THE BETA DECAY OF THE NEUTRON AND THE FIRST LAW OF THERMODYNAMICS

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The process of neutron beta decay was considered within the framework of a thermodynamic heterogeneous system model formed by gas consisting of neutrino particles moving at the speed of light and massive bodies. The calculation results are in satisfactory agreement with the experimental results. Further development of the model could lead to a theory that describes both weak and gravitational interactions.

Keywords: weak interactions, beta decay, neutrino, neutron, gravitational interaction, first law of thermodynamics.

A theory is the more impressive the greater the simplicity of its premises is, the more different kinds of things it relates, and the more extended is its area of applicability. Therefore the deep impression, which classical thermodynamics made upon me. It is the only physical theory of universal content concerning which I am convinced that within the framework of the applicability of its basic concepts, it will never be overthrown.
A. Einstein

The decay process of a free neutron is described by the formula [1]:

$$n = p^{+} + e^{-} + \nu \,. \tag{1}$$

The law of energy conservation is based on Einstein's formula:

$$\Delta E = \Delta m c^{2}\,, \tag{2}$$

where Δm is the mass defect representing the invariant mass [2] of a neutron (n) by deducting the sum of the invariant masses [2] of a proton p^{+} and an electron e^{-}. The excess energy associated with this quantity is distributed between the energy required to form the neutrino and the kinetic energy of the escaping electron. In this process, 783 keV of energy is released, mainly between the electron and antineutrino, which fly off in different directions. The proton carries away between 0 and 751 eV of energy [1]. The spectrum of electrons, classified by their kinetic energy, exhibits a distinctive pattern [3]. Consequently, the value of the antineutrino formation energy remains undetermined.

The introduction of the neutrino decay scheme was motivated by considerations of spin conservation in the decay of a free neutron. A contradiction arose in the decay of a single fermion with its own momentum of ħ/2 into two fermions with spins equal to the same value [4].

This work considers the β-decay process of a free neutron with the same particles as in scheme (1), but in a different sequence. This is based on works [5–7], which demonstrate that gravitational interaction can be considered as the thermodynamics of a heterogeneous system comprising massive particles of non-zero mass and a gas of zero-mass neutrino particles with spin ½ħ, moving at the speed of light.

The correlation between the β-decay rates of S-32 and Cl-36 with the gravitational-wave burst GW 170817, which occurred during the merger of two black holes, was established experimentally [8]. As a result, in [7], a hypothesis was put forward about the commonality of gravitational and weak forces due to a single carrier – the neutrino particle ν_g.

With regard to the elementary process of neutron β-decay, the above-mentioned model of thermodynamics of a heterogeneous system formed by massive particles and gas consisting of neutrino particles moving at the speed of light provides the following explanation.

The gravitational masses of particles (bodies) m are related to the scattering cross section σ of neutrino particles forming the gas surrounding massive objects by the following relationship [7]:

$$\frac{\sigma}{m} = \sqrt{\frac{\gamma}{p\dot{n}}}, \tag{3}$$

where γ – is the gravitational constant, p – is the momentum of the neutrino particle ν_g, or, more precisely, the amount of momentum lost by the neutrino particle ν_g during its scattering by a massive particle. $\acute{n}$ – is the specific (per unit area) angular intensity of the neutrino particle flux coming from the outer boundaries. Thus, processes accompanied by a change in the invariant masses of the products compared to the sum of the invariant masses of the reactants lead to changes in the values of the total cross sections of the reactants and products of the process. The cross section of massive particles is related to their volume by known stereometric relations. If, for example, the topology of massive particles corresponds to a sphere,

$$\sigma = \pi R^2, \quad \text{and} \quad V = \frac{4}{3}\pi R^3, \tag{4}$$

then, taking into account relation (3), it follows that the volume of massive particles is related to the mass by the relation:

$$V = \frac{4}{3} m \sqrt{\frac{\gamma\sigma}{\pi\dot{n}p}}. \tag{5}$$

Thus, a reduction in the total mass of reaction products relative to the mass of reactants leads to an increase in the volume of gas formed by neutrino particles ν_g.

In classical thermodynamics, this corresponds to positive work A, numerically equal to the product of the pressure created by the gas and the change in its volume:

$$A = -P\Delta V. \tag{6}$$

The gas pressure P of neutrino particles ν_g is related to the values included in equation (3):

$$P = \dot{n}\overline{p}\,, \tag{7}$$

where $\overline{p}$ is the average momentum of gas particles forming a closed heterogeneous system. Calculating the value of ΔV is problematic, since according to (5):

$$\Delta mc^2 \neq P\Delta V\,. \tag{8}$$

The analogue of thermal energy in this system is the energy absorbed or scattered by neutrino particles ν_g or electromagnetic radiation quanta. The energy of massless ν_g, like photons, is expressed by their momentum.

$$E = pc\,. \tag{9}$$

The second term on the right side of the equality in the traditional notation of the first law of thermodynamics is internal energy. According to the model under consideration, this corresponds to the kinetic energy of the particles formed from immobile reactants. In the case where the reactants are moving, the change in internal energy during the process should be calculated as the difference between the sum of the kinetic energies of the products and the sum of the kinetic energies of the reactants.

Thus, in the model under consideration, the beta decay process of a free neutron looks like this:

$$n + \nu_g = p^+ + e^-\,. \tag{10}$$

Consequently, the law of conservation of energy of the process (10) in the form of the first law of thermodynamics looks like this:

$$pc = -P\Delta V + E_\beta\,, \tag{11}$$

where E_β – kinetic energy of the ejected electron.

Since the value of the pulse p is not deterministic but has a certain distribution of values, a corresponding spectrum of values E_β is observed for the number of electrons ejected.

Due to the fact that the scattering cross section of a neutron as an elementary particle is quite small, the scattering process can be neglected. Leaving only the absorption process ν_g, whose energy is determined by (9), we obtain the value pc on the left side of the conservation law (11).

The simplest hypothesis about the equilibrium distribution of kinetic energy of neutrino particles is the Fermi–Dirac statistics, since it is assumed that they are fermions:

$$f_g = \frac{g^{-1}}{\exp\frac{E_g - \mu}{kT} + 1}. \tag{12}$$

where g – energy level multiplicity, E_g – kinetic energy of these particles, μ – chemical potential of the gas, T – its temperature. Considering the gas consisting of neutrino particles to be ideal, we have:

$$P = nkT, \tag{13}$$

where n is the volume density of particles, related to the specific angular intensity of the flow by the ratio:

$$\dot{n} = nc. \tag{14}$$

The distribution of ejected electrons by energy, according to (11), will be similar to the distribution in (12):

$$f_\beta = \frac{g^{-1}}{\exp\frac{E_\beta - \mu_\beta}{kT} + 1}. \tag{15}$$

The displacement of distributions (12) and (15) is determined by the law of conservation of energy (11), thus we have the following relationship:

$$\mu_\beta = \mu_g + P\Delta V. \tag{16}$$

Figure 1 below shows experimental data on the beta spectrum of electrons from review [1], with reference to work [3].

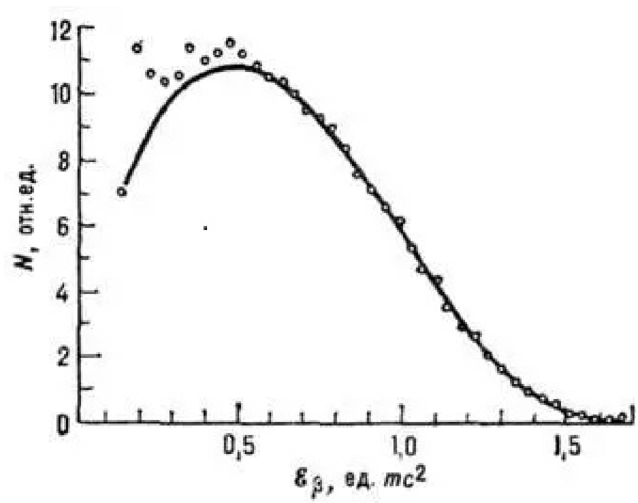

Figure 1. Beta spectrum of free neutron decay obtained in paper [3]. The curve corresponds to the theoretical Fermi spectrum, corrected for the energy resolution of the spectrometer.

According to generally accepted theoretical calculations [1], the specified electron spectrum should become zero at kinetic energy values equal to 1.53 m_ec^2. However, it is evident that this occurs at values significantly exceeding this number. Non-zero electron values are observed up to 1.7 m_ec^2.

A detailed examination of the low-energy electron spectrum shows that their values tend to plateau rather than rush towards zero, as predicted by Fermi's theory [9].

A comparison of the experimental data [3] with the theoretical dependence of the Fermi-Dirac distribution (15) gives the following results:

$$kT \approx 80\ keV \tag{17}$$

$$-P\Delta V \approx 100\ keV \div 300 keV \tag{18}$$

$$\mu_\beta \approx 500\ keV\ . \tag{19}$$

Previously, in works [5-7], it was shown that for a reliable description of gravitational interactions, the following inequality must be satisfied:

$$P = \dot{n}\overline{p} \geq 10^{12}\,Pa\ , \tag{20}$$

consequently

$$n \geq 10^{26} m^{-3}, \tag{21}$$

which corresponds to the concentrations of real molecular gases. This indicates compliance with the statistical criterion for the applicability of the thermodynamic description of the considered heterogeneous system.

DISCUSSION OF RESULTS

Fundamental differences in the description of the beta spectrum according to Fermi's theory and formula (15) relate to the regions of soft and maximum electron energy.

B. Erozolimskiy notes in his review [1]: '...it is desirable to conduct a more thorough study of the soft part in the beta spectrum, especially since it is there, in principle, that deviations from the Fermi graph can be expected'. Since then, more than a hundred reviews on this topic have been published in the literature, but they do not provide experimental data on the beta spectra of ejected electrons during the decay of a free neutron, as, for example, in reviews [10-12]. Perhaps this aspect of the problem, pointed out by B. Erozolimskiy, has lost its relevance.

According to the results of calculations (17) and (19), the value of kT is an order of magnitude lower than the value of μ_g, therefore the Fermi–Dirac distribution of neutrino particle energies may occur. If precision measurements reveal a maximum in the soft part of the beta spectrum, this will entail a radical recalculation of the values of μ_β, μ_g and $P\Delta V$ according to the equations of this model. In this case, the value of kT will exceed the values of μ_g, which will lead to the degeneration of the spectrum of kinetic energies of neutrino particles into the Maxwell–Boltzmann distribution.

It can be assumed that electrons with kinetic energy exceeding 783 keV can also be detected in the high-energy part of the beta spectra.

The last remark concerns the mechanism of process (1). In both chemical [13] and physical kinetics [14], mechanisms involving three-particle interactions are considered to be improbable. In the standard model, this problem is solved by introducing a two-step mechanism. Nevertheless, the decay scheme in the form of (10) is much simpler and preferable to mechanism (1) or others containing successive stages of the free neutron decay process.

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