$$E = h.\nu \quad \text{and} \quad p = h.k = h/\lambda;$$

so, to a free particle moving with constant velocity v (supposing $|v| < c$) must correspond a monochromatic plane wave which propagates in space, in the same direction of the particle's motion (say, along the xx axis), and which phase is $\varphi = kx - \nu t$:

$$\psi(x,t) = Ae^{2\pi i(kx-\nu t)} = Ae^{i/\hbar(px-Et)}.$$

Generally, de Broglie proposed that, in the proper frame of the particle, the frequency ν_0 should correspond to a "periodic vibration" or a "periodic process" mathematically translated by the harmonic function [7]

$$\psi(0,t_0) = A.\exp(-2\pi i\,\nu_0 t_0) = A.\exp(-i/\hbar\,E_0 t_0).$$

From this point of view, the wave is a relativistic effect of such a "rest periodic process", obeying to Lorentz transformation.

This is well known. It is also well known, although often underestimated, that this de Broglie wave (as he himself stated in his 1924 cited paper) propagates with a phase velocity u_φ given precisely by

$$u_\varphi = \frac{\nu}{k} = \frac{mc^2}{mv} = \hat{v}; \tag{1}$$

this is the *associated velocity* of v – a *tachyonic velocity*, then!

In fact, this was the major problem encountered by de Broglie [7].

Allow me to make a resume of some fundamental steps in the theoretical foundations of standard Quantum Theory and some of de Broglie's quite original ideas that conduced him to the "Double Solution Theory". From the begining, as we read above, besides dealing with uncomfortable tachyonic velocities (supposed "forbidden" by Relativity), de Broglie asked himself: How can a faster than light wave transport energy associated to a material particle if this one moves with a velocity necessarily lower then c? He surrounded the problem admitting that instead of associating a moving particle to a single 'pilot-wave', as his original idea suggests, we can express this idea "in another way" [3]:

> *"A group of waves whose frequencies are very nearly equal has a "group velocity" U, which has been studied by the late Lord Rayleigh, and which in the usual theory is the velocity of "energy propagation"."*

In another article [4], the author explains that the *primary wave*, we may call it so, *" represents a special distribution of* phase*, that is to say, it is a* "phase wave"*"* and shows, by means of a mechanical relativistic comparison, *"why a phase wave transports 'phase', but not energy."* And then he states:

> *"The preceding results seem to us to be very important, because with aid of the quantum hypothesis itself, they establish a link between motion of a material body and propagation of a wave, and thereby permit envisioning the possibility of a synthesis of these antagonist theories on the nature of radiation. So, we note that a rectilinear phase*

> *wave is congruent with rectilinear motion of the body; and FERMAT's principle applied to the wave specifies a ray, whereas MAUPERTUIS' principle applied to the material body specifies a rectilinear trajectory, which is in fact a ray for the wave."* Later on, in chapter 2, the author *"generalise this coincidence".*

After this statement, resorting again to a wave group, he clarifies: *"If waves of nearby frequencies propagate in the same direction* Ox *with velocity V, which we call a phase velocity, these waves exhibit, by cause of superposition, a beat if the velocity V varies with the frequency ν. This phenomenon was studied especially be Lord Rayleigh for the case of dispersive media."* He then shows, using *"two waves of nearby frequencies ν and $\nu+\delta\nu$ and velocities V and $V+(dV/d\nu)\,\delta\nu$"*, that the velocity of propagation of the beat, or group velocity, is *"actually equal to the body's velocity. This leads us to remark: in the wave theory of dispersion, except for absorption zones, velocity of energy transport equals group velocity."*

In modern terms, this group of waves the particle is associated with is known as a 'wave packet': a group of monochromatic waves, which frequency slightly differ from the frequency of the former wave and which dispersion relation, directly obtained from $E = c\sqrt{p^2 + m^2c^2}$, is

$$\nu = c\sqrt{k^2 + \left(\frac{mc}{h}\right)^2}.$$

This wave packet is formed by an infinite number of waves which wave number k continually varies in the interval $(0, \infty)$; in this terms, the wave function appears as a Fourier series

$$\psi\,(x,t) = \int_0^\infty a(k)\, e^{2\pi i[kx-\nu(k)t]}\, dk,$$

considering ν as a function of the wave number k. If we choose a value for the amplitude, for instance its maximum, then this value progress with a velocity called *group velocity*, given by [6]

$$u_g = \frac{d\nu}{dk} \quad \text{or} \quad u_g = \frac{d\nu}{d\beta}\Big/\frac{dk}{d\beta} = \left(\frac{m_0 c}{h}\cdot\frac{c\beta}{\sqrt{1-\beta^2}}\right)\Big/\left(\frac{m_0 c}{h}\cdot\frac{1}{\sqrt{1-\beta^2}}\right) = v.$$

It must have been a great happiness for de Broglie to find that $u_g = v$, which he proudly announces [3]: *"The velocity of the moving body is the energy velocity of a group of waves having frequencies* $\nu = \frac{1}{h} \cdot \frac{m_0 c^2}{\sqrt{1-\beta^2}}$ *and velocities* c/β *corresponding to very slightly different values of* β*."*. Furthermore, since each ν is a function of k, the generic expression for u_g implies the *dispersion* of the wave packet. Because of this, de Broglie's 'wave packet' interpretation leads to an uncertainty Δx in the localisation of the particle associated to the dispersion Δk – this means, to an uncertainty of the momentum Δp – formally established by Heinsenberg's uncertainty relation [8]: $\overline{(\Delta x)^2}.\overline{(\Delta p_x)^2} \geq \hbar^2/4$.

As it is known, this approach to the problem is in the basis of Schrödinger successful wave function.

But then, how can a dispersive wave packet drive the movement of the associated particle, which clearly do not disperse in space? This is a big problem, condemning the early attempts of de Broglie and Schrödinger – according to Max Born [6] –, to interpret elementary particles, like electrons, as wave packets. Born also comments that to describe the interaction of two electrons in terms of the collision of two wave packets brings serious difficulties.

Dmitri Blokhintsev [8], on his turn, demonstrates that the classical concept of *trajectory* for a particle movement – or for a statistical ensemble – fails in the quantum world. This classical concept implies that we can define well determined coordinate x and linear momentum p_x, related by

$$x + dx = x + \frac{p_x}{m} dt.$$

Now, the diffraction experiences with elementary particles confirm de Broglie's equation, relating momentum and wave length

$$p = \frac{h}{\lambda}.$$

> *"If λ is really a wave length, this quantity wouldn't be a function of coordinates whatever the nature of the wave is. A statement like "at point x the wave length is equal to λ" doesn't have any sense, because wave length is, by definition, the characteristic of a sinusoidal wave which extends to infinity in space (from $x = -\infty$ to $x = +\infty$).*

> *One may say that λ is a "function" of the wave form but never that it is a function of the coordinates of a point. The second member cannot be a function of an x coordinate. Therefore, the first member of the equation above, the momentum p, also cannot be a function of the x coordinate."*

That's why, Blokhintsev argues, the correlation between position and linear momentum is quite different and peculiar in quantum ensembles:

> *"In the micro-cosmos domain the statement "at point x the momentum is equal to p" doesn't have any sense. As a consequence there aren't in the micro-cosmos particle ensembles which momenta and coordinates have simultaneously well determined values."*

Remark that he draws this conclusion from the 'underlying' *de Broglie wave;* but then he demonstrates it and deduces Heinsenberg's relation using the *wave packet.* But, given his quite logical reasoning basis, it seems also logic to expect a deduction of Heinsenberg's uncertainty from de Broglie wave itself.

On the other hand, Caruso and Oguri write [7], page 446:

> *"The presence of the imaginary unit in Schrödinger's equation implies that the value of the wave ψ is complex (...), never real or purely imaginary, causing serious difficulties in the interpretation of this equation. In this sense, the de Broglie's pilot-wave cannot be directly associated to any dynamical variable or characteristic property of a particle. Besides, the generalisation of Schrödinger's equation to multi-electronic atoms, with N electrons, presuppose a wave function which spatial dependence involves 3N spatial coordinates for the electrons, and this constitutes another argument contrary to the reality of the pilot-wave."*

The same authors also signalise [7], page 138, that the wave representation as a complex exponential function $\psi(x,t) = Ae^{2\pi i(kx-\nu t)}$ is, in Classical Physics,nothing but a convenient procedure, used for the simplicity of calculus, *"reminding that, at the end of the calculus* *of a quantity whatever, we must take the real part of the result. This arbitrariness in the choice which, at the first sight, may seem obvious and general doesn't apply, for instance, in Wave Quantum Mechanics."* But, since de Broglie chose to use this complex representation, it's not surprising that the wave function ψ assumes complex quantities, and this for a *real wave*, with *real characteristics* associated to a *real particle.* The problem seems to lie essentially in this physical interpretation of a mathematical representation.

Finally, bearing in mind all these arguments, the physical nature of de Broglie's wave packet or, properly speaking, of Schrödinger's wave function resumed to Born's interpretation of the wave 'intensity' $|\psi|^2 = \psi^*\psi$ as a probability density, necessarily subordinated to the normalisation condition for $|\psi|^2$:

$$\int_V \psi^*(\mathbf{r}, t)\, \psi(\mathbf{r}, t)\; dv = 1,$$

$\psi^*(\mathbf{r}, t)$ being the complex conjugate of $\psi(\mathbf{r}, t)$.

A tenacious critic of this point of view, besides David Bohm, is J.R. Croca, who, following de Broglie's ideas, developped the application of *wavelet theory* and its *singularity* concept. Opposing the indeterminist standard approach, he presented, for instance, *"a simplified causal local model for the quantum particle"* [10] or a *"wavelet local analysis versus non-local Fourier analyis"* [11]. In a lecture text [12], he wrote:

> *"For Fourier, its analysis represented only a simple mathematical instrument, extremely usefull certainly but devoid of any physical content. It is well known that real physical waves are finite, they have a beginning and necessarily an end. Niels Bohr, on the conctrary, from a simple mathematical rule for functions abstract composition, promotes this analysis to the status of an ontology, claming that everything is made up of infinite waves that exist in all space and in all time."*

Now, it's time to re-enable de Broglie fundamental 'phase waves'.

First of all, we may recall that, in an article presenting his "double solution theory", de Broglie argues [5]:

> *"The presentation given in my thesis had the drawback of only applying to the particular case of a plane monochromatic wave, which is never strictly the case in nature, due to the inevitable existence of some spectral width. I knew that if the complex wave is represented by a Fourier integral, i.e. by a superposition of components, these latter only exist in the theoretician's mind, and that as long as they are not separated by a physical process which destroys the initial superposition,* the superposition is the physical reality. *Just after submitting my thesis, I therefore had to generalise the guiding ideas by considering, on one hand, a wave which could not be monochromatic, and on the other hand, by making a distinction between the real physical wave of my theory and the fictitious ψ wave of statistical significance, which was arbitrarily normed, and which following Schrödinger and Bohr's works was starting to be systematically introduced in the presentation of Wave Mechanics."*

In the same article, the author confesses that: *"Contemplating the success of Quantum Mechanics as it was developed with the Copenhagen School's concepts, I did for some time abandon my 1927 conceptions. During the last twenty years however, I have resumed and greatly developed the theory."*

De Broglie base his theory in two observations:

1. *"The wave* (the author symbolise by v) *is a physical one having a very small amplitude which cannot be arbitrarily normed, and which is distinct from the ψ wave";*

2. *"the particle, precisely located in space at every instant, forms on the v wave a small region of high energy concentration, which may be likened in a first approximation, to a moving singularity"*

Both waves (*"objective"* v and *"subjective"* ψ) are equivalent since they are connected by the simple relation

$$\psi = C.v = C.a \exp\left(i\varphi/\hbar\right),$$

C being *"a normalizing factor such that* $\int_v |\psi|^2\, d\tau$*, V denoting the volume occupied by the v wave."* de Broglie demonstrates that $|C| >> 1$ and gives an interpretation to this result *"by stating that the current statistical theory considers as spread out in the entire wave, devoid of singularity, that which in reality is totally concentrated in the singularity."*. He insists on the fact that

> *"since the publication of Schrödinger's works in 1926, it became customary to only consider the* ψ *wave, of arbitrary normed amplitude. But this wave cannot be considered as a physical wave".*

Add to this, the picture of reality given by the ψ wave is necessarily incomplete. That's why the *"objective"* wave v is fundamental, the distinction between the two of them and their mutual use being essential, thus given birth to a "Double Solution Theory". He also argues, after studying this theory on both Schrödinger and Klein-Gordon's approach, that *"Wave Mechanics is an essentially relativistic theory, as I perceived at its beginning; Schrödinger's equation, being non-relativistic, is improper to reveal its true nature."*

Coming back, the major problems connected with the physical interpretation of $\psi(\mathbf{r}, t)$ seem to lie on the difficulty of admitting tachyonic waves and therefore, denying it, to be forced to conceive the pair 'particle-wave packet' as a whole, a complementary duality of a *single thing*. Due to the embarrassment aroused by the 'absurd' of a tachyonic wave (from a classical point of view), theorists don't usually attach it any *physical signification* [6], and this despite the fact that de Broglie's and Schrödinger's ideas are in the very basis of wave Quantum Mechanics. This is an astonishing point of view because, first of all, what is the sense of a wave (even a conceptual "probability wave" represented by a Fourier superposition) if its velocity of propagation u_φ doesn't have any sense? From the point of view of pseudotachyonic theory, there is indeed a physical signification: for a massive bradyonic particle, it is a *tachyonic wave*, which may only be detected with the associated velocity of u_φ,

$$\hat{u}_\varphi = c^2/\hat{v} = v,$$

that is to say, *the velocity of the particle itself!* This is, I believe, too remarkable to be just a coincidence.

So, in what comes to the impossibility of directly measure the phase velocity u_φ, pointed out by Born [6], it seems to be logic; but this doesn't necessarily mean that the monochromatic wave itself doesn't exist or that its propagation velocity has no physical signification. The process he suggests – following de Broglie and Rayleigh – of fixing a label in the 'infinitely uniform' wave, in order to measure its velocity, thus implying a wave packet, is also logical. We may understand it as a method for detect the 'underlying wave' and its velocity, 'measured' as the *group velocity* $u_g = v = \hat{u}_\varphi$ – which is, and should be, a bradyonic velocity. So, the result of the detection of this tachyonic phenomenon is perfectly coherent with the general proposition of Pseudotachyonic Relativity mentioned in the Introduction.

Removing the classical 'tachyonic objection', it's quite evident that, in fact, the so-called *duality wave/particle* must not mean wave and particle are the *same thing* (or even two *aspects* of the same thing). On the contrary, their velocities being different, we are dealing with *different entities* although intimately associated. What Quantum Mechanics normally does is to deduce the behaviour of a particle from the correspondent behaviour of the wave packet or the ψ wave. Whatever the triumphs of the theory are, this may lead to un incomplete knowledge of the object of study because one element of the duality (the particle) tends to be forgotten. Mainly because of this, a relevant question still arise: *What is* an elementary particle? I think Relativity, in a new (discreet) version, may be a powerful instrument to answer this fundamental question. But this is beyond the scope of the present article.

Meantime, one may notice that the equation (6) in [2], which essentially is de Broglie's "guidance formula" (4) [5],

$$E = p.\hat{v},$$

relates the energy and momentum of a particle (and of its correspondent wave) to the *velocity of the* ***wave****, not the particle.* This is a symptom that, in fact, *it is the* ***wave*** *that 'carries' energy and momentum* and therefore is ultimately responsible for the interactions with other particles/waves. Remark that, ordinarilly, these interactions cannot take place without movement, which implies the existence of waves. On the other hand, except for the proper energy of a material particle (measured in its own frame), energy and momentum *are not* characteristics of the particle itself but the result of a measure that depends on a relative motion.

Finally, I would like to comment the concept of a monochromatic wave periodically infinite in space extension, which is in the basis of several arguments concerning de Broglie waves. Like J.R. Croca notes, we must be aware that this infinite wave isn't but a mathematical abstraction. Even considering a monochromatic wave as an idealisation of the 'real thing', physically it isn't infinite neither in time nor in space. For instance, if the state of movement of the particle is modified, the associated wave modifies as well; if it stops, the wave vanishes, the periodical process consisting only in the above mentioned un-propagated 'rest vibration'. We'll talk about the physical meaning of this vibration in section 4.

3 De Broglie link

What might be the physical nature of the link between a ***tachyonic particle*** *and its* ***associated antiparticle?*** The answer to this question may seemingly be found in de Broglie waves.

We may ask ourselves: to *what* does the wave correspond to in the *pseudotachyonic frame* S^* in which the wave vector $\mathbf{k}^*$ is null (or, in which the 'wave' doesn't actually exist, for it is no more than the 'proper vibration' of the particle, with frequency $\nu_0^* = E_0^*/h$, that doesn't propagate in space)? According to the transformations of table (12) in [2],

$$\begin{cases} \nu^* = \frac{k_x.c-\nu.\beta_w}{\alpha} \\ k_x^* = \frac{k_x.\beta_w-\nu/c}{\alpha} \\ k_y^* = k_y \\ k_z^* = k_z, \end{cases}$$

we obtain the velocity u of the frame S", tachyonic associated of S^*, from

$$k_0^* = \frac{k.u/c-\nu/c}{\sqrt{u^2/c^2-1}} = 0 \quad \Rightarrow \quad k.u = \nu \quad \Rightarrow \quad u = \frac{\nu}{k} = u_\varphi = \hat{v} \ ;$$

so, obviously, S" has the same velocity as the wave. Therefore, since $\beta_u = \hat{\beta} = 1/\beta$,

$$\nu^* = -\frac{\nu/\beta-k.c}{\sqrt{1/\beta^2-1}} = -\frac{\nu-k.v}{\sqrt{1-\beta^2}}, \quad \text{or, identically,} \quad \nu = -\frac{\nu^*-k^*.v}{\sqrt{1-\beta^2}};$$

as a consequence, considering $\nu^* = \nu_0^*$ (for $k_0^* = 0$),

$$\nu_0^* = -\frac{m.c^2}{h}.\sqrt{1-\beta^2} = -\frac{m_0.c^2}{h} = -\nu_0.$$

This means that in the frame S^* the mentioned 'vibration' corresponds to an **immobile antiparticle** — in truth, the antiparticle $\overline{\mathbf{P}}$ associated to the first.

Symmetrically, the wave of a **tachyonic particle** corresponds, in the frame S, to its associated antiparticle. In fact, v being the velocity of the particle P ($v > c$), the wave's velocity will be $\hat{v}$ (now, a subluminal velocity); furthermore, it results from (12) that

$$k = -\tfrac{\beta}{\alpha}.m_0^*.\hat{v}/h \quad \text{and} \quad \nu = -\tfrac{\beta}{\alpha}.\nu_0^*,$$

or, using de Broglie's basic equations,

$$p = -\tfrac{\beta}{\alpha}.m_0^*.\hat{v} \quad \text{and} \quad E = -\tfrac{\beta}{\alpha}.E_0^* \quad \Leftrightarrow \quad m = -\tfrac{\beta}{\alpha}.m_0^*,$$

which is the mass of an antiparticle $\overline{\mathbf{P}}$ moving in S with velocity $\hat{v}$. Finally, the phase velocity of this antiparticle's de Broglie wave must be

$$u = \frac{\nu}{k} = \frac{-\frac{\beta}{\alpha}.\nu_0^*}{-\frac{\nu_0^*}{\alpha.c}} = \beta.c = v,$$

which is, coherently, the associated of the velocity of $\overline{\mathbf{P}}$ — this is, the velocity of **P** itself. So we see that the tachyonic particle, in virtue of its *duality* in S^*, or in S", also appears in the frame S revealing a duality: one aspect, *bradyonic* (the associated antiparticle), the other *tachyonic* (the antiparticle's wave).

All the precedent reasoning leads to the statement that a **de Broglie wave** must be:

1. the *transmitter agent*, in interactions, of energy and linear momentum of the correspondent particle in motion;

2. the *link* between a tachyonic particle and its associated antiparticle (this one being the only possible way to detect that one).

This is quite reassuring because it gives us some reasons for the existence of the duality wave/particle. As a matter of fact, why would Nature produce two things connected if one should be enough?

4 De Broglie "periodic phenomenon" and force fields

What may be the nature of de Broglie's "periodic phenomenon", or the "internal vibration", for a particle at rest?

It is not a mechanical process because, if so, it would naturally create a wave propagating spherically in space – which doesn't happen. Even for a reference frame in which the particle moves, the process gives rise to a plane wave propagating in the same direction. So, like electromagnetic waves, de Broglie waves are not mechanical ones; in fact, electromagnetic waves are a special kind of de Broglie waves, with two components (and phase velocity equal to the velocity of the corresponding photonic particles, since $\hat{c} = c$), for which there isn't any "rest periodic process".

So, what really is this physical process called "periodic phenomenon" which reveals itself as a de Broglie wave for a moving particle? And what is the meaning of its frequency, $\nu_0 = E_0/h$?

We saw above that de Broglie considered 'his' waves, although very real, solely as something he called "phase waves" (i.e. transporting 'phase' but not energy), reminding that *"in the general case of a wave which is not monochromatic, the particle's internal vibration is constantly in phase with the wave on which it is carried (...), the main point of the guidance law"* [5]. But he also introduced *"the idea according to which the particle can be likened to a small clock of frequency $\nu_0 = M_0 c^2$, and to which is given the velocity of equation*

$$\vec{v} = \frac{c^2 \vec{p}}{E} = -c^2 \frac{\vec{grad}\varphi}{\partial\varphi/\partial t} \quad \text{(the“guidance formula”).}$$

For an observer seeing the particle move on its wave with velocity βc, the internal frequency of the clock is $\nu = \nu_0\sqrt{1-\beta^2}$ according to the relativistic slowing down of moving clocks." He advises for the fact that *"the proper mass M_0 (...) is generally not equal to the proper mass m_0 usually given to the particle"* but $M_0 = m_0 + Q_0/c^2$, where the quantity Q_0 is the "quantum potential" of the double solution theory [5].

In adition to this, in section IX of this cited paper, the author presents *" the main ideas of the hidden thermodynamics of particles, which I developed since 1960 as an extension of the double solution theory. The idea of considering the particle as a small clock naturally* *leads to look at the self energy M_0c^2 as the hidden heat of the particle. From this point of view, a small clock has in its proper system an internal periodic energy of agitation which does not contribute to momentum of the whole. This energy is similar to that of a heat-containing body in an internal state of equilibrium."*

These are quite interesting ideas. But I would like to present myself the idea that de Broglie's "periodic process" for a particle – its "clocklike" behaviour – deeply relates to all the **force fields** the particle is the source of. More precisely, adopting the point of view of Quantum Mechanics, we'll consider that every interaction between particles is mediated by certain "messenger particles". But the theoretical consideration of negative energy (like in pseudotachyonic theory) allows us to draw a quite different picture of the interaction between elementary particles. First of all, any force field shall be characterized either by *positive* either by *negative energy*; therefore, we'll classify them as positive (repulsive) or negative (atracctive). And, for our purpose, besides classifying particles as matter or antimatter, since they may create and react to fields we'll classify them, *towards a certain interaction,* in five categories: neutral, positive, negative, proreactive and antireactive particles. Generally, the basis for this classification is what follows:

1. A *positive field* has positive energy; it is mediated by (positively energetic) particles and results repulsive;
2. A *negative field* has negative energy; it is mediated by (negatively energetic) antiparticles and results attactive;
3. A *positive particle* $(\mathbf{P}^+)$ creates a positive field;
4. A *negative particle* $(\mathbf{P}^-)$ creates a negative field;
5. A *proreactive particle* $(\mathbf{P}_+)$ reacts positively to the field (this means drifting away or coming closer respectively in repulsive or attractive fields);
6. An *antireactive particle* $(\mathbf{P}_-)$ reacts negatively to the field (the contrary);
7. A *neutral particle* $\left(\mathbf{P}_0^0\right)$ doesn't react to the field and also doesn't create one.

It's quite evident, and also a logical conclusion (using pseudo-tachyonic transformations), that the classification of a *particle* towards a certain interaction – either creating the field or reacting to one – must be inverted to its *homologous particle*. In fact, a field may be conceived as the statistical result of interactions between its "messenger particles" and other particles; but then, these correlate conclusions arise:

- *If* ϵ *is messenger of a field created by a particle* $\mathbf{P}$*, then* $\bar{\epsilon}$*, homologous of* ϵ*, is messenger of the corresponding field due to the homologous particle* $\overline{\mathbf{P}}$;

- *All the particles that create an opposite field to the one of* $\mathbf{P}$ *do it trough messenger* $\bar{\epsilon}$*.*

Remark that the attractive or repulsive nature of a field doesn't exactly lie in the direction of the resulting movement of a particle placed in it (which is a phenomenological approach to the problem) but in the *linear momentum* the field induces. In case of messenger *particles* (ϵ^+) this linear momentum has the same direction of the messenger movement; in case of messenger *antiparticles* (ϵ^-), it is contrary to its movement [2]. This is why the correspondent fields result respectively repulsive or attractive. Furthermore, *something* in the nature of *antireactive particles* to a certain field respond to these fields like antimatter ordinarily do: for them velocity (or force) and linear momentum have opposite senses [2] and so they react negatively. But we must not conceive an antireactive particle as necessarily an antiparticle. Either a particle or an antiparticle can be in one of the five categories listed above. We also must be aware that a positive (or a negative) particle isn't necessarily a proreactive (or an antireactive) one.

Finally, generally talking, I would like to leave these three suggestions and some immediate consequences of them:

1. *The whole of the* ***messengers*** *emitted in a short period of time by a massive particle* – that is to say, the whole of all interactions the particle is the source of – *must obey to an* ***energetic equilibrium globally null****.* This is due to the law of conservation of energy applied to the particle itself and has this profound consequence that both *positive* and *negative* messenger

particles must be emitted, thus creating positive and negative distinct fields. It seems also to imply the conclusion that a single universal force is impossible. Moreover, because of the necessary conservation of the linear momentum for the particle itself, *each messenger is probably emitted in pairs and in opposite directions.*

2. It seems quite logic that the spontaneous emission of all the messengers by a source particle is not exactly aleatory but obeys to the *internal vibration* of the particle (with frequency $\nu_0 = m_0.c^2/h$, according to de Broglie).

3. In the proper frame of the particle, *the messengers, for each field, have always the same energy.*

Consider an **electron**. We may admit that the **electrostatic field** it creates is due to the emission of **photons**, in order to respect the Compton effect. It is a **positive field**: these photons carry positive energy and a linear momentum with the same direction of its propagation; in electrostatic interaction, then, this momentum is (partially) transferred to another charged particle. If this particle is another electron, a **proreactive** one, it will react driving away from the first one [see Fig. 1a], in which, for simplicity, the angular deviation caused by the Compton effect is not taken into account ; if it is a positron, which is an antiparticle, since for it velocity and linear momentum have opposite senses, it will react approaching the electron [see Fig. 1b]. This means that a positron is an electrostatic **antireactive** particle.

A **positron** is also a negative particle: it produces a **negative field**, an attractive one, through the emission of **antiphotons**; these antiphotons carry negative energy and a linear momentum with the opposite direction of its propagation, that is to say in the direction of the positron itself; eventually, this momentum is (partially) transferred to another charged particle. An electron behaves reacting positively to the momentum received, coming closer to the positron; another positron, however, reacts negatively driving away from it. Quite as well, since the charge of a **proton** is also opposite to the one of an electron, the field it creates – according to our hypothesis – must be **negative**, caused by the emission of **antiphotons**. In regard to electrostatic fields, protons are **negative** and **antireactive**

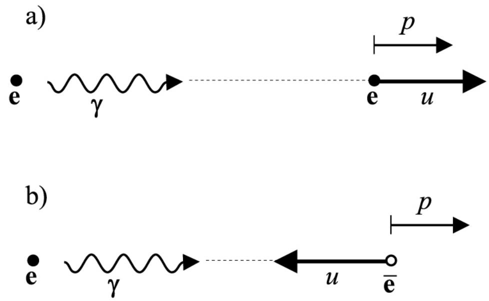

Figure 1: Electron and positron in an electrostatic field.

particles, in the same way positrons are. They create attractive fields and react negatively to another electrostatic field [see Fig. 2a-c].

It's easy to see, then, that the phenomenological result of these interactions follow the experimental rule:

1. Particles of the same charge repel each other;

2. Particles of opposite charge attract each other.

Finally, we may resume the precedent arguments in the symbolic notation:

$$\begin{cases} \mathbf{e}^{+}_{+} & \text{and} \quad \mathbf{p}^{-}_{-} \\ \overline{\mathbf{e}}^{\,-}_{\,-} & \text{and} \quad \overline{\mathbf{p}}^{\,+}_{\,+} \end{cases}$$

We can apply a similar reasoning to the **gravity field**, whose messenger particle (for a material source) is called **graviton**. In regard to this field, since gravity concerns masses – or generally, including photons, energy – we must consider particles ($E > 0$) as being proreactive and antiparticles ($E < 0$) antireactive. But then, since gravity is attractive for matter, we arrive to an immediate conclusion: **the graviton must be an antiparticle**. This means that, in creating gravitational fields, particles are negative and antiparticles are positive. Symbolically: $\mathbf{P}^{-}_{+}$ and $\overline{\mathbf{P}}^{\,+}_{\,-}$.

Remark that, if this statement is correct, the opposite effect of gravity and electrostatic fields becomes quite comprehensible: reaching a particle, the graviton transfers to it a linear momentum opposite

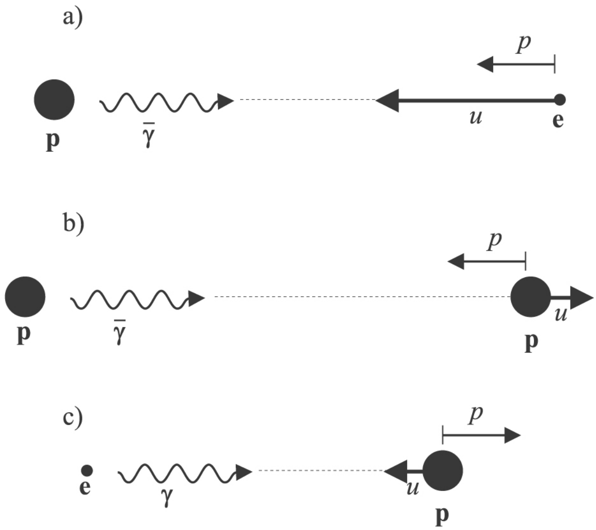

Figure 2: Protons and electrons in electrostatic fields.

to the propagation (to make it simple), that is to say, opposite to the direction of the source [see Fig. 3a,b]; so, the field results **atractive**.

The situation concerning the gravity field created by **antimatter** is precisely the inverse. The pseudotachyonic transformation of the previous scenario makes it clear that this field is due to the emission of **antigravitons** – which are positive particles, with positive energy. In this case, the linear momentum has the same direction than the messenger particle, causing the field to be **repulsive**. A particle will respond to it driving away from the source; an antiparticle will do it negatively, approaching it [see Fig. 4a,b].

To make a summary, we must say that:

1. A particle creates an attractive gravity field; an antiparticle creates a repulsive one;

2. A particle reacts positively to a field; an antiparticle reacts negatively to it.

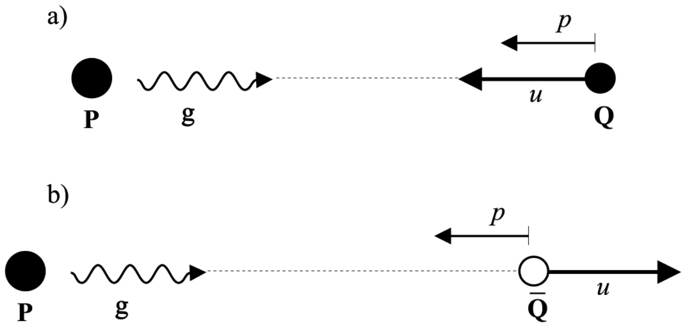

Figure 3: Scheme for matter gravitational field.

¿From these assertions we can conclude the following generic observable effects concerning gravitational interaction:

1. Two particles attract each other;
2. Two antiparticles also attract each other;
3. A particle and an antiparticle repel each other.

Consider now a certain force field. **In the proper frame of the source particle**, the created field is always a static one; in a not disturbed space-time, it results – from a macroscopic point of view – spherically centred in the particle. According to our hypothesis, the number N of messenger particles emitted in a time laps t is given by

$$N = 2\left|\nu_0\right|.t, \quad \text{which means that} \quad \tfrac{dN}{dt} = 2\left|\nu_0\right|.$$

During this time laps, each messenger covers a distance $r = v_{ms}.t$ (so $dr = v_{ms}dt$). We'll briefly study the cases where the messenger mass is null, this is, gravitational and electrostatic interactions. In these cases, the messenger velocity is $v_{ms} = c$ and then $r = c.t$ or $dr = c.dt$. On the other hand, the volume of the spherical sector between radius r and $r + dr$ is given by

$$\begin{aligned} dV &= \tfrac{4}{3}\pi\left[(r+dr)^3 - r^3\right] \\ &= \tfrac{4}{3}\pi\left[3dr.r^2 + 3\left(dr\right)^2.r + \left(dr\right)^3\right] \end{aligned}$$

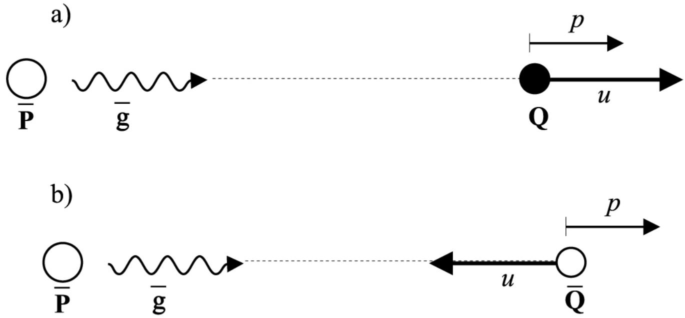

Figure 4: Scheme for antimatter gravitational field.

or, considering $r >> dr$,

$$dV \approx 4\pi dr.r^2 = 4\pi c.dt.r^2 \quad \Rightarrow \quad \tfrac{dV}{dt} \approx 4\pi c.r^2. \tag{2}$$

Therefore, the messengers density in this sector is:

$$\frac{dN}{dV} = \frac{dN}{dt} / \frac{dV}{dt} = \frac{|\nu_0|}{2\pi c.r^2} \tag{3}$$

or

$$\frac{dN}{dV} = \frac{|m_0|.c}{2\pi h.r^2}. \tag{3.a}$$

So we see that (for $r >> dr$) the field vector [a mathematical result of the field positive or negative *average energy density,* which relates to the messengers density] at a certain distance of the source must be – as long as Euclidean geometry remains valid – proportional to the mass of the particle and inversely proportional to the square of the distance. This leads us directly to **Newton's gravitational law** – generalised to antimatter – and, furthermore to the conclusion that *the gravitational constant G is a function of the fundamental relativistic and quantum constants, c and h respectively.*

Besides, the equation (3.4) also leads us to **Coulomb's law** (and that's why both laws are formally identical, the phenomenological result of similar discrete interactions). As a matter of fact, considering electrons as *elementary charge units,* it has been experimentally proved (since Thomson, 1897) that this charge is proportional to the rest mass of the particle [9]:

$$\frac{e}{m_0} = 1.758 \times 10^{11} C/Kg;$$

so, the equation (3.a) turns into

$$\frac{dN}{dV} = \frac{10^{-11}c}{2\pi h \times 1.758} . \frac{|e|}{r^2} Kg/C \tag{4}$$

and it describes the electrostatic field created by an electron. The same relation e/m_0 also applies to the *positive charge units,* the positrons [2], since $\overline{e} = -e$ and $\overline{m}_0 = -m_0$. It results that, for positive charges, dN/dV is given by the same expression. Remark that, in what comes to the electrostatic field produced by a proton, only its 'positive element of charge' (the *'positron within it'*) is relevant, not the total mass of the particle.

In the case of the electron or the positron we obtain for both the gravitational and the electrostatic fields:

$$\tfrac{dN}{dt} = 2.47 \times 10^{20} s^{-1} \quad \text{and} \quad \tfrac{dN}{dV} = \tfrac{6.56 \times 10^{10}}{r^2} m^{-1}.$$

This result also applies to the electrostatic field due to a proton; but not to the gravitational field because, in this case, the whole mass of the particle is relevant and therefore it must be

$$\tfrac{dN}{dt} = 4.53 \times 10^{23} s^{-1} \quad \text{and} \quad \tfrac{dN}{dV} = \tfrac{1.20 \times 10^{14}}{r^2} m^{-1}.$$

These theoretical results using equation (2) presuppose $r >> dr$. If this doesn't happen, the expression for dV cannot be simplified and the messengers density is no longer inversely proportional to r^2. I must signalise, by the way, that this approach to the field problem – and also other reasoning – leads almost necessarily to a discrete conception of space-time structure and, of course, to a quantization of anything that exists in it.

Naturally, for **a system of *n* identical particles** confined in a space we can disregard towards the large propagation of the field (a very small region usually considered as a "point"), the de Broglie total rest frequency is equal to $n.E_0/h = n.\nu_0$, which causes the field to be n times stronger. The phenomenological result, for electrostatic or gravitational fields, is that the field vector must be directly proportional to the total charge or to the total mass of the system, respectively, and inversely proportional to the square of the distance (once again, Coulomb and Newton's Laws).

Finally, in another frame in which the particle moves, the intrinsic vibration take the form of a wave, the frequency ν changes and the field becomes dynamic; it becomes spatially deformed and, at a given point, characterized by a (longitudinal and transversal) Doppler effect [2].

These are the premises for a new Field Theory, concerning all the known forces in the Universe, and some of its consequences. This theory will permit to understand Einstein's *principle of equivalence* for inertial and gravitational mass (simply because these masses are indeed one and the same) and perhaps to overcome recourent problems like the cosmological question of gravity, usually presupposed uniquely attractive, or the troubling enigma of "conservation of energy maintained" [13]:

> *"Matter (protons, neutrons, electrons, etc.) emits energy (like gravitons) and interacts with other matter, and has [done it] for billions and billions of years without decreasing in energy or mass? Perhaps a life cycle of matter involving Negative energy is indicated?"*

5 Conclusion

We have verified that the wave for a particle moving with velocity v has velocity $\hat{v}$; this means that, although the wave is tachyonic (if $|v| < c$), it may only be detected with the velocity of the particle itself. We came to the conclusion that a particle and its de Broglie wave are really different (connected) things and not two aspects of the same thing. We have also establish some reasons for the dependent existence of these two things.

One must be aware that, for any particle (in an extensive sense, massive or not), there is not only the ***wave/particle*** *duality* proposed by de Broglie but also a ***particle-antiparticle*** *duality* and a ***bradyonic-tachyonic*** *duality.* These three dualities are intimately related, mainly resulting from the existence of a 'relativistic barrier' (a limit velocity, the ***c*** *factor*) and also a 'quantum barrier' (the ***h*** *factor*).

Finally, pseudotachyonic theory – in accepting the current existence of negative energy – together with de Broglie "periodic process" opens the door to a new general Field Theory.

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