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Schwarzschild Radius for Electric Charge

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Abstract

The aim of this work is to prove the formula for the Schwarzschild radius analog in case of a static spherically symmetric electric charge. The work contains two elegant proofs of the formula for the gravitational radius and for its analog in the case of an electric charge. The author mathematically proves that the Schwarzschild radius formula should not have a multiplier of 2. Proposed by the author in 2006 the relationship formula between the electric charge and the energy of this electric charge was applied in the proof of the formula for the Schwarzschild radius analog in case of a static spherically symmetric electric charge. And the results are another confirmation of the state- meant validity about the electric charge equivalence and its energy. An analysis was carried out on the correspondence of the formula for the Schwarzschild radius analog in case of a static spherically symmetric electric charge to the Reissner-Nordström and Schwarzschild solutions results and it is shown that they are in full agreement with each other. The radiation temperature expression is pro- posed for a spherically symmetric black hole with a static electric charge, but without rotation. An expression is obtained for the particles production probability estimating in a static electric field of a black hole. The author proposes the Coulomb's law application limit explanation. The author ex- plains the existence possibility of long-lived charged black holes. This work proposes an original method of the gravity formulas converting into the electricity formulas and vice versa, which allows finding unknown dependencies in physics. This work is another step towards the standardization of physics and its formulas and to some general approach in the problems solving from completely different sections of physics. An expression is obtained for the entropy of a spherically symmetric black hole, due to its electric charge.

Keywords: The Schwarzschild Radius, the Electric Charge Non-Invariance, the Coulomb's law Application Limit, the Reissner-Nordström Solution.

Introduction

Modern science has a large number of theories about black holes, their origin and development. The study of black holes is of interest from the view point of the Universe origin understanding. For the first time about very massive bodies, in which the force of gravity is so great that even light can't escape from them, the English astronomer John Mitchell wrote. Thanks to Michel, this hypothesis appeared in (Michell, 1784). For stationary solutions of Einstein's equations, only three variable characteristics are used that correspond to one or another type of black hole: mass M, momentum L, and electric charge e. At first Schwarzschild had decided of the Einstein's equations for a static spherically symmetric mass and he had obtained the solution in the form

$$ds^2=\left(1-\frac{r_g}{r}\right)c^2dt^2-\frac{dr^2}{1-\frac{r_g}{r}}-r^2(d\theta^2+\sin^2\theta d\phi),$$

where $r_g=\frac{2GM}{c^2}$;r = gravitational radius; s = interval; M = mass;

G = gravitational constant; c = velocity of light in vacuum; r, Θ, φ = spherical coordinates [1].

The Reisner-Nordström solution was next the Einstein's equations solution. This is a static solution of the spherically symmetric black hole which has mass and electric charge, but it hasn't the rotation. We can write the metrics of the Reisner-Nordström black hole in the form

$$ds^2 = Fc^2 dT^2 - F^{-1} dR^2 - R^2\left(d\theta^2 + \sin^2\theta d\phi^2\right),$$

where $F = 1 - \frac{2GM}{c^2 R} + \frac{GQ^2}{c^4 R^2}$

The Kerr solution describes the rotating black hole, which has mass M and momentum L, but which hasn't the electric charge [2].

The Kerr-Newman solution was obtained subsequently. The Kerr-Newman solution describes the black hole, which has mass M, momentum L and electric charge e.

Modern science is actively looking for the black holes. If we put the probe inside a black hole, we will get any information from it. That's, everything inside of the black hole can't escape from it. For a static spherically symmetric mass it is possible to construct a Schwarzschild radius which determines the black hole formation possibility from a specific mass

$$r_g = \frac{2GM}{c^2}$$

A similar radius exists for a static spherically symmetric electric charge [3]. And, as follows from the content of this work, this radius for the electric charge can determine the information non-return scope from the volume of a particular electric charge. In other words, just as in gravity we can't obtain information from a black hole, so in electricity we can't obtain information from the electric charge sphere which is limited by the Schwarzschild radius analog.

Looking at the previous formula, we can assume that the formula for the Schwarzschild radius analog will consist of a combination of two constants and an electric charge.

Formulation of the Problem

This work aims to prove the formula for the Schwarzschild radius analog in case of a static spherically symmetric electric charge.

Results

The formula for the Schwarzschild radius analog is obtained

$$r_\lambda = \frac{e}{4\pi\varepsilon_0\lambda}$$

where e = electric charge; ε0 = electric constant; λ = constant ($\lambda \approx 10^6$ V).

The formula for the Schwarzschild radius is written more precise $r_g = \frac{GM}{c^2}$

The Coulomb's law application limit is explained.

An expression is obtained for the entropy of a spherically symmetric black hole, due to its electric charge.

The physical quantities converting method is described, which allows finding unknown dependencies in physics. This work is another step towards the standardization of physics and its formulas from completely different sections of physics.

The radiation temperature expression is proposed for a spherically symmetric black hole with a static electric charge, but without rotation $\theta = \frac{\hbar c \vec{E}}{2\pi\lambda k}$

where ħ = Planck's constant; $\vec{E}$ = electric field strength; k = Boltzmann's constant.

An expression is obtained for the particles production probability we estimating in a static spheric- ally symmetric electric field of a black hole

$$w_e = A \exp\frac{-\beta E}{2\pi k\Theta}$$

where E = λe;

β = dimensionless constant of the order of unity;

A = pre-exponential factor depends on (as well as β) the more detailed characteristics

of the field.

Discussion

First of all, let's formulate the definition of electric charge. Electric charge is a body acceleration measure when only an electric field is applied to the body (it's assumed that the body consists only of an electric charge, that's it hasn't mass).

The Schwarzschild radius clarification

Let's write the formula for the Schwarzschild radius

$$r_g = \frac{2GM}{c^2} \quad (1)$$

Let's try to prove the same formula. The gravitational energy E of resting mass m located at a distance rg from the center of mass M is equal to

$$E = \frac{GMm}{r_g}$$

On the other hand, the same energy can be written in this form $E = mc^2$. Let's equate them.

$$mc^2 = \frac{GMm}{r_g}$$

Whence we obtain formula (2)

$$r_g = \frac{GM}{c^2} \quad (2)$$

The equation (3) is used in the proof of the formula for the Schwarzschild radius

$$\frac{mv^2}{2} = \frac{GMm}{r_g} \quad (3)$$

Kinetic energy is implied on the left-hand side of this equation [4]. But the formula for kinetic energy in classical physics differs from the formula for relativistic kinetic energy. And if we assume that the velocity of the mass m equals to c, then we must also use the formula for the relativistic ki- netic energy E_k

$$E_k = E - E_0,$$

where E = total energy, E_0 = rest energy.

That's, a simple substitution of $\frac{mv^2}{2}$ for $\frac{mc^2}{2}$ is impossible. Therefore, the formula (3) is incorrect in relativistic physics. Therefore, expression (1) is also incorrect. And the expression (2) validity should be recognized.

Schwarzschild Radius in the Electric Charge Space

Continuing the equivalence theme of electric charge and energy, proposed by the author in 2006, the author offers a proof of the formula for the Schwarzschild radius analog (but not for mass, but for electric charge).

Let's carry out similar reasoning for an electric charge.

On the one hand, the energy E of the resting electric charge q, located at a distance r from another electric charge e, is calculated by the formula

$$E=\frac{qe}{4\pi\varepsilon_0 r} \quad (4)$$

On the other hand, according to (Lunin, 2006) one can be written

E = λq , (5)

where E = energy of electric charge q.

Let's equate expressions (4) and (5).

$$\lambda q=\frac{qe}{4\pi\varepsilon_0 r}.$$

Then we get r

$$r=\frac{e}{4\pi\varepsilon_0\lambda}.$$

If we take r on the Schwarzschild sphere, then r = rλ . And now we can write the final form of the formula for the Schwarzschild radius analog in case of a static spherically symmetric electric charge.

$$r_\lambda=\frac{e}{4\pi\varepsilon_0\lambda} \quad (6)$$

Every Atomic Nucleus is a Black Hole

Knowing the positron and electron annihilation energy, in the first approximation, we can calculate the value of λ. And knowing λ, you can calculate the Schwarzschild radius analog for electric charge.

For example, let's calculate the Schwarzschild radius analog for an electron/proton having an al- most elementary electric charge. Let's mark this radius rλe . Firstly calculate λ. The energy (E ≈ 1 MeV) is released during the positron and electron annihilation. This energy can be expressed in joules, $E = 1.6\times10^{-13}$ J . Then we find λ from the formula E = λe .

λ = E/e.

$$\lambda=\frac{1.6\times10^{-13}J}{1.6\times10^{-19}C}.$$

$\lambda = 10^6$ V.

We got λ. Now we can calculate the Schwarzschild radius analog for the electron/proton from (6)

$$r_{\lambda e}=\frac{1.6\times10^{-19}}{4\pi\times8.85\times10^{-12}10^{6}}m.$$

$r_{\lambda e} = 1.44\times10^{-15}$ m ≈ 10^{-15} m

We got the Schwarzschild radius rλe analog for the electron/ proton. And the atomic nuclei dimensions are just of such order (about 10-15 m) (Safarov, 2008). At this distance, the Coulomb's repulsion of protons in the nucleus no longer prevents them from approaching, and a strong interaction begins to appear. It turns out that it is precisely at distances of this order the Coulomb's force be- comes vanishingly small, either by itself or in comparison with the forces of another nature manifested at such distances. It's well known that the deviations from the Coulomb's law occur at distances of this order. In other words, calculating the Schwarzschild radius analog for an electron/pro- ton, we see that this radius coincides with the Coulomb's law application limit.

Comparing the gravitational radius value for electron (rge ≈ 10-57 m, this is a tabular value) and the Schwarzschild radius analog value for electron (rλe ≈ 10-15 m), we see that the black hole formation conditions for electron as an electric charge occur at much greater distances than for electron as the mass owner. Modern science denies the long-lived charged black holes existence possibility, believing that charges of the same sign will quickly scatter in different directions. However, it has to remember that under the black hole conditions, the Coulomb's repulsion forces become

vanishingly small (a complete analogy with protons in a nucleus). Therefore, the charge in a black hole can persist for an arbitrarily long time.

There are the black holes in the Universe and the black holes (atomic nucleus) in every atom. But they have different conditions for the black hole's formation (gravitational or electric). The study of black holes in the Universe can help in the study of atomic nuclei and vice versa, and in quite different aspects.

Another Way to Obtain the Schwarzschild Radius in the Electric Charge Space

Knowing expression (2), we can get expression (6) in another way. We can come to expression (6) by logical considerations. We can assume that mass M will naturally transform into an electric charge e, gravitational constant G will change into electric constant ε0 with multiplier 4π and for two reasons it will be in the denominator of the sought formula. Firstly, the gravitational constant G is numerically equals to the force with which two unit masses interact, when they are at a unit dis- tance from each other. Having written down the Coulomb's law, we can see that the electric con- stant ε0 can't be imagined as the force with which two unit charges interact at a unit distance from each other. But this fraction 1/(4πε0) will already equal numerically to the interaction force of two unit charges located at a unit distance from each other. And, secondly, as can be seen visually at once, in the universal gravitation law and in the Coulomb's law these constants are in the different structural positions: G is in the numerator and 4πε0 is in the denominator. It remains to understand what can replace c2. And here we have to remember the constants that assign energy in accordance to each mass and each electric charge. Einstein assigned the energy E for each mass M through the proportionality coefficient c2. In the work for each electric charge e the author as- signed the energy E through the proportionality coefficient λ [5]. In electricity the constant λ plays the same role as the constant c2 in gravitation.

Then c^2 can be replaced by the constant λ in the Schwarzschild radius formula. Therefore, using expression (2), we can write the formula for the Schwarzschild radius analog in case of a static

spherically symmetric electric charge in this form

$$r_\lambda=\frac{e}{4\pi\varepsilon_0\lambda}$$

and this completely coincides with the expression (6). Thus, we arrived at the proven formula by simple logical reasoning.

These simple substitutions (M ↔ e, c^2 ↔ λ, 1/G ↔ 4πε₀) can become a very effective original method in the unknown dependencies search in physics.

One interesting remark can be made. The specific energy of binding for many nuclei turns out by a constant value, which equals ≈ 8 MeV (Safarov, 2008). You can see that the constant λ differs from this value by about 10 times (per one electron). It's very likely that in the values specifying case of these two physical quantities, it may turn out that their values coincide. And the specific energy (per one electron) of binding will turn out by the physical meaning of the constant λ. The specific energy Y constancy of binding indicates that the nucleus energy $E_{(Z,A)}$ is proportional to the number A of nucleons (Safarov, 2008)

$$E_{(Z,A)} \sim YA$$

Comparison of the Schwarzschild Radius and its Analog

There is an expression was obtained for the Schwarzschild radius square, but for an electric charge

$$r_Q^2 = \frac{e^2 G}{4\pi\varepsilon_0 c^4}. \quad (7)$$

Let's make some remarks about the expressions (2) and (7) [6].

1. Let's think a little about the coefficient 2 in expression (1). There are three independent paths that lead to the same result. Firstly, there is the proven expression (2) in this work. Secondly, if in the expression (7) we replace e with M, as well as this fraction 1/(4πε₀) with G, then we get the ex- pression for the Schwarzschild radius in such form

$$r_g = \frac{GM}{c^2} \quad (8)$$

We see that expressions (8) and (1) are in contradiction with each other. They differ by a multi- plier of 2. This means that some result of the Einstein equations solving is not correct: either the ex - pression (1) or the expressions (7) and (8).

Thirdly, if in the formula (6) for the Schwarzschild radius analog in case of a static spherically symmetric electric charge we do the analogous substitutions, namely e with M, this fraction 1/(4πε0) with G as well as λ with c^2, respectively, then we get the expression for the Schwarzschild radius in this form

$$r_g = \frac{GM}{c^2}$$

Thus, we see that the proven expressions (2), the expression (7) and the formula (6) for the Schwarzschild radius analog in case of a static spherically symmetric electric charge led to the same expression for the Schwarzschild radius. That's, three different paths lead to the same result. From this we can conclude that the coefficient 2 should not be in the formula for the gravitational radius. Therefore, the gravitational radius rg formula will be more correct in the form

$$r_g = \frac{GM}{c^2}.$$

2. Let's compare r_λ^2 and r_Q^2

$$\frac{r_\lambda^2}{r_Q^2} = \frac{e^2}{16\pi^2\varepsilon_0^2\lambda^2}\,\frac{4\pi\varepsilon_0 c^4}{e^2 G}$$

$r_\lambda^2/r_Q^2 \approx 10^{42}$

We get rλ rλ ≈ 10^{21} rQ

That's the Schwarzschild radius analog is 1021 times greater than the one given by the expression

(7). Let's write it down for an electron $r_{\lambda e} \approx 10^{21} r_{Qe}$.

With this is mind $r_{\lambda e} \approx 10^{-15}$ m,

we get $r_{Qe} \approx 10^{-36}$ m.

The difference between these two values is huge. Comparing the values of $r_{\lambda e}$ and r_{Qe}, on the author's opinion, one should opt for the value of $r_{\lambda e}$. It should be done for two reasons. Firstly, the value of $r_{\lambda e}$ is confirmed by the facts that are presented in this work. Secondly, the value of $r_{\lambda e}$ explains the Coulomb's law application limit existence. What explains the value of rQe - it's unknown.

3. Let's try to separate the expression (7) into two parts: electric and gravitational. Let's transform expression (7) to a form in which only electric characteristics will participate, without the participation of G and c. We replace G with fraction 1/(4πε₀) and replace c4 with λ2. After these replacements, it can be assumed that the left-hand side of expression (7) will already be rλ , instead of rQ . Then

$$r_\lambda^2 = \frac{e^2}{16\pi^2\varepsilon_0^2\lambda^2}.$$

And we get rλ $r_\lambda = \dfrac{e}{4\pi\varepsilon_0\lambda}.$ (9)

From this it's clear that after such transformation, expression (9) completely coincides with ex- pression (6) - the formula for the Schwarzschild radius analog in case of a static spherically symmetric electric charge. That's, the formula (6) is in excellent agreement with the Reissner-Nord- ström solution result.

And the gravitational part of the expression (7) will represent the Schwarzschild radius. Let's show it. After the substitution in this expression of e with M, as well as of the fraction 1/(4πε₀) with G, we can write

$$r_g = \frac{GM}{c^2},$$

what coincides with the proven expression (2) for the gravitational radius.

Thus we see that expression (7) is not a final product, it's a semi-finished product (semi manufacture). With a certain refinement, expression (7) is transformed either into the Schwarzschild radius or into the Schwarzschild radius analog. The expression (7) use in practical calculations can lead to erroneous results.

Such transformations of the Reissner-Nordström solution results in the Schwarzschild radius, as well as the transformations of the Schwarzschild radius in the Schwarzschild radius analog and vice versa, are a good confirmation of the formula truth for the Schwarzschild radius analog, which is in full compliance with the existing solutions of the Einstein equations. Consequently, it's possible to assert about the formula validity for connection between an electric charge and its energy E = λe, proposed by the author in 2006 and on the basis of which the formula for the Schwarzschild radius analog was obtained.

Statistical Physics (Including General Entropy of Black Holes)

In 1974-1975, Hawking obtained the radiation temperature expression for a spherically symmetric black hole without an electric charge and rotation. A black hole creates and emits particles in the same way as a black body heated to a temperature Θ

$$\theta = \frac{\hbar \kappa}{2\pi c k}, \quad (10)$$

where κ = a value that characterizes the gravitational field strength near the black hole surface, k = Boltzmann's constant [7].

A similar expression of temperature can be obtained for a spherically symmetric black hole with an electric charge, but without rotation (naturally excluding mass). The electric field strength $\vec{E}$ is the same force characteristic of an electric field, as the value of κ is the force characteristic of the gravitational field. Therefore, instead of the value of κ we write the electric field strength .Since we are interested in a black hole with an electric charge, we now need to understand how to enter the constant λ into the formula for temperature. We have repeatedly replaced c2 with λ and vice versa. Let's make such replacement again: c is replaced by λ/c. Now we can write the formula for temperature in the case of a spherically symmetric black hole with an electric charge, but without rotation (naturally excluding mass)

$$\theta = \frac{\hbar c \vec{E}}{2\pi \lambda k} \quad (11)$$

The particles production probability w in an external static field with intensity Γ is described by an expression of such form (Novikov & Frolov, 1986)

$$w = A \exp \frac{-\beta m^2 c^3}{\hbar g \Gamma}, \quad (12)$$

where g = the charge of the particles being born;

β = dimensionless constant of the order of unity; A = pre-exponential factor depends on (as well as β) the more detailed characteristics of the field.

For gravitational interaction, mass acts as the gravitational charge of the system. Therefore, to estimate the particles production probability w in a static gravitational field, we should put on g = m

and Γ=κ , where $\kappa = \frac{c^4}{4GM}$

The particles production probability w in the field of a black hole

$$w = A \exp \frac{-\beta mc^2 mc}{\hbar g \Gamma} \quad (13)$$

$$w = A \exp \frac{-\beta E c}{\hbar \kappa}$$

$$w = A \exp \frac{-\beta E}{2\pi k \Theta}$$

2πkΘ

In the last expression we replaced ħκ by 2πckΘ [8].

If the black hole has an electric charge, then expression (12) will take on a following form. For electric interaction we should put on g = e, m = e and $\Gamma = \vec{E}$. Let's apply the formula again E = λe.

After replacing mc^2 with λe we can write for a process that characterizes only electric interaction.

Let's write formula (12)

$$w = A \exp \frac{-\beta m^2 c^3}{\hbar g \Gamma}$$

Let's make substitutions

$$w_e = A \exp \frac{-\beta e e \lambda c}{\hbar e \vec{E}} = A \exp \frac{-\beta e \lambda c}{\hbar \vec{E}}.$$

It follows from the formula (11): $\hbar \vec{E}$ = 2πλkΘ/c

We now have a final expression for we

$$w_e = A \exp \frac{-\beta e \lambda c c}{2\pi \lambda k \Theta} = A \exp \frac{-\beta E c c}{2\pi \lambda k \Theta} = A \exp \frac{-\beta E}{2\pi k \Theta}$$

We came to the same expression (13) that was obtained for the Schwarzschild black hole. Only

E = λe.

That's, if we knew that energy can be calculated by the formula E = λe, we could immediately write down the final result for the case of a non-rotating charged black hole. As it was, we had to do some mathematics.

In 1972, J. Bekenstein hypothesized that a black hole has entropy S proportional to its surface area s (for a spherical hole s = 4 $4\pi r_g^2$)

$$S = \frac{s \eta k c^3}{G \hbar}$$

where η = 1/4 .

Let's denote N. $N = \frac{kc^3}{G\hbar}$

Then $S = N \frac{s}{4}$

One can write a similar formula for the entropy Se of a spherically symmetric black hole

with an electric charge, but without rotation. If we make such substitutions (c^2 with λ, and G with the fraction $1/(4\pi\varepsilon_0)$) we can write

$$N_e = \frac{4\pi \varepsilon_0 k \lambda^2}{c\hbar}$$

And we get Se .

$$S_e = N_e \frac{s}{4} = \frac{\pi \varepsilon_0 k \lambda^2}{c \hbar} s$$

This is the entropy of a spherically symmetric black hole, due to its electric charge.

Since entropy is an additive quantity, when calculating the total entropy S_{BH} of a charged black hole, you will have to add two of its parts, namely

$$S_{BH}=\frac{kc^3 s}{4G\hbar}+\frac{\pi\varepsilon_0 k\lambda^2 s}{c\hbar} \tag{14}$$

By applying standard substitutions, we can convert this expression to

$$S_{BH}=\frac{kc^3 s}{4G\hbar}+\frac{k\lambda^2 s}{4Gc\hbar}=\frac{k s}{4G\hbar}(c^3+\lambda^2/c)=\frac{k s}{4G\hbar}(c^4+\lambda^2)/c=\frac{k\lambda^2 s}{2Gc\hbar}=\frac{kc^4 s}{2Gc\hbar}=$$

$$\frac{kc^3 s}{2G\hbar}=\frac{2\pi\varepsilon_0 k\lambda^2 s}{c\hbar}$$

Comparing the last expression with expression (14), it can be seen that

$$\frac{kc^3 s}{4G\hbar}=\frac{\pi\varepsilon_0 k\lambda^2 s}{c\hbar}$$

It turns out that two equal summands contribute to the black hole entropy SBH. That is both mass and electric charge (at their presence) make absolutely equal contribution to the black hole entropy SBH. It is somehow unusual (considering that the electromagnetic interaction is much stronger than the gravitational interaction).

Conclusions

The formulas transforming method of electricity and gravitation, which is described in the work, al- lows us to move towards the physics standardization. A very similar situations are observed in the black holes study and the thermodynamics questions. There are quite a few considerations indicating the close intertwining of black hole physics and thermodynamics [9, 10].

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Data Availability Statement

Data are contained within the article and collected from the references listed in the bibliography.

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