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# The Circular Current Loop as a Model of Fundamental Particles

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## Abstract

The presented circular current loop model reveals that charged fundamental particles such as the electron consist essentially of electric and magnetic energy. The magnetic properties have the same order of magnitude as the electric ones. The electromagnetic field energy is the origin of the inertial mass. The Higgs boson, existing or not, is not needed to "explain" particle mass. The magnetic moment of fundamental particles is not anomalous! The "anomaly" indicates the existence of a small additional amount of kinetic energy. Thus, fundamental particles are not purely field-like such as photons and not (essentially) mass-like such as atoms, they represent a special kind of matter in between. Their kinetic energy is obviously not due to any relativistic effect but is related to an independent physical law that provides, together with the magnetic energy, the angular momentum exactly to be $\hbar/2$. Fundamental particles are (at least) two-dimensional. In the simplest case their core consists of two concentric, nearly identical current loops. Their relative design details, the "anomaly" factor, and the rotational velocity of the uniformly distributed elementary charge follow from the stability condition, *i.e.* electric and magnetic force balance, and do not depend on the particle's rest mass! Fundamental particles are objects of classical physics. Their magnetic forces are the true origin of the weak and strong nuclear interactions. For their explanation bosons and gluons are not needed.

## Keywords

Electric Energy, Magnetic Energy, Rotational Kinetic Energy, Strong and Weak Nuclear Forces

## 1. Physical Properties of Fundamental Particles

Subatomic particles that cannot be subdivided are regarded to be fundamental.

This includes that they are stable. Typical fundamental particles in this sense are the electron and the positron. This investigation is provisionally restricted to them. They are characterized by the following four basic entities:

Charge $\pm e$ anomaly of magnetic moment a rest mass $m_0$ angular momentum $\hbar/2$.

When no additional entities of fundamental particles are known, these four basic ones are sufficient to describe a fundamental particle. An acceptable model of a fundamental particle must represent its four entities accurately and consistently. This ensures that the model represents also derived entities, e.g.

$$\text{Bohr magneton} \quad \mu_B = \frac{\pm e\hbar}{2m_0} \tag{1.1}$$

$$\text{Magnetic moment} \quad \mu = \mu_B\left(1+a\right) \tag{1.2}$$

$$\text{Compton wavelength bar} \quad \lambda\!\!\!^{-}_C = \frac{\hbar}{m_0 c} \tag{1.3}$$

$$\text{Rest mass energy} \quad E_0 = m_0 c^2 \tag{1.4}$$

Strange but true: As electron and positron do not show any internal structure quantum mechanics regards them to be point particles, *i.e.* to have no dimensions at all. Such an object would be totally unrealistic and non-physical. It could not have **any** physical properties: Charge density and mass density would be infinite, angular momentum ("spin") and magnetic moment could not exist. Fortunately, there is a pioneering exception [1]. The approach of this ingenious investigation is quite different from this one, but the results and conclusions are nearly the same.

## 2. The Circular Loop as a Model of Fundamental Particles

A one-dimensional circular current loop according to **Figure 1** having a finite radius $r$ and carrying the charge $e$ is the simplest model that can fulfill the four physical requirements mentioned above:

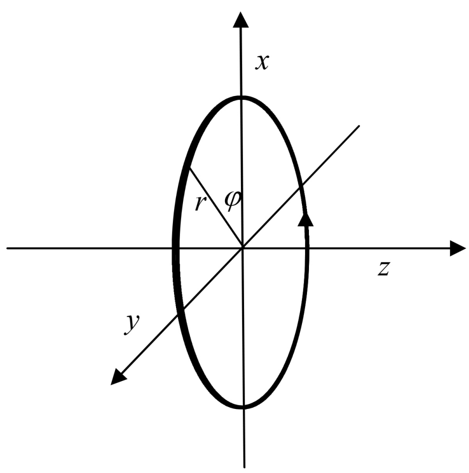


**Figure 1.** One-dimensional circular current loop.

The charge must be distributed homogeneously over its circumference $2\pi r$ and it must rotate at a constant velocity $v_\varphi$. These are the conditions for a constant current

$$I = \frac{ev_\varphi}{2\pi r} = \frac{ec}{2\pi r}\beta_\varphi \tag{2.1}$$

and a constant magnetic field. This is the only chance that the model can represent a stable, non-radiating particle.

The current $I$ creates a magnetic moment

$$\mu = I\pi r^2 = \frac{ec}{2}\beta_\varphi r \tag{2.2}$$

where

$$\beta_\varphi = \frac{v_\varphi}{c} \tag{2.3}$$

## 3. The Nature of the Rest Mass of Fundamental Particles

As the presented current loop model is electromagnetic, basically it does not "know" rest mass $m_0$ and rest mass energy $m_0c^2$. The model provides an electrostatic field due to its charge ±e and a constant magnetic field due to the rotation of the homogeneously distributed charge at constant velocity. Consequently, the energy inventory is expected to be purely electromagnetic as it is with an electromagnetic wave. The charge $\pm e$ does not exist as a concentrated rotating point charge, but as a constant charge density

$$\sigma = \frac{\pm e}{2\pi r} = \frac{\pm ec}{2\pi\hbar}\frac{\lambdabar_C}{r}m_0 \tag{3.1}$$

where

$$\lambdabar_C = \frac{\hbar}{m_0 c} \tag{3.2}$$

is the Compton radius of a particle having rest mass $m_0$.

The amount of the elementary charge, $|e|$, is an entity that is found to be exactly equal with **all** loaded particles. Additionally, they have a magnetic moment including a strange "anomaly" a. This means that the charge (density) of all these particles is rotating at a constant angular velocity. The circular current loop representing an electromagnetic particle model makes transparent that the rest mass basically is an illusion resulting from the electrostatic (Coulomb) field and from the magnetic (Lorentz) field of the particle. Theoretically the electromagnetic field is spread out infinitely wide. When a particle is accelerated in an electric and/or magnetic field, due to the finite velocity of light the electromagnetic field of the particle is distorted. The distorted field tries to pull its escaping central part back. This restoring force is interpreted as being due to the inertia of mass. The rest mass energy $m_0c^2$ of the particle is equivalent to the sum of its electric energy $E_{el}$ and magnetic energy $E_{mag}$:

$$m_0c^2 = E_{el} + E_{mag} \tag{3.3}$$

The particle does **not** possess electric energy $E_{el}$ and magnetic energy $E_{mag}$ **and additionally** rest mass energy $m_0c^2$: The nature of the particle energy $m_0c^2$ is electromagnetic, and the rest mass $m_0$ is a fictive entity although it can be measured.

## 4. The Electromagnetic Properties of the Circular Current Loop

The exact mathematical treatment of the circular current loop is not trivial. But the results of the exact calculation are very useful when the circular current loop is regarded as a model of fundamental particles or at least a basic element for building up such a model. Once done in a proper way the results may serve forever as a universal platform for all respective calculations.

At first the geometric relationship between a circle with radius $r$, centered at the origin of an orthogonal coordinate system, and a point $P(\rho, z)$ has to be analyzed. In **Figure 2** the circle is placed in the $\rho$-$\varphi$-plane of a cylinder coordinate frame.

The distance $\zeta$ of a point on the circle having the coordinates $r$ and $\varphi$ to a point with the coordinates $\rho$ and $\varphi = 0$ is given by

$$\zeta^2 = r^2 \sin^2\varphi + (\rho - r\cos\varphi)^2 \tag{4.1}$$

As

$$\sin^2\varphi + \cos^2\varphi = 1 \tag{4.2}$$

(4.1) becomes:

$$\zeta^2 = r^2 + \rho^2 - 2\rho r\cos\varphi \tag{4.3}$$

The distance $D$ of the point on the circle to a point $P(\rho, z)$ in the $\rho$-$z$-plane is then given by

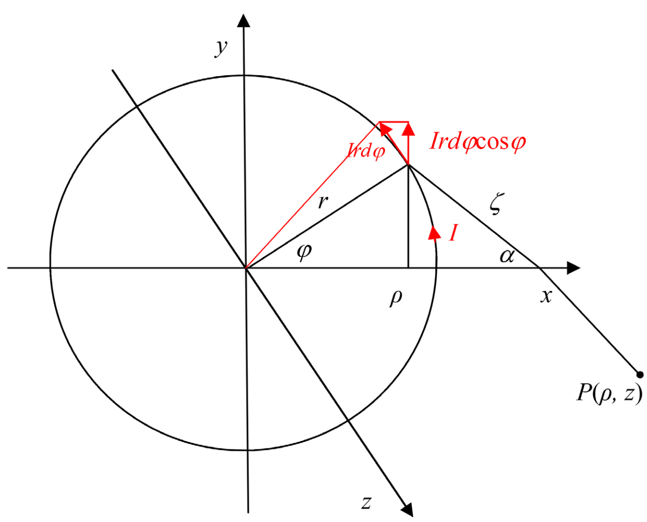


**Figure 2.** Geometric details.

$$D^2 = \zeta^2 + z^2 = r^2 + \rho^2 - 2\rho r\cos\varphi + z^2 \quad (4.4)$$

or

$$\left(\frac{D}{r}\right)^2 = 1 + \left(\frac{\rho}{r}\right)^2 + \left(\frac{z}{r}\right)^2 - 2\frac{\rho}{r}\cos\varphi \quad (4.5)$$

It will turn out to be useful to introduce the abbreviation

$$k = \frac{2\frac{\rho}{r}}{1 + \left(\frac{\rho}{r}\right)^2 + \left(\frac{z}{r}\right)^2} \quad (4.5)$$

Thus, the distance d becomes

$$D = r\sqrt{1 + \left(\frac{\rho}{r}\right)^2 + \left(\frac{z}{r}\right)^2}\sqrt{1 - k\cos\varphi} \quad (4.6)$$

The electrostatic situation is characterized by the continuous and homogenous distribution of the charge $q$ over the circular contour:

$$\mathrm{d}q = \frac{q}{2\pi r} r\mathrm{d}\varphi = \frac{q}{2\pi}\mathrm{d}\varphi \quad (4.7)$$

A particular charge element d$q$ generates at the point $P(\rho, z)$ the incremental contribution d$V$ to the electrostatic potential $V$

$$\mathrm{d}V = \frac{1}{4\pi\varepsilon_0 D}\frac{q}{2\pi}d\varphi = \frac{q}{4\pi\varepsilon_0 r}\frac{1}{\sqrt{1 + \left(\frac{\rho}{r}\right)^2 + \left(\frac{z}{r}\right)^2}}\frac{1}{2\pi}\frac{\mathrm{d}\varphi}{\sqrt{1 - k\cos\varphi}} \quad (4.8)$$

The electrostatic potential $V$ at the point $P(\rho, z)$ is the sum of all these contributions around the complete circle:

$$V = \frac{q}{4\pi\varepsilon_0 r}\frac{1}{\sqrt{1 + \left(\frac{\rho}{r}\right)^2 + \left(\frac{z}{r}\right)^2}}\frac{1}{2\pi}\int_{\varphi=0}^{2\pi}\frac{\mathrm{d}\varphi}{\sqrt{1 - k\cos\varphi}} \quad (4.9)$$

The magnetic situation is described by the vector potential $A$ that is created by the rotation of the uniformly distributed charge at constant velocity $v_\varphi$, thus according to (2.1) and (2.3) representing a constant current

$$I = \frac{ev_\varphi}{2\pi r} = \frac{ec}{2\pi r}\beta_\varphi \quad (4.10)$$

According to the vector behavior of the current each element $I\mathrm{d}s = Ir\mathrm{d}\varphi$ is only effective with its component vertical to the x axis:

$$I\mathrm{d}s_{eff} = Ir\cos\varphi\mathrm{d}\varphi \quad (4.11)$$

Thus, the increment d$A$ of vector potential is

$$\mathrm{d}A = \mathrm{d}A_\varphi = \frac{\mu_0}{4\pi}\frac{I\mathrm{d}s_{eff}}{D} = \frac{\mu_0 I}{2}\frac{1}{\sqrt{1 + \left(\frac{\rho}{r}\right)^2 + \left(\frac{z}{r}\right)^2}}\frac{1}{2\pi}\frac{\cos\varphi\mathrm{d}\varphi}{\sqrt{1 - k\cos\varphi}} \quad (4.12)$$

The vector potential $A$ of the current $I$ along the circle at the point $P(\rho, z)$ is

$$A = A_\varphi = \frac{\mu_0 I}{2} \frac{1}{\sqrt{1+\left(\frac{\rho}{r}\right)^2+\left(\frac{z}{r}\right)^2}} \frac{1}{2\pi} \int_{\varphi=0}^{2\pi} \frac{\cos\varphi \mathrm{d}\varphi}{\sqrt{1-k\cos\varphi}} \tag{4.13}$$

Both the integrals in (4.9) and (4.12) cannot be solved in closed form. It is well known that they can be transformed to combinations of the two standardized elliptical integrals. But this would complicate the situation. The superior method is to develop the identical denominator of the two functions to be integrated into a power series:

$$\frac{1}{\sqrt{1-x}} = 1 + \frac{1}{2}x + \frac{1\cdot 3}{2\cdot 4}x^2 + \frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}x^3 + \frac{1\cdot 3\cdot 5\cdot 7}{2\cdot 4\cdot 6\cdot 8}x^4 + \cdots = \sum_{m=0}^{\infty} c_m x^m \tag{4.14}$$

where

$$x = k\cos\varphi \tag{4.15}$$

The coefficients $c_m$ can be calculated according to the recursion formula

$$c_0 = 1 \quad c_m = c_{m-1}\frac{2m-1}{2m} = c_{2m-2}\cdot\frac{2m-3}{2m-2}\cdot\frac{2m-1}{2m} \quad m > 0 \tag{4.16}$$

Thus, the two integrals can be written as

$$\frac{1}{2\pi}\int_0^{2\pi} \frac{\mathrm{d}\varphi}{\sqrt{1-k\cos\varphi}} = \sum_{m=0}^{\infty}\left[c_m k^m \frac{1}{2\pi}\int_0^{2\pi}\cos^m\varphi \mathrm{d}\varphi\right] \tag{4.17}$$

$$\frac{1}{2\pi}\int_0^{2\pi} \frac{\cos\varphi \mathrm{d}\varphi}{\sqrt{1-k\cos\varphi}} = \sum_{m=0}^{\infty}\left[c_m k^m \frac{1}{2\pi}\int_0^{2\pi}\cos^{m+1}\varphi \mathrm{d}\varphi\right] \tag{4.18}$$

The following survey shows what happens:

$$\int_{\varphi=0}^{2\pi} 1\mathrm{d}\varphi = 2\pi \tag{4.19}$$

$$\int_{\varphi=0}^{2\pi} x\mathrm{d}\varphi = k\int_{\varphi=0}^{2\pi}\cos\varphi \mathrm{d}\varphi = k\sin\varphi\Big|_0^{2\pi} = 0 \tag{4.20}$$

$$x^2 = k^2\cos^2\varphi = \frac{1}{2}k^2\left(1+\cos 2\varphi\right) \tag{4.21}$$

$$\int_{\varphi=0}^{2\pi} x^2\mathrm{d}\varphi = \frac{1}{2}k^2\left(\varphi + \frac{1}{2}\sin 2\varphi\right)\Bigg|_0^{2\pi} = \frac{1}{2}k^2 2\pi \tag{4.22}$$

$$x^3 = k^3\cos^3\varphi = \frac{1}{4}k^3\left(3\cos\varphi + \cos 3\varphi\right) \tag{4.23}$$

$$\int_{\varphi=0}^{2\pi} x^3\mathrm{d}\varphi = \frac{1}{4}k^3\left(3\sin\varphi + \frac{1}{3}\sin 3\varphi\right)\Bigg|_0^{2\pi} = 0 \tag{4.24}$$

Only the terms with even exponents contribute to the solutions. Thus, the integral for the electrostatic potential $V$ selects from the "mother function" (4.14) the even terms and the integral for the vector potential, as each term is multiplied by $\cos\varphi$, selects the odd terms. This indicates the close relationship between $V$ and $A$, and it reveals that both are orthogonal to each other.

Generally

$$\int_{\varphi=0}^{2\pi}\cos^{2n+1}\varphi\,\mathrm{d}\varphi=0 \tag{4.25}$$

and

$$\int_0^{2\pi}\cos^{2n}\varphi\,\mathrm{d}\varphi=\frac{1}{2^{2n}}\binom{2n}{n}\cdot 2\pi=\frac{1}{2^{2n}}\frac{2n(2n-1)(2n-2)\cdots(n+1)}{1\cdot 2\cdot 3\cdots n}\cdot 2\pi \tag{4.26}$$

From (4.26) follows

$$\begin{aligned}\int_0^{2\pi}\cos^{2(n-1)}\varphi\,\mathrm{d}\varphi&=\frac{1}{2^{2n-2}}\binom{2n-2}{n-1}\cdot 2\pi\\&=\frac{1}{2^{2n-2}}\frac{(2n-2)(2n-3)(2n-4)\cdots n}{1\cdot 2\cdot 3\cdots(n-1)}\cdot 2\pi\end{aligned} \tag{4.27}$$

Consequently, the recursion formula for the integration results is

$$\begin{aligned}&\frac{\int_0^{2\pi}\cos^{2n}\varphi\,\mathrm{d}\varphi}{\int_0^{2\pi}\cos^{2(n-1)}\varphi\,\mathrm{d}\varphi}\\&=\frac{1}{2^2}\cdot\frac{2n(2n-1)(2n-2)\cdots(n+1)}{1\cdot 2\cdot 3\cdots n}\cdot\frac{1\cdot 2\cdot 3\cdots(n-1)}{(2n-2)(2n-3)(2n-4)\cdots n}\\&=\frac{1}{4}\cdot\frac{2n(2n-1)}{n^2}=\frac{2n-1}{2n}\end{aligned} \tag{4.28}$$

Accordingly, the first integration results are

$$\frac{1}{2\pi}\int_0^{2\pi}\cos^2\varphi\,\mathrm{d}\varphi=\frac{1}{2^{2n}}\binom{2n}{n}=\frac{1}{4}\cdot\frac{2}{1}=\frac{1}{2} \tag{4.29}$$

$$\frac{1}{2\pi}\int_0^{2\pi}\cos^4\varphi\,\mathrm{d}\varphi=\frac{1}{2^4}\binom{4}{2}=\frac{1}{16}\cdot\frac{4\cdot 3}{2\cdot 1}=\frac{3}{8}=\frac{1}{2}\cdot\frac{3}{4} \tag{4.30}$$

$$\frac{1}{2\pi}\int_0^{2\pi}\cos^6\varphi\,\mathrm{d}\varphi=\frac{1}{2^6}\binom{6}{3}=\frac{1}{64}\cdot\frac{6\cdot 5\cdot 4}{3\cdot 2\cdot 1}=\frac{5}{16}=\frac{1}{2}\cdot\frac{3}{4}\cdot\frac{5}{6} \tag{4.31}$$

To summarize the even terms of (4.14) it is useful to set $m=2n$. It transforms (4.16) and (4.17) to

$$c_{2n}=c_{2n-2}\cdot\frac{4n-3}{4n-2}\cdot\frac{4n-1}{4n} \tag{4.32}$$

and

$$\frac{1}{2\pi}\int_0^{2\pi}\frac{\mathrm{d}\varphi}{\sqrt{1-k\cos\varphi}}=1+\frac{1\cdot 3}{2\cdot 4}k^2\cdot\frac{1}{2}+\frac{1\cdot 3\cdot 5\cdot 7}{2\cdot 4\cdot 6\cdot 8}k^4\cdot\frac{3}{8}+\cdots=\sum_{n=0}^{\infty}a_{2n}k^{2n} \tag{4.33}$$

Consequently, the electrostatic potential according to (4.9) can be written as

$$V=\frac{q}{4\pi\varepsilon_0 r}\frac{\sum_{n=0}^{\infty}a_{2n}k^{2n}}{\sqrt{1+\left(\frac{\rho}{r}\right)^2+\left(\frac{z}{r}\right)^2}} \tag{4.34}$$

where

$$a_0 = 1 \quad a_{2n} = a_{2n-2} \cdot \frac{4n-3}{4n-2} \cdot \frac{4n-1}{4n} \cdot \frac{2n-1}{2n} = a_{2n-2} \cdot \frac{4n-1}{4n} \cdot \frac{4n-3}{4n} \tag{4.35}$$

or

$$a_{2n} = a_{2n-2}\left(1-\frac{1}{4n}\right)\left(1-\frac{3}{4n}\right) \tag{4.36}$$

The first coefficients are

$$a_2 = 1 \cdot \frac{3}{4} \cdot \frac{1}{4} = \frac{3}{16} \quad a_4 = \frac{3}{16} \cdot \frac{7}{8} \cdot \frac{5}{8} = \frac{105}{1024} \quad a_6 = \frac{105}{1024} \cdot \frac{11}{12} \cdot \frac{9}{12} = \frac{1155}{16384} \tag{4.37}$$

Similarly, the final form of (4.13) is achieved by setting $m = 2n + 1$. This results in

$$\begin{aligned} \frac{1}{2\pi}\int_0^{2\pi} \frac{\cos\varphi \mathrm{d}\varphi}{\sqrt{1-k\cos\varphi}} &= \frac{1}{2}k \cdot \frac{1}{2} + \frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}k^3 \cdot \frac{3}{8} + \frac{1\cdot 3\cdot 5\cdot 7\cdot 9}{2\cdot 4\cdot 6\cdot 8\cdot 10}k^5 \cdot \frac{5}{16} + \cdots \\ &= \frac{k}{4}\sum_{n=0}^{\infty} b_{2n}k^{2n} \end{aligned} \tag{4.38}$$

and

$$A = A_\varphi = \frac{\mu_0 I}{2} \frac{\frac{1}{4}\sum_{n=0}^{\infty} b_{2n}k^{2n+1}}{\sqrt{1+\left(\frac{\rho}{r}\right)^2+\left(\frac{z}{r}\right)^2}} \tag{4.39}$$

where

$$b_0 = 1 \quad b_{2n} = b_{2n-2} \cdot \frac{4n-1}{4n} \cdot \frac{4n+1}{4n+2} \cdot \frac{2n+1}{2n+2} = b_{2n-2} \cdot \frac{4n-1}{4n} \cdot \frac{4n+1}{4n+4} \tag{4.40}$$

or

$$b_{2n} = b_{2n-2}\left(1-\frac{1}{4n}\right)\left(1-\frac{3}{4(n+1)}\right) \tag{4.41}$$

The first coefficients are

$$b_2 = 1 \cdot \frac{3}{4} \cdot \frac{5}{8} = \frac{15}{32} \quad b_4 = \frac{15}{32} \cdot \frac{7}{8} \cdot \frac{3}{4} = \frac{315}{1024} \quad b_6 = \frac{315}{1024} \cdot \frac{11}{12} \cdot \frac{13}{16} = \frac{15015}{65536} \tag{4.42}$$

## 5. Energies between Two Circular Current Loops

As a matter of symmetry all points on a second concentric circle having the radius $\rho = r_2$ and axial distance $z = z_2$ from the origin have the same values $V_1$ and $A_1$ generated by a primary circular current loop 1 positioned at the origin.

The electrostatic potential of circle 1 is

$$V_1 = \frac{q_1}{4\pi\varepsilon_0 r_1} \frac{\sum_{n=0}^{\infty} a_{2n}k_{1,2}^{2n}}{\sqrt{1+\left(\frac{r_2}{r_1}\right)^2+\left(\frac{z_2}{r_1}\right)^2}} \tag{5.1}$$

Its vector potential is

$$A_1 = A_{\varphi 1} = \frac{\mu_0 I_1}{2} \frac{\frac{1}{4}\sum_{n=0}^{\infty} b_{2n} k_{1,2}^{2n+1}}{\sqrt{1+\left(\frac{r_2}{r_1}\right)^2+\left(\frac{z_2}{r_1}\right)^2}} \tag{5.2}$$

where

$$k_{1,2} = \frac{2\frac{r_2}{r_1}}{1+\left(\frac{r_2}{r_1}\right)^2+\left(\frac{z_2}{r_1}\right)^2} \tag{5.3}$$

When circle 2 with radius $r_2$ and axial distance $z_2$ is loaded with the uniformly distributed charge $q_2$ the electrostatic energy $E_{el}$ between the two charged loops is

$$E_{el} = V_1(\rho, z) \cdot q_2 \tag{5.4}$$

or

$$E_{el}(r_2, z_2) = \frac{e^2}{4\pi\varepsilon_0 r_1} \frac{q_1}{e} \frac{q_2}{e} \frac{\sum_{n=0}^{\infty} a_{2n} k_{1,2}^{2n}}{\sqrt{1+\left(\frac{r_2}{r_1}\right)^2+\left(\frac{z_2}{r_1}\right)^2}} \tag{5.5}$$

When the charge $q_2$ rotates at velocity $v_{\varphi 2} = c\beta_{\varphi 2}$ the magnetic energy $E_{mag}$ is

$$E_{mag} = q_2 v_{\varphi 2} A_{1\varphi}(\rho, z) \tag{5.6}$$

or

$$E_{mag}(r_2, z_2) = q_2 v_{\varphi 2} \frac{\mu_0 I_1}{2} \frac{\frac{1}{4}\sum_{n=0}^{\infty} b_{2n} k_{1,2}^{2n+1}}{\sqrt{1+\left(\frac{r_2}{r_1}\right)^2+\left(\frac{z_2}{r_1}\right)^2}} \tag{5.7}$$

where

$$q_2 v_{\varphi 2} \frac{\mu_0 I_1}{2} = \frac{q_2}{e} \frac{v_{\varphi 2}}{c} \cdot \frac{\mu_0}{2} \frac{q_1}{e} \frac{v_{\varphi 1}}{c} \frac{1}{2\pi r_1} \cdot e^2 c^2 = \frac{\mu_0 e^2 c^2}{4\pi r_1} \frac{q_1}{e} \frac{q_2}{e} \beta_{\varphi 1} \beta_{\varphi 2} \tag{5.8}$$

To make the electric energy and the magnetic energy comparable and in order to come to a convenient form the following identities are used

$$\frac{e^2}{4\pi\varepsilon_0} = \frac{\mu_0 c^2 e^2}{4\pi} = \alpha\hbar c = 1.439964445 \times 10^{-09}\ \text{eV} \cdot \text{m} \tag{5.9}$$

$$\alpha\hbar c = \alpha m_0 c^2 \frac{\hbar}{m_0 c} = \alpha m_0 c^2 \lambda\!\!\!^{-}_C \tag{5.10}$$

They transform (5.5) and (5.7) to

$$E_{el}(r_2, z_2) = \alpha m_0 c^2 \frac{\lambda\!\!\!^{-}_C}{r_1} \frac{q_1}{e} \frac{q_2}{e} \frac{\sum_{n=0}^{\infty} a_{2n} k_{1,2}^{2n}}{\sqrt{1+\left(\frac{r_2}{r_1}\right)^2+\left(\frac{z_2}{r_1}\right)^2}} \tag{5.11}$$

and

$$E_{mag}(r_2,z_2)=\alpha m_0c^2\frac{\lambda\!\!\!^{-}_C}{r_1}\frac{q_1}{e}\frac{q_2}{e}\beta_{\varphi1}\beta_{\varphi2}\frac{\frac{1}{4}\sum_{n=0}^{\infty}b_{2n}k_{1,2}^{2n+1}}{\sqrt{1+\left(\frac{r_2}{r_1}\right)^2+\left(\frac{z_2}{r_1}\right)^2}} \tag{5.12}$$

The standardized energies $\frac{E_{el}(r_2,z_2)}{\alpha m_0c^2\frac{\lambda\!\!\!^{-}_C}{r_1}\frac{q_1}{e}\frac{q_2}{e}}$ and $\frac{1}{\beta_{\varphi1}\beta_{\varphi2}}\frac{E_{mag}(r_2,z_2)}{\alpha m_0c^2\frac{\lambda\!\!\!^{-}_C}{r_1}\frac{q_1}{e}\frac{q_2}{e}}$ are presented in **Figure 3** and **Figure 4**. $E_{el}-\frac{1}{\beta_{\varphi1}\beta_{\varphi2}}E_{mag}$ is standardized accordingly.

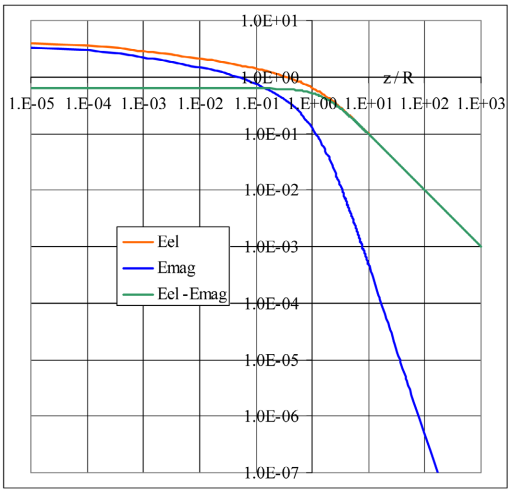


**Figure 3.** Standardized energies $E_{el}$, $|E_{mag}|$, and $E_{el}-|E_{mag}|$ of two concentric current loops with $r_1=r_2=R$ at the relative distance $z/R$.

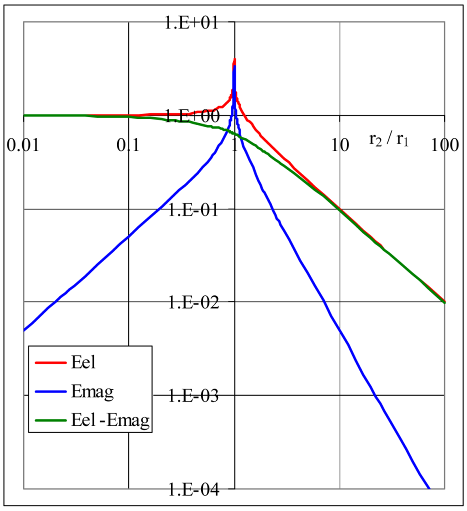


**Figure 4.** Standardized energies $|E_{el}|$, $|E_{mag}|$, and $|E_{el}|-|E_{mag}|$ of two concentric current loops with radii $r_1$ and $r_2$ at distance $z_2 = z_1 = 0$.

## 6. Forces between Two Circular Current Loops

The electric forces $F_{el\,z}$ in $z$ direction and $F_{el\,\rho}$ in $\rho$ direction are

$$F_{el\,z}(r_2,z) = q_2 \frac{\partial V_1(r_2,z)}{\partial z} \tag{6.1}$$

and

$$F_{el\,\rho}(r_2,z) = q_2 \frac{\partial V_1(r_2,z)}{\partial r_2} \tag{6.2}$$

where $V_1(r_2,z)$ is given by (5.1) and (5.3). With applying (5.9) the results are

$$F_{el\,z}(r_2,z) = \frac{\alpha\hbar c}{r_1^2}\frac{q_1}{e}\frac{q_2}{e}\frac{\sum_{n=0}^{\infty} a_{2n}(4n+1)k_{12}^{2n}}{\left[1+\left(\frac{r_2}{r_1}\right)^2+\left(\frac{z}{r_1}\right)^2\right]^{\frac{3}{2}}}\frac{z}{r_1} \tag{6.3}$$

and

$$F_{el\,\rho}(r_2,z) = \frac{\alpha\hbar c}{r_1^2}\frac{q_1}{e}\frac{q_2}{e}\frac{\sum_{n=0}^{\infty} a_{2n}\left[\frac{4n}{k_{12}}-(4n+1)\frac{r_2}{r_1}\right]k_{12}^{2n}}{\left[1+\left(\frac{r_2}{r_1}\right)^2+\left(\frac{z}{r_1}\right)^2\right]^{\frac{3}{2}}} \tag{6.4}$$

The magnetic forces $F_{mag\,z}$ in $z$ direction and $F_{mag\,\rho}$ in $\rho$ direction are

$$F_{mag\,z} = q_2 v_{\varphi 2}\frac{\partial A_{1\varphi}(r_2,z)}{\partial z} \tag{6.5}$$

and

$$F_{mag\,\rho} = q_2 v_{\varphi 2}\frac{1}{r_2}\frac{\partial(r_2 A_{1\varphi})}{\partial r_2} \tag{6.6}$$

where $A_{\varphi 1}$ is given by (5.2) and (5.3). By applying (5.8) and 5.9) the results are

$$F_{mag\,z}(r_2,z) = \frac{\alpha\hbar c}{r_1^2}\frac{q_1}{e}\frac{q_2}{e}\beta_{\varphi 1}\beta_{\varphi 2}\frac{\sum_{n=0}^{\infty} b_{2n}\left(n+\frac{3}{4}\right)k_{12}^{2n+1}}{\left[1+\left(\frac{r_2}{r_1}\right)^2+\left(\frac{z}{r_1}\right)^2\right]^{\frac{3}{2}}}\frac{z}{r_1} \tag{6.7}$$

and

$$F_{mag\,\rho}(r_2,z) = \frac{\alpha\hbar c}{r_1^2}\frac{q_1}{e}\frac{q_2}{e}\frac{v_{\varphi 1}}{c}\frac{v_{\varphi 2}}{c}\frac{\sum_{n=0}^{\infty} b_{2n}\left[n+1-k_{12}\left(n+\frac{3}{4}\right)\frac{r_2}{r_1}\right]k_{12}^{2n}}{\left[1+\left(\frac{r_2}{r_1}\right)^2+\left(\frac{z}{r_1}\right)^2\right]^{\frac{3}{2}}} \tag{6.8}$$

According to (5.10) the factor $\alpha\hbar c/r_1^2$ in (6.3), (6.4), (6.7), and (6.8) may be replaced from

$$\frac{\alpha\hbar c}{r_1^2} = \alpha\frac{m_0c^2}{\lambdabar_C}\left(\frac{\lambdabar_C}{r_1}\right)^2 \tag{6.9}$$

It will turn out that sometimes it is helpful or necessary to define the average radius

$$R = \sqrt{r_1r_2} = r_1\sqrt{\frac{r_2}{r_1}} \tag{6.10}$$

**Figure 5** and **Figure 6** give a survey of the meaning of the four force Equations (6.3), (6.4), (6.7), and (6.8). The two energy Equations (5.11) and (5.12) and the four force equations represent the complete set to calculate all interesting properties of the twin-loop system. The electric and magnetic field components (field strengths) are not explicitly mentioned because they are proportional to the respective force components. Moreover, they are not needed here.

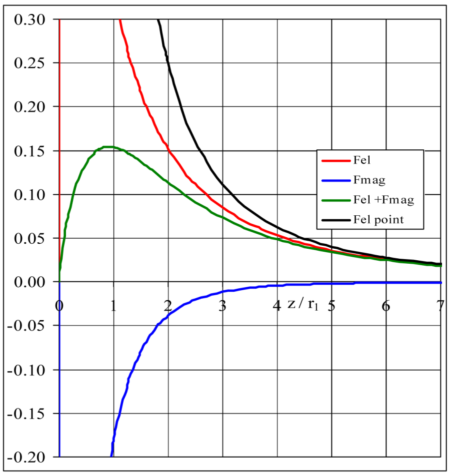


**Figure 5.** Standardized axial forces between two concentric current loops with $r_1 = r_2 = R$ as a function of the relative distance $z/R$ at $\beta_{\varphi 1}\beta_{\varphi 2} = 1$.

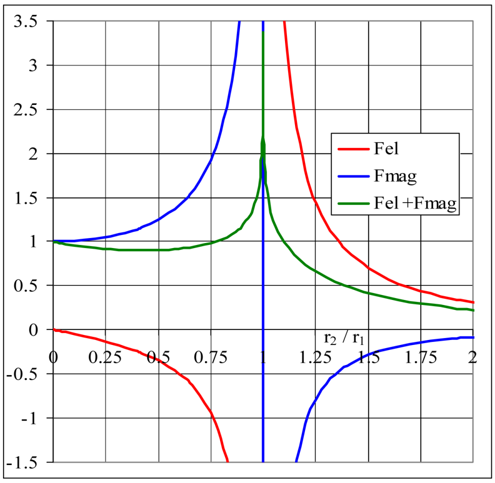


**Figure 6.** Standardized radial forces between two concentric current loops at distance $z_1 = z_2 = 0$ as a function of the ratio $r_2/r_1$ at $\beta_{\varphi 1}\beta_{\varphi 2} = 1$.

## 7. Remarks, Conclusions, and Special Results

A single circular current loop has an electrostatic potential $V$ according to (5.1) and a vector potential $A$ according to (5.2), but no intrinsic electric and magnetic energies. Energies according to (5.11) and (5.12) only exist between (at least) two electric and/or magnetic potentials. **Consequently, the simplest electromagnetic model of a charged particle is two-dimensional and consists of two circular current loops.** Their total load $-e$ or $+e$ is shared between them. Thus, the radial electrostatic forces of a fundamental particle are always repulsive. To establish the opportunity of a force balance, the radial magnetic forces must be attractive. This requires that both currents have the same direction. As the two current loops of a particle are concentrically positioned in the same plane both axial forces, electric and magnetic, are zero.

The sharing of the indivisible elementary load $e$ to two current loops is no physical sin because one loop is only a mathematic item and no physical object. The simplest model of a stable fundamental particle is a twin-loop where the twins cannot be physically separated. Neutral particles (e.g. the neutron) consist of two fundamental particles of opposite electric polarity similar to the hydrogen atom. In contrary to charged fundamental particles, the range of their electromagnetic field and consequently their size are limited.

The six energy and force equations converge when $k < 1$. When $k$ is close to unity, the convergence is very poor. For exact calculations in the most interesting range $0.999 \le k \le 1$ more than $10^8$ terms of the series may be needed. When $z_2 = z_1 = 0$ and simultaneously $r_2 = r_1 = R$, *i.e.* when the two loops touch each other at their circumference, the maximum value $k_{12} = 1$ is reached. In this singular case is $v_{\varphi 2} = v_{\varphi 1} = c$, and the derived series for energies and radial forces do not converge. Thus, the respective values cannot be calculated. But the difference $E_{el} - \left|E_{mag}\right|$ and $\left|F_{el\,\rho}\right| - F_{mag\,\rho}$ converge and can be calculated at nearly unlimited accuracy. Two fascinating results of the calculations with up to $3 \times 10^9$ terms are

$$\frac{E_{el}\left(r_1,0\right) + \frac{1}{\beta_{\varphi 1}\beta_{\varphi 2}} E_{mag}\left(r_1,0\right)\Big|_{\beta_{\varphi 1}=\beta_{\varphi 2}=1}}{\alpha m_0 c^2 \frac{\lambda\!\!\!^{-}_C}{r_1}\frac{q_1}{e}\frac{q_2}{e}} \approx \frac{1}{\sqrt{2}}\left\{\sum_{n=0}^{3\times 10^9} a_{2n} - \frac{1}{4}\sum_{n=0}^{3\times 10^9} b_{2n}\right\} \quad (7.1)$$

$$= 0.636619772329\cdots$$

where

$$\frac{2}{\pi} = 0.636619772368\cdots \quad (7.2)$$

and

$$\frac{F_{el\,\rho}\left(r_1,0\right) + \frac{1}{\beta_{\varphi 1}\beta_{\varphi 2}} F_{mag\,\rho}\left(r_1,0\right)\Big|_{\beta_{\varphi 1}=\beta_{\varphi 2}=1}}{\alpha \frac{m_0 c^2}{\lambda\!\!\!^{-}_C}\left(\frac{\lambda\!\!\!^{-}_C}{r_1}\right)^2 \frac{q_1}{e}\frac{q_2}{e}} \approx \frac{1}{2\sqrt{2}}\left\{\sum_{n=0}^{3\times 10^9} a_{2n} - \frac{1}{4}\sum_{n=0}^{3\times 10^9} b_{2n}\right\} \quad (7.3)$$

$$= 0.318309886167\cdots$$

where

$$\frac{1}{\pi} = 0.318309886184\cdots \tag{7.4}$$

It will be shown that the real model slightly differs from this extreme case.

As to positive or negative signs of energies and forces it has to be emphasized that the energy and force equations concern their amounts, *i.e.* negative signs are omitted. When sums or differences are calculated the correct signs are taken. In the case of (7.3) $F_{el\,\rho}$ is negative and $F_{mag\,\rho}$ is positive as $r_2/r_1 < 1$. When $r_2/r_1 > 1$ it is vice versa. The most important message of (7.1) is: $|E_{mag}|$ is not essentially smaller than $E_{el}$ when $\beta_{\varphi 1}\beta_{\varphi 2}$ is close to unity.

**Figure 3** shows that in $z$ direction at distances $z \gg R$ the electric energy $E_{el}$ decreases proportional to $1/R$ whereas the amount of the magnetic energy $E_{mag}$ decreases proportional to $1/R^3$. The magnetic energy is highly concentrated to the near vicinity of the circular current loops, whereas the electric energy is more distributed over the total space. In terms of electromagnetic field energy the electron is not infinitely small, but infinitely big. The disastrous point-particle theory suppresses the magnetic energy because it cannot exist and cannot be calculated in such a model.

**Figure 5** and **Figure 6** demonstrate the same severe mistake with the forces. In reality the generally neglected magnetic force is very important when the distance of the two current loops is $<3R$. **Figure 5** impressively shows that at $z/R =$ 0.9175741 the sum $F_{el\,z} + F_{mag\,z}$ reaches a maximum value and drops down to zero at $z = 0$. The respective behavior of two pointlike charges is purely electrostatic. The magnetic force is completely missing. Thus, the electric force and consequently the total force would be infinite at $z = 0$. **Figure 5** reveals that the weak and strong nuclear forces are nothing else than the artificially suppressed magnetic forces. The W and Z bosons as well as the "gluons" are not at all concerned in gluing any particles together. For the g or gluon are no measured values available [2]. This example shows how a nonsensical theory challenges the invention of spiritualistic effects and particles.

Two concentric, identical ( $r_2 = r_1 = R$ ), one-dimensional current loops represent the idealized model of an object that according to (7.1) and (7.2) is characterized by

$$E_{el}(R,0) - \left|E_{mag}(R,0)\right|_{v_{\varphi 1}=v_{\varphi 2}=c} = \alpha m_0 c^2 \frac{\lambda\!\!\!^{-}_C}{R}\frac{q_1}{e}\frac{q_2}{e}\cdot\frac{2}{\pi} \tag{7.5}$$

$E_{el}(R,0)$ and $E_{mag}(R,0)$ cannot be calculated from the respective power series because they do not converge. But there is a simple way out that was already sketched in Chapter 3: When the twin loop is accelerated the electric field and the magnetic field corresponding to $E_{el}(R,0)$ and $\left|E_{mag}(R,0)\right|$ create a restoring force each. It is traditionally called inertial force and defines the inertial mass. These masses are

$$m_{el} = \frac{E_{el}(R,0)}{c^2} \tag{7.6}$$

and

$$m_{mag} = \frac{\left|E_{mag}\left(R,0\right)\right|}{c^2} \tag{7.7}$$

The complete field energy is

$$E_{el}\left(R,0\right) + \left|E_{mag}\left(R,0\right)\right| = \left(m_{el} + m_{mag}\right)c^2 = m_0 c^2 \tag{7.8}$$

When the twin loop is to represent a fundamental particle, its total charge must be

$$q_1 + q_2 = -e \tag{7.9}$$

or, in the case of the positron

$$q_1 + q_2 = +e \tag{7.10}$$

As the two loops are (idealized) identical is

$$q_1 = q_2 = \pm\frac{e}{2} \tag{7.11}$$

and

$$\frac{q_1 q_2}{e^2} = \frac{1}{4} \tag{7.12}$$

As already mentioned, the two loops are no physical objects. One loop alone could anyway not possess energy. Electric and magnetic energies arise from the mutual influence of their electromagnetic potentials. Only for mathematical treatment they may carry the non-physical charge $e/2$. When the two loops are brought together from infinite distance to identical position, energy must be spent to create electric energy against their mutual repulsive force. On the other hand, the magnetic force attracts the loops and thus supports the process of particle creation by contributing negative magnetic energy.

From (7.5) and (7.12) follows

$$E_{el} - E_{mag} = m_0 c^2 \frac{\lambda\!\!\!^{-}_C}{R}\frac{\alpha}{2\pi} \tag{7.13}$$

According to (7.8) is

$$E_{el} + E_{mag} = \left(m_{el} + m_{mag}\right)c^2 = m_0 c^2 \tag{7.14}$$

Combination of (7.13) and (7.14) results in

$$E_{el} = \frac{1}{2} m_0 c^2 \left(1 + \frac{\lambda\!\!\!^{-}_C}{R}\frac{\alpha}{2\pi}\right) \tag{7.15}$$

and

$$E_{mag} = \frac{1}{2} m_0 c^2 \left(1 - \frac{\lambda\!\!\!^{-}_C}{R}\frac{\alpha}{2\pi}\right) \tag{7.16}$$

The electrical energy is purely static and thus cannot contribute to dynamic effects such as magnetic moment and angular momentum. Thus, these effects are exclusively attributed to the magnetic energy $E_{mag}$ respectively to the "magnetic" mass

$$m_{mag} = \frac{E_{mag}}{c^2} \tag{7.17}$$

David Bergman formulated this important statement already more than 20 years ago [1]. Latest since this date it should be clear why the angular momentum is $\hbar/2$

$$m_{mag} cR \approx \frac{1}{2} m_0 cR \approx \frac{\hbar}{2} \tag{7.18}$$

From (7.16), (7.17), and (7.18) follows

$$\frac{1}{2} m_0 \left(1 - \frac{\lambda\!\!\!^{-}_C}{R} \frac{\alpha}{2\pi}\right) cR \approx \frac{\hbar}{2} \tag{7.19}$$

or

$$R \approx \frac{\hbar}{m_0 c}\left(1 + \frac{\alpha}{2\pi}\right) = \lambda\!\!\!^{-}_C \left(1 + \frac{\alpha}{2\pi}\right) \tag{7.20}$$

where

$$\lambda\!\!\!^{-}_C = \frac{\hbar}{m_0 c} \tag{7.21}$$

This subject will be investigated exactly in Chapter 9.

With the radius according to (7.20) the energies according to (7.15) and (7.16) become

$$E_{el} \approx \frac{1}{2} m_0 c^2 \left(1 + \frac{\frac{\alpha}{2\pi}}{1 + \frac{\alpha}{2\pi}}\right) \tag{7.22}$$

$$E_{mag} \approx \frac{1}{2} m_0 c^2 \left(1 - \frac{\frac{\alpha}{2\pi}}{1 + \frac{\alpha}{2\pi}}\right) \tag{7.23}$$

Consequently is

$$E_{el} - E_{mag} \approx m_0 c^2 \frac{\frac{\alpha}{2\pi}}{1 + \frac{\alpha}{2\pi}} \tag{7.24}$$

The current in the twin loop is according to (7.20)

$$I \approx \frac{ec}{2\pi R} \approx \frac{ec}{2\pi} \frac{m_0 c}{\hbar} \frac{1}{1 + \frac{\alpha}{2\pi}} \tag{7.25}$$

From (7.25) follows the magnetic moment

$$\mu = \pi R^2 I \approx \pi R^2 \frac{ec}{2\pi R} \tag{7.26}$$

or

$$\mu \approx \frac{ec}{2} R \approx \frac{ec}{2} \frac{\hbar}{m_0 c}\left(1 + \frac{\alpha}{2\pi}\right) \tag{7.27}$$

and finally

$$\mu \approx \frac{e\hbar}{2m_0}\left(1+\frac{\alpha}{2\pi}\right) = \mu_B\left(1+\frac{\alpha}{2\pi}\right) \tag{7.28}$$

where

$$\mu_B = \frac{e\hbar}{2m_0} \tag{7.29}$$

is the Bohr magneton and

$$a_e \approx \frac{\alpha}{2\pi} \approx 1.161\,410\times 10^{-3} \tag{7.30}$$

is the mysterious magnetic moment "anomaly". All these results and statements and some more are already given in [1], and nothing happened in the physical community

## 8. Force Balance

Figure 6 illustrates that at $\beta_{\varphi1}\beta_{\varphi2} = 1$ in the whole range $0 \le r_2/r_1 < 1$ the attractive magnetic force is greater than the repulsive electric force. This is the unique chance that stable fundamental particles may exist. In the total range $0 \le r_2/r_1 < 1$ for each value of $r_2/r_1$ two values of $\beta_{\varphi1}\beta_{\varphi2}\big|_b$ can be found where

$$\beta_{\varphi1}\beta_{\varphi2}\big|_b F_{mag\ \rho} = -F_{el\ \rho} \tag{8.1}$$

This means that force balance exists when

$$\beta_{\varphi1}\beta_{\varphi2}\big|_b = -\frac{F_{el\ \rho}}{F_{mag\ \rho}} \tag{8.2}$$

At the lower value according to (8.2) the force balance is stable. The higher value being extremely close to $r_2/r_1 = 1$ represents instable balance. The most interesting region is the range where $r_2$ is close to $r_1$ and

$$\beta_\varphi = \frac{v_\varphi}{c} = \sqrt{\beta_{\varphi1}\beta_{\varphi2}} \tag{8.3}$$

is close to unity. Therefore, it is convenient to consider the differences

$$\delta\beta_b = 1-\sqrt{\beta_{\varphi1}\beta_{\varphi2}}\Big|_b = 1-\sqrt{\frac{\left|F_{el\ \rho}\right|}{F_{mag\ \rho}}} \tag{8.4}$$

and

$$\delta_r = \frac{r_1 - r_2}{r_1} = 1-\frac{r_2}{r_1} \tag{8.5}$$

Figure 7 shows $\delta\beta_b$ as a function of $\delta_r$ in the case of stable force balance. The smaller $\delta_r$ and $\delta\beta_b$ are, the more steps are necessary to arrive at correct values. This is indicated by the fact that the respective curves start to bend upwards as soon as the number of steps is no longer sufficient for full accuracy.

The cross at $\delta_r \approx 2.471604094 \times 10^{-4}$ and $\delta\beta_b \approx 1.159246494 \times 10^{-3}$ represents the force balance condition of the electron. Its calculation would have required at least $10^8$ steps. To be sure, the maximum number of steps was set at $3 \times 10^9$.

Based on the results of Chapter 9 the resulting force $F_{el\,\rho} + F_{mag\,\rho}$ according to (6.4) and (6.6) in the vicinity of the electron force balance point is shown in **Figure 8**. In contrary to **Figure 6** the impressive numerical values in MN/m are calculated and related to the circumference of the circular current loops. The calculation is based on (6.4) and (6.9) and

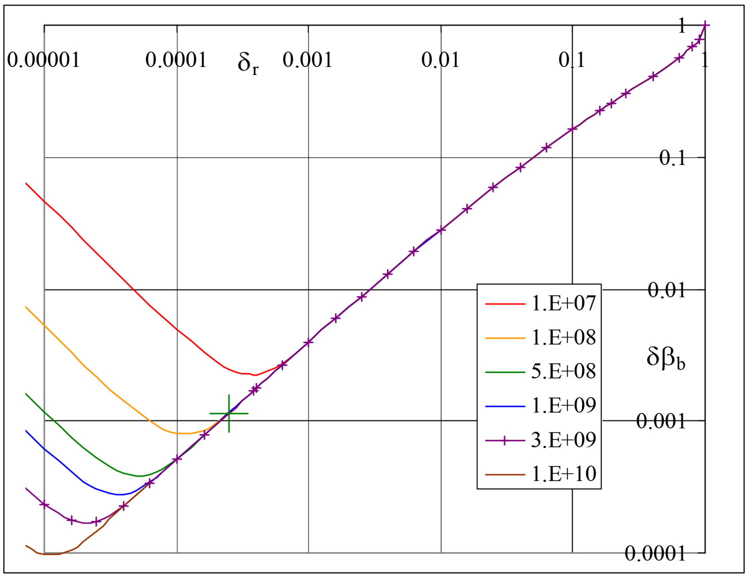


**Figure 7.** Velocity condition for radial force balance as a function of $\delta_r$. Different numbers of steps ranging from $10^{-7}$ to $10^{-10}$ indicate how convergence depends on $\delta_r$. The green cross indicates the electron position.

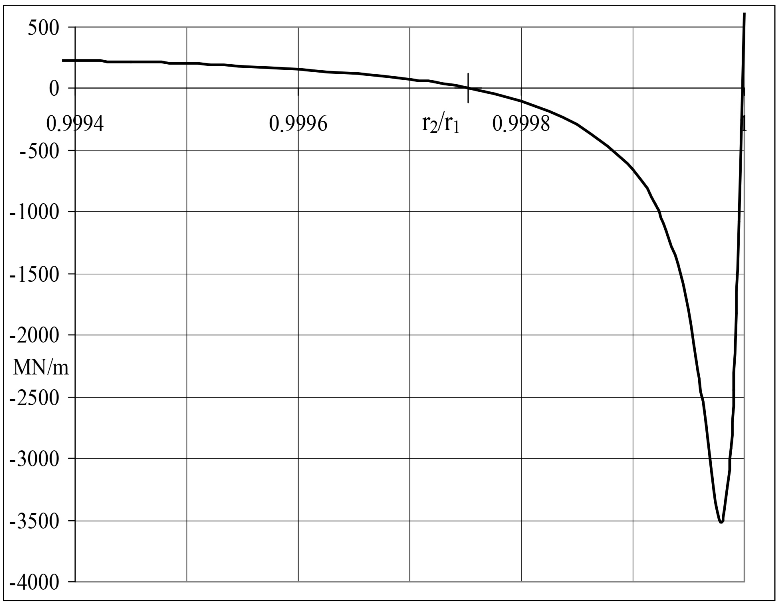


**Figure 8.** Radial force between the two current loops of the electron as a function of $r_2/r_1$.

$$\alpha\hbar c = 2.307077\times10^{-28}\ \mathrm{W\cdot s\cdot m} = 2.307077\times10^{-28}\ \mathrm{N\cdot m^2} \quad (8.6)$$

$$r_1 \approx R \approx \lambda\!\!\!^{-}_C = 386.159268\times10^{-15}\ \mathrm{m} \quad (8.7)$$

The absolute forces are

$$F_{mag\,b} = -F_{el\,b} \approx \frac{1}{4}\frac{\alpha\hbar c}{\lambda\!\!\!^{-}_C{}^2}\times1286.532 = 159.413\times10^{6}\ \mathrm{N} \quad (8.8)$$

and related to the circumference

$$\frac{F_{mag\,b}}{2\pi R} = \frac{-F_{el\,b}}{2\pi R} \approx 65.7\times10^{18}\ \mathrm{N/m} \quad (8.9)$$

## 9. A Model of the Electron

The goal of the following considerations is to find the simplest physical, consistent, electromagnetic model of the electron. The energy and force equations will be specialized to the case $z = 0$, *i.e.* where the two loops are positioned concentrically in the same plane in order to represent a stable fundamental particle. The radial velocities $v_{\varphi1}$ and $v_{\varphi2}$ are assumed to be slightly smaller than $c$:

$$\frac{v_{\varphi1}}{c} = \beta_{\varphi1} = 1-\delta\beta_{\varphi1} \quad \delta\beta_{\varphi1} \ll 1 \quad (9.1)$$

$$\frac{v_{\varphi2}}{c} = \beta_{\varphi2} = 1-\delta\beta_{\varphi2} \quad \delta\beta_{\varphi2} \ll 1 \quad (9.2)$$

$$\frac{v_{\varphi1}}{c}\frac{v_{\varphi2}}{c} = \beta_{\varphi1}\beta_{\varphi2} = \left(1-\delta\beta_{\varphi}\right)^2 \quad \delta\beta_{\varphi} \ll 1 \quad (9.3)$$

The interesting range of $r_2$ is $0 < r_2 < r_1$ where the electric force is negative (repulsive) and the magnetic force is positive (attractive).

According to (7.1) the difference between the electric energy $E_{el}$ and the magnetic energy is given by

$$E_{el} - \frac{E_{mag}}{\beta_{\varphi1}\beta_{\varphi2}} = \alpha m_0 c^2 \frac{\lambda\!\!\!^{-}_C}{r_1}\frac{q_1}{e}\frac{q_2}{e}\frac{2}{\pi} \quad (9.4)$$

As already mentioned in (3.3) the total electromagnetic field energy is

$$E_{el} + E_{mag} = m_0 c^2 \quad (9.5)$$

Combination of (9.4) and (9.5) results in

$$\frac{E_{el}}{m_0c^2} = \frac{1}{1+\beta_{\varphi1}\beta_{\varphi2}} + \frac{\beta_{\varphi1}\beta_{\varphi2}}{1+\beta_{\varphi1}\beta_{\varphi2}}\frac{\lambda\!\!\!^{-}_C}{r_1}\frac{4q_1q_2}{e^2}\frac{\alpha}{2\pi} \quad (9.6)$$

and

$$\frac{E_{mag}}{m_0c^2} = \frac{\beta_{\varphi1}\beta_{\varphi2}}{1+\beta_{\varphi1}\beta_{\varphi2}} - \frac{\beta_{\varphi1}\beta_{\varphi2}}{1+\beta_{\varphi1}\beta_{\varphi2}}\frac{\lambda\!\!\!^{-}_C}{r_1}\frac{4q_1q_2}{e^2}\frac{\alpha}{2\pi} \quad (9.7)$$

Relevant for further evaluation is the difference

$$\frac{E_{el}-E_{mag}}{m_0c^2} = \frac{1-\beta_{\varphi1}\beta_{\varphi2}}{1+\beta_{\varphi1}\beta_{\varphi2}} + \frac{2\beta_{\varphi1}\beta_{\varphi2}}{1+\beta_{\varphi1}\beta_{\varphi2}}\frac{\lambda\!\!\!^{-}_C}{r_1}\frac{4q_1q_2}{e^2}\frac{\alpha}{2\pi} \quad (9.8)$$

**Now it's time to eliminate some more misinterpretations and errors from accepted physics:**

The magnetic moment arises from the circular current $I_\varphi$:

$$I_\varphi = \frac{ev_\varphi}{2\pi R} = \frac{ec}{2\pi R}\beta_\varphi \tag{9.9}$$

where $R$ and $v_\varphi$ according to (6.10) respectively (8.3) are average values. The magnetic moment is

$$\mu = I_\varphi \pi R^2 = \frac{ec}{2}\beta_\varphi R = \frac{1}{2}ev_\varphi R \tag{9.10}$$

or

$$\mu = \frac{e\hbar}{2m_0}\frac{\beta_\varphi R}{\lambda\!\!\!^{-}_C} \tag{9.11}$$

The experimental finding is

$$\mu = \frac{e\hbar}{2m_0}(1+a) \tag{9.12}$$

Of course, this is correct, but the interpretation of $a$ as an "anomaly" is erroneous. As the magnetic moment is due to the current $I_\varphi$ in $\varphi$ direction the result must be related to the mass $m_\varphi$ in $\varphi$ direction rather than to the rest mass $m_0$. What really is measured is

$$\mu = \frac{e\hbar}{2m_\varphi}(1+a) \tag{9.13}$$

The rotational energy component of a rotating object cannot be measured by means of acceleration or gravitational experiments. The result of such measurements is always $m_0c^2$. The difference between $m_\varphi c^2$ and $m_0c^2$ must be interpreted as an additional rotational kinetic energy

$$E_{kin} = m_0c^2 a = 592.581\,\text{eV} \tag{9.14}$$

Consequently is

$$m_\varphi = m_0(1+a) \tag{9.15}$$

and

$$\mu = \frac{e\hbar}{2m_\varphi}(1+a) = \frac{e\hbar}{2m_0(1+a)}(1+a) \tag{9.16}$$

Thus, the real situation is as it has to be in terms of classical physics:

$$\boxed{\mu = \frac{e\hbar}{2m_0} = \mu_B} \tag{9.17}$$

where $\mu_B$ is the Bohr magneton.

From (9.11) and (9.17) arises the law of conservation of angular momentum:

$$\boxed{\beta_\varphi R = \lambda\!\!\!^{-}_C = \frac{\hbar}{m_0c}} \tag{9.18}$$

The existence of the kinetic energy $E_{kin}$ according to (9.14) is important for the angular momentum

$$J = rmv = \hbar/2 \tag{9.19}$$

When (9.19) is applied to the electron it must be observed that only the rotating part

$$m_{dyn} = \frac{E_{mag} + E_{kin}}{c^2} \tag{9.20}$$

of the mass contributes to the angular momentum. The combination of $E_{mag}$ and $E_{kin}$ may appear strange, but it is proven that they are equivalent [3]. The experimental value of $J$ is $\hbar/2$. Thus from (9.7), (9.14), (9.19), and (9.20) follows

$$m_0\left[\frac{\beta_{\varphi1}\beta_{\varphi2}}{1+\beta_{\varphi1}\beta_{\varphi2}} - \frac{\beta_{\varphi1}\beta_{\varphi2}}{1+\beta_{\varphi1}\beta_{\varphi2}}\frac{\lambda\!\!\!^{-}_C}{r_1}\frac{4q_1q_2}{e^2}\frac{\alpha}{2\pi} + a\right]c\beta_\varphi R = \frac{\hbar}{2} \tag{9.21}$$

where $v$ in (9.19) is substituted from $v_\varphi = c\beta_\varphi$ and $r$ is substituted according to (6.10). When (9.18) is used in (9.21) the result is

$$\frac{2\beta_{\varphi1}\beta_{\varphi2}}{1+\beta_{\varphi1}\beta_{\varphi2}} - \frac{2\beta_{\varphi1}\beta_{\varphi2}}{1+\beta_{\varphi1}\beta_{\varphi2}}\frac{\lambda\!\!\!^{-}_C}{r_1}\frac{4q_1q_2}{e^2}\frac{\alpha}{2\pi} + 2a = 1 \tag{9.22}$$

and finally

$$\frac{1-\beta_{\varphi1}\beta_{\varphi2}}{1+\beta_{\varphi1}\beta_{\varphi2}} + \frac{2\beta_{\varphi1}\beta_{\varphi2}}{1+\beta_{\varphi1}\beta_{\varphi2}}\frac{\lambda\!\!\!^{-}_C}{r_1}\frac{4q_1q_2}{e^2}\frac{\alpha}{2\pi} = 2a \tag{9.23}$$

If the kinetic energy $E_{kin} = am_0c^2$ would not have been considered, the right side of (9.23) would have been zero. This would require $\beta_{\varphi1}\beta_{\varphi2} > 1$. So, it would have been impossible to present a realistic model of the electron. Thus, the results given in Chapter 7 and in [1] are identified to be approximations.

Comparison of (9.23) and (9.8) leads to the important result

$$E_{el} - E_{mag} = 2am_0c^2 \tag{9.24}$$

As the electromagnetic field energy is

$$E_{el} + E_{mag} = m_0c^2 \tag{9.25}$$

the following fundamental statements can be formulated:

$$E_{el} = \left(\frac{1}{2} + a\right)m_0c^2 \tag{9.26}$$

$$E_{mag} = \left(\frac{1}{2} - a\right)m_0c^2 \tag{9.27}$$

$$E_{dyn} = E_{mag} + E_{kin} = \frac{1}{2}m_0c^2 \tag{9.28}$$

$$E_{total} = E_{el} + E_{dyn} = (1+a)m_0c^2 \tag{9.29}$$

Now the basic Equations (9.28) and (9.18) explain very simply:

$$J = m_{dyn}v_\varphi R = \frac{1}{2}m_0c\beta_\varphi R = \frac{1}{2}m_0c\frac{\hbar}{m_0c} \tag{9.30}$$

or

$$J = \frac{\hbar}{2} \tag{9.31}$$

Further analysis and evaluation of (9.23) require some reasonable assumptions.

**Assumption 1**

The charge density on the two circular loops is assumed to be the same:

$$\frac{q_1}{r_1} = \frac{q_2}{r_2} \tag{9.32}$$

In (7.9) was already stated that the charge condition of the electron is

$$q_1 + q_2 = e \tag{9.33}$$

From (9.32) and (9.33) follows

$$\frac{q_1}{e} = \frac{1}{1 + \frac{r_2}{r_1}} \tag{9.34}$$

and

$$\frac{q_2}{e} = \frac{\frac{r_2}{r_1}}{1 + \frac{r_2}{r_1}} \tag{9.35}$$

The factor

$$\frac{4q_1}{e}\frac{q_2}{e} = \frac{4\frac{r_2}{r_1}}{\left(1 + \frac{r_2}{r_1}\right)^2} \tag{9.36}$$

will turn out to be very close to unity.

**Assumption 2**

The angular velocities $\omega_1$ and $\omega_2$ of the rotating charges $q_1$ and $q_2$ are equal:

$$\omega_2 = \omega_1 \tag{9.37}$$

This means

$$\beta_{\varphi 2} = \beta_{\varphi 1}\frac{r_2}{r_1} \tag{9.38}$$

and

$$\beta_{\varphi 1}\beta_{\varphi 2} = \beta_{\varphi 1}^2\frac{r_2}{r_1} \tag{9.39}$$

When this is applied to (8.3) the average value $\beta_\varphi$ becomes

$$\beta_\phi = \sqrt{\beta_{\varphi 1}\beta_{\varphi 2}} = \beta_{\varphi 1}\sqrt{\frac{r_2}{r_1}} \tag{9.40}$$

Together with (9.18) and (6.10) this leads to

$$\frac{\lambda_C}{r_1} = \sqrt{\beta_{\varphi 1}\beta_{\varphi 2}}\sqrt{\frac{r_2}{r_1}} \tag{9.41}$$

The assumptions resulting in (9.36), (9.40, and (9.41) allow to transform (9.23) to

$$\frac{1-\beta_\varphi^2}{1+\beta_\varphi^2} + \frac{2\beta_\varphi^3}{1+\beta_\varphi^2}\frac{4\left(\frac{r_2}{r_1}\right)^{\frac{3}{2}}}{\left(1+\frac{r_2}{r_1}\right)^2}\frac{\alpha}{2\pi} = 2a \tag{9.42}$$

It turns out that a is exclusively given by the ratio $r_2/r_1$ because $\beta_\varphi$ is also determined by $r_2/r_1$ via the force balance condition according to (8.4). It allows to calculate for each value of $r_2/r_1$ the respective value of $\beta_\varphi = \beta_{\varphi b}$. Then a can be calculated according to (9.42). **Figure 9** shows the result in the interesting range of $a \approx \alpha/(2\pi)$ and

$$\delta\beta_\varphi = 1-\beta_\varphi \tag{9.43}$$

as a function of

$$\delta_r = 1 - r_2/r_1 \,. \tag{9.44}$$

It is meaningful that $a > \delta\beta_\varphi$ as $\delta_r < 2.471\times10^{-4}$ and that $a < \delta\beta_\varphi$ as $\delta_r > 2.472\times10^{-4}$.

By iteration the crossover point can be found at extremely high accuracy. At

$$\delta_r = 2.471604094\times10^{-4} \tag{9.45}$$

respectively

$$r_2/r_1 = 0.9997528396 \tag{9.46}$$

is

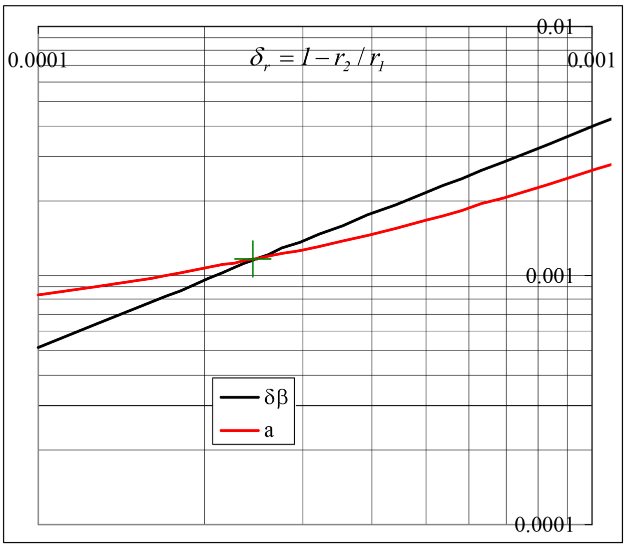


**Figure 9.** The interesting range of $a \approx \alpha/(2\pi)$ and $\delta\beta_\varphi = 1-\beta_\varphi$ as a function of $\delta_r = 1 - r_2/r_1$. The green cross marks the position of the electron.

$$\delta\beta_\varphi = a = 1.159246494\times10^{-3} \tag{9.47}$$

There is no rigorous proof that this significant point also describes the physical reality, but any other choice would be arbitrary. There is no additional condition that in (9.23) could justify another statement then $\delta\beta_\varphi = a$. Nevertheless, the following approximation is given as the only reasonable alternative: When in (9.42) according to (9.43) $\beta_\varphi^2$ is substituted from $\left(1-\delta\beta_\varphi\right)^2 \approx 1-2\delta\beta_\varphi$, then it becomes

$$\frac{\delta\beta_\varphi}{1-\delta\beta_\varphi} + \frac{1-3\delta\beta_\varphi}{1-\delta\beta_\varphi}\frac{4\left(\frac{r_2}{r_1}\right)^{\frac{3}{2}}}{\left(1+\frac{r_2}{r_1}\right)^2}\frac{\alpha}{2\pi} = 2a \tag{9.48}$$

As $\delta\beta_\varphi \ll 1$ and $r_2 \approx r_1$ it is obvious that

$$\frac{1-3\delta\beta_\varphi}{1-\delta\beta_\varphi}\frac{4\left(\frac{r_2}{r_1}\right)^{\frac{3}{2}}}{\left(1+\frac{r_2}{r_1}\right)^2}\frac{\alpha}{2\pi} \approx \frac{\alpha}{2\pi} \approx a \tag{9.49}$$

Consequently is

$$\frac{\delta\beta_\varphi}{1-\delta\beta_\varphi} \approx a \approx \frac{\alpha}{2\pi} \tag{9.50}$$

and

$$\delta\beta_\varphi \approx \frac{\frac{\alpha}{2\pi}}{1+\frac{\alpha}{2\pi}} = 1.160062420055\times10^{-3} \tag{9.51}$$

This corresponds to

$$r_2/r_1 = 0.9997526447 \tag{9.52}$$

and

$$a = 1.159653926\times10^{-3} \tag{9.53}$$

The experimental value of the electron's magnetic moment "anomaly" is [4]

$$a_e = 1.159652181\times10^{-3} \tag{9.54}$$

Despite of the fact that the values of (9.53) and (9.54) are very close together the solution according to (9.46) and (9.47) is preferred because it looks more natural and more systematic, and it avoids the introduction of an additional parameter. Thus, the charge $\pm e$ and the angular momentum $\hbar/2$ are sufficient to derive the new universal constants $\delta_r = 1-r_2/r_1$ and $\delta\beta_\varphi = a$. They define the basic structure of fundamental particles and ensure their stability (force balance). The first one is a shape factor while the second one is necessary for the energy inventory. They are dimensionless numbers similar to the fine-structure constant $\alpha$ and are fundamental physical constants because they hold for all respective particles and are invariant against the average radius $R = \hbar/(m_0 v_\varphi)$ respectively the rest mass $m_0$. Moreover it means that a fundamental particle may widely increase (not decrease!) its radius and decrease (not increase!) its rotational velocity $v_\varphi$, e.g. when it joins other charged particles, as far as according to (9.18) the angular momentum conservation condition

$$R = \frac{\lambda\!\!\!^{-}_C}{\beta_\varphi} = \frac{\lambda\!\!\!^{-}_C}{1-a} = \frac{\hbar}{m_0 v_\varphi} \tag{9.55}$$

is fulfilled. A well-known example is the one-electron atom with the nucleus charge $eZ$ where $\beta_\varphi \approx \alpha Z$ and $R \approx a_0 = \lambda\!\!\!^{-}_C/\alpha$. Moreover, it confirms that fundamental particles show mass-like and relativistic behavior, while their internal structure is non-relativistic and essentially field-like.

One important message is that all free fundamental particles having the charge $\pm e$ and the angular momentum $\hbar/2$ must possess the same values of $r_2/r_1$ and $\delta\beta_\varphi = a$, regardless of their rest mass $m_0$. There is high evidence that this also holds for the **free** proton and the **free** antiproton. It is an important discovery that the magnetic moment "anomaly" a indicates the existence of the kinetic energy $E_{kin} = a m_0 c^2$. It is necessary to make the presented model perfect, and it reveals that fundamental particles internally are not purely field-like such as photons and not (essentially) mass-like such as atoms. They represent a special kind of matter in between. Nevertheless, the fundamental particle is completely an object of classical physics including the non-anomalous magnetic moment $\mu = e\hbar/(2m_0) = e v_\varphi R/2$. The circular current loop model is two-dimensional. It is the simplest one that is consistent and represents all details of fundamental particles at extremely high accuracy. According to (9.54) the rotational velocity $v_{\varphi e}$ of the electron is given by

$$\beta_{\varphi e} = \frac{v_{\varphi e}}{c} = 1 - a_e = 0.998840347819 \tag{9.56}$$

The respective value of the presented model is

$$\beta_\varphi = \frac{v_\phi}{c} = 1 - a = 0.998840753506 \tag{9.57}$$

The maximum and minimum values of the twin loop model are

$$\beta_{\varphi 1} = \beta_\varphi \sqrt{\frac{r_1}{r_2}} = 0.998964213363 \tag{9.58}$$

$$\beta_{\varphi 2} = \beta_\varphi \sqrt{\frac{r_2}{r_1}} = 0.99871708907 \tag{9.59}$$

For practical use it is not necessary to emphasize the twin loop character of a fundamental particle. It will be sufficient to calculate with the average radius according to (9.18)

$$R = \frac{\lambda\!\!\!^{-}_C}{\beta_\phi} \approx \lambda\!\!\!^{-}_C = \frac{\hbar}{m_0 c} \tag{9.60}$$

## Conflicts of Interest

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

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