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Physics and Space Science

Diffusion Waves in Stars

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Highlights

Special Theory of Relativity

Expansion of the Phenomenology

Discovering Thoughts, Inventing Future

VOLUME 18 ISSUE 1 VERSION 1.0

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Contents of the Issue

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Experimental and Theoretical Expansion of the Phenomenology of Thermoelectricity

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Abstract- Investigations of thermoelectric effects in macro-objects obtained by traditional thermoelectric technology have already led several decades ago to the understanding that the thermoelectric figure of merit (the Joffe parameter) can not exceed a certain limit. Therefore, the research cycle, the most significant results of which are presented in this paper, was focused on the study of objects developed using microelectronics technology. As was confirmed in the first part of this work, the practical limit of the thermoelectric figure of merit is macroscopic, and is not the maximum of the efficiency of thermoelectric conversion on micro- and nano-objects on the basis of local thermo-EMFs found in them. To determine the optimum parameters of thermoelectric devices on the basis of local effects, their experimental study was carried out. Also, to take into account local effects in the first order, and not in the form of minor corrections, it was required, as was shown in the previous article, to expand their linear phenomenology, the first part of which is presented in this article.

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EXPERIMENTALANDTHEORETICALEXPANSIONOFTHEPHENOMENOLOGYOFTHERMOELECTRICITY

Strictly as per the compliance and regulations of:

Experimental and Theoretical Expansion of the Phenomenology of Thermoelectricity

Republication

Stanislav Vladimirovich Ordin

Abstract- Investigations of thermoelectric effects in macro-objects obtained by traditional thermoelectric technology have already led several decades ago to the understanding that the thermoelectric figure of merit (the Joffe parameter) can not exceed a certain limit. Therefore, the research cycle, the most significant results of which are presented in this paper, was focused on the study of objects developed using microelectronics technology. As was confirmed in the first part of this work, the practical limit of the thermoelectric figure of merit is macroscopic, and is not the maximum of the efficiency of thermoelectric conversion on micro- and nano-objects on the basis of local thermo-EMFs found in them. To determine the optimum parameters of thermoelectric devices on the basis of local effects, their experimental study was carried out. Also, to take into account local effects in the first order, and not in the form of minor corrections, it was required, as was shown in the previous article, to expand their linear phenomenology, the first part of which is presented in this article.

Keywords: local effects, sharply inhomogeneous media, thermoelectricity, p-n junction, gauss resonance, three-component linear phenomenology.

I. Introduction

The symmetry of the exposure on the p-n junction of the luminous flux and the heat flow is fundamentally different.

For the photoelectric effect, because of the small of the photon momentum, one can confine ourselves to a nonpolar and even isotropic consideration of the effect of light on the p-n junction and, as a consequence, a parametric description of the effect on its characteristics. That is why for the photo-effect within the framework of the linear E-N phenomenology we allow a parametric approach.

For the heat flow, its polar, object-changing effect determines the parameters of the EMF of the macroscopic response. In the longitudinal thermoelectric effect, the polarity of the heat flow determines the polarity of the EMF (for electrons and holes - different), in the transverse thermoelectric effect, the polarity of the heat flow determines the polarity of the EMF similarly, and the orientation of the heat flux relative to the symmetry axes of the crystal or the artificial object affects the magnitude of the EMF.

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Therefore, the Parametric Supplement to the theory of p-n junction allows, albeit roughly, but quantitatively, to describe the photo-effect - in the first approximation, the current-voltage bias. Whereas a similar parametric approach for thermoelectric effects gives only the correct sign of thermo-EMF, and their values tend to infinity at arbitrarily small displacement currents of the p-n junction. But since estimates of the magnitude of the current above the potential barrier on the basis of the Richardson formula gave negligible currents, then these "infinite" EMFs were neglected, assuming their output power to be immeasurable - below the Nainquist noise.

However, experiments on p-n junctions have shown that the values of thermoelectric currents, even at small temperature drop at the p-n junction, are much higher than the Richardson estimates. A rigorous ballistic model of the motion of electrons over a potential barrier showed that the Richardson formula itself, historically constructed to describe the arc current between carbon electrodes at 3000 degrees, is applicable only to the diffuse approximation for large temperature differences and lowers the current value by orders of magnitude for small temperature drop. Thus, both from experiments and from theory it follows that for small temperature differences at the p-n junction we have not infinite but giant EMF and completely measurable currents much higher than thermal noise.

Thus, for the heat flow in the sharply inhomogeneous media, there is no basis for neglecting the additional force: to the E-N phenomenology of the temperature force or to the thermoelectric E-T phenomenology of the concentration force. And to build a non-linear description of processes corresponding to effects on a micro- and nano-scale, one must begin with a strict definition of the zero and first approximations, i.e. with linear phenomenology, which includes both electric, thermal and concentration forces.

Earlier attempts to combine the phenomenology of macroscopic thermoelectricity with the description of contact phenomena were carried out formally, without a general phenomenological approach. The formal transfer of particular models of potential barriers, as will be shown below, did not give a complete self-consistent description and led to contradictions of its individual fragments.

Global Journal of Science Frontier Research (A) Volume XVIII Issue I Version I Year 2018 1

Located on the neighboring chapters of the monographs on the physics of semiconductors and semiconductor devices of the theory of thermoelectricity [1] and contact phenomena [2] could not not be crossed in any way (could not fail to intersect), since Ideally (and in theory!) the thermoelectric device has two contacts of materials with different types of conductivity (Figure 1a).

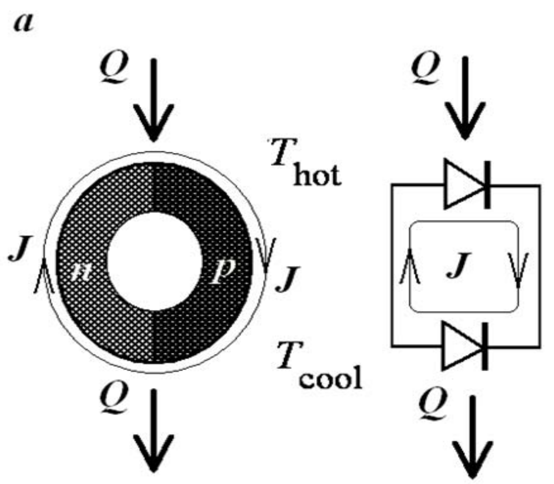

Figure 1: a - The thermoelement and its and equivalent circuit

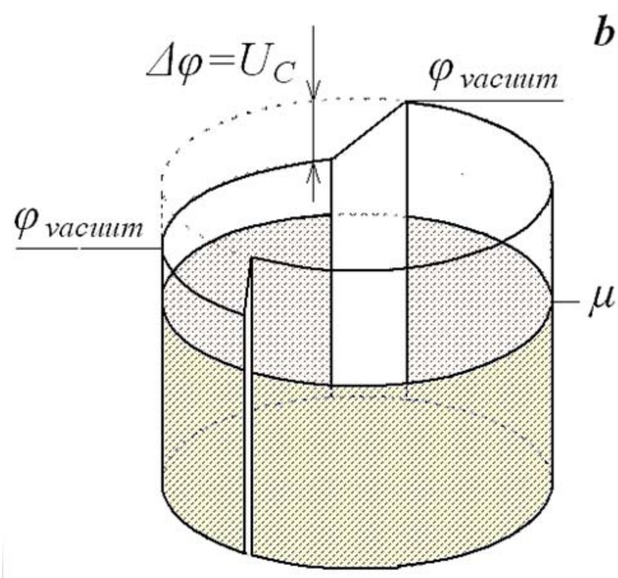

Figure 1: b –The location of the vacuum level (and the forbidden band edge in semiconductors) relative to the level of the chemical potential μ.

Therefore, it is quite natural that the macroscopic thermoelectric power of the material itself was tied to the dependence of the contact potential difference on temperature:

$$\Delta\varphi(T_{\text{hot}})-\Delta\varphi(T_{\text{cool}})=U_c(T_{\text{hot}})-U_c(T_{\text{cool}})$$

(Figure 1b). This attempt led Peltier to the erroneous conclusion about the contact nature of the heat of Peltier he had discovered at the contact. And this erroneous representation, contrary to the principles of symmetry, [3] is included in many of the letters on thermoelectricity, although it has long been corrected [4, 5, 6].

In the framework of this erroneous conception, the attempt to take into account the concentration effects in thermoelectricity was reduced to the speculative application of correction: using a he "chemical" potential and the "observable" electric force F_E^* [3]. With the help of artificially introduced terms, in fact, the EMF of the p-n junction was not painted at a drop on it, but the difference between the EMF of hot and cold p-n junctions whose plates have the same temperature. In the framework of this approach, the equation for the flux of concentration simply "fitted" into the modified equation for an electric current with noncanonical coefficients a:

$$J_E = L_{EE}\cdot F_E + \frac{1}{e}\cdot L_{EE}(!)\cdot F_N + a_{ET}\cdot F_T = a_{EE}\cdot F_E^* + a_{ET}\cdot F_T \quad (1)$$

But we will not be distracted by the analysis of the nonstrict, non-canonical and boundedly applicable equation (1). Moreover, this equation was not used anywhere, except in a simplified and internally contradictory theory. And in macroscopic thermoelectric devices, the p-n junction was simply interfering, and its effect on both contacts (Figure 1) was leveled by a specially developed ohmic contact technology.

In the theory of the p-n junction, as was noted in the first part of this work [7], the small diffuse effects of Seebeck and Peltier and, corresponding to them, a small cross-sectional kinetic coefficient, were rightly dropped from consideration. And in practice, electronic devices based on p-n junctions also used ohmic contact, leveling the action of the opposing barrier layer.

As was shown in the first part, the analysis of non-canonical coefficients requires strict consideration of the conditions for their measurement and! their use is associated with a violation of a number of principles that are strictly applicable only to canonical coefficients. And the extension of the linear phenomenology of thermoelectricity proposed in this paper, the analysis of local effects essentially simplifies and makes more rigorous.

II. Materials and Methods

Samples used to study the appearing on the contacts, in particular in p-n junctions of local thermo-EMFs, the technology of their manufacture and various methods for their measurement, as well as the results of experiments and the first, trial attempts to explain them, described earlier in the cycle noted in the first part of the work, are reflected also in the reviews [8. 9].

III. Results

a) Result of previous experiments.

The conclusion from this cycle of studies, qualitatively confirmed by microscopic analysis, is shown in Figure 2

Experiments have shown that the local thermo-EMF corresponds to a maximum in the dimensional dependence of the thermoelectric power α shown in Figure 2. At the maximum, the volt-watt sensitivity is 3-4 orders of magnitude higher than for the Seebeck macroscopic thermoelectric effect. The experimentally observed thermo currents exceeding in the region of the maximum of the size dependence of the estimate based on Richardson's formula by two orders of magnitude were explained within the framework of the ballistic model [10].

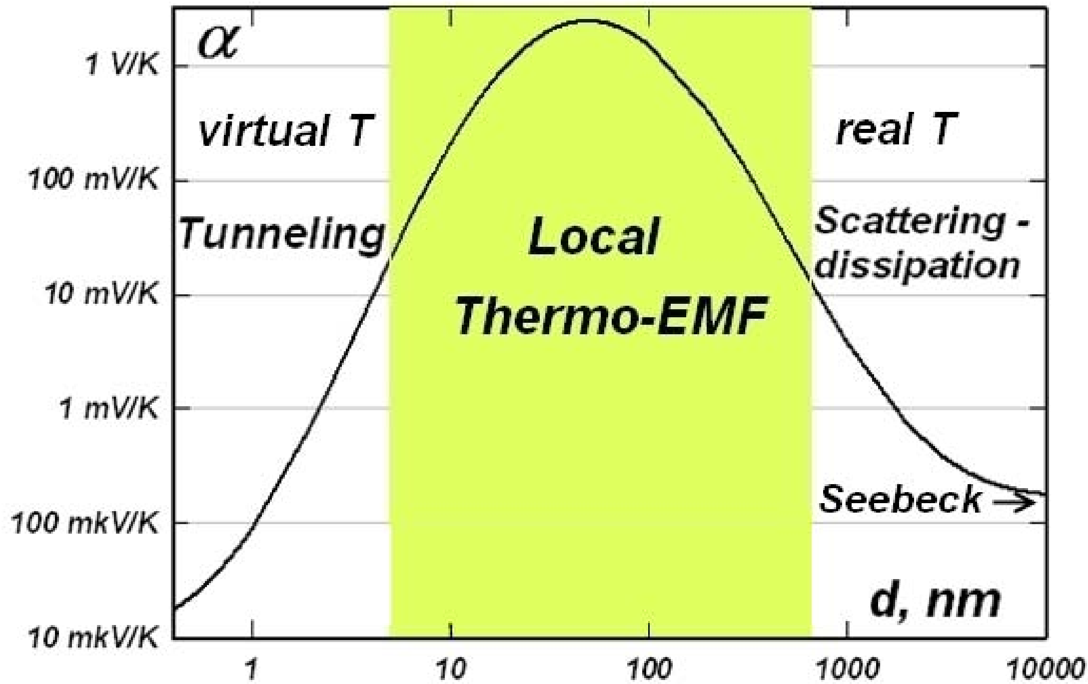

Figure 2: Model (Planck) thermoelectric power dependence on the thickness of the potential barrier

b) Resonance studies of local thermo-EMFs

In this paper, we present only those experimental results that relate to the resonance recorded on local thermo-EMF. Resonance is registered in the figures shown in Figure 3 detectors developed on the basis of longitudinal local thermo-EMFs. When continuous irradiation was applied to the detector, thermo-EMFfs, antiphase photo-EMFs were registered.

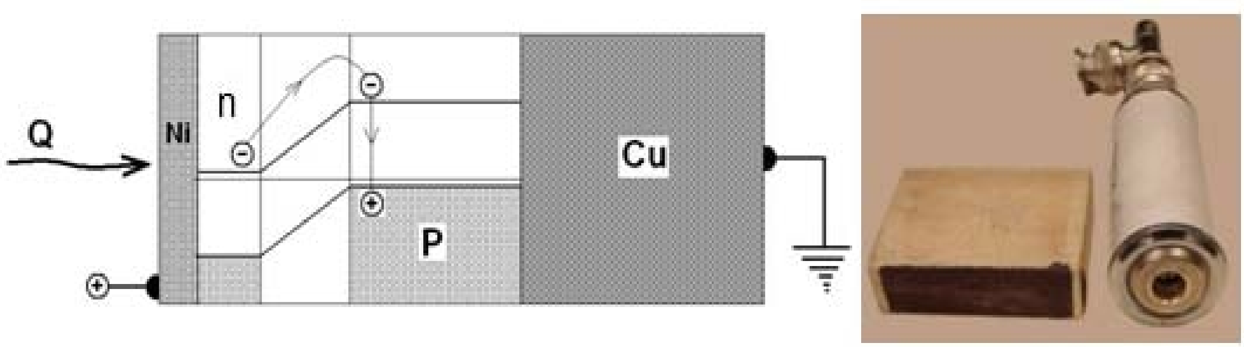

Figure 3: Scheme of generation of the longitudinal thermo-EMF at the p-n junction and its measurement (on the left) and the prototype of the detector under investigation (right)

The frequency dependence of the amplitude of the alternating signal generated by local thermo-EMF at the high-frequency edge of the frequency characteristic of the photoelectric effect for a given p-n junction (without an absorbing metal coating) is observed as a hump resonance (Figure 4).

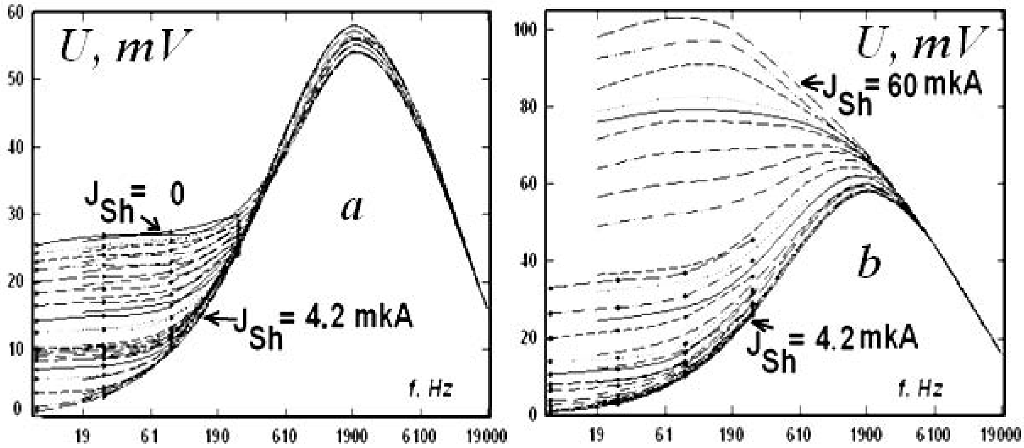

Figure 4: Dependence of the frequency response of local thermo-EMF on the bias current through the p-n junction

When the p-n junction is shifted by a direct current, it is possible to achieve complete compensation of the DC voltage due to the local thermo-EMF by the antiphase voltage of the external current source. In this case, the amplitude of local thermo-EMF at low frequencies passes through zero (Figure 4a), and with a further increase in current increases in antiphase (Figure 4b). With a displacement current determined for a particular p-n junction configuration, the resonance is manifested in the classical form (Figure 5).

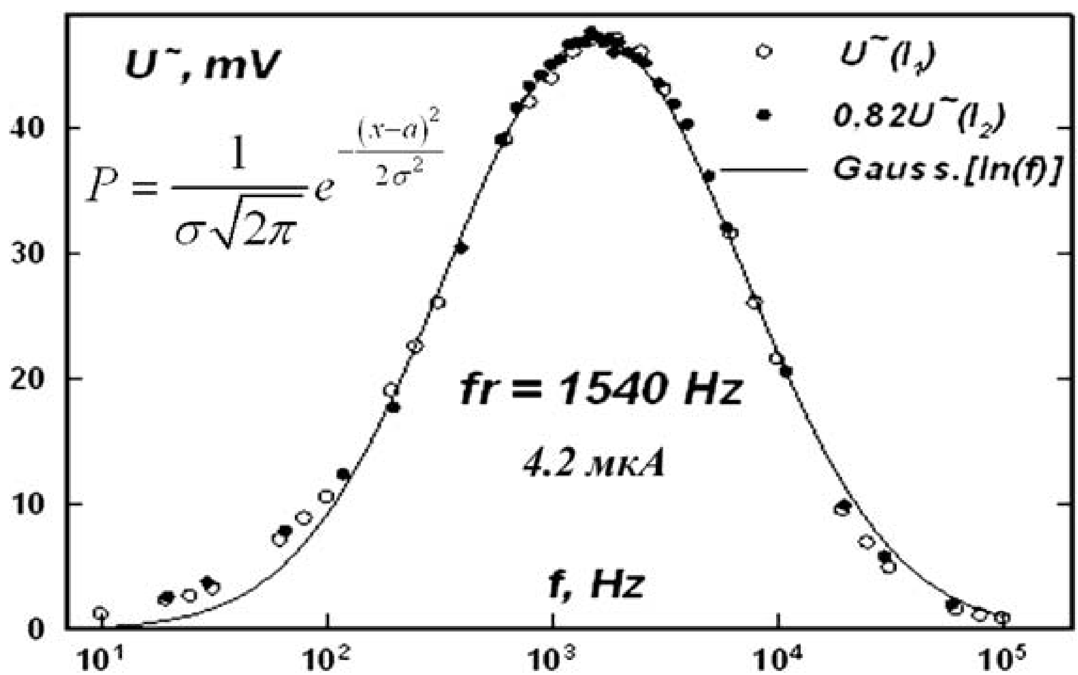

Figure 5: The resonance of the local thermo-EMF measured in the p-n junction, measured at two powers of the modulated heat flow and the corresponding Gaussian distribution

The shape of the resonance is close to the normal (Gauss) (one-dimensional) distribution - probability density P, but! of the logarithm of frequency

$$U = U^{\max} e^{-0.5\left(\frac{x-x_0}{\mathrm{B}}\right)^2} \qquad U^{\max} = 47.2056$$
$$x = \ln(f) \qquad B = 1.5118 \Leftrightarrow \sigma \mapsto 1.0690 \qquad (2)$$
$$x_0 = 7.3456 = \ln(f_r) \Leftrightarrow a$$

Since any of the velocity components of electrons in thermal motion is normally distributed, the shape of the resonance directly indicates its statistical nature. In this case, the dependence on the logarithm of the frequency is more general, more corresponding to an unlimited frequency range than the dependence simply on the frequency, which describes well the narrow frequency resonances. Correction of Gaussian distribution is beyond the scope of this paper.

Global Journal of Science Frontier Research (A) Volume XVIII Issue I Version I Year 2018

On the other hand, the very occurrence of any resonance is determined by the dependence on the frequency of the phase shift between the flow (displacement) and the driving force. In the simplest electrical resonance, the phase shift is given by reactive elements. In the resonance of local thermo-EMF in the p-n junction, in addition to its reactive electrical parameters, it is necessary to take into account the phase shifts of the electric and thermal forces, the integral effect of which forms the electron flux.

IV. Discussion

And so, for large concentration gradients in thermoelectric phenomenology, it is necessary to use a three-component linear thermoelectric E-N-T phenomenology rather than the traditional system of two coupled equations of generalized thermodynamic forces and flows. That is, it is necessary to use the system extended to three equations, which in the one-dimensional case has the following form:

$$\left.\begin{aligned} J_E &= L_{EE}\cdot F_E + L_{EN}\cdot F_N + L_{ET}\cdot F_T \\ J_N &= L_{EN}\cdot F_E + L_{NN}\cdot F_N + L_{NT}\cdot F_T \\ J_T &= L_{ET}\cdot F_E + L_{NT}\cdot F_N + L_{TT}\cdot F_T \end{aligned}\right\} \quad (3)$$

In the extended system of equations (3), in addition to the direct effects that are traditionally taken into account in thermoelectricity: the drift current - $L_{EE}\cdot F_E \to \sigma\cdot E$ and the heat flux - $L_{TT}\cdot F_T \to (\kappa + \mathrm{K}^*)\cdot\Delta T$, the diffusion flux- $L_{NN}\cdot F_N \to D\cdot\Delta T$, which has long been "allowed" in the theory of the p-n junction, but so far "forbidden" in the thermoelectric theory, is strictly taken into account. Additional effects-terms of the equations, crosswise with the diffusion flux are also taken into account.

Moreover, as an additional direct coefficient, each additional cross-ratio corresponds to effects already known from other sections of physics, but not fully taken into account or not considered in thermoelectricity (and p-n junction theory).

In addition to the cross thermoelectric current $L_{ET}\cdot F_T \to \alpha\cdot\sigma\cdot\Delta T$, two additional flows are taken into account in the system of equations (3). An electro-diffusion current $L_{EN}\cdot F_N \to R\cdot\Delta N$ is taken into account, which, in the theory of the p-n junction, must be taken into account, but, as shown above, strictly speaking, was not taken into account. And we took into account the Sorud-Duffur thermo diffusion current $L_{NT}\cdot F_N \to \Phi\cdot\Delta N$, which was only remembered in the physics of semiconductor devices when studying the degradation of p-n junctions, but was not taken into account in its work.

It is to these three equations (2) for the conducting medium (as shown in the first part, after subtracting the phonon and plasma parts - is discarded K^*), one can apply the Onsager symmetry principle, which, in the first approximation, reduces the number of independent coefficients for an ideal medium to 6: up to three direct and three cross.

In principle, it is possible to reduce the number of independent coefficients, since all 3 direct (diagonal) drift coefficients are interrelated - they are determined by the mutual friction of the respective streams about each other.

Using an analysis of fluctuations of independent forces in a freely suspended sample similar to that described in the previous article, we obtain from the system of equations (3) the following system of equalities:

$$\left.\begin{aligned} 0 &= L_{EE}\cdot F_E + L_{EN}\cdot F_N + L_{ET}\cdot F_T \\ 0 &= L_{EN}\cdot F_E + L_{NN}\cdot F_N + L_{NT}\cdot F_T \\ 0 &= L_{ET}\cdot F_E + L_{NT}\cdot F_N + L_{TT}\cdot F_T \end{aligned}\right\} \quad (4)$$

The system of three equations (4), in addition to the trivial solution: $F_E = 0,\ F_N = 0,\ F_T = 0$, as well as

$$\left.\begin{aligned} -\left(L_{ET}^2 L_{NN} - 2L_{EN}L_{ET}L_{NT} + L_{EN}^2 L_{TT}\right) &= L_{EE}\left(L_{NT}^2 - L_{NN}L_{TT}\right) \\ +\left(L_{NT}^2 L_{EE} - 2L_{EN}L_{ET}L_{NT} + L_{EN}^2 L_{TT}\right) &= L_{NN}\left(L_{ET}^2 - L_{EE}L_{TT}\right) \\ +\left(L_{NT}^2 L_{EE} - 2L_{EN}L_{ET}L_{NT} + L_{ET}^2 L_{NN}\right) &= L_{TT}\left(L_{EN}^2 - L_{EE}L_{NN}\right) \end{aligned}\right\} \quad (5)$$

In this case, we find that the cross-correlation coefficients for three thermodynamic forces, similar to those considered in the first part of special cases with two forces, are associated only with a pair of corresponding direct coefficients, but they have an additional factor corresponding to the forces considered:

$$L_{EN}^{i} = C_{EN}^{i} \cdot \sqrt{L_{EE} \cdot L_{NN}}\,, \quad L_{ET}^{i} = C_{ET}^{i} \cdot \sqrt{L_{EE} \cdot L_{TT}}\,, \quad L_{NT}^{i} = C_{NT}^{i} \sqrt{L_{NN} \cdot L_{TT}} \tag{6}$$

In expressions (6), the factors $\mathbf{C}^{\mathbf{i}}$, as in two-component phenology, are determined by the "hidden" parameters, which give a degeneracy for direct coefficients. It should be noted that the more general consideration of the three-component phenomenology revealed the interdependence of the "allowed" cofactors $\mathbf{C}^{\mathbf{i}}$, which was missed when considering the partial two-component phenomenology. The first 4 solutions ($\mathbf{i}$ - the solution number) for the factors $\mathbf{C}^{\mathbf{i}}$.

i	$\mathbf{C}^{\mathbf{i}}_{\mathbf{EN}}$	$\mathbf{C}^{\mathbf{i}}_{\mathbf{ET}}$	$\mathbf{C}^{\mathbf{i}}_{\mathbf{NT}}$
1	-1	-1	+1
2	+1	-1	-1
3	-1	+1	-1
4	+1	+1	+1

(7)

$\mathbf{C}^{\mathbf{i}}$ and in the three-component case one simply determines the sign in the expressions for the cross-correlation coefficients, but the signs are "resolved" only in a combination shown in the matrix (7), which is in strict accordance with the Onsager symmetry principle and for two-component phenomenology (analogous solutions can be obtained for the Casimir principle of symmetry, but they are not thermo-electric).

The first four solutions providing a conditionally-single-phase balance of three forces correspond to real pair-cross coefficients with factors $\mathbf{C}^{\mathbf{i}} = \pm 1$. In this case, the counter-phase nature of the sum of the cross-terms in the equations of system (4) to the direct term is ensured so that the cross members themselves can only be either in phase with each other or in antiphase.

But, unlike the two-component cases, when the "hidden" parameters give only a sign depending on the type of charge carriers, for the three-component phenomenology for pair-cross-correlation coefficients, we have 8 additional solutions for "allowed" complex factors whose absolute magnitudes are equal $\mathbf{1}/\sqrt{\mathbf{2}}$.

i	$\mathbf{C}^{\mathbf{i}}_{\mathbf{EN}}$	$\mathbf{C}^{\mathbf{i}}_{\mathbf{ET}}$	$\mathbf{C}^{\mathbf{i}}_{\mathbf{NT}}$
5	$-\frac{1}{4}+i\frac{\sqrt{7}}{4}$	$-\frac{1}{4}+i\frac{\sqrt{7}}{4}$	$-\frac{1}{4}+i\frac{\sqrt{7}}{4}$
6	$\frac{1}{4}-i\frac{\sqrt{7}}{4}$	$-\frac{1}{4}+i\frac{\sqrt{7}}{4}$	$\frac{1}{4}-i\frac{\sqrt{7}}{4}$
7	$-\frac{1}{4}+i\frac{\sqrt{7}}{4}$	$\frac{1}{4}-i\frac{\sqrt{7}}{4}$	$\frac{1}{4}-i\frac{\sqrt{7}}{4}$
8	$\frac{1}{4}-i\frac{\sqrt{7}}{4}$	$\frac{1}{4}-i\frac{\sqrt{7}}{4}$	$-\frac{1}{4}+i\frac{\sqrt{7}}{4}$
9	$-\frac{1}{4}-i\frac{\sqrt{7}}{4}$	$-\frac{1}{4}-i\frac{\sqrt{7}}{4}$	$\frac{5}{8}-i\frac{\sqrt{7}}{8}$
10	$\frac{1}{4}+i\frac{\sqrt{7}}{4}$	$-\frac{1}{4}-i\frac{\sqrt{7}}{4}$	$-\frac{5}{8}+i\frac{\sqrt{7}}{8}$
11	$-\frac{1}{4}-i\frac{\sqrt{7}}{4}$	$\frac{1}{4}+i\frac{\sqrt{7}}{4}$	$\frac{1}{4}+i\frac{\sqrt{7}}{4}$
12	$\frac{1}{4}+i\frac{\sqrt{7}}{4}$	$\frac{1}{4}+i\frac{\sqrt{7}}{4}$	$-\frac{1}{4}-i\frac{\sqrt{7}}{4}$

(8)

$$\begin{array}{cccc}
i & \mathrm{Arg}[C_{EN}^{i}] & \mathrm{Arg}[C_{ET}^{i}] & \mathrm{Arg}[C_{NT}^{i}] \\
5 & \pi-\mathrm{ArcTan}[\sqrt{7}] & \pi-\mathrm{ArcTan}[\sqrt{7}] & \pi-\mathrm{ArcTan}[\sqrt{7}] \\
6 & -\mathrm{ArcTan}[\sqrt{7}] & \pi-\mathrm{ArcTan}[\sqrt{7}] & -\mathrm{ArcTan}[\sqrt{7}] \\
7 & \pi-\mathrm{ArcTan}[\sqrt{7}] & -\mathrm{ArcTan}[\sqrt{7}] & -\mathrm{ArcTan}[\sqrt{7}] \\
8 & -\mathrm{ArcTan}[\sqrt{7}] & -\mathrm{ArcTan}[\sqrt{7}] & \pi-\mathrm{ArcTan}[\sqrt{7}] \\
9 & -\pi+\mathrm{ArcTan}[\sqrt{7}] & -\pi+\mathrm{ArcTan}[\sqrt{7}] & -\mathrm{ArcTan}\left[\frac{\sqrt{7}}{5}\right] \\
10 & \mathrm{ArcTan}[\sqrt{7}] & -\pi+\mathrm{ArcTan}[\sqrt{7}] & \pi-\mathrm{ArcTan}\left[\frac{\sqrt{7}}{5}\right] \\
11 & -\pi+\mathrm{ArcTan}[\sqrt{7}] & \mathrm{ArcTan}[\sqrt{7}] & \mathrm{ArcTan}[\sqrt{7}] \\
12 & \mathrm{ArcTan}[\sqrt{7}] & \mathrm{ArcTan}[\sqrt{7}] & -\pi+\mathrm{ArcTan}[\sqrt{7}]
\end{array} \tag{9}$$

The "allowed" combinations of complex factors obtained from the vanishing of the fluctuation currents in the one-dimensional case (or in the isotropic case, for collinear thermodynamic forces) can be useful only for estimating the noise level in measurements on a constant heat flux.

But they directly point out that under certain "hidden" parameters conditions can be realized when the contributions from cross effects are shifted in time on the phase concerning the contribution of the direct effect in the equations for the fluxes (4). In this case, when the alternating heat flux is applied to the p-n junction, the resulting relationships give, without loss-damping, the dependence of the magnitude of the local thermo-EMF on the phases of these contributions.

It was checked that the shift of the resonance frequency to the low-frequency or high-frequency region requires connection of a capacitance or inductance by several orders of magnitude larger than the corresponding values typical for the p-n junction and measuring circuits.

Thus, it was shown that it is the phase shift of the contributions of different thermodynamic forces to the total fluxes that determines how with zeroing of the signal at low frequencies, so the resonance itself, and the resulting expressions (6) allow to make not only qualitative conclusions, but also to carry out quantitative calculations.

V. Conclusion

The local thermo-EMFs detected at the contacts were investigated in p-n junctions based on silicon, which is a contact with highly reproducible properties. In the frequency dependences of local thermo-EMF, Gauss resonance was recorded, which directly indicated the balance / imbalance of the phase of contributions from various thermodynamic forces to the signal.

The expansion of the phenomenology of thermoelectricity necessary to take into account the concentration force in the first, linear approximation gave a description of the dependence of the total fluxes on the phase balances / imbalances of contributions on direct and cross effects.

The obtained results already qualitatively allow to optimize micro- and nano-devices in terms of their efficiency, which is essential both for thermoelectric conversion and for any other elements of microelectronics.

The solutions of the extended system of equations (2) for non-zero flows needed for quantitative calculations of the efficiency of micro- and nano-devices will be presented in the next article.

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Derivation of Three Model Dynamics in the Special Theory of Relativity

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DERIVATIONOFTHREEMODELDYNAMICSINTHESPECIALTHEORYOFRELATIVITY

Strictly as per the compliance and regulations of:

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Karol Szostek [α] & Roman Szostek [σ]

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I. Introduction

Kinematics deals with the movement of bodies without taking their physical characteristics into account. The basic concepts of kinematics are: time, location, transformation, speed and acceleration.

Dynamics deals with the movement of material bodies under the action of forces. The basic concepts of dynamics are: mass of inertia, force, momentum and kinetic energy.

Kinematics and dynamics are resulting in mechanics. In the article we deal with relativistic mechanics, i.e. the Special Theory of Relativity, which unlike classical mechanics, also applies to high-speed.

Currently, only one dynamics of the Special Theory of Relativity is known. In the article we presented the author's method of deriving numerous dynamics for this theory. Relativistic dynamics is derived based on the relativistic kinematics and one additional assumption, which allows the concept of mass, momentum and kinetic energy to be introduced into the theory.

II. Kinematic Assumptions of the Special Theory of Relativity

The kinematics of the Special Theory of Relativity is based on the following assumptions:

a) *All inertial systems are equivalent*

This assumption means that there is no such a physical phenomenon, which distinguishes the inertial system. In a particular case, it means that there is no such phenomenon for which the absolute rest is needed to explain. Mathematically, it results from this assumption that time transformation and position coordinate between any two inertial systems has an identical form, depending only on the relative velocity of these inertial systems.

b) *Velocity of light c in vacuum is the same in every direction and in each inertial system.*

c) *Transformation of time and position coordinates between the inertial systems is linear.*

These assumptions are often written in other equivalent forms.

Based on mentioned assumptions, it is possible to derive Lorentz transformation on which the Special Theory of Relativity is based. There are many different derivation ways of this transformation. Two derivations are presented in monograph [3].

Markings adopted in Figure 1. will be convenient for our needs. Inertial systems move along their *x*-axis. The velocity $v_{2/1}$ is a velocity of U_2 system measured by the observer from U_1 system. The velocity $v_{1/2}$ is a velocity of U_1 system measured by the observer from U_2 system. In the Special Theory of Relativity occurs that $v_{2/1} = -v_{1/2}$.

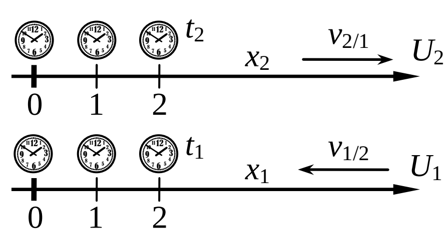

Fig. 1: Relative movement of inertial systems U_1 and U_2 ($v_{2/1} = -v_{1/2}$).

Lorentz transformation from U_2 to U_1 system has a form of:

$$t_1 = \frac{1}{\sqrt{1-(v_{2/1}/c)^2}}\left(t_2 + \frac{v_{2/1}}{c^2}x_2\right) \tag{1}$$

$$x_1 = \frac{1}{\sqrt{1-(v_{2/1}/c)^2}}(v_{2/1}t_2 + x_2) \tag{2}$$

$$y_1 = y_2, \qquad z_1 = z_2 \tag{3}$$

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Lorentz transformation from U_1 to U_2 system has a form of:

$$t_2 = \frac{1}{\sqrt{1-(v_{1/2}/c)^2}}(t_1 + \frac{v_{1/2}}{c^2}x_1) \quad (4)$$

$$x_2 = \frac{1}{\sqrt{1-(v_{1/2}/c)^2}}(v_{1/2}t_1 + x_1) \quad (5)$$

$$y_2 = y_1, \qquad z_2 = z_1 \quad (6)$$

Transformation (1)-(3) and (4)-(6) includes complete information on the relativistic kinematics.

III. Selected Properties of Relativistic Kinematics

In order to derive dynamics we will need two formulas from kinematics, i.e. (11) and (15) from kinematics. We will derive them out of transformation (1)-(3).

The known pattern STR is a formula for summing parallel speeds, which has the form

$$v_{3/1} = \frac{v_{3/2} + v_{2/1}}{1 + \frac{v_{3/2}v_{2/1}}{c^2}} \quad (7)$$

The body is inert in U_3 system and performs a momentary acceleration to U_3 system, then its speed will change in the U_1 and U_2 system. The $v_{2/1}$ speed remains unchanged. To determine the relationship between speed changes $v_{3/1}$ and $v_{3/2}$ we will determine the differentials from formula (7)

$$dv_{3/1} = \frac{d\dfrac{v_{3/2} + v_{2/1}}{1+(v_{3/2}v_{2/1})/c^2}}{dv_{3/2}}dv_{3/2} = \frac{1+\dfrac{v_{3/2}v_{2/1}}{c^2} - (v_{3/2}+v_{2/1})\dfrac{v_{2/1}}{c^2}}{\left(1+\dfrac{v_{3/2}v_{2/1}}{c^2}\right)^2}dv_{3/2} \quad (8)$$

$$dv_{3/1} = \frac{1-\dfrac{v_{2/1}^2}{c^2}}{\left(1+\dfrac{v_{3/2}v_{2/1}}{c^2}\right)^2}dv_{3/2} \quad (9)$$

If U_3 system is U_2 system then it is necessary to replace index 3 with 2. We will receive

$$dv_{3/1} = dv_{2/1}, \quad v_{3/2} = v_{2/2} = 0, \quad dv_{3/2} = dv_{2/2} \quad (10)$$

On this basis, the formula (9) takes a form of

$$dv_{2/2} = \frac{dv_{2/1}}{1-(v_{2/1}/c)^2} \quad (11)$$

Relation (11) is related to the change of body velocity seen in the inertial system U_2, in which the body is located ($dv_{2/2}$), and the change of velocity seen from another inertial system U_1 ($dv_{2/1}$). This is the first necessary formula from STR kinematics.

Determine the differentials from time transformation (1)

$$dt_1 = \frac{1}{\sqrt{1-(v_{2/1}/c)^2}}(dt_2 + \frac{v_{2/1}}{c^2}dx_2) \quad (12)$$

If the body is motionless with regard to U_2 system, then we get for its coordinates

$$\frac{dx_2}{dt_2} = 0 \quad (13)$$

Based on time transformation (12) we receive

$$\frac{dt_1}{dt_2} = \frac{1}{\sqrt{1-(v_{2/1}/c)^2}}(1+\frac{v_{2/1}}{c^2}\frac{dx_2}{dt_2}) \overset{\frac{dx_2}{dt_2}=0}{\Rightarrow} \frac{dt_1}{dt_2} = \frac{1}{\sqrt{1-(v_{2/1}/c)^2}} \tag{14}$$

On this basis we receive the formula for time dilatation of motionless body with regard to U_2 system

$$\frac{dx_2}{dt_2} = 0 \quad \Rightarrow \quad dt_2 = \sqrt{1-(v_{2/1}/c)^2} \cdot dt_1 \tag{15}$$

This is the second necessary formula from STR kinematics.

IV. Dynamics in the Special Theory of Relativity

All dissertations will be conducted only for one-dimensional model, i.e. all analyzed vector values will be parallel to *x*-axis. Each derived dynamic can easily be generalized into three-dimensional cases.

In order to derive dynamics in the Special Theory of Relativity, it is necessary to adopt an additional assumption, which allows the concept of mass, kinetic energy and momentum to be introduced into the theory. Depending on the assumption, different dynamics of bodies are received.

The mass of inertia body resting in inertial frame of reference is determined by m_0 (rest mass). The mass of inertia body mass U_2, as seen from U_1 system, is determined by $m_{2/1}$ (relativistic mass). It is worth to note that the relativistic mass in this case is an inertia mass that occurs in the Newton's second law, rather than mass occurring in the formula for momentum, as assumed in the Special Theory of Relativity. In this way, we have adopted a different definition of relativistic mass, than adopted in the Special Theory of Relativity. Such a definition of the relativistic mass is more convenient in deriving dynamics.

For force, momentum, and kinetic energy, definitions identical as in classical mechanics apply.

The body of m_0 mass is in U_2 system. It is affected by force $F_{2/2}$ that causes acceleration of $dv_{2/2}/dt_2$. Therefore, for the observer from U_2 system, the Newton's second law takes a form of

$$F_{2/2} = m_0 \cdot a_{2/2} = m_0 \frac{dv_{2/2}}{dt_2} \tag{16}$$

For the observer from U_1 system, mass of the same body is $m_{2/1}$. For this observer, the force $F_{2/1}$ acts on the body, causing acceleration of $dv_{2/1}/dt_1$. Therefore, for the observer from U_1 the Newton's second law takes the form of

$$F_{2/1} = m_{2/1} \cdot a_{2/1} = m_{2/1} \frac{dv_{2/1}}{dt_1} \tag{17}$$

For the observer from U_2 system, the change of this body momentum can be recorded in the following forms

$$dp_{2/2} = F_{2/2} \cdot dt_2 = m_0 \cdot a_{2/2} \cdot dt_2 = m_0 \frac{dv_{2/2}}{dt_2} dt_2 = m_0 \cdot dv_{2/2} \tag{18}$$

For the observer from U_1 system, the change of this body momentum can be recorded in the following forms

$$dp_{2/1} = F_{2/1} \cdot dt_1 = m_{2/1} \cdot a_{2/1} \cdot dt_1 = m_{2/1} \frac{dv_{2/1}}{dt_1} dt_1 = m_{2/1} \cdot dv_{2/1} \tag{19}$$

where:

- $dp_{2/2}$ is a change of body momentum with rest mass m_0 in the inertial system U_2, measured by the observer from the same inertial system U_2,
- $dp_{2/1}$ is a change of body momentum in the inertial system U_2, measured by the observer from the same inertial system U_1.

Kinetic energy of the body is equal of the work into its acceleration. For the observer from U_1 system, the change of kinetic energy of this body is as follows

$$dE_{2/1} = F_{2/1} \cdot dx_{2/1} = m_{2/1} \cdot a_{2/1} \cdot dx_{2/1} = m_{2/1} \frac{dv_{2/1}}{dt_1} dx_{2/1} = m_{2/1} \frac{dx_{2/1}}{dt_1} dv_{2/1} = m_{2/1} \cdot v_{2/1} \cdot dv_{2/1} \tag{20}$$

where:

- $dE_{2/1}$ is a change of kinetic energy of the body in inertial system U_2, measured by the observer from the inertial system U_1.

a) STR dynamics with constant force (STR/F)

In this section, a model of dynamics of bodies based on the assumption that the force accelerating of the body (parallel to *x*-axis) is the same for an observer from every inertial system will be derived (hence indication *F*).

i. *The relativistic mass in STR/F*

In the model STR/*F* we assume, that

$$F^F_{2/1} = F_{2/2} \tag{21}$$

Having introduced (16) and (17), we obtain

$$m^F_{2/1}\frac{dv_{2/1}}{dt_1} = m_0\frac{dv_{2/2}}{dt_2} \tag{22}$$

On the base (11) and (15), we have

$$m^F_{2/1}\frac{dv_{2/1}}{dt_1} = m_0\frac{\frac{dv_{2/1}}{1-(v_{2/1}/c)^2}}{\sqrt{1-(v_{2/1}/c)^2}\cdot dt_1} \tag{23}$$

Hence, we obtain a formula for relativistic mass of the body that is located in the system U_2 and is seen from the system U_1, when assumption (21) is satisfied, as below

$$m^F_{2/1} = m_0\left[\frac{1}{1-(v_{2/1}/c)^2}\right]^{3/2} \tag{24}$$

ii. *The Momentum in STR/F*

The body of rest mass m_0 is associated with the system U_2. To determine the momentum of the body relative to the system U_1 we substitute (24) to (19)

$$dp^F_{2/1} = m^F_{2/1}\cdot dv_{2/1} = m_0\left[\frac{1}{1-(v_{2/1}/c)^2}\right]^{3/2} dv_{2/1} = m_0c^3\frac{1}{(c^2-v^2_{2/1})^{3/2}}dv_{2/1} \tag{25}$$

The body momentum is a sum of increases in its momentum, when the body is accelerated from the inertial system U_1 (the body has velocity 0) to the inertial system U_2 (the body has velocity $v_{2/1}$), i.e.

$$p^F_{2/1} = m_0c^3\int_0^{v_{2/1}}\frac{1}{(c^2-v^2_{2/1})^{3/2}}dv_{2/1} \tag{26}$$

From the work [1] (formula 72, p. 167) it is possible to read out, that

$$\int\frac{dx}{(a^2-x^2)^{3/2}} = \frac{x}{a^2\sqrt{a^2-x^2}}, \qquad a\neq 0 \tag{27}$$

After applying the integral (27) to (26) we receive the formula for the body momentum in U_2 system and measured by the observer from U_1 system in a form of

$$p^F_{2/1} = m_0c^3\frac{v_{2/1}}{c^2\sqrt{c^2-v^2_{2/1}}} = m_0v_{2/1}\frac{1}{\sqrt{1-(v_{2/1}/c)^2}} \tag{28}$$

This formula is identical to the formula for momentum known from the Special Theory of Relativity, for the same reasons as in the case of momentum. This is because the dynamics known from the Special Theory of Relativity is derived from the assumption (21). It was adopted unconsciously, because it was considered as necessary. The awareness of this assumption allows to its change and derives other dynamics.

As already mentioned above, the definition of relativistic mass adopted by us is different from the definition adopted in the Special Theory of Relativity. In our case, the relativistic mass is the one, which occurs in the Newton's second law (17). In this particular case, it is expressed in terms of dependency (24). In the Special Theory of Relativity, the relativistic mass is the one, which occurs in the formula (28) per momentum.

iii. *The momentum in STR/F for small velocities*

For small velocity $v_{2/1} << c$ momentum (28) comes down to the momentum from classical mechanics, because

$$v_{2/1}\approx 0 \quad\Rightarrow\quad p^F_{2/1}\approx m_0v_{2/1} \tag{29}$$

iv. *The kinetic energy in STR/F*

We will determine the formula for kinetic energy. To the formula (20), we introduce the dependence for the relativistic mass (24)

$$dE^F_{2/1} = m^F_{2/1}\cdot v_{2/1}\cdot dv_{2/1} = m_0\left[\frac{1}{1-(v_{2/1}/c)^2}\right]^{3/2} v_{2/1}dv_{2/1} = m_0c^3\frac{v_{2/1}}{(c^2-v^2_{2/1})^{3/2}}dv_{2/1} \tag{30}$$

The kinetic energy of body is a sum of increases in its kinetic energy, when the body is accelerated from the inertial system U_1 (the body has velocity 0) to the inertial system U_2 (the body has velocity $v_{2/1}$), i.e.

$$E^F_{2/1} = m_0c^3\int_0^{v_{2/1}}\frac{v_{2/1}}{(c^2-v^2_{2/1})^{3/2}}dv_{2/1} \tag{31}$$

From the work [1] (formula 74, p. 167) it is possible to read out, that

$$\int\frac{xdx}{(a^2-x^2)^{3/2}} = \frac{1}{\sqrt{a^2-x^2}} \tag{32}$$

After applying the integral (32) to (31) we receive the formula for the kinetic energy of the body in

U_2 system and measured by the observer from U_1 system in a form of

$$E_{2/1}^F = m_0 c^3 \frac{1}{\sqrt{c^2 - x^2}}\Bigg|_0^{v_{2/1}} = m_0 c^3 \left(\frac{1}{\sqrt{c^2 - v_{2/1}^2}} - \frac{1}{c} \right) = m_0 c^2 \frac{1}{\sqrt{1-(v_{2/1}/c)^2}} - m_0 c^2 \tag{33}$$

This formula is identical to the formula for kinetic energy known from the Special Theory of Relativity, for the same reasons as in the case of momentum (28).

The kinetic energy (33) can be represented in other forms

$$E_{2/1}^F = m_0 c^2 \frac{1-\sqrt{1-(v_{2/1}/c)^2}}{\sqrt{1-(v_{2/1}/c)^2}} \cdot \frac{1+\sqrt{1-(v_{2/1}/c)^2}}{1+\sqrt{1-(v_{2/1}/c)^2}} \tag{34}$$

$$E_{2/1}^F = \frac{m_0 v_{2/1}^2}{2} \frac{2}{1-\frac{v_{2/1}^2}{c^2}+\sqrt{1-\frac{v_{2/1}^2}{c^2}}} \tag{35}$$

v. *The kinetic energy in STR/F for small velocities*

For small velocity $v_{2/1} << c$ kinetic energy (35) comes down to the kinetic energy from classical mechanics, because

$$v_{2/1} \approx 0 \quad \Rightarrow \quad E_{2/1}^F \approx \frac{m_0 v_{2/1}^2}{2} \frac{2}{1+1} = \frac{m_0 v_{2/1}^2}{2} \tag{36}$$

vi. *The Force in STR/F*

Due to the assumption (21) value measurement of the same force by two different observers is identical.

b) *STR dynamics with constant force to its operation time (STR/F/Δt)*

In this section, a model of dynamics of bodies based on the assumption that the force that accelerates of the body (parallel to *x*-axis) divided by the time of operation of this force is the same for an observer from every inertial system will be derived (hence indication *F*/Δ*t*).

i. *The relativistic mass in STR/F/Δt*

In the model STR/*F*/Δ*t* we assume, that

$$\frac{F_{2/1}^{F/\Delta t}}{dt_1} = \frac{F_{2/2}}{dt_2} \tag{37}$$

Having introduced (16) and (17), we obtain

$$m_{2/1}^{F/\Delta t} \frac{dv_{2/1}}{dt_1} \frac{1}{dt_1} = m_0 \frac{dv_{2/2}}{dt_2} \frac{1}{dt_2} \tag{38}$$

On the base (11) and (15), we have

$$m_{2/1}^{F/\Delta t} \frac{dv_{2/1}}{dt_1^2} = m_0 \frac{\frac{dv_{2/1}}{1-(v_{2/1}/c)^2}}{(1-(v_{2/1}/c)^2) dt_1^2} \tag{39}$$

Hence, we obtain a formula for relativistic mass of the body that is located in the system U_2 and is seen from the system U_1, when assumption (37) is satisfied, as below

$$m_{2/1}^{F/\Delta t} = m_0 \left[\frac{1}{1-(v_{2/1}/c)^2} \right]^2 \tag{40}$$

ii. *The Momentum in STR/F/ Δt*

The body of rest mass m_0 is associated with the system U_2. To determine the momentum of the body relative to the system U_1 we substitute (40) to (19)

$$dp_{2/1}^{F/\Delta t} = m_{2/1}^{F/\Delta t} \cdot dv_{2/1} = m_0 \left[\frac{1}{1-(v_{2/1}/c)^2} \right]^2 dv_{2/1} = m_0 c^4 \frac{1}{(c^2 - v_{2/1}^2)^2} dv_{2/1} \tag{41}$$

The body momentum is a sum of increases in its momentum, when the body is accelerated from the inertial system U_1 (the body has velocity 0) to the inertial system U_2 (the body has velocity $v_{2/1}$), i.e.

$$p_{2/1}^{F/\Delta t} = m_0 c^4 \int_0^{v_{2/1}} \frac{1}{(c^2 - v_{2/1}^2)^2} dv_{2/1} \tag{42}$$

From the work [1] (formula 54, p. 160) it is possible to read out, that

$$\int \frac{dx}{(a^2 - x^2)^2} = \frac{x}{2a^2(a^2 - x^2)} + \frac{1}{4a^3} \ln\left| \frac{a+x}{a-x} \right|, \quad a \neq 0 \tag{43}$$

After applying the integral (43) to (42) we receive the formula for the body momentum in U_2 system and measured by the observer from U_1 system in a form of

$$p_{2/1}^{F/\Delta t} = m_0 c^4 \left[\frac{x}{2c^2(c^2 - x^2)} + \frac{1}{4c^3} \ln\frac{(c+x)}{(c-x)} \right]\Bigg|_0^{v_{2/1}} = m_0 c \left[\frac{c v_{2/1}}{2(c^2 - v_{2/1}^2)} + \frac{1}{4} \ln\frac{(c+v_{2/1})}{(c-v_{2/1})} \right] \tag{44}$$

$$p_{2/1}^{F/\Delta t} = m_0 v_{2/1} \frac{1}{2}\left[\frac{1}{1-(v_{2/1}/c)^2} + \ln\left(\frac{c+v_{2/1}}{c-v_{2/1}}\right)^{\frac{c}{2v_{2/1}}}\right] \tag{45}$$

iii. *The momentum in STR/F/Δt for small velocities*

For small velocity $v_{2/1}$ momentum (45) comes down to the momentum from classical mechanics, because

$$p_{2/1}^{F/\Delta t} = m_0 v_{2/1}\left[\frac{1}{2(1-(v_{2/1}/c)^2)} + \frac{1}{4}\ln\left(\frac{(1+v_{2/1}/c)^{c/v_{2/1}}}{(1-v_{2/1}/c)^{c/v_{2/1}}}\right)\right] \tag{46}$$

$$p_{2/1}^{F/\Delta t} = m_0 v_{2/1}\left[\frac{1}{2(1-(v_{2/1}/c)^2)} + \frac{1}{4}\ln\left(\frac{\left(1+\dfrac{1}{c/v_{2/1}}\right)^{c/v_{2/1}}}{\left(1-\dfrac{1}{c/v_{2/1}}\right)^{c/v_{2/1}}}\right)\right] \tag{47}$$

On this basis, for small values $v_{2/1} \approx 0$ we receive

$$v_{2/1} \approx 0 \quad \Rightarrow \quad p_{2/1}^{F/\Delta t} \approx m_0 v_{2/1}\left[\frac{1}{2} + \frac{1}{4}\ln\left(\frac{e}{1/e}\right)\right] = m_0 v_{2/1}\left[\frac{1}{2} + \frac{1}{4}\ln(e^2)\right] = m_0 v_{2/1} \tag{48}$$

iv. *The kinetic energy in STR/F/Δt*

We will determine the formula for kinetic energy. To the formula (20), we introduce the dependence for the relativistic mass (40)

$$dE_{2/1}^{F/\Delta t} = m_{2/1}^{F/\Delta t} \cdot v_{2/1} \cdot dv_{2/1} = m_0\left[\frac{1}{1-(v_{2/1}/c)^2}\right]^2 v_{2/1} dv_{2/1} = m_0 c^4 \frac{v_{2/1}}{(c^2 - v_{2/1}^2)^2} dv_{2/1} \tag{49}$$

The kinetic energy of body is a sum of increases in its kinetic energy, when the body is accelerated from the inertial system U_1 (the body has velocity 0) to the inertial system U_2 (the body has velocity $v_{2/1}$), i.e.

$$E_{2/1}^{F/\Delta t} = m_0 c^4 \int_0^{v_{2/1}} \frac{v_{2/1}}{(c^2 - v_{2/1}^2)^2} dv_{2/1} \tag{50}$$

From the work [1] (formula 58, p. 160) it is possible to read out, that

$$\int \frac{x\,dx}{(a^2 - x^2)^2} = \frac{1}{2(a^2 - x^2)} \tag{51}$$

After applying the integral (51) do (50) we receive the formula for the kinetic energy of the body in U_2 system and measured by the observer from U_1 system in a form of

$$E_{2/1}^{F/\Delta t} = m_0 c^4 \left.\frac{1}{2(c^2 - x^2)}\right|_0^{v_{2/1}} = \frac{m_0 c^4}{2}\frac{1}{(c^2 - v_{2/1}^2)} - \frac{m_0 c^4}{2}\frac{1}{c^2} \tag{52}$$

$$E_{2/1}^{F/\Delta t} = \frac{m_0 c^2}{2}\frac{1}{1-(v_{2/1}/c)^2} - \frac{m_0 c^2}{2} = \frac{m_0 v_{2/1}^2}{2}\frac{1}{1-(v_{2/1}/c)^2} \tag{53}$$

The formula for kinetic energy (53) was derived from the work [2], due to the fact that the author adopted a different assumption than the one on which the dynamics known from the Special Theory of Relativity was based.

v. *The kinetic energy in STR/F/Δt for small velocities*

For small velocity $v_{2/1}$ kinetic energy (53) comes down to the kinetic energy from classical mechanics, because

$$v_{2/1} \approx 0 \quad \Rightarrow \quad E_{2/1}^{F/\Delta t} \approx \frac{m_0 v_{2/1}^2}{2} \cdot \frac{1}{1} = \frac{m_0 v_{2/1}^2}{2} \tag{54}$$

vi. *The Force in STR/F/Δt*

Body with rest mass m_0 is related to U_2 system. It is affected by force that causes acceleration. For the observer from this system, the acceleration force has in accordance with (16) the following value

$$F_{2/2} = m_0 \frac{dv_{2/2}}{dt_2} \tag{55}$$

For the observer from U_1 system, acceleration force has in accordance with (17) the following value

$$F_{2/1}^{F/\Delta t} = m_{2/1}^{F/\Delta t} \frac{dv_{2/1}}{dt_1} \tag{56}$$

If we will divide parties' equation (56) by (55), then on the basis of (11) and (15) we will receive

$$\frac{F_{2/1}^{F/\Delta t}}{F_{2/2}} = \frac{m_{2/1}^{F/\Delta t}}{m_0} \cdot \frac{dt_2}{dt_1} \cdot \frac{dv_{2/1}}{dv_{2/2}} = \frac{m_{2/1}^{F/\Delta t}}{m_0} (1-(v_{2/1}/c)^2)^{3/2} \tag{57}$$

On the basis of (40) we obtain a relation between measurements of the same force by two different observers

$$F_{2/1}^{F/\Delta t} = \frac{1}{\sqrt{1-(v_{2/1}/c)^2}} \cdot F_{2/2} \tag{58}$$

The lowest value of force is measured by the observer from the inertial system in which the body is located.

c) *STR dynamics with constant mass (STR/m)*

In this section, a model of dynamics of bodies based on the assumption that body weight is the same for an observer from each inertial reference system will be derived (hence indication *m*).

i. *The relativistic mass in STR/m*

In the model STR/*m* we assume, that

$$m_{2/1}^m = m_0 \tag{59}$$

Therefore, for the observer from inertial system U_1, the body mass in U_2 system is the same as the rest mass.

ii. *The Momentum in STR/m*

The body of rest mass m_0 is associated with the system U_2. To determine the momentum of the body relative to the system U_1 we substitute (59) to (19)

$$dp_{2/1}^m = m_{2/1}^m \cdot dv_{2/1} = m_0 dv_{2/1} \tag{60}$$

The body momentum is a sum of increases in its momentum, when the body is accelerated from the inertial system U_1 (the body has velocity 0) to the inertial system U_2 (the body has velocity $v_{2/1}$), i.e.

$$p_{2/1}^m = m_0 \int_0^{v_{2/1}} dv_{2/1} = m_0 v_{2/1} \tag{61}$$

In this relativistic dynamics the momentum is expressed with the same equation as in classical mechanics.

iii. *The kinetic energy in STR/m*

We will determine the formula for kinetic energy. To the formula (20), we introduce the dependence for the relativistic mass (59)

$$dE_{2/1}^m = m_{2/1}^m \cdot v_{2/1} \cdot dv_{2/1} = m_0 v_{2/1} dv_{2/1} \tag{62}$$

The kinetic energy of body is a sum of increases in its kinetic energy, when the body is accelerated from the inertial system U_1 (the body has velocity 0) to the inertial system U_2 (the body has velocity $v_{2/1}$), i.e.

$$E_{2/1}^m = m_0 \int_0^{v_{2/1}} v_{2/1} dv_{2/1} = \frac{m_0 v_{2/1}^2}{2} \tag{63}$$

In this relativistic dynamics the kinetic energy is expressed with the same equation as in classical mechanics.

iv. *The force in STR/m*

Body with rest mass m_0 is related to U_2 system. It is affected by force that causes acceleration. For the observer from this system, the acceleration force has in accordance with (16) the following value

$$F_{2/2} = m_0 \frac{dv_{2/2}}{dt_2} \tag{64}$$

For the observer from U_1 system, acceleration force has in accordance with (17) the following value

$$F_{2/1}^m = m_{2/1}^m \frac{dv_{2/1}}{dt_1} = m_0 \frac{dv_{2/1}}{dt_1} \tag{65}$$

If we will divide parties' equation (65) by (64), then on the basis of (11) and (15) we will receive

$$\frac{F_{2/1}^m}{F_{2/2}} = \frac{dt_2}{dt_1} \cdot \frac{dv_{2/1}}{dv_{2/2}} = (1-(v_{2/1}/c)^2)^{3/2} \tag{66}$$

i.e.

$$F_{2/1}^m = (1-(v_{2/1}/c)^2)^{3/2} \cdot F_{2/2} \tag{67}$$

The highest value of force is measured by the observer from the inertial system in which the body is located.

v. *Discussion on the STR/m Dynamics*

Obtaining a relativistic dynamics, in which there is no relativistic mass, and equations for kinetic energy and momentum are identical as in classical mechanics can be surprising, because in relativistic mechanics it is believed that the accelerated body can achieve maximum speed c. However, this dynamics is formally correct.

If the body velocity $v_{2/1}$ reaches c value, then according to (67)

$$F_{2/1}^{m} = (1-1^{-})^{3/2} \cdot F_{2/2} \approx 0 \tag{68}$$

In the inertial system U_2, in which the body is located, can be affected by acceleration force $F_{2/2}$ of any, but finite value. However, from a perspective of the inertial system U_1, towards which the body has c velocity, the same force is zero. This means that from a perspective of U_1 system, it is not possible to perform work on the body, which will increase its kinetic energy indefinitely. From the relation (63) it results that the kinetic energy, that a body with mass m_0 and velocity c has, a value has

$$E_{\max}^{m} = \frac{m_0 c^2}{2} \tag{69}$$

V. The General form of Dynamics

In article [5], other dynamics of STR were derived. Based on all these examples, can see that assumption for relativistic dynamics is as follows:

$$m_{2/1}^{\{a,b\}} \frac{dv_{2/1}^{a}}{dt_1^{b}} = m_0 \frac{dv_{2/2}^{a}}{dt_2^{b}}, \qquad a,b \in R \tag{70}$$

On the basis of (11) and (15) we receive

$$m_{2/1}^{\{a,b\}} \frac{dv_{2/1}^{a}}{dt_1^{b}} = m_0 \frac{\dfrac{dv_{2/1}^{a}}{(1-(v_{2/1}/c)^2)^{a}}}{(1-(v_{2/1}/c)^2)^{b/2} \cdot dt_1^{b}} \tag{71}$$

We are adopt markings

$$\{x\} \equiv \{a,b\} \qquad \wedge \qquad x = a + \frac{b}{2} \in R \tag{72}$$

Now on the basis of (71) the relativistic mass of body in U_2 system, seen from U_1 system, when an assumption is fulfilled (70), is expressed in dynamics $\{x\}$ by the following formula

$$m_{2/1}^{\{x\}} = m_0 \left[\frac{1}{1-(v_{2/1}/c)^2}\right]^{x} \tag{73}$$

Each such relativistic mass defines a different relativistic dynamics.

According to presented examples, based on formulas (19) and (73), the momentum in dynamics $\{x\}$ is expressed by the following formula

$$p_{2/1}^{\{x\}} = \int_0^{v_{2/1}} dp_{2/1}^{\{x\}} = \int_0^{v_{2/1}} m_{2/1}^{\{x\}} \cdot dv_{2/1} = m_0 \int_0^{v_{2/1}} \left[\frac{1}{1-(v_{2/1}/c)^2}\right]^{x} dv_{2/1} \tag{74}$$

$$p_{2/1}^{\{x\}} = m_0 c^{2x} \int_0^{v_{2/1}} \frac{1}{(c^2 - v_{2/1}^2)^{x}} dv_{2/1} \tag{75}$$

According to presented examples, based on formulas (20) and (73), the kinetic energy in dynamics $\{x\}$ is expressed by the following formula

$$E_{2/1}^{\{x\}} = \int_0^{v_{2/1}} dE_{2/1}^{\{x\}} = \int_0^{v_{2/1}} m_{2/1}^{\{x\}} \cdot v_{2/1} \cdot dv_{2/1} = m_0 \int_0^{v_{2/1}} \left[\frac{1}{1-(v_{2/1}/c)^2}\right]^{x} v_{2/1} dv_{2/1} \tag{76}$$

$$E_{2/1}^{\{x\}} = m_0 c^{2x} \int_0^{v_{2/1}} \frac{v_{2/1}}{(c^2 - v_{2/1}^2)^{x}} dv_{2/1} \tag{77}$$

According to presented examples, based on formulas (16), (17) and (11), (15), the relation between forces in dynamics $\{x\}$ is expressed by the following formula

$$\frac{F_{2/1}^{\{x\}}}{F_{2/2}} = \frac{m_{2/1}^{\{x\}} \dfrac{dv_{2/1}}{dt_1}}{m_0 \dfrac{dv_{2/2}}{dt_2}} = \frac{m_{2/1}^{\{x\}} \dfrac{dv_{2/1}}{dt_1}}{m_0 \dfrac{dv_{2/1}}{1-(v_{2/1}/c)^2} \cdot \dfrac{1}{\sqrt{1-(v_{2/1}/c)^2} \cdot dt_1}} = \frac{m_{2/1}^{\{x\}}}{m_0} (1-(v_{2/1}/c)^2)^{3/2} \tag{78}$$

On the basis of (73) we receive

$$F_{2/1}^{\{x\}} = \left[\frac{1}{1-(v_{2/1}/c)^2}\right]^{x} (1-(v_{2/1}/c)^2)^{3/2} = \left[\frac{1}{1-(v_{2/1}/c)^2}\right]^{x-\frac{3}{2}} \cdot F_{2/2} \tag{79}$$

VI. Summary of Dynamics

In Figure 2 were compared momentums from derived relativistic dynamics.

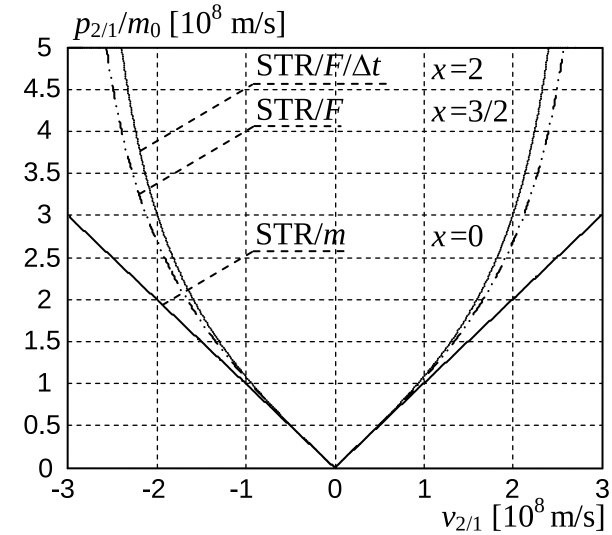

Fig. 2: Module of the momentum in dynamics: STR/ m (x=0), STR/ F (x=3/2) and STR/ F/Δt (x=2).

In Figure 3 were compared kinetic energies from derived relativistic dynamics.

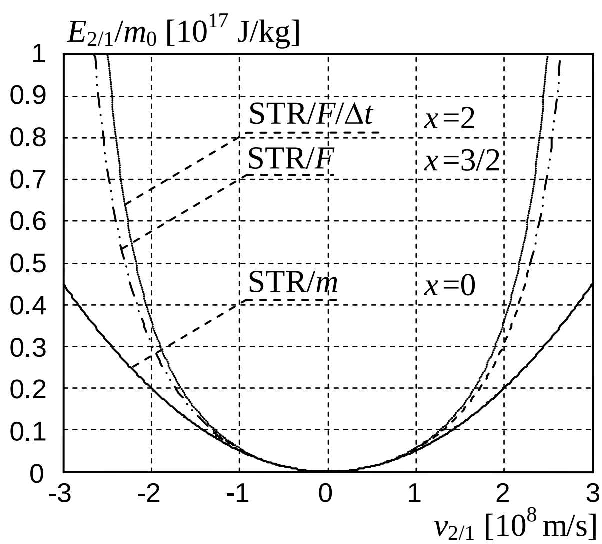

Fig. 3: Kinetic energies in dynamics: STR/ m (x=0), STR/ F (x=3/2) and STR/ F/Δt (x=2).

VII. Final Conclusions

The article presents our author's method of deriving dynamics in the Special Theory of Relativity. Three examples of such deriving were shown.

Derivation of dynamics is based on two formulas applicable in the kinematics of STR, i.e. (11) and (15). In order to derive the dynamics of STR, it is necessary to adopt an additional assumption in kinematics, which allows the concept of mass, kinetic energy and momentum to be introduced into the theory.

The dynamics of STR/*F* is nowadays recognized as the dynamics of the Special Relativity Theory. It is based on the assumption that each force parallel to *x*-axis has the same value for the observer from each inertial frame of reference. However, other dynamics are possible in accordance with the kinematics of the Special Theory of Relativity. In order to derive them, it is necessary to base on a different assumption.

Decision which from all possible dynamics of the Special Theory of Relativity is a correct model of real processes, should be one of the most important tasks of future physics. A calorimeter can be useful for verification of different dynamics. This device can measure the amount of heat released when stopping particles to high speed. On this basis, it is possible to determine graphs of the kinetic energy of accelerated particles as a function of their velocity, analogous to those presented in Figure 3. On this basis, it is possible to indicate the dynamics in which the kinetic energy of particles is compatible with experiments.

The fact that as a part of the Special Theory of Relativity, numerous dynamics can be derived greatly undermines the authenticity of the formula $E = mc^2$. According to our research, on the basis of relativistic mechanics, it is impossible to derive a formula expressing the internal energy of matter [4]. All derivations of this formula are wrong. The relation between mass and energy ($E = mc^2$) can be introduced into the STR as an independent assumption, but it does not result from Lorentz transformation, nor from the assumption (21) on which the dynamics of STR is based. But then there is a need to experimentally show what exactly is the form of such a dependency (e.g. why not $E = mc^2/2$) and experimentally investigate whether sometimes the form of such a dependency does not depend on the type of matter that this formula regards.

The presented method of dynamism derivation can also be used in other theory of body kinematics. In the monograph [3] we have used it to derive four dynamics in the Special Theory of Ether.

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Regular Exact Models with Vanishing Anisotropy Generated using Van Der Waals Equation of State

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Abstract- In this paper, new exact models for Einstein field equations are generated using a Van der Waals equation of state. We consider anisotropic stellar objects with no electromagnetic field distribution. Our models contain previous results as a special case. Models generalized in our performance include a familiar uncharged Einstein model with no pressure anisotropy. It is interesting that our models indicate that when matter variables vanish, gravitational potentials remain constant. This condition agrees with Minkowski spacetime. The physical features of our models show that the gravitational potentials and matter variables are well behaved. We also compute relativistic stellar masses and radii consistent with the stars PSR J1614-2230, Vela X-1, 4U 1538-52, LMC X-4, SMC X-4, Cen X-3, Her X-1, SAX J1808.4-3658 and EXO 1785-248.

Keywords: einstein field equations; vanishing anisotropy; neutral stellar objects; relativistic masses, van der waals equation of state.

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Abstract- In this paper, new exact models for Einstein field equations are generated using a Van der Waals equation of state. We consider anisotropic stellar objects with no electromagnetic field distribution. Our models contain previous results as a special case. Models generalized in our performance include a familiar uncharged Einstein model with no pressure anisotropy. It is interesting that our models indicate that when matter variables vanish, gravitational potentials remain constant. This condition agrees with Minkowski spacetime. The physical features of our models show that the gravitational potentials and matter variables are well behaved. We also compute relativistic stellar masses and radii consistent with the stars PSR J1614-2230, Vela X-1, 4U 1538-52, LMC X-4, SMC X-4, Cen X-3, Her X-1, SAX J1808.4-3658 and EXO 1785-248.

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I. Introduction

Models for gravitating spheres in general relativity are generated by utilizing the Einstein-Maxwell system of equations. In doing so some conditions may be imposed for physical acceptability. The Einstein Maxwell field equations are equations generated by equating the energy momentum tensor and the Einstein tensor involving gravitating stellar bodies with or without electric field distribution. In relativistic models, matter distribution can either be isotropic or anisotropic as Chaisi and Maharaj [1] in their work assumed that the matter distribution is isotropic so that the radial pressure is the same as the transverse pressure. A strong case can be made to study matter distributions which are anisotropic in which the radial component of the pressure is not the same as the transverse pressure.

The electric field is one of the ingredient that can be included in some of the relativistic models for charged stellar spheres. Charged models include the performance by Chattopadhyay et al [2], Maharaj and Thirukkanesh [3], Ivanov [4], Mehta et al [5], Murad and Fatema [6], Pant and Negi [7], Malaver [8], Thirukkanesh and Maharaj [9] and Maharaj and Komathiraj [10]. Mafa Takisa and Maharaj [11] obtained charged compact objects with anisotropic pressures in a core envelope setting.

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Bijalwan [12] indicated that the mass of a stellar star with electric field present is maximized with all degree of suitability. It was investigated the maximum mass of charged star to be $1{:}512 M_{\odot}$ with linear dimension 14:964 km. Maurya and Gupta [13] generated exact solutions for the Einstein's field equations for fluid spheres with pressure anisotropy. On the other hand, Mak and Harko [14] showed that strong magnetic fields could result into pressure anisotropy within stellar objects. Gupta and Maurya [15] found that the presence of electric field have effect on the gravitational collapse due to Colombian repulsive force and the pressure gradient. Neutral stellar models include results generated by Maharaj and Komathiraj [10], Sunzu [16] and Pant *et al* [17].

Relativistic models with linear equation of state have been found in the past. These include models performed by Esculpi and Aloma [18], Sharma and Maharaj [19], and Zdunik [20]. Aktas and Yilmaz [21] found linear models for Einstein field equations for spherical symmetric space-time via conformal motions. Sharma and Maharaj [22] found new exact models with linear equation of state by assuming a particular mass function. Maharaj and Chaisi [23] generated new models with linear barotropic equation of state. Kalam et al [24] proposed a relativistic model for strange quark stars within the framework of MIT bag model. Mak and Harko [14] presented exact anisotropic models consistent to stellar objects with a quark matter. Thirukkanesh and Maharaj [25] on physical grounds imposed a barotropic equation of state for the existence of strange matter. Exact anisotropic models for a charged relativistic spheres with linear equation of state were found by Maharaj and Mafa Takisa [26], Kileba Matondo and Maharaj [27], Maharaj et al [28] and Sunzu et al [29,30] and Sunzu and Danford [31]. Yilmaz and Baysal [32] investigated that quark stars are being formed during the collapsing of the core of a massive star after supernova explosion.

There are several anisotropic models generated using a quadratic equations of state for charged stellar spheres. These include the work by Maharaj and Mafa Takisa [33], Feroze and Siddiqui [34], Thirukkanesh and Maharaj [25] and Malaver [35]. Relativistic stellar models with polytropic equation of state were performed by Herrera and Barreto [36] and Dev and Gleiser [37]. It is often indicated that polytropes describe low or high pressure regimes especially for white dwarfs and neutron stars. Shibata [38] determined secular stability against a quasi-radial oscillation for rigidly rotating stellar objects. Lai and Xu [39] indicated that a theoretical polytropic quark star model could be tested by observations. Thirukkanesh and Ragel [40] indicated that a polytropic model is more stiffer than the conventional bag model. This is regarded more essential for modeling stars with realistic matter such as ideal gas, photon gas, degenerated Fermi gas and in particular quark matter. Other papers with polytropic equation of state include the work performed by Nilsson and Uggla [41], Spaans and Silk [42] and Mafa Takisa and Maharaj [43].

Relativistic stellar models with Van der Waals equations of state include models by Lobo [44], and Malaver [45, 46]. Thirukkanesh and Ragel [47] used Van der waals equation to generated compact anisotropic stellar models. Most of the anisotropic models with Van der waals equation have anisotropy always present and can not regain isotropic models. This is not physical. On the other hand, many of charged treatments in this direction have the electric field always present and can not regain neutral models. This is also not realistic. Uncharged anisotropic models with vanishing anisotropy using Van der waals equation of state are necessary.

The objective of this paper is to find new uncharged anisotropic models with vanishing anisotropy using Van der waals equation of state. In order to achieve this objective we arrange this paper in the following manner: In Sec. 2, we give the Einstein-Maxwell field equations for a neutral matter with anisotropic pressures. In Sect.3, we transform the field equations according to Durgapal and Bannerji [48]. In Sect. 4, we formulate the general differential equation governing the model. In Sect. 5, we generate solutions for nonsingular model I with Van derWaals equation of state. The model in this section generalizes earlier Einstein neutral model and obeys the phenomenon of Minkowski space-times. In Sect. 6, we find solutions for nonsingular model II with Van der Waals equation of state. In Sect. 7, we perform the physical analysis to indicate that the gravitational potentials and matter variables in our models are well behaved. We also generate relativistic stellar masses consistent with observations in this section. In Sect. 8 we give the conclusion.

II. The Anisotropic Model

We generate neutral anisotropic star models in a spacetime that is static and spherically symmetry. The line element in standard form is given by

$$ds^2 = -e^{2\nu(r)}dt^2 + e^{2\lambda(r)}dr^2 + r^2\left(d\theta^2 + sin^2\theta d\phi^2\right), \tag{1}$$

where $\nu(r)$ and $\lambda(r)$ are functions for gravitational potentials. The Schwarzschild [49] line element describing the exterior space time is given as

$$ds^2 = -\left(1-\frac{2M}{r}\right)dt^2 + \left(1-\frac{2M}{r}\right)^{-1}dr^2 + r^2\left(d\theta^2 + sin^2\theta d\phi^2\right), \tag{2}$$

where *M* represents the total mass. The energy momentum tensor for neutral anisotropic matter is given by

$$\tau_{ij} = diag(-\rho, p_r, p_t, p_t), \tag{3}$$

where the energy density ρ, the radial pressure p_r and the tangential pressure p_t, are variables measured relative to a vector u. The vector u^a is comoving, unit and timelike.

According to Krasinski [50], the Einstein-Maxwell field equations for a neutral matter with anisotropic pressures can be written in the form

$$\frac{1}{r^2}\left(1-e^{-2\lambda}\right) + \frac{2\lambda'}{r}e^{-2\lambda} = \rho, \tag{4a}$$

$$-\frac{1}{r^2}\left(1-e^{-2\lambda}\right) + \frac{2\nu'}{r}e^{-2\lambda} = p_r, \tag{4b}$$

$$e^{-2\lambda}\left(\nu'' + \nu'^2 - \nu'\lambda' + \frac{\lambda'}{r} - \frac{\lambda'}{r}\right) = p_t. \tag{4c}$$

Where primes in the system (4) stand for differentiation with respect to the radial coordinate *r*. The mass contained within the neutral sphere is given by

$$m(r) = \frac{1}{2}\int_0^r \omega^2\rho d\omega. \tag{5}$$

We use the Van der Waals equation of state relating the radial pressure and the energy density for the stellar object which is given as

$$p_r = \alpha\rho^2 + \frac{\beta\rho}{1+\gamma\rho}, \tag{6}$$

It is important to note that Eq. (6) becomes quadratic when $\gamma = 0$. It is in linear form when $\alpha = \gamma = 0$.

III. Transformation of the Field Equations

In order to obtain the exact solutions for the Einstein field equations, we transform the system (4) to an equivalent form by introducing independent variable x and new metric functions y and Z. These are defined as

$$x = Cr^2, Z(x) = e^{-2\lambda(r)}, A^2y^2(x) = e^{2\nu(r)}, \tag{7}$$

In the above *A* and *C* are arbitrary real constants. From Eq. (7) the line element (1) becomes

$$ds^2 = -A^2y^2(x)dt^2 + \frac{1}{Z(x)}\frac{1}{4xC}dx^2 + \frac{x}{C}\left(d\theta^2 + \sin^2\theta d\phi^2\right). \tag{8}$$

Then the mass function (5) becomes

$$M(x) = \frac{1}{4C^{\frac{3}{2}}}\int_0^x \sqrt{\omega}\rho d\omega. \tag{9}$$

The transformed Einstein-Maxwell field equations (4) with Van der Waals equation of state can be written as

$$\rho = \left(\frac{1-Z}{x} - 2\dot{Z}\right)C, \tag{10a}$$

$$p_r = \alpha\rho^2 + \frac{\beta\rho}{1+\gamma\rho}, \tag{10b}$$

$$p_t = p_r + \Delta, \tag{10c}$$

$$\Delta = \left[4xZ\frac{\ddot{y}}{y} + \left(1 + 2x\frac{\dot{y}}{y}\right)\dot{Z} + \frac{1-Z}{x}\right]C. \tag{10d}$$

In the above, $\Delta = p_t - p_r$. The system (10) above consists of six variables $(\rho, p_r, p_t, Z, y, \Delta)$ in four equations. The system can be solved if we specify any two variables. We have specified the following variables:

$$\Delta = A_0x + A_1x^2 + A_2x^3, \tag{11}$$

$$y = \frac{1-ax^m}{1+bx^n}, \tag{12}$$

where a, b, A_0, A_1, A_2, m and n are arbitrary real constants.

The metric function (12) is convenient to be used in modeling the stellar objects due to the fact that it is continuous, regular and finite. Similar choice of measure of anisotropy and metric function was made by Sunzu et al [29] in a model with electric field and a linear equation of state. However our model contain no electric field and we are using Van der waals equation of state. This choice of metric function and measure of anisotropy allows us to regain stellar models generated by Sunzu [16]. When the variable $\Delta = 0$, we generate the isotropic model. The condition of isotropic pressure is satisfied when $A_0 = A_1 = A_2 = 0$.

IV. The General Differential Equation for the Model

In this section we formulate the master differential equation governing our models. The differential equation is generated by using the measure of anisotropy and the metric function in Eq. (11) and Eq. (12) respectively. Substituting these equations into Eq. (10d) we have

$$\dot{Z} + \left[\frac{xN(x) - xP(x) - (1-ax^m)(1+bx^n)^2}{x(1+bx^n)(R(x)+Q(x))}\right]Z = \frac{\left(\frac{\Delta}{C} - \frac{1}{x}\right)R(x)}{R(x)+Q(x)}, \tag{13}$$

where for convenience we have set

$$\begin{aligned}
N(x) &= (1+bx^n)\left[4ab\left(n^2 - m^2 + m - n\right)x^{m+n-1}\right. \\
&\quad \left. - 4a\left(m^2 - m\right)x^{m-1} - 4b\left(n^2 - n\right)x^{n-1}\right], \\
P(x) &= \left[8ab^2\left(n^2 - nm\right)x^{m+2n-1} - 8abnmx^{m+n-1} - 8b^2n^2x^{2n-1}\right], \\
Q(x) &= 2ab(n-m)x^{m+n} - 2amx^m - 2bnx^n, \\
R(x) &= (1-ax^m)(1+bx^n).
\end{aligned}$$

We observe that Eq. (13) is in general a nonlinear differential equation in the potential *Z* which when integrated we obtain the function *Z*. We can therefore expressions for the matter variables. The general exact solution for Eq. (13) does not exist. However, we can find the exact solution for the nonlinear differential equation (13) by specifying the values for the constants. By doing so the nonlinear differential equation (13) can be linear and hence tractable. The choice for the constants should be made carefully so that the resulting model is physically well behaved and possible to regain other previous exact models.

V. Solution for Nonsingular Model I with Van Der Waals Equation of State

In this section we use Van der waals equations of state to generate a nonsingular model for specific values of constants. Setting $m = 1$, $n = 1$, $a = 0$ and $b = 0$ we generate the first class of exact solutions for the differential equation (13) with metric function $y = 1$. Doing so Eq. (13) becomes

$$\dot{Z} - \frac{Z}{x} = \frac{A_0 x + A_1 x^2 + A_2 x^3}{C} - \frac{1}{x}. \tag{14}$$

Solving Eq. (14) we obtain

$$Z = \frac{6A_0 x^2 + 3A_1 x^3 + 2A_2 x^4 + 6xCk + 6C}{6C}, \tag{15}$$

where k is a constant of integration. Therefore the gravitational potentials and matter variables in system (10) become

$$e^{2\nu} = A^2, \tag{16a}$$

$$e^{2\lambda} = \frac{6C}{x\left(6A_0 x + 3A_1 x^2 + 2A_2 x^3 + 6Ck\right) + 6C}, \tag{16b}$$

$$\rho = -5A_0 x - \frac{7}{2}A_1 x^2 - 3A_2 x^3 - 3Ck, \tag{16c}$$

$$p_r = \alpha\left(5A_0 x + \frac{7}{2}A_1 x^2 + 3A_2 x^3 + 3Ck\right)^2 - \frac{\beta\left(5A_0 x + \frac{7}{2}A_1 x^2 + 3A_2 x^3 + 3Ck\right)}{1 - \gamma\left(5A_0 x + \frac{7}{2}A_1 x^2 + 3A_2 x^3 + 3Ck\right)}, \tag{16d}$$

$$p_t = \alpha\left(5A_0 x + \frac{7}{2}A_1 x^2 + 3A_2 x^3 + 3Ck\right)^2 - \frac{\beta\left(5A_0 x + \frac{7}{2}A_1 x^2 + 3A_2 x^3 + 3Ck\right)}{1 - \gamma\left(5A_0 x + \frac{7}{2}A_1 x^2 + 3A_2 x^3 + 3Ck\right)} + A_0 x + A_1 x^2 + A_2 x^3, \tag{16e}$$

$$\Delta = A_0 x + A_1 x^2 + A_2 x^3. \tag{16f}$$

Then the mass function (9) becomes

$$M(x) = -\frac{x^{\frac{3}{2}}}{4C^{\frac{3}{2}}}\left(2A_0 x + A_1 x^2 + \frac{2}{3}A_2 x^3 + 2Ck\right). \tag{17}$$

The line element for the exact model in the system (16) becomes

$$ds^2 = -A^2 dt^2 + \frac{6dx^2}{4x\left[x\left(6A_0 x + 3A_1 x^2 + 2A_2 x^3 + 6Ck\right) + 6C\right]} + \frac{x}{C}\left(d\theta^2 + sin^2\theta d\phi^2\right). \tag{18}$$

For isotropic pressure ($\Delta = 0$), we have $A_0 = A_1 = A_2 = 0$. The gravitational potentials and matter variables in the system (16) becomes

$$e^{2\nu} = A^2, \tag{19a}$$

$$e^{2\lambda} = \frac{1}{kx + 1}, \tag{19b}$$

$$\begin{aligned} \rho &= -3Ck, && (19c) \\ p_r = p_t &= \alpha\left(3Ck\right)^2 - \frac{3\beta Ck}{1-3\gamma Ck}. && (19d) \end{aligned}$$

The mass function (17) becomes

$$M(x) = -\frac{x^{\frac{3}{2}}k}{2C^{\frac{1}{2}}}, \tag{20}$$

with the line element

$$ds^2 = -A^2dt^2 + \frac{dx^2}{4xC\left(kx+1\right)} + \frac{x}{C}\left(d\theta^2 + sin^2\theta d\phi^2\right). \tag{21}$$

The line element (21) can be presented as

$$ds^2 = -A^2dt^2 + \left(1 - \frac{r^2}{\Gamma^2}\right)^{-1} dr^2 + r^2\left(d\theta^2 + sin^2\theta d\phi^2\right), \tag{22}$$

where $\Gamma^2 = -\frac{1}{Ck}$ and $k < 0$. The line element (21) becomes a well known neutral isotropic Einstein model. This shows that our model contains other previous models as a special case. Taking $k = 0$ and $\Delta = 0$ we have

$$e^{2\nu} = A^2, e^{2\lambda} = 1, \rho = 0, p_r = p_t = 0, M = 0. \tag{23}$$

We see that the matter variables vanish and the gravitational potentials are constant. This agrees with Minkowski space-times.

VI. Solution for Nonsingular Model II with Van Der Waals Equation of State

We consider different values for the parameters *m, n, a* and *b* given in Eq. (13). We find other exact solutions when the metric function y is not constant. We choose $m = 1$, $n = 1$, $a \neq 0$ and $b = 0$. The metric function (12) becomes

$$y = 1 - ax, \tag{24}$$

and the differential equation (13) becomes

$$\dot{Z} - \left(\frac{1-ax}{x\left(1-3ax\right)}\right)Z = \frac{\left[x\left(A_0x + A_1x^2 + A_2x^3\right) - C\right]\left(1-ax\right)}{Cx\left(1-3ax\right)}. \tag{25}$$

Solving Eq. (25) we obtain

$$\begin{aligned} Z = & -\frac{1}{Ca^3}\left[\left(\frac{2}{5} - \frac{1}{5}ax\right)A_0a^2x \right. \\ & - \left(-\frac{3}{40} - \frac{3}{20}ax + \frac{1}{8}a^2x^2\right)A_1ax \\ & + \left(\frac{1}{55} + \frac{2}{55}ax + \frac{1}{11}a^2x^2 - \frac{1}{11}a^3x^3\right)A_2x - a^3C \\ & \left. - \frac{Cka^3x}{\left(1-3ax\right)^{\frac{2}{3}}}\right]. \end{aligned} \tag{26}$$

Hence the gravitational potentials and matter variables become

$$e^{2\nu} = A^2\left(1-ax\right)^2, \tag{27a}$$

$$
\begin{aligned}
e^{2\lambda} &= -Ca^3\left[\left(\frac{2}{5}-\frac{1}{5}ax\right)A_0a^2x\right.\\
&-\left(-\frac{3}{40}-\frac{3}{20}ax+\frac{1}{8}a^2x^2\right)A_1ax\\
&+\left(\frac{1}{55}+\frac{2}{55}ax+\frac{1}{11}a^2x^2-\frac{1}{11}a^3x^3\right)A_2x-a^3C\\
&\left.-\frac{Cka^3x}{(1-3ax)^{\frac{2}{3}}}\right]^{-1}, \qquad (27b)\\
\rho &= -\frac{1}{a^3(1-3ax)}\left[\left(-\frac{6}{5}-\frac{23}{5}ax+3a^2x^2\right)A_0a^2\right.\\
&-\left(\frac{9}{40}+\frac{3}{40}ax-\frac{25}{8}a^2x^2+\frac{21}{8}a^3x^3\right)A_1a\\
&-\left(\frac{3}{55}+\frac{1}{55}ax+\frac{1}{11}a^2x^2-\frac{30}{11}a^3x^3+\frac{27}{11}a^4x^4\right)A_2\\
&\left.+\frac{Ca^3k(3-5ax)}{(1-3ax)^{\frac{2}{3}}}\right], \qquad (27c)\\
p_r &= \alpha\left(\frac{1}{a^3(1-3ax)}\left[\left(-\frac{6}{5}-\frac{23}{5}ax+3a^2x^2\right)A_0a^2\right.\right.\\
&-\left(\frac{9}{40}+\frac{3}{40}ax-\frac{25}{8}a^2x^2+\frac{21}{8}a^3x^3\right)A_1a\\
&-\left(\frac{3}{55}+\frac{1}{55}ax+\frac{1}{11}a^2x^2-\frac{30}{11}a^3x^3+\frac{27}{11}a^4x^4\right)A_2\\
&\left.\left.+\frac{Ca^3k(3-5ax)}{(1-3ax)^{\frac{2}{3}}}\right]\right)^2-\frac{\beta\rho}{1-\gamma\rho}, \qquad (27d)\\
p_t &= \alpha\left(\frac{1}{a^3(1-3ax)}\left[\left(-\frac{6}{5}-\frac{23}{5}ax+3a^2x^2\right)A_0a^2\right.\right.\\
&-\left(\frac{9}{40}+\frac{3}{40}ax-\frac{25}{8}a^2x^2+\frac{21}{8}a^3x^3\right)A_1a\\
&-\left(\frac{3}{55}+\frac{1}{55}ax+\frac{1}{11}a^2x^2-\frac{30}{11}a^3x^3+\frac{27}{11}a^4x^4\right)A_2\\
&\left.\left.+\frac{Ca^3k(3-5ax)}{(1-3ax)^{\frac{2}{3}}}\right]\right)^2-\frac{\beta\rho}{1-\gamma\rho}\\
&+A_0x+A_1x^2+A_2x^3, \qquad (27e)\\
\Delta &= A_0x+A_1x^2+A_2x^3. \qquad (27f)
\end{aligned}
$$

The mass function (9) becomes

$$\begin{aligned} M(x) \;=\; & \frac{x^{\frac{3}{2}}}{a^3(1-3ax)C^{\frac{3}{2}}}\left[\left(\frac{1}{5}-\frac{7}{10}ax+\frac{3}{10}a^2x^2\right)A_0a^2\right. \\ & -\left(-\frac{3}{80}+\frac{3}{80}ax+\frac{23}{80}a^2x^2-\frac{3}{16}a^3x^3\right)A_1a \\ & +\left(\frac{1}{110}-\frac{1}{110}ax-\frac{1}{110}a^2x^2-\frac{2}{11}a^3x^3+\frac{3}{22}a^4x^4\right)A_2 \\ & \left.-\frac{1}{2}a^3Ck(1-3ax)^{\frac{1}{3}}\right]. \end{aligned} \tag{28}$$

:

The line element for the model in the system (27) becomes

$$\begin{aligned} ds^2 \;=\; & -A^2(1-ax)^2-Ca^3\left[\left(\frac{2}{5}-\frac{1}{5}ax\right)A_0a^2x\right. \\ & -\left(-\frac{3}{40}-\frac{3}{20}ax+\frac{1}{8}a^2x^2\right)A_1ax \\ & +\left(\frac{1}{55}+\frac{2}{55}ax+\frac{1}{11}a^2x^2-\frac{1}{11}a^3x^3\right)A_2x-a^3C \\ & \left.-\frac{Cka^3x}{(1-3ax)^{\frac{2}{3}}}\right]^{-1}\frac{dx^2}{4xC}+\frac{x}{C}\left(d\theta^2+sin^2\theta d\phi^2\right). \end{aligned} \tag{29}$$

Setting $a < 0$, $\alpha = 0$ and $\gamma = 0$ in the system (27) we regain the exact model given by Sunzu [16].

For isotropic pressure ($\Delta = 0$) we have $A_0 = A_1 = A_2 = 0$, and the gravitational potentials and matter variables in (27) become

$$e^{2\nu} = A^2(1-ax)^2, \tag{30a}$$

$$e^{2\lambda} = \frac{(1-3ax)^{\frac{2}{3}}}{kx+(1-3ax)^{\frac{2}{3}}}, \tag{30b}$$

$$\rho = -\frac{Ck(3-5ax)}{(1-3ax)^{\frac{5}{3}}}, \tag{30c}$$

$$p_r = p_t = \alpha\left(\frac{Ck(3-5ax)}{(1-3ax)^{\frac{5}{3}}}\right)^2 - \frac{\beta Ck(3-5ax)}{(1-3ax)^{\frac{5}{3}}-\gamma Ck(3-5ax)}. \tag{30d}$$

The mass function (28) becomes

$$M(x) = -\frac{x^{\frac{3}{2}}k}{2C^{\frac{1}{2}}(1-3ax)^{\frac{2}{3}}}. \tag{31}$$

with the line element

$$ds^2 = -A^2(1-ax)^2dt^2+\frac{(1-3ax)^{\frac{2}{3}}dx^2}{4xC\left[kx+(1-3ax)^{\frac{2}{3}}\right]} + \frac{x}{C}\left(d\theta^2+sin^2\theta d\phi^2\right). \tag{32}$$

Taking $k = 0$ and $\Delta = 0$ we have

$$e^{2\nu} = A^2(1-ax)^2, e^{2\lambda} = 1, \rho = 0, p_r = p_t = 0, M = 0. \tag{33}$$

We see that the matter variables vanish and the gravitational potentials are constant at the centre. This condition agrees with Minkowski space-times.

VII. Discussion

In this section, we indicate that the exact solutions for the field equations given in the system (27) of Sect. (6) are well behaved. The gravitating potentials and the matter variables obtained are finite, regular and continuous. We see that isotropic results are contained in our nonsingular models as a special case. This is possible when the measure of anisotropy $\Delta = 0$, the case when parameters A_0, A_1 and A_2 are set to zero. Of interest is to indicate that the physical analysis is possible. We do this by generating graphical plots for the gravitational potentials, matter variables using the model in the system (27) and mass function (28) in Sect. (6). Python programming language was used to generate these plots for the particular choices a = -3:3, A = 1:0, β = 0:5, α = 0:18, γ = 0:1, C = 1:0, k = 0:3, A_0 = -1.5, A_1 = -0.6 and A_2 = 1:0. The graphical plots generated are for the potential $e^{2\nu}$ (Fig.1), potential $e^{2\lambda}$ (Fig. 2), energy density ρ (Fig. 3), radial pressure p_r (Fig. 4), tangential pressure p_t (Fig. 5), measure of anisotropy Δ (Fig. 6) and the mass M (Fig. 7). All figures are plotted against the radial coordinate r. These quantities are regular and well behaved in the stellar interior.

The potentials in Fig.(1) and Fig. (2) are increasing functions with radial distance. They are finite, regular and continuous similar to those in Komathiraj and Maharaj [52], Sunzu [16] and Sunzu et al [29]. The energy density ρ in Fig. (3), the radial pressure p_r in Fig. (4) and the tangential pressure p_t in Fig. (5) are decreasing functions with the radial coordinate. These profiles are similar to to the one in Kalam et al [24], Sunzu [16] and Thirukkanesh and Maharaj [25]. We observe in Fig. (6) that the measure of anisotropy Δ is a decreasing function from the centre to the region near the surface. This is similar to the findings in Sunzu et al [29] and Kalam et al [24]. The mass M in Fig. (7) increase with radial distance similar to that in Sunzu [16], Sunzu et al [29] and Malaver [45, 46].

We also generate relativistic stellar masses using the transformations $\tilde{A}_0 = A_0R^2$, $\tilde{A}_1 = A_1R^2$, $\tilde{A}_2 = A_2R^2$, $\tilde{C} = CR^2$ and $\tilde{a} = aR^2$. We are using the mass function (28) of Sect. (6) to generate masses consistent with observations. We generated stellar masses consistent with the one observed by Demorest *et al* [53] for a star PSR J1614-2230, Rawls et al [54] for stars Vela X-1, 4U 1538-52, LMC X-4, SMC X-4 and Cen X-3, Abubekerov et al [55] for a star Her X-1, Elebert *et al* [56] for a star SAX J1808.4-3658 and Ozel *et al* [57] for a star EXO 1785-248. Computation is done by choosing different values for the constants $\tilde{a}, \tilde{A}_0$, $\tilde{A}_1$ and $\tilde{A}_2$. Conveniently, for computation purposes we have set R = 55.00. Therefore our exact model produce finite masses consistent with astronomical objects. The parameters producing these relativistic masses are indicated in Table (1).

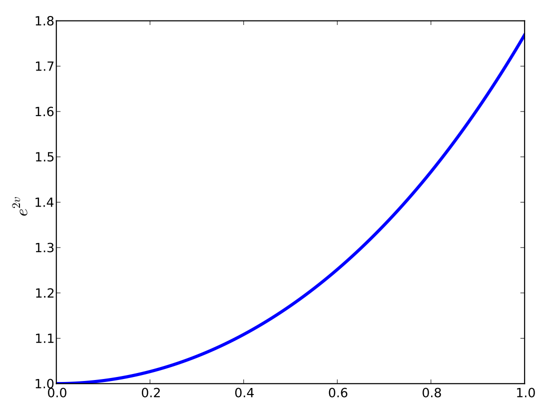

Figure 1: The gravitational potential $e^{2\nu}$ against the radial distance

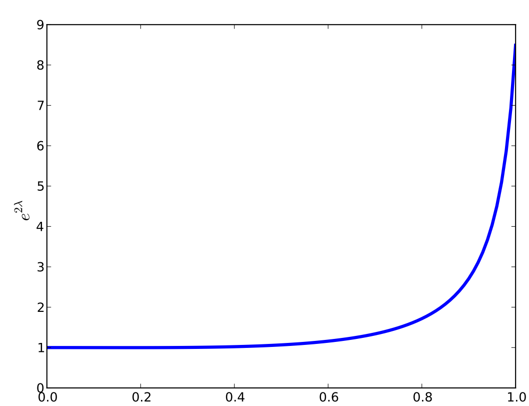

Figure 2: The gravitational potential $e^{2\lambda}$ against the radial distance

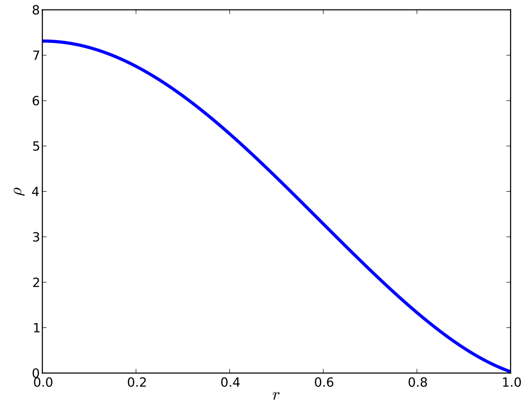

Figure 3: Energy density ρ against the radial distance

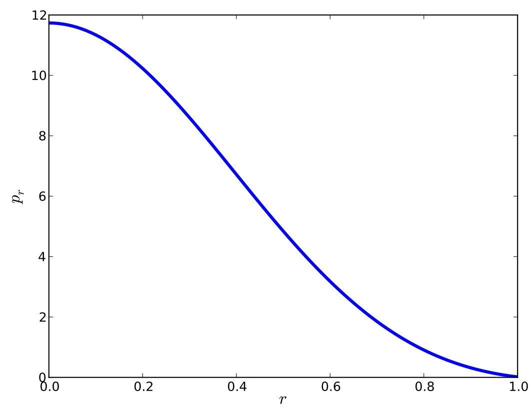

Figure 4: Radial pressure p_r against the radial distance

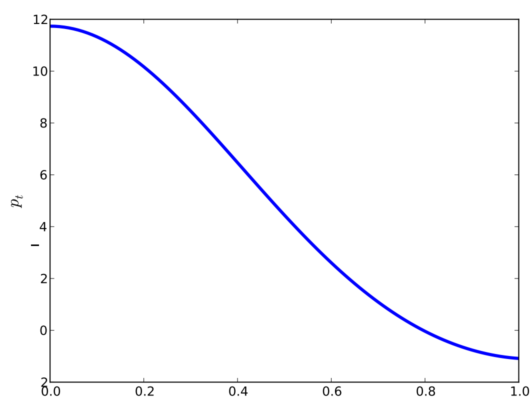

Figure 5: Tangential pressure p_t against the radial distance

Global Journal of Science Frontier Research (A) Volume XVIII Issue I Version I Year 2018

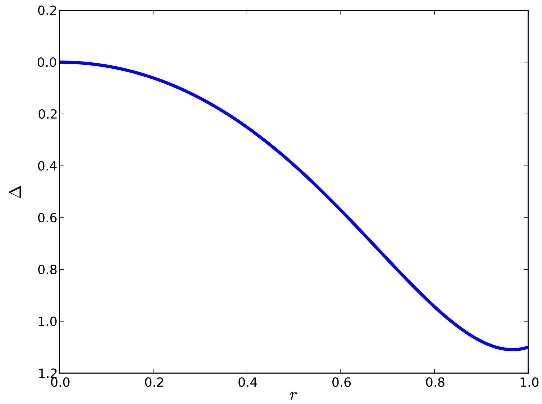

Figure 6: Measure of anisotropy Δ against the radial distance

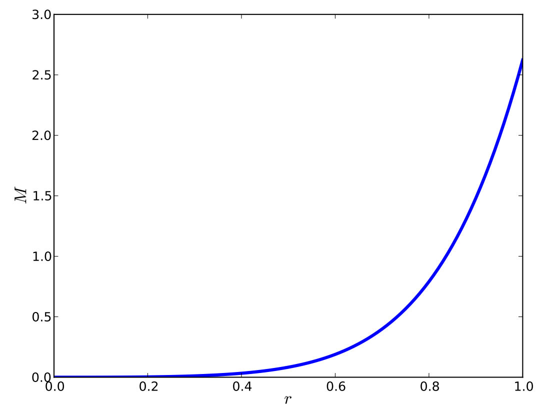

Figure 7: Mass *M* against the radial distance

Table 1: Particular stellar star masses obtained for various parameter values

$\tilde{a}$	$\tilde{C}$	$\tilde{A}_0$	$\tilde{A}_1$	$\tilde{A}_2$	$\tilde{k}$	$R(Km)$	$M(M_\odot)$	$Star$	$References$
9.5	2.0	2.0	3.0	1.9	1.0	9.69	1.97	$PSR\,J1614-2230$	Demorest *et al* [53]
9.5	2.0	2.0	1.3	1.8	1.0	9.56	1.77	$Vela\,X-1$	Rawls *et al* [54]
9.9	2.0	2.0	1.3	1.8	1.0	7.866	0.87	$4U\,1538-52$	Rawls *et al* [54]
9.9	2.0	1.1	3.5	1.8	1.0	8.301	1.04	$LMC\,X-4$	Rawls *et al* [54]
9.8	2.0	1.1	3.5	1.8	1.0	8.831	1.29	$SMC\,X-4$	Rawls *et al* [54]
9.7	2.0	1.1	3.0	1.8	1.0	9.178	1.49	$cen\,X-3$	Rawls *et al* [54]
9.7	2.0	1.1	2.0	1.5	1.0	8.1	0.85	$Her\,X-1$	Abubekerov *et al* [55]
9.7	2.0	1.1	2.0	1.7	1.0	7.951	0.9	$SAX\,J1808.4-3658$	Elebert *et al* [56]
9.6	2.0	1.1	2.5	1.7	1.0	8.849	1.3	$EXO\,1785-248$	Ozel *et al* [57]

VIII. Conclusion

We have generated new exact relativistic models for neutral anisotropic stars using Einstein-Maxwell field equations. We have used a Van der Waals equation of state relating the energy density and the radial pressure. In our new models, the energy density ρ, the radial pressure p_r and the tangential pressure p_t are finite decreasing functions. The mass M and the gravitational potentials $e^{2\nu}$, $e^{2\lambda}$ are increasing functions, continuous and finite inside the stellar interior. The measure of anisotropy Δ is a decreasing negative function showing that $p_t < p_r$. We have indicated that for specific conditions our models agree with earlier Einstein isotropic neutral model and Minkowski spacetime. In this paper neutral relativistic models described are physically reasonable and have astrophysical significance. We have generated masses consistent with observations. The masses generated are those consistent with the star PSR J1614-2230, Vela X-1, 4U 1538-52, LMC X-4, SMC X-4, Cen X-3, Her X-1, SAX J1808.4-3658 and the star EXO 1785-248. Our models are significant for studies of relativistic compact neutral stellar objects in astrophysics. For further research, these models could be used to study the interior structures of the stellar objects by considering new choice of measure of anisotropy, metric functions and equation of states.

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Mende Transformations in the Concept of Scalar-Vector Potential

By F. F. Mende

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Strictly as per the compliance and regulations of:

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I. Introduction

The special theory of relativity (STR) was developed by Albert Einstein in 1905. Its basis are the postulates, one of which (the so-called second postulate) says, that the speed of set is invariant, i.e., it does not depend on observation system. This means that under no circumstances the speed of light cannot exceed its standard value, which in the vacuum is equal 299 792 458 $\pm$ 1,2 m/s (it is rounded 300000 km / s). Second postulate STR contradicts the common sense, since the speed is a value relative. Passenger, edushchiy in the railroad car of train, with respect to the railroad car is fixed, whereas according to the relation to the station buildings he moves with the speed of train. In STR this not thus. If inside the railroad car light beam moves with the standard speed, then with respect to the station buildings it moves with the same speed.

From the moment of creation STR were carried out the numerous experiments, in which the experimenters attempted to prove the inaccuracy of the second postulate. For this they used radiation sources, which moved with respect to the observation system with the given speed, but, values of the speed of light in the observation system obtained in such experiments always proved to be equal to the standard value of the speed of light [1-9].

Such experiments in the diverse variants were carried out and outstanding scientific Michaelson, with the aid of the invented by it interferometer, but also these experiments also ended by failure.

Michelson interferometer was invented by American physicist by Albert Abrakhamom by Michaelson at the beginning of past century. A number of important scientific and applied problems was solved with the aid of this interferometer, the speed of light was in particular with the high accuracy measured. However, in the experiments, carried out by Michaelson, that are concerned checking second postulate STR, were significant errors. It completed these errors, then it attempted to prove that the speed of electromagnetic (EM) wave is added to the speed of its source, which would contradict the second postulate. Michaelson considered to the end of his life that there is an elastic medium (ether), in which are extended EM of wave. Therefore the results of the experiments, which it conducted together with Morley [10] for the detection of this medium, were for it large unexpected contingency, since ether was not discovered. Attempting to improve experiment, it attempted as the radiation source to use light of star, but it it here awaited still large failure. Studies showed that the measured speed of light, does not depend on the speed of star and is equal to the previously measured by it standard value.

In the works [11,12] it is shown that for similar studies the Michelson interferometer is unfit, with which and were connected its errors. And only after the invention of interferometer with the mechanical division of ray became possible the correct checking of the second postulate of STR [11]. The results of this checking are represented in the work [12], which they showed that the speed of light is added to the rate of radiation source, which corresponds to the conversions of Galileo, but not to the conversions of Lorenz. But if this then the conversions of Lorenz are erroneous, then should be searched for them replacement. To this question is dedicated the proposed article.

II. Mende Transformations in the Concept of Scalar-Vector Potential

Let us explain for the solution of the problem presented, what dynamic potentials and fields generate the moving charges. The first step, demonstrated in the works [13-15], was made in this direction a way of the introduction of the symmetrical laws of magnetoelectric and electromagnetic induction. They are written in the following form [16-20]:

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$$\int \mathbf{E}'dl' = -\int \frac{\partial \mathbf{B}}{\partial t} d\mathbf{s} + \int [\mathbf{v} \times \mathbf{B}] dl' \quad , \qquad (2.1)$$
$$\int \mathbf{H}'dl' = \int \frac{\partial \mathbf{D}}{\partial t} d\mathbf{s} - \int [\mathbf{v} \times \mathbf{D}] dl'$$

or

$$rot\mathbf{E}' = -\frac{\partial \mathbf{B}}{\partial t} + rot[\mathbf{v} \times \mathbf{B}] \quad . \qquad (2.2)$$
$$rot\mathbf{H}' = \frac{\partial \mathbf{D}}{dt} - rot[\mathbf{v} \times \mathbf{D}]$$

For the constants fields on these relationships they take the form:

$$\mathbf{E}' = [\mathbf{v} \times \mathbf{B}] \quad . \qquad (2.3)$$
$$\mathbf{H}' = -[\mathbf{v} \times \mathbf{D}]$$

In relationships (2.1)-(2.3), which assume the validity of the Galileo conversions, prime and not prime values present fields and elements in moving and fixed IRS respectively.

The relationships (2.1)-(2.3), which present the laws of induction, do not give information about how arose fields in initial fixed IRS. They describe only laws governing the propagation and conversion fields on in the case of motion with respect to the already existing fields.

The relationship (2.3) attest to the fact that in the case of relative motion of frame of references, between the fields $\mathbf{E}$ and $\mathbf{H}$ there is a cross coupling, i.e., motion in the fields $\mathbf{H}$ leads to the appearance fields on $\mathbf{E}$ and vice versa. From these relationships escape the additional consequences, which were for the first time examined in the work [13,15, 21].

If the charged rod has a linear charge g, its electric field $E = \frac{g}{2\pi\varepsilon r}$ decreases according to the law $\frac{1}{r}$, where r isdistance from the central axis of the rod to the observation point. If we in parallel to the axis of rod in the field E begin to move with the speed Δv another IRS, then in it will appear the additional magnetic field $\Delta H = \varepsilon E \Delta v$. If we now with respect to already moving IRS begin to move third frame of reference with the speed Δv, then already due to the motion in the field ΔH will appear additive to the electric field $\Delta E = \mu\varepsilon E (\Delta v)^2$. This process can be continued and further, as a result of which can be obtained the number, which gives the value of the electric field $E'_v(r)$ in moving IRS with reaching of the speed $v = n\Delta v$, when $\Delta v \to 0$, and $n \to \infty$. In the final analysis in moving IRS the value of dynamic electric field will prove to be more than in the initial and to be determined by the relationship:

$$E'(r, v_\perp) = \frac{gch\frac{v_\perp}{c}}{2\pi\varepsilon r} = Ech\frac{v_\perp}{c}.$$

If speech goes about the electric field of the single charge e, then its electric field will be determined by the relationship:

$$E'(r, v_\perp) = \frac{ech\frac{v_\perp}{c}}{4\pi\varepsilon r^2} \quad ,$$

where $v_\perp$ - normal component of charge rate to the vector, which connects the moving charge and observation point.

Expression for the scalar potential, created by the moving charge, for this case will be written down as follows:

$$\varphi'(r, v_\perp) = \frac{ech\frac{v_\perp}{c}}{4\pi\varepsilon r} = \varphi(r)ch\frac{v_\perp}{c}, \qquad (2.4)$$

where $\varphi(r)$- scalar potential of fixed charge. The potential $\varphi'(r, v_\perp)$ can be named scalar-vector, since it depends not only on the absolute value of charge, but also on speed and direction of its motion with respect to the observation point. Maximum value this potential has in the direction normal to the motion of charge itself. Moreover, if charge rate changes, which is connected with its acceleration, then can be calculated the electric fields, induced by the accelerated charge.

During the motion in the magnetic field, using the already examined method, we obtain:

$$H'(v_\perp) = Hch\frac{v_\perp}{c}.$$

where $v_\perp$ - speed normal to the direction of the magnetic field.The same result can be obtained by another method.

Let us designate field variables in the fixed frame of reference without the prime, and in the mobile – with the prime.In the differential form let us write down the formulas of the mutual induction of electrical and magnetic fields on in the mobile frame of reference as follows:

$$dH' = \varepsilon E' dv_\perp, \qquad (2.5)$$

$$dE' = \mu H' dv_\perp. \qquad (2.6)$$

Or otherwise,

$$\frac{dH'}{dv_\perp} = \varepsilon E', \qquad (2.7)$$

$$\frac{dE'}{dv_\perp} = \mu H', \qquad (2.8)$$

where (2.7) it corresponds (2.5), and (2.8) it corresponds (2.6).

After dividing equations (2.7) and (2.8) on E and H, we will obtain respectively:

$$\frac{d\left(H'/E\right)}{dv_\perp} = \varepsilon \frac{E'}{E}, \qquad (2.9)$$

$$\frac{d\left(E'/E\right)}{dv_\perp} = \mu \frac{H'}{H}. \qquad (2.10)$$

Differentiating both parts (2.10), we have:

$$\frac{d^2\left(E'/E\right)}{d^2 v_\perp} = \mu \frac{d\left(H'/E\right)}{dv_\perp}. \qquad (2.11)$$

After substituting (2.9) in (2.11), we will obtain:

$$\frac{d^2\left(E'/E\right)}{d^2 v_\perp} = \mu\varepsilon \frac{E'}{E}. \qquad (2.12)$$

The function is the general solution (2.12) of differential equation

$$\frac{E'}{E} = C_2 ch\left(\frac{v_\perp}{c}\right) + C_1 sh\left(\frac{v_\perp}{c}\right), \qquad (2.13)$$

where c – the speed of light, C_1, C_2 – arbitrary constants.

Since with $v_\perp = 0$ must be made $E' = E$, that from (2.13) we will obtain:

$$C_2 = 1. \qquad (2.14)$$

After substituting (2.14) in (2.13), we finally have the general solution, into which enters one arbitrary constant C_1:

$$\frac{E'}{E} = ch\left(\frac{v_\perp}{c}\right) + C_1 sh\left(\frac{v_\perp}{c}\right).$$

Selecting $C_1 = 0$, we obtain

$$E' = Ech\left(\frac{v_\perp}{c}\right).$$

If we apply the obtained results to the electromagnetic wave and to designate components fields on parallel speeds IRS as $E_\uparrow$, $H_\uparrow$, and $E_\perp$, $H_\perp$ as components normal to it, then conversions fields on they will be written down [1-3, 9]:

$$\begin{aligned}
&\mathbf{E}'_\uparrow = \mathbf{E}_\uparrow, \\
&\mathbf{E}'_\perp = \mathbf{E}_\perp ch\frac{v}{c} + \frac{Z_0}{v}\left[\mathbf{v}\times\mathbf{H}_\perp\right] sh\frac{v}{c}, \\
&\mathbf{H}'_\uparrow = \mathbf{H}_\uparrow, \\
&\mathbf{H}'_\perp = \mathbf{H}_\perp ch\frac{v}{c} - \frac{1}{vZ_0}\left[\mathbf{v}\times\mathbf{E}_\perp\right] sh\frac{v}{c},
\end{aligned} \qquad (2.15)$$

where $Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$ - impedance of free space, $c = \sqrt{\frac{1}{\mu_0\varepsilon_0}}$ - speed of light. Let us name conversions (2.2) the Mende transformation.

We derive them in the matrix form [22, 23] and show that the form of the transformations is determined by the law of addition of velocities (classical or relativistic).

Let us examine the totality IRS of such, that IRS K_1 moves with the speed Δv relative to IRS K, IRS K_2 moves with the same speed Δv relative to K_1, etc. If the module of the speed Δv is small (in compare IRSn with the speed of light s), then for the transverse components fields on in IRS $K_1 K_2$,. . . we have:

$$\mathbf{E}_{1\perp} = \mathbf{E}_\perp + \Delta\mathbf{v}\times\mathbf{B}_\perp \qquad \mathbf{B}_{1\perp} = \mathbf{B}_\perp - \Delta\mathbf{v}\times\mathbf{E}_\perp / c^2$$

$$\mathbf{E}_{2\perp} = \mathbf{E}_{1\perp} + \Delta\mathbf{v}\times\mathbf{B}_{1\perp} \qquad \mathbf{B}_{2\perp} = \mathbf{B}_{1\perp} - \Delta\mathbf{v}\times\mathbf{E}_{1\perp} / c^2. \qquad (2.16)$$

Upon transfer to each following IRS of field are obtained increases in $\Delta\mathbf{E}$ and $\Delta\mathbf{B}$

$$\Delta\mathbf{E} = \Delta\mathbf{v}\times\mathbf{B}_\perp, \qquad \Delta\mathbf{B} = -\Delta\mathbf{v}\times\mathbf{E}_\perp / c^2, \qquad (2.17)$$

where the fields $\mathbf{E}_\perp$ and $\mathbf{B}_\perp$ relate to current IRS. Directing the Cartesian axis x along $\Delta\mathbf{v}$, let us rewrite (2.17) in the components of the vector

$$\Delta E_y = -B_z \Delta v, \qquad \Delta E = B_y \Delta v, \qquad \Delta B_y = E_z \Delta v / c^2. \qquad (2.18)$$

Relationship (2.18) can be represented in the matrix form

$$\Delta U = AU\Delta v \qquad \begin{pmatrix} 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1/c^2 & 0 & 1 \\ -1/c^2 & 0 & 0 & 0 \end{pmatrix} \qquad U = \begin{pmatrix} E_y \\ E_z \\ B_y \\ B_z \end{pmatrix}$$

If one assumes that the speed of system is summarized for the classical law of addition of velocities, i.e., the speed of final IRS $K' = K_N$ relative to the initial K is $v = N\Delta v$, then we will obtain the matrix system of the differential equations

$$\frac{dU(v)}{dv} = AU(v), \qquad (2.19)$$

with the matrix of the system v independent of the speed A. The solution of system is expressed as the matrix exponential curve $\exp(vA)$:

$$U' \equiv U(v) = \exp(vA)U, \qquad U = U(0), \quad (2.20)$$

here U - matrix column fields on in the system K, and U' - matrix column fields on in the system K'.

Substituting (2.20) in the system (2.19), we are convinced, what U' is actually the solution of the system (2.19):

$$\frac{dU(v)}{dv} = \frac{d\left[\exp(vA)\right]}{dv}U = A\exp(vA)U = AU(v)$$

It remains to find this exponential curve by its expansion in the series:

$$\exp(va) = E + vA + \frac{1}{2!}v^2A^2 + \frac{1}{3!}v^3A^3 + \frac{1}{4!}v^4A^4 + \ldots$$

where E - unit matrix with the size 4×4. For this it is convenient to write down the matrix A in the unit type form

$$A = \begin{pmatrix} 0 & -\alpha \\ \alpha/c^2 & 0 \end{pmatrix}, \qquad \alpha = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}, \qquad 0 = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}.$$

Then

$$A^2 = \begin{pmatrix} -\alpha^2/c^2 & 0 \\ 0 & -\alpha/c^2 \end{pmatrix}, \qquad A^3 = \begin{pmatrix} 0 & \alpha^3/c^2 \\ -\alpha^3/c^4 & 0 \end{pmatrix},$$

$$A^4 = \begin{pmatrix} \alpha^4/c^4 & 0 \\ 0 & \alpha^4/c^4 \end{pmatrix}, \qquad A^5 = \begin{pmatrix} 0 & -\alpha^5/c^4 \\ \alpha^5/c^6 & 0 \end{pmatrix}$$

And the elements of matrix exponential curve take the form

$$\left[\exp(vA)\right]_{11} = \left[\exp(vA)\right]_{22} = I - \frac{v^2}{2!c^2} + \frac{v^4}{4!c^4} - \ldots.,$$

$$\left[\exp(vA)\right]_{21} = -c^2\left[\exp(vA)\right]_{12} = \frac{\alpha}{c}\left(\frac{v}{c}I - \frac{v^3}{3!c^3} + \frac{v^5}{5!c^5} - \ldots..\right),$$

where I - the unit matrix 2×2. It is not difficult to see that $-\alpha^2 = \alpha^4 = -\alpha^6 = \alpha^8 = \ldots. = I$; therefore we finally obtain

Global Journal of Science Frontier Research (A) Volume XVIII Issue I Version I Year 2018

$$\exp(vA)=\begin{pmatrix} Ich\ v/c & -c\alpha sh\ v/c \\ \left(\alpha sh\ v/c\right)/c & Ich\ v/c \end{pmatrix}=$$

$$\begin{pmatrix} ch\ v/c & 0 & 0 & -csh\ v/c \\ 0 & ch\ v/c & csh\ v/c & 0 \\ 0 & \left(ch\ v/c\right)/c & ch\ v/c & 0 \\ -\left(sh\ v/c\right)/c & 0 & 0 & ch\ v/c \end{pmatrix}.$$

Now we return to (2.20) and substituting there $\exp(vA)$, we find

$$E'_y = E_y ch\ v/c - cB_z sh\ v/c, \qquad E'_z = E_z ch\ v/c + cB_y sh\ v/c,$$
$$B'_y = B_y ch\ v/c + \left(E_z/c\right) sh\ v/c, \quad B'_z = B_z ch\ v/c - \left(E_y/c\right) sh\ v/c$$

Or in the vector record

$$\mathbf{E}'_\perp = \mathbf{E}_\perp ch\ \frac{v}{c} + \frac{v}{c}\mathbf{v}\times\mathbf{B}_\perp sh\frac{v}{c},$$
$$\mathbf{B}'_\perp = \mathbf{B}_\perp ch\ \frac{v}{c} - \frac{1}{vc}\mathbf{v}\times\mathbf{E}_\perp sh\frac{v}{c} \qquad (2.21)$$

This is Mende transformation (2.15).

Appears a regular question; therefore they are differed from the appropriate conversions fields on in the classical electrodynamics, indeed in it with the low speeds $\Delta\vec{v}$ occur initial relationships (2.16) and (2.17). The fact is that according to the relativistic law of addition of velocities, are added not speeds, but rapidities (https://ru.wikipedia.org/wiki/ Быстрота). According to definition the rapidity is introduced as

$$\theta = c\ arth\frac{v}{c}. \qquad (2.22)$$

Precisely, if the rapidity of the systems K_1 and K, K_2 and K_1, K_3 and K_2, etc., they are distinguished to $\Delta\theta$, then rapidity the rapidity IRS $K' = K_N$ relative to K is $\theta = N\Delta\theta$. With the low speeds $\Delta\theta \cong \Delta v$. Therefore formula (2.17) it is possible to write down so

$$\Delta\mathbf{E} = \Delta\theta\times\mathbf{B}_\perp, \qquad \Delta\mathbf{B} = -\Delta\boldsymbol{\theta}\times\mathbf{E}_\perp/c^2,$$

where $\boldsymbol{\theta} = \theta\frac{\mathbf{v}}{v}$. System (2.19) taking into account the additivity of rapidity, but not speed, it is substituted by the system of equations

$$\frac{dU(\theta)}{d\theta} = AU(\theta).$$

Thus, all computations will be analogous given above, only with the difference that in the expressions instead of the speeds will figure rapidity. In particular formulas (2.21) take the form

$$\mathbf{E}'_\perp = \mathbf{E}_\perp ch\ \frac{\theta}{c} + \frac{\theta}{c}\boldsymbol{\theta}\times\mathbf{B}_\perp sh\frac{\theta}{c},$$
$$\mathbf{B}'_\perp = \mathbf{B}_\perp ch\ \frac{\theta}{c} - \frac{1}{\theta c}\boldsymbol{\theta}\times\mathbf{E}_\perp sh\frac{\theta}{c},$$

or

$$\mathbf{E}'_\perp = \mathbf{E}_\perp ch\ \frac{\theta}{c} + \frac{v}{c}\mathbf{v}\times\mathbf{B}_\perp sh\frac{\theta}{c},$$
$$\mathbf{B}'_\perp = \mathbf{B}_\perp ch\ \frac{\theta}{c} - \frac{1}{vc}\mathbf{v}\times\mathbf{E}_\perp sh\frac{\theta}{c}, \qquad (2.23)$$

Since

$$ch\frac{\theta}{c}=\frac{1}{\sqrt{1-th^2(\theta/c)}},\qquad sh\frac{\theta}{c}=\frac{th(\theta/c)}{\sqrt{1-th^2(\theta/c)}},$$

That substitution (2.22) in (2.23) leads to the well-known conversions fields on

$$\begin{gathered}\mathbf{E}'_{\perp}=\frac{1}{\sqrt{1-v^2/c^2}}\left(\mathbf{E}_{\perp}+\mathbf{v}\times\mathbf{B}_{\perp}\right)\\ \mathbf{B}'_{\perp}=\frac{1}{\sqrt{1-v^2/c^2}}\left(\mathbf{B}_{\perp}-\frac{1}{c^2}\mathbf{v}\times\mathbf{E}_{\perp}\right)\end{gathered},\qquad(2.24)$$

with the small relative conversion rates (2.21) and (2.24) differ, beginning from the terms of the expansion of the order v^2/c^2.

We show how to use therelationships (2.2) it is possible to explain the phenomenon of phase aberration, which did not have within the framework existing classical electrodynamics of explanations. We will consider that there are components of the plane wave H_z, E_x, which is extended in the direction y, and primed system moves in the direction of the axis x with the speed v_x. Then components fields on in the prime coordinate system in accordance with relationships (2.2) they will be written down:

$$E'_x=E_x,$$

$$E'_y=H_z sh\frac{v_x}{c},$$

$$H'_z=H_z ch\frac{v_x}{c}.$$

Thus, is a heterogeneous wave, which has in the direction of propagation the component E'_y.

Let us write down the summary field E' in moving IRS:

$$E'=\left[\left(E'_x\right)^2+\left(E'_y\right)^2\right]^{\frac{1}{2}}=E_x ch\frac{v_x}{c}.\qquad(2.25)$$

If the vector $\mathbf{H}'$ is as before orthogonal the axis y, then the vector $\mathbf{E}'$ is now inclined toward it to the angle α, determined by the relationship:

$$\alpha\cong sh\frac{v}{c}\cong\frac{v}{c}.\qquad(2.26)$$

This is phase aberration. Specifically, to this angle to be necessary to incline telescope in the direction of the motion of the Earth around the sun in order to observe stars, which are located in the zenith.

The Pointing vector is now also directed no longer along the axis y, but being located in the plane xy, it is inclined toward the axis y to the angle, determined by relationships (2.26). However, the relation of the absolute values of the vectors $\mathbf{E}'$, $\mathbf{H}'$ in both systems they remained identical. However, the absolute value of the very vector of Pointing increased. Thus, even transverse motion of inertial system with respect to the direction of propagation of wave increases its energy in the moving system. This phenomenon is understandable from a physical point of view. It is possible to give an example with the rain drops. When they fall vertically, then is energy in them one. But in the inertial system, which is moved normal to the vector of their of speed, to this speed the velocity vector of inertial system is added. In this case the absolute value of the speed of drops in the inertial system will be equal to square root of the sum of the squares of the speeds indicated. The same result gives to us relationship (2.25).

Is not difficult to show that, if we the polarization of electromagnetic wave change ourselves, then result will remain before. Conversions with respect to the vectors $\mathbf{E}$, $\mathbf{H}$ are completely symmetrical, only difference will be the fact that to now comes out the wave, which has to appear addition in the direction of propagation in the component H'_y.

Such waves have in the direction of its propagation additional of the vector of electrical or magnetic field, and in this they are similar E, H of the waves, which are extended in the waveguides. In this case appears the uncommon wave, whose phase front is inclined toward the Pointing vector to the angle, determined by relationship (2.26). In fact obtained wave is the superposition of plane wave with the phase speed $c=\sqrt{\frac{1}{\mu\varepsilon}}$ and additional wave of plane wave with the infinite phase speed orthogonal to the direction of propagation.

Let us examine one additional case, when the direction of the speed of the moving system coincides with the direction of propagation of electromagnetic wave. We will consider that there are components of the plane wave E_x, H_z, and also component of the speed $\pm v_y$. Taking into account that in this case is fulfilled the relationship $E_x=\pm Z_0 H_z$, we obtain:

$$E_x{}' = E_x\left(ch\frac{v_y}{c} - sh\frac{v_y}{c}\right) = E_x \exp\left(\mp\frac{v_y}{c}\right),$$

$$H_z{}' = H_z\left(ch\frac{v_y}{c} - sh\frac{v_y}{c}\right) = H_z \exp\left(\mp\frac{v_y}{c}\right).$$

I.e. amplitudes fields on exponentially they diminish or they grow depending on direction of motion.

The wave of the strength of an electrical (or magnetic) field of the type satisfies wave equation

$$E(t,y) = E_0 \sin(\omega t - ky),$$

where $k = \frac{2\pi}{\lambda}$ - wave number.

Upon transfer into the inertial system, which moves with the speed $\pm v_y$, is observed Doppler frequency shift.

The transverse Doppler effect, who long ago is discussed sufficiently, until now, did not find its confident experimental confirmation. For observing the star from moving IRS it is necessary to incline telescope on the motion of motion to the angle, determined by relationship (2.26). But in this case the star, observed with the aid of the telescope in the zenith, will be in actuality located several behind the visible position with respect to the direction of motion. Its angular displacement from the visible position in this case will be determined by relationship (2.26). But this means that this star with respect to the observer has radial it sped, determined by the relationship

$$v_r = v\sin\alpha.$$

Since for the low values of the angles $\sin\alpha \cong \alpha$, and $\alpha = \frac{v}{c}$, Doppler frequency shift will compose

$$\omega_{d\perp} = \omega_0 \frac{v^2}{c^2}. \qquad (2.27)$$

This result numerically coincides with results SR, but it is fundamentally different from it results in that the SR deemed that the transverse Doppler effect, defined by (2.27) actually exists, where as in this case it is only an apparent effect.

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III. Conclusion

In the article, field transformations are obtained in the transition from one ISO to another. In contrast to the Lorentz transformations, the basis of such transformations are Galileo transformations and symmetric induction laws. In this case, complete derivatives that take into account their convective part are used. This made it possible to explain the phenomenon of phase aberration of light and to find out the causes of the transverse Doppler effect, which is only an apparent effect.

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Kantowski-Sachs Bulk Viscous String Cosmological Model in $f(R,T)$ Gravity with Time Varying Deceleration Parameter

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Abstract- We propose a specially homogeneous and anisotropic Kantowski-Sachs string cosmological model with bulk viscosity in the framework of $f(R,T)$ gravity by considering two cases (i) the special form and (ii) linearly varying deceleration parameter. To obtain a deterministic solution of the field equation we have been used some physical plausible condition. In this theory, cosmological model is presented in both cases. Also some important features of the models, thus obtained, have been discussed.

Keywords: $f(R,T)$ *gravity, bulk viscous fluid, cosmic string, deceleration parameter.*

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I. Introduction

In the light of the recent discovery of the accelerated expansion of the universe [1-3]. However, final satisfactory explanation about physical mechanism and driving force of accelerated expansion of the universe is yet to achieve as human mind has not achieved perfection. It is known that a point of universe is filled with dark energy. It has been addressed by various slow rolling scalar fields. It is supposed that the dark energy is responsible for producing sufficient acceleration in the late time of evolution of the universe. Thus, it is much more essential to study the fundamental nature of the dark energy and several approaches have been made to understand it. The cosmological constant is assumed to be the simplest candidate of dark energy. It is the classical correction made to Einstein's field equation by adding cosmological constant to the field equations. The introduction of cosmological constant to Einstein's field equation is the most efficient way of generating accelerated expansion, but it faces serious problems like fine tuning and cosmic coincidence problem in cosmology [4, 5]. Quintessence [6], phantom [7], k-essence [8], tachyons [9], and Chaplygin gas [10] are the other representative of dark energy. However, there is no direct detection of such exotic fluids. Dark energy can be explored in several ways, and modifying the geometric part of the Einstein-Hilbert action [11] is treated as the most efficient possible way. Based on its modifications, several alternative theories of gravity came into existence. Modified theories of gravity are attracting more and more attention of cosmologists because of the fact that these theories may serve as the possible candidates for explaining the late time acceleration of the universe. Some of the modified theories of gravity are (T), (R), (G), and (R, T) gravity. These models are proposed to explore the dark energy and other cosmological problems. Sharif and Azeem [12] discussed the Cosmological evolution for dark energy models in (T) gravity. Jamil et al. [13] have studied the stability of the interactive models of the dark energy, matter, and radiation for a FRW model in (T) gravity. Generalized second law of thermodynamics in (T) gravity with entropy corrections has been studied by Bamba et al. [14]. Recently, Harko et al. [15] developed another modified gravity known as $f(R, T)$ gravity. In this theory, the gravitational Lagrangian is given by an arbitrary function of the Ricci scalar R and of the trace of T of the stress energy tensor. In this paper, we concentrate on (R, T) gravity, with f being in this case a function of both R and T, manifesting a coupling between matter and geometry. Before going into the details of (R, T) gravity, The field equations of $f(R, T)$ gravity obtained from the action

$$S = \frac{1}{16\pi}\int \left[f(R, T) + L_m \right]\sqrt{-g}\, d^4x, \tag{1}$$

where $f(R, T)$ is an arbitrary function of the Ricci scalar R, T is the stress energy tensor T_{ij} of matter and L_m is the matter Lagrangian density, are given by

$$R_{ij} - \frac{1}{2} g_{ij} R = 8\pi T_{ij} + 2 f'(T) T_{ij} + \left[2 p f'(T) + f(T)\right] g_{ij}. \tag{2}$$

Studies of cosmic strings and bulk viscosity are crucial as they play an important role in structure formation of the early stages of evolution of the universe. Cosmic strings are one dimensional topological defects, which may be formed during symmetry breaking phase transition in the early universe along with other defects like domain walls and monopoles. Bulk viscosity driven

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inflation is primarily due to the negative effective pressure which may overcome the pressure due to the usual gravity of matter distribution in the universe and provides an impetus for rapid expansion of the universe. Hence construction of bulk viscous string cosmological models have received considerable attention of research workers in the field. Many authors have investigated the astrophysical and cosmological implications of the (R, T) gravity [16–19]. Jamil et al. [20] have reconstructed some cosmological models for some specific forms of (R, T) in this modified gravity. Shamir et al. [21] obtained exact solution of anisotropic Bianchi type I and type V cosmological models whereas Chaubey and Shukla [22] have obtained a newclass of Bianchi cosmological models using special law of variation of parameter. Using a decoupled form of (R, T), that is, $(R, T) = (R) + (T)$ for Bianchi type V universe, Ahmed and Pradhan [23] have studied the energy conditions of perfect fluid cosmological models and Yadav [24] obtained some string solutions. Pawar and Solanke [25] have studied cosmological model filled with perfect fluid source in (R, T) gravity. Pawar and Agrawal [26] have obtained the solutions of dark energy cosmological model in the framework of the (R, T) theory of gravity. Recently Pawar et al. [27] have explored two fluid cosmological models in (R, T) theory. Mishra and Sahoo [28] solved the field equations of Bianchi type-VI*h* cosmological model in presence of perfect fluid in f (R,T) gravity. Sahoo and Mishra [29] studied Kaluza–Klein dark energy model in form of wet dark fluid in this theory. Reddy et al. [30] presented Kantowski-Sachs bulk viscous string model in (R, T) theory. Recently, Naidu et al. [31], Kiran and Reddy [32], and Reddy et al. [33] discussed the Bianchi type-V, Bianchi type-III, Kaluza-Klein space time with cosmic strings, and bulk viscosity in $f(R, T)$ gravity, respectively. Caroll et al.[34], Nojiri and Odintsov [35-37] and Chiba et al.[38] are some of the authors who have investigated several aspects of *f (R)* gravity. Recently, Adhav [39] has obtained Bianchi type-I cosmological model in *f (R,T)* gravity. Reddy et al.[40, 41] have discussed Bianchi type-III and Kaluza-Klein cosmological models in *f (R,T)* gravity while Reddy and Shantikumar [42] studied some anisotropic cosmological models and Bianchi type-III dark energy model, respectively, in *f (R,T)* gravity. Subsequently Kiran and Reddy [43] established the non-existence of Bianchi type-III bulk viscous string cosmological model in *f (R,T)* gravity. Recently, Naidu et al. [44] presented Bianchi type-V bulk viscous string model in *f (R,T)* gravity while Reddy et al. [45] have obtained the same in Saez-Ballester theory. We describe some important features of the (R) gravity. The recent motivation for studying (R) gravity came from the necessity to explain the apparent late-time accelerating expansion of the universe. Detailed reviews on (R) gravity can be found in [46–49]. Thermodynamic aspects of (R) gravity have been investigated in the works of [50, 51].

Inspired by the above investigation and discussion, in this paper we investigate the role of variable deceleration parameter in Kantowski-Sachs space time with bulk viscous string and $f(R, T)$ gravity. The plan of this paper is as follows: In sec. 2, we derive the field equations of $f(R, T)$ gravity in Kantowski-Sach space-time when the matter source is bulk viscous fluid with on dimensional cosmic strings. In Section 3, we find the solution of the field equations and the model. Some physical and kinematical properties of the model are discussed in section 4. Concluding remarks are presented in section 5.

II. Metric and Field Equations

The Spatially homogeneous and anisotropic Kantowski-Sachs space-time in the form

$$ds^2 = dt^2 - A^2 dr^2 - B^2\left(d\theta^2 + \sin^2\theta\, d\phi^2\right), \quad (3)$$

where A and B are the cosmic time t only.

The energy momentum tensor for a bulk viscous fluid containing one dimensional cosmic string is considered as

$$T_{ij} = \left(\rho + \bar{p}\right)u_i u_j - \bar{p} g_{ij} - \lambda x_i x_j , \quad (4)$$

$$\bar{p} = p - 3\xi H , \quad (5)$$

where ρ is the rest energy density of the system, $3\xi H$ is usually known as bulk viscous pressure, H is Hubble's parameter, p is the pressure and λ is the string tension density. Also $u^i = \delta_4^i$ is the four velocity vector, which satisfies

$$g_{ij} u^i u_j = -x^i x_j = 1, \qquad u^i x_i = 0 \quad (6)$$

Here, we also consider $\rho,\ \bar{p},\ \lambda$ as functions of cosmic time t only.

Now, by adopting commoving coordinates the field equations (2) of $f(R, T)$ gravity for the metric (3), with the help of eqs. (4)-(6), for the particular choice of the function

$$f(T) = \mu T \quad (7)$$

where μ is constant, can be written as

$$2\frac{\ddot{B}}{B} + \frac{\dot{B}^2}{B^2} + \frac{1}{B^2} = \bar{p}(8\pi + 3\mu) - \lambda(8\pi + 3\mu) - \mu\rho \quad (8)$$

$$\frac{\ddot{A}}{A}+\frac{\ddot{B}}{B}+\frac{\dot{A}\dot{B}}{AB}=\bar{p}(8\pi+3\mu)-\mu\lambda-\mu\rho \quad (9)$$

$$2\frac{\dot{A}\dot{B}}{AB}+\frac{\dot{B}^2}{B^2}+\frac{1}{B^2}=\mu\bar{p}-\rho(8\pi+3\mu)-\mu\lambda \quad (10)$$

where an overhead dot indicates differentiation with respect to t.

Spatial volume and the scale factor for the metric (3) are respectively, defined by

$$V=AB^2 \quad (11)$$

$$a=\left(AB^2\right)^{\frac{1}{3}} \quad (12)$$

The physical quantities which play a significant role in the discussion of cosmological models are expansion scalar θ the mean anisotropy parameter A_h and shear scalar σ^2 which are defined as

$$\theta=3H=3\left(\frac{\dot{A}}{A}+2\frac{\dot{B}}{B}\right) \quad (13)$$

$$3A_h=\sum_{i=1}^{3}\left(\frac{\Delta H_i}{H}\right)^2,\ \Delta H_i=H_i-H,\ i=1,\ 2,\ 3 \quad (14)$$

$$\sigma^2=\frac{1}{2}\sigma^{ij}\sigma_{ij}=3A_h{}^2-H^2 \quad (15)$$

where H is the mean Hubble parameter.

III. Solutions of the Field Equations

The field equations (8)-(10) reduce to the following two independent equations:

$$\frac{\ddot{A}}{A}-\frac{\ddot{B}}{B}-\frac{\dot{B}^2}{B^2}+\frac{\dot{A}\dot{B}}{AB}-\frac{1}{B^2}=(8\pi+2\mu)\lambda \quad (16)$$

$$\frac{\ddot{A}}{A}+\frac{\ddot{B}}{B}-\frac{\dot{B}^2}{B^2}-\frac{\dot{A}\dot{B}}{AB}-\frac{1}{B^2}=\bar{p}(8\pi+2\mu)+\rho(8\pi+2\mu) \quad (17)$$

Here there are two equations involving five unknowns. Since the field equations are highly nonlinear for the complete determinacy, we need extra conditions among the variables. We consider these conditions in the form case (i) and case (ii) as defined below

(i) The scalar expansion θ in the model is proportional to the shear scalar σ^2 which yields

$$A=B^m \quad (18)$$

where $m\neq 1$ is a constant, takes care of anisotropy of the space-time (Collins et al. [52])

(ii) The combined effect of the proper pressure and the bulk viscous pressure for barotropic fluid can be written as

$$\bar{p}=p-3\xi H=(\varepsilon_0-\gamma)\rho,\quad 0\leq\varepsilon_0\leq 1,\ \ p=\varepsilon_0\rho \quad (19)$$

where ε_0 and γ are constants.

Case (i)

The case (i) consists of (i), (ii) and special form of deceleration parameter [53]

$$q=-1+\frac{\beta}{1+a^{\beta}} \quad (20)$$

where $\beta>0$ is a constant and a is a scale factor of the metric.

In this case, we have discussed the solution of the field equations by considering the extra conditions as above.

The Hubble parameter H is defined as $H=\frac{\dot{a}}{a}$ and from (20) we obtained

$$H=\frac{\dot{a}}{a}=a_1\left(1+a^{-\beta}\right) \quad (21)$$

where a_1 is a constant of integration.

Integrating (21) and using the initial conditions $a=0\ at\ t=0$ we have found

$$a=\left(e^{a_1\beta t}-1\right)^{\frac{1}{\beta}} \quad (22)$$

The scale factor of metric (3) is defined as

$$a=\left(AB^2\right)^{\frac{1}{3}} \quad (23)$$

With the help of (18), (22)and (23), we have found

$$A=\left(e^{a_1\beta t}-1\right)^{\frac{3m}{\beta(2+m)}} \quad (24)$$

$$B=\left(e^{a_1\beta t}-1\right)^{\frac{3}{\beta(2+m)}} \quad (25)$$

Using (24) and (25), the metric (3) can be written as

$$ds^2 = dt^2 - \left(e^{a_1\beta t} - 1\right)^{\frac{6m}{\beta(2+m)}} dr^2 - \left(e^{a_1\beta t} - 1\right)^{\frac{6}{\beta(2+m)}} \left(d\theta^2 + \sin^2\theta\, d\phi^2\right) \tag{26}$$

From (16), with the help of (24)-(25) we obtain the string tension density λ as

$$\lambda = \frac{1}{(8\pi + 2\mu)} \left\{ \frac{(m-1)m_1 e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)} \left[\beta\left(1 + \beta_1 \frac{e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)}\right) + \frac{m_{11} e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)} \right] - \frac{1}{\left(e^{a_1\beta t} - 1\right)^{\frac{6}{\beta(2+m)}}} \right\} \tag{27}$$

where $m_1 = \dfrac{3a_1^2}{(2+m)}$, $\beta_1 = \dfrac{3}{\beta(2+m)} - 1$, $m_{11} = \dfrac{3(m+1)}{\beta(2+m)}$

From (17), with the help of (19) and (25), we obtained the rest energy density ρ as

$$\rho = \frac{1}{(8\pi + 2\mu)(\varepsilon_0 - \gamma + 1)} \left\{ \frac{m_1 e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)} \left[(m+1)\beta\left(1 + \beta_1 \frac{e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)}\right) + \frac{3\left(m^2 - 2m - 1\right)e^{a_1\beta t}}{(2+m)\left(e^{a_1\beta t} - 1\right)} \right] - \frac{1}{\left(e^{a_1\beta t} - 1\right)^{\frac{6}{\beta(2+m)}}} \right\} \tag{28}$$

From (19), with the help of (28), we have obtained the total pressure $\overline{p}$, proper pressure p and the coefficient of bulk viscosity ξ as follows:

$$\overline{p} = \frac{(\varepsilon_0 - \gamma)}{(8\pi + 2\mu)(\varepsilon_0 - \gamma + 1)} \left\{ \frac{m_1 e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)} \left[(m+1)\beta\left(1 + \beta_1 \frac{e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)}\right) + \frac{3\left(m^2 - 2m - 1\right)e^{a_1\beta t}}{(2+m)\left(e^{a_1\beta t} - 1\right)} \right] - \frac{1}{\left(e^{a_1\beta t} - 1\right)^{\frac{6}{\beta(2+m)}}} \right\} \tag{29}$$

$$p = \frac{\varepsilon_0}{(8\pi + 2\mu)(\varepsilon_0 - \gamma + 1)} \left\{ \frac{m_1 e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)} \left[(m+1)\beta\left(1 + \beta_1 \frac{e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)}\right) + \frac{3\left(m^2 - 2m - 1\right)e^{a_1\beta t}}{(2+m)\left(e^{a_1\beta t} - 1\right)} \right] - \frac{1}{\left(e^{a_1\beta t} - 1\right)^{\frac{6}{\beta(2+m)}}} \right\} \tag{30}$$

$$\xi = \frac{\gamma\left(e^{a_1\beta t} - 1\right)}{9a_1(8\pi + 2\mu)(\varepsilon_0 - \gamma + 1)e^{a_1\beta t}} \left\{ \frac{m_1 e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)} \left[(m+1)\beta\left(1 + \beta_1 \frac{e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)}\right) + \frac{3\left(m^2 - 2m - 1\right)e^{a_1\beta t}}{(2+m)\left(e^{a_1\beta t} - 1\right)} \right] - \frac{1}{\left(e^{a_1\beta t} - 1\right)^{\frac{6}{\beta(2+m)}}} \right\} \tag{31}$$

a) *Some Physical Properties of the Model*

Some physical properties of the model are given below, which have crucial role in the discussion of cosmological models are the spatial volume V, scalar expansion θ, The Hubble's parameter H, shear scalar σ^2 and mean anisotropy parameter A_h, for the model (26) the above quantities are given by

$$V = \left(e^{a_1\beta t} - 1\right)^{\frac{3}{\beta}} \tag{32}$$

$$\theta = \frac{9a_1 e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)} \tag{33}$$

$$H = \frac{3a_1 e^{a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)} \tag{34}$$

$$3A_h = \frac{6 + 4m + 2m^2}{(2+m)^2} \tag{35}$$

$$\sigma^2 = \frac{\left(6 + 4m + 2m^2\right)^2}{3(2+m)^4} - \frac{9{a_1}^2 e^{2a_1\beta t}}{\left(e^{a_1\beta t} - 1\right)^2} \tag{36}$$

In this model we observed that at initial epoch the values of energy density ρ, proper pressure p, total pressure $\overline{p}$, coefficient of bulk viscosity ξ, and Hubble prarmaeter H are very high and these quantities gradually decreases with the evolution of time; and as $t \to \infty,\ \rho, p, \overline{p}, \xi, H \to 0$. Spatial volume increases with the evolution of time; that is $t \to \infty,\ V \to \infty$, when $t = 0$ spatial volume vanishes and the expansion scalar is infinite. Which shows that the universe starts evolving with zero volume. The scale factor vanishes at $t = 0$ and hence the model has a point singularity at the initial epoch. As t increases, the scale factor and the spatial volume increases but the expansion scalar decreases. Anisotropy parameter is constant which shows that model is model remains anisotropic throughout the evolution of the universe. It is noted that bulk viscosity in the universe decreases with time so that, we obtain, inflationary models. In this model as t increases string tension density λ increases slowly.

Case (ii)

The case (ii) consists of (i), (ii) and special form of deceleration parameter [54]

$$q = -kt + n - 1 \tag{37}$$

From (37) we have Akarsu and Dereli [54]:

$$= {}_1 \exp\left[\frac{2}{\sqrt{n^2 - 2c_1 k}} \arctan h\left(\frac{kt-n}{\sqrt{n^2-2c_1 k}}\right)\right] \qquad for\ k>0 \quad n \geq 0 \tag{38}$$

And $$a = \begin{cases} k_2(nt+c_2)^{\frac{1}{n}} & for\ k=0 \quad n>0 \\ k_3 e^{c_3 t} & for\ k=0 \quad n=0 \end{cases}$$

where $k_1, k_2, k_3, c_1, c_2, c_3$ are constants of integration. The last two values of a give the constant deceleration parameter. So we neglect these values of a as $q = cons\tan t$ is studied by earlier researcher. Thus we focus on the first value of scale factor.

The scale factor a can also be expressed as follows for $n > 1 \quad c_1 = 0$

$$a = k_1 \exp\left[\frac{2}{n} \arctan h\left(\frac{kt-n}{n}\right)\right] \tag{39}$$

$$a = k_1 e^{\left[\frac{2}{n}\arctan h\left(\frac{kt}{n}-1\right)\right]}$$

With the help of (18), (23) and (39) we have obtained

$$A = k_1^{\frac{3m}{(2+m)}} \exp\left[\frac{6m}{n(2+m)} \arctan h\left(\frac{kt}{n}-1\right)\right] \tag{40}$$

$$B = k_1^{\frac{3}{(2+m)}} \exp\left[\frac{6}{n(2+m)} \arctan h\left(\frac{kt}{n}-1\right)\right] \tag{41}$$

From (16), with the help of (41), we found the string tension density as

$$\lambda = \frac{1}{(8\pi+2\mu)}\left\{\frac{k_{11}}{(2n-kt)^2 t^2}[kt + k_{12} + k_{13}] - \frac{1}{k_1^{\frac{6}{(2+m)}} \exp\left[\frac{12}{n(2+m)} \arctan h\left(\frac{kt}{n}-1\right)\right]}\right\} \tag{42}$$

where $k_{11} = \dfrac{12(m-1)}{(m+2)}, \quad k_{12} = \dfrac{3}{(m+2)} - n, \quad k_{13} = \dfrac{3(m+1)}{(m+2)}$

From (17), with the help of (19) and (42), we found the rest energy density ρ :

$$\rho = \frac{1}{(8\pi + 2\mu)(\varepsilon_0 - \gamma + 1)} \left\{ \frac{4k_{13}}{(2n - kt)^2 t^2} [kt + k_{12} + k_{14}] - \frac{1}{k_1^{\frac{6}{(2+m)}} \exp\left[\frac{12}{n(2+m)} \arctan h\left(\frac{kt}{n} - 1 \right) \right]} \right\} \tag{43}$$

where $k_{14} = \frac{3(m^2 - 2m - 1)}{(m^2 + 3m + 2)}$.

From (19), with the help of (43), we obtained the total pressure $\overline{p}$, proper pressure p and the coefficient of bulk viscosity ξ as follows:

$$\overline{p} = \frac{(\varepsilon_0 - \gamma)}{(8\pi + 2\mu)(\varepsilon_0 - \gamma + 1)} \left\{ \frac{4k_{13}}{(2n - kt)^2 t^2} [kt + k_{12} + k_{14}] - \frac{1}{k_1^{\frac{6}{(2+m)}} \exp\left[\frac{12}{n(2+m)} \arctan h\left(\frac{kt}{n} - 1 \right) \right]} \right\} \tag{44}$$

$$p = \frac{\varepsilon_0}{(8\pi + 2\mu)(\varepsilon_0 - \gamma + 1)} \left\{ \frac{4k_{13}}{(2n - kt)^2 t^2} [kt + k_{12} + k_{14}] - \frac{1}{k_1^{\frac{6}{(2+m)}} \exp\left[\frac{12}{n(2+m)} \arctan h\left(\frac{kt}{n} - 1 \right) \right]} \right\} \tag{45}$$

$$\xi = \frac{\gamma\, t(2n - kt)}{18(8\pi + 2\mu)(\varepsilon_0 - \gamma + 1)} \left\{ \frac{4k_{13}}{(2n - kt)^2 t^2} [kt + k_{12} + k_{14}] - \frac{1}{k_1^{\frac{6}{(2+m)}} \exp\left[\frac{12}{n(2+m)} \arctan h\left(\frac{kt}{n} - 1 \right) \right]} \right\} \tag{46}$$

b) Some Physical Properties of the Model

Some physical properties of the model are given below, which have significant role in the discussion of cosmological models are the spatial volume V, scalar expansion θ, The Hubble's parameter H, shear scalar σ^2 and mean anisotropy parameter A_h, the above quantities are given by

$$V = k_1^3 \exp\left[\frac{6}{n} \arctan h\left(\frac{kt}{n} - 1 \right) \right] \tag{47}$$

$$\theta = \frac{18}{t(2n - kt)} \tag{48}$$

$$H = \frac{6}{t(2n - kt)} \tag{49}$$

$$3A_h = \frac{6 + 4m + 2m^2}{(2 + m)^2} \tag{50}$$

$$\sigma^2 = \frac{(6 + 4m + 2m^2)^2}{3(2 + m)^4} - \frac{9a_1^2 e^{2a_1\beta t}}{(e^{a_1\beta t} - 1)^2} \tag{51}$$

In this model the energy density ρ, proper pressure p, total pressure $\overline{p}$, coefficient of bulk viscosity ξ, and Hubble prarmaeter H gradually decrease with the evolution of time. Spatial volume increases with evolution of time, after that it also diverges. Anisotropy parameter is constant so the model is anisotropic model throughout the evolution of the universe. In this model cosmic string decreases as t increases.

IV. Concluding Remarks

In this paper we have studied the Kantowski-Sachs bulk viscous string cosmological model in $f(R, T)$ theory of gravity with variable deceleration parameters. According the choice of deceleration parameter (20) and (37) we have presented two cosmological models. The observations of both the models are as follows:

- It is observed that in the first case the model has point singularity at the initial epoch. In the second case there is no point type singularity.
- In both the model as $t \to \infty$ *then* $\rho, p, \bar{p}, \xi, H \to 0$
- In both cases the mean anisotropy parameter $A_h \neq 0$ the model do not approach isotropy and it is time independent in which gives the indication that the anisotropy in expansion rates is maintained throughout the cosmic evolution.
- In the first model The spatial volume is zero at $t = 0$ and the expansion scalar is infinite, which suggest that the universe starts evolving with zero volume at $t = 0$, i.e. we have big bang scenario.
- We observed that the type of time variations of deceleration parameter considered here affect the nonexistence of cosmic string in this model. Hence the consideration of variable deceleration parameter contribute towards the existence of cosmic strings in the theory of Kantowski-Sachs space time.

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Chemical in Homogeneities, Electric Currents, and Diffusion Waves in Stars

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Abstract- The stars of the middle main sequence often have spot-like chemical structures at their surfaces. We consider diffusion caused by electric currents and argue that such current-driven diffusion can form chemical in homogeneities in plasma. Diffusion was considered using partial momentum equations derived by the Chapman-Enskog method. We argue that diffusion caused by electric currents can substantially change the surface chemistry of stars and form spotted chemical structures even in a relatively weak magnetic field. The considered mechanism can be responsible for a formation of element spots in Hg-Mn and Ap-stars. Diffusion in the presence of electric currents can be accompanied by propagation of a particular type of magneto hydrodynamic modes in which only the impurity number density oscillate. Such modes exist if the magnetic pressure is much greater than the gas pressure and can be the reason of variations of the abundance peculiarities in stars.

Keywords: *stars: magnetic fields - stars: abundances - stars: chemically peculiar- stars: spots.*

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CHEMICALINHOMOGENEITIESELECTRICCURRENTSANDDIFFUSIONWAVESINSTARS

Strictly as per the compliance and regulations of:

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Abstract- The stars of the middle main sequence often have spot-like chemical structures at their surfaces. We consider diffusion caused by electric currents and argue that such current-driven diffusion can form chemical in homogeneities in plasma. Diffusion was considered using partial momentum equations derived by the Chapman-Enskog method. We argue that diffusion caused by electric currents can substantially change the surface chemistry of stars and form spotted chemical structures even in a relatively weak magnetic field. The considered mechanism can be responsible for a formation of element spots in Hg-Mn and Ap-stars. Diffusion in the presence of electric currents can be accompanied by propagation of a particular type of magneto hydrodynamic modes in which only the impurity number density oscillate. Such modes exist if the magnetic pressure is much greater than the gas pressure and can be the reason of variations of the abundance peculiarities in stars.

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I. Introduction

The stars of the middle main sequence often have relatively quiescent surface layers, and the abundance peculiarities can develop in their atmospheres since, in general, there are physical processes that lead to evolution of atmospheric chemistry during the main sequence lifetime. Chemical composition can evolve in the atmospheres of such stars, for example, because of loss of heavy ions caused by gravitational settling. Also, the atmosphere can acquires ions driven upwards by radiative acceleration due to the radiative energy flux (see Michaud 1970, Michaud et. al. 1976, Vauclair et al. 1979, Alecian & Stift 2006). Many stars with peculiar chemical abundances show line-profile variations caused by element spots on their surface (see, e.g., Pyper 1969, Khokhlova 1985, Silvester et al. 2012). The exact reasons of inhomogeneous surface distributions on stars are unknown. It was thought that chemical spots can only occur in the presence of a strong organized magnetic field. Indeed, some stars exhibit the presence of such magnetic fields. For example, Ap stars show variations of both spectral lines and magnetic field strength that can be caused by rotation of chemical and magnetic spots. Often such stars have the strongest concentration of heavy elements around the magnetic poles (see, e.g., Havnes 1975). A reconstruction of the stellar magnetic geometry from observations is a very complex problem for decade. The magnetic Doppler imaging code developed by Piskunov & Kochukhov (2002) makes it possible to derive the magnetic map of a star self-consistently with the distribution of chemical elements. The reconstructions show that the magnetic and chemical maps can be extremely complex (Kochukhov et al. 2004a). For instance, Kochukhov et al. (2004b) have found that almost all elements (except, may be, Li and O) of the Ap-star HR 3831 do not follow the symmetry of the dipolar magnetic field but are distributed in a rather complex manner. The calculated distributions demonstrate the complexity of diffusion in Ap-stars and discard a point of view that diffusion leads to a formation of the chemical spots symmetric with respect to the londitudinal magnetic field (Kochukhov 2004). Likely, chemical distributions are affected by a number of poorly understood phenomena in the surface layers of stars.

Often, a formation of the chemical spots is related to anisotropic diffusion in a strong magnetic field. Indeed, the magnetic field of Ap-stars ($\sim 10^3$–10^4G) can magnetize electrons in plasma that, generally, leads to anisotropic transport. Anisotropy of diffusion in a magnetized plasma is characterized by the the Hall parameter, $x_e = \omega_{Be}\tau_e$, where $\omega_{Be} = eB/m_e c$ is the gyrofrequency of electrons and τ_e is their relaxation time; B is the magnetic field. If the base ground plasma is presumably hydrogen, then $\tau_e = 3\sqrt{m_e}(k_b T)^{3/2}/4\sqrt{2\pi}e^4 n\ \Lambda$ (see, e.g., Spitzer 1998) where n and T are the number density of electrons and their temperature, Λ is the Coulomb logarithm. At $x_e \geq 1$, the rates of diffusion along and across the magnetic field become different. The condition $x_e \geq 1$ yields the following estimate of the magnetic field that magnetizes plasma

$$B \geq B_e = 2.1 \times 10^3 \Lambda_{10} n_{15} T_4^{-3/2}\ \text{G}, \qquad (1)$$

where $\Lambda_{10} = \Lambda/10$, $n_{15} = n/10^{15}$, and $T_4 = T/10^4 K$. Some Ap-stars that exhibit spot-like chemical structures have a sufficiently strong magnetic field that satisfies this condition. Note, however, that the magnetic field (1) magnetizes only electrons and, as a result, its effect on diffusion of heavy ions is relatively weak. Perhaps, a much stronger field that magnetizes protons is required in order to produce strong chemical in homogeneities in stars. In this case, one requires $y > 1$ where $y = eB\tau_p/m_p c$ is the Hall parameter for protons and

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$\tau_p = 3\sqrt{m_p}(k_B T)^{3/2}/4\sqrt{2\pi}e^4 n\,\Lambda$ is the relaxation time for protons (see, e.g., Spitzer 1998). The condition $y > 1$ yields

$$B > B_p = 10^5 n_{15} T_4^{-3/2} \Lambda_{10} \ \text{G}. \quad (2)$$

Such field is substantially stronger than the field detected at the surface of Ap-stars.

In recent years, the discovery of chemical inhomogeneities in the so-called Hg-Mn stars has rised additional doubts regarding the magnetic origin of these inhomogeneities. The aspect of inhomogeneous distribution of some chemical elements over the surface of HgMn stars was discussed first by Hubrig & Mathys (1995). In contrast to Ap-stars, no strong large-scale madnetic field of kG order has ever been detected in HgMn stars. For instance, Wade et al. (2004) find no longitudinal field above 50 G in the brightest Hg-Mn star αAnd with distributed inhomogeneously chemical elements. The authors also establish an upper limit of the global field at $\approx$ 300 G that is obviously not sufficient to magnetize plasma. Weak magnetic fields in the atmospheres of Hg-Mn stars have been detected also by a number of authors (see, e.g., Hubrig & Castelli 2001, Hubrig et al. 2006, Makaganiuk et al. 2011, 2012). In a recent study by Hubrig et al. (2012), the previous measuments of the magnetic field have been re-analysed and the presence of a weak longitudinal magnetic field up to 60-80 G has been revealed in several HgMn stars. On the other hand, magnetic fields up to a few hundred Gauss have been detected in several HgMn stars (see, e.g., Mathys & Hubrig 1995). Measurements by Hubrig at al. (2010) reveal a longitudinal magnetic field of the order of a few hundred Gauss in the spotted star AR Aur. The complex interrelations between the magnetic field and the chemical structures clearly indicate how incomplete is our understanding of diffusion in stars.

In this paper, we consider one more diffusion process that can be responsible for a formation of chemical inhomogeneities in stars. This process is relevant to electric currents and well studied in a laboratory plasma (see, e.g., Vekshtein et al. 1975) but have not been considered in detail in stellar conditions. By making use of a simple model, we show in this paper that interaction of the electric currents with different sorts of ions leads to their diffusion in the direction perpendicular to both the electric current and magnetic field. This type of diffusion can alter the surface chemical distributions even if the magnetic field is substantially weaker than B_e.

II. Basic Equations

Consider a cylindrical plasma configuration with the magnetic field parallel to the axis z, $\vec{B} = B(s)\vec{e}_z$; (s, φ, z) and $(\vec{e}_s, \vec{e}_\varphi, \vec{e}_z)$ are cylindrical coordinates and the corresponding unit vectors. The electric current in such configuration is

$$j_\varphi = -(c/4\pi)(dB/ds). \quad (3)$$

We suppose that $j_\varphi \to 0$ at large s and, hence, $B \to B_0$=const at $s \to \infty$. Note that $B(s)$ can not be arbitrary function of s because, generally, the magnetic configurations can be unstable for some dependences *B(s)* (see, e.g., Tayler 1973, Bonanno & Urpin 2008a,b). The characteristic timescale of this instability is usually of the order of the time taken for an Alvén wave to travel around the star that is much shorter than the diffision timescale. Therefore, a formation of chemical structures in such magnetic configurations is impossible. Note that, in some cases, the considered configuration can mimic real magnetic fields with a high accuracy. This is valid, for example, for the magnetic field near the magnetic pole where the fild lines are very close to a cylindrical geometry (see, e.g., Urpin & Van Riper 1993).

We assume that plasma is fully ionized and consists of electrons e, protons p, and a small admixture of heavy ions *i*. The number density of species *i* is small and does not influence the dynamics of plasma. Therefore, these ions can be treated as trace particles interacting only with a background hydrogen plasma. The hydrostatic equilibrium in such plasma is given by

$$-\nabla p + \vec{F} + \frac{1}{c}\vec{j} \times \vec{B} = 0, \quad (4)$$

where p is the gas pressure, ρ is the density, and $\vec{F}$ is an external force acting on plasma. Since the baseground plasma is hydrogen and fully ionized, $p \approx 2nk_B T$ where k_B is the Boltzmann constant. In stellar conditions, $\vec{F}$ is usually the sum of two forces, $\vec{F} = \vec{F}_g + \vec{F}_{rad}$, where $\vec{F}_g = \rho\vec{g}$ is the gravity force and $\vec{F}_{rad}$ is caused by radiative acceleration due to the radiative energy flux from the interior. We assume that the both external forces $\vec{F}_g$ and $\vec{F}_{rad}$ act in the vertical direction. Then, the z-component of Eq. (4) determines the vertical distribution of a background plasma and reads $\partial p/\partial z = F_z$. The s-component of these equation describes the transverse structure of a magnetic atmosphere. For the sake of simplicity, we consider the case T=const and neglect the contribution of thermodiffusion. Integrating the scomponent of Eq. (4), we obtain

$$n = n_0 \left(1 + \beta_0^{-1} - \beta^{-1}\right), \quad (5)$$

where $\beta = 8\pi p_0/B^2$; $(p_0, n_0, T_0, \beta_0$ are the values of (p, n, T, β) at $s \to \infty$.

The partial momentum equations in fully ionized multi component plasma have been considered by a number of authores (see, e.g., Urpin 1981). This study deals mainly with the hydrogen-helium plasma. However, the derived equations can be applied for hydrogen plasma with a small admixture of any other ions if their number density is small. If the mean hydrodynamic velocity of plasma is zero and only small

Global Journal of Science Frontier Research (A) Volume XVIII Issue I Version I Year 2018

diffusive velocities are non-vanishing, the partial momentum equation for the species *i* reads

$$-\nabla p_i + Z_i e n_i \left(\vec{E} + \frac{\vec{V_i}}{c} \times \vec{B} \right) + \vec{R}_{ie} + \vec{R}_{ip} + \vec{F}_i = 0, \tag{6}$$

where Z_i is the charge number of the species i, p_i and n_i are its partial pressure and number density, $\vec{E}$ is the electric field in plasma, and $\vec{V_i}$ is the diffusion velocity. Since diffusive velocities are usually very small, we neglect the terms proportional $(\vec{V_i} \cdot \nabla)\vec{V_i}$ in the momentum equation (6). The force $\vec{F_i}$ is the external force on species i; in stellar conditions, $\vec{F_i}$ is the sum of gravitational and radiative forces. The forces $\vec{R}_{ie}$ and $\vec{R}_{iH}$ are caused by the interaction of ions i with electrons and protons, respectively. Note that forces $\vec{R}_{ie}$ and $\vec{R}_{iH}$ are internal, but the sum of internal forces over all plasma components is zero in accordance with Newton's third law. If n_i is small compared to the number density of protons, $\vec{R}_{ie}$ is given by

$$\vec{R}_{ie} = -(Z_i^2 n_i / n) \vec{R}_e \tag{7}$$

where $\vec{R}_e$ is the force acting on the electron gas (see, e.g., Urpin 1981). Since $n_i \ll n, \vec{R}_e$ is determined mainly by scattering of electrons on protons but scattering on ions i gives a small contribution to $\vec{R}_e$. Therefore, we can use for $\vec{R}_e$ the expression for hydrogen plasma calculated by Braginskii (1965). In our model of isothermal plasma, the expression for $\vec{R}_e$ reads

$$\vec{R}_e = -\alpha_\parallel \vec{u}_\parallel - \alpha_\perp \vec{u}_\perp + \alpha_\wedge \vec{b} \times \vec{u}, \tag{8}$$

where $\vec{u} = -\vec{j}/en$ is the current velocity of electrons; $\vec{b} = \vec{B}/B$; the subscripts $\parallel, \perp$, and $\wedge$ denote the parallel, perpendicular, and the so called Hall components of the corresponding vector; $\alpha_\parallel, \alpha_\perp$ and $\alpha_\wedge$ are the coefficients calculated by Braginskii (1965). Taking into account Eq.(3), we have

$$\vec{u} = (c / 4\pi e n)(dB/ds) \vec{e}_\varphi. \tag{9}$$

Since $\vec{B} \perp \vec{u}$ in our model, we have $\vec{u}_\parallel = 0$. In this paper, we consider diffusion only in a relatively weak magnetic field that does not magnetize electrons, $x_e \ll 1$. Substituting Eq.(8) into Eq.(7) and using coefficients $\alpha_\perp$ and $\alpha_\wedge$ calculated by Braginskii (1965) with the accuracy in linear terms in x_e, we obtain

$$R_{ie\varphi} = Z_i^2 n_i \left(0.51 \frac{m_e}{\tau_e} u \right), \quad R_{ies} = Z_i^2 n_i \left(0.21 x \frac{m_e}{\tau_e} u \right). \tag{10}$$

If T =const, the friction force $\vec{R}_{ip}$ is proportional to the relative velocity of ions *i* and protons. Like $\vec{R}_e$ (see Eq.(8)), this force also has a tensor character and, generally, depends on the magnetic field.

The force $\vec{R}_{ip}$ has an especially simple shape if $A_i = m_i / m_p \gg 1$ (see Urpin 1981) and we consider only this case. We neglect the influence of the magnetic field on $\vec{R}_{ip}$ since this influence becomes important only in a strong magnetic field $\geq B_p$. Taking into account that the velocity of the background plasma is zero, $\vec{V_p} = 0$, the friction force $\vec{R}_{ip}$ can be written as

$$\vec{R}_{ip} = (0.42 m_i n_i Z_i^2 / \tau_i)(-\vec{V_i}), \tag{11}$$

where $\tau_i = 3\sqrt{m_i}(k_B T)^{3/2} / 4\sqrt{2\pi} e^4 n \Lambda; \tau_i / Z_i^2$ is the timescale of ion-proton scattering; we assume that Λ is the same for all types of scattering (see, e.g., Urpin 1981).

III. Diffusion Velocity

The cylindrical components of Eq.(6) yield

$$-\frac{d}{ds}(n_i k_B T) + Z_i e n_i \left(E_s + \frac{V_{i\varphi}}{c} B \right) + R_{ies} + R_{ips} = 0, \tag{12}$$

$$Z_i e n_i \left(E_\varphi - \frac{V_{is}}{c} B \right) + R_{ie\varphi} + R_{ip\varphi} = 0, \tag{13}$$

$$-\frac{d}{dz}(n_i k_B T) + Z_i e n_i E_z + R_{iez} + R_{ipz} + F_{iz} = 0. \tag{14}$$

In our simplified magnetic configuration, we have $R_{iez} = 0$. Eqs.(12)-(14) depend on cylindrical components of the electric field, E_s, E_φ, and E_z. These components can be determined from the momentum equations for electrons and protons

$$-\nabla(n k_B T) - en \left(\vec{E} + \frac{\vec{u}}{c} \times \vec{B} \right) + \vec{R}_e + \vec{F}_e = 0, \tag{15}$$

$$-\nabla(n k_B T) + en\vec{E} - \vec{R}_e + \vec{F}_p = 0. \tag{16}$$

In these equations, we neglect collisions of electrons and protons with the ions i since these ions are considered as the test particles and their number density is assumed to be small. The sum of Eqs.(15) and (16) yield the equation of hydrostatic equilibrium (4). The difference of Eqs.(16) and (15) yields the following expression fo the electric field

$$\vec{E} = -\frac{1}{2} \frac{\vec{u}}{c} \times \vec{B} + \frac{\vec{R}_e}{en} - \frac{1}{2en}(\vec{F}_p - \vec{F}_e). \tag{17}$$

Taking into account the friction force $\vec{R}_e$ (Eq. (8)) and the coefficients $\alpha_\perp$ and $\alpha_\wedge$, calculated by Braginskii (1965), we obtain with accuracy in linear terms in x_e

$$E_s = -\frac{uB}{2c} - \frac{1}{e}\left(0.21 \frac{m_e u}{\tau_e} x_e \right), \; E_\varphi = -\frac{1}{e}\left(0.51 \frac{m_e u}{\tau_e} \right),$$

$$E_z = -\frac{1}{2en}(F_{pz} - F_{ez}). \qquad (18)$$

Substituting Eqs.(7) and (19) into vertical component of the momentum equation (15), we obtain the following expression for the velocity of vertical diffusion

$$V_{iz} = -D\frac{d\ln n_i}{dz} + \frac{D}{n_i k_B T}F_z^{(i)}, \qquad (19)$$

where $D = 2.4c_i^2\tau_i/Z_i^2$ is the diffusion coefficient, $c_i^2 = k_B T/m_i$, and

$$F_z^{(i)} = F_{iz} - \frac{Z_i n_i}{2n}(F_{pz} - F_{ez}). \qquad (20)$$

Often, radiative acceleration due to the radiative energy flux and gravitational settling give the main contribution to the external force $F_z^{(i)}$ (Michaud et al. 1976). The diffusion velocity caused by these forces can be relatively large and, therefore, the vertical diffusion often is faster than diffusion in the tangential direction parallel to the surface. As a result, the vertical distribution of chemical elements reaches a quasi-steady equilibrium on a relatively short timescale. We will show, however, that the horizontal diffusion can form spots faster than the vertical diffusion if the magnetic field is weak.

The tangential components of the difusion velocity can be obtained from Eqs. (13) and (14). Taking into acount Eq. (12) for $\vec{R}_{ip}$, one can transform Eqs. (13)-(14) into

$$V_{is} - qV_{i\varphi} = A, \quad V_{i\varphi} + qV_{is} = G, \qquad (21)$$

where

$$A = \frac{D}{n_i k_B T}\left(-\frac{dp_i}{ds} + Z_i e n_i E_s + R_{ies}\right), \qquad (22)$$

$$G = \frac{D}{n_i k_B T}\left(Z_i e n_i E_\varphi + R_{ie\varphi}\right), \quad q = 2.4\frac{eB}{Z_i m_i c}\tau_i. \qquad (23)$$

Then, the diffusion velocities in the s- and φ-directions are

$$V_{is} = \frac{A + qG}{1+q^2}, \quad V_{i\varphi} = \frac{G - qA}{1+q^2}. \qquad (24)$$

The parameter q is of the order of $\omega_{Bi}\tau_i$ and is small even for magnetic fields typical for Ap-stars. Then, we have for $q \ll 1$

$$V_{is} \approx A, \quad V_{i\varphi} \approx G. \qquad (25)$$

Substituting Eqs. (10) and (19) into expressions (23)-(24) for A and G, we obtain the following expressions for the diffusion velocities

$$V_{is} = V_{n_i} + V_B, \quad V_{n_i} = -D\frac{d\ln n_i}{ds}, \quad V_B = D_B\frac{d\ln B}{ds} \qquad (26)$$

$$V_{i\varphi} = D_{B\varphi}\frac{dB}{ds} \qquad (27)$$

V_{ni} is the velocities of ordinary diffusion and V_B is the diffusion velocity caused by the electric current. The corresponding diffusion coefficients are

$$D = \frac{2.4c_i^2\tau_i}{Z_i^2}, \quad D_B = \frac{2.4c_A^2\tau_i}{Z_i A_i}(0.21Z_i - 0.71), \qquad (28)$$

$$D_{B\varphi} = 1.22\sqrt{\frac{m_e}{m_i}}\frac{c(Z_i - 1)}{4\pi e n Z_i}. \qquad (29)$$

where $c_i^2 = k_B T/m_i$ and $c_A^2 = B^2/(4\pi n m_p)$. Eqs. (27)-(28) describe the drift of ions i under the combined influence of ∇n_i and $\vec{j}$.

IV. Distribution of Ions Caused by Electric Currents

Consider the equilibrium distribution of heavy ions in our model. In equilibrium, we have $V_{is} = 0$ and Eq.(27) yields

$$D\frac{d\ln n_i}{ds} = D_B\frac{d\ln B}{ds}. \qquad (30)$$

The term on the r.h.s. describes the effect of electric currents on the distribution of impurities. Note that this type of diffusion is driven by the electric current rather than an inhomogeneity of the magnetic field. The conditions $dB/ds \neq 0$ and $j \neq 0$ are equivalent in our simplified magnetic configuration. Eq. (4) yields

$$\frac{d}{ds}(nk_B T) = -\frac{B}{8\pi}\frac{dB}{ds}. \qquad (31)$$

Substituting Eq. (32) into Eq.(31) and integrating, we obtain

$$\frac{n_i}{n_{i0}} = \left(\frac{n}{n_0}\right)^\mu, \qquad (32)$$

where

$$\mu = -2Z_i(0.21Z_i - 0.71) \qquad (33)$$

and n_{i0} is the value of n_i at $s \to \infty$. Denoting the local abundance of the element i as $\gamma_i = n_i/n$ and taking into account Eq. (5), we have

$$\frac{\gamma_i}{\gamma_{i0}} = \left(\frac{n}{n_0}\right)^{\mu-1} = \left(1 + \frac{1}{\beta_0} - \frac{1}{\beta}\right)^{\mu-1}, \qquad (34)$$

where $\gamma_{i0} = n_{i0}/n_0$. Local abundances turn out to be flexible to the field strength and, particularly, this concerns ions with large charge numbers. The exponent (μ–1) can reach large negative values for elements with large Z_i and, hence, produce strong abundance anormalies. For instance, (μ–1) is equal 1.16, -0.52, and -2.04 if Z_i =2, 3, and 4, respectively. Note that (μ–1) changes its sign as Z_i increases: (μ–1) > 0 if Z_i= 2 but (μ – 1) < 0 for $Z_i \geq 3$. Therefore, elements with $Z_i \geq 3$ are in deficit ($\gamma_i < \gamma_{i0}$) in the region with a weak magnetic field ($B < B_0$) but, on the contrary, these elements should be overabundant in the spot where the magnetic field is stronger than the external field B_0.

Note that the dependence of the exponent (μ–1) on Z_i can be responsible for the increase in He abundance in magnetic stars with stellar age. This increase was first discovered by Bailey et al. (2014) and is very unexpected within the frame of the standard theory because radiative levitation of He is very weak and becomes weaker as the star evolves. However, the increase in He abundance seems to be rather natural if one takes into account the current-driven diffusion. Indeed, observations indicate that the magnetic field decreases with the stellar age (see, e.g., Bailey et al. (2014)) because of ohmic dissipation and, hence, a contrast between the magnetic spots and ambient plasma becomes weaker. As it follows from Eq. (34), a weaker contrast of the magnetic field leads to a higher local abundance of He in a spot.

It is generally believed that the standard diffusion smoothes chemical in homogeneities on a timescale of the order of L^2/D where L is the length scale of a nonuniformity. However, this is not the case for a chemical distribution given by Eq. (34) which can exist during a much longer time than $\sim L^2/D$. In our model, distribution (34) is reached due to balance of two diffusion processes, standard ($\propto \nabla n_i$) and current-driven ($\propto dB/ds$) diffusion which push heavy ions in the opposite directions. As a result, V_{is} = 0 in the equilibrium state and this state can be maintained as long as the electric currents exist. Therefore, the characteristic lifetime of chemical structures is of the order of the decay time of electric currents that is determined by ohmic dissipation and is $\sim 4\pi\sigma L^2/c^2$ where σ is the electrical conductivity. Decay of the magnetic field is very slow in stellar conditions and the decay timescale can be longer than the diffusion timescale if $D > c^2/4\pi\sigma$. Under such conditions, the lifetime of a spot is entirely determined by the ohmic decay time.

Note tha V_{is} = 0 in the equilibrium state but the φ-component of the diffusion velocity is non-zero. It turns out that impurities rotate around the magnetic exis even if equlibrium is reached, $V_{i\varphi} \neq 0$. The direction of rotation depends on the sign of dB/ds and is opposite to the electric current. Since electrons move in the same direction, heavy ions turn out to be carried along electrons. Different ions move with different velocities around the axis, and the difference between different sorts of ions, $\Delta V_{i\varphi}$, is of the order of

$$\Delta V_{i\varphi} \sim \frac{c}{4\pi e n}\sqrt{\frac{m_e}{m_i}}\frac{dB}{ds} \sim 3\times10^{-3}\frac{B_4}{n_{14}L_{10}A_i^{1/2}}\frac{\text{cm}}{\text{s}}, \quad (35)$$

where $B_4 = B/10^4$ G, $n_{14} = n/10^{14}\text{cm}^{-3}$, and $L_{10} = L/10^{10}$. Since different impurities rotate around the magbetic axis with different velocities, periods of such rotation also are different for different ions. The difference in periods can be estimated as

$$\Delta P = \frac{2\pi L}{\Delta V} \sim 10^6\frac{L_{10}^2 n_{14} A_i^{1/2}}{B_4} \text{ yrs.} \quad (36)$$

If the distribution of impurities is non-axisymmetric then such diffusion in the azimuthal direction should lead to slow variations in the abundance peculiarities.

V. Diffusion Waves

In our model of plasma with a cylindrical symmetry, the continuity equation for ions i reads

$$\frac{\partial n_i}{\partial t} - \frac{1}{s}\frac{\partial}{\partial s}\left(sD\frac{\partial n_i}{\partial s} - sn_i\frac{D_B}{B}\frac{dB}{ds}\right) = 0. \quad (37)$$

Together with Eqs. (29)-(30), this equation describes diffusion of ions i in the presence of electric currents.

Let us assume that plasma is in a diffusion equilibrium (Eq. (31)) and, hence, the distribution of elements in such a basic state is given by Eqs.(33)-(35). Consider the behaviour of small disturbances of the number density of impurity from this equilibrium by making use of a linear analysis of Eq. (36). Since the number density of impurity *i* is small, its influence on parameters of the basic state is negligible. For the sake of simplicity, we assume that small disturbances are axisymmetric and do no depend on the vertical coordinate, z. Such disturbances have a shape of cylindrical waves. Denoting disturbances of the impurity number density by δn_i and linearizing Eq. (36), we obtain the equation governing the evolution of such small disturbances,

$$\frac{\partial \delta n_i}{\partial t} - \frac{1}{s}\frac{\partial}{\partial s}\left(sD\frac{\partial \delta n_i}{\partial s} - s\delta n_i\frac{D_B}{B}\frac{dB}{ds}\right) = 0. \quad (38)$$

We consider disturbances with the wavelength shorter than the lengthscale of B. In this case, we can use the so called local approximation and assume that disturbances are $\propto \exp(-iks - M\varphi)$ where k is the wavevector, $ks \gg 1$, and *M* is the azimuthal wavenumber. Since the basic state does not depend on t, δn_i can be represented as $\delta n_i \propto \exp(i\omega t - iks - iM\varphi)$ where ω should be calculated from the dispersion equation. We consider two particular cases of the compositional waves, $M = 0$ and $M \gg ks$.

Cylindrical waves with $M = 0$. Substituting δn_i into Eq. (38), we obtain the dispersion equation for $M = 0$

$$i\omega = -\omega_R + i\omega_B, \ \omega_R = Dk^2, \ \omega_B = kD_B(d\ln B/ds). \tag{39}$$

This dispersion equation describes cylindrical waves in which only the number density of impurity oscillates. The quantity ω_R characterizes decay of waves with the characteristic timescale $\sim (Dk^2)^{-1}$ typical for a standard diffusion. The frequency ω_B describes oscillations of impurities caused by the combined action of electric current and the Hall effect. Note that the frequency can be of any sign but ω_R is always positive. The compositional waves are aperiodic if $\omega_R > |\omega_B|$ and oscillatory if $|\omega_B| > \omega_R$. This condition is equivalent to

$$c_A^2/c_s^2 > Z_i^{-1}|0.21Z_i - 0.71|^{-1}kL, \tag{40}$$

where c_s is the sound speed, $c_s^2 = k_B T/m_p$. Compositional waves become oscillatory if the field is strong and the magnetic pressure is substantially greater than the gas pressure. The frequency of diffusion waves is higher in the region where the magnetic field has strong gradients. The order of magnitude estimate of ω_I is

$$\omega_I \sim kc_A(1/Z_i A_i)(c_A/c_i)(l_i/L), \tag{41}$$

where $l_i = c_i \tau_i$ is the mean free-path of ions i. Note that different impurities oscillate with different frequences.

Non-axisymmetric waves with $M \gg ks$. In this case, the dispersion equation reads

$$i\omega = -\omega_R + i\omega_{B\varphi}, \quad \omega_{B\varphi} = (M/s)BD_{B\varphi}(d\ln B/ds). \tag{42}$$

Non-axisymmetric waves rotate around the cylindric axis with the frequency $\omega_{B\varphi}$ and decay slowly on the diffusion timescale $\sim \omega_R^{-1}$. The frequency of such waves is typically higher than that of cylindrical waves. One can estimate the ratio of these frequencies as

$$(\omega_{B\varphi}/\omega_B) \sim (BD_{B\varphi}/D_B) \sim (1/A_i x_e)(M/ks). \tag{43}$$

Since we consider only weak magnetic fields ($x_e \gg 1$), the period of non-axisymmetric waves is shorter for waves with $M > A_i x_e (ks)$. The ratio of the diffusion timescale and period of non-axisymmetric waves is

$$(\omega_{B\varphi}/\omega_R) \sim (1/x_e)(c_A^2/c_s^2)(Z_i/A_i)(1/kL) \tag{44}$$

and can be large. Hence, these waves can be oscillatory.

VI. Conclusion

We have considered diffusion of elements under a combined influence of standard and current-driven diffusion mechanisms. A diffusion velocity caused by the electric current can be estimated as

$$V_B \sim c_A(c_A/c_i)(1/Z_i A_i)(l_i/L \tag{45}$$

if the magnetic field is relatively weak and electrons are not magnetized. Generally, this velocity can be comparable to velocities caused by other diffusion mechanisms. The current-driven mechanism can form chemical inhomogeneities in plasma even if the magnetic field is weak ($\sim 10 - 100$ G) whereas other diffusion processes require a substantially stronger magnetic field (see Eqs. (1) and (2)). Using Eq. (48), the velocity of current-driven diffusion can be estimated as

$$V_B \sim 1.1 \times 10^{-4} A_i^{-1/2} B_4^2 n_{15}^{-2} T_4^{3/2} \Lambda_{10} L_{10}^{-1} \ \ \text{cm/s}, \tag{46}$$

where $\Lambda_{10} = \Lambda/10$, $B_4 = B/10^4$ G, and $L_{10} = L/10^{10}$ cm The velocity V_B turns out to be sensitive to the field ($\propto B^2$) and, therefore, diffusion in a weak magnetic field requires a longer time to reach equilibrium abundances (34).

The current-driven mechanism leads to a drift of ions in the direction perpendicular to both the magnetic field and electric current. Therefore, a distribution of chemical elements in plasma depends essentially on the geometry of fields and currents. The mechanism considered can operate both in laboratory plasma and in various astrophysical bodies where the electric currents are non-vanishing.

The considered mechanism does not depend on the nature of electric currents and can operate if the current is maintained by some mechanism or if it is of the fossil origin. In the latter case, the decay time of Ohmic dissipation in the spot must be longer than the diffusion time scale. If the length scale of the field is L, the decay time scale is $t_d \sim 4\pi\sigma L^2/c^2$ where σ is the conductivity. In subphotospheric layers, we can estimate $\sigma \sim 3 \cdot 10^{14}$ s^{-1} and $t_d \sim 10^7 L_{10}^2$ yrs. The time scale of diffusion from subphotospheric layers is $t_B \sim H/V_B$ where H is the heigh scale. Using Eq. (34) and assuming $B \sim 100$ G, we obtain $t_B \sim 3 \cdot 10^6 H_8 L_{10}$ yrs where H8 = H/108 cm. Hence, the current-driven diffusion is faster than the Ohmic dissipation if $L_{10} > 1$ and it can form the observed chemical inhomogeneities.

Like other diffusion processes, the current-driven diffusion can lead to a formation of chemical spots if the star has relatively quiescent surface layers. This condition is fulfilled in various type of stars and, therefore, the current-driven diffusion can manifest itself in different astrophysical bodies. For example, this mechanism can contribute to formation of element spots in Ap-stars. The magnetic fields have been detected in many of such spotted stars and, likely, these magnetic fields are maintained by electric currents located in the surface layers. Quiescent surface layers may exist in other types of stars as well, for example, in white dwarfs and neutron stars. Many neutron stars have strong magnetic fields and, most likely, topology of these fields is very complex with spot-like structures at the surface. As it was shown, such magnetic configurations can be responsible for the formation of a spotlike element distribution at the surface. Such chemical structures can be important, for instance, for the emission spectra, diffusive nuclear burning (Brown et al. 2002, Chang & Bildsten 2004), etc. Evolution of neutron stars is very complicated, particularly, in binary systems (see, e.g., Urpin et al. 1998a,b) and, as a result, a surface chemistry can be complicated as well. Diffusion processes may play an important role in this chemistry.

Our study reveals that a particular type of magnetohydrodynamic waves exist in multicomponent plasma in the presence of electric currents. These waves are characterized by oscillations of the impurity number density and exist only if the magnetic pressure exceeds essentially the gas pressure. The frequency of such waves is given by Eq.(39) and turns out to be relatively small. Note that different impurities oscillate with different frequences. Therefore, the local abandances of different elements can exhibit variations with the time. The characteristic timescale of these variations is shorter in plasma with a stronger magnetic field.

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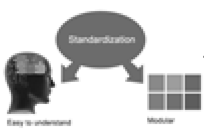

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The FARSS is eligible to earn from sales proceeds of his/her researches/reference/review Books or literature, while publishing with Global Journals. The FARSS can decide whether he/she would like to publish his/her research in a closed manner. In this case, whenever readers purchase that individual research paper for reading, maximum 60% of its profit earned as royalty by Global Journals, will be credited to his/her bank account. The entire entitled amount will be credited to his/her bank account exceeding limit of minimum fixed balance. There is no minimum time limit for collection. The FARSS member can decide its price and we can help in making the right decision.

The FARSS member is eligible to join as a paid peer reviewer at Global Journals Incorporation (USA) and can get remuneration of 15% of author fees, taken from the author of a respective paper. After reviewing 5 or more papers you can request to transfer the amount to your bank account.

MEMBER OF ASSOCIATION OF RESEARCH SOCIETY IN SCIENCE (MARSS)

The ' MARSS ' title is accorded to a selected professional after the approval of the Editor-in-Chief / Editorial Board Members/Dean.

The “MARSS” is a dignified ornament which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., MARSS or William Walldroff, M.S., MARSS.

MARSS accrediting is an honor. It authenticates your research activities. After becoming MARSS, you can add 'MARSS' title with your name as you use this recognition as additional suffix to your status. This will definitely enhance and add more value and repute to your name. You may use it on your professional Counseling Materials such as CV, Resume, Visiting Card and Name Plate etc.

The following benefitscan be availed by you only for next three years from the date of certification.

MARSS designated members are entitled to avail a 25% discount while publishing their research papers (of a single author) in Global Journals Inc., if the same is accepted by our Editorial Board and Peer Reviewers. If you are a main author or co-author of a group of authors, you will get discount of 10%.

As MARSS, you will be given a renowned, secure and free professional email address with 30 GB of space e.g. johnhall@globaljournals.org. This will include Webmail, Spam Assassin, Email Forwarders,Auto-Responders, Email Delivery Route tracing, etc.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time.This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.

The MARSS member can apply for approval, grading and certification of standards of their educational and Institutional Degrees to Open Association of Research, Society U.S.A.

Once you are designated as MARSS, you may send us a scanned copy of all of your credentials. OARS will verify, grade and certify them. This will be based on your academic records, quality of research papers published by you, and some more criteria.

It is mandatory to read all terms and conditions carefully.

Auxiliary Memberships

Institutional Fellow of Global Journals Incorporation (USA)-OARS (USA)

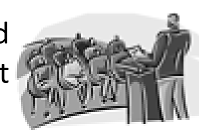
Global Journals Incorporation (USA) is accredited by Open Association of Research Society, U.S.A (OARS) and in turn, affiliates research institutions as "Institutional Fellow of Open Association of Research Society" (IFOARS).

The "FARSC" is a dignified title which is accorded to a person's name viz. Dr. John E. Hall, Ph.D., FARSC or William Walldroff, M.S., FARSC.

The IFOARS institution is entitled to form a Board comprised of one Chairperson and three to five board members preferably from different streams. The Board will be recognized as "Institutional Board of Open Association of Research Society"-(IBOARS).

The Institute will be entitled to following benefits:

The IBOARS can initially review research papers of their institute and recommend them to publish with respective journal of Global Journals. It can also review the papers of other institutions after obtaining our consent. The second review will be done by peer reviewer of Global Journals Incorporation (USA) The Board is at liberty to appoint a peer reviewer with the approval of chairperson after consulting us.
The author fees of such paper may be waived off up to 40%.



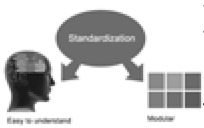
The Global Journals Incorporation (USA) at its discretion can also refer double blind peer reviewed paper at their end to the board for the verification and to get recommendation for final stage of acceptance of publication.

The IBOARS can organize symposium/seminar/conference in their country on behalf of Global Journals Incorporation (USA)-OARS (USA). The terms and conditions can be discussed separately.

The Board can also play vital role by exploring and giving valuable suggestions regarding the Standards of "Open Association of Research Society, U.S.A (OARS)" so that proper amendment can take place for the benefit of entire research community. We shall provide details of particular standard only on receipt of request from the Board.

The board members can also join us as Individual Fellow with 40% discount on total fees applicable to Individual Fellow. They will be entitled to avail all the benefits as declared. Please visit Individual Fellow-sub menu of GlobalJournals.org to have more relevant details.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time. This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.



After nomination of your institution as "Institutional Fellow" and constantly functioning successfully for one year, we can consider giving recognition to your institute to function as Regional/Zonal office on our behalf.
The board can also take up the additional allied activities for betterment after our consultation.

The following entitlements are applicable to individual Fellows:

Open Association of Research Society, U.S.A (OARS) By-laws states that an individual Fellow may use the designations as applicable, or the corresponding initials. The Credentials of individual Fellow and Associate designations signify that the individual has gained knowledge of the fundamental concepts. One is magnanimous and proficient in an expertise course covering the professional code of conduct, and follows recognized standards of practice.

Open Association of Research Society (US)/ Global Journals Incorporation (USA), as described in Corporate Statements, are educational, research publishing and professional membership organizations. Achieving our individual Fellow or Associate status is based mainly on meeting stated educational research requirements.

Disbursement of 40% Royalty earned through Global Journals : Researcher = 50%, Peer Reviewer = 37.50%, Institution = 12.50% E.g. Out of 40%, the 20% benefit should be passed on to researcher, 15 % benefit towards remuneration should be given to a reviewer and remaining 5% is to be retained by the institution.

We shall provide print version of 12 issues of any three journals [as per your requirement] out of our 38 journals worth $ 2376 USD.

Other:

The individual Fellow and Associate designations accredited by Open Association of Research Society (US) credentials signify guarantees following achievements:

- The professional accredited with Fellow honor, is entitled to various benefits viz. name, fame, honor, regular flow of income, secured bright future, social status etc.

- In addition to above, if one is single author, then entitled to 40% discount on publishing research paper and can get 10%discount if one is co-author or main author among group of authors.
- The Fellow can organize symposium/seminar/conference on behalf of Global Journals Incorporation (USA) and he/she can also attend the same organized by other institutes on behalf of Global Journals.
- The Fellow can become member of Editorial Board Member after completing 3yrs.
- The Fellow can earn 60% of sales proceeds from the sale of reference/review books/literature/publishing of research paper.
- Fellow can also join as paid peer reviewer and earn 15% remuneration of author charges and can also get an opportunity to join as member of the Editorial Board of Global Journals Incorporation (USA)
- • This individual has learned the basic methods of applying those concepts and techniques to common challenging situations. This individual has further demonstrated an in–depth understanding of the application of suitable techniques to a particular area of research practice.

Note :

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- In future, if the board feels the necessity to change any board member, the same can be done with the consent of the chairperson along with anyone board member without our approval.
- In case, the chairperson needs to be replaced then consent of 2/3rd board members are required and they are also required to jointly pass the resolution copy of which should be sent to us. In such case, it will be compulsory to obtain our approval before replacement.
- In case of "Difference of Opinion [if any]" among the Board members, our decision will be final and binding to everyone.

"

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.

Before and during Submission

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

1. Authors must go through the complete author guideline and understand and *agree to Global Journals' ethics and code of conduct,* along with author responsibilities.
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.
5. Authors should submit paper in a ZIP archive if any supplementary files are required along with the paper.
6. Proper permissions must be acquired for the use of any copyrighted material.
7. Manuscript submitted *must not have been submitted or published elsewhere* and all authors must be aware of the submission.

Declaration of Conflicts of Interest

It is required for authors to declare all financial, institutional, and personal relationships with other individuals and organizations that could influence (bias) their research.

Policy on Plagiarism

Plagiarism is not acceptable in Global Journals submissions at all.

Plagiarized content will not be considered for publication. We reserve the right to inform authors' institutions about plagiarism detected either before or after publication. If plagiarism is identified, we will follow COPE guidelines:

Authors are solely responsible for all the plagiarism that is found. The author must not fabricate, falsify or plagiarize existing research data. The following, if copied, will be considered plagiarism:

- Words (language)
- Ideas
- Findings
- Writings
- Diagrams
- Graphs
- Illustrations
- Lectures

- Printed material
- Graphic representations
- Computer programs
- Electronic material
- Any other original work

Authorship Policies

Global Journals follows the definition of authorship set up by the Open Association of Research Society, USA. According to its guidelines, authorship criteria must be based on:

1. Substantial contributions to the conception and acquisition of data, analysis, and interpretation of findings.
2. Drafting the paper and revising it critically regarding important academic content.
3. Final approval of the version of the paper to be published.

Changes in Authorship

The corresponding author should mention the name and complete details of all co-authors during submission and in manuscript. We support addition, rearrangement, manipulation, and deletions in authors list till the early view publication of the journal. We expect that corresponding author will notify all co-authors of submission. We follow COPE guidelines for changes in authorship.

Copyright

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Appealing Decisions

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.

Declaration of funding sources

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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.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

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:

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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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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

Index

A

B

D

E

I

P

Q

T

Z

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