



## Behavior of Cosmic Rays and Propellant-Free Microwave Thruster Can Support the Hypothesis of Crystalline Vacuum

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### Abstract

The paper suggests an explanation of the efficiency of the EmDrive device based on the hypothesis of a crystalline vacuum, previously successfully used to explain the cutoff of the cosmic-ray spectrum. The hypothesis of crystalline vacuum enables to transform part of momentum directly to vacuum crystalline lattice giving rise to reaction force which allow to ensure the fulfillment of the momentum conservation law during EmDrive functioning. Therefore crystalline vacuum plays the role of a supporting medium for all wave vectors of electromagnetic oscillations in a conical resonator, which causes the appearance of forces and momentums of rotation, the optimization of which can open up a tempting prospect for creating of unique aircraft.

### Introduction

The appearance of the first reports on the creation of the EmDrive device by Roger Shawyer [1-2], driven by a manner without exhaust and eject of substance, caused the effect of a bomb exploding. Indeed such a device in the form of a truncated cone, in shape resembling a bucket, violates the momentum conservation law. This circumstance explains the initial negative attitude of the scientific community. However, the confirmation of the workability of EmDrive in the NASA laboratory [3-4] partially neutralized the first negative effect and led to attempts to explain the observed phenomena.

The first attempt to explain was Shawyer's own hypothesis of creating thrust due to imbalance of radiation pressure of microwaves on the end surfaces of the bucket [5]. However, the author's arguments were criticized, since the thrust of the radiation pressure of light is less than the thrust of EmDrive by several orders of magnitude. Then, various authors put forward hypotheses in one way or another related to the change in existing ideas about the nature of the vacuum. The authors of [4] explained the thrust of EmDrive due to creation of a virtual plasma toroid under quantum oscillations of the vacuum. McCulloch [6] suggested the existence of a modified photon mass due to the Unruh effect, in another case [7], the appearance of thrust in the engine is explained by the destructive interference of microwaves, which is also related to the Unruh effect and a rethinking of the notions of a physical vacuum. The explanation proposed in this paper is also connected with the modification of the notions of a physical vacuum, proposing its crystalline structure [8]. The idea of crystalline vacuum is the development of representation about Bose-Einstein vacuum condensate in the form of quantum Bose liquid [9-10] i.e. a medium where bodies can flow without any apparent friction, as in superfluid  $^4\text{He}$ , in agreement with the experimental results [11]. Evaluation of Bose-Einstein condensation (BEC) critical temperature  $T_c$  for diluted gases and liquids gives rise to the value of degree fractions. However Bose superfluid liquid cannot provide the reaction force which can produce a crystalline vacuum. On analogy with the scenario of condensed matter emergence of crystalline state can be expected under further decreasing of temperature especially in the case of very high particle density considered in Ref.[8] leading to a significant increase in  $T_c$  and stabilization of crystal vacuum for very earlier epoch of the Universe history.

Paradoxical as it may seem at first glance, such a view has serious grounds connected with the presence of a large number of geometric concepts in the physics of elementary particles, such as the mixing angles of quarks, the Weinberg angle, chiral invariance, etc. The violation of spatial, charge and time symmetry and conservation of their combinations in the form of CPT theorem, in addition to the constancy of the speed of light and of course zero-point oscillations of vacuum can also be a reflection of the crystalline structure of vacuum. The idea of a crystalline vacuum is not a return to the concept of ether rejected in the twentieth century. The appearance in physics of solitons - crystal lattice excitations, obeying the Lorentz relations, allowing to resolve the contradiction of the "ether wind" and other paradoxes of the ether concept and opens the possibility to construct a material world from a Lorentz - invariant particles - solitons. However the



violation on Lorentz invariance takes place in crystalline vacuum like the other lattice, analogy gravity [12] and BEC [13] models, which predicts Lorentz violated (LV) corrections proportional to powers of  $E^2/E_p^2$ , where  $E$  is the characteristic energy scale of the process under consideration (typically, the center-of-mass energy for a scattering experiment) and  $E_p$  is the Planck scale. In case of crystalline vacuum also there is the LV when wave vector  $k$  attains the value of lattice vector  $G$  (see below). However in this case LV has a character of reentrant LV described in [14] when the momentum  $M$  is a two-valued function at the points  $k=G$ , namely  $M(k=G) = M_0$  and  $M(k=G)=0$ . Momentum  $M_0$  is exactly the value which is transferred to vacuum crystalline lattice. This gives rise to fulfillment of the momentum conservation law during EmDrive functioning. More details about arguments supporting a crystalline vacuum hypothesis can be found in [15-17]. The idea of the crystalline structure of a vacuum is useful in connection with the possibility to transfer a part of the photon momentum to the crystal lattice of the vacuum as a whole. This allows getting a rebound and fulfilling the momentum conservation law under EmDrive functioning. Earlier, the idea of a crystalline vacuum was used to explain the cutoff of the cosmic-ray spectrum [8]. Surprisingly, the magnitude of the momentum transmitted by resonant vibrations in EmDrive is consistent with the data on the "lattice momentum" produced by cosmic rays.

### EmDrive analysis in frame of hypothesis of crystalline vacuum

The experimental installation of EmDrive is a magnetron that generates microwaves whose oscillation energy is stored in the form of standing electromagnetic waves, which are a source of thrust in a closed high  $Q$  resonator, which is a copper truncated cone. The thrust is measured by the displacement of the torsion pendulum on which the EmDrive cone is mounted. The absence of a consumable working fluid in this engine creates the appearance of a violation of the momentum conservation law. The assumption of the crystal structure of the vacuum makes it possible to avoid violating the momentum conservation law. As it is well known [18] the crystal structure is described by two spaces - the direct and reversed lattices. If  $\mathbf{p} = m\mathbf{a} + n\mathbf{b} + p\mathbf{c}$  is the vector of the direct lattice, and  $\mathbf{G} = h\mathbf{A} + k\mathbf{B} + l\mathbf{C}$  is the reciprocal lattice vector, then  $\mathbf{G} \cdot \mathbf{p} = 2\pi n$ , where  $n$  is an integer. Then we obtain

$$\exp(i\mathbf{G} \cdot \mathbf{p}) = 1. \quad (1)$$

Since in the description of wave processes the wave vector  $\mathbf{k}$  always occurs in the combination  $\exp(-i\mathbf{k} \cdot \mathbf{p})$ , then whenever the vector  $\mathbf{k}$  increases by the magnitude of the reciprocal-lattice vector  $\mathbf{G}$ , the exponent (1) turns into unity, so we have:

$$(\mathbf{k} + \mathbf{G}) \cdot \mathbf{p} = \mathbf{k} \cdot \mathbf{p} + 2\pi n, \exp(-i(\mathbf{k} \cdot \mathbf{p} + 2\pi n)) = \exp(-i\mathbf{k} \cdot \mathbf{p}). \quad (2)$$

Thus, when the wave vector reaches the value of  $\mathbf{G}$ , the value of  $\mathbf{k}$  decreases abruptly to zero and, with a further increase in  $\mathbf{k}$ , passes the whole spectrum of values up to a value of  $\mathbf{G}$ , in order to repeat the known cycle. A momentum equal to the modulus of the reciprocal-lattice vector  $\mathbf{G}$  is transmitted to the crystal as a whole, and according to the momentum conservation law, a recoil momentum is generated, which is transmitted to the EmDrive resonator, causing its displacement. It follows from the above scenario that the movement of the device must occur by jumps. This is confirmed in the test experiments with EmDrive, one of which is illustrated in Fig. 1, taken from [3].

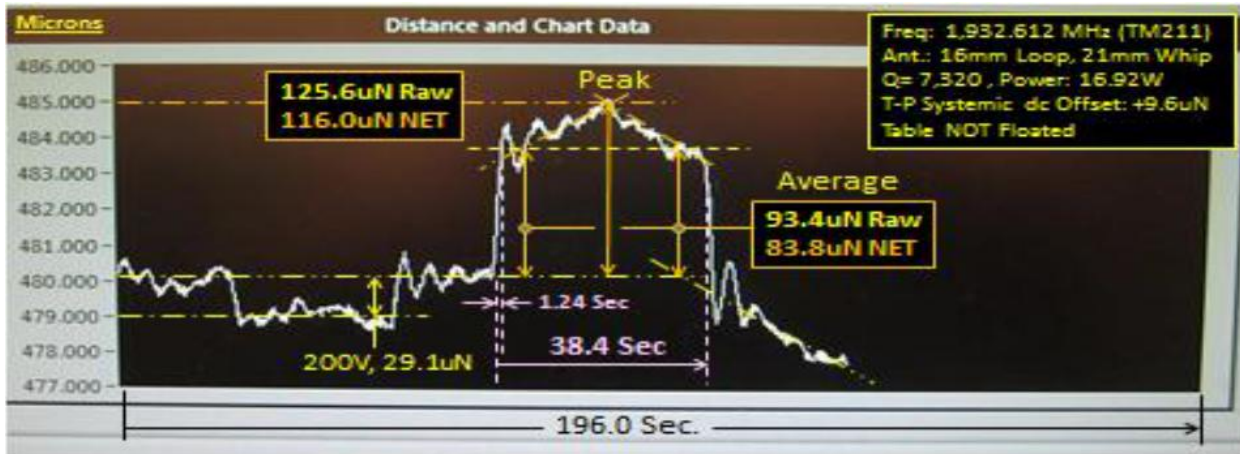


Fig.1. Dependence of the EmDrive movement on time when RF power is applied to the resonator.

The cone-shaped form of the EmDrive resonator is chosen to ensure its maximum quality factor  $Q$ . Electromagnetic waves are repeatedly reflected from internal copper walls, gradually turning into a standing resonant wave. If the shape of the resonator were cylindrical, the resonance would occur too quickly, and the quality factor would be low. Thus, the high quality factor is due to the delay time  $\tau$  necessary to include as much of the electromagnetic waves as possible in the resonance pulse allowed by the resonator geometry. The relationship of these parameters is described by the expression [19]:

$$\tau \approx Q / (\pi f), \quad (3)$$

where  $f$  is the frequency of the resonator. Substituting in (3) the values of the parameters of the EmDrive resonator from [4]  $f = 1937$  MHz,  $Q = 7320$ , we obtain  $\tau \approx 1 \mu\text{s}$ , which is much higher than the characteristic picosecond propagation times of electromagnetic waves in a cylindrical resonator. In [4], when simulating the EmDrive resonator in the COMSOL medium, a value of  $\tau = 36 \mu\text{s}$  was obtained, with a  $Q$  factor of 77500, i.e. the real form of the resonator further tightens the resonance pulse. It is clear that simple expressions of the form (3) cannot describe the process in resonators of a complex shape, but simple expressions make it possible to obtain qualitative estimates to within an order of magnitude.

Next, we calculate the force that causes the EmDrive to move. The energy released in the resonance pulse:

$$W = P \tau = PQ/(\pi f), \quad (4)$$

where  $P$  is the RF power pumped into the resonator. Then the magnitude of the amplitude of the resonance pulse is determined by the expression:

$$I = W / V_g = PQ^2/(\pi f c), \quad (5)$$

where  $V_g = c / Q$  is the group velocity of the resonant pulse, and  $c$  is the speed of light. It makes sense to compare this value with the lattice momentum determined from the analysis of data on the cutoff of the cosmic-ray spectrum. When using the data of [4]  $P = 20$  W,  $f = 1937$  MHz,  $Q = 7320$ , we have  $I = 6 \cdot 10^{-10}$ , if we use the value of  $Q = 77500$  obtained in [4] with the COMSOL simulation, we get  $I = 6.3 \cdot 10^{-8}$ . Using the COMSOL simulation time as the delay time will increase  $I$  to a value of  $2 \cdot 10^{-7}$ . The results of this comparison are shown in Fig. 2, which shows the dependence of the reciprocal lattice momentum on the cosmic-ray energy, where the data on the range of the scatter of the momentum  $I$  are also plotted, along with the possible energy of cosmic rays. It can be seen that the spread of the magnitude of the resonant momentum agrees with the corridor of the permissible values of the reciprocal lattice momentum, and also with the cosmic-ray energy that are admissible under the cutoff conditions.

Finally, the EmDrive acting force is determined by the expression:

$$F = PQ/c. \quad (6)$$

Substituting  $P = 20W$ ,  $Q = 7320$  into expression (6), we obtain  $F = 500 \mu N$ , which is approximately five times higher than the maximum value registered in the experiments [3, 4]. The difference can be explained by the fact that in this model the repulsion from the vacuum crystal lattice occurs everywhere, and not only from the lateral surfaces of the cone, as is assumed in alternative models [4-8]. Therefore, it is important to have information about the projections of all wave vectors of this mode on the longitudinal axis EmDrive. Unfortunately, in the descriptions of experiments this information is not available. The difference in the projective sum of the wave vectors can also explain the discrepancy between some experimental values (especially at high values of  $Q$ ) calculated by means of expressions (3) - (6).

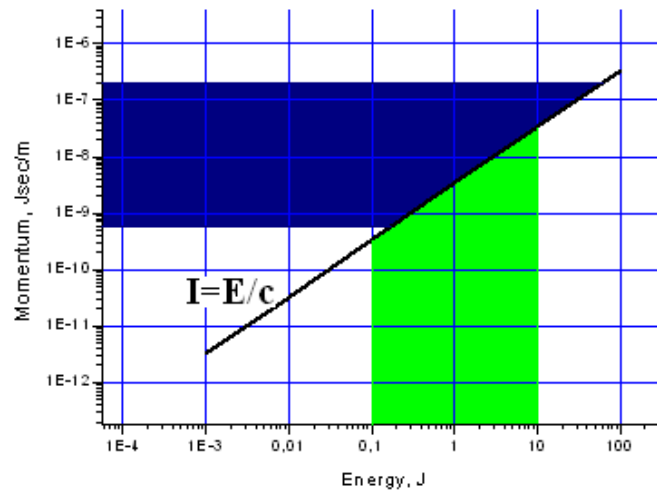


Fig.2. Dependence of the photon momentum on their energy. The horizontal axis indicates the range of cosmic rays possible from the point of view of cosmic-ray cutoff. The vertical axis indicates the range of possible EmDrive momentum from the point of view of the crystal vacuum hypothesis.

## Discussion

The hypothesis of crystalline vacuum allows ensuring the fulfillment of the momentum conservation law under EmDrive functioning. The movement of such devices, according with the relations (1) - (2), is carried out by impulse jumps in time intervals (3), which have the characteristic values of 1-40  $\mu s$ , which is confirmed by the "dentate" structure of displacements. Relation (3) poorly describes the actual situation, which is evident under comparison with the calculations in the COMSOL package. Nevertheless, the qualitative course of the processes is described correctly, which is confirmed by the coincidence of the linear dependence  $W(P)$  of the relation (4) with the experimental dependence in [3]. The proportionality coefficient in (4) differs greatly from the experimental value. The spread can be explained both by the difference in the  $Q$ -factors and by the complexity of the truncated cone configuration. The magnitude of the force given by expression (6) is five times higher than the characteristic experimental values, although this is an order of magnitude lower than the limit of Shawyer's estimate of 333 mN / kW [5]. As can be seen from Fig. 2, the magnitude of the amplitude of the resonant momentum (5) falls within the range of admissible values determined by the cosmic-ray spectrum cutoff. The differences of calculations on the expressions (3) - (6) and experimental data are largely explained by the absence of taking into account the projections of the wave vectors of electromagnetic waves in the resonator and their orientations relative to the axes of symmetry. In contrast to the previously advanced explanations of the experiments with EmDrive, in this consideration the crystal vacuum plays the role of a support medium for all wave vectors of electromagnetic oscillations in a cone-shaped resonator. This means that in addition to the force that drives the device, there may also be moments of force relative to different axes, which can lead to rotations. The hypothetical possibility of optimizing these forces and momentums can open up a tempting prospect for creating of the unique aircraft. It is interesting to speculate about the specific momentum of EmDrive. The specific momentum  $I_s$  is the characteristic of the jet engine, equal to the ratio of



the momentum created by it to the mass fuel consumption. The higher the specific momentum, the less fuel you need to spend to get a certain amount of traffic.  $I_s$  of the solid rocket engine is about 2600 m/s. The maximum value of the specific momentum has a plasma engine with  $I_s = 3 \cdot 10^5$  m/s. In the case of EmDrive  $I_s = G \cdot c^2 / (hf) \sim 10^{33}$  m/s, which indicates of its unique efficiency.

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