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БИБЛИОТЕКА

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Об одной гипотетической возможности поиска монополя Дирака

В настоящей работе для магнитных зарядов g вводятся обособленные уравнения Максвелла, в которых $\mathrm{div}\vec{B} = 4\pi\rho_m$, а $\mathrm{div}\vec{D}=0$, т.е. уравнения, описывающие электромагнитные явления в мире, построенном только из магнитной материи/"мир g"/. Постулируется, что магнитная материя состоит из атомов, подобных атому Бора, а постоянная тонкой структуры универсальна для нашего мира /"мира e"/ и "мира g", т.е. $\frac{e^2}{\hbar_e c} = \frac{e^2}{\hbar_g c} \equiv \alpha$. Вследствие чего при $e \neq g$ постоянные Планка h_g и h_e миров g и e неодинаковы ($h_g \neq h_e$). При связи между g и e предсказанной Дираком ($g=\frac{e}{2\alpha}n$), получено соотношение между h_g и h_e в виде $h_g=\frac{n^2}{4\alpha^2}h_e$. Обсуждаются возможные проявления магнитной материи в Космосе и в опытах на ускорителях.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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On a Hypothetical Possibility of the Search for Dirac's Monopole

The present investigation for the magnetic charges "g" introduces the independent equations of Maxwell where $\mathrm{div}\vec{B}=4\pi\rho_m$ and $\mathrm{div}\vec{D}=0$, i.e., the equations describing electromagnetic phenomena in the world consisting of only magnetic matter (the "g" world). It is postulated that magnetic matter should consist of atoms similar to Bohr's ones, and the fine structure constant should be universal for our world (the world "e") and the world "g", i.e. $\frac{e^2}{\hbar_e c}=\frac{e^2}{\hbar_g c}\equiv\alpha$. As a result, with $e\neq g$, the Planck constants h_g and h_e of the "g" and "e" world are not equal ($h_g \neq h_e$). With the relationship of "g" and "e" predicted by Dirac ($g=en/2\alpha$) it is possible to obtain the relation for h_g and h_e as $h_g=\frac{n^2}{4\alpha^2}h_e$. Some possible displays of magnetic matter in-space and at accelerators are discussed.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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1. INTRODUCTION

As many as 50 years have passed since Dirac /1/ has predicted possible existence of magnetic charges in nature. Over this period numerous experimental studies on searching for the Dirac monopole have been carried out by various methods using cosmic rays and at the largest accelerators which all have yielded a negative result*. The present state of the problem both in theoretical and experimental fields is very well covered in the literature by Stevens /2/, Carrigan /3/ and in a monograph written by Strazhev and Tomilchik /4/.

Newmeyer and Trefil /5/ see the reason of experimental failures of discovering the magnetic charge in the fact that strong electromagnetic interactions of the monopole and antimonopole generated in the reaction of type $p+p \to p'+p''+g+\tilde{g}$ not only considerably reduce the production cross section of free magnetic charges but lead also to their annihilation with the emission of quite a number of hard gamma-quanta.

On the basis of the hypothesis presented below it is predicted that in annihilation of the monopole-antimonopole pairs gamma-quanta of special nature originate (the quanta described by Planck's another constant).

2. MAXWELL EQUATIONS FOR THE MAGNETIC MATTER

Dirac /1/ has been the first to introduce the magnetic charge "g" to the Maxwell equations to attribute to them a full symmetry in the relations of the fields $\vec{E}$ and $\vec{H}$ by writing them as**

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*Not to mention the disputable paper by P.B.Price et al., Phys.Rev.Lett., 1975, 35, No.8, p.487.

**Negative sign before the magnetic current density in these equations follows from the continuity condition of the magnetic charge $\frac{\partial\rho_m}{\partial t} = -\mathrm{div}\vec{j}_m$.

$$\left.\begin{aligned} \mathrm{rot}\,\vec{H} &= \frac{4\pi}{c}\vec{j}_e + \frac{1}{c}\frac{\partial \vec{D}}{\partial t}, \\ \mathrm{div}\,\vec{D} &= 4\pi\rho_e, \\ \mathrm{rot}\,\vec{E} &= -\frac{1}{c}\frac{\partial \vec{B}}{\partial t} - \frac{4\pi}{c}\vec{j}_m, \\ \mathrm{div}\,\vec{B} &= 4\pi\rho_m . \end{aligned}\right\} \qquad (1)$$

The successive solution of eqs. (1) provided that $\mathrm{div}\,\vec{B} \neq 0$ required introducing an additional fictitious magnetic field H_f ($\mathrm{rot}\,\vec{A} = \vec{H} + \vec{H}_f$) which is treated as an infinite solenoid- "Dirac's string" along which the magnetic flux for compensating the Coulomb field of the monopole $\vec{H} = \frac{g\vec{r}}{r^3}$ is fed to the place of the magnetic charge "g" residence. The consideration of the dynamics of the electron motion in the field of such a source of the magnetic field in the case of "Dirac's veto" application (the electron never hits the "Dirac's string") results in the quantum condition

$$g = \frac{e}{2\alpha} n, \qquad (2)$$

where $\alpha = \frac{e^2}{\hbar c}$ is the constant of the fine structure, while $n = 0, \pm 1, \pm 2, \pm 3, \ldots$.

However, such a way of introducing the magnetic charge is not a single one. If there really is magnetic matter (the world "g") in the Universe, for the world "g", in our opinion, one must introduce special Maxwell's equations with $\mathrm{div}\,\vec{B} \neq 0$, in which the electric charge is absent ($\mathrm{div}\,\vec{D} = 0$), i.e.,

$$\left.\begin{aligned} \mathrm{rot}\,\vec{E}' &= \frac{4\pi}{c}\vec{j}_m + \frac{1}{c}\frac{\partial \vec{B}'}{\partial t}, \\ \mathrm{div}\,\vec{B}' &= 4\pi\rho_m, \\ \mathrm{rot}\,\vec{H}' &= -\frac{1}{c}\frac{\partial \vec{D}'}{\partial t}, \\ \mathrm{div}\,\vec{D}' &= 0, \end{aligned}\right\} \qquad (3)$$

where ρ_m is the density of the magnetic charge.

These equations are completely symmetric to the normal Maxwell's equations describing the electromagnetic processes in our world (the world "e").

$$\left.\begin{aligned} \mathrm{rot}\,\vec{H} &= \frac{4\pi}{c}\vec{j}_e + \frac{1}{c}\frac{\partial \vec{D}}{\partial t}, \\ \mathrm{div}\,\vec{D} &= 4\pi\rho_e, \\ \mathrm{rot}\,\vec{E} &= -\frac{1}{c}\frac{\partial \vec{B}}{\partial t}, \\ \mathrm{div}\,\vec{B} &= 0. \end{aligned}\right\} \qquad (4)$$

Take now equal fluxes of the electromagnetic energy in the world "e" and the world "g"

$$\vec{S}_e = \vec{S}_g , \qquad (5)$$

where $\vec{S}_e = \frac{c}{4\pi}[\vec{E}, \vec{H}]$, while $\vec{S}_g = \frac{c}{4\pi}[\vec{H}', \vec{E}']$, and compare these fluxes with the number of quanta N_e and N_g with equal frequency ν in the worlds "e" and "g".

For the world "e", as we know, this is given by

$$N_e = \frac{S_e}{h_e \nu}, \qquad (6)$$

where h_e is the Planck constant for our world.

For the magnetic world "g" we postulate that it should consist of magnetic atoms, i.e., of atoms consisting of particles carrying only magnetic charges, having the planetary structure, completely similar to Bohr's atom, exclusive that the conditions of quantization of magnetic atoms are expressed by Planck's another constant h_g which is not equal to Planck's normal constant of the world "e" h_e, i.e., $h_g \neq h_e$ *.

In this case the number of magnetic quanta corresponding to the energy flux S_g is

$$N_g = \frac{S_g}{h_g \nu}. \qquad (7)$$

In view of the postulate $h_g \neq h_e$, $N_e \neq N_g$ (with $S_e = S_g$). What is the value of h_g then?

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* Note that it is Dirac (Sc. Amer., 1963, vol. 208, No. 5, p.45-53) who was inclined to think that of the three values e, $\hbar$ and c leading to the fine structure constant, $\hbar$ is, most probably, not a fundamental one. (This fact has been indicated to me by J.Ružička).

Since we have introduced into consideration the magnetic substance, magnetic atoms (similar to Bohr's one), we make now one more step and consider that the constant of the fine structure for the "magnetic" atom is the same as for our world, i.e.,

$$\frac{g^2}{\hbar_g c} = \frac{e^2}{\hbar_e c} = \alpha\,, \tag{8}$$

or $\alpha_g = \alpha_e = \alpha$, where g is the magnetic charge, e is the electric charge, $\hbar_g = \frac{h_g}{2\pi}$, $\hbar_e = \frac{h_e}{2\pi}$, c is the light velocity in vacuum.

From condition (8) it follows that the relationship between h_g and h_e is determined by the ratio $\{\frac{g}{e}\}^2$. By introducing the magnetic charge to the Maxwell normal equations Dirac had deduced relation (2) for g and e.

By substituting it into eq. (8) one obtaines

$$h_g = \frac{n^2}{4}\,\frac{h_e}{\alpha^2}\,. \tag{9}$$

With $n = 2$ $g = e/\alpha$ (the Schwinger charge)*

$$h_g = \frac{h_e}{\alpha^2} \cong 1.88 \times 10^4\, h_e\,. \tag{10}$$

In the approach to the magnetic matter developed in this paper one must consider Dirac's theory /1/ as a method for comparing the values of the charges e and g.

Indeed, "an observer" in the world of the magnetic matter for which eq. (3) holds also symmetrizes them with respect to the fields $\vec{E}$ and $\vec{H}$ by introducing into these equations the electric charge "e" and obtains the following system of equations

$$\left.\begin{aligned} \operatorname{rot}\vec{E}' &= \frac{4\pi}{c}\vec{j}_m + \frac{1}{c}\frac{\partial \vec{B}'}{\partial t}\,, \\ \operatorname{div}\vec{B}' &= 4\pi\rho_e\,, \\ \operatorname{rot}\vec{H}' &= -\frac{1}{c}\frac{\partial \vec{D}'}{\partial t} - \frac{4\pi}{c}\vec{j}_e\,, \\ \operatorname{div}\vec{B}' &= 4\pi\rho_m\,. \end{aligned}\right\} \tag{11}$$

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*This relationship between h_g and h_e is constantly used below.

When solving the system of equations (11) with $\operatorname{div}\vec{D}' \neq 0$ by the analogy to system (1) it is necessary to introduce the fictitious electric field $\vec{E}_f$ ($\operatorname{rot}\vec{C} = \vec{E} + \vec{E}_f$), where $\vec{C}$ is a vector potential, which must be treated as an infinite electric solenoid - "the electric string", along which the electric flux E_f is fed to the electric charge place for compensating the Coulomb electric field of the charge "e" $E_f = \frac{e\vec{r}}{r^3}$. By imposing the prohibition on the magnetic charge hitting the "electric string" following Dirac's consideration, one can come again to the condition of quantization (2) with only one difference that h_e is replaced by h_g,

$$eg = \frac{n}{2}\hbar_g c\,. \tag{12}$$

Thus, "an observer" in the world "g" knowing his constant of the fine structure α_g "obtains" that with $n = 2$ $e = g/\alpha_g$, i.e., with $\alpha_g \cong 1/137$ $e \cong 137 g$.

3. HYDROGEN-LIKE MAGNETIC ATOM (HLMA)

If the magnetic atoms are a complete similarity of Bohr's atom, i.e., a negative magnetic charge g_- with the mass m_{g-} is rotating around the positive nucleus of the magnetic atom with the charge Kg_+, the frequencies of quanta emitted by such an atom with the charge transition g_- from a stable orbit to another one are determined by the formula

$$\nu = \frac{m_{g-}c^2K^2}{2h_g}\,\alpha_g^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right), \tag{13}$$

where α_g is a fine structure constant, while n_1 and n_2 are major quantum numbers ($n_2 = n_1 + n_i$, where $n_i = 1, 2, 3, \ldots$).

When the nucleus of the magnetic atom has a charge $K = 1$, we have a hydrogen-like magnetic atom (HLMA). The frequencies of quanta emitted by such HLMA must coincide with all the series of a conventional hydrogen atom provided that

$$\frac{m_{g-}c^2}{h_g} = \frac{m_e c^2}{h_e}\,, \tag{14}$$

where $m_{g-}c^2$ and $m_e c^2$ are, respectively, the rest energies of the monopole and the electron, from (14) it also follows that

$$m_{g-} = \frac{h_g}{h_e}\,m_e\,. \tag{15}$$

By using eq. (9) for h_g/h_e and substituting into (15) one obtains

$$m_{g-} = m_e \frac{n^2}{4\alpha^2} . \qquad (16)$$

$$\text{With } n = 1 \quad m_{g-}c^2 = 2.4 \text{ GeV}, \qquad n = 2 \quad m_{g-}c^2 = 9.6 \text{ GeV}. \qquad (17)$$

These evaluations coincide with "canonical" masses of the monopole made on the basis of the equalization of the classical electron radius to the monopole radius (see, e.g., ref. /16/).

It goes without saying that if the condition of the coincidence of the frequencies of quanta emitted by Bohr's atoms and HLMA is not applied, the masses of magnetic charges m_{g-} can differ from the above-mentioned evaluations (17).

We have evaluated the mass of the negative magnetic charge being on the HLMA orbit, i.e., "a light monopole". What is the mass of the positively charged nucleus of M_{g+} hydrogenlike magnetic atom?

If one accepts that

$$\frac{M_{g+}}{m_{g-}} = \frac{m_p}{m_e} , \qquad (18)$$

where m_e and m_p are respectively, the electron and proton masses, then the mass of the magnetic nucleon $M_{g+} = m_{g-}\frac{m_p}{m_e} = 17.6$ TeV with $m_{g-}c^2 = 9.6$ GeV. This mass of the magnetic nucleon is close to that of the monopole following from the Hooft-Polyakov /7,8/ model.

Note that such a model of the magnetic hydrogen-like atom built of the Dirac monopole and the Hooft-Polyakov monopole has been recently applied /9/ for explaining unusual properties of the magnetic charge detected by Price et al./10/.

The sizes of the hydrogenlike magnetic atom are determined by the radius of the first HLMA orbit, i.e., by the value

$$r_g = \frac{g^2}{m_{g-}c^2\alpha_g^2} , \qquad (19)$$

and the ratio of r_g to the radius of Bohr's atom of the world "e" is

$$\frac{r_g}{r_e} = \frac{m_e c^2}{m_{g-}c^2\alpha_g^2} . \qquad (20)$$

With $m_{g-}c^2 = 9.6$ GeV $r_g/r_e \cong 1$.

The binding energy of the light monopole with m_{g-} in HLMA with its nucleus (or the ionization energy of HLMA) is determined by the Ridberg magnetic constant

$$R_g = \frac{m_{g-}c^2}{2}\alpha^2 . \qquad (21)$$

With $m_{g-}c^2 = 9.6$ GeV $R_g \cong 256$ KeV.

The heavy photon energy spectrum of the Lyman series (n=1) of HLMA (condition (14) being valid and $m_{g-}c^2 = 9.6$ GeV) starts with an energy $(h_g\nu)_{max} \cong 250$ keV, whereas the Paschen series (n=3) starts with an energy $(h_g\nu)_{min} = 28$ keV.

Thus, HLMA at photon frequencies corresponding to our optical spectrum can emit magnetic optical quanta in the energy scale belonging to the X-ray region ~(28÷250) keV.

If the magnetic world "g" by analogy to the world "e" contains besides HLMA some other atoms whose nuclei have the charge $K > 1$ (i.e., the set of these atoms is a kind of the Periodic System of magnetic atoms), then the maximum energy of the heavy quantum which can be emitted by the same atoms in their excitation according to (11) is as follows

$$E_{max}^{\gamma g} \cong (h_g\nu)_{max} K^2 . \qquad (22)$$

With the maximum charge of the magnetic nucleus $K = 100$, $E_{max}^{\gamma g} = 2.5$ GeV, i.e., this is quantum energy of the magnetic atoms corresponding to the X-ray quanta of our world "e".

4. POSSIBLE MANIFESTATIONS OF THE MAGNETIC MATTER IN SPACE AND IN ACCELERATOR EXPERIMENT

1) X-ray Radiation in Space

As has been stated above, the energy spectrum of heavy quanta of HLMA at frequencies corresponding to our optical range covers the interval from about 28 to about 250 keV. Thus, the magnetic matter consisting of magnetic atoms emits heavy quanta of the energy corresponding to the X-ray one and in a harder part of the spectrum. A question arises whether magnetic matter can manifest itself in such global phenimena as specific radiation in space.

In a recently published book by Shklovsky [11] there is detailed information on extremely powerful sources of X-ray radiation first discovered in 1969 by an American patrol squadron conltrolling the agreement on the ban of nuclear tests in the atmosphere. The spectrum of this misterious X-ray radiation is just within the energy range from 10 to 250 keV, while the flux is about 10^{-4} Erg/cm^2 sec.

At present it has been established that the sources of this radiation are the so-called ball stellar clusters. The maximum value of this radiation is about 3×10^{38} Erg/sec, which is comparable, as Shklovsky remarks, with the bolometric luminocity of the whole ball cluster amounting to some hundred thousand stars. It is worth mentioning that if the energy radiated by the Sun $W_{\odot}\sim 3,8\times10^{33}$ Erg/sec is multiplied by the ratio of the Planck constants $\frac{h_g}{h_e} = \frac{1}{\alpha^2} \cong 2\times10^4$ one obtaines $W = \frac{W_{\odot}}{\alpha^2} \cong 8\times10^{37}$ Erg/sec which is close to the above-said maximum value of the X-ray sources.

In view of the concept developed here one can put a question whether this powerful pulsed X-ray radiation of stellar cluster might be magnetic matter radiation.

The measurements of the Planck constant of this radiation, e.g., by means of the Compton effect, could be a direct evidence of the above statement.

2) Peculiarities of the Compton-Effect of Quanta Having the Planck Constant $h_g = h_e/\alpha_g^2$

The variation of the wavelength of the X-ray quanta (with the normal Planck constant h_e) scattered on electrons is

$$\Delta\lambda = \frac{h_e}{m_e c}(1-\cos\theta), \qquad (23)$$

where m_e is the rest electron mass, c is the velocity of light, θ is the angle between the directions of the incident and scattered protons. The maximum change of the wavelength in backward quantum scattering ($\theta = \pi$) is $(\Delta\lambda)_{max} = 0.0484$Å.

When the radiation having the Planck constant $h_g = h_e/\alpha^2$ is scattered on the electron, the variation of such quanta is increased as $\frac{h_g}{h_e} = \frac{1}{\alpha^2}$, i.e., the maximum variation of the wavelength $(\Delta\lambda)_{max} = 0.0484\times1.88\times10^4$ Å$\cong$900Å. The corresponding maximum change of the quantum energy $\Delta(h_g\nu)$ is

$$\Delta(h_g\nu)_{max} \cong 2\frac{(h_g\nu)^2}{m_e c^2}\,. \qquad (24)$$

3) Light Flashes Observed by American Astronauts

It is known [12] that in the "Apollo" space flight to the Moon American astronauts could regularly observe bright white flashes occuring in the eyes as frequently as 1-2 flashes per minute. Although these flashes have been already explained and confirmed experimentally on the basis of Vavilov-Cherenkov radiation from relativistic nuclei, this effect might occur as a result of "optical" radiation of magnetic matter.

Let's admit thus unusual X-ray radiation mentioned above in item I of this Section to be like this. Its flux in the near-Earth space is about $\sim10^{-4}$ Erg/cm^2 sec. With the average energy of this radiation quanta of $h_g\nu \sim 0.1$ MeV this corresponds to about 6×10^2 quanta/cm^2 sec. If these quanta have optical frequencies, i.e., if their wavelength exceeds essentially the atomic sizes, they must undergo coherent scattering [13] on electrons, whose total cross section should be $\sigma\sim\sigma_0 Z^2$, where σ_0 is the cross section of the Thomson scattering on electrons, and Z is the atomic number.

The calculations show that with the 1.5 cm aluminium coating of the "Apollo" spaceship, the flux of unusual quanta inside the coating is about 4.5×10^{-5} of the initial one. With the area of the human eye of about 2.5 cm^2 as many as 4 quanta per minute could hit it, which is in good agreement with the astronauts' observations*. With a 95% probability such a quantum can be scattered coherently on the electrons of the eye's liquid. According to formula (24) a quantum with an average energy of $\overline{h_g\nu} = 0.1$ MeV transfers the energy of $\Delta(h_g\nu) = 40$ keV to electrons which at the frequency of the original quantum $\nu = 1.3\times10^{15}$ sec^{-1} emit quanta (with the conventional Planck constant h_e) amounting

*As has been reported [14], no one of the Soviet cosmonauts, except N.N.Rukavishnikov, observed such flashes. This can be explained, however, by a thicker coating of the Soviet spaceship "Soyuz" and the space station "Salyut".

to $\frac{\Delta(h_g \nu)}{h_e \nu} \cong 10^4$ quanta. Such a light flash exceeds the sight threshold about 2-3 orders of magnitude.

4) Possible Displays of Unusual Quanta in Accelerator Experiment

Basing on the Trefill-Newmeyer concept [5] of searching for magnetic charges by means of high energy gamma-quanta from annihilation pairs $(g,\tilde{g})$ produced in prompt particle collisions with nucleons a number of experiments [16-21] have been performed at high energy accelerators. However, these experiments were performed in such a way that they detected only the events of multiple hard gamma-quanta production.

According to the present concept, it should be mentioned that all annihilation quanta have a considerably large Planck constant, therefore, they must interact specifically (just keeping in mind that they cannot be absorbed by normal atoms).

In our opinion, the soft part of the unusual photons originating as bremsstrahlung of the monopole-antimonopole pair or monopolium (by analogy with the positronium) is of interest.

The calculations involving the formulas given in the book [21] show that the number of bremsstrahlung quanta with the Planck constant in the frequency range from $\nu_1 \cong 2\text{x}10^{15}\ \text{sec}^{-1}$ to $\nu_2 \cong 10^{16}\ \text{sec}^{-1}$ is about 25*. With the average energy $h_g\nu \sim 0.5$ MeV this amounts to about 0.05% of the total monopole mass $2m_g c^2 = 20$ GeV.

Such quanta with $\bar{\nu} = 6\text{x}10^{15}\ \text{sec}^{-1}$ in their interaction with a medium due to a multiple coherent scattering can pass to the frequency range of the visible spectrum and in detection, e.g., on the colour film, must cause noticeably monocoloured blackening, as quantum energy (with the constant $h_g \cong 1.9\text{x}10^4 h_e$ and $\nu \cong 10^{15}\ \text{sec}^{-1}$) $h_g \bar{\nu} \cong 1.2\text{x}10^{-7}$ Erg is equivalent to $\sim 2\text{x}10^4$ quanta with the normal h_e.

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*This evaluation is strongly dependent upon the fact that the frequency ν_1 is close to that $\nu_0 = \frac{3g^2}{8a_0 h_g}$, where the radius $a_0 = \frac{r_g}{\alpha^2}$ (in this case $\nu_0 - \nu_1 = 10^{-10}\nu_0$).

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