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Research paper

Equivalence of magnetic flux and energy

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Abstract

Magnetic flux and energy equivalence is the principle that everything that has magnetic flux has an equivalent amount of energy, and vice versa.
The main methods used: transformation of natural units, algebra, analogy.
The equivalence of magnetic flux and energy, despite its widespread use in describing the principles of physics, has not yet been formulated. This paper presents the formula for this equivalence. This is done based on known measurement systems, parameters and principles of physics.
Five examples (Stoney units, Planck units, standard gravitational parameter, Lorentz force, and Ampere force) of the algebraic representation of this principle show its universality. Five examples should justify the universality of the new principle and its use in physics and astrophysics.
Using the equivalence of magnetic flux and energy, new physical units of mass and magnetic flux are proposed, each of which is suitable for measuring both mass and magnetic flux. Natural values of electric current and voltage, linear density of electric capacitance and inductance, linear density of magnetic flux, linear density of electric charge, as well as natural units of electric voltage and current, electrical resistance, magnetic flux, electrical capacitance and inductance are also described.
The article presents the Einstein field equation (additional magnetic stress–energy–momentum tensor) and a standard astrophysical parameter for refining the orbits of celestial bodies.

Keywords: *Axiom; Astrophysical Parameter; Energy; Equivalence; Magnetic Flux; Schwarzschild Radius; Tensor; Physical Units; Physical Constants.*

1. Introduction

The article presents the first five historical examples based on the proposed equivalence. This equivalence can be found in the principles of electromagnetism, considering these principles in extreme values: the speed of light, the Planck force, in natural units of measurement. These principles are averaged as axioms. Based on the axiomatic method, a conclusion is made about the presence of this equivalence in nature.
The perspective on the use of this equivalence is given: eight examples from different areas of physics:

1) Two universal units of measurement of mass and magnetic flux.
2) Magnetic flux in Stoney units and in Planck units.
3) Standard magnetic parameter for celestial bodies.
4) Standard astrophysical parameter for celestial bodies.
5) Analogue of the Schwarzschild radius for a celestial body with magnetic flux.
6) Refinement of the Einstein field equation.
7) The equivalence of physical quantities is shown.
8) Our ideas about the natural values of physical quantities have been expanded.

1.1. History

The first description of a physical principle that pointed to the equivalence of magnetic field and energy was made by Faraday in 1831, when he described electromagnetic induction. Faraday's law described the EMF of a transformer, which is created by an electric force due to a changing magnetic field. James Clerk Maxwell drew attention to this principle in 1861. [1]
In 1881, Joseph John Thomson (1856 – 1940) introduced the concept of electromagnetic mass and presented this mass as part of the inertial mass of a magnetized body. This was a pointer to the equivalence of magnetic flux and mass (energy). [2]
Stoney in 1881 and Planck in 1899, 1900 in their natural units once again laid the foundation for the proposed equivalence. [3] [4]
Ampere's law was described in 1886. [5] [6]
In 1895, the Lorentz force was defined, which is also based on the proposed equivalence. The Lorentz force was described in 1910. [7] [8]

The unity of the nature of mass (energy) and magnetic flux was formulated in 2003. [9]

2. Methods

To record the proposed equivalence, natural units of measurement are used: Stoney units and Planck units, as well as the standard gravitational parameter, Lorentz force, Ampere force (after their algebraic processing).
If we write down the equivalence of magnetic flux and energy in each of these systems of units and of formulas for describing these laws, then we will receive confirmation of the proposed principle.
The laws of attraction of masses, electric charges and magnetic fluxes among themselves are an analogy of these principles and the joint recording of the formulas of these principles serves as confirmation of the proposed principle.
An axiomatic method according to which the connection between the equivalence of magnetic flux and energy with known physical principles, proves the existence of this principle in nature.

2.1. First step

Maxwell's second equation is based on Faraday's law of electromagnetic induction, namely, electromotive force (EMF) U equal to the rate of change of magnetic flux Φ : [1]

$$U = \frac{d\Phi}{dT} \quad (1)$$

Hence the amount of energy $E.$ for unit values $U., I., T.$ and Φ. of equal to one:

$$E. = U.I.T. = \Phi.I. \quad (2)$$

If a unit value of electric current $I.$ does not change in magnitude and direction when flowing in a conductor, but only appears or disappears, then this current strength $I.$ is the equivalence coefficient $k_{e\phi}$ between Φ and E .

$$E = \Phi k_{\phi e} \quad (3.0)$$

Here $k_{\phi e}$ is equivalence constant of magnetic flux and energy. And vice versa:

$$k_{\phi e} = I. \quad (3)$$

And vice versa:

$$\Phi = E\frac{1}{k_{\phi e}} \quad (4)$$

For the equivalence of magnetic flux Φ and energy E , the variables are Φ and E (3).
If we take as a coefficient not $I.$, but Φ. , which does not change in magnitude and direction, but only appears by the value of one unit of measurement, then we obtain the equivalence of current I and energy E :

$$E = I\Phi. \quad (5)$$

And vice versa, the equivalence of energy E and electric current I :

$$I = E\frac{1}{\Phi.} \quad (6)$$

Here $\frac{1}{\Phi.} = k_{ei}$ is equivalence constant of energy E and electric current I .

3. Examples of equivalence formulas

Five well-known fundamental examples of this equivalence in physics are given, which are among the first in the history of physics, and which are easy to understand.

3.1. Natural units

If we write the equivalence of magnetic flux and energy in natural units: Stoney units [3] and Planck units [4], we will receive confirmation of this principle.

3.2. Stoney units

Stoney units represent the following units of measurement: mass m_s , energy E_s , length L_s , electric charge Q_s and time T_s : [3]

Stoney mass is $m_s = \sqrt{\frac{k_e e^2}{G}}$,
Stoney energy is $E_s = m_s c^2$,

Stoney time is $T_s = \sqrt{\frac{Gk_e e^2}{c^6}}$,

Stoney length is $L_s = \sqrt{\frac{Gk_e e^2}{c^4}}$,

Stoney electric charge is $Q_s = e$
Here k_e is the Coulomb constant, e is the charge on the electron, c is the speed of light in vacuum, and G is the gravitational constant,
Hence the Stoney electric current I_s :

$$I_s = \frac{Q_s}{T_s} = \sqrt{\frac{c^6}{Gk_e}} \quad (7.0)$$

From the formulas (2) and (3):

$$E_s = \Phi_s I_s \quad (7)$$

Or

$$E_s = \Phi_s \sqrt{\frac{c^6}{Gk_e}} \quad (8)$$

This is the magnetic flux equivalence formula Φ_s and energy E .
Here $\sqrt{\frac{c^6}{Gk_e}} = k_{\Phi e}$ is equivalence constant of magnetic flux and energy in Stoney units. In this case, the Stoney electric current I_s is physical constant $k_{\Phi e}$ (3):

$$k_{\Phi e} = I_s \quad (9)$$

This is the first example presented here of calculating the proposed equivalence.
Based on this, we write down the magnetic flux Φ in Stoney units Φ_s :

$$\Phi_s = \frac{E_s}{I_s} = \sqrt{\frac{k_e e^2}{G}} c^2 \sqrt{\frac{Gk_e}{c^6}} = \frac{k_e e}{c} \quad (10)$$

So

$$\Phi_s = \frac{k_e e}{c} \quad (10.1)$$

Recording the magnetic flux Φ_s in Stoney units increases the capabilities of the Stone measurement system.

3.2. Planck units

Planck units are the following units: mass m_p , energy E_p , length L_p , electric charge Q_p and time T_p : [4]

$T_p = \sqrt{\frac{\hbar G}{c^5}}$ is Planck time,

$m_p = \sqrt{\frac{\hbar c}{G}}$ is Planck mass,

$E_p = m_p c^2$ is Planck energy,

$L_p = \sqrt{\frac{\hbar G}{c^3}}$ is Planck length,

$Q_p = \sqrt{\frac{\hbar c}{k_e}}$ is Planck electric charge. [10, formula (11.0)]
Here ħ is reduced Planck constant.
Hence the Planck electric current I_p :

$$I_p = \frac{Q_p}{T_p} = \sqrt{\frac{c^6}{Gk_e}} \quad (11)$$

From here

$$E_p = m_p c^2 = c^2 \sqrt{\frac{\hbar c}{G}} = \Phi_p \sqrt{\frac{c^6}{Gk_e}} \quad (12)$$

Determining the Planck magnetic flux Φ_p :

$$\Phi_p = \sqrt{\frac{\hbar k_e}{c}} \tag{13}$$

Magnetic flux Φ_p in Planck units increases the capabilities of this measurement system. From here, from the formulas (11), (13) and (12):

$$E_p = \Phi_p I_p \tag{14}$$

This corresponds to formulas (2), (3), (7), (8) and (13). It should be noted that

$$I_p = I_s = k_{\Phi e} = \sqrt{\frac{c^6}{G k_e}} \tag{15}$$

This is the second example of calculating the proposed equivalence. Based on formulas (10.1) and (13), it should be noted that

$$\frac{\Phi_p}{L_p} = \frac{\Phi_s}{L_s} = \Phi_L = \sqrt{\frac{k_e c^2}{G}} \tag{16}$$

And

$$\dim \Phi_L = \mathrm{MLT^{-2}I^{-1}} \tag{17}$$

Here dim Φ_L is unit of measurement of linear magnetic flux density.
From formulas (12), (15) and (16) we can express the Planck force F_p :

$$F_p = \Phi_L k_{\Phi e} \tag{18}$$

Here Planck force F_p is equal to the product of linear magnetic flux density Φ_L and Planck electric current I_p ($k_{\Phi e}$).

3.3. Standard parameter

An additional standard gravitational parameter μ_m is known for the conditions of equality of interacting masses [10, formula (9)]:

$$\mu_m = M\sqrt{G} \tag{19}$$

Here $\sqrt{G}=k$ is Gaussian gravitational constant. [11]
This parameter was obtained by appropriate (equality of interacting masses) consideration of Newton's law. [12]
Namely [10, formula (8)]:

$$F_G = G\frac{M^2}{R^2} \tag{19.1}$$

By analogy with formula (19.1), for two magnetic fluxes Φ (equal in magnitude), we consider Newton's law [13, formulas (7.0 – 9)]:

$$F_\Phi = k_\Phi \frac{\Phi^2}{R^2} \tag{19.2}$$

We will get an additional standard magnetic parameter μ_Φ :

$$\mu_\Phi = \Phi\sqrt{k_\Phi} \tag{20}$$

Here k_Φ is the constant that can be called the magnetic interaction constant. If in formulas (19.1) and (19.2)

$$F_G = F_\Phi \tag{21}$$

Then based on (19) – (21) we obtain the equivalence of additional standard parameters: gravitational and magnetic:

$$M\sqrt{G} = \Phi\sqrt{k_\Phi} \tag{22}$$

Hence the equivalence of magnetic flux Φ and mass M :

$$M = \Phi\sqrt{\frac{k_\Phi}{G}} \tag{23}$$

And the equivalence of magnetic flux Φ and energy E :

$$Mc^2 = E = c^2\Phi\sqrt{\frac{k_\Phi}{G}} = \Phi k_{\Phi e} \tag{24}$$

Here $k_{\Phi e}$ is equivalence constant of magnetic flux and energy:

$$k_{\Phi e} = c^2 \sqrt{\frac{k_\Phi}{G}} = \sqrt{\frac{c^6}{G k_e}} \tag{24.1}$$

This corresponds to the formulas (7.0), (11) and (15). This is the third way to calculate the equivalence of magnetic flux and energy (mass) proposed here. From here and from formulas (11), (15) and (24.1) we determine k_Φ :

$$k_\Phi = \frac{c^2}{k_e} = \frac{4\pi}{\mu_o} \tag{24.2}$$

Dimensionality of magnetic interaction constant k_Φ :

$$\dim k_\Phi = \mathrm{M}^{-1}\,\mathrm{L}^{-1}\,\mathrm{T}^2\,\mathrm{I}^2 \tag{24.3}$$

3.4. Determination of the equivalence of magnetic flux and energy for the Lorentz force

The second part of the Lorentz force formula F_L : [7] [8]

$$F_L = qVB \tag{25}$$

Here V is speed of movement of electric charge q in a magnetic B .
Magnetic flux Φ is equal to the product of a unit of magnetic field B and area S .
In Stoney units:

$$\Phi_s = B_s\, S_s \tag{26}$$

Here S_s=L_s^2 :

$$S_s = \frac{G k_e\, e^2}{c^4} \tag{27}$$

From formulas (10.1), (26) and (27):

$$B_s = \frac{k_e\, e}{c} \frac{c^4}{G k_e\, e^2} \tag{28}$$

Or

$$B_s = \frac{c^3}{Ge} \tag{29}$$

Stoney magnetic field B_s will expand Stoney units. From formulas (25) and (29):

$$F_{Ls} = ec\,\frac{c^3}{Ge} \tag{30}$$

Or

$$F_{Ls} = \frac{c^4}{G} = F_{p(s)} \tag{31}$$

Here $F_{p(s)}$ is Planck force (Stoney force). From formulas (25), (30) and (31):

$$E_{Ls} = L_s\, ec\,\frac{c^3}{Ge} \tag{32}$$

Or

$$E_{Ls} = F_{Ls}\, L_s = \frac{c^4}{G} \sqrt{\frac{G k_e\, e^2}{c^4}} = c^2 \sqrt{\frac{k_e\, e^2}{G}} \tag{33}$$

This corresponds to formulas (8) and (10).
If we take into account the formula of magnetic flux Φ_s (10.1) and electric current I_s (7.0), then we will receive confirmation of the formula of the proposed principle (7), (8) and (9):

$$E_{Ls} = I_s\, \Phi_s = \sqrt{\frac{c^6}{G k_e}} \frac{k_e\, e}{c} = c^2 \sqrt{\frac{k_e\, e^2}{G}} \tag{34}$$

Or

$$E_{Ls} = k_{\phi e}\Phi_s \tag{35}$$

The same from formula (25) in Planck units:

$$F_{Lp} = q_p\, V_p\, B_p = \frac{q_p\, V_p\, \Phi_p}{S_p} \tag{36}$$

Or

$$F_{Lp} = \sqrt{\frac{\hbar c}{k_e}}\, c \sqrt{\frac{\hbar k_e}{c}}\, \frac{c^3}{\hbar G} = \frac{c^4}{G} \tag{37}$$

Or by analogy with the formula (33):

$$E_{Lp} = F_{Lp}\, L_p = I_p\, \Phi_p \tag{37.1}$$

Or taking into account formula (13) for Φ_p :

$$E_{Lp} = \sqrt{\frac{c^6}{Gk_e}} \sqrt{\frac{\hbar k_e}{c}} = c^2 \sqrt{\frac{c\hbar}{G}} \tag{37.2}$$

Or

$$E_{Lp} = k_{\phi e}\Phi_p \tag{37.3}$$

Formulas (35) and (37.3) confirm for the fourth time the equivalence of magnetic flux and energy.

3.5. Similarly for the ampere force

For a wire of length L , through which an electric current I flows, and which is placed in a magnetic field, each of the moving charges q, creating this electric current, experiences an Ampere force: [5] [6]

$$F_A = \frac{\mu_o\, I_1\, I_2\, L}{4\,\pi\, R} \tag{37.4}$$

Or for all represented quantities equal to one:

$$F_A = \frac{I^2\, L}{4\,\pi\, \varepsilon_o\, c^2\, L} \tag{37.5}$$

And also in natural units:

- In Stoney units:

$$F_{As} = \frac{k_e\, I_s^2}{c^2} \tag{38}$$

- In Planck units:

$$F_{Ap} = \frac{k_e\, I_p^2}{c^2} \tag{39}$$

In both cases, taking into account that $I_p = I_s$, from formula (15) we obtain the Planck force F_p :

$$F_p = \frac{k_e}{c^2}\, \frac{c^6}{Gk_e} = \frac{c^4}{G} \tag{40}$$

Doing the same for Ampere energy E_A :

$$E_A = F_A\, L \tag{41}$$

We will get:

- In Stoney units:

$$E_{As} = \frac{k_e\, L_s\, I_s^2}{c^2} \tag{42}$$

Or according to the formula (10.1):

$$E_{As} = \frac{k_e}{c^2} \sqrt{\frac{c^6}{Gk_e}} \sqrt{\frac{c^6}{Gk_e}} \sqrt{\frac{Gk_e\, e^2}{c^4}} = \sqrt{\frac{c^6}{Gk_e}} \sqrt{\frac{k_e^2\, e^2}{c^2}} = k_{\Phi e}\Phi_s \tag{43}$$

The same from the formula (41)

- in Planck units:

$$E_{Ap}=\frac{k_e\,L_p\,I_p^2}{c^2} \tag{44}$$

Or according to the formula (13):

$$E_{Ap}=\frac{k_e}{c^2}\sqrt{\frac{c^6}{Gk_e}}\sqrt{\frac{c^6}{Gk_e}}\sqrt{\frac{\hbar G}{c^3}}=\sqrt{\frac{c^6}{Gk_e}}\sqrt{\frac{k_e^2\,c^6}{c^4Gk_e}\frac{\hbar G}{c^3}}=\sqrt{\frac{c^6}{Gk_e}}\sqrt{\frac{\hbar k_e}{c}}=k_{\Phi e}\Phi_p \tag{45}$$

This, together with formula (43), confirms the proposed equivalence for the fifth time.

4. Prospects

The proposed equivalence will expand our understanding of the physics of nature.

4.1. Measurements

Taking into account the properties of the medium: G and k_e , we have the opportunity to measure the electric charge Q (Coulomb) in units of mass M (kg) [13, formula (13)]:

$$Q=M\sqrt{\frac{G}{k_e}} \tag{46}$$

And vice versa, measure mass M (kg) in units of electric charge Q (Coulomb):

$$M=Q\sqrt{\frac{k_e}{G}} \tag{47}$$

Equivalence of additional standard parameters [13, formula (24)]:

$$M\sqrt{G}=Q\sqrt{k_e}=Щ \tag{48.0}$$

Here Щ is universal unit of measurement for M and Q .
We supplement formula (48.0) with magnetic additional standard parameters: gravitational and magnetic, formula (22), we get:

$$M\sqrt{G}=Q\sqrt{k_e}=\Phi\sqrt{k_\Phi}=Ч \tag{48}$$

Here Ч – universal unit of measurement for M, Q and Φ . This makes it possible to measure magnetic flux Φ (Wb) and electric charge Q (Coulomb) in units of mass M (kg):

$$M=\Phi\sqrt{\frac{k_\Phi}{G}}=Q\sqrt{\frac{k_e}{G}} \tag{49}$$

Or

$$M=\frac{Ч}{\sqrt{G}} \tag{50}$$

Formulas (49) and (50) are already known for Щ and for Q [13, formula (25)]. We can also measure the electric charge Q (Coulomb) and mass M (kg) in units of magnetic flux Φ (Wb):

$$\Phi=Q\sqrt{\frac{k_e}{k_\Phi}}=M\sqrt{\frac{G}{k_\Phi}} \tag{51}$$

Or

$$\Phi=\frac{Ч}{k_\Phi} \tag{52}$$

Given the formula (24.2):

$$\Phi=Q\frac{k_e}{c} \tag{52.1}$$

And

$$Q=\frac{Ч}{\sqrt{k_e}} \tag{52.2}$$

Such possibilities, formulas (46) − (52), indicate (and these formulas are based on) the equivalence of physical quantities: mass M , electric charge Q and magnetic flux Φ :

$M - Q - \Phi -$ Equivalence (53)

4.2. Standard astrophysical parameter

Formula (48) indicates the equivalence of the standard gravitational parameter $\mu = MG$ and standard: electric μ_Q=$Q\sqrt{Gk_e}$ and magnetic flux $\mu_\Phi = \Phi\sqrt{Gk_\Phi}$ parameters:

$$MG = Q\sqrt{Gk_e} = \Phi\sqrt{Gk_\Phi} \quad (54)$$

Formula (54) defines the standard astrophysical parameter $\mu_{M+Q+\Phi}$, which is a continuation to the formula μ_{M+Q} [13, formula (31)]:

$$\mu_{M+Q+\Phi} = \mu_{M+Q} + \mu_\Phi = \mu + \mu_Q + \mu_\Phi = MG + Q\sqrt{Gk_e} + \Phi\sqrt{Gk_\Phi} \quad (55)$$

which is a continuation to the formula − formula μ_{M+Q} for μ *and* μ_Q [13, formula (30)].

4.3. Analogy with Schwarzschild radius

The Schwarzschild radius [14] [15] is known: $r_s = \frac{2GM}{c^2}$
Based on the equivalences of electric charge Q [13], magnetic flux Φ and mass M (53) and (54), we present the Schwarzschild radius r_Φ (for mass M) in the form of a similar radius r_Φ for magnetic flux Φ :

$$r_\Phi = \frac{2\Phi\sqrt{Gk_\Phi}}{c^2} \quad (56)$$

Resulting Radius $r_{s\Sigma}$:

$$r_{s\Sigma} = r_s + r_Q + r_\Phi \quad (57)$$

Here r_Q is Schwarzschild radius for electric charge Q [13].
In determining the conditions under which a celestial body collapses into a gravitational singularity, magnetic and electrical additions to the Schwarzschild radius will provide increased precision in the theory of gravity and general relativity.

4.4. Analogues of the energy-momentum tensor and the Einstein field equation

Einstein field equation [16] for local scale:

$$G_{\mu\nu} = \frac{\kappa_g\, G}{c^4} T_{\mu\nu} \quad (58)$$

Here $T_{\mu\nu}$ – energy-momentum tensor (gravitational energy-momentum tensor), κ_g=8π .
Tensor $T_{\mu\nu}$ and magnetic energy–momentum tensor $T_{\mu_\Phi\nu}$ – equivalence:

$$T_{\mu\nu} = \frac{k_\Phi}{G} T_{\mu_\Phi\nu} \quad (59)$$

Or

$T_{\mu\nu} - T_{\mu_\Phi\nu}$ – Equivalence (60)

Here $T_{\mu_\Phi\nu}$ – for the case when a magnetic flux is created around a celestial body from $\Phi \to\infty$ (or this Φ is significantly greater in magnitude than the magnetic flux of the other celestial bodies surrounding this Φ , so much so that they can be neglected).
For the case when the field is created by a cluster of identical celestial bodies or a homogeneous nebula:

$T_{\mu\nu} - T_{\mu\phi\nu}$ – Equivalence (61)

Here $T_{\mu\phi\nu}$ – magnetic energy–momentum tensor for a homogeneous medium.

$$T_{\mu\nu} = \sqrt{\frac{k_\Phi}{G}}\, T_{\mu\phi\nu} \quad (62)$$

Then Einstein's equation (41.0) for the magnetic flux will take two forms:
1) Around the celestial body:

$$G_{\mu\nu_\Phi} = \frac{\kappa_g\, k_\Phi}{c^4} T_{\mu_\Phi\nu} \quad (63)$$

2) And for a homogeneous medium:

$$G_{\mu\nu_{\Phi}} = \frac{\kappa_g \sqrt{Gk_{\Phi}}}{c^4} T_{\mu\Phi\nu} \quad (64)$$

The addition of the magnetic component to Einstein's equation will allow us to expand our understanding of the gravitational field equation and more fully present the description of curved space-time by adding a magnetic flux component to this equation.

5. Equivalence of physical quantities

Equivalence of magnetic flux and energy is the principle that everything that has magnetic flux Φ has an equivalent amount of energy E (8), (14), (24), (37.3) and (45):

$$E = \Phi c^2 \sqrt{\frac{k_{\Phi}}{G}} = \Phi k_{\Phi e} \quad (65)$$

And vice versa:

$$\Phi = \frac{E}{c^2}\sqrt{\frac{G}{k_{\Phi}}} = \frac{E}{k_{\Phi e}} \quad (66)$$

Or

E — Φ Equivalence (66.1)

And vice versa:

Φ — E Equivalence (66.2)

Taking into account the equivalences time–space–mass–energy [10, formulas (53) and (54)] as well as the equivalence of electric charge and energy [13, formulas (52) and (53)], we can construct a sequence of equivalences:

$\Phi – E – T – L – m – Q$ — Equivalence (67)

Or

$$c^2\Phi\sqrt{\frac{k_{\Phi}}{G}} = E = \frac{Tc^5}{G} = \frac{Lc^4}{G} = mc^2 = c^2 Q\sqrt{\frac{k_e}{G}} \quad (68)$$

Or

$$\Phi\sqrt{\frac{k_{\Phi}}{G}} = \frac{Tc^3}{G} = \frac{Lc^2}{G} = m = Q\sqrt{\frac{k_e}{G}} \quad (69)$$

This extended equivalence indicates that the system of natural units of Stoney and Planck (7), (8) and (14) were created on the basis of the equivalence of physical quantities (67) – (69), as well as the equivalence of physical constants [13 , formulas (16) – (20)].
Now this dependence is just a confirmation of equivalences in physics, which is another confirmation of the proposed equivalence (equivalence of magnetic flux and energy).
From formulas (68) and (69) it follows that magnetic flux and space are equivalence:

$$L = \frac{\Phi}{c^2}\sqrt{Gk_{\Phi}} \quad (70)$$

Or

$$L = \Phi\mu_o\sqrt{G\varepsilon_o} \quad (71)$$

A space in a gravitational field G with vacuum magnetic permeability μ_o and dielectric constant ε_o is equivalent to magnetic flux Φ . In this case, the equivalence coefficient ($\mu_o\sqrt{G\varepsilon_o}$) is directly proportional to the space L and inversely proportional to the magnetic flux Φ .
The proposed magnetic flux–energy equivalence is a consequence of space being in a gravitational field and in a medium with magnetic and electrical properties.
From formulas (68) and (69) it also follows that magnetic flux and time are equivalent:

$$T = \frac{\Phi}{c^3}\sqrt{Gk_{\Phi}} \quad (72)$$

And also from formulas (68) and (69) it follows that magnetic flux and electric charge are equivalent:

$$Q = \Phi\sqrt{\frac{k_{\Phi}}{k_e}} = \Phi\frac{c}{k_e} = \Phi\frac{k_{\Phi}}{c} \quad (73)$$

By analogy with the equivalence of mass and energy, the proposed equivalences can also open up our understanding of the excess (defect) of magnetic flux, electric charge and space–time.

6. Natural values of physical quantities

Equivalence coefficients of physical quantities are fundamental constants (natural values of physical quantities).
The list of these natural values (constants), both known and discussed in this article:

1) Speed of light is c . [16]
2) Planck force is F_p .
3) Electric current is I_o , both Planck and Stoney is $I_p = I_s = I_o$, formulas (7.0) and (11):

$$I_o = \sqrt{\frac{c^6}{Gk_e}} \quad (74)$$

4) Linear magnetic flux density is Φ_L , formula (16):

$$\Phi_L = \sqrt{\frac{k_e c^2}{G}} \quad (75)$$

5) For the equivalence of space, time and energy [10, formula (54)], when reducing (dividing) both parts of the formula by the space value L , both in Planck and Stoney units, on the right side of the formula we have the product of the equivalence coefficient of space, time and energy $k_{Le} = \frac{c^4}{G}$ and by the linear space density L_L equal to unity, while the product of both coefficients on the right side of the equation is equal to the Planck force:

$$F_p = L_L \times \frac{c^4}{G} \quad (76)$$

Here

$$L_L = \frac{L_s}{L_s} = \frac{L_p}{L_p} = 1 \quad (76.1)$$

Namely

$$L_L = 1 \quad (76.2)$$

6) For the equivalence of mass and energy $E = mc^2$ [16], when dividing both sides of the formula by the space value L , both in Planck and Stoney units, on the right side of the formula we have the product of the coefficient of mass and energy equivalence c^2 by the linear mass density $M_L = \frac{M}{L}$, while the product of both of these coefficients on the right side of the equation is equal to the Planck force:

$$F_p = M_L \times c^2 \quad (77)$$

Here

$$M_L = \frac{m_s}{L_s} = \frac{m_p}{L_p} = \frac{c^2}{G} \quad (77.1)$$

Namely

$$M_L = \frac{c^2}{G} \quad (77.2)$$

7) For the equivalence of electric charge and energy [13, formula (53)], when reducing (dividing) both parts of the formula by the space value L on the right side of the formula, we have the product of the equivalence coefficient of electric charge and energy $k_{qe} = c^2\sqrt{\frac{k_e}{G}}$ and of the linear density of the electric charge $Q_L = \frac{Q}{L}$, while the product of both coefficients on the right side of the equation is equal to the Planck force:

$$F_p = Q_L \, c^2 \sqrt{\frac{k_e}{G}} \quad (78)$$

Here

$$Q_L = \frac{q_s}{L_s} = \frac{q_p}{L_p} = \sqrt{\frac{c^4}{Gk_e}} \quad (78.1)$$

Namely

$$Q_L = \sqrt{\frac{c^4}{Gk_e}} \quad (78.2)$$

8) The natural value of electric voltage U_o , both Planck and Stoney: U_o=U_p=U_s , is determined from the second Maxwell equation, formula (2): for the natural values I_o and T_o :

$$U_o = \frac{E_s}{I_o\,T_s} = \frac{E_p}{I_o\,T_p} \quad (79)$$

Or from formula (1):

$$U_o = \frac{\Phi_s}{T_s} = \frac{\Phi_p}{T_p} \quad (79.1)$$

Namely

$$U_o = \sqrt{\frac{k_e\,c^4}{G}} \quad (80)$$

9) The natural value of electrical resistance R_o , both Planck and Stoney: R_o= R_p=R_s , is determined from Ohm's law [17]: the natural value of electric current I_o for the natural values U_o and R_o :

$$I_o = \frac{U_o}{R_o} \quad (81)$$

Or

$$R_o = \frac{U_o}{I_o} \quad (81.1)$$

Namely

$$R_o = \frac{k_e}{c} \quad (82)$$

10) Natural value of electrical power W_o :

$$W_o = U_o\,I_o \quad (82.1)$$

Here U_o is natural value of electric voltage, formula (80), I_o is natural value of electric current (74).

11) Inductance $\boldsymbol{L}$ for variable values of magnetic flux Φ and electric current I [18]:

$$\boldsymbol{L} = \frac{\Phi}{I} \quad (83)$$

When reducing (dividing) both parts of the formula by the space value L , both in Planck and Stoney units, on the left side of the formula we have the linear inductance density $\boldsymbol{L}_L$, and on the right side – the linear density magnetic flux Φ_L (16) and (75) divided by the natural value of electric current I_o (7), (11) and (74):

$$\boldsymbol{L}_L = \frac{\Phi_L}{I_o} \quad (84)$$

Or

$$\boldsymbol{L}_L = \sqrt{\frac{k_e\,c^2}{G}}\,\sqrt{\frac{Gk_e}{c^6}} = \frac{k_e}{c^2} \quad (85)$$

Namely, taking into account formula (24.2):

$$\boldsymbol{L}_L = \frac{k_e}{c^2} = \frac{1}{k_\Phi} \quad (86)$$

12) Electric capacitance C for electric charge Q and electric voltage U [19]:

$$C = \frac{Q}{U} \quad (87)$$

When reducing (dividing) both parts of the formula by the space value L , both in Planck and Stoney units, on the left side of the formula we have the linear density of the electric capacity C_L , and on the right side - the linear density of the electric charge Q_L (78.1) divided by the natural electrical voltage value U_o (80):

$$C_L = \frac{Q_L}{U_o} \quad (88)$$

Or

$$C_L = \sqrt{\frac{c^4}{Gk_e}} \sqrt{\frac{G}{k_e\, c^4}} = \frac{1}{k_e} \tag{89}$$

Namely

$$C_L = \frac{1}{k_e} = \frac{k_\Phi}{c^2} \tag{90}$$

These twelve examples of Planck (Stoney) units of physical quantities represent two known (c and F_p) and ten new natural values of these quantities (fundamental constants):

1) Natural value of electric current, formula (7.0), (11) and (74),
2) Linear magnetic flux density (75),
3) Linear density of space (76),
4) Linear mass density (77),
5) Linear density of electric charge (78),
6) Natural value of electrical voltage (80),
7) Natural value of electrical resistance (82),
8) Natural value of electric power (82.1),
9) Natural value of inductance (86) and
10) Natural value of electrical capacity (90).

Each of these fundamental constants can be used as a unit of measurement for the corresponding physical quantities. Moreover, these physical quantities, both in Stoney and Planck units, are equal to each other.

7. Equivalence of physical quantities

Newton's law in the natural values of physical quantities (81) is the basis of three equivalences of physical quantities: electric current I , voltage U and resistance R .

The natural values of physical quantities: electric current I_o (74), voltage U_o (80) and resistance R_o (82), are the equivalence coefficients of these physical quantities:

1) Equivalence of electrical voltage U and resistance R :

$$R = \frac{1}{I_o} U \tag{91.0}$$

Here $\frac{1}{I_o}$ is equivalence coefficient U and R . Here I_o (74), from here:

$$R = \sqrt{\frac{Gk_e}{c^6}}\, U \tag{91}$$

And vice versa:

$$U = I_o\, R \tag{92.0}$$

Here I_o (74) is equivalence coefficient R and U , from here:

$$U = \sqrt{\frac{c^6}{Gk_e}}\, R \tag{92}$$

2) Equivalence of electrical voltage U and electric current I :

$$I = \frac{1}{R_o} U \tag{93.0}$$

Here $\frac{1}{R_o}$ is equivalence coefficient U and I . Here R_o (82), from here, taking into account formula (24.2):

$$I = \frac{c}{k_e} U = \frac{k_\Phi}{c} U \tag{93}$$

And vice versa:

$$U = IR_o \tag{94.0}$$

Here R_o (82) is equivalence coefficient I and U , from here:

$$U = \frac{k_e}{c} I = \frac{c}{k_\Phi} I \tag{94}$$

3) Equivalence of the reciprocal value of electrical resistance $\frac{1}{R}$ and electric current I:

$$I = U_o \frac{1}{R} \tag{95.0}$$

Here U_o (80) is equivalence coefficient $\frac{1}{R}$ and I , from here:

$$I = \sqrt{\frac{k_e c^4}{G}} \frac{1}{R} \tag{95}$$

And vice versa:

$$R = U_o \frac{1}{I} \tag{96.0}$$

Here U_o (80) is equivalence coefficient $\frac{1}{I}$ and R , from here:

$$R = \sqrt{\frac{k_e c^4}{G}} \frac{1}{I} \tag{96}$$

8. New Planck and Stoney units

1) Multiplying the linear density of electrical capacitance C_L (90) by the length (L_p and L_s), we obtain the electric capacitance in Planck C_p and Stoney C_s units:

$$C_p = C_L L_p = \frac{1}{k_e} \sqrt{\frac{\hbar G}{c^3}} = \sqrt{\frac{\hbar G}{k_e^2 c^3}} \tag{97}$$

And

$$C_s = C_L L_s = \frac{1}{k_e} \sqrt{\frac{G k_e e^2}{c^4}} = \sqrt{\frac{G e^2}{k_e c^4}} \tag{98}$$

2) Multiplying the linear density of inductance – $\boldsymbol{L}_L$ (86) by the length (L_p and L_s), we get the inductance in Planck $\boldsymbol{L}_p$ and Stoney $\boldsymbol{L}_s$ units:

$$\boldsymbol{L}_p = \boldsymbol{L}_L L_p = \frac{k_e}{c^2} \sqrt{\frac{\hbar G}{c^3}} = \sqrt{\frac{\hbar G k_e^2}{c^7}} \tag{99}$$

And

$$\boldsymbol{L}_s = \boldsymbol{L}_L L_s = \frac{k_e}{c^2} \sqrt{\frac{G k_e e^2}{c^4}} = \sqrt{\frac{G k_e^3 e^2}{c^8}} \tag{100}$$

8.1. Magnetic moment in Planck and Stoney units

Magnetic moment $\boldsymbol{m}$ for a flat single circuit S :

$$\boldsymbol{m} = IS \tag{101}$$

Here I is the current in the circuit.
The value of the magnetic moment with the natural value of the current I_o in natural systems of units (Stoney $\boldsymbol{m}_s$ and Planck $\boldsymbol{m}_p$):

$$\boldsymbol{m}_s = I_o L_s^2 \tag{102}$$

And

$$\boldsymbol{m}_p = I_o L_p^2 \tag{103}$$

Or

$$\boldsymbol{m}_s = I_o \frac{G k_e e^2}{c^4} \tag{104}$$

End

$$\boldsymbol{m}_p = I_o \frac{\hbar G}{c^3} \tag{105}$$

Here I_o is natural electric current strength (74), L_s and L_p is Stoney and Planck space of the unit contour. Also:

$$\boldsymbol{m}_s = \sqrt{\frac{c^6}{Gk_e}\frac{Gk_e\,e^2}{c^4}} = \sqrt{\frac{Gk_e\,e^4}{c^2}} \quad (104.1)$$

And

$$\boldsymbol{m}_p = \sqrt{\frac{c^6}{Gk_e}\frac{\hbar G}{c^3}} = \sqrt{\frac{\hbar^2 G}{k_e}} \quad (105.1)$$

9. Equivalence of magnetic moment and energy

Energy of magnetic moment E can be determined from the equation:

$$\boldsymbol{m} = \frac{E}{B} \quad (106)$$

Here B – magnetic induction. Or

$$\boldsymbol{m} = \frac{ES}{\Phi} \quad (107)$$

Or, given the formulas Φ_L (16) and L (68):

$$\boldsymbol{m} = \frac{EL}{\Phi_L} = \frac{E^2 G}{c^4\,\Phi_L} = \frac{E^2 G}{c^4}\sqrt{\frac{G}{k_e\,c^2}} = \frac{E^2}{c^5}\sqrt{\frac{G^3}{k_e}} \quad (108)$$

And vice versa:

$$E = \sqrt{\boldsymbol{m}}\,\sqrt{c^5\sqrt{\frac{k_e}{G^3}}} \quad (109)$$

In this case, formula (108) is the equivalence of the square of energy E^2 and magnetic moment $\boldsymbol{m}$, and vice versa, formula (109) is the equivalence of the root of the square of magnetic moment $\sqrt{m}$ and energy E . Further

$$E = B\boldsymbol{m} = \frac{\Phi_L}{L}\boldsymbol{m} = \frac{\Phi_L}{L} I_o S \quad (110)$$

Or

$$E_L = \Phi_L\, I_o = \sqrt{\frac{k_e\,c^2}{G}}\sqrt{\frac{c^6}{Gk_e}} = \frac{c^4}{G} \quad (111)$$

Here $E_L = \frac{E}{L}$ is linear energy density. Also E_L is in Stoney units E_{L_S} :

$$E_{L_S} = \frac{E_s}{L_s} = c^2\sqrt{\frac{k_e\,e^2}{G}}\sqrt{\frac{c^4}{Gk_e\,e^2}} = \frac{c^4}{G} \quad (112)$$

E_L is in Planck units E_{L_p} :

$$E_{L_p} = \frac{E_p}{L_p} = c^2\sqrt{\frac{\hbar c}{G}}\sqrt{\frac{c^3}{\hbar G}} = \frac{c^4}{G} \quad (113)$$

This means that physical quantities E_L , Φ_L and I_o from the formula (111) are fundamental constants (physical constants).
The proposed equivalence reveals the nature of the magnetic moment anomaly.

10. Equivalence of electrical capacitance, inductance and energy

Electrical capacitance equivalence C and energy E :

$$E = C\,\frac{k_e\,c^4}{G} \quad (114)$$

Here $\frac{k_e\,c^4}{G} = k_{ce}$ is electrical capacitance equivalence coefficient C (97), (98) and energy E :

$$E = Ck_{ce} \quad (115)$$

And vice versa:

$$C = E k_{ec} \quad (115)$$

Here k_{ec} is coefficient of equivalence of energy E and electrical capacitance C :

$$k_{ec} = \frac{G}{k_e c^4} \quad (116)$$

Inductance equivalence $\boldsymbol{L}$ and energy E :

$$E = \boldsymbol{L} k_{\boldsymbol{L}e} \quad (117)$$

Here $k_{\boldsymbol{L}e}$ is electrical inductance equivalence coefficient $\boldsymbol{L}$ (99), (100) and energy E :

$$k_{\boldsymbol{L}e} = \frac{c^6}{G k_e} \quad (118)$$

And vice versa:

$$\boldsymbol{L} = E k_{e\boldsymbol{L}} \quad (119)$$

Here

$$k_{e\boldsymbol{L}} = \frac{G k_e}{c^6} \quad (120)$$

11. Conclusion

We can observe the equivalence of magnetic flux and energy in all areas of physics. Examples of such observations include:
1) Algebraic expansions in two natural systems of units: Stoney units (7) and (8),
2) The same in Planck units (12) and (14),
3) Standard gravitational parameter (24),
4) Lorentz force (37.3) and
5) Ampere power (45).

Writing down the known principles of physics for natural (limit) quantities: the speed of light, the Planck force leads to writing the proposed equivalence.
In 1905, Albert Einstein published a work on special relativity, a deductive theory based on the axiomatic method. [16]
This work also uses the axiomatic method.
The proposed equivalence is formulated using various examples from physics, which corresponds to the deductive construction and confirms the existence of this equivalence in nature:

$$\Phi - E \text{ – Equivalences} \quad (121)$$

Taking into account the known equivalences (67) and those proposed here, we have a sequence of equivalences:

$$\Phi - E - T - L - m - Q - \sqrt{\boldsymbol{m}} - C - \boldsymbol{L} \text{ — Equivalences} \quad (122)$$

This can be seen from formulas (7), (13), (37.4), (43), (45), (53), (65), (67), (68), (109), (115) and (117).
The equivalences of energy E , mass m , space L , time T , electric charge Q and magnetic flux Φ (67) are sufficient (based on the axiomatic method [16]) to confirm the equivalence of all physical quantities in nature.
The proposed equivalence of magnetic flux Φ and energy E (8), (13) opens up the possibility for us to describe magnetic standard parameters in astrophysics (55), write down magnetic analogues of the energy–momentum tensor (59), (62) and Einstein's field equations (63), (64), and also present a magnetic analogue of the Schwarzschild radius (56).
Based on gravitational and magnetic additional standard parameters, a standard astrophysical parameter (55) and two independent units of measurement of mass and magnetic flux (49) – (52) are proposed, each of which is suitable for measuring both mass and magnetic flux.
The list of natural values of physical quantities that can be considered as physical constants has been added: current strength (74), linear magnetic flux density (75), linear space density (76.1), linear electric charge density (78.1), natural linear mass density (77.2) natural linear energy density (77.3) and (111) – (113), natural value of electrical power (82.1), linear density of electrical capacitance (86) and induction (90), natural values of electrical voltage (80) and electrical resistance (82).
The natural values of physical quantities are analogues of the Planck force, and can be presented as units of measurement of the corresponding physical quantities in the Planck and Stoney systems of units.
Using the equivalence of magnetic flux and energy as a basis, natural units are proposed: magnetic flux (10.1) and (13), magnetic moment (104) and (105), as well as electric capacitance (97) and (98) and inductance (99) and (100), both Stoney and Planck.
The proposed equivalences can open up our understanding of the excess (defect) of physical quantities and reveal the nature of the magnetic moment anomaly. [20]

References

[1] Maxwell, J. C. (1861). On physical lines of force. *Philosophical Magazine*. 90 (139): 11–23. URL: https://doi.org/10.1080/14786446108643033.
[2] J. J. Thomson (1881). On the electric and magnetic effects produced by the motion of electrified bodies. *Philosophical Magazine*. Vol. 11. P. 229–249. https://doi.org/10.1080/14786448108627008 , https://www.tandfonline.com/doi/abs/10.1080/14786448108627008 and URL:

https://ia800708.us.archive.org/view_archive.php?archive=/22/items/crossref-pre-1909-scholarly-works/10.1080%252F14786448108626989.zip&file=10.1080%252F14786448108627008.pdf
[3] G. Stoney (1881). On The Physical Units of Nature. *Phil. Mag*. 11, S. 381–391. https://doi.org/10.1080/14786448108627031.
[4] M. Planck (1900). Über irreversible Strahlungsvorgänge. *Ann. Phys*. 4(1). P. 69–122. https://doi.org/10.1002/andp.19003060105.
[5] P. Duhem (1886). Sur la loi d'Ampère. *J. Phys. Theor*. Appl. Volume 5, Numéro 1, P. 26 - 29. URL: https://doi.org/10.1051/jphystap:01886005002601.
[6] Duhem, Pierre Maurice Marie (2018). Ampère's Force Law: A Modern Introduction. Alan Aversa. Retrieved 3 July 2019. (EPUB).
[7] Whittaker E. T. (1910). A History of the Theories of Aether and Electricity: From the Age of Descartes to the Close of the Nineteenth Century. Longmans, Green and Co. P. 420–423. ISBN: 1-143-01208-9. URL: https://ia804708.us.archive.org/32/items/historyoftheorie00whitrich/historyoftheorie00whitrich.pdf. https://doi.org/10.5962/bhl.title.19630.
[8] Lorentz, Hendrik Antoon (1895). Versuch einer Theorie der electrischen und optischen Erscheinungen in bewegten Körpern. LEIDEN. − E. J. BRILL. URL: https://books.google.co.uk/books?id=eZHOAAAAMAAJ&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false (German).
[9] Суханов В. Н. (2003). Изобретательское творчество. Природа физических величин иявлений. “4. Природа магнитного поля”. Казань: *ФолиантЪ*. ISBN: 5949900022. (Russian): https://www.researchgate.net/publication/361799177_Priroda_Fiziceskih_Velicin_i_Avlenij_Cast_11 и URL: https://www.worldcat.org/title/izobretatelskoe-tvorchestvo/oclc/55576505.
[10] Vladimir Nikolayevich Sukhanov (2024). Space−time−energy equivalence. *International Journal of Physical Research*, 12(1):10-23. URL: https://www.sciencepubco.com/index.php/IJPR/article/view/32527/17817. https://doi.org/10.14419/n7tgaw97.
[11] Gauss, Carl Friedrich; Davis, Charles Henry (1857). Theory of the Motion of the Heavenly Bodies Moving about the Sun in Conic Sections. Boston: Little, Brown and Company. p. 2. URL: https://archive.org/details/bub_gb_1TIAAAAAQAAJ. https://doi.org/10.5962/bhl.title.19023.
[12] Newton (1687). Philosophiæ Naturalis Principia. *De Motu Corporum*. London URL: https://www.newtonproject.ox.ac.uk/view/texts/normalized/NATP00078.
[13] Vladimir Nikolayevich Sukhanov (2024). Equivalence of electric charge and energy. *International Journal of Physical Research*. https://doi.org/10.14419/bhmxn335.
[14] Schwarzschild, Karl (1916). Über das Gravitationsfeld eines Massenpunktes nach der Einsteinschen Theorie. Sitzungsberichte der Königlich Preußischen Akademie der Wissenschaften (Berlin), Seite 189-196. (German) URL: https://articles.adsabs.harvard.edu/pdf/1916SPAW.189S.
[15] Karl Schwarzschild (1916). Über das Gravitationsfeld einer Kugel aus inkompressibler Flussigkeit nach der Einsteinschen Theorie. Sitzungsberichte der Deutschen Akademie der Wissenschaften zu Berlin, Klasse fur Mathematik, *Physik, und Technik*. P. 424. URL: https://ui.adsabs.harvard.edu/abs/1916skpa.conf..424S/abstract , URL: https://www.jp-petit.org/Schwarzschild-1916-interior-de.pdf.
[16] Albert Einstein (1905). Zur Elektrodynamik bewegter Körper. *Annalen der Physik* 17: 891. (German) URL: https://doi.org/10.1002/andp.19053221004 , https://onlinelibrary.wiley.com/doi/10.1002/andp.19053221004 URL: https://www.fourmilab.ch/etexts/einstein/specrel/www/.
[17] Ohm, Georg Simon (1827). Die galvanische Kette. Mathematisch bearbeitet. Berlin: T. H. Riemann. (German). https://doi.org/10.5479/sil.354716.39088005838644.
[18] Lorenz, L. (1879). Ueber die Fortpflanzung der Electricität. *Annalen der Physik*, vol. 243, Issue 6, pp. 161-193. https://doi.org/10.1002/andp.18792430602.
[19] Maxwell, J. C. (1878). On the electrical capacity of a long narrow cylinder and of a disk of sensible thickness. *Proceedings of the London Mathematical Society*. Vol. IX. P. 94—101. https://doi.org/10.1112/plms/s1-9.1.94.
[20] Vladimir Nikolayevich Sukhanov (2020). Equivalence of magnetic flux and energy. *ResearchGate*. http://dx.doi.org/10.13140/RG.2.2.35828.17282