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Electromagnetic Interaction: A New Theoretical Approach

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Abstract

All the four fundamental interactions describe phenomena of attraction except one, the electromagnetic interaction, which also describes phenomena of repulsion. If the matter that constitutes our universe is subject to the same physical laws, then the four fundamental interactions should all express the same phenomena: either attraction or repulsion. In this work, a new approach called the binding cord approach was introduced to describe the electromagnetic interaction. In this new approach, electromagnetic repulsion will be described as a consequence of attraction.

Keywords

Interaction, Electromagnetic, Attraction, Repulsion, Stable, Unstable

1. Introduction

Particle physics is a branch of physics that probes the infinitely small. It demonstrates that any material system in the universe can be fully defined by four fundamental interactions [1]:

- The strong interaction
- The weak interaction
- The electromagnetic interaction
- The gravitational interaction

Moreover, she adds that all these interactions describe phenomena of attraction except the electromagnetic interaction which also involves phenomena of repulsion.

If we hope one day to unify these four interactions in a single universal theory, these four interactions must a priori describe the same phenomena:

- Consider phenomena of attraction;

- Consider phenomena of repulsion.

It goes without saying, given that all these interactions involve phenomena of attraction, and these are the only serious leads that could one day lead us to a theory of universal unification. Thus, in this work, we will answer questions similar to these:

- How do two charged particles with the same signs repel each other (such as the Coulomb repulsion between two protons)?
- How to explain the levitation of a superconducting element above a magnet (the Meissner effect)?

To answer these questions, we will introduce a new approach that will describe electromagnetic repulsion as a consequence of attraction. This new approach called the "binding cord approach" will also allow us to explain the stability and instability of a large number of particles.

2. Yukawa Approach [1]

In 1935, Yukawa, H. proposed an approach in which each interaction corresponds to an exchange of bosons between the interacting particles. Thus, the strong interaction corresponds to an exchange of gluons (g), the weak interaction corresponds to an exchange of intermediate vector bosons ($W^{\pm}$, Z^{0}), the electromagnetic interaction corresponds to an exchange of photons (γ) and the gravitational interaction corresponds to an exchange of gravitons (still not observed until today).

Starting from the Heisenberg uncertainty principle on energy and time, *i.e.*, $\Delta E \cdot \Delta t \geq \hbar$, Yukawa demonstrated that the range R of the interaction is inversely proportional to the mass m of the exchanged boson. So we have: $R \approx \frac{1}{m}$. Thus, with the photon being zero mass, the electromagnetic interaction is of infinite range (long range).

3. New Approach: The Binding Cord Approach

3.1. Principle

Before introducing this approach, we start with illustrating it in a rather banal but very important way with a game that we are used to seeing children play. Two little girls each place themselves at the ends of a rope. One like the other pulls to her side to try to attract the other towards her. If all of a sudden, the rope gave way and was cut in two, the two little girls will be thrown, each on their side, and it will look like our two little girls have pushed each other away. Let us now replace our two little girls with two charged particles, the cord by the electromagnetic interaction and we have our model which we have named: the binding cord approach.

Thus, a composite system will be said to be stable if the string corresponding binder holds whatever happens and cannot be broken. On the other hand, the system will be said to be unstable if the binding cord hangs by a single thread and could therefore break. So you understand that in this way of seeing things, repulsion becomes a consequence of attraction.

3.2. Mathematical Formalism

Let us also start from Heisenberg's uncertainty relation on energy and time, *i.e.* $\Delta E \cdot \Delta t \geq \hbar$. With:

- ΔE, the energy of the interaction, that is of the electromagnetic field (the exchanged particles being photons).
- Δt, is the lifetime of the system, its time of existence.
- $\hbar = \frac{h}{2\pi}$, with h, Planck's constant ($h = 6.62 \times 10^{-34}\ \text{J} \cdot \text{s}$).

In quantum field theory, the energy of the electromagnetic field is quantified using the quantum harmonic oscillator [2]. We can then write: $\Delta E = n\hbar\omega$; With n, the number of photons and ω is the pulsation (or the frequency) of the electromagnetic wave. In classical electrodynamics, it is shown that the total energy of a charged particle placed in an electromagnetic field is given by [3]:

$$E_{tot} = \frac{1}{2m}(\boldsymbol{P} - q\boldsymbol{A})^2 + \int_V \mathrm{d}^3 r \left(\frac{\varepsilon_0}{2} |\boldsymbol{E}(\boldsymbol{r}, t)|^2 + \frac{1}{2\mu_0} |\boldsymbol{B}(\boldsymbol{r}, t)|^2 \right) \tag{1}$$

where:

- $\boldsymbol{P}$ is the momentum of the particle with charge q and mass m
- $\boldsymbol{A}$ is the vector potential related to the electromagnetic field
- $\boldsymbol{E}$ is electric field
- $\boldsymbol{B}$ is the magnetic field
- ε_0 is the electric permittivity of vacuum
- μ_0 is the magnetic permeability of vacuum

Thus, as a first approximation, we can consider that the first term on the right $\frac{1}{2m}(\boldsymbol{P} - q\boldsymbol{A})^2$ corresponds to the energy of the charged particle while the second term $\int_V \mathrm{d}^3 r \left(\frac{\varepsilon_0}{2} |\boldsymbol{E}(\boldsymbol{r}, t)|^2 + \frac{1}{2\mu_0} |\boldsymbol{B}(\boldsymbol{r}, t)|^2 \right)$ corresponds to the energy of the electromagnetic field. Indeed, for a particle with zero charge, the energy of the system is given by $E_{tot} = \frac{1}{2m}\boldsymbol{P}^2 + \int_V \mathrm{d}^3 r \left(\frac{\varepsilon_0}{2} |\boldsymbol{E}(\boldsymbol{r}, t)|^2 + \frac{1}{2\mu_0} |\boldsymbol{B}(\boldsymbol{r}, t)|^2 \right)$ and we see that the first term depends only on the particle while the second depends only on the electromagnetic field. This allows us to write:

$$\Delta E = \int_V \mathrm{d}^3 r \left(\frac{\varepsilon_0}{2} |\boldsymbol{E}(\boldsymbol{r}, t)|^2 + \frac{1}{2\mu_0} |\boldsymbol{B}(\boldsymbol{r}, t)|^2 \right) \tag{2}$$

We can thus define the number of photons that constitute the electromagnetic wave by:

$$n = \frac{\int_V \mathrm{d}^3 r \left(\frac{\varepsilon_0}{2} |\boldsymbol{E}(\boldsymbol{r}, t)|^2 + \frac{1}{2\mu_0} |\boldsymbol{B}(\boldsymbol{r}, t)|^2 \right)}{\hbar\omega} \tag{3}$$

Here, it is about real photons, that is to say those that we manage to detect thanks to a photomultiplier. This is not the case for the photons exchanged during an electromagnetic interaction. These photons are called "virtual". In particle physics, it is assumed that these virtual photons exist for a time Δt very short as $\Delta E \cdot \Delta t < \hbar$ and therefore cannot be detected by a photomultiplier. To better understand it, it suffices to consider the uncertainty relation on energy and time, we have:

$$\Delta E \cdot \Delta t \approx \hbar$$

$$\Leftrightarrow n\hbar\omega \cdot \Delta t \approx \hbar$$

$$\Leftrightarrow \Delta t \approx \frac{1}{n\omega}$$

Then, for a stable system, we have $\Delta t = \infty$, which implies $n = 0$ and this demonstrates perfectly that the photons exchanged during an electromagnetic interaction are undetectable. Starting once again from this same relationship of uncertainty and introducing now Equation (2), lifetime Δt is then given by:

$$\Delta t = \frac{\hbar}{\int_V \mathrm{d}^3 r \left(\frac{\varepsilon_0}{2} \left| \boldsymbol{E}(\boldsymbol{r},t) \right|^2 + \frac{1}{2\mu_0} \left| \boldsymbol{B}(\boldsymbol{r},t) \right|^2 \right)} \tag{4}$$

NB:

- The electric field $\boldsymbol{E}$ will be defined by the total charge q of the system. We have: $\left|\boldsymbol{E}\right| = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2}$
- The magnetic field $\boldsymbol{B}$ has two components [4]:

  1) A component $\boldsymbol{B}_c$ due to the charged particle when it is not at rest.

  2) A component $\boldsymbol{B}_s$ due to the spin of the particle.

  We will have so $\boldsymbol{B} = \boldsymbol{B}_c + \boldsymbol{B}_s$.

  For all the cases that we will study here, $\boldsymbol{B}_c$ will be defined by the electrons moving around the nucleus. This component $\boldsymbol{B}_c$ is so small in front $\boldsymbol{B}_s$ which will be neglected in the sequel.

  We will therefore have $\boldsymbol{B} = \boldsymbol{B}_s$. The magnetic moment due to the spin of the electron can also be neglected given its smallness.
- The integral in the denominator is always greater than or equal to zero. It is equal to zero if only $\boldsymbol{E} = 0$ and $\boldsymbol{B} = 0$, it is greater than zero otherwise. This means that the lifetime of any system will always be greater than zero, which makes physical sense.

3.3. Study of the Different Cases

1) Particles charged with opposite signs

We consider a composite system made up of a proton and an electron (such as the hydrogen atom, for example).

Since the total charge of the system is zero, the electric field $\boldsymbol{E}$ is too. Following the Pauli Exclusion Principle, the two particles will occupy opposite spin states. So we have the magnetic field $\boldsymbol{B} = \boldsymbol{B}_s = \mathbf{0}$. Hence the lifetime will be given by:

$$\Delta t = \frac{\hbar}{0} = \infty .$$

The system is therefore stable.

2) Particles charged with the same signs

We consider a system (a nucleus) composed of two protons. The total charge of the system being different from zero, we also have $E \neq 0$. On the other hand, following the Pauli Exclusion Principle, the two particles will occupy opposite spin states. We will therefore have: $\boldsymbol{B} = \boldsymbol{B}_s = \mathbf{0}$. The lifetime of the system is then given by:

$$\Delta t \approx \frac{\hbar}{\int_V \mathrm{d}^3 r \frac{\varepsilon_0}{2} \left| \boldsymbol{E}(\boldsymbol{r}, t) \right|^2} < \infty$$

$\Delta t < \infty$ means the lifetime of the system is finite. As $\hbar = \frac{6.62 \times 10^{-34}\ \mathrm{J \cdot s}}{2\pi}$, we will have $\Delta t \ll 1\ \mathrm{s}$, the lifetime of the system composite is extremely short. This explains the fact that in nature, we have never observed an atom with a nucleus made up of only two protons. In other words, the isotope ${}^{2}_{2}\mathrm{He}$ of helium has never been observed.

3) Magic numbers [5]

In nuclear physics, so-called magic numbers are defined as corresponding to stable nuclei. These nuclei are such that their numbers N and Z are both even (N is the number of neutrons and Z is the number of protons). These are the nuclei for which the numbers Z and N are equal to 2, 8, 20, 28, 40, 50, 82, 114, 126. The energies required to separate a neutron or a proton from one of these nuclei are high. In nuclear spectroscopy, it is demonstrated that the nuclei having the numbers Z and A both even have zero total spins (A is the mass number, we have $A = N + Z$) [6]. This implies the corresponding magnetic field $\boldsymbol{B} = \boldsymbol{B}_s = \mathbf{0}$. Since the total charge of the atom is zero, we will also have an electric field $\boldsymbol{E} = \mathbf{0}$. The lifetime is therefore given by:

$\Delta t \approx \frac{\hbar}{0} = \infty$; the system is therefore stable.

4) Instability of charged particles

After illustrating in the preceding paragraph the instability of a particle due to a non-zero spin, what about a particle with a non-zero charge?

To answer this concern, we are going to present here a fact, very familiar to the specialists in the science of the radioelements, which attracted my attention in a rather particular way. In fact, when we carefully observe the family of a given radioactive element and the radiation it emits; usually one decay α is directly followed by two decays β^- successive. This fact can only be explained by the instability of the particle due to its charge. Disintegration α being an emission of a helium nucleus, it strips the atom of two positive charges. The new particle is negatively charged and therefore unstable. To return to a slightly more stable state, the particle will then have to transmute into a new neutral isotope of the parent atom by undergoing two disintegrations β^-.

Examples: Uranium 238 family, Thorium 232 family, …

5) Instability of radioactive elements

Most cores radioactive comprise numbers Z and A such that the two are not even at the same time.

For such nuclei, nuclear spectroscopy demonstrates that they are characterized by a non-zero total spin, more precisely a spin always $\geq \frac{1}{2}$ [6]. This involves a magnetic field $\boldsymbol{B} = \boldsymbol{B}_s \neq \mathbf{0}$. The atom being of neutral charge, the electric field $\boldsymbol{E} = \mathbf{0}$. The lifetime is then given by: $\Delta t \approx \dfrac{\hbar}{\int_V d^3 r \frac{1}{2\mu_0} \left|\boldsymbol{B}(\boldsymbol{r},t)\right|^2} < \infty$.

The system is therefore unstable, it is said to be radioactive.

6) The fission reaction [5]

A massive unstable nucleus can absorb a neutron. This increases its magnetic field $\boldsymbol{B} = \boldsymbol{B}_s$ due to its total spin. That increase in the magnetic field corresponds to a sudden decrease in the lifetime of the system. The nucleus then splits into several pieces (2 to 3 in general), we say that there is fission.

7) State transition

A stable particle (of zero spin and charge) can absorb a photon and pass from the ground state to an excited state. The photon being of unity spin, the new particle has a nonzero spin. Its magnetic field $\boldsymbol{B} = \boldsymbol{B}_s$ is therefore also non-zero. Its lifetime is then given by:

$$\Delta t \approx \frac{\hbar}{\int_V d^3 r \frac{1}{2\mu_0} \left|\boldsymbol{B}(\boldsymbol{r},t)\right|^2} < \infty.$$

This particle is therefore unstable. It can return to the stable ground state by emitting a photon.

8) Baryon instability [1]

Baryons are half-integer spin hadrons. They are generally formed of three quarks $\left|qqq\right\rangle$ (this is the case with nucleons: the proton $\left|uud\right\rangle$ and the neutron $\left|ddu\right\rangle$). Their total spins will therefore always be non-zero. This implies that the magnetic field matches $\boldsymbol{B} = \boldsymbol{B}_s \neq \mathbf{0}$. We will therefore always have $\Delta t < \infty$.

Thus, we can say that any system composed of three quarks will always be unstable.

9) The Meissner effect

When a ferromagnetic element changes to the superconducting state by considerably lowering its temperature, its magnetic properties change radically. When the superconducting element is placed near a magnet, it is repelled by the magnetic field produced by it. This is the Meissner effect. One of the best-known applications of this effect is the levitation of a superconducting element above a magnet. This phenomenon can be explained by the binding cord approach. Here, the system is formed by the magnet and the metallic element. On the one hand, we can first consider that the two components of the system are not electrically charged. In this case, we have: $\boldsymbol{E} = \mathbf{0}$. On the other hand, when the metallic element is in a ferromagnetic state, the magnetic field vectors due to the spins of the atoms are aligned. The resultant $\boldsymbol{B}_s$ of these vectors is such that $\boldsymbol{B} = \boldsymbol{B}_s + \boldsymbol{B}_a = 0$, with $\boldsymbol{B}_a$, the magnetic field of the magnet. Hence $\Delta t \approx \frac{\hbar}{0} = \infty$, the system is stable. And when the metallic element is in a superconducting state, the magnetic field vectors due to the spins of the atoms are no longer aligned. The resultant $\boldsymbol{B}_s$ is such that $\boldsymbol{B} = \boldsymbol{B}_s + \boldsymbol{B}_a \neq 0$. From where:

$$\Delta t \approx \frac{\hbar}{\int_V \mathrm{d}^3 r \frac{1}{2\mu_0} \left|\boldsymbol{B}(\boldsymbol{r},t)\right|^2} < \infty.$$

The system is unstable, the superconducting element is repelled by the magnet.

10) Stability of elementary particles

Every elementary particle is stable. It cannot therefore disintegrate into new particles. To date, only four have been distinguished: the electron, the quark, the photon and the neutrino.

- Case of the electron: the electron is the only particle found in an isolated state and at rest, which is stable. This stability implies a lifetime $\Delta t = \infty$. Having nonzero charge and spin, the electron is defined by a electric field $\boldsymbol{E}$ and a magnetic field $\boldsymbol{B} = \boldsymbol{B}_s$ nonzero such that:

$$\int_V \mathrm{d}^3 r \left(\frac{\varepsilon_0}{2} \left|\boldsymbol{E}(\boldsymbol{r},t)\right|^2 + \frac{1}{2\mu_0} \left|\boldsymbol{B}(\boldsymbol{r},t)\right|^2 \right) \cong 0.$$

- Case of the quark: the quark is a particle with non-zero spin and charge. This means that the corresponding electric field and magnetic field are both non-zero. However, the quark is always found in the bound state (a quark in the isolated state has never been observed). Its stability may therefore be due to the fact that it is always in interaction with another quark or with an anti-quark.

Thus, one can affirm that if a quark found itself in an isolated state, it would immediately disintegrate into new particles and this could be the reason why a quark in an individual state has never been observed.

- Case of the photon: the photon is a particle with neutral charge and spin 1. It is therefore characterized by a magnetic field $\boldsymbol{B} = \boldsymbol{B}_s \neq \mathbf{0}$. However, we find that the photon is always in a state of motion (at the speed of light). Its stability may therefore be due solely to the fact that it is always in motion at very high speed. Thus, we can say that if a photon was at rest, it would immediately disintegrate into new particles. This is exactly what happens when a photon collides with a nucleus. The photon immediately disintegrates into two new particles with opposite charges and momenta:

$$\gamma \to e^+ + e^-$$

where: γ is the photon

e^+ is the positron (or positive electron);

e^- is the electron.

One would expect the opposite reaction to occur, ie. that the annihilation of an electron-positron pair produces a photon at rest. But alas, this is not the case. This annihilation instead produces two high energy photons in opposite directions. This is explained by the fact that the photon is stable if and only if it is in motion, but it is unstable otherwise.

- Case of the neutrino: by analogy to the photon, the neutrino is also a particle with zero charge and spin 1/2, it is therefore characterized by a non-zero magnetic field $\boldsymbol{B} = \boldsymbol{B}_s \neq \boldsymbol{0}$.

However, like the photon, we always find the neutrino in a state of motion (at a speed close to that of light). Its stability may therefore be due solely to the fact that it is always in motion at a very high speed. Thus, we can also affirm that if a neutrino was at rest, it would immediately disintegrate into new particles.

Remarks:

- In the expression of the energy of the electromagnetic field, we have here neglected the magnetic field $\boldsymbol{B}_c$ due to the movement of the charged particles of the system and we considered only the spin magnetic field $\boldsymbol{B}_s$.

This approximation holds all its meaning in the description of the light elements but it becomes obsolete for heavy elements. In fact, the magnetic field $\boldsymbol{B}_c$ increases with the number of electrons in the atom and the total magnetic field $\boldsymbol{B} = \boldsymbol{B}_c + \boldsymbol{B}_s$, will therefore always be non-zero. This has the direct consequence that any heavy element will always be unstable. Thus, when we study the physicochemical properties of the various elements of the periodic table of Mendeleïev, we notice that all the elements from Polonium and beyond are radioactive. We can therefore call a "heavy" element any element whose atomic number $Z \geq 84$.

- It should be noted that the binder-cord model offers a new way of estimating the rate of decay λ of an unstable system. We will have:

$$\lambda = \frac{1}{\Delta t} \approx \frac{\int_V \mathrm{d}^3 r \left(\frac{\varepsilon_0}{2} \left| \boldsymbol{E}(\boldsymbol{r},t) \right|^2 + \frac{1}{2\mu_0} \left| \boldsymbol{B}(\boldsymbol{r},t) \right|^2 \right)}{\hbar}$$

- The number of photons that contains a wave electromagnetic can be obtained from the uncertainty relation, *i.e.*:

$$\Delta E \cdot \Delta t \approx \hbar$$

$$\Leftrightarrow n\hbar\omega \cdot \Delta t \approx \hbar$$

$$\Leftrightarrow n \approx \frac{1}{\omega \cdot \Delta t}$$

We will then have:

a) For a stable particle, we know that $\Delta t = \infty$ and this implies that $n = 0$. In more technical terms, this simply means that the stable system always occupies the ground state and therefore cannot deenergize by emitting radiation.

b) For an unstable particle occupying an excited level, the system can return to the fundamental level by radiative de-excitation. It then emits a photon. So for $n=1$, we have:

$$1 \approx \frac{1}{\omega \cdot \Delta t}$$

$$\Leftrightarrow \Delta t \approx \frac{1}{\omega};$$

With Δt, the lifetime of the excited level and ω is the frequency of the emitted wave.

4. Conclusions

The binding cord approach allowed us to perceive the repulsion between particles in electromagnetic interaction as a consequence of attraction. It also allowed us to explain the stability and instability of a number of systems knowing only the electric field and the magnetic field associated with the system. Thus, a system characterized by a zero electric field and a zero magnetic field, is stable (*i.e.* the binding cord holds whatever happens) and in the opposite case, the system is unstable (*i.e.* the binding rope hangs by a thread and it can break at any time).

This approach also allows us to justify the lifetimes of systems with similar physical properties. Thus, now we can understand why a particle and the corresponding antiparticle are always characterized by identical lifetimes.

It is however important to remember that to build our model, we started from an approximation of the total energy of the electromagnetic field and we neglected certain components of this one. This justifies the fact that this approach explains the stability and instability of a certain number of systems but does not explain them all. One can cite for example the pawn π° which is unstable while it is characterized by neutral charge and zero spins. However, the general principle of the binding cord theory is simple: **any particle with nonzero charge or total spin will always be unstable**. In particular, for a stable atom, we will have two cases:

- For an atom with a nucleus of zero spins (magic numbers), the total spin of the electrons is also zero.
- For an atom with a quadrupole nucleus *i.e.* of nonzero spin, the total spin of the electrons is equal and opposite to the spin of the nucleus.

Moreover, the opposite of the principle stated above is not always true, and a counter-example is the case of the neutral pawn.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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