Relativism is closer than we think

Haletsky M. B.

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hal123mih@gmail.com

Abstract

Theory and solution of problems on head-on collision of electrons using formulas of Elementary Theory of Relativity (ETR). Elementary theory is fundamentally different from Einstein's Special Theory of Relativity.

Keywords: momentum, energy, speed, collision, distance, radius, theory, problems.

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Topic 1. Brief information on the ETR theory

1. The velocities of elementary particles are divided into three main ranges:

a) non-relativistic $0 \leq v < 1.095 \cdot 10^6\ ms^{-1}$;

b) relativistic $1{,}095 \cdot 10^6 \leq v \leq 10 \cdot 10^6\ ms^{-1}$;

c) ultra-relativistic $10 \cdot 10^6 \leq v \leq 299.972 \cdot 10^6\ ms^{-1}$.

2. In the non-relativistic range, elementary particles obey the laws of classical Newtonian mechanics (momentum, kinetic energy):

$$\vec{p} = m\vec{v}\,; \qquad E_k = \frac{mv^2}{2}\,.$$

The particle enters the relativistic state abruptly at a velocity of 1.095· $10^6\ ms^{-1}$.

3. In relativistic ranges, the particle moves under the action of two mechanical impulses: classical and relativistic. The relativistic component is associated with the particle's own torsion [1]. Such an impulse is called generalized:

$$\vec{p} = m\vec{v} + \frac{m\vec{v}}{\sqrt{1+\frac{v^2}{c^2}}} + \frac{\alpha^2}{8}\frac{m\vec{v}}{\sqrt{1+\frac{v^2}{c^2}}}\ ; \qquad (1)$$

$$\vec{p} = \vec{p}_s + \vec{p}_r + \vec{p}_h\ .$$

Here: $\vec{p}_s -$ is the impulse of translational motion;

$\vec{p}_r -$ linear analogue of the momentum of proper torsion;

$\vec{p}_h -$ momentum of precession of proper torsion;

$\alpha -$ fine structure constant (7,297 352 569 $\cdot 10^{-3}$).

When solving problems, the precession momentum $\vec{p}_h$ is neglected, it is much less than $\vec{p}_s$. The entry for the total kinetic energy of a relativistic particle has the following form:

$$E_k = \frac{mv^2}{2} + \left(mc^2 - \frac{mc^2}{\sqrt{1+\frac{v^2}{c^2}}}\right) - \frac{\alpha^2}{8}\frac{mc^2}{\sqrt{1+\frac{v^2}{c^2}}}\ ; \qquad (2)$$

$$E_k = E_s + E_r - E_h\ .$$

Here: $E_s -$ energy of translational motion;

$E_r -$ energy of relativistic torsion;

$E_h -$ energy of torsion precession.

4. In the relativistic range of velocities, using the example of a free electron, formulas (1) and (2) can be simplified based on approximate relationships.

$$|\vec{p}_r| \cong |\vec{p}_s| = |m\vec{v}|\ ;$$

$$mc^2 - \frac{mc^2}{\sqrt{1+\frac{v^2}{c^2}}} \approx \frac{mv^2}{2}\ ;$$

$$\frac{\alpha^2}{8}\frac{mc^2}{\sqrt{1+\frac{v^2}{c^2}}} \approx 3.4\ eV.$$

After simplification, the generalized momentum and kinetic energy of one electron are written as follows:

$$\vec{p} = 2m\vec{v}\ ;$$

$$E_k = mv^2 - 3.4\ eV.$$

The precession energy is expressed in electron volts (eV). There is no absorption of photons in a vacuum. Particle collisions should be considered elastic. The laws of conservation of generalized mechanical momentum and total energy of the system of interacting particles are satisfied. The mechanical system is considered closed.

$$\vec{p} = \sum_i 2m\vec{v}_i = const.;$$

$$W = \sum_i\left(mv_i^2 - 3.4\ eV\right) + W_p = const\ .$$

For electrons, all particles are equal in mass and charge. W is the total energy of the charge system $W_p -$ is the potential energy of interaction of charged particles. When solving problems in the laboratory frame of reference, a convenient coordinate system is chosen.

5. The dependence of the electron velocity on the accelerating voltage, in the first approximation, is determined by the formulas:

$v = 594\sqrt{U}\ \ -$ classical mechanics, , $km \cdot s^{-1}$;

$v = 420\sqrt{U + 3{,}4\ V}\ \ -$ relativistic mechanics, $km \cdot s^{-1}$.

Here U is the potential difference of the accelerating (external) electric field at infinity. For the relativistic range of speeds, the value of U is in the range from 3.4 V to 600 V. For the ultra-relativistic range, the formula for the dependence of the velocity on voltage has a complex form:

$Ue = \frac{mv^2}{2} + mc^2 - \frac{mc^2}{\sqrt{1+\frac{v^2}{c^2}}}; -$ ultra-relativistic interval.

The precession energy is neglected. The accelerating voltage reaches 400 thousand volts. The speed of the electron approaches the speed of light. The difference in the characteristics of the motion of nonrelativistic and relativistic electrons is shown in Figure 1.

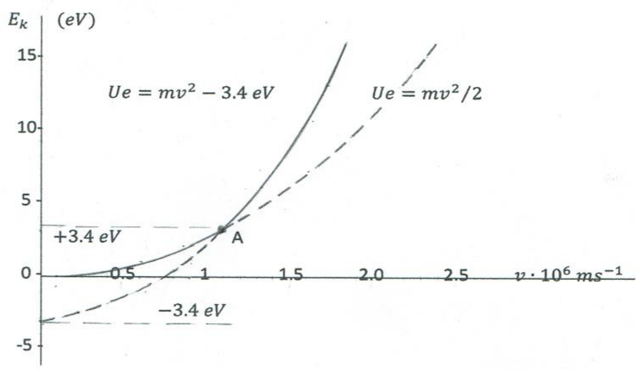


Fig. 1

For solving problems, only the initial part of the characteristics is of interest. At point A, the electron passes from the classical state to the relativistic one. The work function of electrons from metals is usually greater than 3.4 eV (for example, thorium). There are metals with a work function less than 3.4 eV (for example, cesium). But such metals are a rare exception to the rule. Based on a comparison of the characteristics, it can be assumed that in an ideal vacuum, all electrons are relativistic. Electrons do not stand still they are constantly moving. The minimum speed of motion outside the substance is $v = 1.095 \cdot 10^6\ ms^{-1}$. Inside the substance, the speed of thermal motion of electrons is an order of magnitude less, $v \approx 10^5\ ms^{-1}$.

6. The radius of the wave sphere of relativistic and ultra-relativistic electrons depends on the speed of translational motion [2]. The greater the speed, the smaller the radius. The graph of the dependence $r_n = f(v_n)$ is shown in Figure 2. The minimum radius at $v \to c,\ r_{min} = 0.0101$ Å, the maximum is 2.12Å at $v = 1.095 \cdot 10^6\ ms^{-1}$.

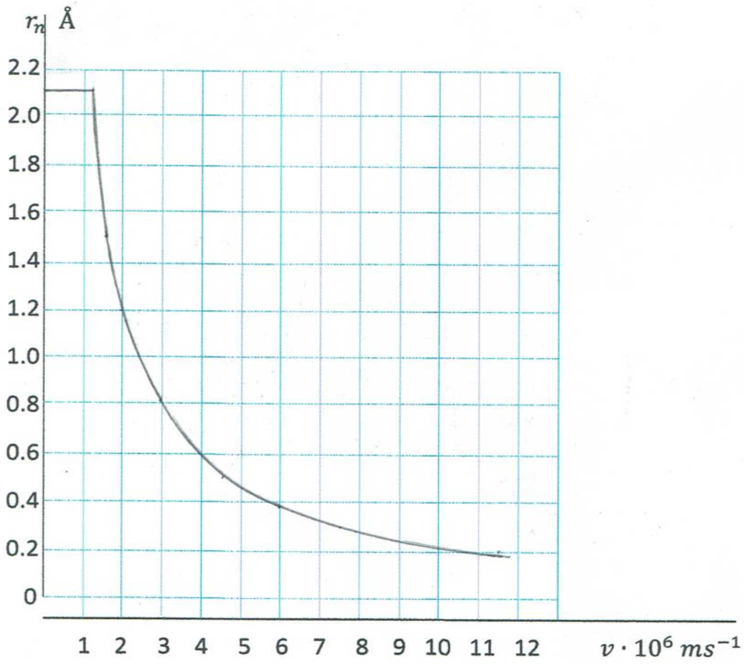


Fig. 2, $1Å = 10^{-10}\ m$.

The question is, why only head-on collisions are considered. The answer is, to ignore the Lorentz force from the interaction of the incident electron with the magnetic field of the opposite particle. Taking the Lorentz force into account requires determining the impact distance and the effective cross-section of the interaction. These parameters determine the probability of a head-on collision. The probability of such an event is very low, perhaps one in a billion consecutive collisions. This problem is solved in charged particle accelerators on colliding beams. The more charged particles in the beam, the greater the probability of recording the results of a head-on collision event.

In the classical representation, electrons elastically collide as solid charged particles and fly apart without destruction in opposite directions.

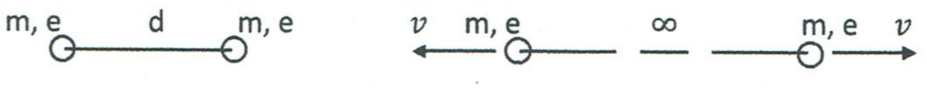
In the relativistic representation, electrons overcome the potential barrier, intersect in wave form and fly apart in opposite directions without destruction.

In tasks #1; 2; 3; the classical representation of electrons is used. In tasks #4; 5; 6; 7; the relativistic representation is used.

Task #1

Two electrons in a bound state are at a distance **d** from each other. When the bond is broken, the electrons are acted upon by repulsive Coulomb forces. Determine the distance **d** if, in a free state, the electrons acquire a minimum relativistic velocity at infinity, $v = 1.095 \cdot 10^6\ ms^{-1}$. Compare the obtained distance with the dimensions of the electron wave circle and the Compton sphere.

Solution: [The connection is broken the electrons fly apart at high speed in a straight line. At infinity, the Coulomb forces have virtually no effect. The particles move by inertia at a constant speed. The speeds are the same].



State 1 State 2

In state 1, the kinetic energy of the system of two electrons is zero. The sum of the momenta is zero. There is only the potential energy of the electrical interaction of a pair of charged particles, W_p.

$$\sum\nolimits_1 p_i = 0; \quad \sum\nolimits_1 E_{ki} = 0; \quad W_p = k\frac{e^2}{d}.$$

Here: $k -$ is the proportionality coefficient in Coulomb's law, $9 \cdot 10^9\ Nm^2C^{-2}$;

e $-$ is the elementary charge of an electron, $1{,}6022 \cdot 10^{-19}$ C .

In state 2, at infinity, the potential energy of the electric field is zero. There is only the kinetic energy of two electrons. The geometric sum of momenta is zero.

$$\sum\nolimits_2 p_i = 2mv_1 - 2mv_2 = 0; \ v_1 = v_2 = v;$$

$$W_p = 0;$$

$$\sum_2 E_{ki} = 2(mv^2 - 3.4\ eV).$$

Determine the distance $\boldsymbol{d}$. The laws of conservation of mechanical momentum and total energy of the charge system are satisfied: $\sum_1 p_i = \sum_2 p_i = 0;\ W_1 = W_2$.

$$v_1 = v_2 = v = 1.095 \cdot 10^6\ ms^{-1};$$

$$k\frac{e^2}{d} = 2(mv^2 - 3.4\ eV);$$

$$d = k\frac{e^2}{2(mv^2 - 3.4\ eV)}.$$

Substitute the numerical values of the parameters. Electron mass $m = 9.11 \cdot 10^{-31}\ kg$. We convert electron volts to joules, $3{,}4 \cdot 1{,}6022 \cdot 10^{-19}\ J$. We get:

$$d = 9 \cdot 10^9 \frac{1.6022^2 \cdot 10^{-38}}{2(9.11 \cdot 10^{-31} \cdot 1.095^2 \cdot 10^{12} - 3.4 \cdot 1.6022 \cdot 10^{-19})} = 2.11\ \text{Å}.$$

The radius of the wave circle of an electron in a state of relative rest is equal to, $r_{n\,max} = 2{,}12\ \text{Å}$. The radius of the Compton sphere is $r_c = 0{,}00386\ \text{Å}$. We find the ratios:

$$\frac{d}{r_{n\,max}} = \frac{2{,}11\ \text{Å}}{2{,}12\ \text{Å}} \approx 1; \quad \frac{d}{r_c} = \frac{2.11\ \text{Å}}{0.00386\ \text{Å}} \approx 547.$$

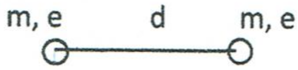
The converse is true. If electrons move from infinity towards each other, with minimal relativistic velocity, then the distance of minimal approach of particles is equal to the maximum radius of the electron. For an electron to become relativistic, its work function from matter must exceed 3.4 eV. In a mutual collision of relativistic electrons, the Compton spheres do not intersect. Task solved.

Task #2

Two electrons fly out from infinity towards each other with the same speed $v = 10 \cdot 10^6\ ms^{-1}$**.** Spherical wave shells of electrons are not a solid surface. The question is, at what minimum distance will the particles approach each other? Determine the ratio of the minimum distance to the radius of the Compton sphere.

Solution. [Under the action of Coulomb forces, the electrons will slow down, losing speed. All kinetic energy is converted into the energy of electrical interaction. The total geometric momentum of the two particles is automatically conserved. The electrons avoid a head-on collision and fly apart in opposite directions].

State 1



State 2

We use the law of conservation of energy in a closed system of two charged particles. The geometric sum of momenta in both states is zero.

In state 1, the system has only kinetic energy. The potential electric energy is zero.

$$W_p = 0; \qquad W_1 = \sum_1 E_{ki} = 2(mv^2 - 3.4\ eV).$$

In state 2, the system has only potential electric energy of interaction. The kinetic energy is zero. The particles stop for a moment, then run away in opposite directions.

$$W_p = k\frac{e^2}{d}\ ; \quad W_2 = W_p.$$

The law of conservation of energy in a closed system of two particles is satisfied:

$$2(mv^2 - 3.4\ eV) = k\frac{e^2}{d}.$$

We determine the distance of minimum approach of electrons:

$$d = k\frac{e^2}{2(mv^2 - 3.4\ eV)}.$$

Substitute the numerical values of the parameters:

$$d = 9 \cdot 10^9 \frac{1.6022^2 \cdot 10^{-38}}{2(9.11 \cdot 10^{-31} \cdot 10^2 \cdot 10^{12} - 3.4 \cdot 1.6022 \cdot 10^{-19})} = 0.01276\ \text{Å}.$$

The ratio of the distance **d** to the radius of the Compton sphere:

$$\frac{d}{r_c} = \frac{0.01276\ \text{Å}}{0.00386\ \text{Å}} = 3{,}306.$$

The Compton spheres do not intersect. The Task is solved.

Task #3

Two electrons fly from infinity towards each other with initial speeds of $v_1 = 8 \cdot 10^6\ ms^{-1}$ and $v_2 = 3 \cdot 10^6\ ms^{-1}$. Determine the minimum distance at which the particles will approach each other and its ratio to the radius of the Compton sphere.

Solution. [Under the action of electrostatic repulsion forces, the particles will lose speed. At some point in time, the particle with the smaller initial momentum modulus will stop, turn around and start moving in the opposite direction. Both particles will slow down and will move in the same direction with the same speed. The particles will approach each other at a minimum distance].

State 1 State 2

We use the laws of conservation of energy and generalized mechanical momentum in a closed system of two charged particles.

In state 1, the system has only kinetic energy. The potential energy of electrical interaction is zero.

$$\sum_1 p_i = 2mv_1 - 2mv_2;$$

$$W_1 = \sum_1 E_{ki} = 2(mv_1^2 - 3.4\ eV).$$

In state 2, the system has kinetic energy and potential electric energy.

$$\sum_2 p_i = 2mu + 2mu = 4mu;$$

$$W_2 = 2(mu^2 - 3.4\ eV) + k\frac{e^2}{d}.$$

From the conservation laws we have: $\sum_1 p_i = \sum_2 p_i$; $W_1 = W_2$.

$$2mv_1 - 2mv_2 = 4mu;$$

$$mv_1^2 + mv_2^2 - 6.8\ eV = 2(mu^2 - 3.4\ eV) + k\frac{e^2}{d}.$$

The x -axis is directed along the trajectory of motion. Let's express the velocity u from the first equation:

$$u = \frac{v_1 - v_2}{2}.$$

Let's substitute the velocity $\boldsymbol{u}$ into the second equation. The constant terms of the equation 6.8 eV will cancel out. We get:

$$mv_1^2 + mv_2^2 = 2m\left(\frac{v_1 - v_2}{2}\right)^2 + k\frac{e^2}{d}.$$

We make simple transformations and determine the minimum distance between particles:

$$d = 2k\frac{e^2}{m(v_1+v_2)^2} = 2 \cdot 9 \cdot 10^9 \frac{1.6022^2 \cdot 10^{-38}}{9.11 \cdot 10^{-31}(8+3)^2 \cdot 10^{12}} = 0.04192\ \text{Å}.$$

We determine the ratio of the distance $\boldsymbol{d}$ to the radius of the Compton sphere:

$$\frac{d}{r_c} = \frac{0.04192\ \text{Å}}{0.00386\ \text{Å}} = 10.86.$$

The minimum distance is much larger than the Compton sphere. Task solved.

Topic 2. Relativistic correction to Coulomb's law

1. Let us write down Coulomb's formulas for the force and intensity of the electrical interaction of a pair of charged particles:

$$F_c = k\frac{q_1 q_2}{r^2}; \quad E_1 = \frac{F_c}{q_2} = k\frac{q_1}{r^2}.$$

The entire electric field between the particles is assigned to the first charge. The second particle is depersonalized, i.e. has no field. This is the accepted practice in classical electrostatics. At rest and at low speeds, this approach justifies itself. In electrodynamics and especially in relativistic mechanics, this approach causes difficulties. Each charge must manifest itself independently. However, the situation with different charges can be reduced to the situation with identical (equivalent) charges. We determine the field strength separately for each particle, the distance between the particles is preserved:

$$E_1 = \frac{F_c}{q_2} = k\frac{q_1}{r^2}\ ; \qquad E_2 = \frac{F_c}{q_1} = k\frac{q_2}{r^2}.$$

Let's find the product of the intensities and denote it as E^2:

$$E^2 = E_1E_2 = k^2\frac{q_1q_2}{r^4}.$$

Then:

$$E = k\frac{\sqrt{q_1q_2}}{r^2} = k\frac{q}{r^2}; \qquad q = \sqrt{q_1q_2}$$ – is the equivalent charge.

The work of moving a physical or equivalent charge from point 1 to point 2 is the same:

$$A = \int_1^2 Eqdr = kq^2\int_1^2\frac{dr}{r^2} = kq^2\left(\frac{1}{r_1} - \frac{1}{r_2}\right);$$

$$A = kq_1q_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right).$$

All energy characteristics of charges are performed automatically.

2. A classical electron in a bound state inside a substance has the shape of a charged ring. **Its own magnetic field** is open to interaction with other particles and fields. Along the ring there are standing longitudinal oscillations **of constant mass** and electric charge. The Compton sphere is absent.

In the relativistic state ($v \geq 1.095 \cdot 10^6\ ms^{-1}$), outside the substance, the electron changes its structure. The electron ring begins to rotate in the transverse direction. An outer wave sphere with the Compton sphere inside is formed. The radius of the wave sphere decreases with increasing translational motion velocity. There is a negative charge on the surface of the sphere. The constant mass of the electron is located in the inner Compton sphere. Standing radial oscillations of the relativistic mass and energy pulsate between the spheres. The effective mass is equal to the sum of the constant and relativistic masses. As an assumption, there is a small positive charge on the surface of the Compton sphere, such that $q_2 - q_1 = -e$. It ensures the stability of the outer wave sphere. The proper magnetic field circulates between the spheres, is screened by them and practically does not go outside. Let us assume that the Compton sphere rotates instead of the outer sphere. Such a description of the electron simplifies the understanding of the proper torsion of the particle in rotating reference frames. Based on simple considerations of the balance of rotational forces and Coulomb forces for opposite particles, we can write:

$$E_1 \propto \frac{m\omega_1^2}{qr_c}; \;\; E_2 \propto \frac{m\omega_2^2}{qr_c}; \;\; E^2 = E_1E_2 \propto \frac{m^2\omega_1^2\omega_2^2}{q^2r_c^2} \propto \omega_1^2\omega_2^2.$$

Here: $\omega_1 -$ cyclic rotation frequency of the first electron;

$\omega_2 -$ cyclic rotation frequency of the second electron;

$r_c -$ Compton sphere radius.

3. Two electrons are accelerated at infinity by external electric fields to the same ultra-relativistic speeds. The radius of the wave sphere of each electron decreases. The photon load between the outer and inner spheres of the electrons increases. Then the particles, by inertia, fly towards each other. The energy density of the total field along the interaction line is:

$$\mathcal{w}_e = \frac{\varepsilon_0 E^2}{2} = \frac{\varepsilon_0}{2}\left(E_0 \frac{\omega^2}{\omega_0^2}\right)^2.$$

Here:

$E_0 -$ the electric field strength of the electron in the classical form;

$\omega_0 -$ the initial frequency of rotation of the Compton sphere at $v \approx 1.095 \cdot 10^6\ ms^{-1}$;

$\omega -$ the current frequency of rotation of the Compton sphere at $v \geq 10 \cdot 10^6\ ms^{-1}$.

Braking occurs, the speed of the particles decreases. The kinetic energy of each electron is converted into the energy of the total electric field of two particles. The outer wave sphere of the electrons increases. The photon load inside each electron decreases. When ultra-relativistic electrons rapidly decelerate in a material medium, they emit photons of electromagnetic energy. Radiation is not considered in this article. Electrons are smoothly decelerated in opposite fields. The total energy of the system of two electrons is conserved. Electric fields have a wave structure. The normal Doppler effect must be fulfilled. Depending on the speed, one electron perceives the other electron as a particle with an increased charge.

$$\frac{\omega}{\omega_0} = \frac{1+\beta}{1-\beta}; \quad \beta = \frac{v}{c}; \quad \mathcal{w}_e = \frac{\varepsilon_0 E_0^2}{2}\left(\frac{1+\beta}{1-\beta}\right)^4;\ c - \text{ is the speed of light.}$$

The fundamental law of Coulomb and the potential energy for approaching electrons can be written in relativistic form:

$$F_c = k\frac{q^2}{d^2}\left(\frac{1+\beta}{1-\beta}\right)^4; \quad W_p = k\frac{q^2}{d}\left(\frac{1+\beta}{1-\beta}\right)^4.$$

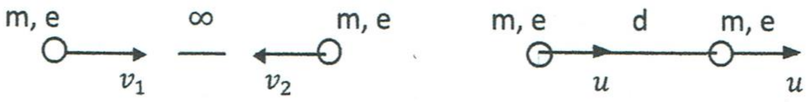
Here d is the distance of approach of electrons in a straight line.

When slowing down, classical electrons should reach zero speed in a vacuum. In reality, this does not happen. They intersect or diverge along parallel, helical and hyperbolic trajectories. At the minimum relativistic speed, electrons change their state of aggregation. They turn into a wave (wave circle). In this state, electrons intersect without damage as in atoms. They gain speed and again turn into relativistic particles. The dual nature of the electron is manifested. The distance of minimum approach $\boldsymbol{d}$ is the area of transient processes and the subject of study of theoretical physics. However, in any transient processes the basic laws of conservation of energy and momentum must be fulfilled. This is how the author of the article sees the physics of free electrons in a vacuum. The theoretical basis of the relativistic correction is given in abbreviated form. **The tasks are solved within the framework of formal logic**

Task #4

Two electrons fly out from infinity towards each other, with different ultra-relativistic speeds: $v_1 = 250 \cdot 10^6\ ms^{-1}$; $v_2 = 200 \cdot 10^6\ ms^{-1}$. Determine the minimum distance at which the particles will approach each other in the ultrarelativistic form.

Solution. [Under the action of electrostatic repulsion forces, at some point in time, both particles begin to lose speed. During the transition process, the second particle will turn around and both electrons will move in the same direction, with the same speed $\boldsymbol{u}$].



State 1 State 2

At ultra-relativistic speeds, it is necessary to use full expressions for momentum and kinetic energy. Coulomb's law is written in relativistic form. Momentum and precession energy are neglected.

In state 1, within the framework of formal logic, the system has only kinetic energy. We determine the numerical values of the pulses. We take the value of the speed of light $c = 300 \cdot 10^6\ ms^{-1}$.

$$p_1 = mv_1 + \frac{mv_1}{\sqrt{1+\beta_1^2}}; \quad \beta_1 = \frac{v_1}{c} = \frac{250}{300} = 0.8333\ ;$$

$$p_2 = mv_2 + \frac{mv_2}{\sqrt{1+\beta_2^2}}; \quad \beta_2 = \frac{v_2}{c} = \frac{200}{300} = 0.6667\ ;$$

$$p_1 = 4027 \cdot 10^{-25}\ gms^{-1}; \quad p_2 = 3338 \cdot 10^{-25}\ gms^{-1}.$$

Total geometric momentum taking into account the direction of speed:

$$\textstyle\sum_1 (p_1 - p_2) = 689 \cdot 10^{-25}\ gms^{-1} \Longrightarrow \frac{\sum_1 (p_1 - p_2)}{mc} = 0.2521 = 2a\ .$$

Here $\boldsymbol{2a}$ is the total momentum in dimensionless form.

In state 2, the system has mechanical momentum and potential energy of the electric field. The collision is considered elastic. The momenta after the collision are the same and coincide in direction.

$$\frac{\sum_2 (p_u + p_u)}{mc} = \frac{2p_u}{mc} = 2\left(\beta_u + \frac{\beta_u}{\sqrt{1+\beta_u^2}}\right) = 2a; \quad \beta_u = \frac{u}{c}\ ;$$

$$\beta_u + \frac{\beta_u}{\sqrt{1+\beta_u^2}} = a = \frac{0.2521}{2} = 0.12605\ .$$

The last equation is reduced to a full fourth-degree equation with constant coefficients:

$$\beta_u^4 - 2a\beta_u^3 + a^2\beta_u^2 - 2a\beta_u + a^2 = 0\ ;$$

or in numerical form,

$$\beta_u^4 - 0{,}2521\beta_u^3 + 0{,}01589\beta_u^2 - 0{,}2521\beta_u + 0{,}01589 = 0\,.$$

Solving the equation in the Online calculator gives two real values. Complex values are ignored.

$$\beta_{u1} = 0.698913; \quad u_1 = \beta_{u1}c \approx 210 \cdot 10^6\ ms^{-1}\,;$$

$$\beta_{u2} = 0.063093; \quad u_2 = \beta_{u2}c \approx 19 \cdot 10^6\ ms^{-1}\,.$$

Only the first solution (β_{u1}) is used. It is closer in magnitude to the generalized relative speed $\triangle = \sqrt{v_1 v_2} = 223.6\ ms^{-1}$[1]. It is necessary to take into account the rounding of the speed of light and the inaccuracy of the calculations. The second solution has a right to exist, but on the condition that photons are emitted into the environment. This option is not considered.

In state 1, we calculate the total kinetic energy of two particles:

$$E_{k1} = \frac{mv_1^2}{2} + mc^2 - \frac{mc^2}{\sqrt{1+\beta_1^2}}\,;$$

$$E_{k2} = \frac{mv_2^2}{2} + mc^2 - \frac{mc^2}{\sqrt{1+\beta_2^2}}\,;$$

$$E_{k1} = 9.11 \cdot 10^{-31}\left(\frac{250^2}{2} + 300^2 - \frac{300^2}{\sqrt{1+0.8333^2}}\right)10^{12} = 474\,712.55 \cdot 10^{-19} J\,;$$

$$E_{k1} = 9.11 \cdot 10^{-31}\left(\frac{200^2}{2} + 300^2 - \frac{300^2}{\sqrt{1+0.6667^2}}\right)10^{12} = 319\,912.46 \cdot 10^{-19} J;$$

$$\textstyle\sum_1 (E_{k1} + E_{k2}) = 794\,625 \cdot 10^{-19} J.$$

In state 2, we calculate the final kinetic energy of two particles:

$$2E_{ku} = 2\left[9.11 \cdot 10^{-31}\left(\frac{210^2}{2} + 300^2 - \frac{300^2}{\sqrt{1+0.698913^2}}\right)10^{12}\right] = 698\,172 \cdot 10^{-19}\ J.$$

We write the energy balance in two states, taking into account the potential energy of electrical interaction:

$$W_1 = \textstyle\sum_1 (E_{k1} + E_{k2}) = 794\,625 \cdot 10^{-19}\ J\,;$$

$$W_2 = 2E_{ku} + W_p = 698\,172 \cdot 10^{-19} + k\frac{e^2}{d}\left(\frac{1+\beta_u}{1-\beta_u}\right)^4;$$

$$W_1 = W_2;$$

$$(794\,625 - 698\,172)10^{-19} = 9 \cdot 10^9\,\frac{1.6022^2 \cdot 10^{-38}}{d}\left(\frac{1+0.698913}{1-0.695913}\right)^4.$$

We determine the minimum distance of approach of particles in counter motion, at ultra-relativistic speeds:

$$d = 9 \cdot 10^9 \frac{1.6022^2 \cdot 10^{-38}}{96\,453 \cdot 10^{-19}} \cdot 1014 = 0.24288\ \text{Å}\,.$$

.

We determine the ratio of $\boldsymbol{d}$ to the radius of the Compton sphere:

$$\frac{d}{r_c} = \frac{0.24288\ \text{Å}}{0.00386\ \text{Å}} = 63.$$

The Compton spheres do not intersect. The task is solved.

Task #5

An electron moves in a straight line at a speed close to the speed of light. It is required to determine the minimum radius of the electron's wave sphere.

Solution. [Let us find this radius from the following considerations. The article [3] provides a derivation of the formula for relativistic energy through the ratio of the sizes of the wave sphere and the Compton sphere].

Let us write the formula for the relationship between relativistic energy and the size of an electron:

$$E_r = 2mc^2 \frac{r_c^2}{r_n^2}.$$

Here: $r_c -$ is the radius of the Compton sphere (0.00386 Å);

$r_n -$ current radius of the outer wave sphere of the electron.

Let us direct the electron's velocity to the speed of light, $v \to c$.

Then:

$$E_k = E_s + E_r = \frac{mc^2}{2} + 2mc^2 \frac{r_c^2}{r_n^2};$$

Or $$2E_k = mc^2 + 4mc^2 \frac{r_c^2}{r_n^2}.$$

On the other hand, direct calculation of energy using formula (2) of this article yields the expression:

$$E_k = \frac{mc^2}{2} + mc^2 - \frac{mc^2}{\sqrt{2}} = \frac{1}{2}mc^2\left(3 - \sqrt{2}\right); \quad \beta = \frac{v}{c} = 1;$$

Or $$2E_k = 1{,}5858mc^2.$$

We obtain the identity:

$$1.5858mc^2 \equiv mc^2 + 4mc^2 \frac{r_c^2}{r_n^2}.$$

We perform the reduction by mc^2. We determine the minimum radius of the electron wave sphere:

$$r_{n\,min} = 2 \cdot 0.00386 \sqrt{\frac{1}{0.5858}} = 0.0101\ \text{Å}\,;$$

$$\frac{r_{n\,min}}{r_c} = 2.59\,.$$

The task is solved. For reference, in classical electrodynamics, the radius of an electron is defined as a constant value equal to 0,000028 Å .

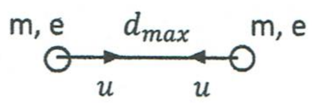
Task #6

Two electrons fly out from infinity towards each other at the speed of light. Determine the distance of the closest approach. **Formal logic does not work** the sum of the momenta is always zero. Such problems cannot be solved directly.

Let's change the condition of the problem. It is necessary to determine the speed of particles at a distance of two maximum radii of the electron wave sphere.

Solution. [The maximum radius of the wave spheres corresponds to the minimum relativistic speed of electrons, $d_{max} = 2r_{n\,max} = 4{,}24$ Å. We neglect the kinetic energy at the minimum speed. It is very small compared to the initial energies of the particles at the speed of light. After crossing, the electrons fly apart to infinity].

State 1



State 2

We use the results of solving the previous problem #5. Let us write the balance of kinetic and potential electric energy of two electrons in ultra-relativistic form:

$$2E_k = k\frac{e^2}{d_{max}}\left(\frac{1+\beta_u}{1-\beta_u}\right)^4;$$

Or $$1.5858mc^2 = k\frac{e^2}{d_{max}}\left(\frac{1+\beta_u}{1-\beta_u}\right)^4.$$

Let us find the relative velocity at a distance d_{max}:

$$\left(\frac{1+\beta_u}{1-\beta_u}\right)^4 = \frac{1.5858mc^2 d_{max}}{ke^2}\ ;$$

$$\left(\frac{1+\beta_u}{1-\beta_u}\right)^4 = \frac{1.5858\cdot 9.11\cdot 10^{-31}\cdot 300^2\cdot 10^{12}\cdot 4.24\cdot 10^{-10}}{9\cdot 10^9\cdot 1.6022^2\cdot 10^{-38}} = 238\ 616;$$

$$\frac{1+\beta_u}{1-\beta_u} \approx 22.1\,.$$

We find the value of the effective velocity of electrons at a distance d_{max}:

$$23.1\beta_u = 21.1 \quad \Rightarrow \quad \beta_u = 0.91342\,;$$

$$u = 300 \cdot 10^6 \cdot 0.91342 = 274 \cdot 10^6\, ms^{-1}.$$

What happens next? Electrons briefly hit a potential barrier with inclined walls. As they climb the barrier, their velocities decrease to their minimum values, $u = 1.095 \cdot 10^6\, ms^{-1}$. The density of the barrier's electric energy increases. At the top of the barrier, the electrons change their state of aggregation. Wave spheres and Compton spheres transform into wave circles. They intersect without destruction, as in atoms. They roll off the barrier and pick up speed again. Coulomb's repulsive forces act. The process of electron scattering occurs without changing directions. Speeds are restored to near-light values, Figure 3.

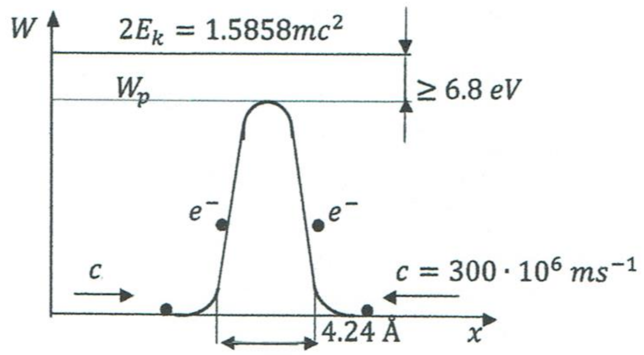


Fig. 3

The transient process of electron collisions in a vacuum occurs in the form of a wave. Energy quanta (photons) are not emitted. In general, the task is solved. The exact solution to such a problem is determined by the equations of quantum mechanics.

Task #7

A free electron hits the surface of a stationary metal target in a vacuum at a speed close to the speed of light. Determine the maximum quantum of energy it emits upon collision with the target.

Solution. [The total kinetic energy of an electron is represented as the sum of a series of individual portions of relativistic energy, $\boldsymbol{E_k} = \sum_{i=1}^{i=n-1} \boldsymbol{E_{ri}} + \boldsymbol{E_{r,n}}$. The series changes from minimum to maximum values. Here $\boldsymbol{E_{r,n}}$ is a portion of the relativistic energy of the electron's proper rotation at a given moment in time. The remaining energy of the series is accumulated in the form of kinetic energy of translational motion. The loss of relativistic energy due to **bremsstrahlung** is replenished from the remaining series.] [5]

Let us direct the electron's velocity to the speed of light. The radius of the outer wave sphere tends to a minimum. The Compton sphere remains unchanged. The photon load between the spheres increases. Let us write the balance of electromagnetic energy of bremsstrahlung and the quantum of relativistic energy of an electron at the speed of light (see problem #5):

$$E_{rn} = \hbar\omega_n = hf_n \ ;$$

$$E_{r\,max} = 2mc^2 \frac{r_c^2}{r_{n\,min}^2} = hf_{n\,max} \ .$$

Here: $h -$ is Planck's constant, $6.626 \cdot 10^{-34}\, J \cdot s$;

$f_n -$ is the frequency of the photon electromagnetic wave, Hz.

Maximum energy of a bremsstrahlung photon:

$$E_{r\,max} = 2 \cdot 9.11 \cdot 10^{-31} \cdot 300^2 \cdot 10^{12} \left(\frac{0.00386\ \text{Å}}{0.0101\ \text{Å}}\right)^2 = 239\,509 \cdot 10^{-19}\, J;$$

$$E_{r\,max} = 149.487\ keV.$$

Maximum frequency of electromagnetic energy of a bremsstrahlung photon:

$$f_{n\,max} = \frac{239\,509 \cdot 10^{-19}}{6.626 \cdot 10^{-34}} = 3.62 \cdot 10^{19}\ Hz.$$

If the target thickness is large enough, the electron sequentially emits the entire series of relativistic energy quanta [5]. Bremsstrahlung ceases at $E_k \geq 3.4\ eV$. **Inside the substance, at the atomic level, relativism is absent.** However, there is a characteristic radiation of energy, the transition of electrons in an atom from one energy level to another. Such transitions are studied by atomic physics. In general, the task is solved.

Appeal to readers

To explain any physical process, a theory and a clear mathematical apparatus are needed. There can be many theories and different mathematics. The simpler the mathematics, the easier it is to explain the physical process. Using examples of the collision of two free electrons in a vacuum, the author of the article shows and proves the applicability of the Elementary Theory of Relativity (ETR) to solving problems of physics of the micro world. Only a stationary, laboratory frame of reference is used. The theory observes all three of Newton's laws and the laws of conservation of generalized momentum and total energy in a closed mechanical system. Searching for the truth, jumping from a stationary frame of reference to a moving one, at ultra-relativistic speeds, is a thankless task. It seems that Newton was right when he recognized the presence of an absolute stationary frame of reference in nature.

There are many critical articles addressed to Einstein's Special Theory of Relativity. The author is well acquainted with them and understands their validity. The development of any theory begins with paradoxes and contradictions. The development of the Special Theory has been going on for more than 100 years. Einstein's high image as a famous physicist hinders this process. But when quantum mechanics needs to cover up or explain its own contradictions, it willingly uses relativistic effects. The author fully agrees that the Special Theory of Relativity requires revision and updating. But one cannot unequivocally abandon relativism. It contains a deep physical and philosophical meaning.

The author is sure that relativism exists in nature. Relativistic mass exists as an addition to constant mass. The task of physics specialists is to develop a mathematical apparatus for describing relativism without paradoxes and contradictions. Lorentz coordinate transformations do not help in this matter; there are many of them, including quadratic transformations.

The Elementary Theory of Relativity is an attempt to create a consistent, understandable mathematical apparatus of relativistic mechanics. To what extent this attempt was successful or not, judge for yourselves, dear readers.

Sources

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