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Waveguide Accurate Calculation

Highlights

Interpretation of the Universe

Criticism of the Theory of Relativity

Discovering Thoughts, Inventing Future

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Circular Section Metal Wall Cut-Off Waveguide Accurate Calculation when used as a Standard Attenuator

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Abstract- In this paper, the mathematical analysis is carried out from many angles, so that the theoretical calculation problem of the circular metal wall cut-off waveguide used as a premary attenuation standard is completely solved, and the Chinese national standard of the attenuation quantity is established. The benchmark was completed by the Chinese National Institute of Metrology (NIM) with an accuracy of 5×10^{-5}; Reach the international advanced level. The calculation accuracy provided in this paper is $10^{-6}\sim10^{-7}$. This is a good example of a project combining theory and practice.

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Circular Section Metal Wall Cut-Off Waveguide Accurate Calculation when used as a Standard Attenuator

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There are a series of original achievements in this paper: (1) a new method for solving CMS equation accurately is proposed; (2) The precise attenuation constant formula is derived by the surface impedance perturbation method, that is, the formula later called the Huang's equation is proposed; (3) The general theory of metal-walled circular waveguides lined with dielectric layers, namely the Huang Zen equation, is presented. (4) The influence of oxide layer on the inner surface of the circular waveguide is analyzed and calculated. The calculation results of HE_{11} mode of circular cut-off waveguide are obtained. Therefore, the basic mathematical physics equations are also contributed.

Keywords: cut-off waveguide attenuator; national standard for attenuation; the accuracy of the attenuation constant; metal wall circular waveguide lined with dielectric layer; mathematical physics equation.

I. Introduction

In microwave measurement technology, the parameters to be measured are frequency, power, impedance, attenuation, phase shift, etc., and attenuation measurement occupies a prominent position[1]. Microwave attenuation measurement methods, an important method is the replacement method, including high frequency replacement method (microwave replacement method), medium frequency replacement method, low frequency replacement method (audio replacement method), the essence is to compare the unknown attenuation with the known precise value, so as to measure the value of the unknown attenuation. Therefore, a high precision standard attenuator is required. The attenuator of WBCO (cut-off waveguide attenuator) is commonly used for IF substitution[2]. Because the receiving electrode is usually a mobile structure (mounted on a piston), it is also called piston attenuator[3]. In addition, because of its highest accuracy, it can be used as a national measurement standard, also known as the primary standard of attenuation.

It must be pointed out that the accuracy of the microwave attenuation measurement system is lower than that of the cutoff attenuator used as the standard; For example, if the accuracy of the latter is 5×10^{-5}, the former is $10^{-3}\sim10^{-4}$. In China, the microwave attenuation measurement system produced by microwave instrument factories in the 1980s had an error of no more than one thousandth. Of course, the accuracy of 5×10^{-5} standard attenuator is difficult to do, but in 1980 by the Chinese Academy of Metrology (NIM) research group completed the project reached this level, known as the first attenuation standard or National attenuation basic standard. Below this is the Secondary attenuation standard, its standard cut-off attenuator accuracy is 5×10^{-4}, then the accuracy of the entire microwave attenuation measurement system is 10^{-3}, that is, the error is not more than one thousandth.

From 1966 to 1980, the American Bureau of Standards (NBS), the National Institute of Physics Labaratory (NPL), and NIM all built a first-stage attenuator working in the medium frequency (30MHz), all using a cut-off waveguide attenuator. Professor Mengzong Song of NIM is the chief designer, and engineers Yongjian Xia and Ronggen Mo are responsible for the structural design[4]. The machining problem of precision circular waveguide is solved[5]. Zhi-xun Huang is responsible for theoretical calculation and error analysis[6]. In addition, there are other researchers involved in this project, after several years of efforts finally successful, technical indicators reached the international advanced level. This paper is a comprehensive theoretical summary by the author, including my new equations, which are contributions to the basic waveguide theory.

II. Standard Attenuators in Microwave Attenuation Measurement

The working principle of the cutoff waveguide attenuator is the exponential decline characteristic of the evanescent field in the waveguide when the waveguide

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cutoff point is below ($f < f_c$, $\lambda > \lambda_c$), and a circular waveguide is placed along the direction z :

$$E = E_0 e^{-\alpha z}$$

The field strength at z =0(starting point) is E_0. If $z = l$, the field strength is E_1, there is:

$$E_l = E_0 e^{-\alpha l} \quad (1)$$

If the attenuation generated by a waveguide of length l is defined as A, then there is

$$A = \ln\frac{E_0}{E_l} = \alpha l \text{ (Np)} \quad (2)$$

For example, when A =20dB=2.3Np, e^{-A} =0.1. This means that when the design is α =1dB/mm, the field strength decreases to 1/10 of the starting value after only 20mm along the direction z. This is a fast rate of descent, indicating that large attenuation, such as more than 100dB, can be obtained only with a shorter cut-off waveguide.

When the electromagnetic wave propagates in the metal wall waveguide, there will be a cutoff phenomenon, that is, only the frequency $f > f_c$ wave, above the cutoff frequency, can propagate. At the frequency of $f < f_c$, the evanescent field is characteristic, which is a reactive energy storage field. Such devices, known as cut-off waveguides (WBCO), have prominent uses in electronic instrument design. In 1942, E. Linder[7] gave a formula for calculating the attenuation constant of the cutoff waveguide:

$$\alpha = \frac{2\pi}{\lambda_c}\sqrt{1-\left(\frac{\lambda_c}{\lambda}\right)^2} \quad (3)$$

The cut-off wavelength λ_c is determined by the size of the waveguide cross section. We know that length and time are the two basic units of metrology; It is now associated with two basic units, which determines that it can obtain α high accuracy (if the waveguide machining size is very precise).... Of course, Linder's formula is not very accurate, so improving the formula is a work for future generations. Both R. Grranthan[8] in 1948 and R. Rauskolb[9] in 1962 made efforts, but the accuracy of their formulas was not high enough to meet the requirements for the design and construction of first-order standard attenuators. The problem was solved by me.

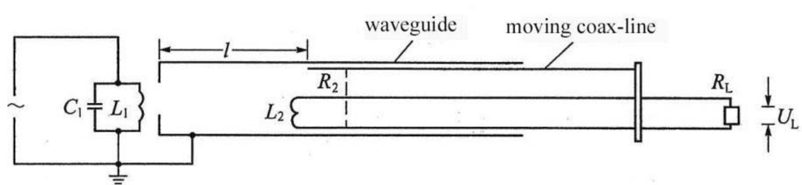

Figure 1: Example of Output Attenuator for a Meter Wave Standard Signal Generator

To visualize the actual operating state of the cut-off waveguide, Figure 1 shows the output circuit of a standard signal generator capable of obtaining a voltage output in the microvolt (μV) range[3]. When the receiving electrode (L) mounted on the coaxial line is moved, the output voltage U is uniformly and continuously changed for use by the experimenter. Here, l represents the length of the actual operating cut-off waveguide.

The main mode of the circular waveguide, strictly written as HE_{11} mode, indicates that the effect of the finite conductivity of the wall cannot be ignored, and the H_{11} mode (TE_{11} mode) under ideal conditions will be slightly affected by the mode coupling[4]. But generally speaking, the main mode in the circular waveguide is H_{11} mode (TE_{11} mode); If its inner diameter is $2a$, the cutoff wavelength of the mode is

$$\lambda_{c.11} = \frac{2\pi}{k} a = 3.412a \quad (4)$$

Set λ to the operating wavelength (depending on the signal source), so in order to obtain the H_{11}-mode evanescent field must be satisfied:

$$a < \frac{\lambda}{3.412} \quad (5)$$

Here are the transverse dimensions of the circular waveguide used in the primary attenuation standards built by the highest metrological institutions in several countries: $2a$ =3.2cm (NIM);$2a$ ≈5.06cm(NPL); $2a$ ≈8.12cm(NBS).

The relation A-l equation of the cutoff attenuator is not linear at all locations and has A nonlinear segment at smaller l (and therefore smaller A)[3]. In order to maintain high accuracy, the application can avoid this section, that is, avoid the initial attenuation section of about 20dB, that is, maintain the linear relationship $A = \alpha l$. The laser length measurement technology can be accurately measured, so the focus of the study turns to the attenuation constant α. It must be pointed out that the outstanding contribution of the author is the monograph 《Introduction to the Theory of Waveguide Cutoff Below》, published in 1991, which makes the cutoff waveguide theory into a complete system, and derives some new equations and formulas, and gives the solution methods[10]. In the book, it is pointed out that for microwave attenuation measurement, a branch of metrology, in the 30 years from 1950 to 1980, the accuracy of the cutoff attenuator standard was increased from 5×10^{-3} to close to 5×10^{-5}, because it is basically a calculation standard, and the attenuation constant is mainly determined by the basic unit (length and frequency). In the case of the increasing level of machining and surface treatment technology, it is required to theoretically derive the attenuation constant formula with higher accuracy (higher than 5×10^{-5}). For the HE_{11} mode in the metal-walled circular waveguide, the formula is derived as[4]:

$$\alpha_{11}=\frac{2\pi}{\lambda_c}\sqrt{\frac{1}{2}\left[1-\left(\frac{\lambda_c}{\lambda}\right)^2\varepsilon_r-J_{11}\right]+\frac{1}{2}\sqrt{\left[1-\left(\frac{\lambda_c}{\lambda}\right)^2\varepsilon_r-J_{11}\right]^2+J_{11}^2}} \quad \text{(Np/m)} \qquad (6)$$

among

$$J_{11}=\frac{g\tau}{a}=\mu_{rc}\left[1+\frac{1}{k_{11}^2-1}\left(\frac{\lambda_c}{\lambda}\right)^2\right]\frac{\tau}{a} \qquad (7)$$

Where μ_{rc} is the relative magnetic permeability of the wall metal; ε_r is the relative dielectric constant of the filling medium; τ is the skin depth of the inner wall, $\tau=(\pi\mu\sigma f)^{-1/2}$, where σ is the RF conductivity of the wall metal, $\mu=\mu_{rc}\mu_0$ is the magnetic permeability of the wall metal. The calculation shows that the formula derived by the author is the most accurate one of the same kind (the accuracy is 1×10^{-6}), which can meet the calculation needs of establishing high precision national attenuation standard.

It can be obtained from formula (2):

$$dA=\frac{d\alpha}{\alpha}A+\alpha\cdot dl \qquad (8)$$

The above formula indicates the method of giving electrical performance indicators for standard cutoff attenuators, which is very important. The first term on the right side of the equation is caused by the circular cut-off waveguide, and the second term is caused by the length measuring (displacement measuring) mechanism. Since the 1970s, due to the development of laser length measurement technology, the second item has been greatly reduced (such as displacement resolution up to 0.0001dB), so the main task is to reduce $d\alpha/\alpha$. The basic parameters of the first order cutoff attenuation standard developed successfully by various countries are derived from two main factors: the uncertainty of the radius of the circular waveguide (da/a) and the uncertainty of the RF conductivity of the waveguide wall material ($d\sigma/\sigma$). The operating mode is $H_{11}(TE_{11})$, and the operating frequency is 30MHz.

Now look at where the US and China have reached. According to literature [11], the NBS of the United States in 1960 was as follows: the average inner diameter of the cut-off waveguide was 81.21015mm(at 20℃), the diameter machining uniformity was ±0.762μm, the diameter measurement uncertainty was ±1.27mm, the radio frequency conductivity of the tube wall was $1.2825\times10^{-7}(\Omega\cdot m)^{-1}$, and the uncertainty was $d\sigma/\sigma=\pm5\%$.For such a waveguide, the attenuation constant $\alpha=0.393701$ dB/mm(at 20℃).The partial error and the uncertainty of pipe diameter caused by $\pm3\times10^{-5}$, the small change of temperature in the constant temperature room caused by $\pm1\times10^{-5}$, and the uncertainty of pipe wall conductivity caused by $\pm2.6\times10^{-5}$.NBS technical report gives $\alpha=0.393701$ dB/mm. $d\alpha/\alpha=\pm1\times10^{-4}$, that is, one part in 10,000.

In addition, according to literature [4], the situation of NIM in China in 1980 was as follows: average inner diameter of cutoff waveguide 31.96254mm(at 20℃), non-uniformity of pipe diameter processing ±0.5μm, uncertainty of pipe diameter measurement ±0.6μm, radio frequency conductivity of pipe wall $=1.6034\times10^{-7}(\Omega\cdot m)^{-1}$, uncertainty ±4%. In this case, the attenuation constant $\alpha=0.99995775$ dB/mm (20℃); After synthesizing the partial errors, the NIM technical report gives $d\alpha/\alpha=5\times10^{-5}$, that is, 5 parts per 100,000.

It can be seen that the attenuation standard established by China's NIM is better than that established by the NBS of US. As for a lot of theoretical analysis work is not NBS.

III. Historical Background: from Thomson Equation to CMS Equation

British scientist Joseph Thomson (1856-1940) won the Nobel Prize in Physics in 1906 for his discovery of the electron. In 1893 J. Thomson published a book: Notes on New Research in Electromagnetics - a continuation of Professor Clerk Maxwell's 《Treatises on Electricity and Magnetism》 [12]. It fully affirms the realizability of transmitting electromagnetic waves in a circular metal-walled tube (that is, a circular waveguide). Why is Thomson so early can come to the right conclusion? This is mainly because his mathematical starting point is correct: first analyze the electrical vibration of the cylindrical cavity inside the conductor, that is, solve the two-dimensional wave equation. This made him the first scientist in history to predict waveguides.

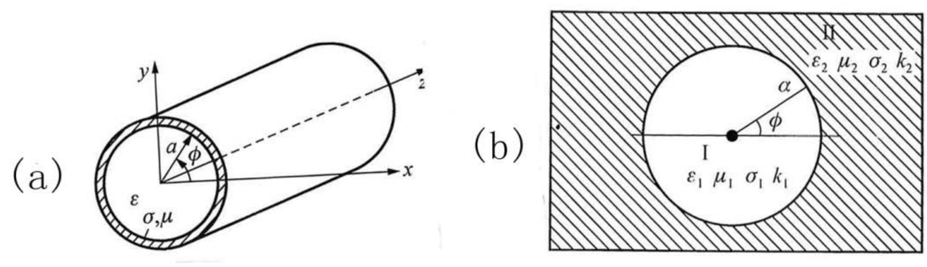

Figure 2: Circular Waveguide

For the reader's ease of understanding, Thomson's analysis is presented in today's notation, and its system of units is changed to SI. A medium cylinder with radius of (a) is buried in a uniform infinite conductor space (ε_c, μ_c), and the cylindrical coordinate system (r, ϕ, z) is taken for analysis (FIG. 2). Thomson showed that the following partial differential equations held in the medium:

$$\frac{\partial^2 H_z}{\partial x^2}+\frac{\partial^2 H_z}{\partial y^2}=\frac{1}{V^2}\frac{\partial^2 H_z}{\partial t^2}$$

He called V "the speed of electrodynamic action" propagating through a medium, which is actually the speed of electromagnetic waves. The following partial differential equation holds in the conductor:

$$\frac{\partial^2 H_z}{\partial x^2}+\frac{\partial^2 H_z}{\partial y^2}=\sigma\mu_c\frac{\partial^2 H_z}{\partial t}$$

Where σ is electrical conductivity. The above two formulas can be written as

$$\nabla_t^2 H_z=\frac{1}{V^2}\frac{\partial^2 H_z}{\partial t^2} \quad \text{(in medium)}$$

$$\nabla_t^2 H_z=\sigma\mu_c\frac{\partial^2 H_z}{\partial t} \quad \text{(in conductor)}$$

This was Thomson's starting point. When you take a cylindrical coordinate system, then

$$\frac{\partial^2 H_z}{\partial r^2}+\frac{1}{r}\frac{\partial^2 H_z}{\partial r}+\frac{1}{r^2}\frac{\partial^2 H_z}{\partial \phi^2}=\frac{1}{V^2}\frac{\partial^2 H_z}{\partial t^2} \qquad \text{(in medium)}$$

$$\frac{\partial^2 H_z}{\partial r^2}+\frac{1}{r}\frac{\partial^2 H_z}{\partial r}+\frac{1}{r^2}\frac{\partial^2 H_z}{\partial \phi^2}=\sigma\mu_c\frac{\partial^2 H_z}{\partial t} \qquad \text{(inside the conductor)}$$

Thomson assumed H_z changes according to the law of $\cos m\phi \cdot e^{j\omega t}$, which in fact introduced the steady state, monochromatic simple harmonic concept proposed by Helmholtz (1821-1894) in 1860. In this way, two ordinary differential equations are obtained:

$$\frac{d^2 H_z}{dr^2}+\frac{1}{r}\frac{dH_z}{dr}+\left(\frac{\omega^2}{V^2}-\frac{m^2}{r^2}\right)H_z \quad =0 \qquad \text{(in medium)} \tag{9}$$

$$\frac{d^2H_z}{dr^2}+\frac{1}{r}\frac{dH_z}{dr}-\left(j\omega\sigma\mu_c+\frac{m^2}{r^2}\right)H_z=0 \quad \text{(in conductor)}$$

Where m is a positive integer.Let $\gamma_c=\sqrt{j\omega\mu_c\sigma}$, then the equation in the conductor is

$$\frac{d^2H_z}{d(\gamma_c r)^2}+\frac{1}{\gamma_c r}\frac{dH_z}{d(\gamma_c r)}-\left[1+\frac{m^2}{(\gamma_c r)^2}\right]H_z=0 \tag{10}$$

The equation in the medium is Bessel equation, while in the conductor it is Bessel equation with virtual variable.

Obviously, the equation in the medium has only the following special solutions:

$$H_z^I=A\cos m\phi\cdot J_m\left(\frac{\omega}{V}r\right)\cdot e^{j\omega t} \tag{11}$$

Where A is the constant. The other particular solution of the general solution (Neumann function) does not exist, because it is necessary to ensure that the field at $r=0$ is finite. For the equation in the conductor, there may be two special solutions are I_m $(\gamma_c r)$ and K_m $(\gamma_c r)$, but the bigger, r I_m bigger, this does not meet the physical reality, so there is only one special solution:

$$H_z^{II}=B\cos m\phi\cdot K_m\,(j\gamma_c r)\cdot e^{j\omega t} \tag{12}$$

Where B is the constant. Therefore, the change in the medium field is according to the Bessel function; Within the conductor, the field is modified by the second class Bessel function. The latter description is what makes him unique.

Thomson derived the characteristic equations of circular waveguide H_{mn} modes, and it is surprising that this work succeeded at the end of the 19th century. His method was to obtain two different equations with two boundary conditions, combine them to eliminate the two arbitrary constants, and finally obtain a transcendental equation, called the characteristic equation (a term later used in the 20th century, but not by Thomson). The two boundary conditions are as follows:

1. At the interface between the medium and the conductor, the "magnetic field line" parallel to the surface is continuous, which can be written as

$$H_z^I\big|_{r=a}=H_z^{II}\big|_{r=a}$$

2. The interface between the medium and the conductor is continuous with r the vertical "electric strength". In the present expression, it can be written as

$$E_\phi^I\big|_{r=a}=E_\phi^{II}\big|_{r=a}$$

The first boundary condition causes

$$A\,J_m\left(\frac{\omega}{V}a\right)=B\,K_m\,(j\gamma_c a)$$

However, in order to apply the second boundary condition, we must first write the expression, i.e

$$E_\phi^I\approx-\frac{1}{j\omega\varepsilon}\frac{dH_z^I}{dr} \quad \text{(in medium)}$$

$$E_\phi^{II}\approx-\frac{1}{\sigma}\frac{dH_z^{II}}{dr} \quad \text{(in conductor)}$$

This way, we can write

$$\frac{dH_z^I}{dr}=A\cos m\phi\;J'_m\left(\frac{\omega}{V}r\right)e^{j\omega t}\,\frac{\omega}{V}$$

$$\frac{dH_z^{II}}{dr}=B\cos m\phi\;K'_m\,(j\gamma_c r)\;e^{j\omega t}\;j\gamma_c$$

By the second boundary condition, we get

$$A\,\frac{1}{j\omega\varepsilon}\,\frac{\omega}{V}\,J'_m\left(\frac{\omega}{V}a\right)=B\,\frac{1}{\sigma}\,j\gamma_c\;K'_m(j\gamma_c a)$$

Simultaneous solution, and set $\mu=\mu_0$, $\mu_c=\mu_{rc}\mu_0$, then

$$\frac{\omega}{Va}\,\frac{J'_m\left(\frac{\omega}{V}a\right)}{J_m\left(\frac{\omega}{V}a\right)}=\frac{\mu_{rc}}{j\gamma_c a}\,\frac{K'_m(j\gamma_c a)}{K_m(j\gamma_c a)} \tag{13}$$

This is the characteristic equation of the circular waveguide when the wall conductivity is finite, that is, the equation (86) in Thomson's book[5].

Thomson pointed out that when "the wavelength of the electric vibration can be compared with the diameter of the cylinder ($2a$)", that is, when the wavelength is very short and the frequency is very high, it is $\gamma_c a$ very large, then

$$K_m(j\gamma_c a)=(-1)^m e^{-\gamma_c a}\sqrt{\frac{\pi}{2\gamma_c a}}$$

Thus there is

$$K'_m(j\gamma_c a)=jK_m(j\gamma_c a)$$

At this time, the right end of equation (13) becomes $\mu_{rc}/\gamma_c a$, which is a small quantity, so when the frequency is very high (i.e. microwave), the following equation is obtained as an approximate solution of the equation:

$$J'_m\left(\frac{\omega}{V}a\right) \tag{14}$$

This means that the tangential component of the electric field strength at the interface is zero. At this time, take $m=1$ to obtain the equation of "maximum period of electric vibration" :

$$\frac{\omega}{V}a=1.841$$

From this, the cut-off wavelength of the H_{11} mode is

$$\lambda_{c.11}=0.543\times 2\pi a=3.142a \tag{15}$$

This is slightly larger than half a circumference (πa). The above concept is completely correct, but Thomson did not have a "mode" at the time.

Thomson pointed out that if $\lambda > \lambda_c$ (the operating wavelength is greater than the cut-off wavelength), "the electrical vibration is not attenuated", which is the electromagnetic wave transmission. However, if we carefully examine the right side of the characteristic equation, we find that there is a small imaginary number term, "which marks the gradual reduction of vibration". That is to say, when the finite conductivity of the wall is taken into account, there is a small attenuation in the propagation of the electromagnetic wave.

The "wave whose wavelength is comparable to the diameter of a cylinder" predicted by Thomson turned out to be the microwave. The circular waveguide he predicted was realized 43 years later (i.e. 1936) by scientists at Bell Laboratories (BTL) in the United States[13]. This shows that the predictions of science can be made much earlier than the development of technology, and demonstrates the power of applied mathematics. It is commendable that he deals with the finite conductive wall at the beginning, thus making the discussion close to reality and giving people a deeper impression. Under microwave conditions, he pointed out that his characteristic equation can be solved according to the ideal conductive wall, so as to find the cutoff frequency and cutoff wavelength, and the error is not large. In this way, Thomson correctly solved the problem of calculating the sum of the principal modules. In addition, he pointed out that the finite conductive wall must cause a small attenuation of the guided wave. His shortcomings lie in: (1) In the derivation process, it is assumed that the conductor σ is very large and the medium $\sigma=0$;(2) From the beginning, it is stipulated that it is a type of magnetic wave mode. Two points (1) and (2) determine that his analysis is not very strict, especially the second point is the most important.

Thomson started with the H_z scalar wave equation. However, when the conductivity is finite, the electric and magnetic fields must be superimposed to satisfy the boundary conditions at $r=a$ .Therefore, the resultant field is neither a transverse magnetic field nor a transverse electric field, but a hybrid mode. A TM or TE mode can exist alone only if the wall conductivity $\sigma=\infty$.

From 1893 to 1936, a long gap was formed in the field of waveguide theory. It was not until 1936 that J. arson and three others published a characteristic equation that solved the problem of both assuming finite wall conductivity and mixed mode analysis.[7] This is known as the Carson-Mead-Schelkunoff equation, and since both are finite wall analyses, it should be possible to derive J. Thomas's equation from the CMS equation. On account of

$$j\gamma_c a=j\sqrt{j\omega\mu_c\sigma}a=\sqrt{-j\omega\mu_c\sigma}a=a\omega\sqrt{\frac{\mu_c\sigma}{j\omega}}$$

So when $\sigma \gg \omega\varepsilon$, there is

$$j\gamma_c a=a\omega\sqrt{\mu_c\varepsilon_c}=ak$$

Where ream $k=\omega\sqrt{\mu_c\varepsilon_c}$, let

$$v=a\sqrt{k^2+\gamma^2}$$

So when $k^2 \gg \gamma^2$, there is

$$v\approx j\gamma_c a$$

So the right end of the characteristic equation is

$$\frac{\mu_{rc}}{ak}\frac{K'_m(ak)}{K_m(ak)}=\frac{\mu_{rc}}{v}\frac{K'_m(v)}{K_m(v)}$$

On the other hand, if the medium is a vacuum (ε_0, μ_0), then

$$\frac{\omega}{V} a = \omega\sqrt{\mu_0 \varepsilon_0}\, a = k_0 a$$

Where $k_0 = \omega\sqrt{\mu_0\varepsilon_0}$, let

$$u = a\sqrt{k_0^2 + \gamma^2}$$

When $k_0^2 \gg \gamma^2$, we have

$$u = \frac{\omega}{V} a$$

So Thomson's characteristic equation can also be written as

$$\frac{1}{u}\frac{J'_m(u)}{J_m(u)} = \frac{\mu_{rc}}{v}\frac{K'_m(v)}{K_m(v)} \tag{16}$$

But mathematics knows

$$K_m(jx) = (-1)^m \left(\frac{\pi}{2} j^{m+1}\right) H_m^{(1)'}(x)$$

Where $H_m^{(1)}$ is the first kind of order Hankel function, so there is m

$$\frac{K'_m(jx)}{K_m(jx)} = \frac{H_m^{(1)'}(x)}{H_m^{(1)}(x)}$$

The characteristic equation can be obtained as

$$\frac{1}{u}\frac{J'_m(u)}{J_m(u)} = \frac{\mu_{rc}}{v}\frac{H_m^{(1)'}(v)}{H_m^{(1)}(v)} \tag{17}$$

Obviously, this is part of the CMS equation, or it can be immediately derived from the CMS equation[14]. It can also be seen that Thomson's equation does not contain waveguide propagation constant γ , which will undoubtedly greatly reduce the application value of the equation.

IV. A New Method for Accurate Solution of CMS Equation

In the development of waveguide theory, a prominent research direction is the characteristic equation method, which is remarkably effective for cylindrical guided wave systems and can be applied in other cases. The essence of the method is to derive the eigen equation containing the longitudinal propagation constant ($\gamma = \alpha + j\beta$), which is actually the eigen value equation. For cylindrical guided wave structures, the initial derivation was for metal-walled circular waveguides, but it was soon found that this method could be generalized to other guided wave systems.

Figure 2(b) shows a vacuum cylinder (ε_0, μ_0) embedded in an infinitely large conducting medium (ε_c, μ_c). For the sake of universality, the macro parameters of region I are ε_1, μ_1, σ_1 and the macro parameters of region II are ε_2、 μ_2、 σ_2. In this way, a generalized mathematical physical model can be constructed, which is applicable not only to metal wall circular waveguides, but also to a series of other guided waveguides, such as single-line surface waveguides, dielectric tube circular waveguides, dielectric rod circular waveguides, and optical fibers. The generalized characteristic equation is derived by J. Carson et al., in cylindrical coordinate system, the field vector is written as

$$\boldsymbol{E} = E_r \boldsymbol{i}_r + E_\phi \boldsymbol{i}_\phi + E_z \boldsymbol{i}_z$$

$$\boldsymbol{H} = H_r \boldsymbol{i}_r + H_\phi \boldsymbol{i}_\phi + H_z \boldsymbol{i}_z$$

Where $\mathbf{i}$ is the unit vector. Starting from the two curl equations ($\nabla\times \mathrm{H} = j\omega\varepsilon\, \mathrm{E}$, $\nabla\times \mathrm{E} = -j\omega\mu\, \mathrm{H}$) in Maxwell equations, the relationship between the transverse field component and the longitudinal field component can be found out when electromagnetic wave propagates along the cylinder. First specify the following symbols:

$$h_1 r = r\sqrt{\omega^2\varepsilon_1\mu_1 + \gamma^2}$$

$$h_2 r = r\sqrt{\omega^2\varepsilon_2\mu_2 + \gamma^2}$$

Ignoring the mathematical derivation, the CMS equation can be obtained[14]:

$$-\left[\frac{\mu_1}{u}\frac{J'_m(u)}{J_m(u)} - \frac{\mu_2}{v}\frac{H'_m(v)}{H_m(v)}\right]\left[\frac{k_1^2}{\mu_1 u}\frac{J'_m(u)}{J_m(u)} - \frac{k_2^2}{\mu_2 v}\frac{H'_m(v)}{H_m(v)}\right] = m^2\gamma^2\left(\frac{1}{u^2} - \frac{1}{u^2}\right)^2 \tag{18}$$

Where $u = h_1 a$, $v = h_2 a$. The above equation is the generalized characteristic equation of cylindrical wave. The cylindrical function in the formula is a transcendental function with infinite roots for each value, so the solution of the above equation is a discrete spectrum, and a value can be obtained for each normal wave type, so it is an eigen value equation. m γ_{mn}

Carson et al.'s paper used 8th-order determinants to find non-zero solutions under Bezout condition when 8 constants were treated as variables, while we use 4th-order determinants. This is because we only take cosmϕ or sinmϕ for analysis; This can be done because these two types of modes are polarially degenerate. However, the derivation is an eigen-valued equation, and the degeneracy model of the eigen-valued problem can be ignored, so the derivation method can be greatly simplified.

For the most common non-ideal conductive wall circular waveguide, region 1 is air and region 2 is conductive medium, so the characteristic equation becomes

$$-k_0^2\left[\frac{1}{u}\frac{J'_m(u)}{J_m(u)}-\frac{\mu_{rc}}{v}\frac{H'_m(v)}{H_m(v)}\right]\left[\frac{\varepsilon_{r1}}{u}\frac{J'_m(u)}{J_m(u)}-\left(\varepsilon_{r2}+\frac{\sigma}{j\omega\varepsilon_0}\right)\frac{1}{v}\frac{H'_m(v)}{H_m(v)}\right]=m^2\gamma^2\left(\frac{1}{v^2}-\frac{1}{u^2}\right)^2 \tag{19}$$

it is

$$u=a\sqrt{\mu_{r1}k_0^2+\gamma^2}$$

$$v=a\sqrt{k_2^2+\gamma^2}$$

Zhixun Huang and Jin Pan propose a theoretical analysis and a new numerical solution, see below[15].

Suppose the region Ⅰ is the non-dissipative medium and the region Ⅱ is conductor, then

$$\varepsilon_1=\varepsilon_{r1}\varepsilon_0;\quad \mu_1=\mu_0;\quad \mu_2=\mu_c=\mu_{rc}\mu_0$$

$$\varepsilon_2=\varepsilon_c=\varepsilon_{r2}\varepsilon_0+\frac{\sigma}{j\omega}=\varepsilon_0\left(\varepsilon_{r2}+\frac{\sigma}{j\omega\varepsilon_0}\right)$$

where $\varepsilon_2\,(\varepsilon_c)$ is the complex permittivity. Then the wave numbers of two regions become:

$$k_1^2=\omega^2\,\varepsilon_{r1}\varepsilon_0\mu_0=\varepsilon_{r1}\,k_0^2;\quad k_2^2=\omega^2\varepsilon_c\mu_c=\mu_{rc}\,k_0^2\left(\varepsilon_{r2}+\frac{\sigma}{j\omega\varepsilon_0}\right)$$

so we have:

$$-k_0^2\left[\frac{1}{u}\frac{J'_m(u)}{J_m(u)}-\frac{\mu_{rc}}{v}\frac{H'_m(v)}{H_m(v)}\right]\left[\frac{\varepsilon_{r1}}{u}\frac{J'_m(u)}{J_m(u)}-\left(\varepsilon_{r2}+\frac{\sigma}{j\omega\varepsilon_0}\right)\frac{1}{v}\frac{H'_m(v)}{H_m(v)}\right]-m^2\gamma^2\left(\frac{1}{v^2}-\frac{1}{u^2}\right)^2=0 \tag{20}$$

Equation (20) is the basic propagation equation for cirular waveguides, the field components in the guide for the (m, n) mode are proportional to exp[j $(\omega\varepsilon-\gamma z-m\phi)$]. But

$$v^2=a^2k_2^2+a^2\gamma^2=a^2k_1^2\left[\left(\frac{k_2}{k_1}\right)^2-1\right]+u^2$$

Equation (20) can be written in the form:

$$F(u)=0 \tag{21}$$

The algorithm for solving equation (21) is based upon the Newton-Raphson method, which is based upon the preliminary determination by trial of an approximate root u_0:

– First guess u_0,

– Next guess u_1, $u_1=u_0-[F(u_0)/F'(u_0)]$,

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– Third guess u_2, $u_2 = u_1$-[F (u_1)/ F' (u_1)].

This process may be repeated until the desired degree of approximation is attained:

$$u_n = u_{n\text{-}1} - \frac{F(u_{n\text{-}1})}{F'(u_{n\text{-}1})}$$

where n is the calculation number, not mode index. And now we may have:

$$\frac{u_n - u_{n\text{-}1}}{u_n} < 1\times10^{-7}$$

In common case, it has been assumed that the bounding conductor is lossfree, but in practice, this assumption will not be true. Because of the finite conductivity of the surrounding con ductor, the electric field will penetrate into the metal, and the resistance losses thereby incurred will cause the coupling of wave modes, except the circular symmetrical modes in the circular waveguide. When $\mathrm{m} \neq 0$, this case yields waves of the type HE $_{\mathrm{mn}}$ ($E_z \neq 0$) and EH ^{mn} ($H_z \neq 0$), named with the first derivation given by Carson-Mead-Schelkunoff. We must bear firmly in mind, that the hybrid wave has six field components. So we can strictly distinguish between the hybrid modes HE ^{mn} and the transverse electric modes H_{mn} .

Putting $\mathrm{m} = 1$*, from the CMS equation on HE mode, we have:*

$$F(u) = -k_0^2\left[\frac{1}{u}\frac{J_1'(u)}{J_1(u)} - \frac{\mu_{rc}}{v}\frac{H_1'(v)}{H_1(v)}\right]\left[\frac{\varepsilon_{r1}}{u}\frac{J_1'(u)}{J_1(u)} - \left(\varepsilon_{r2} + \frac{\sigma}{j\omega\varepsilon_0}\right)\frac{1}{v}\frac{H_1'(v)}{H_1(v)}\right] - m^2\gamma^2\left(\frac{1}{v^2} - \frac{1}{u^2}\right)^2 \quad (22)$$

But

$$J_1'(u) = J_0(u) - \frac{1}{u}J_1(u);\quad H_1'(v) = H_0'(v) - \frac{1}{v}H_1(v)$$

Then

$$F(u) = -k_0^2\left[\varepsilon_{r1}\left(\frac{1}{u}\frac{J_0(u)}{J_1(u)} - \frac{1}{u^2}\right)^2 - \left(\frac{1}{u}\frac{J_0(u)}{J_1(u)} - \frac{1}{u^2}\right)\left(\varepsilon_{r1}\mu_{rc} + \varepsilon_{r2} + \frac{\sigma}{j\omega\varepsilon_0}\right)\times\right.$$
$$\left.\frac{1}{v}\left(\frac{H_0(v)}{H_1(v)} - \frac{1}{v}\right) + \mu_{rc}\left(\varepsilon_{r2} + \frac{\sigma}{j\omega\varepsilon_0}\right)\frac{1}{v^2}\left(\frac{H_0(v)}{H_1(v)} - \frac{1}{v}\right)^2\right] - \left(\frac{u^2}{a^2} - \varepsilon_{r1}k_0^2\right)^2\left(\frac{1}{v^2} - \frac{1}{u^2}\right)^2 \quad (23)$$

$$F'(u) = -k_0^2\frac{2\varepsilon_{r1}}{u^2}\left(\frac{J_0(u)}{J_1(u)} - \frac{1}{u}\right)\left[\frac{2}{u^2} - 1 - \left(\frac{J_0(u)}{J_1(u)}\right)^2\right] + k_0^2\left(\varepsilon_{r1}\mu_{rc} + \varepsilon_{r2} + \frac{\sigma}{j\omega\varepsilon_0}\right)\times$$
$$\left\{\frac{1}{uv}\left[\frac{2}{u^2} - 1 - \left(\frac{J_0(u)}{J_1(u)}\right)^2\right]\left(\frac{H_0(v)}{H_1(v)} - \frac{1}{v}\right) + \left(\frac{J_0(u)}{J_1(u)} - \frac{1}{u}\right)\frac{1}{v^2}\times\right.$$
$$\left.\left[\frac{1}{v}\frac{H_0(v)}{H_1(v)} - \left(\frac{H_0(v)}{H_1(v)}\right)^2 - 1 + \frac{1}{v^2}\right] - \left(\frac{J_0(u)}{J_1(u)} - \frac{1}{u}\right)\frac{1}{v^3}\left(\frac{H_0(v)}{H_1(v)} - \frac{1}{v}\right)\right\} -$$
$$k_0^2\,\mu_{rc}\left(\varepsilon_{r2} + \frac{\sigma}{j\omega\varepsilon_0}\right)\frac{2u}{v^3}\left(\frac{H_0(v)}{H_1(v)} - \frac{1}{v}\right)\left[\frac{2}{v^2} - 1 - \left(\frac{H_0(v)}{H_1(v)}\right)^2\right] -$$
$$2\left(\frac{1}{v^2} - \frac{1}{u^2}\right)\frac{u}{a^2}\left(\frac{1}{v^2} - \frac{1}{u^2}\right) + 2\left(\frac{u^2}{a^2} - \varepsilon_{r1}k_0^2\right)\left(\frac{1}{u^3} - \frac{u}{v^4}\right)\Big] \quad (24)$$

Now, in our practical condition $f \ll f_c$, the attenuation constant α is very large, so we have

$$u_0 = a\sqrt{k_0^2 + \gamma_0^2} \approx a\gamma_0$$

Putting

$$\gamma_0 = \alpha_0 \left(1 + j\frac{\tau}{2a}\right)$$

Using Linder's formula:

$$\alpha_0 = \frac{2\pi}{\lambda_c}\sqrt{1-(\lambda_c/\lambda)^2}$$

Then

$$u_0 = \frac{2\pi}{\lambda_c}\sqrt{1-(\lambda_c/\lambda)^2}\left(a + j\frac{\tau}{2}\right) \quad (25)$$

So that the $F(u_0)$ and $F'(u_0)$ can be obtained by computer analysis. The skin depth of the walls of the guide is given by

$$\tau = \frac{1}{\mathrm{Re}(j\omega^2\mu_c\varepsilon_c)}$$

For the most important mode HE_{11}, the cutoff wavelength may be written in the form

$$f_c = \frac{2\pi a}{1.84118378} = 3.4125791\,a$$

The calculations will be made for the brass guide. It will be assumed that the original data are given by :

u_0 = 4×10^{-7}H/m (permeability of free space),

ε_0 = 8.854187818×10^{-12}F/m (permittivity of free space),

ε_{r1} =1.000537(relative permittivity of air),

μ_{rc} = 0.99998(relative permeability of brass),

σ = 1.6034×10^{7} 1/Ωm (RF conductivity of guide wall),

a = 1.598125×10^{-2}m (inner radius of circular guide),

f = 30MHz (signal frequency).

Now, we calculate the α and β:

ε_{r1} =1, α =0.9999593 dB/mm, β =0.0827073 rad/m

ε_{r1} =1.000537, α =0.9999593 dB/mm, β =0.0827073 rad/m

ε_{r1} =2, α =9999440 dB/mm, β =0.0827096 rad/m

It shows how the attenuation constan α and phase constant β depend on the relative permittivity of medium in the guide. It is seen that the difference between vacuum and air should not be sufficient large to be observed.

The attenuation constant of 30MHz WBCO attenuator standard built in NIM is 0.99995775 dB/mm. As a numerical example, we calculated the attenuation constant of same attenuator, the final result is 0.99995930dB/mm. This value is larger than that mentioned above, the correction will be 1.55 part in 10^6.

V. Using the Surface Impedance Perturbation Method to Derive an Accurate Attenuation Constant Formula: the Huang Equation

Zhi-xun Huang has tried to directly derive the calculation formula of the attenuation constant of the precise cut-off waveguide by using other analytical methods instead of starting from the characteristic equation of the cylindrical structure, and has succeeded. We use the surface impedance theory of the waveguide. Let's start with the Maxwell curl equation, let

$$\varepsilon_c = \varepsilon + \frac{\sigma}{j\omega} = \varepsilon\left(1 + \frac{\sigma}{j\omega\varepsilon}\right) \quad (26)$$

we have

$$\nabla \times \boldsymbol{H}_c = j\omega\varepsilon_c \boldsymbol{E}_c$$

The subscript c stands for conductor. The planar metal surface impedance is defined as

$$Z_s = \sqrt{\frac{\mu_c}{\varepsilon_c}} \quad (27)$$

Plug in the formula (26) and get

$$Z_s = \sqrt{\frac{j\omega\mu_c}{\sigma + j\omega\varepsilon}} \quad (28)$$

There are good conductors

$$Z_s \approx \sqrt{\frac{j\omega\mu_c}{\sigma}} = \sqrt{\frac{\omega\mu_c}{\sigma}}e^{j\pi/4} \quad (29)$$

In 1948, Leontovich deduced the relationship between tangential electric field and tangential magnetic field in metal as follows[16].

$$\boldsymbol{E}_c \approx \sqrt{\frac{\omega\mu_c}{\sigma}} e^{j\pi/4} (\boldsymbol{i}_n \ \boldsymbol{H}_c \quad (30)$$

Where $\boldsymbol{i}_n$ is the unit vector perpendicular to the metal surface; Take the axis to the metal surface as the origin point to the coordinates inside the metal, then it can be written

$$\boldsymbol{E}_c = \boldsymbol{E}_s \ e^{-\gamma_c r}$$

Where subscript s represents surface. So we can derive

$$\boldsymbol{E}_s \approx \sqrt{\frac{\omega\mu_c}{\sigma}} e^{j\pi/4} (\boldsymbol{i}_n \ \boldsymbol{H}_s) \quad (31)$$

Because σ is very large and $\boldsymbol{E}_s$ is small, the magnetic field is mainly in the inner surface of the conductor. It can now be concluded that

$$\boldsymbol{E}_s \approx Z_s (\boldsymbol{i}_n \ \boldsymbol{H}_s) \quad (32)$$

The approximate sign means that the displacement current in the conductor is ignored. The above equation is a concise form of the surface boundary condition of a nonideal conductor, where the surface impedance is the scale coefficient in this vector equation and is scalar. A good conductor is small, and therefore $\boldsymbol{E}_s$ is small.

Leontovich condition describes the relationship between the surface electromagnetic field components of a non-ideal conductor with good conductivity. Despite the small $\boldsymbol{E}_s$ size of a good conductor, the calculations considered are obviously much better than those considered when the conductivity is infinite. It can be seen that Leontovich's condition already implies the concept of surface impedance. The application of Leontovich condition is as follows: ① When electromagnetic wave passes through an object, the complex refractive index is $n = n' + jn''$, requiring n'' »1; ②Let the skin layer be τ, $\tau \ll \lambda/2\pi$;③Let it be the radius of curvature of the surface of the object, $\tau \ll r$ (a surface with little curvature can treat the wave of the adjacent surface as a plane wave).

Metal-walled circular waveguides are not flat metals and are more complicated to deal with. On the inner surface of such a waveguide, since the inner radius is a, the coordinates of any point on the cylinder are (a, ϕ, z), and the tangential vector field of the point is

$$\boldsymbol{E}_s = E_\phi \boldsymbol{i}_\phi + E_z \boldsymbol{i}_z$$

$$\boldsymbol{H}_s = H_\phi \boldsymbol{i}_\phi + H_z \boldsymbol{i}_z$$

Define the impedance dyadic of the circular waveguide as

$$\overset{\leftrightarrow}{\boldsymbol{Z}} = Z_\phi \boldsymbol{i}_\phi \boldsymbol{i}_\phi + Z_z \boldsymbol{i}_z \boldsymbol{i}_z \quad (33)$$

Where Z_ϕ is the circumferential surface impedance; Z_z is the axial surface impedance; $\boldsymbol{i}_\phi \boldsymbol{i}_\phi$ is a dyadic circumferential unit vector; $\boldsymbol{i}_z \boldsymbol{i}_z$ is the dyadic axial unit vector. The electric field vector and the magnetic field vector of the inner surface of the circular waveguide are related by the following formula:

$$\overset{\leftrightarrow}{\boldsymbol{Z}}_s = \boldsymbol{Z} (\boldsymbol{H}_s \ \boldsymbol{i}_r) \quad (34)$$

This is also a way of writing surface boundary conditions, which can be shortened to Leontovich conditions under certain conditions. On account of

$$\boldsymbol{H}_s \times \boldsymbol{i}_r = (H_\phi \boldsymbol{i}_\phi \ H_z \boldsymbol{i}_z) \times \boldsymbol{i}_r = H_z \boldsymbol{i}_\phi - H_\phi \boldsymbol{i}_z$$

Therefore,

$$\overset{\leftrightarrow}{\boldsymbol{Z}} (\boldsymbol{H}_s \ \boldsymbol{i}_r) = \begin{bmatrix} 0 & 0 & 0 \\ 0 & Z_\phi & 0 \\ 0 & 0 & Z_z \end{bmatrix} \begin{bmatrix} H_z \\ -H_\phi \end{bmatrix}$$

The first row and column of the first matrix to the right of the equation are zero, so the remaining factors can be used:

$$\overset{\leftrightarrow}{\boldsymbol{Z}} \cdot (\boldsymbol{H}_s \ \boldsymbol{i}_r) = \begin{bmatrix} Z_\phi & 0 \\ 0 & Z_z \end{bmatrix} \begin{bmatrix} H_z \\ -H_\phi \end{bmatrix} = Z_\phi H_z \boldsymbol{i}_\phi - Z_z H_\phi \boldsymbol{i}_z$$

hence

$$\boldsymbol{E}_s = Z_\phi H_z \boldsymbol{i}_\phi - Z_z H_\phi \boldsymbol{i}_z \quad (35)$$

Thus writable

$$E_\phi = Z_\phi H_z$$
$$E_z = -Z_z H_\phi$$

hence

$$Z_\phi = \left. \frac{E_\phi}{H_z} \right|_{r=a} \quad (36)$$

$$Z_z = -\left. \frac{E_z}{H_\phi} \right|_{r=a} \quad (37)$$

Where Z_ϕ is the circumferential surface impedance of the inner wall of the circular waveguide; Z_z Is the axial surface impedance of the inner wall of the circular waveguide, which is generally mode dependent. For certain patterns, they may not differ much. In short, for circular waveguide and cylindrical resonator, the definition of surface impedance must be expanded to two. Since both are complex:

$$Z_\phi = R_\phi + jX_\phi \tag{38}$$

$$Z_z = R_z + jX_z \tag{39}$$

So there are four real quantities that need to be determined. If the two impedances are normalized to the vacuum wave impedance (=376.62), the symbol is $Z_{00}\,\Omega$

$$\tilde{Z}_\phi = \frac{Z_\phi}{Z_{00}} \tag{40}$$

$$\tilde{Z}_z = \frac{Z_z}{Z_{00}} \tag{41}$$

The above statement shows that it is necessary to distinguish between the two surface impedances for non-planar metals. The ambiguity of the surface impedance reflects the non-unity of the field relation of the surface. In the simple theory, the difference between the two kinds of surface impedance in the inner wall of the circular waveguide is ignored

$$\tilde{Z}_\phi \approx \tilde{Z}_z \tag{42}$$

In fact, the normalized surface impedance of the flat metal Z_f (i.e. Z_s) is taken instead of the two. This approach loses its rigor, but simplifies the derivation considerably.

The surface impedance analysis of metal-walled waveguides must lead to the theory of coupled modes. Given the surface impedance is equivalent to given the tangential field. Strictly speaking, as long as the loss of the waveguide wall is considered, there is no separate wave or magnetic wave in the circular waveguide except H_{0n} wave and E_{0n} wave, because the surface impedance makes the wave and magnetic wave coupling. The strict theory when the coupling is not ignored is the coupled wave theory. The solution to the problem of wave propagation in an ideal waveguide with a given shape is known, and the mode is assumed M_0 .When the wall of the waveguide is a non-ideal conductor, the field in the waveguide is given by:

$$\psi = M_0 + \sum_{i=1}^{\infty} C_\tau M_i \tag{43}$$

In the formula M_i is the orthogonal module. For non-ideal waveguides, there is no longer a pure, single normal mode. As indicated in the above equation, a new factor is introduced into the orthogonal normalizing function set - the self-coupling coefficient C of the mixed mode. It is no longer possible to classify TM and TE modes in the waveguide. The cause of C can be described from different angles, one of which is the surface impedance. To get a better sense of this, consider the E_{mn} (EH ^{mn} , to be precise) mode groups in circular waveguides. Let the longitudinal electric field component in the ideal waveguide be

$$E_z = J_m(hr)\cos m\phi$$

Let's just write down the time phase factor of the field. For a non-ideal conductive wall waveguide, the surface impedance will couple a certain amount of H-wave energy, resulting in

$$H_z = C_i\, J_m(hr)\sin m\phi$$

In the case of ideal waveguide. H_ϕ is

$$H_\phi^E = -j\frac{k_0}{h_0}\, J_m'(hr)\cos m\phi$$

The coupling is caused by H waves

$$H_\phi^H = C_i\left[-j\frac{\beta_0 m}{h_0^2 r}\, J_m(hr)\cos m\phi\right]$$

hence

$$H_\phi\big|_{r=a} = \left[-j\frac{k_0}{h_0}\, J_m'(ha) - jC_i\frac{\beta_0 m}{h_0^2 a} J_m(ha)\right]\cos m\phi$$

On the other hand

$$E_z\big|_{r=a} = J_m(ha)\cos m\phi$$

Combine the above types can be obtained

$$\tilde{Z}_z = \frac{J_m(ha)}{-j\frac{k_0}{h_0} J_m'(ha) + jC_i\frac{\beta_0 m}{h_0^2 a} J_m(ha)} \tag{44}$$

Expand the pair by Taylor series, and take the first term, and get $J_m(ha)\ h_0 a$

$$J_m(ha) \approx a\,(\delta h)\, J_m'(h_0 a)$$

Plug in the above formula and get

$$\tilde{Z}_z \approx \frac{a\delta h}{j\frac{k_0}{h_0} + jC_i\frac{\beta_0 m}{h_0^2 a}\delta h} \tag{45}$$

If we ignore the first term in the right denominator, we get

$$\tilde{Z}_z \approx \frac{h_0^2 a}{jC_i\beta_0 m} \tag{46}$$

That is

$$C_i \approx \frac{h_0^2 a}{\beta_0 m}\frac{1}{j\tilde{Z}_z} \tag{47}$$

make

$$C_\tau = \frac{1}{C_i} \tag{48}$$

we have

$$C_\tau \approx \frac{\beta_0 m}{h_0^2 a}\, j\tilde{Z}_z \tag{49}$$

Because Z_z is small, C_τ is also a small amount; And when $Z_z \to 0$, then $C_\tau \to 0$.This means that all E waves in the circular waveguide are stable. In addition, when $m=0$, $C_\tau=0$.Therefore, the purity of E_{0n} mode is not impaired by Z_z existence.

In a similar way, we can lead the circumferential surface impedance of the exit mode E_{mn}

$$\tilde{Z}_\phi = \frac{j\frac{\beta_0 m}{h_0^2 a}J_m(ha) + jC_i\frac{k_0}{h_0}J'_m(ha)}{C_i J_m(ha)} \tag{50}$$

In addition to the approximation relation of Bessel function, $J'_m(\mathrm{ha}) \approx J'_m(\mathrm{h_0 a})$ is taken, so it is obtained

$$\tilde{Z}_\phi = \frac{\beta_0 m}{h_0^2 a}\frac{1}{C_i} + j\frac{k_0}{h_0}\frac{1}{a\cdot\delta h} \tag{51}$$

If we ignore the second term on the right, we get

$$C_i \approx \frac{\beta_0 m}{h_0^2 a}\frac{1}{\tilde{Z}_\phi} \tag{52}$$

Thus obtained

$$C_\tau = \frac{h_0^2 a}{\beta_0 m}(j\tilde{Z}_\phi) \tag{53}$$

So Z_ϕ to 0, $C_\tau \to 0$.

The case of $\mathrm{H_{mn}}$ (strictly HE^{mn}) pattern groups is discussed below. Let the longitudinal magnetic field component in the ideal waveguide be

$H_z = J_m(hr)\cos m\phi$

For non-ideal waveguides, the inner wall surface impedance will be coupled to a certain wave energy, resulting in E

$$H_z = J_m(hr)\cos m\phi$$

Follow the previous way to extrapolate

$$\tilde{Z}_\phi = j\frac{k_0}{h_0}\frac{J'_m(ha)}{J_m(ha)} - jC_i\frac{\beta_0 m}{h_0^2 a} \tag{54}$$

$$\tilde{Z}_z = \frac{C_i J_m(ha)}{-j\frac{\beta_0 m}{h_0^2 a}J_m(ha) + jC_i\frac{k_0}{h_0}J'_m(ha)} \tag{55}$$

The characteristic equation can also be derived from the surface impedance analysis. For example, for the $\mathrm{H_{mn}}$ (strictly HE^{mn}) pattern group, from the formula (54) and the formula (55), make them equal, and specify ($\gamma_0 = j\beta_0$), thus it can be deduced:

$$\frac{k_0^2}{h_0^2}\left[\frac{J'_m(ha)}{J_m(ha)}\right]^2 + j\frac{k_0}{h_0}\left(\tilde{Z}_\phi + \frac{1}{\tilde{Z}_z}\right)\left[\frac{J'_m(ha)}{J_m(ha)}\right] + \left[\left(\frac{m\gamma_0}{h_0^2 a}\right)^2 - \frac{\tilde{Z}_\phi}{\tilde{Z}_z}\right] = 0 \tag{56}$$

The above equation is called the surface impedance characteristic equation in order to distinguish it from the characteristic equation established by the field matching method. make

$$\frac{k_0}{h_0}\frac{J'_m(ha)}{J_m(ha)} = y \tag{57}$$

we have

$$y^2+j\left(\tilde{Z}_\phi+\frac{1}{\tilde{Z}_z}\right)y+\left[\left(\frac{m\gamma_0}{h_0^2 a}\right)^2-\frac{\tilde{Z}_\phi}{\tilde{Z}_z}\right]=0 \qquad (58)$$

So it can be solved

$$y=-\frac{j}{2}\left(\tilde{Z}_\phi+\frac{1}{\tilde{Z}_z}\right)\pm\frac{1}{2}\sqrt{-\left(\tilde{Z}_\phi+\frac{1}{\tilde{Z}_z}\right)^2-4\left[\left(\frac{m\gamma_0}{h_0^2 a}\right)^2-\frac{\tilde{Z}_\phi}{\tilde{Z}_z}\right]}=0 \qquad (59)$$

Take a plus sign (HE ^{mn} pattern group) or a minus sign (EH ^{mn} pattern group). Let $\tilde{Z}_\phi \ll 1$, approximate equation for HE ^{mn} can be obtained:

$$\frac{k_0}{h_0}\frac{J'_m(ha)}{J_m(ha)}\approx -j\tilde{Z}_\phi+j\frac{m\gamma_0}{h_0^2 a}\tilde{Z}_z \qquad (60)$$

The above formula can be solved by perturbation method.

Now let's see how we derive the attenuation constant. When propagating with an ideal conductive wall, the field component is proportional to $e^{j\omega t-\gamma_0 z}$, $\gamma_0 = \sqrt{h_0^2-k_0^2}$ .When the waveguide wall is not ideally conductive, the field component is proportional to $e^{j\omega t-\gamma z}$, $\gamma = \sqrt{h_0^2-k_0^2}$ .If the non-ideal waveguide is regarded as a perturbation of the ideal waveguide, it can be proved

$$\gamma=\sqrt{\gamma_0^2+2h_0\delta h+(\delta h)^2}$$

When $\lambda > \lambda_c$, $\gamma_0=\alpha_0$, therefore

$$\gamma=\sqrt{\alpha_0^2+2h_0\delta h+(\delta h)^2}$$

So the problem is finding δh, it is a complex quantity, $\delta h = h_1 + jh_2$. Thus it can be proved that

$$\alpha=\mathrm{Re}=\gamma\frac{2\pi}{\lambda_c}\sqrt{\frac{1}{2}\left(\frac{\lambda_c}{2\pi}\right)^2 A+\frac{1}{2}\sqrt{\left(\frac{\lambda_c}{2\pi}\right)^4(A^2+B^2)}} \qquad (61)$$

$$A=\alpha_0^2+2h_0h_1+h_1^2-h_2^2$$

$$B=2h_2(h_0+h_1)$$

In the perturbation method, δh is a function of the surface impedance and the waveguide geometry. In order to derive the H_{11} wave, the derivation is a little more complicated. The normalized value of the wave surface impedance is given. The above formula can be expressed as the binary simultaneous equations of, and a new equation is obtained after elimination τ_s :

$$\left[\frac{k_0}{h_0}\frac{J'_m(ha)}{J_m(ha)}\right]^2+j\left[\frac{k_0}{h_0}\frac{J'_m(ha)}{J_m(ha)}\right]\left(Z_\phi+\frac{1}{Z_z}\right)+\left[\left(\frac{\beta_0 m}{h_0^2 a}\right)^2-\frac{Z_\phi}{Z_z}\right]=0 \qquad (62)$$

we have

$$\frac{k_0}{h_0}\frac{J'_m(ha)}{J_m(ha)}=-\frac{j}{2}\left(Z_\phi+\frac{1}{Z_z}\right)\left[1-\sqrt{1+\left(\frac{2}{Z_\phi+\frac{1}{Z_z}}\right)^2\left(\frac{\beta_0 m}{h_0^2 a}-\frac{Z_\phi}{Z_z}\right)}\right] \qquad (63)$$

By using function expansion, it can be obtained approximately

$$\frac{J'_m(ha)}{J_m(ha)} = \frac{h_0}{k_0}\left\{\frac{-jZ_\phi - \left(\frac{\beta_0 m}{h_0^2 a}\right)^2 jZ_z}{1+Z_\phi Z_z}\right\}\left\{1+Z_z\frac{Z_\phi - \left(\frac{\beta_0 m}{h_0^2 a}\right)^2 Z_z}{(1+Z_\phi Z_z)^2}\right\}$$

Finally get

$$\alpha = \frac{2\pi}{\lambda_c}\sqrt{\frac{1}{2}(M-\mathrm{J})+\frac{1}{2}\sqrt{(M-\mathrm{J})^2+\mathrm{J}^2\left(1-\mathrm{J}+\frac{\mathrm{J}^2}{4}\right)}} \tag{64}$$

Where J represents the influence of the finite conductivity (or skin depth) of the waveguide material. If the term J^3、 J^4, is ignored, there is

$$\alpha = \frac{2\pi}{\lambda_c}\sqrt{\frac{1}{2}(M-\mathrm{J})+\frac{1}{2}\sqrt{(M-\mathrm{J})^2+\mathrm{J}^2}} \tag{65}$$

it is

$$\alpha = \frac{2\pi}{\lambda_c}\sqrt{\frac{1}{2}\left[1-\left(\frac{\lambda_c}{\lambda}\right)^2-\mathrm{J}\right]+\frac{1}{2}\sqrt{\left[1-\left(\frac{\lambda_c}{\lambda}\right)^2-\mathrm{J}\right]^2+\mathrm{J}^2}} \tag{66}$$

Where J is related to the wave pattern:

$$\begin{cases} \mathrm{J}_{01} = \frac{\mu_r\tau}{a}\left(\frac{\lambda_c}{\lambda}\right)^{2\;\;2} \\ \mathrm{J}_{11} = \frac{g\tau}{a} \\ g = (1+0.4186]\,\mu_r\left(\frac{\lambda_c}{\lambda}\right)^2 \end{cases}$$

Formula (66) is the main result of this section. It's called Huang's equation. In the derivation process, Leontovich condition is assumed to be true, which naturally has errors; Bessel function operation and final formula shape sorting, there are also errors. However, the formula (66) is more accurate than the formulas listed in foreign literature, and its accuracy can reach 10^{-7}.

In formula (66), if the term J^2 is zero, then

$$\alpha = \frac{2\pi}{\lambda_c}\sqrt{1-\left(\frac{\lambda_c}{\lambda}\right)^2-\mathrm{J}} \tag{67}$$

This is Rauskolb's formula, where J= $g\frac{\tau}{a}$. If we take g =1 and J= g/a, we get Grantham and Freeman's formula

$$\alpha_{11} = \frac{2\pi}{\lambda_c}\sqrt{1-\left(\frac{\lambda_c}{\lambda}\right)^2-\frac{\tau}{a}} \tag{68}$$

Therefore, we can see that the formulas in this paper can summarize the previous formulas.

In summary, for HE_{11} modes in a metal-walled circular waveguide, Huanng's equation is:

$$\alpha_{11}=\frac{2\pi}{\lambda_0}\sqrt{\frac{1}{2}\left[1-\left(\frac{\lambda_c}{\lambda}\right)^2-J_{11}\right]+\frac{1}{2}\sqrt{\left[1-\left(\frac{\lambda_c}{\lambda}\right)^2\varepsilon_r-J_{11}\right]^2+J_{11}^2}} \tag{69}$$

$$J_{11}=\frac{g\tau}{a}=\mu_{rc}\left[1+\frac{1}{k_{11}^2-1}\left(\frac{\lambda_{c\varepsilon}}{\lambda}\right)^2\right]\frac{\tau}{a} \tag{70}$$

And $\lambda_c=\frac{2\pi a}{k_{11}}$, where $k_{11}=1.84118378$; The formula α_{11} derived by me is the most accurate of its kind, and can fully meet the needs of establishing high-precision national attenuation standards.

As mentioned earlier, for microwave attenuation measurement, between 1950 and 1980, the accuracy of the cutoff attenuation standard was increased from 5×10^{-3} to close to 5×10^{-5}, because it is basically a calculation standard, and the attenuation constant is mainly determined by the basic unit (length and time).In the case of the increasing level of machining and surface treatment technology, it is required to theoretically derive the attenuation constant formula with higher precision. This gives rise to the so-called Huang equation.

VI. General Theory of Metal-Walled Circular Waveguides Lined with Dielectric Layers: Huang Zeng Equation

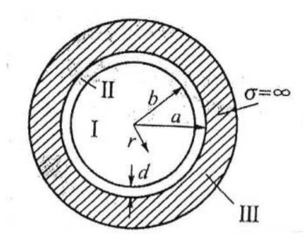

Figure 3: Metallic Wall Circular Waveguide Lined with Dielectric Layer

In 1943, H. Buchholz[18] published the paper "Circular waveguides filled with dielectric matter", which first put forward the problem of the influence of dielectric filled waveguides. In 1950, H. Wachowski and R. Beam[19] published an article entitled "Dielectric rod waveguide with Shielding". In the above paper, the characteristic equation (assuming the conductivity of the waveguide material $\sigma=\infty$) when the inner wall of the circular waveguide is artificially added with a uniform dielectric layer (FIG. 3) is derived, which is called the BWB equation. In 1957, Unger[20] proposed a perturbed approximate solution to the BWB equation."These works are called "artificial dielectric layer circular waveguide theory". In 1949, J. Brown[21] published a paper entitled "Correction of attenuation constant of piston type attenuator", which analyzed the normal mode of circular waveguides with uniform oxide layer on the inner wall, and also assumed that the conductivity of the waveguide material $\sigma=\infty$;The eigen equation derived under this assumption is called Brown equation, and its shape is different from that of BWB equation. In 1993, Zhi-xun Huang and Cheng Zeng[17] published the most general formula, called the Huang Zeng equation.

In early applications, the lined waveguide is mainly used as a long-distance transmission tool in the micro wave and infrared bands, that is, the application of the lined uniform dielectric layer to obtain a small attenuation of the main low-order mode. Later, in the study of mode suppression and how to reduce the radar reflection cross section (RCS), the opposite application of low-loss long-distance transmission has appeared, that is, the use of lining the medium layer to obtain a large attenuation of the main low-order mode; The theoretical basis is that since the internal radiation of the low-order mode in the terminal short-circuit waveguide is the main contribution to RCS, the RCS can be greatly reduced as long as the lined dielectric layer can effectively inhibit the main low-order mode.

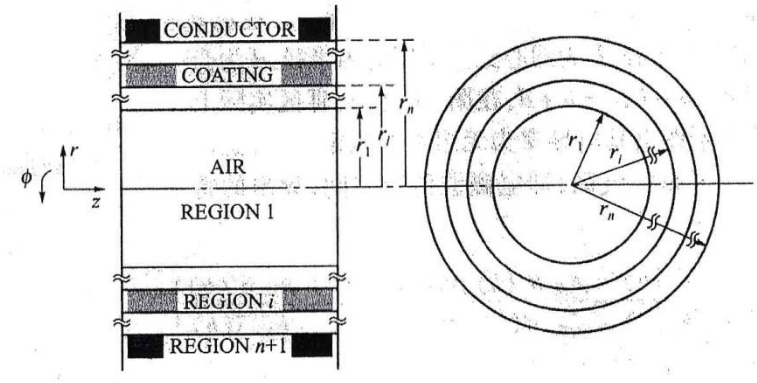

Figure 4: Multi-Layer Dielectric Lined Metal Wall Circular Waveguide

When assuming the physical model, Zhi-xun Huang and Cheng Zeng[14] stipulate that the dielectric lining of the metal-walled circular waveguide can be multi-layered, that is, multilayered coated circular waveguide, as shown in FIG. 4.A difficult mathematical analysis results in the following characteristic equation:

$$k_0^2\left(\frac{\varepsilon_{r1}}{h_1}\frac{J'_m(u)}{J_m(u)}-\frac{\varepsilon_{r2}}{h_2}\frac{F'_e(q)}{F_e(q)}\right)\left(\frac{\mu_{r1}}{h_1}\frac{J'_m(u)}{J_m(u)}-\frac{\mu_{r2}}{h_2}\frac{F'_h(q)}{F_h(q)}\right) \tag{71}$$

$$=\eta_b^2+\left(R_e(q)R_h(q)\eta_a^2-\frac{1}{k_0^2}P_2^2(q)\eta_a^2\eta_b^2+\frac{8\mu_{r2}\varepsilon_{r2}\eta_a\eta_b}{\pi^2 abh_2^4}\right)\frac{1}{R_e(q)R_h(q)}$$

$$\eta_b=\eta_1,\quad \eta_a=\eta_2$$

$$u=h_1b,\quad q=h_2b,\quad v=h_3a$$

$$F_e(q)=\frac{\varepsilon_{r2}}{h_2}Q_2(q)-\frac{\varepsilon_{r3}}{h_3}\frac{H'^{(2)}_m(v)}{H^{(2)}_m(v)}P_2(q)(72) \tag{72}$$

$$R_e(q)=\frac{\varepsilon_{r2}}{h_2}P'_2(q)-\frac{\varepsilon_{r3}}{h_3}\frac{H'^{(2)}_m(v)}{H^{(2)}_m(v)}P_2(q)(73) \tag{73}$$

among

$$P_i(h_ir_{i-1})=J_m(h_ir_{i-1})\ N_m(h_ir_i)-J_m(h_ir_i)\ N_m(h_ir_{i-1}) \tag{74}$$

$$Q_i(h_ir_{i-1})=J_m(h_ir_{i-1})\ N'_m(h_ir_i)-J'_m(h_ir_i)\ N_m(h_ir_{i-1}) \tag{75}$$

$$P'_i(h_ir_{i-1})=J'_m(h_ir_{i-1})\ N_m(h_ir_i)-J_m(h_ir_i)\ N'_m(h_ir_{i-1}) \tag{76}$$

$$Q'_i(h_ir_{i-1})=J'_m(h_ir_{i-1})\ N'_m(h_ir_i)-J'_m(h_ir_i)\ N'_m(h_ir_{i-1}) \tag{77}$$

Our new equation can be used to deal with the situation of artificially adding dielectric layer to the inner wall of the circular waveguide, and to analyze the effect of forming oxide layer in the precision cutoff attenuator.

VII. Calculation of the Influence of Oxide Layer on the Inner Surface of Circular Waveguide[6]

Microwave attenuation measurement technology mainly uses IF instead of the method, that is, the standard cut-off waveguide attenuator as the core, to form a comparable standard at IF (30MHz). If its accuracy reaches 5×10^{-5}, the overall microwave attenuation measurement accuracy can reach $10^{-3}\sim10^{-4}$. In short, the circular cut-off waveguide is the heart of the cut-off attenuation standard, and its processing conditions meet the requirements of high precision and low roughness to ensure that the electrical index is qualified. The entire attenuation standard should be placed in a laboratory with constant temperature and humidity. Taking the standard of the National Institute of Metrology (NIM) as an example, the accuracy is dA $=\pm(5\times10^{-5}+0.0002)$dB; This means that i.e. $\frac{d\gamma_{11}}{\gamma_{11}}$ $=\pm5\times10^{-5}$, $\alpha\cdot$dl =0.0002dB.Other indicators are: measuring range 0~120dB, resolution ±0.0001dB (0.1mdB). Accordingly, two examples of accuracy data can be calculated: ±0.0007dB/10dB(i.e., $\pm7\times10^{-5}$); ±0.0052dB/100dB(i.e. $\pm5.2\times10^{-5}$). The high resolution length measurement guarantees a reduction of dl, which is due to the use of laser length measurement technology.

Below the national standards, there are so-called secondary standards, which are distributed in various industrial sectors and assume the task of regional standards. The fixed-point same frequency comparison method (based on the medium frequency substitution method) is adopted, which is based on the cut-off attenuator as the core standard component. For example, the domestic T0-7 attenuation standard measuring instrument, its total index is: frequency 1GHz~12.5GHz(fixed intermediate frequency 30MHz after conversion), attenuation range 100dB, attenuation measurement accuracy 5×10^{-4}[20]. Specifically for the standard cutoff attenuator, the circular cutoff waveguide is made of H59 brass, the diameter is 2a =31.962mm, the diameter machining accuracy is ±5μm, and the internal surface roughness Ra is 0.2μm.Corresponding attenuation constant α =1dB/mm; The length measurement technique used is raster, not laser, but also achieves high resolution - reading resolution of 0.002dB(2mdB).

For the cut-off waveguide attenuators with accuracy up to 5×10^{-5}, the oxidation layer on the inner wall of the guided wall is a problem that needs to be considered. The thickness of this oxide layer is small, but it is a factor in error. As mentioned earlier, the relevant equations are the starting point for our analysis. For example, Brown's equation assumes that the oxide film is a pure medium and its dielectric constant is ε_0 ~∞. Brown's[21] approximate analysis shows that the error of the propagation constant for H_{11} mode in the cutoff region is

$$\frac{d\gamma_{11}}{\gamma_{11}}=(1\sim1.8)\frac{d}{a} \tag{78}$$

Where a is the inner diameter of circular waveguide; d is the oxide film thickness. Therefore, Brown believes that if the attenuation constant error is required to be $<1\times10^{-5}$, the oxide film thickness is required to be d $<10^{-4}$mm(0.1μm). These can be called "circular cut-off waveguide theories for naturally occurring thick layers of oxide film".

The characteristics of this section are as follows: ① The characteristic equation of the metal-walled circular waveguide with dielectric layer is discussed;②Brown equation was derived from Buchholz-Wachowski-Beam equation (BWB equation);③The perturbation solution (H_{mn} mode) of Brown equation is discussed. ④The case of H-mode below the truncated frequency is further obtained;$_{11}$ ⑤The reasons for the inconsistency between the two sets of theoretical results are analyzed. ⑥The H_{11}-mode cut-off waveguide is numerically calculated, the influence of oxide layer is numerically analyzed, and the limit of tolerable oxide layer thickness is obtained.

If we follow Figure 3 for discussion, we have $a=b+d$, $\rho=b/a<1$, $x_1=h_1a$, $x_2=$, h_2a $\rho x_1=h_1b$, $\rho x_2=h_2b$. Here, is the radial propagation constant:

$$h_1^2=+k_0^2\ \gamma^2$$
$$h_2^2=k_2^2+\gamma^2\approx\varepsilon_r k_0^2+\gamma^2 \tag{79}$$

Where γ is the axial propagation constant: k_2 is a parameter that characterizes the performance of the medium is:

$$k_2=\sqrt{\omega^2\varepsilon_2\mu_2-j\omega\mu_2\sigma_2}$$

Where ε_2 is the dielectric constant of the dielectric layer μ_2 is the permeability of the dielectric layer, $\mu_2=\mu_r\mu_0$ σ_2 is the conductivity of the dielectric layer. For the actual medium, $\sigma_2\approx0$, so there are

$$k_2=\omega\sqrt{\varepsilon_2\mu_2}=k_0\sqrt{\varepsilon_r\mu_r}$$

take the medium $\mu_r=1$, so get

$$k_2\approx\sqrt{\varepsilon_r k_0} \tag{80}$$

Unger gives the form of the BWB equation as: [12]

$$m^2\left[\frac{1}{x_1^2}-\frac{1}{x_2^2}\right]^2-\rho^2\frac{x_2^2-x_1^2}{x_2^2-\varepsilon_r x_1^2}\left[\frac{1}{x_1}\frac{J_m'(\rho x_1)}{J_m(\rho x_1)}+\frac{\varepsilon_r W_m(\rho x_2)}{\rho x_2^2 U_m(\rho x_2)}\right]\cdot\left[\frac{1}{x_1}\frac{J_m'(\rho x_1)}{J_m(\rho x_1)}+\frac{1}{\rho x_2^2}\frac{V_m(\rho x_2)}{Z_m(\rho x_2)}\right]=0 \quad (81)$$

$$U_m(\rho x_2)=J_m(\rho x_2)\,N_m(x_2)-N_m(\rho x_2)J_m(x_2)$$

$$V_m(\rho x_2)=\rho x_2^2\,[\,J_m'(\rho x_2)\,N_m'(x_2)-N_m'(\rho x_2)J_m'(x_2)\,]$$

$$W_m(\rho x_2)=\rho x_2^2\,[\,J_m(x_2)\,N_m'(\rho x_2)-J_m'(\rho x_2)\,N_m(x_2)\,]$$

$$Z_m(\rho x_2)=x_2\,[\,J_m'(x_2)\,N_m(\rho x_2)-J_m(\rho x_2)N_m'(x_2)\,]$$

Now we want to transform the formula, for example

$$\rho^2\frac{x_2^2-x_1^2}{x_2^2-\varepsilon_r x_1^2}=\rho^2\frac{h_2^2-h_1^2}{h_2^2-\varepsilon_r h_1^2}=\rho^2\frac{(\varepsilon_r-1)k_0^2}{(1-\varepsilon_r)\gamma^2}=\rho^2\frac{k_0^2}{-\gamma^2}=\frac{k_0^2 b^2}{k_z^2 a^2}$$

again, let's deal with the following items:

$$\frac{\varepsilon_r}{\rho x_2^2}\frac{W_m(\rho x_2)}{U_m(\rho x_2)}=\frac{\varepsilon_r}{x_2}\frac{J_m(x_2)N_m'(\rho x_2)-J_m'(\rho x_2)N_m(x_2)}{J_m(\rho x_2)N_m(x_2)-N_m(\rho x_2)J_m(x_2)}-\frac{\varepsilon_r}{h_2 a}\frac{J_m'(h_2 b)N_m(h_2 a)-J_m(h_2 a)N_m'(h_2 b)}{J_m(h_2 b)N_m(h_2 a)-J_m(h_2 a)N_m(h_2 b)}$$

It is

$$P_m(h_2 r)=J_m(h_2 r)\;N_m(h_2 a)-J_m(h_2 a)\;N_m(h_2 r)$$

where r represents radial coordinates. Then there is

$$P_m(h_2 b)=J_m(h_2 b)\;N_m(h_2 a)-J_m(h_2 a)\;N_m(h_2 b)$$

$$P_m'(h_2 b)=J_m'(h_2 b)\;N_m(h_2 a)-J_m(h_2 a)\;N_m'(h_2 b)$$

Therefore available

$$\frac{\varepsilon_r}{\rho x_2^2}\frac{W_m(\rho x_2)}{U_m(\rho x_2)}=-\frac{\varepsilon_r}{h_2 a}\frac{P_m'(h_2 b)}{P_m(h_2 b)}$$

It is

$$Q_m(h_2 r)=J_m(h_2 r)\;N_m'(h_2 a)-J_m'(h_2 a)\;N_m(h_2 r)$$

the same can be proved:

$$\frac{1}{\rho x_2^2}\frac{V_m(\rho x_2)}{Z_m(\rho x_2)}=-\frac{1}{h_2 a}\frac{Q_m'(h_2 b)}{Q_m(h_2 b)}$$

After this kind of sorting, the BWB equation becomes

$$\left[\frac{1}{h_1}\frac{J_m'(h_1 b)}{J_m(h_1 b)}-\frac{\varepsilon_r}{h_2}\frac{P_m'(h_2 b)}{P_m(h_2 b)}\right]\cdot\left[\frac{1}{h_1}\frac{J_m'(h_1 b)}{J_m(h_1 b)}-\frac{\mu_r}{h_2}\frac{Q_m'(h_2 b)}{Q_m(h_2 b)}\right]=\frac{m^2}{b^2}\frac{k_z^2}{k_0^2}\left[\frac{1}{h_1^2}-\frac{1}{h_2^2}\right]^2 \quad (82)$$

the above formula is strict when the waveguide material is ideally conductive ($\sigma=\infty$).

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We tried to derive the Brown equation from the BWB equation, and now we have

$$h_1 a = h_1 b + h_1 d$$
$$h_2 a = h_2 b + h_2 d$$

Suppose $d \ll b$, cylindrical functions can be expanded by variables. $h_1 b$ and $h_2 b$. The Taylor series shows:

$$f(x_0+\Delta)= f(x_0)+ f'(x_0)\Delta+\frac{1}{2!} f'(x_0)\Delta^2+...$$

linear expansion is preferable if Δ small:

$$f(x_0+\Delta)= f(x_0)+ f'(x_0)\Delta$$

Therefore there may be

$$J_m(h_2 a) = J_m(h_2 b) + h_2 d\ J'_m(h_2 b)$$

$$J'_m(h_2 a) = J'_m(h_2 b) + h_2 d\ J''_m(h_2 b)$$

The second type of Bessel function also has a similar relationship, so it can be proved that:

$$\frac{P'_m(h_2 b)}{P_m(h_2 b)} \approx -\frac{1}{h_2 d} \tag{83}$$

Now we need to utilize the Wronsky relation of the integer order Bessel function:

$$J_m(x)N'_m(x) - J'_m(x)N_m(x) = J_{m+1}(x)N_m(x) - J_m(x)N_{m+1}(x) = J_m(x)N_{m-1}(x) - J_{m-1}(x)N_m(x) = \frac{2}{\pi x}$$

and

$$J_m(x)N''_m(x) - J''_m(x)N_m(x) = -\frac{2}{\pi x^2}$$

$$J'_m(x)N''_m(x) - J''_m(x)N'_m(x) = \frac{2}{\pi x}\left(1-\frac{m^2}{x^2}\right)$$

It can therefore be proved that:

$$\frac{Q'_m(h_2 b)}{Q_m(h_2 b)} \approx h_2 d \left(1-\frac{m^2}{h_2^2 b^2}\right) \tag{84}$$

The following symbols are also introduced:

$$u = h_1 b = b\sqrt{k_0^2+\gamma^2} \tag{85}$$

$$q = h_2 b = b\sqrt{k_2^2+\gamma^2} \tag{86}$$

and consider the following relationship:

$$k_z^2 = -\gamma^2$$

This style (82) can be arranged as

$$-\left[k_0^2\frac{J'_m(u)}{J_m(u)}+\frac{buk_2^2}{\mu_1 dq^2}\right]\cdot\left[\frac{J'_m(u)}{J_m(u)}-\frac{\mu_r ud}{b}\left(1-\frac{m^2}{q^2}\right)\right]=m^2\gamma^2u^2\left(\frac{1}{u^2}-\frac{1}{q^2}\right)^2$$

can also be written as

$$-\left[\frac{k_0^2}{\mu_0}\frac{J'_m(u)}{J_m(u)}+\frac{buk_2^2}{dq^2\mu_2}\right]\cdot\left[\mu_0\frac{J'_m(u)}{J_m(u)}-\frac{\mu_r ud}{b}\left(1-\frac{m^2}{q^2}\right)\right]=\frac{m^2\gamma^2}{u^2}\left[1-\frac{u^2}{q^2}\right]^2 \quad (87)$$

this is Brown's characteristic equation. The error only comes from ignoring small quantities of higher order during linear expansion, which requires very little (the oxide film is very thin).Brown's equation is correct, but it cannot be used for film thickness.

Equation (87) can also be written as

$$\left[\frac{k_0^2}{\mu_0}\frac{J'_m(u)}{J_m(u)}+\frac{buk_2^2}{dq^2\mu_2}\right]\cdot\left[\mu_0\frac{J'_m(u)}{J_m(u)}-\frac{\mu_r ud}{b}\left(1-\frac{m^2}{q^2}\right)\right]=\frac{m^2k_z^2}{u^2}\left[1-\frac{u^2}{q^2}\right]^2 \quad (88)$$

Now the perturbation solution of Brown's equation is required; Multiply the left side of the formula and expand it, multiply the left and right side by d/b, omit the $(d/b)^2$ term, and set $\delta=d/b$ to obtain the approximate equation:

$$k_2^2\frac{\mu_0}{\mu_2}\left[\frac{J'_m(u)}{J_m(u)}\right]+k_0^2\delta\left[\frac{J'_m(u)}{J_m(u)}\right]^2-k_2^2\frac{u^2}{q^2}\delta\left(1-\frac{m^2}{q^2}\right)-m^2k_z^2u^2\delta\left(\frac{1}{u^2}-\frac{1}{q^2}\right)^2=0 \quad (89)$$

It is actually

$$f(u)=0 \quad (90)$$

now we're going to approximate it. For the sake of comparison with Brown's original text, using one of his symbols, it is actually:

$$h_{mn}=j\gamma_{mn} \quad (91)$$

hence

$$h_{mn}^2=k_0^2-\frac{u_{mn}^2}{b^2} \quad (92)$$

perturbation is for $\delta=0$ (no oxide film present).Case of $\delta=0$:

$$J'_m(u)=0$$

let the root be

$$u_{mn}=k_{mn}$$

when a thin oxide film is present, perturbations are generated:

$$u_{mn}=+k_{mn}\,du_{mn} \quad (93)$$

now we're going to do the Newton-Raphson process, which is

$$du_{mn}\approx-\frac{f(k_{mn})}{f'(k_{mn})} \quad (94)$$

However, it can be proved that:

$$\frac{\mathrm{d}h_{mn}}{h_{mn}}=-\frac{u_{mn}}{b^2h_{mn}^2}\,\mathrm{d}u_{mn} \tag{95}$$

and

$$\frac{\mathrm{d}h_{mn}}{h_{mn}}=\frac{\mathrm{d}\gamma_{mn}}{\gamma_{mn}} \tag{96}$$

So when $u_{mn}=k_{mn}$,

$$\frac{\mathrm{d}\gamma_{mn}}{\gamma_{mn}}=-\frac{k_{mn}^2}{b^2h_{mn}^2}\,\mathrm{d}u_{mn}=\frac{k_{mn}}{b^2h_{mn}^2}\,\frac{f(k_{mn})}{f'(k_{mn})} \tag{97}$$

So let's figure $\mathrm{d}u_{mn}$ out first. From formula (89), when $\mathrm{J}'_m(u)=0$,

$$f(u)=-k_2^2\frac{u^2}{q^2}\left(1-\frac{m^2}{q^2}\right)\delta-m^2k_z^2u^2\left[\frac{1}{u^2}-\frac{1}{q^2}\right]^2\delta$$

Thus obtained

$$f(k_{mn})=-k_2^2\frac{k_{mn}^2}{q_{mn}^2}\left(1-\frac{m^2}{q_{mn}^2}\right)\delta-\left(k_2^2\frac{\delta}{q_{mn}^2}\right)\frac{m^2k_z^2k_{mn}^2q_{mn}^2}{k_2^2}\left[\frac{1}{k_{mn}^2}-\frac{1}{q_{mn}^2}\right]^2$$

replace it with k_z^2, and arrange it h_{mn}^2

$$f(k_{mn})=-k_2^2\frac{\delta}{q_{mn}^2}\left\{k_{mn}^2\left(1-\frac{m^2}{q_{mn}^2}\right)+\frac{m^2h_{mn}^2q_{mn}^2}{k_2^2k_{mn}^2}\left(1-\frac{k_{mn}^2}{q_{mn}^2}\right)^2\right\} \tag{98}$$

look below; $f'(k_{mn})$ Just take the first term of formula (89) (zero-order approximation) and set then there is $\mu_2=\mu_0$,

$$f(u)=k_2^2\frac{u}{q^2}\left[\frac{\mathrm{J}'_m(u)}{\mathrm{J}_m(u)}\right]$$

The expression is obtained by solving according to the differential rule obtain $f'(u)$, and then $J'_m(\mathrm{k}_{mn})$ equal to 0, so that's it

$$f'(k_{mn})=\frac{k_2^2}{q_{mn}^2}k_{mn}\frac{\mathrm{J}''_m(k_{mn})}{\mathrm{J}_m(k_{mn})}$$

Using the Bessel recurrence formula:

$$\mathrm{J}''_m(k_{mn})=-\left(1-\frac{m^2}{k_{mn}^2}\right)\mathrm{J}_m(k_{mn})$$

Finally get

$$f'(k_{mn}) = -\frac{k_2^2}{q_{mn}^2} k_{mn} \left(1 - \frac{m^2}{k_{mn}^2}\right) \tag{99}$$

thus obtained

$$\frac{\mathrm{d}\gamma_{mn}^{(b)}}{\gamma_{mn}^{(b)}} \approx \frac{\delta}{h_{mn}^2 b^2} \left[k_{mn}^2 \left(1 - \frac{m^2}{q_{mn}^2}\right) + \frac{m^2 h_{mn}^2 q_{mn}^2}{k_2^2 k_{mn}^2} \left(1 - \frac{k_{mn}^2}{q_{mn}^2}\right)^2 \right] \frac{k_{mn}^2}{k_2^2 - m^2} \tag{100}$$

h_{mn} : obtained from formula (92)

$$h_{mn}^2 = k_0^2 - \frac{k_{mn}^2}{b^2} \tag{101}$$

It can be determined by the following formula: q_{mn}

$$q_{mn}^2 = k_2^2 b^2 + \gamma_{mn}^2 b^2 = k_2^2 b^2 - h_{mn}^2 b^2 = k_2^2 b^2 - k_0^2 b^2 + k_{mn}^2 \tag{102}$$

These results are consistent with Brown's.

The opposite formula (100) can be deformed. On account of

$$k_{mn}^2 - \frac{m^2 k_{mn}^2}{q_{mn}^2} = (k_{mn}^2 - m^2) + m^2 \left(1 - \frac{k_{mn}^2}{q_{mn}^2}\right) = (k_{mn}^2 - m^2) + m^2 k_{mn}^2 \left(\frac{1}{k_{mn}^2} - \frac{1}{q_{mn}^2}\right)$$

So the equation (100) can be written as

$$\frac{\mathrm{d}\gamma_{mn}^{(b)}}{\gamma_{mn}^{(b)}} = \frac{\delta k_{mn}^2}{h_{mn}^2 b^2} + \frac{m^2 \delta}{h_{mn}^2 b^2} \left\{ k_{mn}^2 \left(\frac{1}{k_{mn}^2} - \frac{1}{q_{mn}^2}\right) + \frac{k_{mn}^2 q_{mn}^2}{k_2^2 k_{mn}^2} \left(1 - \frac{k_{mn}^2}{q_{mn}^2}\right)^2 \right\} \frac{k_{mn}^2}{k_{mn}^2 - m^2}$$

where The symbol (b) indicates that this result is obtained by expanding the reference radius (not). The second term on the right can be simplified to

$$\frac{m^2 \delta}{h_{mn}^2 b^2} \left\{ \frac{q_{mn}^2 - k_{mn}^2}{q_{mn}^2} + \frac{h_{mn}^2 (q_{mn}^2 - k_{mn}^2)}{k_2^2 k_{mn}^2 q_{mn}^2} \right\} \frac{k_{mn}^2}{k_{mn}^2 - m^2} = \frac{m^2 \delta}{h_{mn}^2 b^2} \frac{q_{mn}^2 - k_{mn}^2}{k_{mn}^2 - m^2} \left\{ \frac{k_2^2 k_{mn}^2 + h_{mn}^2 (q_{mn}^2 - k_{mn}^2)}{k_2^2 q_{mn}^2} \right\}$$

however

$$q_{mn}^2 - k_{mn}^2 = k_0^2 b^2 (\varepsilon_{\mathrm{r}} - 1) \tag{103}$$

It can therefore be proved that:

$$k_2^2 k_{mn}^2 + h_{mn}^2 (q_{mn}^2 - k_{mn}^2) = k_0^2 q_{mn}^2 \tag{104}$$

we plug in these results

$$\frac{\mathrm{d}\gamma_{mn}^{(b)}}{\gamma_{mn}^{(b)}} = \frac{\delta k_{mn}^2}{h_{mn}^2 b^2} + \frac{m^2 \delta}{h_{mn}^2 b^2} \frac{q_{mn}^2 - k_{mn}^2}{k_{mn}^2 - m^2} = \frac{k_0^2}{k_2^2} \frac{\delta k_{mn}^2}{h_{mn}^2 b^2} + m^2 \delta \frac{\varepsilon_{\mathrm{r}} - 1}{k_{mn}^2 - m^2} \frac{k_0^2}{k_2^2} \frac{k_0^2}{h_{mn}^2}$$

However . $k_0^2 \, / k_2^2 \, \_ \, \varepsilon_r$, In addition can be ordered

$$G_{mn}^2 = \frac{h_{mn}^2}{k_0^2} = 1 - \frac{k_{mn}^2}{b^2 k_0^2} = 1 - \frac{\lambda^2}{\left(\frac{2\pi b}{k_{mn}}\right)^2} = 1 - \frac{\lambda^2}{\lambda_{c.mn}^2}$$

hence

$$\frac{\mathrm{d}\gamma_{mn}^{(b)}}{\gamma_{mn}^{(b)}} = \frac{\delta k_{mn}^2}{h_{mn}^2 b^2} + m^2 \delta \frac{\varepsilon_r - 1}{\varepsilon_r} \frac{1}{(k_{mn}^2 - m^2)} G_{mn}^2$$

however

$$F_{mn}^2 = \frac{h_{mn}^2 b^2}{k_{mn}^2} = \frac{b^2 k_0^2}{k_{mn}^2} - 1 = \left(\frac{2\pi b}{k_{mn}}\right)^2 \frac{1}{\lambda^2} - 1 = \frac{\lambda_{c.mn}^2}{\lambda^2} - 1 \tag{105}$$

So finally get

$$\frac{\mathrm{d}\gamma_{mn}^{(b)}}{\gamma_{mn}^{(b)}} = \frac{\delta}{F_{mn}^2} + \frac{m^2 \delta (\varepsilon_r - 1)}{\varepsilon_r (k_{mn}^2 - m^2) G_{mn}^2} \tag{106}$$

This expression is relatively comprehensive, Brown has not given such a clear expression.

VIII. Analysis of Circular Cut-Off Waveguide and H_{11}-Mode

Approximation theory still admits that positive scale can exist. Start with a clear formula, which is obtained from equation

$$\frac{\mathrm{d}\gamma_{mn}^{(b)}}{\gamma_{mn}^{(b)}} = \frac{d/b}{\left(\frac{\lambda_{c.mn}}{\lambda}\right)^2 - 1} + \frac{d}{b} \frac{m^2}{k_{mn}^2 - m^2} \left(1 - \frac{1}{\varepsilon_r}\right) \frac{1}{1 - \left(\frac{\lambda}{\lambda_{c.mn}}\right)^2} \tag{107}$$

Let $m = n = 1$, get the formula applicable to H_{11}mode

$$\frac{\mathrm{d}\gamma_{11}^{(b)}}{\gamma_{11}^{(b)}} = \frac{d/b}{\left(\frac{\lambda_{c.11}}{\lambda}\right)^2 - 1} + \frac{d}{b} \frac{1}{k_{11}^2 - 1} \left(1 - \frac{1}{\varepsilon_r}\right) \frac{1}{1 - \left(\frac{\lambda}{\lambda_{c.11}}\right)^2} \tag{108}$$

For the specific case of the cut-off waveguide attenuation standard, $\lambda \gg \lambda_c$, it is obtained

$$\frac{\mathrm{d}\gamma_{11}^{(b)}}{\gamma_{11}^{(b)}} \approx -\frac{d}{b} - \frac{d}{b} \frac{1}{k_{11}^2 - 1} \left(1 - \frac{1}{\varepsilon_r}\right) \left(\frac{\lambda_{c.11}}{\lambda}\right)^2 \tag{109}$$

Obviously, the second term on the right side of the equation is small, so

$$\frac{\mathrm{d}\gamma_{11}^{(b)}}{\gamma_{11}^{(b)}} \approx -\frac{d}{b} \tag{110}$$

The minus sign indicates that the oxidation film reduces the attenuation constant.

Now proceed from equation (24) of Brown's paper[13]; Let $\mu_2 = \mu_0$, $m = n = 1$, then the formula becomes

$$\frac{d\gamma_{11}^{(b)}}{\gamma_{11}^{(b)}} = \frac{d}{b}\frac{1}{h_{11}^2 b^2}\frac{k_{11}^2}{k_{11}^2-1}\left\{k_{11}^2\left(1-\frac{1}{q_{11}^2}\right)+\frac{h_{11}^2 q_{11}^2}{k_2^2 k_{11}^2}\left(1-\frac{k_{11}^2}{q_{11}^2}\right)^2\right\}$$

Brown, however, "takes the unperturbed decay constant k_{11}/b ", which has two caveats.

1. This assumption is only true if the terms k_0 in the formula are ignored. By numerical verification, it is proved that it is allowed to work in the cut-off area.
2. Brown lost a minus sign and should have taken it instead

$$h_{11}^2 b^2 = -k_{11}^2 \tag{111}$$

hence

$$\frac{d\gamma_{11}^{(b)}}{\gamma_{11}^{(b)}} = -\frac{d}{b}\frac{k_{11}^2}{k_{11}^2-1}\left\{1-\frac{1}{q_{11}^2}+\frac{h_{11}^2 q_{11}^2}{k_2^2}\left(\frac{1}{k_{11}^2}-\frac{1}{q_{11}^2}\right)^2\right\} = -\frac{d}{b}\frac{k_{11}^2}{k_{11}^2-1}\left\{1-\frac{1}{q_{11}^2}-\frac{q_{11}^2}{b^2 k_2^2 k_{11}^2}+\frac{2}{b^2 k_2^2}-\frac{k_{11}^2}{b^2 k_2^2 q_{11}^2}\right\} \tag{112}$$

If ε_r »1 is assumed, then $k_2^2 » k_0^2$, therefore desirable:

$$q_{11}^2 =\approx b^2 k_2^2 - b^2 k_0^2 + k_{11}^2\ b^2 k_2^2 + k_{11}^2 \tag{113}$$

Hence there

$$\frac{q_{11}^2}{b^2 k_2^2 k_{11}^2}+\frac{k_{11}^2}{b^2 k_2^2 q_{11}^2}=\frac{b^2 k_2^2 + k_{11}^2}{b^2 k_2^2 k_{11}^2}+\frac{q_{11}^2 - b^2 k_2^2}{b^2 k_2^2 q_{11}^2}=\frac{1}{k_{11}^2}+\frac{2}{b^2 k_2^2}-\frac{1}{q_{11}^2}$$

You get it when you plug it in

$$\frac{d\gamma_{11}^{(b)}}{\gamma_{11}^{(b)}} \approx -\frac{d}{b} \tag{114}$$

This result is correct, and Brown's original formula is:

$$\frac{dh_{11}}{h_{11}} = \frac{d}{b}\frac{1}{k_{11}^2-1}\left\{\frac{k_{11}^4 - k_{11}^2 + b^2 k_2^2 (k_{11}^2+1)}{k_{11}^2 + b^2 k_2^2}\right\}$$

this is wrong, because of the loss of a minus sign. Brown is wrong, but his conclusion is still correct on an order of magnitude scale.

We discuss the perturbation of BWB equation (H^{mn} -mode) and H_{11}-mode cases. There is now

$$h_1 b = h_1 a - h_1 d$$

$$h_2 b = h_2 a - h_2 d$$

Suppose d « a , cylindrical functions can be expanded by variables $h_1 a$ 、 $h_2 a$. Introduce the following symbols:

$$u = h_1 a = a\sqrt{k_0^2 + \gamma^2} \tag{115}$$

$$x_2 = h_2 a = a\sqrt{k_2^2 + \gamma^2} \tag{116}$$

And let $\delta = d/a$, similar analysis is obtained

$$k_2^2\frac{u}{x_2^2}\left[\frac{J_m'(u)}{J_m(u)}\right]+k_0^2\delta\left[\frac{J_m'(u)}{J_m(u)}\right]^2 - k_2^2\frac{u^2}{x_2^2}\delta K - m^2 h_{mn}^2 u^2 \delta\left[\frac{1}{u^2}-\frac{1}{x_2^2}\right]^2 = 0 \tag{117}$$

The term δ^2 was omitted from the derivation. Where K is

$$K=\frac{J'_m(u)}{J_m(u)}+\left(1-\frac{m^2}{x_2^2}\right) \tag{118}$$

Take formula (117) as

$$f\,(u)=0 \tag{119}$$

It can be proved that:

$$\frac{d\gamma_{mn}^{(a)}}{\gamma_{mn}^{(a)}}=-\frac{k_{mn}}{a^2h_{mn}^2}\,du_{mn} \tag{120}$$

It can also be proved that:

$$\frac{d\gamma_{mn}^{(a)}}{\gamma_{mn}^{(a)}}=\frac{m^2\delta}{h_{mn}^2a^2}\left\{1-\frac{k_{mn}^2}{x_{2.mn}^2}+\frac{h_{mn}^2x_{2.mn}^2}{k_2^2k_{mn}^2}\left[1-\frac{k_{mn}^2}{x_{2.mn}^2}\right]^2\right\}\frac{k_{mn}^2}{k_{mn}^2-m^2} \tag{121}$$

and

$$h_{mn}^2=k_0^2-\frac{k_{mn}^2}{a^2} \tag{122}$$

$$x_{2.mn}^2=k_2^2a^2-k_0^2a^2+k_{mn}^2 \tag{123}$$

But the formula has been rearranged to become

$$\frac{d\gamma_{mn}^{(a)}}{\gamma_{mn}^{(a)}}=\frac{m^2\delta}{h_{mn}^2a^2}\,\frac{x_{2.mn}^2-k_{mn}^2}{k_{mn}^2-m^2}\left\{\frac{k_2^2k_{mn}^2+h_{mn}^2(x_{2.mn}^2-k_{mn}^2)}{k_2^2x_{2.mn}^2}\right\}$$

However ($x_{2.mn}^2-k_{mn}^2$) can be written as:

$$x_{2.mn}^2-k_{mn}^2=k_0^2a^2\,(\varepsilon_r-1) \tag{124}$$

And know $k_0^2 ,k_2^2=1/\varepsilon_r$, so the last can be obtained

$$\frac{d\gamma_{mn}^{(a)}}{\gamma_{mn}^{(a)}}=m^2\delta\frac{(\varepsilon_r-1)}{\varepsilon_r}\,\frac{1}{(k_{mn}^2-m^2)G_{mn}^2} \tag{125}$$

and

$$G_{mn}^2=\frac{h_{mn}^2}{k_0^2}=1-\left(\frac{\lambda}{\lambda_{c.mn}}\right)^2 \tag{126}$$

$$\lambda_{c.mn}=\frac{2\pi\alpha}{k_{mn}} \tag{127}$$

The formula can be written as

$$\frac{d\gamma_{mn}^{(a)}}{\gamma_{mn}^{(a)}}=\frac{d}{a}\,\frac{m^2}{k_{mn}^2-m^2}\left(1-\frac{1}{\varepsilon_r}\right)\frac{1}{1-\left(\frac{\lambda}{\lambda_{c.mn}}\right)^2} \tag{128}$$

Let $m=n=1$, get the formula applicable to H_{11} modes:

$$\frac{d\gamma_{11}^{(a)}}{\gamma_{11}^{(a)}}=\frac{d}{a}\,\frac{1}{k_{11}^2-1}\left(1-\frac{1}{\varepsilon_r}\right)\frac{1}{1-\left(\frac{\lambda}{\lambda_{c.11}}\right)^2} \tag{129}$$

for the specific case of the cut-off attenuation standard, $\lambda \gg \lambda_c$, thus obtained

$$\frac{d\gamma_{11}^{(b)}}{\gamma_{11}^{(b)}}\approx-\frac{d}{a}\,\frac{1}{k_{11}^2-1}\left(1-\frac{1}{\varepsilon_r}\right)\left(\frac{\lambda_{c.11}}{\lambda}\right)^2 \tag{130}$$

equation (130) shows that the artificial application of dielectric layer on the inner wall causes only a small effect and can be ignored.

So why are the results of the two theories inconsistent?

First, the formula should be written as

$$h_{mn}^{(b)}=\sqrt{k_0^2-\frac{u_{mn}^2}{b^2}}=\sqrt{k_0^2-\frac{k_{mn}^2}{b^2}} \tag{131}$$

the other formula should be written as

$$h_{mn}^{(a)} = \sqrt{k_0^2 - \frac{k_{mn}^2}{a^2}} \tag{132}$$

the difference between them can therefore be found:

$$h_{mn}^{(b)} - h_{mn}^{(a)} = \sqrt{k_0^2 - \frac{k_{mn}^2}{b^2}} - \sqrt{k_0^2 - \frac{k_{mn}^2}{a^2}}$$

however

$$\delta = \frac{d}{a} = \frac{a-b}{a} = 1 - \frac{b}{a}$$

hence

$$b^2 = a^2 (1-\delta)^2 \tag{133}$$

Hence there

$$h_{mn}^{(b)} = \sqrt{k_0^2 - \frac{k_{mn}^2}{a^2(1-\delta)^2}} \approx \sqrt{k_0^2 - \frac{k_{mn}^2}{a^2}(1+2\delta)} - h_{mn}^{(a)} \sqrt{1 - \frac{2k_{mn}^2}{a^2 h_{mn}^{(a)2}} \delta}$$

Again, we approximate, we get

$$h_{mn}^{(b)} \approx h_{mn}^{(a)} \left[1 - \frac{k_{mn}^2}{a^2 h_{mn}^{(a)2}} \delta \right]$$

Thus obtained

$$h_{mn}^{(b)} - h_{mn}^{(a)} = -\frac{\delta k_{mn}^2}{a^2 h_{mn}^{(a)}} \tag{134}$$

On the other hand, formula (121) can be deformed and arranged into the following form:

$$\frac{\mathrm{d}h_{mn}^{(a)}}{h_{mn}^{(a)}} = +-\frac{\delta k_{mn}^2}{a^2 h_{mn}^{(a)}} + \frac{\delta}{a^2 h_{mn}^{(a)2}} \left\{ k_{mn}^2 \left(1 - \frac{m^2}{x_{2.mn}^2} \right) \frac{m^2 h_{mn}^2 x_{2.mn}^2}{k_2^2 k_{mn}^2} \left[1 - \frac{k_{mn}^2}{x_{2.mn}^2} \right]^2 \right\} \frac{k_{mn}^2}{k_{mn}^2 - m^2}$$

compared to the past formula, hence

$$\mathrm{d}h_{mn}^{(a)} - \mathrm{d}h_{mn}^{(b)} = -\frac{\delta k_{mn}^2}{a^2 h_{mn}^{(a)}} \tag{135}$$

Therefore, it is obtained from formula (134) and formula (135):

$$h_{mn}^{(a)} + \mathrm{d}h_{mn}^{(a)} = h_{mn}^{(b)} + \mathrm{d}h_{mn}^{(b)} \tag{136}$$

hence

$$\gamma_{mn}^{(a)} + \mathrm{d}\gamma_{mn}^{(a)} = \gamma_{mn}^{(b)} + \mathrm{d}\gamma_{mn}^{(b)} \tag{137}$$

That is to say, after the propagation constant is perturbed, the result is the same whether it is expanded a or expanded b. In other words, under first-order approximation, the results obtained by BWB equation are consistent with those obtained by Brown equation.

Consider the following formula:

$$\gamma_{11}^{(a)} + \mathrm{d}\gamma_{11}^{(a)} = \gamma_{11}^{(b)} + \mathrm{d}\gamma_{11}^{(b)} \tag{138}$$

the sum is the same, but the items are different. To give a number like this:

$$1.0001000+0.0000006=1.0000006+0.0001 \tag{139}$$

Even though the equation is true, the small quantity on the left is 6×10^{-7}, and the small quantity on the right is 1×10^{-4}.So the end result is different.

If the medium layer is not artificially laid, but caused by natural oxidation, the use of Brown analysis is obviously more reasonable, because just finished processing is the radius b, the propagation constant; $\gamma_{11}^{(b)}$. Oxidation expands the ideal conductive boundary to cause perturbation. From an experimental point of view, the propagation constant in the presence of an oxide layer can only be compared with that in the absence of oxidation $\gamma_{11}^{(b)}$, and cannot be compared with that in the absence of oxidation $\gamma_{11}^{(a)}$.

The conclusion is that the process of naturally forming an oxide layer on the inner surface of a copper or brass circular waveguide may cause an error of 10^{-5}

orders of magnitude in the attenuation constant (depending on the thickness), which cannot be ignored for high accuracy standards! Brown's analysis had a few flaws at the end, but it was mostly correct. As for the sign of the error, all analyses indicate that the presence of an inner dielectric layer reduces the attenuation constant. There are no contradictions or differences to explain here.

We finally discuss the numerical calculation of the H_{11}-mode case where the operating frequency is much less than the cutoff frequency, or the operating wave is longer than the cutoff wavelength. Then, the H_{11}-mode can be numerically calculated by the formula (140) and written as

$$\frac{\Delta\alpha_{11}}{\alpha_{11}} \approx -\frac{d}{a} \tag{140}$$

hence

$$\left|\frac{\Delta\alpha_{11}}{\alpha_{11}}\right| \approx \frac{d}{b} \tag{141}$$

namely

$$d \approx b\left|\frac{\Delta\alpha_{11}}{\alpha_{11}}\right| \tag{142}$$

For example, if there is such a copper (or brass) waveguide with an internal radius b of 16000.00μm, there is

$$d \approx 1.6\times10^{4}\left|\frac{\Delta\alpha_{11}}{\alpha_{11}}\right| \quad \mu\text{m} \tag{143}$$

It can be seen that when it is specified that $|\Delta\alpha_{11}|/\alpha_{11}$ is less than a certain value, it is also necessary to ensure that the thickness of the oxide film is less than a certain value. For example, $<5\times10^{-5}$, oxide film thickness $d \leq 0.8$μm.

It can be seen that if we want to make a cutoff attenuation standard with an uncertainty of 5×10^{-5}, it is necessary to take appropriate anti-oxidation measures for copper (or brass) waveguides. Because even if the error assigned to this aspect is 1×10^{-5}, the oxide film thickness is still required to be $d < 0.16$μm. In the scientific research of surface physics and surface chemistry, there are special instruments and methods for measuring the thickness of oxide film, such as the ellipsometer method (using the polarization of the metal and the oxide film to measure) and the film resistance method, which can be selected, and this paper will not be described.

IX. Conclusion

Based on a research project I participated in at NIM in China in the past, based on the mathematical equations in the waveguide theory and a lot of mathematical analysis, this paper makes an original research on the cut-off waveguide theory used in first-order attenuation criteria, and gets a series of new achievements. They are unknown to the international scientific community, such as the later named equations (Huang equation, Huang Zeng equation), as well as some unique algorithms. This paper is a complete summary, a large number of mathematical analysis work has been elevated to the level of physical significance, so that this paper is not only a contribution to metrology, but also to the enrichment of basic scientific theories - providing new mathematical equations in teaching, and strengthening the waveguide theory in physics.

From the development and experimental results, NIM reached a high level of accuracy of 5×10^{-5} for the cut-off attenuation standard in 1980. This requires a theoretical calculation accuracy better than 1×10^{-6}. It is best to reach 1×10^{-7}. This paper shows how the author achieved this requirement through hard work, and vividly illustrates the twists and turns and hardships of scientific research work.

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A Classical Interpretation of the Quantum Universe Extrapolated from the Fine Structure Constant (α)

By John R. Crary

Abstract- The Fine Structure Constant (FSC) model of the universe is a conceptual perspective based on a classical method for analyzing the Fine Structure Constant (α). A Python algorithm calculates prime number property sets where the sum of the elements equals the whole number values for α equal to 137 and139. A hybrid coupling of these property sets produces a U{137/139}twin prime metaverse where α =137.036, an almost exact match to the observed value. The FSC Model projects that the Fractional Coupling Constant (α_{137} = 0.036)is a more accurate measure of its relative electromagnetic (EM) strength. This same calculation is used to determine the Fractional Coupling Constants (α_m) for the twin prime metaverses (U{2/3}, U{3/5}, U{5/7}through U{197/199}) to estimate their respective electromagnetic forces. The results suggest that this model mirrors our observable universe and offers an abstract landscape into the quantum nature of electromagnetic forces, including Baryonic Matter, Dark Matter, Dark Energy, and a possible variable speed of light.

Keywords: fine structure constant, quantum, matter, dark matter, dark energy, electromagnetic, conceptual model, primordial black holes.

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Abstract- The Fine Structure Constant (FSC) model of the universe is a conceptual perspective based on a classical method for analyzing the Fine Structure Constant (α). A Python algorithm calculates prime number property sets where the sum of the elements equals the whole number values for α equal to 137 and139. A hybrid coupling of these property sets produces a U{137/139}twin prime metaverse where α =137.036, an almost exact match to the observed value. The FSC Model projects that the Fractional Coupling Constant (α_{137} = 0.036)is a more accurate measure of its relative electromagnetic (EM) strength. This same calculation is used to determine the Fractional Coupling Constants (α_m) for the twin prime metaverses (U{2/3}, U{3/5}, U{5/7}through U{197/199}) to estimate their respective electromagnetic forces. The results suggest that this model mirrors our observable universe and offers an abstract landscape into the quantum nature of electromagnetic forces, including Baryonic Matter, Dark Matter, Dark Energy, and a possible variable speed of light.

Keywords: fine structure constant, quantum, matter, dark matter, dark energy, electromagnetic, conceptual model, primordial black holes.

I. Introduction

The Fine Structure Constant alpha(α) value is ~1/137, precisely measured as 137.035999206[1], which characterizes the strength of the electromagnetic interaction between elementary charged particles. The FSC Model proposes that there may be a classical interpretation for this unitless QED number as described in a previous article [2], "A Conceptual Model of our Universe Derived from the Fine Structure Constant (α)."

The FSC Model calculates the value of α at 137.036 by assuming that our universe is a hybrid of the twin prime number metaverses U{137} and U{139} where α=137.000 and α=139.000 respectively. The FSC theory assumes that the whole number part of α, 137 is due to it being associated with the U{137/139} metaverse and that the fractional part of α_{137} = 0.036 is the actual measure of the electromagnetic force (EM) that binds charged particles.

Most importantly, the Fractional Coupling Constants (α_m) values can be generated for the other twin prime metaverses, and together, those differences drive the functional nature of our universe. The questions being investigated are comprehensive and include attempts to align the FSC Model property set calculations with existing scientific theories to ultimately define a collective inference for why we have Matter, Dark Matter, and Dark Energy.

II. FSC Fine Structure Constant Calculations

The Python-generated Fine Structure (α) calculations are shown in Table 1, which displays the property counts for hypothetical metaverses U{139} and U{137}. The top row represents the U{139} property counts where α = 139.000, while the bottom row represents the U{137} property counts for α= 137.000. In each case, the generated α values represent the sum of the prime number elements in their respective property sets.

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Table 1: FSC Fine Structure Calculations

Metaverse	D01	D02	D03	D04	D05	D06	D07	D08	D09	D10	*P*-Sum	α/α_m
U{139}	1	1	48	54	240	235	109	86	2	0	776	α = 139.000
U{139/137}	{139} → {2,137} ↓	{2,U{137}} ↓	*Fractional Coupling Constant α $_{U\{137/139\}}$* ((U{139}+1) - (U{137}-1))/(U{139} + U{137}) → (777 - 723)/(777 + 723)								777	α = 137.036
~~U{137}~~	~~1~~	0	54	34	235	214	86	98	0	2	723	α = 137.000

The yellow section in the middle describes a hybrid U{137/139} metaverse that produces an α = 137.036 with a Fractional Coupling value of α_{137} = 0.036 based on the U{137} and U{139} property counts.

The red font describes how the U{137} property set must originate from the U{139} metaverse to create the hybrid U{137/139} metaverse. This subtracts the D01 = ~~1~~ property from U{137} and pulls it from the U{139} D02 property set (+1) to create the hybrid configuration determining the fractional α_{137}value.

This hybrid FSC model gives the Fine Structure Constant (α) a classical mathematical definition using a Relative Dominance (RD) calculation of the (U{139} minus U{137})/U{137/139} for the property calculations described in blue. This RD/α_m calculation (A-B)/(A+B) is then applied to the other twin prime metaverses to identify how their hybrid fractional EM forces compare to the U{137/139} metaverse.

Lastly, the FSC property sets represent a dissection of the Fine Structure Constant (α) into a range of n-dimensional sets of prime numbers that define focal points of quantum energy for each metaverse. The theory is that the higher the twin prime ratio of these property sets, the more matter-like its quantum nature. As an example, the U{137} 10^{th}-dimension has two property sets, {2-3-5-7,11-13,17-19,23,37} and {2-3-5-7,11-13,17-19,29-31}where the elements sum to 137 and the "-" indicate pairing of twin prime values. This represents the highest twin prime ratios for our U{137/139} metaverse [2] and is presumably the most functional.

The supposition is that only prime number sets represent stable quantum states, whereas composite numbers are unstable and cannot form property elements. Properties from different metaverses seem to have the same "quantum gravity," but the higher the twin prime pair, the larger the number of property sets they generate.

III. Metaverse Coupling Constants

The difference between α and α_m *is* that α reflects the fact that it is extracted from the U{137/139} hybrid metaverse, while α_{137} *is* a measure of its actual Electromagnetic Force (EM), where:

$$\alpha = U\{137/139\} + \alpha_{137} = 137 + 0.036 = 137.036$$

The FSC Metaverses represent absolute energy levels, while the Fractional Coupling Constants (α_m) represent their relative EM strength between the hybrid metaverses.

Table 2 illustrates the Fractional Coupling Constant (α_m) calculations for the twin prime metaverses U{2/3} through U{197/199}. The U{137/139} hybrid metaverse row for light is highlighted in yellow. The higher α_m values (Baryonic Matter) are highlighted in green, while those with lower α_m values in grey represent the Dark Metaverses.

Table 2: Twin Prime Metaverse Hierarchy

Metaverse U{P1/P2}	P1/P2 Ratios	α	αm	P1 Sums	Metastate
U{2,3}	1/1	3.000	1.00000	585	Baryonic Matter
U{3,5}	1/2	4.000	1.00000		
U{5/7}	2/2	5.500	0.50000		
U{11/13}	1/2	12.000	1.00000		
U{17/19}	2/3	17.600	0.60000		
U{29/31}	7/9	29.250	0.25000		
U{41,43}	14/15	41.103	0.10345		
U{59,61}	35/39	59.081	0.08108		
U{71,73}	61/67	71.063	0.06250		
U{101,103}	204/224	101.051	0.05140		
U{107/109}	257/278	107.043	0.04299		
U{137/139}	724/776	137.036	0.03600	724	Light
U{149/151}	1064/1136	149.034	0.03364	11,604	Dark Matter & Dark Energy
U{179/181}	2601/2761	179.030	0.03021		
U{191/193}	3645/3863	191.029	0.02930		
U{197/199}	4294/4549	197.029	0.02906		
Higher Twin Prime Metaverses					

The premise is that the larger the α_m values have stronger EM force, while those with lower α_m values have less EM force. What this means for our FSC Model universe is outlined below.

- Baryonic Matter, highlighted in green, represents EM forces stronger than $\alpha_{137} = 0.036$. The presumption is that the stronger the EM force, the more tightly it binds matter & energy, giving our universe its quantum-level chemistry and physics.
- The table row highlighted in yellow represents electromagnetic radiation (photons of light) free from baryonic internment and able to travel through space. This is where the EM value of α_{137} is too weak to bind with matter but can transfer energy to the lower metaverses, presumably when the U{137/139} EM wavelength matches the quantum energy in a lower metaverse.
- The grey section describes the Dark Metaverses, characterized by decreasing EM forces and the inability to absorb or emit EM radiation or form matter. However, they would have enough EM forces to influence Light and Baryonic metaverses.
- The Dark Metaverses describes a medium through which light must travel and is best described as an ocean of weakly interacting twin prime metaverses U{149/151} and above. Much like the speed of light slowing when it travels through glass or water, this implies that the Dark Metaverse is a possible determinant for the speed of light.

If the Dark Metaverse had a higher density in the past, it may have reduced the speed of light. The effect would mimic an expanding universe, as described by ChatGPT-3.5, "In this scenario, it could give the illusion of a more accelerated expansion, potentially making it seem like the universe is expanding at a faster rate than it is. This effect could be analogous to the observations that led to the discovery of dark energy, which is thought to be responsible for the accelerated expansion observed today."

IV. The Big Bang & Dark Metaverse

The FSC Model aligns with current theories that Dark Matter results from Primordial Black Holes (PBHs) created during the Big Bang[3]. These represent tiny black holes from which our universe evolved. The Dark Metaverse theory supports the possibility of their dimensional property sets D01-D(n) manifesting as primordial singularities. These singularities would range differently in size, each with quantum scale gravity.

Depending on the size and number of these singularities, where the larger twin prime metaverses represent more cumulative energy, four things can happen:

1. The smallest singularities quickly dissipate their energy into the cosmos via Hawking radiation, creating a cascade of baryonic matter an instant after the Big Bang.
2. The remaining singularities, too large to dissipate the entirety of their energy as Hawking radiation, survive today as Dark Matter. These FSC singularities would have little or no EM forces, cannot interact with light, and have no physical structure except to encapsulate a tiny amount of quantum gravity[4].
3. The Dark Energy conjecture has three possible answers:
   a) It is an illusion due to a slower speed of light in the past because the Dark Metaverse was denser, as described in the previous section.
   b) Dark Energy is due to PBHs emitting Hawking radiation faster now than in the past and possibly increasing as the density of Dark Matter decreases and the universe cools.
   c) or both.
4. Lastly, early in the universe's evolution, the largest singularities would coalesce into Black Holes and be the focal points in forming stars and galaxies.

This process describes our universe's formation much like liquid droplets (Coacervates) in water[5], which involves dissolution into the surrounding media, possible phase separation, and, eventually, a state of equilibrium in a turbulent system.

V. Conclusion

The FSC Model represents a conceptual description of the quantum nature of our universe based on the idea that set theory can replicate the value of the Fine Structure Constant α= 137.036. Mainly, it provides a Python algorithm [6] for fractionating the value of α into prime number property sets where α =137 and α =139 and forming a hybrid metaverse that mathematically matches the observed α= *137.035999206.* The theory is that these property sets give a granular understanding of implied quantum states of matter and energy. It does not alter existing sciences but potentially provides a theoretical scaffolding that defines the universe.

The FSC theory presumes that the Fractional Coupling Constant for U{137/139} α_{137}= 0.036 represents the true EM force and that these α_m forces can be calculated for all the twin prime metaverses. These EM forces present a new paradigm for understanding Matter, Dark Matter, and Dark Energy.

The FSC Model supports the theory that an array of primordial twin prime singularities may contribute to the gravitational force we call Dark Matter. Dark Energy is due to an increasing speed of light or an accelerating dissipation of Hawking radiation from Dark Matter as the universe expands.

The FSC Model provides an abstract perspective of our universe based on classical math, set theory, and deductive reasoning for a magical number (α) that previously defied scientific inquiry. It is not intended as a proof of concept but as a novel approach for aligning a conceptual model with the science that describes our universe.

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Three Properties of Matter

By Li Xuefeng

Introduction- Let me talk about three concepts first, which may not be very accurate but I haven't found a better description. Radiation is the process by which particulate matter radiates energy as it cools. A quantum is a unit of energy radiated outward during the cooling process of particle matter. Temperature is a measure of the ability of particulate matter to radiate externally."The Law of Cooling", the matter composed of elementary particles, every atom in it, builds a temperature field that is high inside and low outside, continuously radiates energy outward, cools itself, and makes its own state more stable Stablize. At the same time, it is constantly absorbing the energy transmitted from other nearby atomic substances. Every substance composed of elementary particles maintains a balance in this dynamic state of heat release and heat absorption. Heat release is active and heat absorption is passive. There is a substantial difference between "The Law of Cooling" and "The Theorem of Heat Exchange" learned in middle school. Heat exchange is understood from the molecular level. The law of cooling is the heat exchange explained from the quantum level. It is important to note here that active cooling is a basic property of matter. This feature was previously unrecognized. What is the temperature? We use a thermometer to measure the temperature, high and low, what exactly are we measuring? In air, is the velocity of the gas being measured? Obviously not, is the amplitude of the crystal oscillator measured in the solid? Is pressure measured in liquids? Obviously neither.

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THREEPROPERTIESOFMATTER

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I. Introduction

Let me talk about three concepts first, which may not be very accurate but I haven't found a better description. Radiation is the process by which particulate matter radiates energy as it cools. A quantum is a unit of energy radiated outward during the cooling process of particle matter. Temperature is a measure of the ability of particulate matter to radiate externally."The Law of Cooling", the matter composed of elementary particles, every atom in it, builds a temperature field that is high inside and low outside, continuously radiates energy outward, cools itself, and makes its own state more stable Stablize. At the same time, it is constantly absorbing the energy transmitted from other nearby atomic substances. Every substance composed of elementary particles maintains a balance in this dynamic state of heat release and heat absorption. Heat release is active and heat absorption is passive. There is a substantial difference between "The Law of Cooling" and "The Theorem of Heat Exchange" learned in middle school. Heat exchange is understood from the molecular level. The law of cooling is the heat exchange explained from the quantum level. It is important to note here that active cooling is a basic property of matter. This feature was previously unrecognized. What is the temperature? We use a thermometer to measure the temperature, high and low, what exactly are we measuring? In air, is the velocity of the gas being measured? Obviously not, is the amplitude of the crystal oscillator measured in the solid? Is pressure measured in liquids? Obviously neither.

What is the temperature we measure indoors? It is still radiation, which is the determination of the radiant energy of indoor materials. In solids and liquids, the temperature we measure is still their radiative capacity. Therefore, temperature is a measure of the ability of particle matter to radiate to the outside. These are just personal knowledge, for reference only.

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a) The essence of frictional heat generation

When we were young, we often played the game of smashing sparks at night, that is, smashing the small stone in our hand on the big stone, you will find that if there is sliding, the spark will be very small, and the spark will be when it touches will be great. This is in great contradiction with the theory of frictional heat generation that we have learned. Is there any other explanation? The current popular explanation, the energy transformation of objects. If we must understand in this way , we will further consider how these energies are converted from kinetic energy to heat energy of molecular motion.

To talk about the essence of frictional heat generation, we must first talk about the essence of friction. The relative motion of two objects forms friction. From a macro perspective, the relative motion of two objects is the relative displacement of the two contact surfaces. From the perspective of microscopic particles, it is the relative displacement of the two particle clusters. The contact surface of the two particle clusters has obvious unevenness, and friction is the mutual collision of the convex parts of the contact surface. collision, we can infer that it is the pressure generated by the particles in the contact part. It can be considered that the essence of friction is: the pressure generated by the collision between the particles of the convex parts of the two relative motion contact surfaces .From the point of view of weak gas pressure, the molecular kinetic energy is increased, the molecular oscillation is intensified, and the radiation energy is in increased. From the perspective of high-intensity pressure, just like the principle of proton collider, proton collision produces the same effect of splitting, resulting in great atomic splitting and releasing a lot of energy. Therefore, the heat generated by friction is generated by The strong pressure between the contact parts. When the pressure is strong, the particle structure can be broken and changed, resulting in breaking excitation, thereby releasing a large amount of energy.

Its formula uses iron as an example to illustrate:

A (The Big Atom) B (Little atoms)+C (Little atoms) +Energy

From the calculation point of view, the frictional heat generation Q, is proportional to the contact surface pressure, P and speed V. It can be seen from this that pressure plays a decisive role in frictional heat generation.

The pressure formula for the collision of moving objects, p=mv/st. m is the mass, ΔV is the decrement in velocity, s is the contact area, and Δt is the action time. Substituting the data in can calculate the pressure at the touch. This formula extends to collisions between small particles and can be transformed into $p=mv^2/2\pi r^3$. V is the velocity and r is the particle radius.

Why, when there is a lot of stress, energy is generated? We know that there are a large number of high-speed moving electrons around each atomic nucleus. Although two relatively stationary objects are stationary when viewed as a whole, they still have high - speed electrons at the level of the atoms in the contact surface and relative motion. As long as the pressure is large enough to make the two particles come into close contact with each other, breaking the respective laws of motion of electrons around their nuclei, The particle structure will change, resulting in mass-energy conversion to release energy. This is the essence of frictional heat generation.

We know that there is a large space around the nucleus, and there is a magnetic field generated by the movement of electrons. When the pressure on the material is greater than the binding energy, the normal feeling is that the object begins to change in shape or diffuse and slide around. But what happens if there is no room for activity? Let us boldly imagine that matter begins to compress space. At first, it compresses the circulation space of magnetic field lines around the nucleus. The magnetic cycle of a single atom cannot be completed, and the large cycle of the magnetic field of matter is forcibly completed, and the magnetic energy is collectively released to the outside, forming external magnetism. In the past, matter had no magnetism, because individual particles had their own magnetic cycles and exhibited random magnetism to the outside world, so there was no magnetism. Under the action of pressure, the magnetism is concentrated and released in a concentrated direction, so it appears magnetic to the outside. This is the principle of the formation of magnetism, and the magnetism of geomagnetism and stars is formed in this way. This is my reasoned understanding of the formation of the Earth's magnetic field, and I hope you can refer to it.

Under the pressure of the magnetic cycle, the pressure continues to increase, and the electron circulation around the nucleus is blocked. In order to achieve the cycle, the atom releases a part of the energy ions to keep itself intact. Due to the release of heat energy, the object begins to heat up, and as the pressure continues to increase, the material slowly liquefies, then vaporizes, and finally completes ionization. Continuing, the ions begin to decompose. First, the large ions are decomposed into small ions, and the small ions continue to decompose into a soup composed of protons, neutrons, and quarks. Finally, the quantization is completely decomposed, and the energy generation process of a star is completed. The reaction of protons in the ion soup of proton quarks is the pattern in the proton collider. The ions collide with each other and break apart, forming smaller ions.

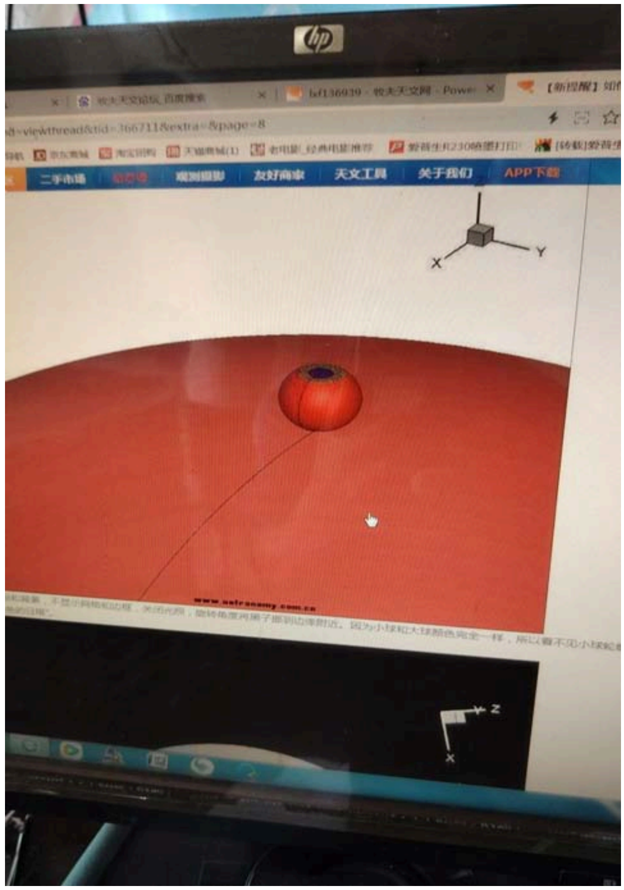
Triboelectricity is a phenomenon we all know, and the phenomenon of stone tip sparks shows that there is an ultra-high temperature energy release process at the stone tip. The power of one person completes the spark of the stone tip, the power of the earth's plates, produces a volcanic eruption, and the power of the earth has geothermal heat. This is what I know about the source of the earth's heat.

b) *The following is my understanding of the sun*

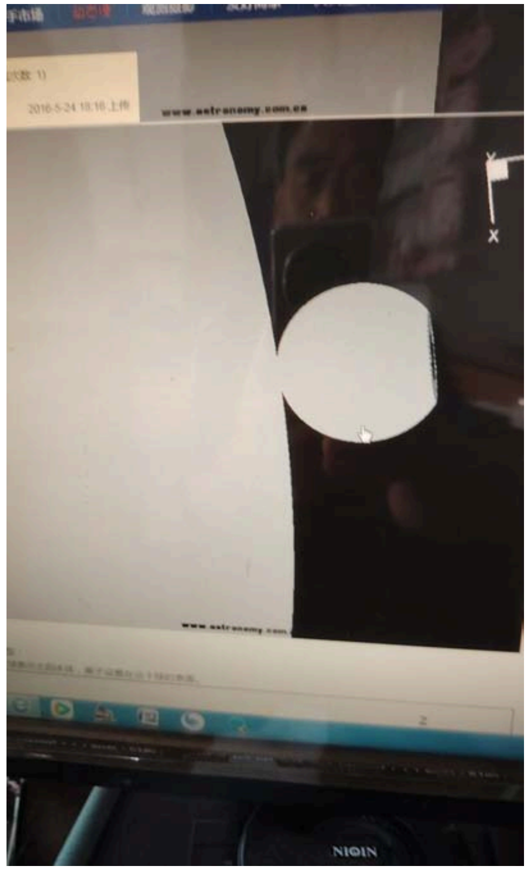
The sun is a liquid sun, which is substantially different from the gaseous sun recognized by the current mainstream of science. How stable is the gaseous sun, a series of problems such as the greater the mass, the lower the density. In particular, the understanding of the sunspot prominence flare is even more unclear and cannot be explained accurately.

The sun is a huge liquid metal hollow sphere, and its structure can be roughly divided into four layers: from the outside to the inside, respectively, the outer metal atmosphere layer, the liquid metal layer, the inner gas ion layer with metal large ions decreasing to small particle ions, The last formed quantum core area.

The extreme temperature and extreme pressure inside the star converts metal ions into light quanta to generate huge energy, which is the source of the huge energy of the sun. This huge energy heats and boils the metal on the surface of the sun, turns into metal gas and flies into space, forming the metal gas layer of the sun. This layer is what we usually think of as the burning surface of the sun. Thus forming the radiant feeling that people see. Most of the vaporized metal molecules liquefied and fell back to the sun after cooling in space, forming metal rain on the surface of the sun. Among them, the lighter metal molecules (such as sodium) gasify and cool down in the upper atmosphere for a long time to form solids. Because of its lower temperature, it is darker than its surroundings. The solid blocks are large, and they are seen on the earth. This is sunspots outbreak phenomenon. It forms like hailstones on Earth. When the sunspots fall back to the sun, they gather a large amount of other liquid or solid substances to form a larger volume, and when they fall, they splash huge waves to form solar prominences. The aroused liquid shallow place causes the overflow of internal ion hot, which can also form the eruption of solar flares. The prominence flare formed in this way is only accidental. Most of the prominence changes and flares are formed in this way. Solar prominences are formed by the cooling of the sun's atmospheric material in the air, just like the clouds on the earth. The darker black prominences are generally higher in height and relatively lower in temperature, and the shadows left on the surface of the sun are more obvious, but they will not Obviously, there are vague performances. As the height decreases, due to the heating of the prominence by solar radiation, a relatively high-temperature space is formed between the prominence and the sun's surface due to the greenhouse effect. As the temperature of the prominence increases, the color of the shadow will be roughly consistent with the color of the sun's surface. At this time, there will be an inconspicuous appearance, but there will be an obvious prominence phenomenon at the edge, but it will not be obvious after turning into the sun, and it will feel difficult to be found. As time goes by, the height will further decrease, and the temperature of the prominence will further increase. As it rises, the color begins to shine and it becomes white spots. As the temperature continues to rise, the cloud begins to evaporate or sublimate, and its volume expands rapidly, forming an evaporative flare explosion. Such a flare often has a large inner high pressure of the prominence, which produces a self-expansion, forming a huge flare. Such flares tend to push part of the prominence material directly out of the sun. Black shadow prominences generally do not fall back to the sun, only concentrated sunspot prominences will fall back to the sun, forming a splash-type flare explosion, if the sunspots are evaporated before falling back to the sun, it will form an evaporative flare explosion just like the black shadow prominence. There is a colorless stage between the white white spot and the black prominence, which gives people a wrong understanding, the shadow disappears automatically, the flare is produced instantaneously, and the place where there are sunspots is often the place where the prominence is concentrated, so the two are in the same place. The odds are high together, which is what I know about prominence sunspot flares.



These understandings are seen and summarized in the high-definition map of the sun. The pictures I collected on the Internet in 2021 show a spoon-like celestial system appearing in the space of the sun. Although the sunspot model described ten years ago does not have a handle, the body system is exactly the same. The photos show that the sunspots described by the mainstream theory are far from each other. So far, no one at home and abroad can explain this phenomenon clearly.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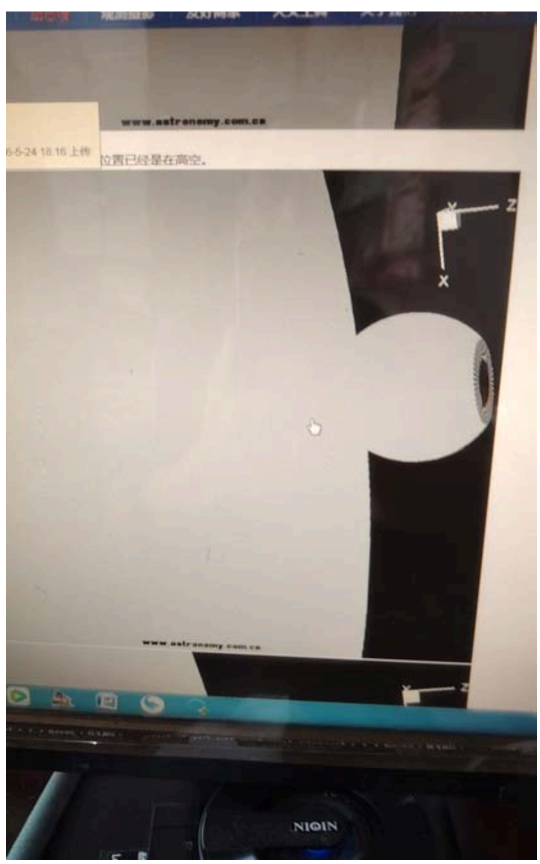
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The Sun, almost perfectly explained all the mysteries of the sun. A solid, almost unquestionable sun. In the past, hydrogen polymerization was said to solve the problem of solar energy. It has been more than a hundred years since hydrogen polymerization released energy, and there has been no successful experiment so far. There are too many doubts in spectral analysis, and my cooling law can better explain the problem of radiation spectrum.

Frictional heat generation is a phenomenon we all know. The phenomenon of sparks at the tip of the stone indicates that there is an ultra-high temperature energy release process at the tip of the stone. The power of a person completes the spark of the tip of the stone; the power of the earth's plate produces a volcanic eruption; the power of the earth has geothermal heat. The power of Jupiter has Dahongban; the power of the sun has radiance. From the perspective of natural phenomena, we make such inferences. However, whether our reasoning is correct or not can only be determined through the verification of pressure experiments, and the change state of matter under pressure is the root of unlocking the essence of frictional heat generation. (Note: In my planetary model, there is no gaseous planet, the sun is liquid, and Jupiter is a semi-liquid planet, which is the period when the earth collapsed. The description of the geomagnetic field here is definitely the current world, and the geomagnetic phenomenon, strongest explanation).

c) Three properties of matter

In my opinion, matter composed of elementary particles has three major properties:

1. Thermal radiation of the substance;
2. Cold polymerization of substances;
3. The thermal composition of matter.

Since my understanding of the properties of matter originated from the thinking of the sun and the universe, when explaining these issues, it is connected with the evolution of galaxies.

1. *Thermal radiation of matter*

Under extremely high pressure and temperature conditions, matter changes matter from atoms into ion matter, and then into a basic ion soup composed of protons, neutrons, etc., and then these ions collide with each other and annihilate each other in a high-energy state, becoming quantum beyond the speed of light is emitted into space, and this process happens inside the stars, and the sun is the closest one to us. It is in this form that stars eject matter. (Ions collide with each other in a high-energy state and annihilate into quanta, which has been proved in the European proton collision experiment.) No matter can exist in the ion state at the star's constant center. Can ions be completely quantized inside the star? Is the standard to measure whether a star can be established.

2. *Cold polymerization of substances*

The interior of the star annihilates matter, and starts its parabolic cosmic journey at the speed of light, and finally gathers in the extremely cold place on the edge of the galaxy to form a molecular cloud that revolves around the galaxy. Due to the rotation of the galaxy, the propagation of these light-speed matter The distance is greatly increased, and finally most of these substances cannot escape from the stars and galaxies vertically, and finally form molecular clouds at the edge of the galaxies, that is to say, the space with the galaxies as the reincarnation unit shrinks due to the rotation. These molecular clouds formed giant molecular clouds after cooling in the later stages of the galaxy. Matter is cooled in the low-temperature state at the edge of the galaxy, and the quantum is re-gathered, combined, and under the cooperation of pressure. The process of recombining into elementary particles and massive atoms is the cold polymerization of matter, and this process is also the reverse process of matter annihilation.

3. *Temperature composition of matter*

It is based on the current temperature of the earth, modern scientific research, and the various physical and chemical changes that occur between atoms and molecules that are composed of elementary particles used by people in production and life. All are temperature combination properties of matter. For example: C burns to generate CO_2, and then cools into dry ice; C, H, O form inorganic state, organic state, plants, animals, etc. are warm combinations of substances. Like iron changing from solid to liquid, and then into particle gas, it is also a combination of temperature. Until the process of becoming ion soup of protons and neutrons under high temperature and high pressure and annihilation to become quantum later, it is the heat dissipation of matter. The decay of massive atoms is also the thermal radiation of matter.

The three major properties of matter, the physical and chemical changes in modern people's understanding, research, and use of life, are only its warm composition, and its radiation radiation has been contacted, but not understood; the cold polymerization of matter, people There is neither contact nor awareness, and it happens in the black hole region where people have mysterious awareness. Some people have studied the cold polymerization of substances in the past, but there has been no progress so far. I think that the first is that the conditions are limited—the coldness is too small; the second is that the characteristics of cold polymerization and warm combination of substances have not been distinguished. What is said here is the key point of cold aggregation.

The main breakthrough of my thinking is to complete the imagination of the critical stage of the theory of cold aggregation, and to realize that matter is a complete cosmic cycle from radiation to aggregation. Since the starting point of my thinking is the cold aggregation of matter, it is the same as the hot aggregation of the current science. Mainstream has a substantial difference. As a result, there are great differences in views on things in the universe. For example, I think the cloud-shrouded Large Magellan system is a galaxy that is going out, while the clear Small Magellan system is a galaxy that has just been born.

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Physics of Gravity. Comments and Criticism of the Theory of Relativity

By I. V. Kuzminov

Abstract- The proposed article is an analytical review of previously published articles in the series "Physics of Gravity" and "The picture of the world according to the second law of thermodynamics". The main topic is the physics of gravity. This article presents the proposed hypothesis on the physics of gravity in a brief form. A critique of existing views on the topic of gravity is also presented. Currently, the generally accepted and dominant theory in the field of gravity is the General Theory of Relativity. The proposed hypothesis is based on the concepts and laws of classical Newton physics. At the same time, a critique of the existing theory of gravity, based on postulates, conventions and assumptions, is presented.

Keywords: physics of gravity, gyroscopic forces of rotation of electrons, temperature dependence, quadratic dependence of gravitational forces on distance.

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I. Introduction

As stated in the abstract, a review of the articles "Physics of gravity" and "The picture of the world according to the second law of thermodynamics" is offered [1], [2]. In other words, the article proposes an alternative version of the physics of gravity and rejects all existing ones put forward over the past hundred years. The proposed hypothesis is based on the concepts of classical Newton physics, the planetary model of the structure of the atom.

The article consists of two main parts. The first part is the proposed version with comments and additions, the second part is a criticism of existing versions. The very fact of the existence of many versions is evidence of the relevance of the topic of gravity. The article is constructive in nature, since a new alternative version, a hypothesis, is proposed. The proposed hypothesis explains the physics of gravity as such and the inverse temperature dependence of the forces of gravity. All existing versions (theories) of gravity physics do not even note the inverse temperature dependence of gravity forces.

II. The Proposed Version

The articles[1], [2] are conceptually related. The articles present the mechanism of formation of gravitational forces as a cumulative reaction of gyroscopic forces of rotation of electrons to the external impact of the Expansion of the Universe. The articles also note the inverse temperature dependence of the forces of gravity, namely, an increase in the temperature of objects reduces the forces of gravity, and vice versa. The inverse temperature dependence is explained by the change in the stiffness of interatomic, intramolecular, intermolecular bonds depending on the temperature of the object. Interatomic and intermolecular bonds are schematically represented in the form of a lattice. Electron rotation is the dynamic part of the gyroscope, interatomic and intermolecular bonds are the static part of the gyroscope. The reaction of the dynamic part is transmitted to the static part of the gyroscope. The result of an external influence (gravity) depends on the rigidity of the lattice. As the temperature increases, the rigidity of the lattice decreases, and vice versa. For example, an increase in stiffness increases the effect of the reaction of the gyroscopic forces of rotation of electrons on the lattice itself, thereby increasing gravity, and vice versa. The proposed article[1] presents an attempt to explain the quadratic dependence of gravity forces on the distance between objects. To understand the workings of the forces of gravity, it is necessary to constantly keep in mind that the Expansion of the Universe is initially, everywhere, constantly, isotropic. Accordingly, the reaction (gravity) is initially, everywhere, constantly, isotropic. Yes, there is a gravitational field. Any field must have an energy source. For the forces of gravity, this energy source is the energy of the Big Bang and its consequences – the Expansion of the Universe. This field extends to the entire universe. This is an indirect proof of the common origin of all things. Yes, there are controversial statements about the Big Bang. In any case, by indirect signs, we are in the phase of the expansion process. Moreover, it is quite possible that this expansion has a local character on the scale of the multiverse.

The main property of a gyroscope is the desire to maintain its original position, the desire to return to its original position. It is this property that is the main one in the formation of the forces of gravity and inertia. The proposed hypothesis does not question the existing calculation base, since it has an empirical basis.

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III. Criticism of General and Special Relativity

The main, dominant, generally accepted version on the topic of gravity is the General Theory of Relativity. The main points of criticism of the general theory of relativity are presented in the article [3]. In this article, we will consider some points in the theory of relativity. To begin with, there should be a general belief that classical physics should have priority in the study of physical phenomena. In other words, there is an objective physical phenomenon. There is a need to describe this phenomenon. Let's assume that classical physics cannot give a description of this phenomenon. In this case, some assumptions, postulates, and conventions are possible. In this case, some tricks are possible, the creation of some new theories. But if classical physics is quite capable of describing the phenomenon, why do we need these new theories, tricks, and so on. As an example, let's take the speed of light and Einstein's postulates on this topic, namely, postulate 1 and postulate 2. Wonderful postulate 1, everything is clear and understandable, there is nothing new, everyone agrees. But here postulate 2 arises. At first, everything is fine too – the speed of light has a limit. Like the speed of sound. There are no questions. The interpretation of this point raises questions. It is necessary to start with the fact that speed is a relative concept. It is pointless to impose any restrictions on this phenomenon. There are portable speeds, there is an addition of speeds, there is no absolute rest, that is, the whole universe is constantly in motion. Then there is classical mechanics, there is wave theory. Light has a wave nature, that is, it must obey the wave theory. The wave theory says that the speed of the wave does not depend on the speed of the wave source. The speed of light, the speed of sound, and the speed of the wave from the stem of the vessel must obey this law. A model for understanding this phenomenon can be taken as a wave from the stem of a vessel. There is nothing new in the statement that the speed of light does not depend on the speed of the light source.

Now let's return to postulate 1. We have two reference frames. Let's assume that the reference frame 1 is stationary. The reference frame 2 moves relative to the system 1 at a speed of V. The speed of light in the system 2 is C. For system 1, the speed of light of system 2 will also be equal to C, because the information (return signal) about this speed will pass at the speed of C. In other words, the illusion is created that the speed of C remains the speed of C in all reporting systems, the addition of speeds is excluded. The illusion is that in reality, the speed of the light front of system 2 in system 1 propagates at a speed of C+V. This illusion is described by the Lorentz transformations. The Lorentz transformations show the process of inhibition of signal transmission, while (in Einstein's interpretation) they exclude the existence of real events, namely the phenomenon of C+V. Postulate 2 (as amended by the general theory of relativity) assumes a certain absolutely stationary frame of reference and asserts the absoluteness of the speed of light. Now it is proposed to solve the problem. Let's say that engineers and scientists have created a spacecraft capable of moving in space for a long time with constant acceleration "g". How long will it take for the speed of the device to reach the speed of light? The answer is about 300 days, almost 1 year. Earthlings are constantly under the influence of acceleration equal to "g". It turns out that those who are now 50 years old have already overcome the speed of light 50 times. None of these people dissolved, disappeared, and so on, according to postulate 2. Einstein's postulates set the blinders on scientific research at the stage of hypotheses and assumptions.

For example, in the article[3] it was suggested that dark matter is material objects that move relative to us at superluminal speed. Accordingly, we are also dark matter in relation to this dark matter. It turns out that the blinders set by Einstein narrow the scope of research in this direction. Currently, dark matter is literally perceived as some kind of matter with special properties.

IV. Conclusions

The main conclusion of the article is that the gyroscopic forces of rotation of electrons are the basis for the formation of gravitational forces. The forces of gravity are the cumulative reaction of the gyroscopic forces of rotation of electrons from the Expansion of the Universe. It should also be noted that the Expansion of the Universe occurs initially, constantly, everywhere, isotropic, respectively, the reaction (gravity) is initially, constantly, everywhere, isotropic. Gravity is an indirect evidence of the common origin of all things – visible and invisible. The basis of the forces of gravity is the dynamics of the rotation of electrons, the combined gyroscopic forces from the rotation of electrons. With changes in temperature and distances between objects, the main influence on the change in gravitational forces is exerted by the forces of interatomic, intramolecular and intermolecular bonds, which form a kind of rigid lattice. The formation of a "rigid lattice" does not contradict the concepts of nuclear interactions. Changes in body temperature, distances between bodies change the rigidity of this lattice, respectively, changes the reaction forces, respectively, the forces of gravity. It is also necessary to note the general nature of the forces of gravity and inertia. As a conclusion to the article, it should be noted that postulate 2 contradicts postulate 1 of the special theory of relativity. Attempts have already been made to revise postulate 2. This article proposes a new version of postulate 2. Postulate 2. The speed of light in a vacuum is constant in all coordinate systems (tied to a light source in accordance with the theory of waves), moving rectilinearly and uniformly relative to each other in accordance with postulate 1. The speed of light is the limiting speed of transmission of the return signal during the transition (recalculation) from one coordinate system to another, while working the classic addition of speeds.

With modern approaches (special relativity theory) to this issue, the position arises that the Earth is the center of the Universe.

Lorentz transformations describe illusions that occur at near-light speeds. It is necessary to affirm in the minds of the general public that mass is a scalar quantity. Currently, mass is associated with gravity in the general public. It is for this reason that theories like Einstein's general theory of relativity arise. Einstein's theory is based on the action of gravity, which "deforms space", forms certain pits, and other matter rolls into these pits, again under the influence of gravity. Yes, gravity arises (in the form of a reaction) when a certain force from the outside, an external force, is applied to the mass. For example, the constantly acting external force of the expansion of the Universe. The force of the Expansion of the Universe causes a reaction in the form of gravity. Inertia forces are also a reaction to some other external influences. Centrifugal forces are also a reaction to giving rotational motion, momentum to a material body, mass. This is confirmed by the fact that if the external forces are balanced, then a state of weightlessness occurs.

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Instruction of Paralogistics Thermodynamics

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Аннотация- На ряде конкретных примеров показано, что подмена энергоносителя тепловой формы движенияэнтропией как координатой теплообмена приводит к ряду паралогизмов, число которых растёт по мере расширения сферы приложения термодинамики. Вскрыты гносеологические корни этих паралогизмов и предложенаболее общая мера количества хаотического движения, названная для краткости термоимпульсом. Показано, как его применение вместо энтропии устраняетпрактически все известные и обнаруженные авторомпаралогизмы, включая предсказание тепловой смерти Вселенной идеградации биологических систем.Сделан вывод, что замена энтропии термо-импульсомоткрываетпуть к расширению возможностей термодинамического метода при исследовании неравновесных систем и нестатических процессов, к синтезу термодинамики с другими фундаментальными дисциплинами и к более глубокому пониманию мироустройства.

Ключевые слова: энергия и энтропия, теплообмен и работа, диссипация и необратимость, биологическая и космологическая эволюция, парадоксы и паралогизмы.

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INSTRUCTIONOFPARALOGISTICSTHERMODYNAMICS

Strictly as per the compliance and regulations of:

Instruction of Paralogistics Thermodynamics

УСТРАНЕНИЕ ПАРАЛОГИЗМОВ ТЕРМОДИНАМИКИ

V. Etkin

Аннотация- **На ряде конкретных примеров показано, что подмена энергоносителя тепловой формы движенияэнтропией как координатой теплообмена приводит к ряду паралогизмов, число которых растёт по мере расширения сферы приложения термодинамики. Вскрыты гносеологические корни этих паралогизмов и предложенаболее общая мера количества хаотического движения, названная для краткости термоимпульсом. Показано, как его применение вместо энтропии устраняетпрактически все известные и обнаруженные авторомпаралогизмы, включая предсказание тепловой смерти Вселенной идеградации биологических систем.Сделан вывод, что замена энтропии термо-импульсомоткрываетпуть к расширению возможностей термодинамического метода при исследовании неравновесных систем и нестатических процессов, к синтезу термодинамики с другими фундаментальными дисциплинами и к более глубокому пониманию мироустройства.**

Ключевые слова: энергия и энтропия, теплообмен и работа, диссипация и необратимость, биологическая и космологическая эволюция, парадоксы и паралогизмы.

I. Введение

Прошло более полутора столетий с той поры, как в естествознание вошло понятие энтропии и принцип её возрастания в необратимых процессах [1]. Однако до сих пор не утихают споры о сокровенном смысле этого понятия и о физических основаниях упомянутого принципа [2], приведшего к утрате термодинамикой былой славы теории, «чьи выводы никогда и никем не будут опровергнуты»[3]. В обширной научной и околонаучной литературе ей посвящены сотни книг и тысячи статей, где эти вопросы обсуждены с различных точек зрения [4]. Тем не менее до сих пор не доказана исчерпывающим образом несостоятельность теории тепловой смерти Вселенной Р. Клаузиуса [2] и не устранено «вопиющее противоречие термодинамики с эволюцией» [5]. Тем временем понятие энтропии перешагнуло границы физики и проникло в самые сокровенные области человеческой мысли. Наряду с термодинамической энтропией Р. Клаузиуса появилась статистическая, информационная, математическая, лингвистическая, интеллектуальная и т. п. энтропии, что ещё более осложнило интерпретацию этого многоликого и плохо поддающегося интуитивному восприятию понятия.

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На этом фоне оставались незамеченными попытки доказать неадекватность понятия энтропии существу дела [6]. Напротив, сходная с парадоксом Гиббса и теорией тепловой смерти ситуация возникла практически в каждой области приложения термодинамики, включая излучение, нетепловые и релятивистские машины, биологические системы и системы с отрицательными абсолютных температурами и дискретной энергией, и т. п. [7]. Энтропия стала «ахиллесовой пятой» термодинамики и «козлом отпущения» за «любую и всякую» необратимость [8].

Цель этой статьи – показать, насколько полезной может быть замена энтропии термоимпульсом как более адекватной экстенсивной мерой теплового движения.

II. Необходимость Переопределения или Изгнания Энтропии из Термодинамики

Понятие энтропии в термодинамике Р. Клаузиуса[1] неразрывно связано с его представлением о теплоте Qи работе W как о двух единственно возможных способах энергообмена системы с окружающей средой. Это следует из его записи её основного закона (1-го начала термодинамики) в виде:

$$dU = \delta Q - \delta W = TdS - pdV, \qquad (1)$$

где U – внутренняя энергия системы;δQ,δW-элементарные количества тепла, поглощённого системой, и работы, совершённой ею; T, S – абсолютная температура и энтропия;p, V- абсолютное давление и объём системы.

Между темдо Клаузиуса существовало другое представление о теплоте как о невесомом и неуничтожимым флюиде, именуемым теплородом. При этом теплотарассматривалась в одном ряду с такими явлениям, как свет, электричество, магнетизм и т. п., т. е. как функция состояния, а не процесса. Такое понимание теплоты до сих пор сохранилось в классической термодинамике в понятии теплоёмкости системы[9] и в теории теплообмена, который определяется как процесс обмена между телами внутренней тепловой энергией[10]. Более того, такое понимание оказалось единственно приемлемым и для термодинамики необратимых процессов (ТНП), оперирующей понятием внутренних источников тепла[11-1 4.]Да и сам Р. Клаузиус первоначально оперировал понятием «полной теплоты тела» как суммы теплоты, подведённой извне и выделившейся внутри тела в результате совершения «работы

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дисгрегации» диссипативного характера [1]. Однакотакая подмена понятия теплоты стала более заметной с переходом к изучению открытых систем, где наряду с теплообменом и работой существует по крайней мере ещё двавида энергообмена: массообмен, характеризующийся изменением массы системы при неизменности её состава, и диффузияk-го вещества через границы системы, характеризующаяся изменением состава системы при неизменности её массы. При этом на границе, где имеет место массообмен или диффузия, «классические понятия теплоты и работы теряют свой смысл» [15]. Ещё более проблемным стало деление энергообмена на теплообмен и работу в сложных (поливариантных) системах, совершающих помимо работы расширения δW_p= pdV другие виды внешней работы W^e (механических, электрических и т. п. сил). Элементарные количества этих видов внешней работы dW^e измерялось произведением вектора результирующей силы F на вызванное ею перемещение drобъекта её приложения, а сама работаd W^e= dE = $F_i \cdot dr_i$ представляла собой количественную меру процесса превращения внешней энергии E из одной (i-й) её формы E_i в другую (j-ю)E_j. Такая работа не зависела от пути процесса, а её элементарное количество dW^e являлось полным дифференциалом.К ней относилась и работа газа в потоке –Vdp[16]. Этивиды работы принципиально отличалась от работы всестороннего расширения pdVпрежде всего направленностью процесса перемещения (векторной природой своих координат $\mathbf{r}_i$), а также зависимостью от пути (характера) процесса (последнее подчёркивается обозначением её элементарного количества через δW). Такого вида работа совершается не только при расширении, но и при вводе в систему вещества, заряда, импульса и любого другого энергоносителя. К их числу следует отнести и теплообмен, поскольку он также связан с изменением импульса хаотического движения частиц, составляющих систему.

Чтобы различать две эти независимые категории работ, целесообразно называть их соответственно «техническими» $W^т$и«нетехническими» $W^н$. Непонимание того, что «работа работе рознь», до сих пор мешает осознать, что истинная «линия водораздела» проходит не между теплотой Q и работой W, а между упорядоченными$W_i^т$ и неупорядоченными $W_i^н$ видами работ как количественными мерами принципиально различных процессов «*энергопревращения*» и «*энергопереноса*»[17]. Следует заметить, что для сложных систем, в которых протекают и те, и другие процессы,доказательств существования энтропии как координаты теплообменадо настоящего времени не существует [18].

Имеется ещё одно обстоятельство, вынуждающее возвратиться к поиску более общей экстенсивной меры теплоты (её энергоносителя), нежели энтропия. Оно заключается в том, что в механике, на основе которой возникла термодинамика, все процессы считались обратимыми (идущими как в прямом, так и в обратном направлении без каких-либо остаточных изменений в окружающей среде). Таковой была и теория тепловых машин С. Карно [19], базирующаяся на предложенном им методе циклов. Само понятие цикла предполагало возможность возвращения рабочего тела тепловой машины в исходное состояние, т. е. обратимость происходящих с нимпроцессов, что вполне соответствовало представлению о теплороде как носителе тепловой формы энергии. По-видимому, лишь полное крушениепредставлений о неуничтожимых и невесомых флюидах помешало Клаузиусу увидеть это и перейти к трактовке теплоты лишь как количественной меры процесса теплообмена. Возможно, этому способствовало и свойство теплоты перетекать «самопроизвольно» лишь в направлении понижения температуры, которое было положено им в основание его формулировки 2-го начала термодинамики [1]. В любом случае понимание теплоты как «энергии в состоянии перехода», т. е. как функции процесса, потребовало отыскания координаты этого процесса, т. е. параметра, с необходимостью изменяющегося приего протекании и остающегося неизменным в его отсутствие (в адиабатических системах). Эту координату Р. Клаузиус нашёл путём рассмотрения того же самого цикла идеальной (обратимой) тепловой машины, однако он назвал её «энтропией», подчёркивая тем самым противоположное теплороду свойство этого энергоносителя возрастать в результате появления внутренних источников тепла. Нагляднее всего это проявилось в записи уравнения баланса энтропии[11]:

$$dS = d_eS + d_uS, \qquad (2)$$

где совершенствования методов анализа, = $\delta_e Q^e/T$ и d_uS = $\delta Q^e/T$ – части изменения энтропии, обусловленные соответственно внешним теплообменом Q^e и внутренними источниками тепла $Q^д$.

Согласно этому выражению, любые необратимые процессы, вызывают изменение одного и того же параметра – энтропии S. Так энтропия превратилась в «козла отпущения» за «любую и всякую необратимость», хотя изначально предназначалась для описания теплообмена. Не изменился статус энтропии и после того, как обнаружились внутренние источники или стоки и у других параметров, в частности, у чисел молей k-х веществ N_k, возникающих или исчезающих в ходе химических реакций. С расширением термодинамики на сложные (поливариантные) и неравновесные (в том числе открытые, биологические и химически реагирующие) системы, а также на нетепловые и нециклические машины, связанные с энтропией паралогизмы стали возникать практически в каждой области приложения термодинамики [20]. Энтропия стала «раковой опухолью и «ахиллесовой пятой» термодинамики [21]. Однако понимание того, что все эти неудачи объясняются попытками изучать необратимые процессы средствами равновесной термодинамики, оставалось достоянием лишьнемногих

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учёных-одиночек [22]. Этим, по-видимому, и объясняется живучесть этого понятия и отсутствие попыток построения термодинамики на безэнтропийной основе.

Для поиска более адекватной меры количества хаотического движения, играющей по отношению к внутренней энергии U_q роль энергоносителя, целесообразнообратиться к понятиям«количества движения» Mv и«живой силы» Mv^2, введённых ещё в XVII столетии Р. Декартом[23]и Г. Лейбницем [24]. Обе эти меры относились к внутреннему колебательномудвижению. Именно «живая сила» была переименована по предложению Т. Юнга (1807) в «энергию», а после введения потенциальной энергии – во внутреннюю энергию U. Именно она послужила основой для определения энергии эфира U = Mc^2Г. Шрамму (1871); Н. Н. Умов у (1873); Дж. Томсону (1881); О. Хэвисайду (1890), А. Пуанкаре (1898) иФ. Хазенорлю (1904). Эта энергия вдвое больше кинетической энергиинаправленного движения $M\mathbf{v}^2/2$ при том же значении средней скорости v = |**v**|, которое возникает в системе в результате коллективного (макроскопического) движения при вращении, диффузии и т. п. [14]). Тогда может возникнуть его результирующий импульс J = Mv, энергиякоторого становится внешней $E_{кин}$. По мере же затухания колебаний (v→0) и возникновения устойчивых структур часть «живой силы» переходит во внутреннюю потенциальную энергию $U_{пот}$. Эта энергия также становится внешней $E_{пот}$, если центр массы системы изменяет своё положение относительно окружающей среды.Таким образом, внутренняя энергия U – отнюдь не всегда является рассеянной частью внешней энергии, каковой её представляет закон сохранения энергии в механике неконсервативных систем:

$$(E_{кин} + E_{пот} + U)_{из} = const. \quad (3)$$

То, что внутренняя энергия является целым, а не частью, становится особенно очевидным, если учесть, что для изолированных системпонятие внешней энергии утрачивает всякий смысл. Таким образом, именно внутренняя энергия U является величиной, сохраняющейся в изолированных системах, и лишь её часть за вычетом упорядоченных составляющих $U_{кин}$ и$U_{пот}$ целесообразно назватьвнутренней тепловой энергией U_q. Это соответствует закону сохранения вида:

$$(U_q + U_{кин} + U_{пот})_{из} = const. \quad (4)$$

Такой подход способствует устранению создавшейся ситуации, когда «современная физика не знает, что такое энер гия» [2 5.] Если к тому же под абсолютной температурой Т(К) пониматьмеру интенсивности хаотического движения, то внутреннюю тепловую энергию U_qможно представить по аналогии со «связанной энергией» Гельмгольца TS в виде произведения $U_q = T\Theta_q$, понимая под Θ_q экстенсивную меру количества этого движения[26]:

$$\Theta_q = U_q/T, (Дж\ К^{-1}) \quad (5)$$

назвав её для кр аткости « тер моимпульсом» (т. е. импульсом, утратившим векторную природу вследствие хаотичности движения).Этот термоимпульс включает в себя поступательную, вращательную и колебательную составляющую скорости v, что делает его зависящим, подобно теплоёмкости, от числа степеней свободы частиц системы. Правомерность представления U_qв виде произведения $\Theta_q T$ (Дж) подтверждается тем, что в этом случае её дифференциал

$$dU_q = Td\Theta_q + \Theta_q dT \quad (6)$$

корректно отражает изменение внутренней тепловой энергии как вследствие внешнего теплообмена $Td\Theta_q$, так и при возникновениивнутренних источников тепла$\Theta_q dT$ вследствие диссипации. Такое представление dU_q, справедливость которого будет подтверждена ниже, полностью укладывается в рамки правил дифференциального исчисления, чего не скажешь о слагаемых d_eS и d_iS в уравнении (2).Отличие внутренней тепловой энергии U_qот связанной энергии TS, которую также можно интерпретировать как энергию, связанную с тепловым движением, связано с членом $\Theta_q dT$, который обращается в нуль в изотермических процессах, например, вхимических реакциях, где $\delta Q = Td\Theta_q = TdS$. В таких случаях понятия свободной энергии Гельмгольца U–TSи энергии Гиббса U+pV –TSсохраняют свой смысл. Однако в других случаях это р азличие проявляется весьма наглядно, что и будет показано ниже.

III. Устранение Паралогизмов, Связанных С Энтропией

Как было показано выше, подмена Р. Клаузиусом понятия «теплоты тела» как количественной меры его внутренней тепловой энергии U_q более узким понятием «теплоты процесса» Q как количественной мерой процесса теплообмена и введение энтропии как координаты этого процесса ограничила термодинамику рассмотрением равновесных систем и обратимых процессов, у которых отсутствуют внутренние источники тепла. Это превратило классическую термодинамику Клаузиуса в термостатику, ограничивающуюся изучением равновесных систем и бесконечно медленных процессов. Поскольку с появлением упомянутых внутренних источников тепла энтропия могла только возрастать, был сделан ошибочный вывод об односторонней направленности всех процессов во Вселенной и навязало ей не свойственную природе вещей «стрелу времени». В этом отношении несомненным преимуществом термоимпульса Θ_qперед энтропией является его способность как возрастать в процессах перехода упорядоченных форм энергии в тепловую, так и убыватьв процессах эволюции, сопровождающихся возникновением «порядка» их

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«хаоса» [27]. Именно таковы процессы формирования всех (микроскопических и макроскопических) форм вещества Вселенной.

Существование термоимпульса обладает той степенью очевидности, которая удовлетворяет понятию феноменологической теории. Онзаведомо существует в системах с максвелл-больцмановским распределением скорости и импульса частиц, что освобождает от необходимости поиска путей обоснования существования энтропии в неравновесных системах и её применимости к реальным процессам. Его интерпретациине требует привлечения молекулярно-кинетической и статистико-механической теорий, что делает термодинамику вполне самодостаточной теорией. Остаётся показать, что использование термоимпульса вместо энтропии устраняет практически все упомянутые выше паралогизмы термодинамики.

a) Исключение неравенств из математического аппарата термодинамики

Известно, что объединённое уравнение 1-го и 2-го законов термодинамики в случае необратимых процессов принимает вид неравенства:

$$TdS>dU + pdV. \qquad (6)$$

Причиной возникновения неравенств является то, что в отсутствие равновесия в системе появляются внутренние источники тепла, в результате которых$TdS>\delta Q$. Аналогичные неравенства возникают, вообще говоря, и у других параметров Θ_i, в том числе и для её объёма V, который может увеличиваться при расширении системы в пустоту без совершения работы $\delta W_p{}^н= pdV$. Это обстоятельство является основным препятствием для применения термодинамического метода исследования к другим дисциплинам, изучающим реальные (нестатические) процессы.

Между тем возможен иной подход к выводу основного уравнения термодинамики, изначально ориентированный на исследование внутренне неравновесных (неоднородных) систем с протекающими в них нестатическими процессами. Этот метод основан на представлении внутренней энергии U_iкаждойi-йстепени свободы системы неизменного объёма Vв параметров неравновесности системы как целого Z_i. Эти параметры можно найти по известному распределению плотности $\rho_i = d\Theta_i/dV$ их энергоносителейΘ_i (массы M, числа молей k-х веществ, термоимпульсаΘ_q, заряда З, импульса J =Mv, его момента Lи т. д.) по объёму системы V. При этом неоднородность их распределения выражаетсясмещением радиус-вектора их центра R_i от егоположения в равновесном (однородном) состоянии R_{io}, Последние определяются известным образом[28]:

$$R_i = \Theta_i^{-1}\int\rho_i (r, t)rdV;\ R_{io} = \Theta_i^{-1}\int\rho_{io}(t)\, rdV, \qquad (7)$$

гдеr - бегущая (эйлерова) пространственная координата; t - время.

Отсюда следует существование в неоднородных системах некоторого «момента распределения», имеющего смысл вектора поляризации системы в самом общем понимании этого термина:

$$Z_i=\Theta_i(R_i - R_{io}) =\int[\rho_i (r, t) - \rho_{io}(t)]\, rdV \qquad (8)$$

с плечом$\Delta R_i= R_i - R_{io}$, названым нами «вектором смещения».

Поскольку в равновесии $R_{io}=0$, $dZ_i= \Theta_i dR_i$, товнутренняя энергия системы в целом U как сумма парциальныхэнергий $U_i=U_i (Z_i)$ становится функцией независимых переменныхΘ_i и R_i:$U = \Sigma_i U_i (Z_i)$. В таком случае её полный дифференциал можно представить в виде тождества [27]:

$$dU\equiv\Sigma_i\Psi_i d\Theta_i+ \Sigma_i F_i\cdot dR_i, \qquad (9)$$

где $\Psi_i\equiv (\partial U_i/\partial\Theta_i)_R$– усреднённые значения обобщённых локальных потенциалов ψ_i (абсолютной температурыTи давление p, химического потенциала*k*-го компонентаμ_k, его электрического φ и гравитационного потенциала ψ_g и т.п.); $F_i\equiv (\partial U_i/\partial R_i)_\Theta= \nabla U_i$– силы в их общефизическом понимании.

Члены 1-й суммы этого тождества описывают процессы приобретения или утраты парциальной энергии U_i независимо от того, чем они вызваны: переносом энергоносителя Θ_i через границы системы или появлением его внутренних источников. Члены же 2-й суммы описывают внутреннюю работу, совершаемую при превращении в i-ю энергию U_i других её форм, т. е. её внутренние источники. В однородных системах (dR_i=0) это выражение переходит в объединённое уравнение 1-го и 2-го начал классической термодинамики поливариантных систем $dU \equiv \Sigma_i\Psi_i d\Theta_i$[9].

Главное достоинство тождества (9) состоит в том, что оно устраняет неопределённость понятия парциальной энергии любой степени свободы неравновесной системы U_iи даёт единое определение понятия силы F_i как её градиента. Действительно, выражение $F_i\cdot dR_i$ легко преобразовать к виду $\Theta_i d\Psi_i$ как аналогу работы газа в потоке Vdp, или к выражению $X_i\cdot J_i dt$, если ввести понятия термодинамической силы $X_i = F_i/\Theta_i$ и потока $J_i=dZ_i/dt= \Theta_i v_i$, каковыми оперирует ТНП. В таком случае выражения (5) и (6) становятся частным случаем общего выражения парциальной энергии $U_i=\Psi_i\Theta_i$ любой степени свободы системы как произведения её количественной и качественной меры, а термодинамические силы X_iи потоки J_i приобретают однозначный смысл напряжённости состояния энергоносителя и его импульса.

Визолированных системахизменение параметров Θ_i обусловлено исключительно возникновением их внутренних источников $d\Theta_i/dt$, так чтозакон сохранения энергии в них dU/dt=0 принимает простой вид:

$$\Sigma_i\Psi_i d\Theta_i/dt+ \Sigma_i X_i\cdot J_i =0. \qquad (10)$$

Уникальность этого закона состоит в том, что он утверждает наличие источников или стоков энергоносителя $d\Theta_i/dt$ не только у энтропии, но в общем случае у любой степени свободы системы. Это означает не только возможность возникновенияв изолированной неравновесной системе неё новых свойств и исчезновения старых, т.е. её эволюции и инволюции, и отсутствие в ней законов сохранения любого из энергоносителей [29], чего современная физика не допускает.

С другой стороны, выражение (10) дает возможность исследования внутренних процессов в изолированных системах, не расчленяя их на элементарные объёмы dVи не увеличивая тем самым число степеней их свободы до бесконечности. При этом сохраняются так называемые «системные» свойства объекта исследования, отсутствующие в его отдельных частях.

Наконец, уравнения (9) и (10) дает единое определение понятий, которыми оперирует термодинамика, механика, электродинамика идругие дисциплины. Это открывает возможность их дальнейшего синтеза [30].

b) *Устранение неопределённости потенциала компонента*

Начало применению равновесной термодинамики к исследованию процессов диффузии, химических и фазовых превращений, связанных с изменением массы и состава исследуемой системы, положили работы Дж. Гиббса[31]. Он преодолел ограниченность классической термодинамики гомогенными системами остроумнейшим способом, представив закрытую в целом систему как совокупность открытых однородных подсистем, т. е. сведя внутренние процессы изменения состава системы в химических реакциях, процессах диыызии и т п. к процессам анешнего избирательного массообмена через полупроницаемые мембраны, воображаемые вентили и т. п. Однако некоторые процессы в открытых системах оказались настолько своеобразными, что «объяснить и подтвердить их закономерности на основе классических концепций не представляется возможным» [32]. В частности, наряду с теплообменом и работой расширенич в таких системах появились ещё два вида энергообмена: обычный массообмен (пернос вещества без изменения состава системы) и избирательный массообмен (диффузия *k*-х веществ через границы системы, связанная с изменением состава системы без изменения ее массы).

В таком случае внутренняя энергия системы *U* становится функцией чисел молей N_kвсех *k*-х независимых компонентов и фаз системы $U= U(S, V, N_k)$, а объединённое уравнение 1-го и 2-го начал равновесной термодинамики принимает вид соотношения Гиббса [9]:

$$dU = TdS – pdV + \Sigma_k \mu_k dN_k \qquad (11)$$

где S, V – внутренняя энергия, энтропия и объем открытой системы;$p = -(\partial U/\partial V)_{T,Nk}$,$T = (\partial U/\partial S)_{V,Nk}$ – абсолютные давление и температура$\mu_k= (\partial U/\partial N_k)_{S,V,Nm}$ – химический потенциал компонента, найденный в условиях постоянства S, V и числа молей N_mвсех

Записывая это выражение, Гиббс полагал, что «энергия *U*, очевидно, будет функцией S, Vи M_k» как независимых переменных, а первый и второй члены (11) по-прежнему характеризуют теплообмен и работу расширения равновесной системы. Однако в дальнейшем [20]выяснилось, что это далеко не так. Энтропия $S = sM$и объём $V = \upsilon M$ многокомпонентной системы с необходимостью изменяется как при массообмене ($M\neq const$),так и при изменении её составаNk/N):$S = s_kN_k$, $V = \upsilon_kN_k$ при неизменных парциальных молярных энтропиях s_{k}и объёмахυ_k компонентов. Это явным образом нарушают условие постоянства энтропии Sи объёме *V* в уравнении (11) , заложенное Дж. Гиббсом при определении понятия химического потенциала μ_k, вследствие чего значение потенциала компонента в процессах массообмена, диффузии и осмоса оказываются различными со всеми вытекающими для термохимии последствиями [20].

Положение меняется, если вместо энтропии как координаты теплообмена используется термоимпульс Θ_qкак более общий параметр, изменяющийся не только при теплообмене, но и в процессах диффузии и осмоса. В этом случае постоянство Θ_q гарантирует их отсутствие, так что производная$\mu_k= dU_k/dN_k$ однозначно задаёт удельную величину энергии k-го компонента, вводимого в систему. Это соответствует записи соотношения Гиббса (11) в компактной форме, основанной на гипотезе локального равновесия [14]:

$$dU = \Sigma_i\psi_i d\Theta_i. \qquad (12)$$

При этом свободные энергии Гельмгольца F и Гиббса G сохраняют свой смысл и величину, поскольку в этом случае $dU = Td\Theta_q= TdS$.

c) *Устранение произвола в выборе движущих сил реальных процессов*

Когда говорят о революции в физике XX столетия, то обычно имеют в виду квантовую механику (КМ) и теорию относительности (СТО и ОТО). Между тем наряду с ними в первой трети того же столетия возникла ещё одна не менее фундаментальная теория – термодинамика необратимых процессов (ТНП). Эта теория, получившая название термодинамики необратимых процессов [12-14], базировалась на пионерских работахбудущего нобелевского лауреата Л. Онзагера [33], который в1931 г. предложил «квазитермодинамическую» теорию скорости необратимых физико-химических процессов. Эта теория впервые преодолелаограниченность термодинамики квазистатическими процессами [11-14]. Основными величинами, которыми оперирует она, являютсяскалярные «термодинамические» силы X_i и «потоки» J_i. Эти величины находятся в ней на основе

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выражения для скорости возникновения энтропии dS/dt как функции неких параметров α_i, характеризующих удаление таких систем от равновесия:

$$dS/dt = \Sigma_i(\partial S/\partial \alpha_i)\, d\alpha_i/dt = \Sigma_i X_i J_i. \qquad (13)$$

Однако параметры α_i равновесной термодинамике были заведомо неизвестны.Поэтому его теория оставалась, по существу, пустым формализмом до тех пор, пока другой будущий нобелевский лауреат И. Пригожин не предложил метод нахождения этих величин для «стационарных» необратимых процессов [9]. Для этого он выдвинул гипотезу локального равновесия, согласно которой в элементах объёма континуума dV существует равновесие (несмотря на протекание в них нестатических процессов), так что их состояние характеризуется тем же набором переменных Θ_i, что и в равновесии (несмотря на появление дополнительных термодинамических сил X_i), а к ним применимы все соотношения равновесной термодинамик (несмотря на неизбежный переход их в неравенства).

При всей своей внутренней противоречивости эта гипотеза позволяла находить векторные силы X_i и потоки J_i, используязаконы сохранения массы, импульса, заряда и энергии, взятые из других дисциплин. Это требовало составления довольно сложных и громоздких уравнений их баланса с целью выделения из dS/dtтой их части d_uS/dt, которая характеризует «производство» энтропии вследствие диссипации. Однако и в этом случае разложить «производство энтропии» на сомножители X_iи J_i можно множеством способов. Это обусловило известный произвол в их физическом смысле и размерности.Такой произвол совершенно недопустим, когда речь идёт не о рассеянии энергии, а о процессах её преобразования, поскольку искажает ихразмерность и физический смысл сомножителей [36]. Этот недостаток устраняется, если силы X_iи потоки J_i находить непосредственно из соотношения (10). При этом отпадает необходмсость в составлении упомянутых уравнений баланса, что составляет основную трудность приложения ТНП к различным системам [14].

d) Устранение «приоритета» теплового равновесия

В уже упомянутой работе [31] Дж. Гиббс, применяя в качестве условия равновесия минимум внутренней энергии U, нашёл условия термического, механического и материального равновесия гетерогенных систем:

$T' = T''$; (тепловое равновесие);

$p' = p''$; (механическое равновесие) (14)

$\mu_k' = \mu_k''$. (материальное равновесие),

где одним и двумя штрихами обозначены температура T, давление p и химический потенциалμ_k k-го вещества многокомпонентной системы.

Иной результат получается при использовании в качестве критерия равновесия принципа максимум энтропии $S = S(U, V, N_k) = \max$, вариация которой δS по энергии U, объёму V и числам молей N_k приводит к условиям равновесия [13]:

$$T' = T''\,;\; p'/T' = p''/T''\,;\; \mu_k'/T' = \mu_k''/T''. \qquad (15)$$

Несложно заметить, что два последних равенства требуют предварительного выполнения условия теплового равновесия T = T̎. Отсюда обычно делается вывод об особой роли теплового равновесия, без которого якобы не может наступить ни механическое, ни материальное равновесие. Несоответствие этого результата экспериментам, при которых наблюдалось прекращением обмена k-ми веществами в условиях нарушения теплового равновесия, общеизвестно [13]. Между темстремление ТНП удовлетворить условиям (13) приводит к тому, что термодинамические силы $X_i=\Delta\psi_i/T$в ТНП в обязательном порядке содержат температуру, что делает разнородные силы взаимосвязанными. Последнее и послужило основой Л. Онзагеру для постулирования зависимости скорости любого релаксационного процесса J_i от всех действующих в системе сил X_i, ощибочность которого будет показана ниже.Таким образом, замена энергетических критериев равновесия энтропийными не просто искажает условия механического и материального равновесия, найденные Гиббсом, но и меняет результаты термодинамического анализа.

e) Устранение конфликта ТНП с понятием результирующей силы

ТНП обогатила физическую мысль XX столетия рядом принципов общефизического зарактера и установила принципиальную возможность самоорганизации в системах, далёких от равновесия. Онавернула в термодинамику понятие силы, утраченное со времён С. Карно, и объяснила множество эффектов, возникающих при одновременном протекании в одних и тех же областях пространства нескольких разнородных необратимых процессов. Вклад ТНП в парадигму XX столетия был оценён присуждением двух Нобелевских премий (Л. Онзагер, 1968, И. Пригожин, 1977).

Однако ТНП до сих пор базируется на принципе возрастания энтропии и ряде гипотез и постулатов, что лишает её необходимой полноты и строгости. Один из таких постулатов – принцип линейности Л. Онзагера, согласночто которому любой независимый поток J_i (тепла, вещества, заряда, импульса и т. п.) линейно зависит от всех действующих в системе термодинамических сил X_j [33]:

$$J_i = \Sigma_j L_{ij} X_j, (i, j = 1,2,\ldots n) \qquad (16)$$

где L_{ij}– коэффициенты пропорциональности, названные Онзагером «феноменологичес-кими», как и сами эти уравнения.

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Главный смысл этих законов заключался в утверждении всеобщей взаимосвязанности реальных (нестатических) процессов. Положительный знак всех членов суммы (16) дал основание идее «синергетизма», т. е. усиления эффекта в результате кооперативного действия. Однако эти уравнения расходились с законами теплопроводности (Фурье), диффузии (Фика), электропроводности (Ома), фильтрации (Дарси), вязкого трения (Ньютона) и т. п., в которых упомянутые потоки имели единственную (результирующую) движущую силу F_i, выражающуюся градиентытемпературы, химического и электрического потенциала, давления, скорости и т. п.

$$J_i = - L_i F_i, \qquad (17)$$

Коэффициенты L_i в этих законах являлись функциями параметров и структуры системы и не были величинами постоянными, так что законы (14) были нелинейными. Поэтом отнесение уравнений (16) к «феноменологическим» (полученным из опыта) не соответствовало, строго говоря, действительности. Это относится и положительному знаку всех членов матричной формы (15), что, как показал Х. Казимир [12-14], справедливо далеко не для всех сил. Кроме того, оставалось совершенно непонятным, каким образом могут быть связаны заведомо независимые потоки.

Причину указанного несоответствия можно понять, если исходить не из идеи «наложения» (суммирования) источников энтропии, вызванных действием разнородных диссипативных сил X_j, а из механики, утверждающей существование результирующей F_i этих сил. В изолированных системах сумма внутренних сил $\Sigma_i F_i (i = 1, 2…n)$ всегда равна нулю. Это означает, что в согласии с третьим законом Ньютона любую из приложенных сил них F_i можно выразить суммой n-1 сил реакции F_j иного, j-го рода: $F_i = - \Sigma_{n-1} F_j$. Поскольку $X_i = F_i/\Theta_i$, законы (16) можно представить в матричной форме, подобной (15):

$$J_i = L_i \Sigma_{n-1} (\Theta_j/\Theta_i) X_j = \Sigma_j L_{ij} X_j. \qquad (18)$$

Коэффициенты $L_{ij} = L_i \Theta_j/\Theta_i$ в этом выражении объединяют в себе кинетические и термодинамические факторы, что и объясняет, почему их аналоги L_{ij} в (14) не имеют смысла ни тех, ни других [12]. Таким образом, появляется возможность обосновать матричную форму законов переноса, не прибегая к их постулированию, и в то же время упростить их путем нахождения результирующей движущей силы любого независимого процесса и приведения законов (16) к их «диагональной» форме (18) [35].

f) Устранение «дискриминации» тепловых машин

Принято считать как нечто само собой разумеющееся, что максимальный КПД любой нетепловой машины (механической, гидравлической, электрической и т. п) близок к единице, тогда как для тепловых машин-двигателей, энергия к которым подводится в форме тепла Q_1, он ограничен температурами подвода и отвода тепла и на практике редко превышает 40%.

Такая «дискриминация» тепловых машин основана на убеждении, что энергия, подведённая к машине в упорядоченной форме, может быть целиком превращена в любой другой её вид[9]. Отсюда –деление всех форм энергии на *энтропийные* и *безэнтропийные* [36]. Отголоски такого деления звучат в утверждениях о неприменимости2-го закона термодинамики (принципа исключённого вечного двигателя 2-го рода) к нетепловым машинам, а такжев необоснованных упрёках в адрес тепловых электрических станций (ТЭС) в «расточительстве» ими большей части теплоты сгорания топлива. При этом в научной и околонаучной литературе редко слышатся голоса тех, кто понимает причину такой разноголосицы мнений. Между тем она лежит в применении оного и того же термина КПД к двум принципиально различным типам преобразователей энергии различными критериями их эффективности.

Понятие КПД было введено в науку и технику в конце XIX века, когда уже существовали не только механические и электрические, но и тепловые машины. Однако ихКПД определялся различным образом. У механических и подобных им машинах, для которых была известна не только совершаемая ими работа W, но и мощность $N = dW/dt$, КПД η определялся отношением их выходной мощности N'' к мощности на входе N' или же отношением совершаемой машиной полезной работы W^e к теоретически возможной W^t.В термодинамике такого рода КПД называются *относительными.* Иначе определяется «термический» КПД тепловой машины η_t, относящийся к разряду *абсолютных*. В циклических тепловых машинах, где наряду с источником тепла Q_1 необходим теплоприемник Q_2, он определяется отношениемполезной работы W^e к подведённой от горячего источника теплоте Q_1 и зависит от средних температур рабочего тела установкив процессе подвода и отвода тепла $\overline{T}_1$ и $\overline{T}_2$ [37]:

$$\eta_t \equiv W/Q_1 = 1 - \overline{T}_2/\overline{T}_1 < 1, \qquad (19)$$

Эти КПД характеризуют *степень превратимости* тепловой энергии, подводимой к тепловой машине. Такого рода абсолютные КПД могут быть определены для любой формы энергии, подводимой к преобразователю энергии воздействием, описываемым 1-й суммой тождества (9). При таком подходе естественным образом возникает представление о единстве выражения абсолютного КПД тепловой или нетепловой циклической машины η_i как об отношении совершаемой в цикле полезной работы $W_ц$ к поступающей на вход машины энергии U_i. Этот КПД удобно выразить через средние потенциалы энергоносителя Θ_i в процессах его входа и выхода из установки Ψ_1 и Ψ_2 как аналоговсреднетермодинамической температуры подвода и отвода тепла $\overline{T}_1 = \Delta S_1^{-1}\int T_1 dS_1$ и $\overline{T}_2 = \Delta S_2^{-1}\int T_2 dS_2$. При этом выражение абсолютного кпд любой (циклической и нециклической) машины примет вид [38]:

$$\eta_{max} = W_ц/E_1 = 1 - \Psi_2/\Psi_1. \qquad (20)$$

Таковы, например, расширительные машины (детандеры), осуществляющие расширение потока газа от давления p_1 до $p_2 < p_1$, магнитогидродинамические генераторы, работающие по открытой схеме с энтальпией плазмы на входе и выходе генератора h_1 и $h_2 < h_1$; ветроэнергетические установки со скоростями ветра на входе и выходе v_1 и $v_2 < v_1$; электростатические машины, получающие заряд при потенциале φ_1 и отдающие его при потенциале $\varphi_2 < \varphi_1$ и т.д. Для всех них абсолютные кпд меньше единицы, поскольку абсолютные значения потенциала приёмника энергии Ψ_2 не могут быть равны нулю ни теоретически (поскольку при этом взаимодействие с ним становится невозможным), ни тем более практически.Это обстоятельство свидетельствует о единстве законов преобразования любых форм энергии. При этом различие η_{max} преобразователей различных форм энергии определяются не самой этой формой, а степенью неравновесности источника преобразуемой энергии, т. е. отношением располагаемого перепадаобобщённого потенциала $\Delta\Psi_i$ к абсолютной величине этого потенциала. В качестве примера рассмотрим абсолютный КПД гидроэлектростанции с перепадом уровней воды между её, верхним и нижним бьефом $\Delta H = 30$ м, если гравитационный потенциал массы М падающей воды определять выражением $\Psi_g = MgH$, а его абсолютную величину H_1 отсчитывать от центра Земли с радиусом $R \cong 6 \cdot 10^6$ м.Тогда её «абсолютный» КПД составит величину $\eta_g = \Delta H / H_1 \cong 5 \cdot 10^{-6}$. Таким образом, мы очень далеки от возможности использовать «всю гравитационную энергию», так что тепловые машины - отнюдь не самые «расточительные» в отношении использования потенциала Ψ_1 преобразуемой формы энергии.

Единство выражения КПД тепловых и нетепловых циклических машин, выража-емое соотношением (20), позволяет обосновать принципы исключённого вечного двигателя 1-го и 2-го рода, не прибегая к постулатам. Если энергия E_1, подводимая к машине, равна нулю, то согласно (20) будет равна нулю и работа такой машины $W_ц$ (1-е начало термодинамики). Если среда, являющаяся источником энергии Е, однородна, т. е.$\Psi_1 = \Psi_2$, то КПД такой машины $\eta = 0$, как и её работа$W_ц$. Это положение может быть обобщено и на нециклические машины [39].

g) Опровержение теории «тепловой смерти Вселенной»

При обосновании принципа возрастания энтропии Р. Клаузиус основывался на казавшемся очевидным постулате о том, что термический КПД любой необратимой тепловой машины $\eta_t = 1 - Q_2/Q_1$ меньше, чем в обратимом цикле Карно $\eta_t^K = 1 - T_2/T_1$ при тех же температурах теплоисточника T_1 и теплоприемника T_2 и количествах подведённого Q_1 и отведённого Q_2 тепла.В таком случае $dS_2 = \delta Q_2/T_2 > dS_1 = \delta Q_1/T_1$, т. е. энтропия системы, включающей источник тепла, циклически действующую тепловую машину и теплоприёмник, возрастает.

Не найдя в этом рассуждении каких-либо противоречий, Р. Клаузиус придал этому выводу статус общефизического «принципа возрастания энтропии» и положил его в основу «теории тепловой смерти Вселенной». Эта теория предсказывала прекращение во Вселенной в целом каких-либо макропроцессов вследствие наступления в ней термодинамического равновесия, что было равносильно утверждению о её «сотворимости». Эта теория до сих пор не опровергнута несмотря на то, что упомянутая «тепловая смерть» не наступила и через 13–14 миллиардов лет, отпущенных ей этой моделью.

Между тем в рассуждения Клаузиуса вкралась ошибка, не замеченная ни его современниками, ни последователями. Она станет более очевидной, если использовать выражение (11),согласно которому при одних и тех же $\overline{T}_1$ и $\overline{T}_2$ КПД обратимой и необратимой тепловой машины одинаковы. Следовательно, ошибка Клаузиуса состояла в утверждении, что сравниваемые машины имели одинаковые температуры горячего и холодного источников.

Столь же несостоятельными оказываются на поверку и другие доказательства этого принципа [40]. Более того, можно показать, что, оставаясь в рамках равновесной термодинамики, доказать принцип возрастания энтропии вообще невозможно. Для этого достаточно рассмотреть систему, внутренняя энергия которой Uопределяетсяэнтропией S иобъёмом V, т. е.$U = U(S, V)$. Тогда, рассматривая обычным образом энтропию как обратную функцию $S = S(U, V)$, мы с необходимостью придём к выводу, что в изолированных системах, где в силу законов сохранения U и V, = const, энтропиятакже должна оставаться неизменной [41]:

$$S_{из} = S(U, V)_{из} = const. \qquad (21)$$

Кардинальное решение этого вопроса даёт введение термоимпульса Θ_qкак истинной меры внутренней тепловой энергии $U_q = T\Theta_q$. Согласно этому выражению, термоимпульс системы может убывать не только при затухании колебаний и превращении тепловой энергии U_q во внутреннюю потенциальную энергию той же системы E^r, но и при её превращении в кинетическую энергию упорядоченного движения E^w. Действительно, по мере приближения скорости системы к предельной скорости распространения возмущений, когда её превышение в колебательном процессе становится невозможным, этот процесс прекращается, т. е. тепловое (неупорядоченное) движение вырождается. Именно по этой причине температура Т излучения или физического вакуума, в которых скорость света максимальна, равна нулю. Следовательно, термоимпульс вырождается и при взрыве «сверхновых», сопровождающимся превращением вещества в излучение. Этот процесс может служить примером возникновения «порядка» из «хаоса», возможность которого обосновал И. Пригожин [27]. Тем самым замена энтропии термоимпульсом устраняет навязанную термодинамикой Клаузиуса одностороннюю направленность процессов во Вселенной, допуская возможность её неограниченного во времени и пространстве функционирования, минуя состояние равновесия.

h) Устранение парадокса Гиббса

Среди парадоксов физики едва ли найдётся ещё один столь же известный и столь же загадочный, как «парадокс Гиббса» – утверждение о скачкообразном возрастании энтропии при смешении невзаимодействующих идеальных газов в отсутствие каких-либо тепловых или объёмных эффектов. В своей знаменитой работе «О равновесии гетерогенных веществ» [42] Дж. Гиббс распространид методы термодинамики закрытых систем, представив их как совокупность открытых систем, разделённых условными полупроницаемыми перегородками. Тем самым он заменил внутренние процессы изменения состава системы процессами внешнего избирательного массообмена (диффузии через границы подсистем). При этом он обнаружил, что разность между энтропией смеси двух масс идеальных газов M_1 и M_2, каждый из которых занимал вначале половину полного объёмасмеси V, больше суммы энтропий тех же газов до смешения на постоянную величину

$$\Delta S_{см} = R_c \ln 2, \qquad (22)$$

определяемую исключительно газовой постоянной смесиR_c.

Характерно, что сам Гиббс, основываясь на статистической интерпретации энтропии, не усматривал в этом результате ничего парадоксального, считая, что он «всецело определяется числом смешиваемых молекул» и зависит лишь от того, считаем ли мы их тожественными или раздичимыми. Однако по мере изучения этого вопроса исследователи наталкивались на все большие и большие трудности, что и обусловило появление словосочетания «парадокс Гиббса».

В течение полутора столетия этот результат не раз становился объектом исследования как физиков, так и философов. Многим его исследователям казалось, что они сумели, наконец, объяснить странную независимость скачка энтропии от степени и характера различия смешиваемых газов наряду с недопустимостью упомянутого скачкапри смешении тождественных газов. Однако подобно легендарному сфинксу этот парадокс вновь и вновь возникал на страницах научных книг и журналов и не сошёл с них вплоть до настоящего времени. В итоге большинство исследователей этого парадокса склонилось к мнению, что он «не разрешим в плоскости классической термодинамики» [45].

Иначе обстоит дело, если вместо энтропии, имеющей конфигурационную составляющую, использовать термоимпульсΘ_q, обладающий простым физическим смыслом. Тогда становится очевидным, что при смешивании невзаимодействующих газов с одинаковой температурой и давлением термоимпульс не меняется хотя бы в силу закона сохранения импульса системы в целом. Это тем более очевидно, что оба газа ещё до смешения находились в термическом и барическом равновесии, являющемся для системы с двумя степенями свободы полным.

i) Устранение противоречия термодинамики с теорией эволюции

Известно«вопиющее противоречие термодинамики с теорией биологической эволюции»[27], обусловленное тем, что принцип возрастания энтропии предписывает природе лишь её деградацию. Вероятностная трактовка энтропии Больцманом не разрешала это противоречие, поскольку давала Вселенной лишь ничтожный шанс избежать «тепловой смерти».

Между тем несложно доказать, что какие-либо реальные процессы $d\rho_i/dt \neq 0$ могут возникнуть только в неравновесных системах (где $\rho_i \neq \overline{\rho}_i$), а ихскоростив разных частях системы элементах объёма dVимеют противоположный знак. В этом легко убедиться, представив любой экстенсивный параметр неоднородной системы Θ_i (её массуM, число молейk-хвеществ N_k, энтропиюS, электрический заряд$З$, импульс $\boldsymbol{P}$, его момент $\boldsymbol{L}$ и т. п.) интегралом от его локальной$\rho_i = d\Theta_i/dV$ и средней $\overline{\rho}_i = \Theta_i/V$ плотности выражением $\Theta_i = \int \rho_i dV = \int \overline{\rho}_i \, dV$.Тогда

$$\int [(d(\rho_i - \overline{\rho}_i)/dt] dV \equiv 0. \qquad (23)$$

Легко видеть, что это тождество выполняется только в том случае, когда процессы $d(\rho_i - \overline{\rho}_i)/dt$ противонаправлены. Это положение, названное нами «*принципом противо-направленности процессов*», может рассматриваться как математическое выражение диалектического закона «единства и борьбы противоположностей». Эвристическая ценность этого принципа как одного из наиболее общих законов естествознания состоит в обнаружении специфического класса процессов «*поляризации*» системы в самом общем понимании этого термина как появления в ней частей (областей, фаз, компонентов) с противоположными свойствами.

Этот принцип устраняет навязанную термодинамикой Клаузиуса одностороннюю направленность процессов во Вселенной. К такому же выводу мы приходим, базируясь на законе сохранения энергии в изолированной системе $(dU/dt)_{из} = 0$ и тождестве (10), если представим $F_i \cdot v_i$ в виде произведения сил и потоков $X_i \cdot J_i$, как это принято в неравновесной термодинамике [11-14]. Поскольку же в изолированных системах изменение параметров Θ_i обусловлено исключительно наличием у них внутренних источников, то противоположный знак имеют и мощности $X_i \cdot J_i$разноимённых процессов превращения энергии. Это означает, что наряду с процессами диссипации, в которых $X_i \cdot J_i > 0$, в изолированных системах неизбежны и процессы «самоорганизации» некоторых j-х степеней свободы, в которых произведение $X_j \cdot J_j < 0$. Таковы, в частности, процессы «восходящей диффузии» (переноса вещества в сторону возрастания его концентрации), явления «сопряжения» химических реакций (протекания реакций в направлении возрастания её сродства), «активного транспорта» (накопления в органах веществ с большей энергией Гиббса) и т.п. Таким образом в неравновесных системах с необходимостью возникают противонаправленные процессы эволюции и инволюции (деградации), когда одна степень свободы системы приближается к равновесию, в то время как другая – удаляется от него. Это и устраняет отмеченное выше противоречие термодинамики с эволюцией.

Более того, тождество (10) содержит термодинамические силы, выражаемые градиентами потенциала $X_i = \nabla\psi_i$, изменение которых отражает без дополнительных расчётов не только приближение или удаление системы от состояния равновесия по любой i-й степени её свободы в отдельности, но и условие равновесия данного рода:

$$dX_i > 0 \text{ (эволюция)}; \; dX_i = 0 \text{ (равновесие)}; \; dX_i < 0 \text{ (инволюция)}. \quad (23)$$

Это даёт в руки исследователей более наглядный, более «физичный» и более информативный инструмент анализа проблем эволюции, нежели не поддающийся вычислению максимум энтропии [44, 45]. При этом выясняется, что до тех пор, пока в системе протекают какие-либо процессы, среди них обязательно будут имеющие эволюционных характер. Тем самым утверждается, что природе свойственны не только разрушительные, но и созидательные тенденции. Это и наблюдается в живой и неживой природе на всех уровнях мироздания.

j) Устранение парадокса отрицательных абсолютных температур.

Понятие отрицательной абсолютной (спиновой) температуры возникло во второй половине XX в после открытия спиновых систем, в которых с помощью обращения знака магнитного поля или высокочастотного импульса удавалось создать «инверсию заселённостей» энергетических уровней обладающих спином элементарных частиц –состояние, в которых большинство элементарных частиц находится на верхнем энергетическом уровне [46].

Основанием для введения этого понятия послужила все та же статистическая трактовка понятия энтропии. Если статистическую энтропию принять тождественной термодинамической на том основании, что обе величины аддитивны и достигают максимума в состоянии равновесия (принцип Больцмана), то, сопоставляя выражение производной $(\partial U/\partial S)$ для статистически определённой внутренней энергии Uи энтропии Sc известным определением термодинамической температуры термомеханической системы

$$T \equiv (\partial U/\partial S)_{\Theta}, \quad (24)$$

можно прийти к заключению, что системе ядерных спинов в состоянии инверсной заселённости следует приписать отрицательное значение абсолютной температуры $T < 0$.Характерно, что при такой «подгонке под классику» пришлось допустить, что состояния спиновых систем с отрицательной абсолютной температурой в них лежат … выше бесконечно высоких температур $T = \infty$!

Следует отметить, что существование систем с инверсной заселённостью уровней является в настоящее время твёрдо установленным фактом. Первой подсистемой, удовлетворившей этим требованиям, явилась упомянутая выше система ядерных спинов ионов лития в кристаллах фторида лития (LiF). Если кристаллы LiF поместить в магнитное поле, а затем быстро изменить направление внешнего поля (как это было в опытах Е. Парсела и Р. Паунда, 1951), то ядерные магниты оказываются неспособными последовать за ним, и бо льшая их часть окажется в верхнем энергетическом состоянии – произойдёт инверсия заселенности.В таких установках, как лазеры, она создаётся «подкачкой» их энергией микроволнового излучения, благодаря чему создаётся стационарное неравновесное состояние системы.

Однако инверсной заселённостиещё недостаточно, чтобы говорить об отрица-тельной абсолютной температуре – важно, чтобы система оставалась во внутреннем равновесии при инверсной заселённости. Действительно, согласно (24), отрицательные значения термодинамической температуры могут быть достигнуты только в том случае, когда система путем обратимого теплообмена будет переведена в состояние с большей внутренней энергией *U* и с меньшей энтропией *S*. Между тем оба известных способа достижения инверсной заселённости в системе ядерных спинов (инверсия внешнего магнитного поля и воздействие радиочастотным импульсом) не удовлетворяют этим условиям. В первом способе изменение направления внешнего магнитного поля осуществляется, как это подчёркивается Парселом, настолько быстро, что ядерные спины не успевают изменить свою ориентацию. Следовательно, внутреннее состояние системы (в том числе ее энтропия *S*) оставались при этом неизменными – изменялась лишь внешняя потенциальная (зеемановская) энергия спинов в магнитном поле, входящая в гамильтониан системы наряду с энергией спин-спинового взаимодействия. Внутренняя же энергия системы U, которая по определению не зависит от положения системы как целого во внешних полях, оставалась при этом неизменной. В противном случае (при изменении U) нарушалось бы условие постоянства в выражении (16) координат всех видов работы, а не только объёма. Это касается и другого способа инверсии заселённости, достигаемого с помощью высокочастотного (180-градусного) импульса. Это воздействие никак нельзя отнести к категории теплообмена, поскольку оно так же имеет направленный характер и соответствует адиабатическому процессу совершения над системой внешней работы.

Интерпретация упомянутых экспериментов изменяется, если вместо энтропии в выражении (16) фигурирует термоимпульс Θ_q, который, как и модуль скорости v, не меняет знака при инверсии магнитного поля. При этом сразу обращает на себя внимание нарушение принципа различимости процессов. Это нарушение состоит в том, что интерпретацияо бнаруженного в эксперименте особого, качественно отличимого и несводимого к другим процесса спин-решёточной релаксации как теплообмена. То обстоятельство, что между тепловой формой движения и ориентацией спинов существует некоторая связь, ещё не даёт оснований приписывать эту форму спиновой системе. Известно, например, что охлаждение конденсированных сред практически до абсолютного нуля температур не приводит к исчезновению собственного момента вращения ядер.В таком случае оснований для трактовки температуры T как отрицательной, не остаётся.

Эти эксперименты подтвердили (с приемлемой точностью) справедливость закона сохранения момента количества движения при спин-спиновом взаимодействии и показали, что «температура» смеси определяется выражением:

$$T = (\Sigma_i C_i/T_i)/\Sigma_i C_i, \qquad (25)$$

где T_i – температура какой-либо части спиновой системы; C_i – весовой коэффициент, названный экспериментаторами «спиновой теплоемкостью». Как следует из выражения (23), в нем со «спиновой теплоёмкостью» C_i сопряжена величина, обратная абсолютной температуре.Таким образом, речь в этих экспериментах идёт вовсе не о термодинамической температуре, а о некоем статистическом параметре распределения, выдаваемом за неё.

k) Исключение «инверсии» 2-го начала термодинамики

Введение понятия отрицательной абсолютной температуры, к сожалению, не ограничились инверсией шкалы температур. Последовал неизбежный вывод об «инверсии» в таких системах и самого принципа исключённого вечного двигателя 2-го рода [46]. Эта «инверсия» состоит в утверждении возможности полного превращения в таких системах теплоты в работу и в невозможности, напротив, полного превращения работы в теплоту. Действительно, по Рамсею, горячим в области T<0 следует считать тело с бóльшей температурой (т. е. с меньшей по абсолютной величине отрицательной температурой). Ели теперь представить себе цикл Карно, осуществляемый при отрицательных температурах горячего и холодного тел T_1 и T_2, то термический кпд обратимой машины Карно $\eta_t^K = 1 - T_2/T_1$ станет отрицательным, поскольку горячим в области T < 0 следует считать тело с меньшей по абсолютной величине отрицательной температурой (T_2/T_1 > 1) [9]. Этот более чем «удивительный» результат означает, что совершаемая в этой области температур работа цикла Карно будет положительной, если тепло Q_2 отбирается от «холодного» источника, а теплоприемником является более горячее тело. Поскольку же с помощью теплового контакта между теплоисточником и теплоприемником все тепло Q_1, переданное «горячему» источнику, может быть путем теплообмена возвращено «холодному», то в непрерывной последовательности циклов работа будет производиться за счёт теплоты только одного «холодного» тела без каких-либо остаточных изменений в других телах в нарушение 2-го начала термодинамики. Тем самым претерпели «инверсию» не только понятие термодинамической температуры как величины сугубо положительной, но и принцип исключённого вечного двигателя 2-го рода. Характерно, что такой вывод был сделанна основании…того же второго начала! В самом деле, возможность полного превращения тепла в работу означает, что обычное выражение КПД () не применимо в области T <0. Но тогда, очевидно, утрачивают силу и все выводы, основанные на нем! Налицо «порочный круг»! Тем не менее, утверждение об «инверсии» принципа исключённого вечного двигателя 2-го рода проникло на страницы учебников и стало воспроизводиться даже в лучших из них. Это лишь один из множества примеров того, как отождествление термодинамической и статистической энтропии подрывает былую уверенность в непогрешимости термодинамики и непреложной справедливости её следствий.

l) Устранение парадокса релятивистских тепловых машин

В годы, последовавшие за появлением фундаментальной работы А. Эйнштейна (1905), содержавшей формулировку специальной теории относительности (СТО), физики стремились придать классическим законам такой вид, который был бы инвариантен во всех инерциальных системах отсчёта. В области термодинамики это осуществил впервые М. Планк в 1907 г. [47]. Он пришёл к выводу, что энтропияSдолжна оставаться лоренц–инвариантной, поскольку ускорение системы осуществляется адиабатически, в то время как внутреннюю энергию U, теплоту Q и температуру T следует преобразовывать в соответствии с выражениями:

$$U' = U_o/\gamma; Q' = Q\gamma; T' = T\gamma, \quad (26)$$

где Q´, T´ – теплота и температура в системе отсчёта, движущейся относительно наблюдателя со скоростью v; $\gamma = (1 - v^2/c^2)^{½}$ – множитель Лоренца;c – скорость света в вакууме.

В результате он пришёл к выводу, что КПД релятивистского цикла Кано определяется выражением:

$$\eta_t^{K} \equiv W_ц{}'/Q'_г = 1 - T_2/T_1\gamma. \quad (27)$$

Найденные Планком соотношения получили одобрение А. Эйнштейна и ни у кого не вызывали сомнения, пока в 1963 г. Х. Отт [48] не обнаружил абсурдность этого результата с точки зрения термодинамики.Действительно, по Планку температура движущегося источника всегда ниже измеренной в неподвижной системе отсчёта, и в соответствии с (19) преобразованиями η_t^{K}*всегда меньше, чем у классического, а* при определённыхγ может оказаться даже *отрицательным*. По Отту, напротив, температура движущегося источника *всегда выше*, и его машина Карно *имеет бóлее высокий кпд, чем классическая*:

$$\eta_{t\,(Отт)}^{K} = 1 - T_2\gamma/T_1. \quad (28)$$

Вскоре к такому же выводу независимо от Х. Отта пришёл Х. Арзельс [49]. Однако в отличие от Отта, он счёл неправильными и формулы преобразования энергии и импульса. На этот раз работа была замечена, и последовала лавина публикаций, приведших к оживлённой дискуссии на международных симпозиумах в Брюсселе (1968) и Питтсбурге (1969). Эти дискуссии обнаружили такой хаос в области определения базовых понятий и концепций термодинамики, что Х. Арзельс заявил о «современном кризисе термодинамики». И дело здесь не только в отсутствии единства в релятивистских преобразованиях энергии, теплоты и работы, а *в нежелании исследователей возвращаться к основаниям термодинамики всякий раз, когда возникает необходимость обобщения ее методов на более общий класс систем*. Вместо этого авторы многочисленных работ пытались «примирить» различные преобразования. Договаривались даже до того, что применение той или иной формулы преобразования зависит от положения термометра в пространстве.В результате проблема релятивистских преобразований термодинамических величин была «заметена под ковёр».

Между тем, как было показано нами[20], релятивистская машина Карно представляет собой комбинацию тепловой и механической машины, получающей наряду с теплотойQ′кинетическую энергию $\Delta E_{кин} = Q'(1/\gamma_г - 1)$, необходимую для поддержания его скорости.КПД такой машины должен определяться отношением суммарной работы к суммарному же количеству подведённой к нему тепловой Q´и механической $E_{кин}$энергии.Этот КПД принимает промежуточное значение между чисто тепловой и чисто механической машины и переходит в классические выражения их абсолютных КПД по мере изменения их доли в производительности комбинированной машины. Однако само по себе это не решает проблемы релятивистских преобразований термодинамических величин. Здесь на помощь вновь приходит понятие термоимпульса как функции количества движения. В отличие от энтропии, он изменяется со скоростью, в то время как внутренняя тепловая энергия U_q,напротив, остаётся неизменной по определению. Тогда и их КПД остаётся инвариантным по отношению к любым преобразованиям энтропии и абсолютной температуры [20].

IV. Заключение.

Утрата термодинамикой статуса теории, чьи следствия носили характер непреложных истин, обусловлен использованием энтропии в несвойственной ей роли носителя тепловой формы энергии. Будучи ошибочно введённой Р. Клузиусом в качестве координаты теплообмена, энтропияпородила ряд неочевидных противоречий, число которых множилось по мере расширения области её приложения. Как показано в статье, устранить эти паралогизмы из термодинамики можно лишь путём замены энтропии более адекватным, общим и физически прозрачным понятием термоимпульса. Это позволяет не только устранить известные и вновь обнаруженные паралогизмы термодинамики и вернуть ей былой статус безгипотезной теории, но и отрывает возможность объединения равновесной и неравновесной термодинамики и их синтеза с другими фундаментальными дисциплинами на единой понятийной и концептуальной основе с учётом необратимости реальных процессов. При этом устраняется «вопиющее противоречие» термодинамики с теорией биологической и космологической эволюции и существенно упрощается преподавание этой дисциплины путём совершенствования методов анализа, устранения термодинамических неравенств, строго доказательства всех её положений, отказа от изложения термодинамики на основе постулируемых «начал» и т. п.[50].

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ASSOCIATE OF SCIENCE FRONTIER RESEARCH COUNCIL is the membership of Global Journals awarded to individuals that the Open Association of Research Society judges to have made a 'substantial contribution to the improvement of computer science, technology, and electronics engineering.

> The primary objective is to recognize the leaders in research and scientific fields of the current era with a global perspective and to create a channel between them and other researchers for better exposure and knowledge sharing. Members are most eminent scientists, engineers, and technologists from all across the world. Associate membership can later be promoted to Fellow Membership. Associates are elected for life through a peer review process on the basis of excellence in the respective domain. There is no limit on the number of new nominations made in any year. Each year, the Open Association of Research Society elect up to 12 new Associate Members.

Benefit

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Global Journals sends a letter of appreciation of author to the Dean or CEO of the University or Company of which author is a part, signed by editor in chief or chief author.

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Career | Financial

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Financial

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Associates are authorized to organize symposium/seminar/conference on behalf of Global Journal Incorporation (USA). They can also participate in the same organized by another institution as representative of Global Journal. In both the cases, it is mandatory for him to discuss with us and obtain our consent. Additionally, they get free research conferences (and others) alerts.

Career | Credibility | Financial

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Associate	Fellow	Research Group	Basic
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Certificate, LoR and Momento 2 discounted publishing/year **Gradation** of Research 10 research contacts/day **1 GB** Cloud Storage **GJ** Community Access	**Certificate,** LoR and Momento **Unlimited** discounted publishing/year **Gradation** of Research **Unlimited** research contacts/day **5 GB** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**Certificates,** LoRs and Momentos **Unlimited** free publishing/year **Gradation** of Research **Unlimited** research contacts/day **Unlimited** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**GJ** Community Access

Preferred Author Guidelines

We accept the manuscript submissions in any standard (generic) format.

We typeset manuscripts using advanced typesetting tools like Adobe In Design, CorelDraw, TeXnicCenter, and TeXStudio. We usually recommend authors submit their research using any standard format they are comfortable with, and let Global Journals do the rest.

Alternatively, you can download our basic template from https://globaljournals.org/Template.zip

Authors should submit their complete paper/article, including text illustrations, graphics, conclusions, artwork, and tables. Authors who are not able to submit manuscript using the form above can email the manuscript department at submit@globaljournals.org or get in touch with chiefeditor@globaljournals.org if they wish to send the abstract before submission.

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Authors must ensure the information provided during the submission of a paper is authentic. Please go through the following checklist before submitting:

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2. Authors must accept the privacy policy, terms, and conditions of Global Journals.
3. Ensure corresponding author's email address and postal address are accurate and reachable.
4. Manuscript to be submitted must include keywords, an abstract, a paper title, co-author(s') names and details (email address, name, phone number, and institution), figures and illustrations in vector format including appropriate captions, tables, including titles and footnotes, a conclusion, results, acknowledgments and references.
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7. Manuscript submitted *must not have been submitted or published elsewhere* and all authors must be aware of the submission.

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2. Drafting the paper and revising it critically regarding important academic content.
3. Final approval of the version of the paper to be published.

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Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

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Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

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Tips for Writing a Good Quality Science Frontier Research Paper

Techniques for writing a good quality Science Frontier Research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of science frontier then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.
- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

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	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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