Thrust in Physical Vacuum Space

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Abstract

The inertia in Newton's first law and the action-reaction in Newton's third law of motion are peculiar characteristics embodied in natural phenomena, from which the law of conservation of momentum and energy is established in classical mechanics in which the action in Newton's third law is indispensable for the reaction. Nevertheless, some propellant-less devices have been developed, which can generate the thrust of spacecraft without propellant or any mechanical action; however, propellant-less device, the idea itself seems to be still in debate because it is impossible in the domain of contemporary physics. The feasibility of those devices is reviewed with physical vacuum in 4-D complex space.

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Introduction

In Newton's laws of motion, Newton's first law is about the inertia saying the tendency of physical object resisting any change in its motion and the inertia is expressed as the inertial mass in Newton's second law, $F = Ma$, and weak equivalence principle, which is the foundation principle of general theory of relativity, says that the inertial mass of object is equal to its gravitational mass. Newton's third law is about action and reaction saying that for every action there is a reaction followed in opposite direction with the same amount as in the action, which means that net momentum in a mechanical system is conserved if an external force is not applied. The inertial force in Newton's first law — so called fictitious force since it appears whenever a mass object is being accelerated — can be interpreted as the origin of the reaction in Newton's third law.

In traditional propulsion system the action in Newton's third law is necessary for the reaction to get a driving force for the system; hence, a propellant in propulsion system is indispensable factor. However, what if there is a way to generate the driving force without the propellant? If it is possible, it means that Newton's third law of motion is not valid and the momentum is not conserved in the mechanical system.

In fact, this audacious and challenging idea has a long history. In 1921, a high school student discovered the link between electricity and gravity in his experiments with Coolidge x-ray tube; his name was Thomas Townsend Brown. (L. A. Brown, AltThink, T. T. Brown) Since then, for the propellant-free propulsion or a possibility of *the reaction without an action* in Newton's third law of motion, any acceptable theoretical explanation still has been absent in general. Nevertheless, there have been many discussions and suggestions how interstellar travel can be possible without fuel; some devices have been designed and tested for their feasibilities. (Mallow, Naudin 2001, Tajmar 2004, A. A. Martins 2011, Valone 2013) (EmDrive, Tajmar 2013, Harold White 2017, Müller 2021) (A. A. Nassikas 2011, 2012, 2014, 2015)

Those researches can be put into four different categories depending on their designs and theories: the first one is T. T. Brown type using DC electric discharge between anode and cathode; the second type is using electromagnetic (EM) wave resonating in a frustum shaped cavity; the third one is magnetic field modulation using superconductivity, in which the thrust is generated through maintaining asymmetrically modulated magnetic fields; the last one is esoteric, which is based on physical theories; however, we are not going to review them at this time.

Newton's laws of motion

Since the ontological interpretation was given for physical vacuum space, we could understand the fundamental natures of physical laws and physical interactions, through which we became to know that mass-charge interaction exists; gravitational interaction and electromagnetic interaction is not independent to each other, which means that Newton's third law can be violated if electromagnetic interaction is involved in gravitational interaction (Kim 2008, 2017).

Now, we need to figure out what the inertia is in Newton's first law; in other words, how it works in physical vacuum space. Firstly, it should be the spontaneous reaction from physical vacuum space against any disturbance in equilibrium states represented with number density of vacuum particles in physical space (4-D complex space), in which each vacuum particle has negative mass, positive charge and spin (like a positron), and the disturbance in physical vacuum space can be made by physical mass, electric charges, or their physical motions.

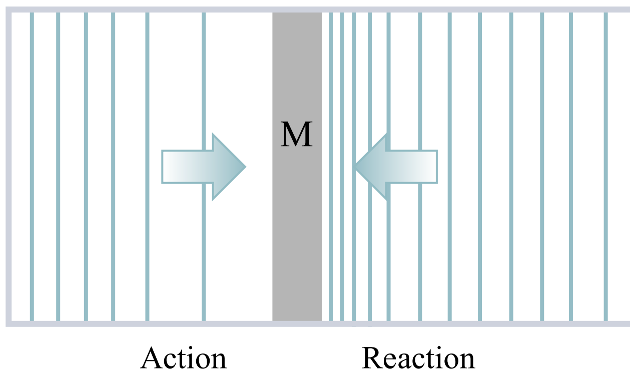

Fig. 1: rearrangement of vacuum particles against an action on physical object with mass M

A schematic drawing in Fig. (1) describes the action on a physical object with mass M and the immediate disturbance of vacuum particles for the action, in which the intervals of vertical lines indicate number density of vacuum particles. The reaction is supposed to be coming from the recoiled or high number density of vacuum particles on right-hand side of the object, which can be supposed with the first principle given on physical vacuum space as in physical interactions such as gravitational interaction, electric interaction, and magnetic interaction in physical space.

For instance, gravitational interaction of two mass objects is attractive to each other because vacuum-particles-sharing between two mass objects is the most appropriate way to get an equilibrium in physical space in which the equilibrium of net charge density is much more preferred to the equilibrium of net mass density in physical space because the strength of electric interaction is much bigger than gravitational interaction in phenomena (Kim 2017). In fact, reasonable suspicions about the link between gravitational interaction and electromagnetic interaction have been inquired already (AltThink, Assis 1993, Mario Goto 2010).

T. T. Brown Type Thrust

Fig. (2) shows a low-pressure gas-filled tube in which two electrodes, anode and cathode, are connected to an external DC high voltage source. In the series of process, such as ionization inside the tube -- generating charged particles, movements of charged particles – positive charges to cathode and negative charges to anode, discharges of charged particles at the electrodes, if the momentum in classical mechanics is considered, net momentum in the system is not changed because there is no external force applied during the process ($\sum_j F_j^{\text{int}} = 0,\ \ F^{ext} = 0$).

However, for charged particles with the electric interaction as above there is a difference made in physical vacuum space. First of all, we need to review how physical momentum is interpreted in physical space (4-D complex space); the physical momentum of a mass object in real space is the manifestation for the vacuum particle distribution in imaginary space that is following the object (Kim 1997). Hence, if mass M object is moving with speed V, the number of vacuum particles in the distribution following the mass object can be estimated as $N_{vac} \sim M/|m_{vac}|$, in which $m_{vac} \approx -m_e$.

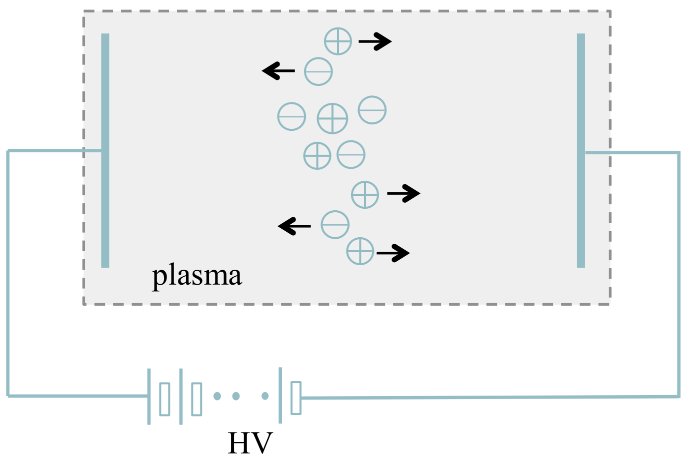

Fig. 2: ionized particles being dragged to electrodes

Let's say, the speed of negative charges (electrons), being discharged on anode (positive electrode) in Fig. (2), is $\langle \upsilon_- \rangle$ in average and the number of negative charges is n_- reaching to the anode per second. Then, the change of momentum acting on the anode can be estimated as $|\Delta P_{anode}| \sim n_- m_e \langle \upsilon_- \rangle$, as shown in the inertial force appeared on an object being decelerated.

On the other hand, the momentum change of positive ions on the cathode (negative electrode) can be explained similarly; the speed of positive charges on cathode is $\langle \upsilon_+ \rangle$ in average, and the number of positive ions is n_+ reaching to the cathode per second; hence, the momentum change on the cathode can be estimated as $|\Delta P_{cathode}| \sim n_+ N_{vac}^+ m_e \langle \upsilon_+ \rangle$, in which the positive ion mass $M^+ \sim N_{vac}^+ m_e$.

On cathode, the positive ion is discharged; the momentum of positive ion is transferred to the cathode leaving a neutral one. However, the momentum transferred by the positive ion is canceled out by the reaction one by the device itself since $F^{ext} = 0$. On anode, meanwhile, the negative ion (electron) is discharged; the momentum of electron is transferred to the anode and it is supposed to be canceled out with the reaction one by anode; however, the vacuum particle distribution for the electron's momentum doesn't have a core to confine the distribution to itself since the electron has been discharged; hence, the vacuum particle distribution that has been followed the electron can be dispersed out without imparting the momentum of electron to anode (positive electrode).

Therefore, it is possible that the electron momentum transfer to anode, which supposes to cancel out the opposite momentum of anode, is not completed and leaving a net force as $F_{net} \sim \varepsilon\, n_{-} m_e \langle \upsilon_{-} \rangle$ in the direction of anode to cathode, in which ε is efficiency ($0 \le \varepsilon \le 1$). Considering the device geometries in experiments done by many people including T. T. Brown, the efficiency seems to be high if the device geometry is asymmetric. Thus, the efficiency is supposed to be dependent on geometry of anode and cathode in the device.

For the thrust generated in Fig. (2), the order of magnitude can be estimated with a simple approximation; let's say, the current $I = 2nq_{+}$, in which it is assumed that $n = n_{+} = n_{-}$, $q_{+} = e$, and $q_{-} = -e$ (charge of electron). The kinetic energy of negative ion (electron) reaching at anode can be estimated as $\frac{1}{2} m_e \langle \upsilon_{-} \rangle^2 \le \mathrm{e}V$ since the ionization can happen at any place between anode and cathode. A possible maximum thrust can be

$$F_{thrust}^{\max} \sim \sqrt{\frac{m_e}{2e}} \frac{W}{\sqrt{V}} = \beta \, \frac{W}{\sqrt{V}} \quad (\mathrm{N}), \tag{1}$$

in which $W = IV$, $\frac{|e|}{m_e} = 1.76 \times 10^{11}\ \mathrm{C \cdot kg^{-1}}$; thus, β=1.69×10^{-6}. If the charge carriers in the tube are only electrons as in an X-ray tube, $\beta = 3.38 \times 10^{-6}$. In addition, with an asymmetrical geometry of anode and cathode that can be made in Fig. (2), the thrust in Eqn. (1) can be optimized. However, in general,

$$F_{thrust} \le 3.38 \times 10^{-6} \frac{W}{\sqrt{V}} \quad (\mathrm{N}) \tag{2}$$

In T. T. Brown's 1955-1956 Paris Experiments, he demonstrated a thrust with a device he called flying disc; however, the thrust was yet to be known since it was violating Newton's third law of motion (LaViolette 2012, AltThink). However, in his vacuum chamber test ($\mathrm{P} \sim 5 \times 10^{-5}$ mmHg) he observed the disc always moved toward the positive direction, which seems to be different from the one expected in Eqn. (1). Then, the direction of thrust in Eqn. (1) needs to be rephrased as following; the direction of thrust made by each electron being discharged on anode is the same as the direction of electric field on anode electrode; hence; the thrust in a system is the vector sum of all small thrusts occurred on each electron's discharge on anode, and the direction of thrust depends on geometry of the system. (Naudin 2001, hec031 2011, A. A. Martins 2011)

In Fig. (1), an unbalanced vacuum particle distribution[2] across the physical object, which is showing an action and the reaction for the action, can be generated through electric interaction, magnetic interaction, or electromagnetic interaction because each vacuum particle has electric charge and magnetic spin as well. Therefore, through whatever interaction, no matter it is, if an unbalanced vacuum particle distribution is made, which generates a net force in a physical system, it can be called the reaction without an action in classical mechanics; if the unbalanced distribution keeps being maintained, which generates a thrust for the physical system, it can be called the propellant-free thrust.

EM wave resonant in conical frustum cavity

The second type of devices is using electromagnetic waves to generate the thrust without propellant (EmDrive). Also, it is called 'impossible drive' since the proposed mechanism itself explaining how to generate the thrust is apparently violating Newton's third law of motion as in the first type (T. T. Brown type). Anyhow, let's check it out whether it is possible or not.

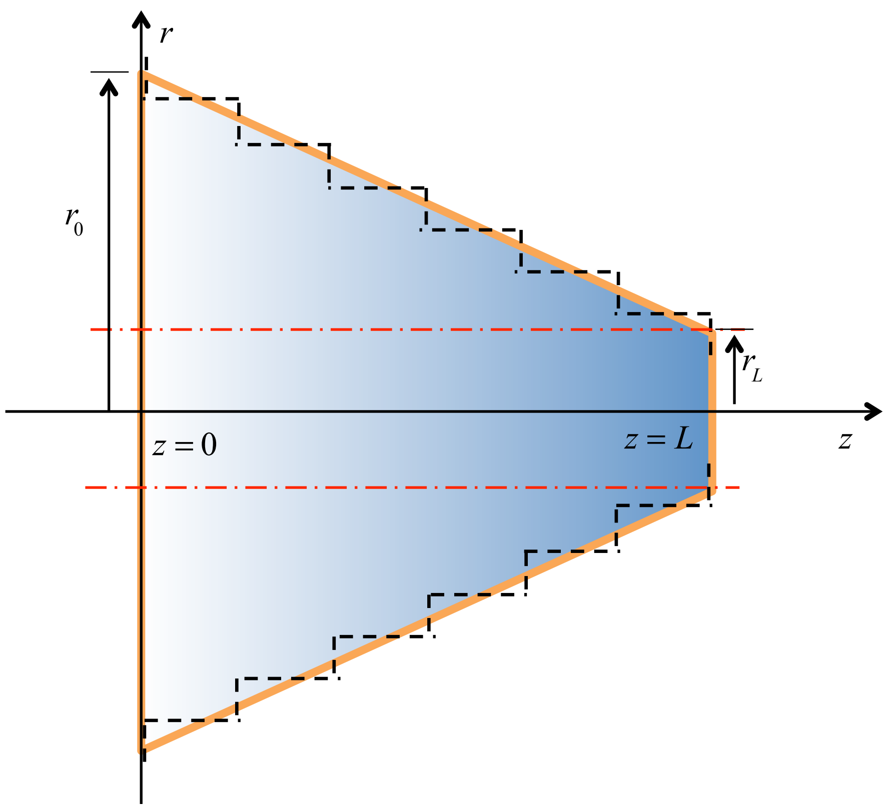

Fig. 3: side view of conical frustum resonant cavity

[2] unstable distribution imposed by an external interaction

Fig. (3) shows a conical frustum cavity, in which electromagnetic (EM) waves are supposed to be resonating with boundary conditions at inner surface of frustum cavity. To make it simple, let's say, the boundary surface is made of a perfect conducting metal, which means that there is no energy loss inside the cavity.

If λ_0 is the wavelength of EM waves fed in the cavity, the cutoff wavelength λ_c is given as $\lambda_c(z) = 2\mathrm{k}_{mn} r(z)$ in the cavity[3], and the group velocity is expressed as $\upsilon_g = c\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$ from the dispersion relations in the cavity, which shows that group velocity $\upsilon_g < c$ (c is light velocity in free space); however, $\upsilon_g(0)$ is bigger than $\upsilon_g(L)$ in the cavity.

In the description of EM waves in the cavity, the group velocity is more physically meaningful and appropriate with particle-like view than wave-like view for physical entity in the cavity. Therefore, instead of the EM waves resonating inside the cavity, let's think, a number of photons are moving around and bouncing on the surface of cavity with the group velocity.

Now, let's say, energy of each photon $\varepsilon = h\nu_0$ in which h is Plank's constant given as $h \sim 6.626\times10^{-34}$ (J·sec) and $\nu_0 = c/\lambda_0$. Then, photon momentum density inside the cavity is expected as

$$p(z) = \frac{n(z)h\nu_0}{c^2}\upsilon_g(z) \tag{3}$$

in which n is photon number density. Now, it is natural to expect the momentum density of photons should be uniform in the cavity; otherwise, a diffusion process takes place, which means that the radiation pressure on the wall of cavity also should be uniform and $n(z)\upsilon_g(z) =$ constant inside the cavity. As shown in Fig. (3) with the blue color getting darker toward $z = L$, the photon number density will be increased toward $z = L$ since $n(z)\upsilon_g(z) = n(0)\upsilon_g(0)$. Then, the photon number density and, thus, energy density inside the cavity are not uniform although the momentum density is uniform.

Since the physical entity of a photon is interpreted as a part of a vacuum-particle-string vibration in 4-D complex space (Kim 1997), correspondingly vacuum particle number density is not uniform inside the cavity, which means that net force in the system of cavity is not zero if vacuum

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[3] k_{mn} is mode constant. (Shawyer 2020)

particle number densities are compared across the wall of cavity as the inertial force shown in Fig. (1) in which the reaction is made by the difference of vacuum particle distribution across the object.

Now, In Fig. (3) let's compare the difference of vacuum particle distribution across the wall of cavity. Let's assume that background vacuum particle distribution outside cavity is uniform. Then, the net force in the system of cavity is coming from both walls at $z=0$ and $z=L$ because all contributions at the slant side wall of cavity are canceled out; in radial direction, it is canceled out by the axial symmetry of cavity; in axial direction, it also has no contribution if the slant side is considered as like the steps drawn in Fig. (3). Then, the thrust in the system of cavity $\vec{F}_{thrust} \propto \left[n(L)-n(0)\right]s(L)$ in positive axial direction in Fig. (3), in which $s(L)=\pi r_L^2$. If a medium number density is defined as $n_m = n(z_m)$ with corresponding group velocity $\upsilon_g(r_m)$ in a cylindrical cavity with the same length L and corresponding r_m for the same volume as in the frustum cavity; then, $r_m^2 = \frac{1}{3}\left(r_0^2 + r_0 r_L + r_L^2\right)$ and n_m is corresponding to the average photon number density as $n_m = n_0 = N_0/V$, in which N_0 is total number of photons and V is volume of the frustum cavity. The thrust in the cavity system is expressed as

$$\vec{F}_{thrust} \sim K_\gamma \; n_0 \upsilon_g(r_m)\left[\frac{1}{\upsilon_g(L)} - \frac{1}{\upsilon_g(0)}\right]s(L)\;\hat{z}_1 \tag{4}$$

in which $\upsilon_g(r_m) = c\sqrt{1-\left(\frac{\lambda_0}{\mathrm{k}_{mn} r_m}\right)^2}$; k_{mn} is mode constant, and K_γ is a proportional constant with energy unit, which should be the average energy needed for a unit photon number difference on the surfaces at $r = r_o$ and $r = r_L$.

In Appendix, K_γ is evaluated with an approximation using many small steps as shown in Fig. (3). The K_γ in Eqn. (4) is dependent on geometry of the resonant cavity in a tapered conical shape (conical frustum) – the difference of surface area between the top and the base of cavity and energy of photon ($\varepsilon = h\nu_0$); however, it is not dependent on energy inside the cavity and cavity length (L) although the thrust ($\vec{F}_{thrust}$) generated in the cavity is proportional to the energy (E) inside the cavity.

For example, for similar frustum cavities with different diameters of top and base, in which the volume of cavity is constant, height $L = 16.15$ cm, and energy inside the cavity $E = 1$ Joule, it is shown that thrust is dependent on frequency that can be expected in the resonant frustum cavity. Fig. (4) shows the dependency of thrust on frequency. In fact, resonant frequencies, expected in normal operation of resonant cavity, are not continuous.

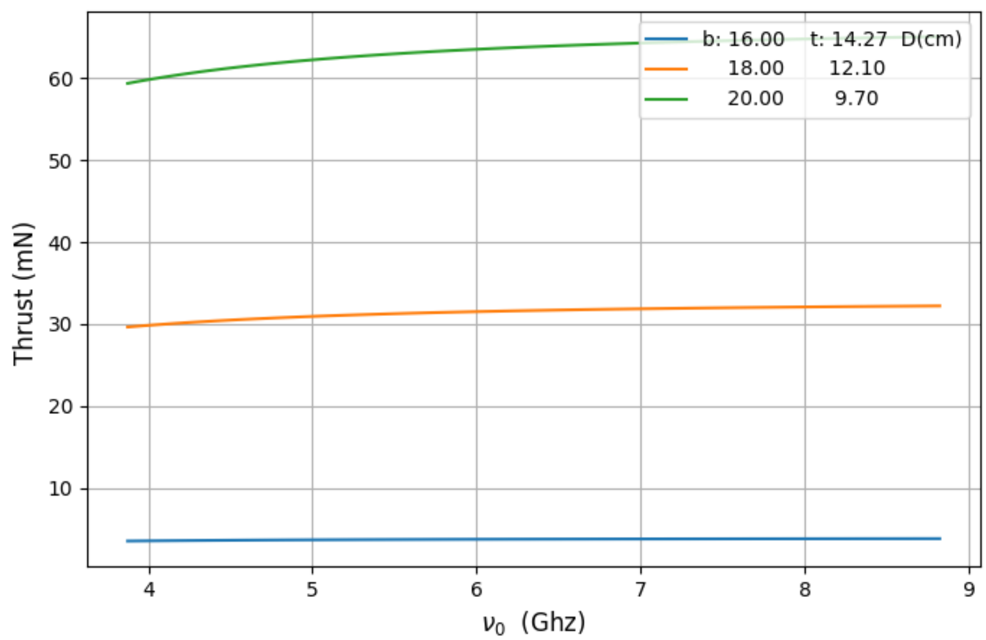

Fig. 4: thrusts with different top and base diameters in frustum cavity

In Fig. (4), one of cases that is representing with green line (base: 20 cm, top: 9.7 cm) can be compared with the experimental result in 2010 (Shawyer 2017), the thrust $\vec{F}_{thrust} \sim 60$ mN at frequency $\nu_0 = 3.8736$ GHz in the figure, which is the operating resonant frequency in the experiment. Using the Q factor[4] for operating device in the experiment, which was estimated as 73243 (Max Theoretical Q) and 55172 (unloaded Q), and the resonant frequency 3.853GHz, the specific thrust can be estimated, which is much smaller than the one reported in the experiment, though.

As shown in Fig. (A2) the photon number density (n_0) increases toward top side of the cavity; thus, the energy density ($\varepsilon_n = E/V$) inside the cavity is also increased to the top side since

[4] $Q = 2\pi f \cdot E_{stored} / E_{lost}$

$\varepsilon_n = n_0 h \nu_0$, which means that in the resonant cavity there are only some preferable resonant modes in classical EM theory. Therefore, it is important to choose a proper resonant mode and corresponding resonant frequency to get the thrust with maximum efficiency in the device. Although the efficiency of EM wave resonant frustum cavity can be another matter, the thrust can be generated in the cavity as shown above.

Asymmetrical static magnetic fields

The third type of thrust is using static magnetic fields from a permanent magnet, and the magnetic field lines are modulated by using superconductivity as shown in Fig. (5), which is a schematic drawing for the device as shown in references (A. A. Nassikas 2011, 2012); however, two springs are added to explain internal interactions in the device.

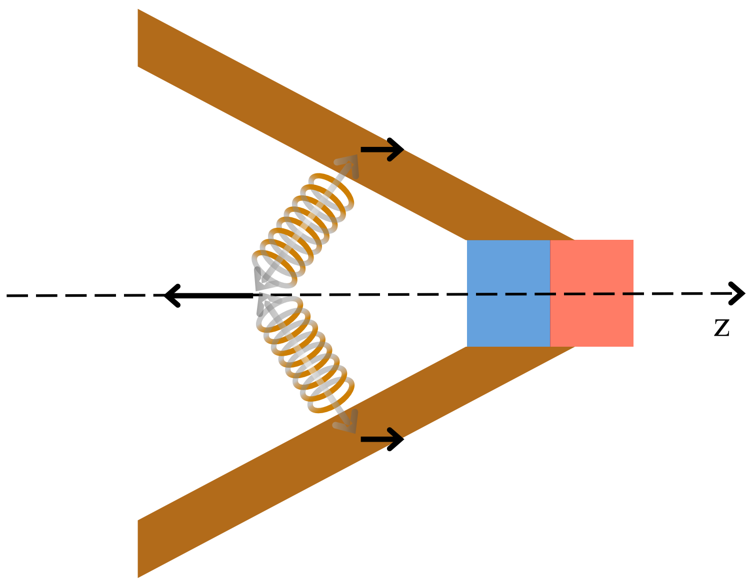

Fig. 5: a permanent magnet and superconducting devices

The superconducting part attached to the permanent magnet is indicated by brown color in the figure. Now, let's say the superconducting part is working as it purports to be; hence, all magnetic fields, which can trespassing into the part otherwise, are being pushed out of the part, which can be explained as spontaneously currents are induced inside the superconducting materials and generate magnetic fields to push out the magnetic fields trespassing into the superconducting materials, which means that the interactions between the magnetic fields from the permanent magnet and the magnetic fields generated inside the superconducting materials are magnetic field-to-field internal interactions. Therefore, the internal interactions do not produce any excess force or net thrust in the system because the internal interactions are mutual as representing with springs in Fig. (5). Nevertheless, it has been reported that a thrust is generated; then, the question is how the thrust can be generated.

The ontological interpretation of magnetic field in physics is for the spontaneous reaction of vacuum particles aligning their spins to minimize any current or dynamic effect in 4-D complex space, which means; magnetic field lines[5] are interpreted as strings of vacuum particles, of which spins are aligned along the string, and the tension in the string or between vacuum particles in the string is constant along the string of vacuum particles in physical vacuum space.

Now, in consideration of the first principle given in 4-D complex space, with which fundamental physical interactions and physical laws can be explained, or simply considering the distribution of vacuum particles for the action and reaction shown in Fig. (1), we can compare the directional magnetic flux density $\vec{B}$ at surface of the permanent magnet in Fig. (5).

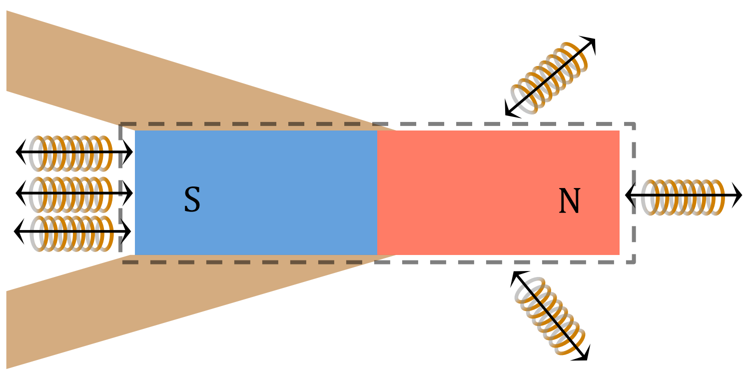

Fig. 6: asymmetrical $\vec{B}$ fields made by superconductor

A schematic drawing in Fig. (6) explains the asymmetrical $\vec{B}$ field distribution of a permanent magnet made by a superconductor in its superconducting state, which symbolically shows that three $\vec{B}$ field lines are coming into the magnetic south but only one of them is going out in the same direction as before; however, $\vec{B}$ field flux is conserved in a closed surface enclosing the permanent magnet. Hence, net thrust in the system is generated in the direction to magnetic north in Fig. (6) or $\hat{z}_1$ in Fig. (5), which can be expected as $F_{thrust} \propto -\int_S \vec{B}_z \cdot d\vec{a}$ in which the surface S encloses the permanent magnet as shown in Fig. (6) with dotted line.

[5] pictorial representation of $\vec{B}$ field strength.

With choosing a proportional constant that makes the dimension of thrust, it can be expressed as

$$F^{j}_{thrust} \sim -\frac{1}{\mu}\left\langle B_j \right\rangle_{|S_j|} \int_{S_j} \vec{B}_j \cdot d\vec{a} \tag{5}$$

in which j represents each component in Cartesian coordinates; μ, magnetic permeability, and $\left\langle B_j \right\rangle_{|S_j|}$ is the average of B_j over the surface ($|S_j| \neq 0$), in which $S_j = \vec{S} \cdot \hat{j}_1$ that is j component of surface normal $\vec{S}$. The expression on right-hand side in Eqn. (5) is showing the comparison of magnetic field energy density on the surface S enclosing the permanent magnet with weighting the surface normal in the direction of thrust. Therefore, for the thrust generated with magnetic field modulation as above, it is suggested that the thrust can be expressed as

$$F^{j}_{thrust} \sim -\frac{1}{2\mu} \int_{S_j} B_j \; (\vec{B}_j \cdot d\vec{a}) \tag{6}$$

in general. Now, let's compare the thrust in Eqn. (5) or Eqn. (6) with the experiment in 2012 (A. A. Nassikas 2012), in which the thrust was reported as $F_{thrust} = 0.05$ N. If the thrust in Eqn. (5) is expressed for a device as shown in Fig. (5) or the device in the experiment, $F_{thrust} \sim \frac{1}{2\mu}\left(B_{in} + B_{out}\right)\left(B_{in} - B_{out}\right)S$ in the direction to magnetic north in Fig. (5), in which B_{in} is magnetic field intensity at the surface of magnetic south; B_{out}, at the surface of magnetic north of permanent magnet, and S is the surface area of magnetic south end or magnetic north end. In the experiment, $B_{out} = 0.07$ T and $S = 1.25$ cm^2, but B_{in} is not known; however, $B_{in} \geq B_{out}$ as shown in Fig. (6). For the thrust reported as $F_{thrust} \sim 0.05$ N in the experiment, B_{in} can be estimated as $B_{in} = 0.077$ T that is about 10 % bigger than B_{out}, in which $\mu \sim \mu_0 = 4\pi \times 10^{-7}$ (H/m) of free space.

Discussion

The propellant-less thrust, which means, Newton's third law of motion is violated, then, the momentum in a mechanical system is not conserved. In turn, the energy in the system is not conserved either. This is very serious problem because the law of conservation of momentum and energy is a major cornerstone in physics that has been believed. However, we don't have to worry about the problem anymore if the momentum and energy in the propellant-less thrust device is considered in the physical vacuum of 4-D complex space (Kim 2020).

The conservation of energy and momentum is still valid for thrusters of T. T. Brown type if the radiation energy, which can be generated from the momentum of electrons being discharged on anode electrode, is considered together. For the other two types, on the other hand, the mechanical energy and momentum is not conserved because the thrust in device is generated from the asymmetrical vacuum particle distributions in photon number density (EM wave resonating type) and magnetic flux density (magnetic field modulation type) as long as the status of asymmetry is maintained. Anyhow, T. T. Brown type, EM wave resonating type, and asymmetrical magnetic field modulation type, all three of them are feasible, even though the practicability of devices is another matter. Once again, we confirm that in natural phenomena, many things look different and apparently seem to be independent to each other; however, if we go one step further under the surface, they are all connected.

With the pictorial description to understand the reaction in Newton's third law of motion, we need to review briefly the weak equivalence principle in general theory of relativity. As shown in Fig. (1) vacuum particle distributions on left-hand side and right-hand side of the object are different, which is not symmetric. Now, let's think of a free-falling object in a gravitational field, in which the action is given by gravitational force on the object, and the reaction is followed as shown in Fig. (1); then, according to the weak equivalence principle in general theory of relativity, also known as Galilean equivalence principle, a frame of reference with moving with the object cannot be distinguished with an inertial frame of reference in free space. In classical physics dealing with physical phenomena on macroscopic scales, the weak equivalence principle is supposed to be valid; however, in quantum realm that is at microscopic scale, it doesn't seem to be valid as shown in Fig. (1). Then, a question arises whether general theory of relativity is valid in the domain of quantum scale or not.

It was a high school student who made the start of a long journey for the propellant-less thrust; the student was Thomas Townsend Brown in 1921. Among the works done by T. T. Brown, there is a particularly interesting experimentation, which was called 'Electrogravitic Communication' in his Project Winterhaven (L. A. Brown). It is about a signal produced with thrust in the device of T. T. Brown type and was detected with voltage measurements in a nearby device.

According to his explanation for the experimentation in 1950s, the signal can penetrate a shielding medium that EM wave signal cannot pass through, which means that it is not EM waves (transverse) as he mentioned in the Project Winterhaven. In addition, the asymmetrical geometry of anode and cathode in the device seems to be important to generate more signals as well as to get more thrust from the device. Considering the interpretation how the thrust is generated in the vacuum tube as shown in Fig. (2), in which the thrust is generated when the momentum of discharging electrons is not transferred to anode; then, it is natural to suppose that the momentum of electrons can be made to a wave signal in physical vacuum space and the signal should be in the form of longitudinal waves. Not only did he find the way of interstellar travel a century ago, but he also suggested a new way of communication using longitudinal waves as early as in the 1950s.

Works Cited

A. A. Martins, M. J. Pinheiro. "On the propulsive force developed by asymmetric capacitors in a vacuum." *science Procedia* (ScienceDirect.com) 20 (2011): 112-119.

AltThink. *T.T. Brown Electrogravity Vacuum Experiments 1958 to 1960.* https://alt-think.only1egg.com/portfolio/electrogravitics-the-history-and-theory/.

Assis, A. K. T. "Changing the Inertial Mass of a Charged Particle." *Journal of the Physical Society of Japan* 62, no. 5 (May 1993): 1418-1422.

Brown, Linda Ann. *The Thomas Townsend Brown Family Website.* https://thomastownsendbrown.com/index.htm (accessed May 12, 2021).

Brown, T. Townsend. "Project Winterhaven." *starburstfound.org.* https://starburstfound.org/aerospace/projectwinterhaven.pdf (accessed May 12, 2021).

Circular waveguides. https://www.qwed.eu/CircularWaveguides.pdf.

EmDrive. *A New Concept in Spacecraft Propulsion.* SPR Ltd. www.emdrive.com.

Harold White, et al. "Measurement of Impulsive Thrust from a closed Radio Frequecny Cavity in Vacuum." *Journal of Propulsion and Power*, July-August 2017.

hec031. *Asymmertic capacitor operating in high vacuum_v1.wmv.* hec031. 06 21, 2011. https://www.youtube.com/watch?v=CGN65lse5yE.

Kim, Kiyoung. "Electric Energy from Physical Vacuum Space." *viXra.org e_Print archive.* 02 06, 2020. http://vixra.org/pdf/2002.0124v1.pdf.

—. "Paradigm Shift in Physics." *viXra e-prints.* vixra.org. 02 2017. http://vixra.org/pdf/1702.0179v1.pdf.

—. "Primitive Virtual Negative Charge." *arXiv e-print.* 11 2008. www.arxiv.org/pdf/0811.0522.pdf.

—. "The Wave Function in Quantum Mechanics." *arXiv e-prints.* 01 1997. https://arxiv.org/pdf/quant-ph/9701023v3.pdf.

LaViolette, P. "T. T. Brown's 1955-1956 Paris Experiments Revealed." *starburstfound.org.* 05 13, 2012. https://starburstfound.org/electrograviticsblog/.

Müller, Andreas. *Latest EmDrive tests at Dresden University shows "impossible Engine" does not develop any thrust.* March 21, 2021. https://www.grenzwissenschaft-aktuell.de/latest-emdrive-tests-at-dresden-university-shows-impossible-engine-does-not-develop-any-thrust20210321/ (accessed May 05, 2021).

Mallow, Eugene F. "The 'Lifter" Phenomenon: Electrogravitics, Antigravity, and More." *Infinite Energy.* https://www.infinite-energy.com/iemagazine/issue45/thelifterphen.html.

Mario Goto, et al. "On the equivalence principle and gravitational and inertial mass relation of classical charged particles." July 2010. https://www.researchgate.net/publication/45931664.

Nassikas, A. A. "A Proposed Experiment to Verify Gravitational Electromagnetic Interaction." *Proceedings of the NPA.* College Park, MD, 2011.

—. "Experimental Verification of Superconducting Self Propulsion." *Proceedings of the NPA.* Albuquerque, NM, 2012.

—. "Superconducting self propulsion requires beyond the standard model." *AIP Conference Proceedings.* 2014. 1024-1027.

Nassikas, Athanassios A. Magnetic Propulsion Device Using Superconductors. Patent US 8952773 B2. Feb. 10, 2015.

Naudin, Jean-Louis. "The Asymmetrical Capacitor Thruster v2.0." 11 22, 2001. http://jnaudin.free.fr/lifters/act/html/actv2tst.htm.

—. *The Enhanced T. Brown Electrokinetic experiment.* 09 27, 2001. http://jnaudin.free.fr/html/enhbbexp.htm.

Shawyer, Roger. "An EmDrive Thruster for Cubesats." *The EmDrive.* SPR Ltd. 2020. http://www.emdrive.com/IAC20paper.pdf.

—. "Report on the Design, Development and Test of a C-Band Flight Thruster September 2010 Issue 2." *The EmDrive.* December 2017. http://www.emdrive.com/flighthrusterreportissue2.pdf.

Tajmar, M. "Biefeld-brown effect: Misinterpretation of corona wind phenomena." *AIAA journal* 42, no. 2 (02 2004): 315-318.

—. "Propellantless Propulsion with Negative Matter Generated by Electric Charges." *49th AIAA/ASME/SAE/ASEE Joint Propulsion Conference.* San Jose,CA: the American Institute of Aeronautics and Astronautics, Inc., 2013. 3913.

Valone, Thomas F. "In:Gravitoelectromagnetic Theories HISTORY OF ELECTROGRAVITICS." ResearchGate. 01 2013. https://www.researchgate.net/publication/258847712.

—. "Progress in Electrogravitics and Electrokinetics for Aviation and Space Travel." *integrityresearchinstitute.org.* https://www.integrityresearchinstitute.org/pdf/ElectrogravitcsElectrokineticsValone.pdf.

Appendix

The coefficient K_γ in Eqn. (4) is corresponding to the energy for making unit photon number difference on the surfaces at r_0 and at r_L in Fig. (3). To estimate K_γ let's make a simple case as following:

A cylindrical resonant cavity, which is with radius r_0 and length $2L$ as shown in Fig. (A1) with dotted lines, is deformed as following; right half is shrunken to radius r_1 but left half is expanded to radius r_2; however, the volume is not changed, which means that $r_1^2 + r_2^2 = 2r_0^2$.

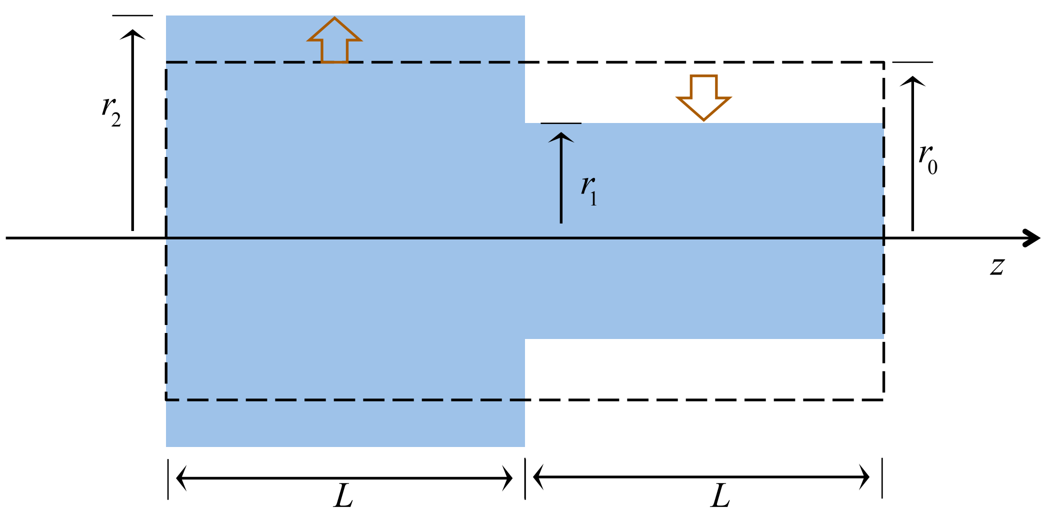

Fig. A7: cylindrical resonant cavity and its asymmetrical deformation

During the deforming process, let's assume, there is a divider in the middle of the cavity from which total number of photons (N) in each side is not changed.

The radiation pressure inside the cavity $p_\gamma = \dfrac{2nh\nu_0}{c}\upsilon_g$, in which n is photon number density; c, light velocity; $h\nu_0$, photon energy; υ_g, group velocity given as $\upsilon_g = c\sqrt{1-\left(\dfrac{\lambda_0}{br}\right)^2}$ where $\lambda_0 = c/\nu_0$ and $b = 2\pi/1.8412$ that is the lowest mode constant in circular wave guide[6].

[6] 1.8412 (TE11); 2.405 (TM01) in circular waveguide

To shrink the right half of cylindrical cavity, an external force is needed as $F = 2\pi rL \cdot P(r)$ against the pressure $P(r)$ from $r = r_0$ to $r = r_1$ in which $\vec{P}(r) = \frac{2h\nu_0}{c}\frac{N}{\pi r^2 L}\cdot \upsilon_g(r)\,\hat{r}_1$. Hence, a work is needed as

$$W_R = -\, 4N \cdot h\nu_0 \int_{r_0}^{r_1} \frac{1}{r^2}\sqrt{r^2 - \left(\frac{\lambda_0}{b}\right)^2}\, dr \tag{A1}$$

Now, let's say, $1-\left(\frac{a}{r}\right)^2 \equiv t^2$, in which $a = \frac{\lambda_0}{b}$. the integration in Eqn. (A1) is $I = \int_{t_0}^{t_1}\left(\frac{1}{1-t^2} - 1\right) dt$, where $t_1 = \sqrt{1-\left(\frac{a}{r_1}\right)^2}$ and $t_0 = \sqrt{1-\left(\frac{a}{r_0}\right)^2}$. Therefore, $W_R = 4N \cdot h\nu_0 \left[\frac{1}{2}\ln\left|\frac{1+t}{1-t}\right| - t\right]_{t_1}^{t_0}$. Similarly, for the left half of cylindrical cavity $W_L = 4N \cdot h\nu_0 \left[\frac{1}{2}\ln\left|\frac{1+t}{1-t}\right| - t\right]_{t_2}^{t_0}$, in which $t_2 = \sqrt{1-\left(\frac{a}{r_2}\right)^2}$. To deform the cavity the external work is needed as $W = W_L + W_R$; now, the divider in the middle of cavity is removed, then spontaneously a diffusion process takes place until the momentum of photons inside the cavity is uniform; correspondingly $\Delta n = n_0 \upsilon_{g0}\left[\frac{1}{\upsilon_{g1}} - \frac{1}{\upsilon_{g2}}\right]$, in which n_0 is photon number density and υ_{g0} is group velocity for both sides of cylindrical cavity at $r = r_0$; υ_{g1} and υ_{g2}, group velocity for left half and right half of the cylindrical cavity after deformed, respectively. Hence, $K_\gamma = \frac{W}{S_0 \Delta n}$ ($S_0 = \pi r_0^2$), which is the average energy to make a unit photon number difference on the surfaces at $r = r_1$ and $r = r_2$; however, it is dependent on geometric factors of cavity in general. For example, for the cavity as shown in Fig (A1) K_γ is dependent on r_0, r_1, r_2, λ_0; however, it is not dependent on length L and energy E of the cavity.

Using many small steps approximation as shown in Fig. (3) K_γ is evaluated for the resonant cavity of conical frustum. Fig. (A2) shows photon number density n_0 distribution for conical frustums, each of which has different top and base diameters, but its height and volume is constant ($h = 16.15$ cm) and the EM energy is 1 Joule inside the cavity with frequency $\nu_0 = 3.8736$ GHz; K_γ shows the dependency on frequency of photon ($\nu_0 = c/\lambda_0$). For each case, the number density is getting bigger toward the top of cavity; the difference of number densities is correlated to the difference of diameters at the top and the base of cavity.

In addition, if the diameter at the top is close to the cutoff wavelength given as $\lambda_c = \pi D/1.8412$, the difference is getting bigger significantly. On the other way, if the diameter at the top is getting far bigger than the cutoff wavelength, the difference of diameters doesn't make any big difference of the number density. On the other hand, K_γ is dependent on the difference of diameters at both sides of cavity as shown in Fig. (A2).

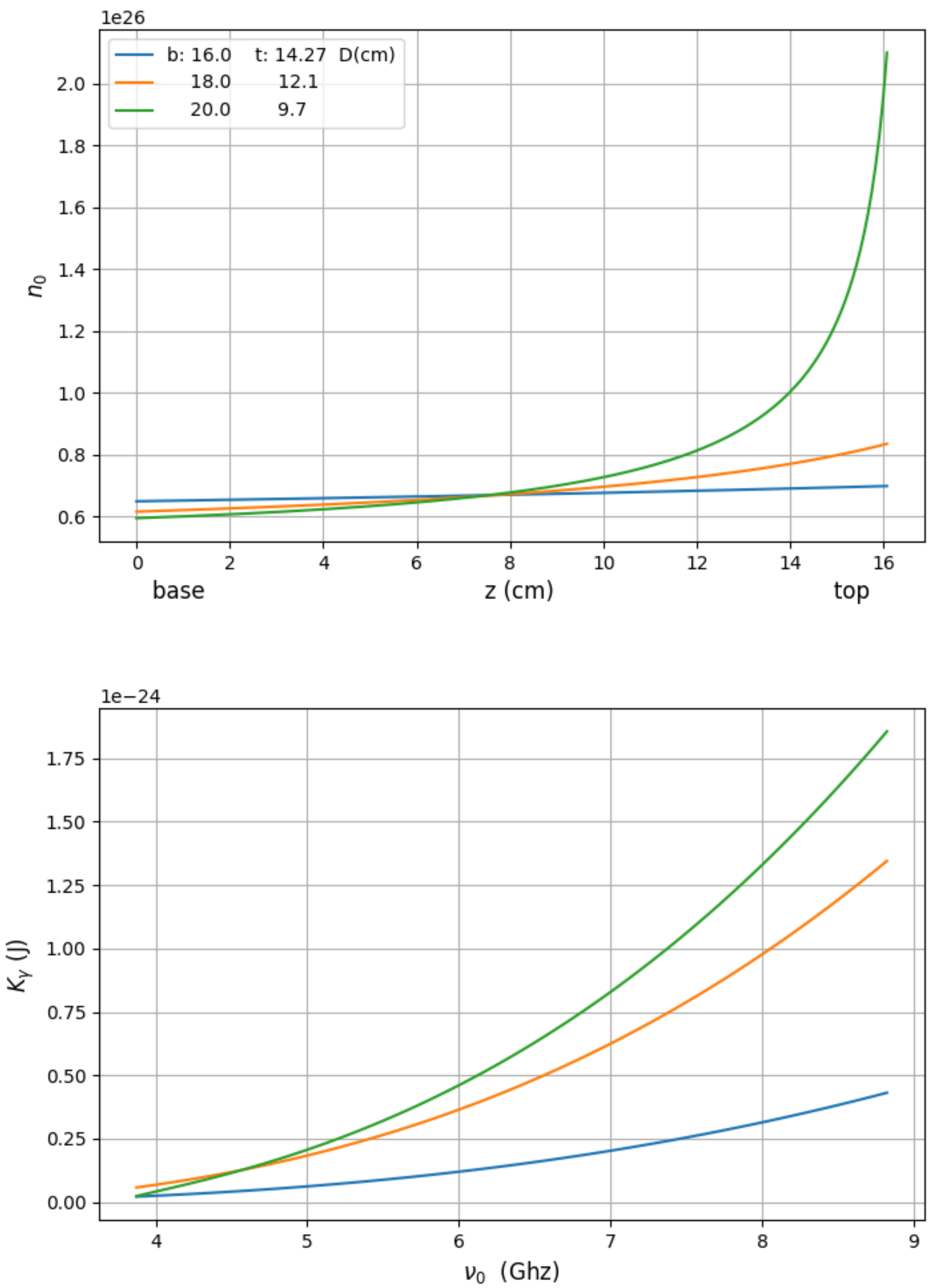

Fig. A2: photon number density n_0 and K_γ for resonant cavities with a constant volume