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Lanczos Potential for The Weyl Tensor

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Abstract:

For arbitrary spacetimes with Petrov types O, N and III, we indicate general results about the Lanczos potential for the corresponding Weyl tensor.

Keywords: Conformal tensor, Lanczos generator, Newman-Penrose formalism, Petrov classification, Weyl-Lanczos equations, 2-spinors, Spin coefficients.

1. Introduction

We shall employ the notation and quantities explained in [1-6]. The Lanczos potential $K_{abc}$ [7-12] is a generator for the Weyl tensor in four dimensions; in [9] was used the Newman-Penrose (NP) formalism [4, 6, 13-17] to determine the Lanczos spin tensor for any spacetime of Petrov types [12-15, 18-21] N, O, and III, thus:

$$S_{abc} = K_{abc} + iK'_{abc} = \frac{2q}{3} [V_{ab}(-3\nu l_c - \pi n_c + 3\lambda m_c + \mu \bar{m}_c) + U_{ab}(\tau l_c + 3\kappa n_c - \rho m_c - 3\sigma \bar{m}_c) + M_{ab}(-\mu l_c + \rho n_c + \pi m_c - \tau \bar{m}_c)],$$

with $q = \frac{1}{2}$ and 1 for the types O, N, and III, respectively; besides [22]:

$$V_{ab} = l_a \times m_b, \quad U_{ab} = \bar{m}_a \times n_b, \quad M_{ab} = m_a \times \bar{m}_b + n_a \times l_b,$$  \hspace{1cm} (2)

for the corresponding canonical null tetrad [15, 21]:

$$l^a \leftrightarrow o^A o^B, \quad n^a \leftrightarrow i^A i^B, \quad m^a \leftrightarrow o^A i^B, \quad \bar{m}^a \leftrightarrow i^A o^B, \quad o_A i^A = 1.$$  \hspace{1cm} (3)

In Sec. 2 we obtain the Lanczos spinor $L_{ABCD}$ [2, 23-30] associated to the tensorial result (1):

$$L_{ABCD} = \frac{1}{4} \sigma^a_{AE} \sigma^b_{EB} \sigma^c_{CD} S_{abc},$$  \hspace{1cm} (4)

where $\sigma^r_{r'd'}$ are the Infeld-van der Waerden symbols [19, 29-31], in accordance with [28].

We note that a better understanding of the Lanczos potential permits to know more about the Liénard-Wiechert field, for example, to obtain the physical meaning of the Weert generator [32-34] and to construct [35] a Petrov classification [12-15, 18-21] for the electromagnetic field produced by a point charge in arbitrary motion. The Lanczos spin tensor is known for arbitrary types O, N and III 4-spaces [9], Kerr geometry [36-41], Gödel cosmological model [42-44], plane gravitational waves [45], and several spacetimes [46-50] of interest in general relativity. The deduction of $K_{\mu\nu\alpha}$ for arbitrary types I, II and D is an open problem. Lanczos [7] determined his potential for weak gravitational fields, and in the corresponding calculations showed up the Dirac equation for spin-1/2 without the mass term, hence he had hoped that $K_{abc}$ may be important in a future quantum gravity theory.
In Sec. 3, for arbitrary metrics of Petrov types III, N, O, and D (empty), we determine the Andersson-Edgar’s generator [51, 52] for the Lanczos spinor.

2. Lanczos spinor

From (2) and (3) are immediate the relations:

\[ a_A a_B = \frac{1}{2} \sigma_A^a \sigma_B^b \mathcal{E} \mathcal{V}_{ab}, \quad \ell_A \ell_B = \frac{1}{2} \sigma_A^a \sigma_B^b \mathcal{E} \mathcal{U}_{ab}, \quad a_A \ell_B + o_B \ell_A = - \frac{1}{2} \sigma_A^a \sigma_B^b \mathcal{E} \mathcal{M}_{ab}, \tag{5} \]

then (1), (4) and (5) imply:

\[ L_{\ell CD} = \frac{q}{3} \left( a_A a_B \left( (\mu \ell_c - 3 \nu c) \ell_D + (3 \lambda c - \pi D) \ell_D \right) + \right. \]

\[ + a_A \ell_B \left( (\tau c - 3 \sigma c) \ell_D + (3 \kappa c - \rho D) \ell_D \right) + a_B \ell_A \left( (\mu \ell_c + \tau c) \ell_D - (\pi c + \rho D) \ell_D \right), \]

which can be written in compact form; in fact, it is simple to deduce the following expression [4]:

\[ \nabla_{\ell D} (a_A \ell_B) = a_A a_B \left[ (\nu c - \mu c) \ell_D + (\pi c - \lambda c) \ell_D \right] + \]

\[ + a_A \ell_B \left[ (\sigma c - \tau c) \ell_D + (\rho c - \kappa c) \ell_D \right], \tag{7} \]

therefore (6) acquires the structure [2]:

\[ L_{\ell AB} = -q \nabla_{\ell C} a_A \ell_B), \quad q = \frac{1}{2}, 1. \tag{8} \]

The equation (8) gives the Lanczos potential in terms of the spin coefficients associated to the corresponding canonical null tetrad for the Petrov types O, N, and III; we can verify (8) via its connection with the Weyl tensor [3, 28, 29]:

\[ \psi_{ABCE} \equiv \psi_0 a_A a_B c_C c_E - 4 \psi_1 o_{(A} b c_{C} c_{E)} + 6 \psi_2 o_{(A} o_{B} c_{C} c_{E)} - 4 \psi_3 o_{(A} o_{B} o_{C} c_{E)} + \psi_4 o_{A} o_{B} o_{C} o_{E}, \tag{9} \]

\[ = 2 \nabla_{\epsilon} a_{C} L_{ABCD}. \tag{10} \]

We know [30] the formula \( \nabla_{\ell} a_{C} \nabla_{C} = \frac{1}{2} \mathcal{E}_{C} \square - \square_{EC}, \) hence:

\[ -\nabla_{\ell} a_{C} \nabla_{(C} a_{D)} = \square_{EC}(a_A \ell_B); \tag{11} \]

thus (8), (10) and (11) imply:

\[ \psi_{ABCE} = 2q \left[ o^{E} \psi_{F(ABC)} + t^{E} \psi_{F(ABC)} \right], \]

\[ = 2q \left[ \psi_0 a_A a_B c_C c_E + 2 \psi_1 o_{(A} a_{B} c_{C} c_{E)} - 2 \psi_3 o_{(A} o_{B} o_{C} c_{E)} + \psi_4 o_{A} o_{B} o_{C} o_{E} \right]. \tag{12} \]

whose comparison with (9) gives \( q = \frac{1}{2} \) and 1 for the Petrov types O, N, and III, respectively, about the canonical tetrad [15, 21].

200
3. Andersson-Edgar’s potential for the Lanczos spinor

In [46] was obtained the Lanczos generator for an arbitrary empty spacetime of Petrov type D, with the following Newman-Penrose (NP) components:

\[ \Omega_2 = \pi \frac{\psi^2}{2}, \quad \Omega_6 = \mu \frac{\psi^2}{2}, \quad \Omega_r = 0, \quad r \neq 2, 6, \]  \hspace{1cm} (13)

in terms of the spin coefficients associated to the canonical null tetrad, hence for the type D the Lanczos spinor is given by [53]:

\[ L_{ABC\bar{D}} = \psi^{-\frac{2}{3}} \left( o_A o_B o_C \right) \left( o_A + i_B o_C \right) \left( -\mu o_D + \pi o_B \right). \]  \hspace{1cm} (14)

Similarly [9]:

\[ \Omega_0 = q \kappa, \quad \Omega_3 = -q \lambda, \quad \Omega_4 = q \sigma, \quad \Omega_7 = -q \nu, \]  \hspace{1cm} (15)

\[ \Omega_1 = \frac{q}{3} \rho, \quad \Omega_2 = -\frac{q}{3} \pi, \quad \Omega_5 = \frac{q}{3} \tau, \quad \Omega_6 = -\frac{q}{3} \mu, \]

for the types N \((q = \frac{1}{2})\) and III \((q = 1)\), in the corresponding canonical tetrad, with the Lanczos spinor:

\[ L_{ABC\bar{D}} = i_A i_B i_C \left( \Omega_3 i_D - \Omega_4 o_B \right) + \left( i_A i_B o_C + \left( o_A + i_B o_C \right) \left( -\Omega_4 i_D + \Omega_3 o_B \right) \right) + \left( o_A o_B i_C + \left( o_A + i_B o_C \right) \left( \Omega_2 o_D - \Omega_6 o_B \right) + o_A o_B o_C \left( -\Omega_3 i_D + \Omega_7 o_B \right) \right). \]  \hspace{1cm} (16)

For the type O we may employ \( q = \frac{1}{2} \) or \( q = 1 \).

On the other hand, Andersson-Edgar [51, 52] proved that any Lanczos spinor can be generated via the relation:

\[ L_{ABC\bar{D}} = \nabla^E_D T_{ABCE}, \quad T_{ABCE} = T_{(ABC)E}, \]  \hspace{1cm} (17)

then we shall construct \( T_{ABCE} \) for the cases (14) and (16). Thus, in (17) we use the expansion:

\[ T_{ABCE} = i_A i_B i_C \left( \Lambda_0 i_E - \Lambda_4 o_E \right) + \left( i_A i_B o_C + \left( o_A + i_B o_C \right) \left( -\Lambda_4 i_E + \Lambda_3 o_E \right) \right) + \left( o_A o_B i_C + \left( o_A + i_B o_C \right) \left( \Lambda_2 i_E - \Lambda_6 o_E \right) + o_A o_B o_C \left( -\Lambda_3 i_E + \Lambda_7 o_E \right) \right), \]  \hspace{1cm} (18)

to obtain the set of NP equations:

\[ \Omega_0 = \bar{\Lambda} \Lambda_0 - \Delta \Lambda_4 + \left( \frac{3}{4} \right) \Lambda_9 + 3 \rho \Lambda_1 + \left( 2 \varepsilon + \rho \right) \Lambda_4 - 3 \kappa \Lambda_5, \]

\[ \Omega_1 = \bar{\Lambda} \Lambda_1 - \Delta \Lambda_5 - \lambda \Lambda_0 + \left( \frac{3}{4} \right) \Lambda_9 + 3 \rho \Lambda_1 + \left( 2 \varepsilon + \rho \right) \Lambda_4 - 3 \kappa \Lambda_5, \]

\[ \Omega_2 = \bar{\Lambda} \Lambda_2 - \Delta \Lambda_6 - 2 \lambda \Lambda_1 + \pi \Lambda_2 + \rho \Lambda_3 + 2 \pi \Lambda_5 + \left( \rho - 2 \varepsilon \right) \Lambda_6 - \kappa \Lambda_7, \]

\[ \Omega_3 = \bar{\Lambda} \Lambda_3 - \Delta \Lambda_7 - 3 \lambda \Lambda_2 + \left( 2 \pi + \pi \right) \Lambda_3 + 3 \pi \Lambda_6 + \left( \rho - 4 \varepsilon \right) \Lambda_7, \]  \hspace{1cm} (19)

\[ \Omega_4 = \Delta \Lambda_0 - \delta \Lambda_4 + \left( \mu - 4 \gamma \right) \Lambda_0 + 3 \tau \Lambda_1 + \left( 2 \beta + \tau \right) \Lambda_4 - 3 \sigma \Lambda_5, \]

\[ \Omega_5 = \Delta \Lambda_1 - \delta \Lambda_5 - \nu \Lambda_0 + \left( \mu - 2 \gamma \right) \Lambda_1 + 2 \tau \Lambda_2 + \mu \Lambda_4 + \tau \Lambda_5 - 2 \sigma \Lambda_6, \]
\[
\Omega_6 = \Delta \Lambda_2 - \delta \Lambda_6 - 2v \Lambda_1 + \mu \Lambda_2 + \tau \Lambda_3 + 2\mu \Lambda_5 + (\tau - 2\beta) \Lambda_6 - \sigma \Lambda_7 ,
\]
\[
\Omega_7 = \Delta \Lambda_3 - \delta \Lambda_7 - 3v \Lambda_2 + (2\gamma + \mu) \Lambda_3 + 3\mu \Lambda_6 + (\tau - 4\beta) \Lambda_7 ,
\]

hence (19) implies (15) for \( \Lambda_2 = -\Lambda_5 = \frac{q}{r} \), \( \Lambda_r = 0 \), \( r \neq 2,5 \), that is:
\[
T_{ABC} = \frac{2}{3} \left[ (o_A o_B o_C + (o_A * o_B) o_C) \mu - (\mu o_B o_C) o_A \right] ,
\]

is a generator of the Lanczos spinor (16) for arbitrary spacetimes of Petrov types O, N, and III, in the canonical null tetrad.

Let’s remember that for type D vacuum geometries [3, 15]:
\[
\kappa = \sigma = \lambda = v = 0, \quad \psi_2 \neq 0, \quad \psi_r = 0, \quad r \neq 2,
\]

\[
D \psi_2 = 3\rho \psi_2 , \quad \Delta \psi_2 = -3\mu \psi_2 , \quad \delta \psi_2 = 3\tau \psi_2 , \quad \delta \psi_2 = -3\pi \psi_2 ,
\]

then (13) is consequence from (19) for the values \( \Lambda_2 = -\frac{3}{2} \Lambda_5 = \frac{3}{5} \psi_2^{-2/3} \), therefore:
\[
T_{ABC} = \frac{1}{5} \psi_2^{-2/3} \left[ 3(o_A o_B o_C + (o_A * o_B) o_C) \mu - 2(\mu o_B o_C) o_A \right] ,
\]

is a potential for the Lanczos spinor (14).

The construction of \( L_{ABCD} \) for arbitrary 4-spaces of Petrov types I, II, and D, is an open problem, and we consider that the equations (19) are important in such research.

References


Thermodynamics of Dipolar Hard Sphere System

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Abstract

The thermodynamic properties of real physical systems are greatly influenced by the inter particle interactions. Recent experimental progress in trapping and cooling of molecular gases creates great interest in the study of gases with dominant dipole-dipole interactions with electric or magnetic dipole moments. In this paper we use mean field method to find out the non ideal equation of state and thermodynamic properties of a dipolar system.

Indexing terms/Keywords: Equation of state, Polar systems, Mean field Theory

Subject Classification

1. Introduction

In statistical mechanics, the study of real systems with interactions are always an interesting research topic. Real systems are usually modelled by interaction potential models of different types [1,2,3,4,5]. The use of Mayer cluster expansion was one major way to study interacting systems [1]. The high density equation of state and condensation of gases with Lennard-Jones potential was studied recently by Ushcats [6,7] using Mayer cluster expansion with a new generating function. The thermodynamic properties and equation of state of non ideal system has got great importance at high densities, where the system will show the phase transition [1, 2, 3, 4, 5].

The van der Waals model [8] was the first known example of an interacting system derived phenomenologically. This model explains the existence of molecular structure, interactions between particles and provided an explanation for phase transition, which can be derived by using mean field methods [5] or by using cluster expansion [1,2,3,4]. In mean field approximation an interacting system is approximated by a non interacting system in a self-consistent external field. In another way an approximate free energy is expressed in terms of an unknown parameter, and the free energy is then minimized with respect to that parameter to study the phase transition. Mean field method is applicable to interacting many particle systems such as fluids, magnets, binary alloys etc. [5, 9] to study the thermodynamic properties and phase transition. For non polar molecules the mutual interaction potential like Lennard- Jones, normally arises due to the orbital charge cloud fluctuations and due to the hard core repulsion of the molecules. When the particles possess permanent dipole moments of electric or magnetic nature as in polar gases, then the dipole-dipole interactions will be the dominating factor which effects the thermodynamic properties of the system and such a system can be treated as an interacting system. The long range and anisotropic character of dipole dipole interactions makes dipolar systems unique. These forces can be partially repulsive and partially attractive and this makes the dipole dipole interaction have very important consequences for the scattering properties of the particles in ultra-cold gas [10]. The increased level of experimental control, together with specific physical properties of dipole-dipole interactions, provide a unique possibility to find new physical phenomena and practical applications [10]. These unique properties of dipolar systems are utilised in the production of Bose Einstein Condensate of polar molecules at low temperatures [10].

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\(^1\) Under FDP from Govt. Brennen College, Thalassery, Kannur, Kerala.
Potential energy for a dipolar system

Consider a system of identical molecules on a lattice with permanent electric dipole moment in the absence of any external field. The electric field due to the first dipole at a distance \( r_{12} \) is given by

\[
\vec{E}_1 = \frac{1}{4\pi\varepsilon_0} \frac{3(r_{12}\vec{p}_1)(r_{12}-\vec{r}_1)}{r_{12}^3}
\]  

(1)

In the presence of another dipole at a distance \( r_{12} \) with dipole moment \( \vec{p}_2 \), the interaction energy is given by

\[
U_{12} = -\frac{1}{4\pi\varepsilon_0} \frac{3(r_{12}\vec{p}_1)(r_{12}\vec{p}_2)-\vec{r}_1\vec{p}_2}{r_{12}^3}
\]  

(2)

The potential energy of the molecule 1 with all other molecules in the system \( \epsilon_1 \) can be calculated using the mean field approximation by taking average over the orientations of \( j \)th dipole molecule with dipole moment \( \vec{p}_j \), this is taken as average dipole moment \( \langle \vec{p} \rangle \) [9], then

\[
\epsilon_1 = -\vec{p}_1 \cdot \sum_j \left( \frac{3(r_{12}\langle\vec{p}\rangle)(r_{12}-\vec{r}_1)}{4\pi\varepsilon_0 r_{1j}^3} \right)
\]  

(3)

This equation can be written as

\[
\epsilon_1 = -\vec{p}_1 \cdot \vec{E}_1
\]  

(4)

where \( \vec{E}_1 \) is the local field given by

\[
\vec{E}_1 = \sum_j \left( \frac{3(r_{1j}\langle\vec{p}\rangle)r_{1j}-\vec{r}_1}{4\pi\varepsilon_0 r_{1j}^3} \right) = \frac{a}{4\pi\varepsilon_0} \vec{P}_e
\]  

(5)

where \( a \) is a dimensionless term coming from the sample shape, \( \vec{P}_e = \rho \langle \vec{p} \rangle \) is the polarization, and \( \rho = \frac{N}{V} \) is the number density of particles in the system. Since all the dipoles are of equal dipole moment \( p \)

\[
\epsilon_1 = -\vec{p}_1 \cdot \vec{E}_1 = -c\rho p \vec{P}_e \cos\theta
\]  

(6)

where \( c = \frac{a}{4\pi\varepsilon_0 \rho} = \frac{a}{\rho} \) with \( \alpha = \frac{a}{4\pi\varepsilon_0} \) and \( \theta \) is the angle between \( \vec{p}_1 \) and \( \vec{P}_e \). This single particle potential correctly predict the torque acting on the molecule 1 due to all other molecules, but this value over counts the mean value by a factor of 2. Then the suitable single particle potential can be obtained as [9]

\[
u_1 = \epsilon_1 - \frac{1}{2}(\epsilon_1)
\]  

(7)

In this case it can be shown that[9]

\[
u_1 = -c\rho p \vec{P}_e \cos\theta + \frac{1}{2}c\rho^2 \vec{P}_e^2
\]  

(8)

This equation gives the correct average energy \( U = N(u_1) \) with out taking the criteria of over counting of pair potential. Then total interaction energy of the system is

\[
U = -Nc\rho p \vec{P}_e \cos\theta + \frac{1}{2}Nc\rho^2 \vec{P}_e^2
\]  

(9)

So the total energy is
\[ E = \sum_{i=1}^{2N} \frac{p_i^2}{2m} - NcP_e \cos \theta + \frac{1}{2} NcP_e^2 \] \hspace{1cm} (10)

**Calculation of Number of micro states**

The hard core nature of interacting dipoles prevents two dipoles come closer than the diameter of the dipole molecule \((d = 2\sigma)\). If the system contains \(N\) particles, the difference between actual physical volume \((V)\) and the excluded volume for dipoles gives the corrected volume \((V')\).

\[ V' = V - Nb' \] \hspace{1cm} (11)

where \(b' = \frac{2\pi d^3}{3}\).

The total number of micro states \((\Omega)\) is given by [1, 2, 3, 4, 5]

\[ \Omega = \frac{\text{Total phase space volume}}{Nh^{3N}} \] \hspace{1cm} (12)

\[ \Omega = \left( \frac{V - Nb'}{Nh^{3N}} \right)^N V_p \] \hspace{1cm} (13)

where \(V_p\) is the volume of \(3N\) dimensional momentum sphere.

\[ V_p = \frac{\pi^N 3N}{(2N)!} \] \hspace{1cm} (14)

Using the equation for total energy of dipolar system, the radius of hyper sphere is

\[ R = \sqrt{2m \left[ E - \left( -NcP_e \cos \theta + \frac{1}{2} NcP_e^2 \right) \right]} \] \hspace{1cm} (15)

Then the total number of micro states can be calculated as

\[ \Omega = \] \hspace{1cm} (16)

By Boltzmann’s equation, statistical entropy \(S\) is given by

\[ S = k \ln \Omega \] \hspace{1cm} (17)

Substituting \(\Omega\)

\[ S = \frac{5}{2} Nk + Nk \ln \left( \frac{V - Nb'}{N} \right) + Nk \ln \left( \frac{4\pi m}{3Nh^3} \right) \left( E + NcP_e \cos \theta - \frac{1}{2} NcP_e^2 \right) \] \hspace{1cm} (18)

Knowing the value of entropy and using the first law of thermodynamics, the thermodynamic properties can be calculated. We have,

\[ TdS = dE + PdV - \mu dN \] \hspace{1cm} (19)

where \(T\) is the absolute temperature, \(P\) is the pressure and \(\mu\) is the chemical potential.

The equation of state can be obtained from
\( \left( \frac{\partial S}{\partial V} \right)_{E,N} = \frac{P}{T} \)  

(20)

\[ P = \frac{Nk}{V-Nb'} - \frac{3}{2} Nk \left[ \frac{aP_e^2}{2} \left( \frac{1}{E - \frac{1}{2} NcP_e^2 + NcppP_e \cos \theta} \right) \right] \]  

(21)

The value of \( E \) can be calculated from

\[ \left( \frac{\partial S}{\partial E} \right)_{N,V} = \frac{1}{T} \]  

(22)

\[ E = \frac{3}{2} NkT + \left( \frac{1}{2} NcP_e^2 - NcppP_e \cos \theta \right) \]  

(23)

Substituting the value of \( E \), the equation of state is obtained from Eq.(21) as

\[ (P + \frac{aP_e^2}{2})(V - Nb') = NkT \]  

(24)

If total polarization is represented in terms of number density of particles, this non ideal equation of state takes the form similar to the van der Waals equation of state.

**Conclusions**

Finding the equation of state and thermodynamics of a real physical system is an important area in statistical mechanics. Here we discussed a system of dipolar particles with permanent electric dipole-dipole interaction, and make use of the mean field theory to derive the non ideal equation of state and thermodynamics. The equation of state takes the form of the van der Waals equation when the polarization is taken as a function of number density.

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**REFERENCES**


Multiply Charged Ions and Their Effective Applications

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Abstract

The creation of high-power lasers has opened a new era in the development of basic research and cutting-edge technologies in various fields of practical application. All this is, first of all, due to the unique properties of laser sources of high-power coherent radiation. They include: a) high monochromaticity (i.e. a small width of the emission line), which offers new opportunities in high-resolution spectroscopy; b) high spatial and temporal coherence (i.e. the occurrence of light oscillations in a coordinated manner, resulting thereby in a distinct interference pattern), which gives a strong impetus to the development of holography and optical information processing methods; c) a relatively high specific energy that can be emitted by the laser, d) a possibility of varying the length of time during which the energy stored in the laser can be emitted in a wide range of durations: from continuous to femtoseconds; e) a possibility of variations in the temporal structure of radiation from tens of Hz up to tens of GHz; and f) a small divergence, which enables tight focusing. Due to these properties, the laser power density, which can affect the substance, reaches a giant value on the order of $10^{20}$ W/cm$^2$. Consequently, it is possible to expose a substance to radiation whose power density exceeds all known today values characterizing natural and artificial sources. This fantastic opportunity has been thoroughly investigated in the recent decades by scientists from different countries. Clearly, by gradually increasing the laser energy and reducing the length of time during which that energy is emitted, it is possible to observe several stages of an interaction like this.
Thus, we first observe a gradual increase in temperature, which will result in heating of almost any substance up to the melting temperature. Then, a further increase in the rate of energy input into the material leads to such a rapid heating that an intensive evaporation starts, bypassing the liquid phase. Under these interaction conditions, one can observe a phenomenon, which seems surprising at first glance: with increasing power density the amount of the evaporated mass of the matter remains virtually unchanged. The explanation of this phenomenon is simple enough. It consists in the fact that as a result of intense evaporation, the material's vapor begins to screen the irradiated surface. Therefore, a significant portion of the laser energy no longer reaches the surface and is absorbed in the vapor produced by laser radiation. In this case, with increasing flux density of the laser energy the vapor temperature should increase, which will lead to the formation of plasma, i.e., ionization of the evaporated material and creation of a plasma screen, preventing a further input of energy into matter. This fact is not surprising and, moreover, extremely high vapor temperatures, up to strong ionization of evaporated material atoms, can be achieved. The temperatures reached due to laser irradiation were so high that scientists had a desire to try to realize the fusion of light nuclei, i.e., to implement a fusion reaction on the scale of a pinhead.

The idea of laser fusion, associated with the ability to create conditions for thermonuclear reactions in the area of laser radiation focusing on a solid target, gave birth to a new area of research, i.e., physics of the interaction of intense laser pulses with matter, whereas the plasma obtained by this method was called “laser plasma”. This

Figure 1. Scheme of a laser-plasma ion source: 1 – laser, 2 – focusing lens, 3 – target, 4 – laser plasma, 5 – ion beam having a maximum charge and maximum energy.
new direction has progressed dramatically for the last 40 years due to the rapid development of laser physics and engineering. Long-term efforts on the experimental and theoretical study of the properties and characteristics of laser plasma have extended the range of effective applications of laser plasma, originally associated only with laser thermonuclear fusion.

Instead of laser radiation one can also use high-energy particle beams, which provides a significantly more efficient transmission of the deuterium-tritium fuel energy. A beam of heavy multiply charged ions seems the most promising in this case, because particles with a high charge can be easily accelerated to high energies. Besides, it is easier to obtain higher current values, since the greater the mass, the smaller the influence of the repulsion of ions in the beam due to a space charge. In addition, the beams of heavy multiply charged ions will transfer energy to a target with maximum efficiency. In this case, there arises a question of how to obtain primary beams of heavy multiply charged ions for subsequent acceleration to high energies in accelerator systems. From this perspective, a simple way to implement an inertial controlled thermonuclear reaction is first to obtain the beams of heavy multiply charged ions with the help of high-power laser radiation and then to use these beams for irradiating a deuterium-tritium target in order to reach the fusion temperature. Thus, the methods of obtaining high temperatures and a highly ionized state are of great practical interest.

The main parameters of an-ion source are the charge-state distribution of the ions produced and the intensity of the extracted ion beams. Most of the currently existing types of multiply charged ion sources are based on subsequent electron-impact ionization. By 1970s heavy-ion accelerators had mainly relied on the use of an-ion source based on a reflective (Penning) discharge with oscillating electrons. Ion sources like these exhibited a theoretical limit of charged particles and the intensity of extracted beams, which is determined by the temperature, density and lifetime of the plasma. The electron-beam method of multiply charge ion production was proposed by E.D. Donets in 1967. This ion source, later called an electron-beam ion source (EBIS), was conceived as a pulsed source to produce multiply charged ions for high-energy ion accelerators. To increase the charge of the ion produced by an EBIS, the energy of ionizing electrons should be equal to 100 – 200 keV, and the retention time of the ions should amount to tens of seconds or even minutes. The EBIS uses a linear electron accelerator operating in the continuous mode. Ion sources with a short electron beam having a length of less than 10 cm formed a separate line of research and were called an electron-beam ion trap (EBIT). During the 1970s and 1980s the EBIS’s were used to produce record-high charge states of heavy ions. Using a KRION-2 cryogenic electron-beam ionizer, scientists at the Joint Institute for Nuclear Research (JINR) (Dubna, Russia) managed to produce highly charged xenon ions, while using an EBIT, researches at the Lawrence Livermore National Laboratory (LLNL) (Livermore, USA) produced highly charged uranium ions. The main disadvantages of the EBIS in comparison with other types of sources are ion losses and relatively low intensity (10^{10} s^{-1}) of the produced ions. The most widely used sources of multiply charged ions for accelerators and nuclear physics are electron-
cyclotron resonance (ECR) sources. An ECR source is an open magnetic trap for plasma confinement. Electrons and ions are generated as a result of electron impact ionization. In turn, the electrons resulting from the ionization of neutrals and ions are heated to an energy of several keV by the microwave radio-frequency field, whose frequency is equal to the Larmor frequency of the electron spin in the longitudinal magnetic field of the trap.

Increasing the degree of ionization in the ion source is the result of successive ionization during the holding period of the ions. To date, all large accelerator centers in the world are equipped with such ion sources. However, modern requirements to the sources significantly exceed their capabilities. The first step is to increase the ion beam current because ESR sources are promising for continuous ion accelerators due to their ability to generate rather intense (up to $10^{13} \text{s}^{-1}$) beams of medium and heavy ions in continuous mode.

In contrast, a laser-plasma generator of multiply charged ions produces a large number of heavy ions in the mode of short periodic pulses, which is of interest for ion accelerators operating in pulsed mode. The source of this type is also promising for research in the field of heavy-ion fusion. The principle idea of a laser-plasma source of multiply charged ions was proposed 45 years ago together with author of the book by researchers at the Moscow Engineering Physics Institute (MEPhI). The laser-plasma generator is based on the physical phenomenon of generation of highly ionized states of atoms under irradiation of the surface a solid target by a high-power, focused laser pulse [1]. When expanding into a vacuum, high-temperature laser plasma produces a powerful stream of charged particles. The advantages of a laser-plasma source as compared to other types of ion-pulse generators include:

- ability to generate multiply charged ions of almost any elements of the periodic table, and
- the ability to generate an intense, short (1 – 100 µs) ion pulse with a record-high brightness.

The main difference of the laser plasma from other high-temperature plasma objects is a high energy density in matter, caused by the ability of lasers to concentrate in a short time the energy in small volumes of material ($10^6 \text{ cm}^{-3}$). Changing the power and wavelength of heating radiation allows one to control the temperature and the laser plasma density. Irradiation of a target surface by focused laser radiation with a power density $>10^8$ W/cm² produces a plasma plume with a large temperature and density. Depending on the laser radiation parameters, the electron temperature in the plume can be as high as $T_e = 2.10 \text{ keV}$ at an electron density of $10^{19} – 10^{21} \text{ cm}^{-3}$. This allows one to produce highly charged states of ions in the laser plasma. Such characteristics of the ion component of the laser plasma as highly charged states, intensity and type of angular distribution are exceptionally favorable for its use as a source of multiply charged ions for accelerators. The first laser-plasma generator for an accelerator complex was constructed thirty years ago (joint work of MEPhI and JINR researchers). Requirements imposed by accelerators to ion sources (pulse repetition rate, up to 10 Hz; stability of the output parameters of the ion beam, ± 10%; and time of continuous operation) set strict limits as to the choice of the
laser type and its maximum achievable energy. Due to the development of laser technology in the last 30 years, transverse discharge pumped CO$_2$ lasers seem most attractive for the use in laser-plasma generators. The output energy of these lasers can vary from 1 to 1000 J at laser pulse durations from 0.01 µs to 1 µs and a pulse repetition rate up to 10 Hz. Using CO$_2$ lasers to generate multiply charged ions from laser plasma, due to their high level of technical development, relative ease and low cost even in the configuration of a low-frequency repetitively pulsed facility with a long running time, is currently very promising. An increase in the repetition rate of high-power and short laser pulses up to 30 – 50 kHz will significantly increase the yield of multiply charged ions and dramatically enhance the efficiency of laser-plasma generators.

Thus, evaporation of the material and heating of the vapor lead to a plasma state, i.e., when vapor is heated, electrons are detached from atoms due to a temperature rise. In this case, the higher the temperature, the more electrons are ‘torn away’ from an atom. Therefore, an ionized vapor, i.e., a plasma, consists of electrons and ions. If we assume that the temperature of the electrons and ions is the same, and since the electrons are much lighter than the ions, they travel much faster. Due to such a high velocity, the electrons in the process of the gas-dynamic expansion will be the first to fly out of the plasma region. Then, at the forefront of expanding plasma there occurs separation of the negative charge of the emitted electrons and the positive charge of the ions. In this case, due to the Coulomb interaction, the electrons pull the ions. This process will lead to the separation of electrons and ions in space and time (quenching effect), which interferes with the recombination of electrons and ions in a laser plasma. Therefore, a directional flow of highly charged ions is produced in the form of a beam that propagates in a direction normal to the target surface. For ions with a maximum charge and energy, the angle of their departure decreases, and one can observe the effect of self-focusing of ions, depending on the charge multiplicity. In this case, the interaction of a focused laser beam with a high energy flux density gives us a very simple and effective source of multiply charged ions without the need for any pulling or focusing fields.

Fig. 1 shows a scheme of a laser-plasma source. In this laser-plasma source of ions, the ionization degree is controlled by the power density of laser radiation and can reach a few dozen; this means that it is possible to completely ionize a significant part of the elements of the periodic table. It should be noted that prior to the advent of lasers it was practically impossible to achieve the degree of ionization $Z>10$ and thus, for example, to measure the bonding energy of the electrons in the atom. We emphasize that in this case new practical and promising applications, rather than purely fundamental results, proved to be important.

A laser-plasma source of ions and nuclei is promising for charged particle accelerators. In January 1976, MEPhI and JINR scientists realized for the first time in the world the acceleration of carbon nuclei from the laser-plasma source (Fig. 2). Carbon nuclei from the laser-plasma source were introduced into a linear accelerator and accelerated in the synchrotron channel to energy of 50 GeV. If previously the accelerator accelerated singly
charged protons, the use of multiply charged ions made immediately increased the energy of accelerated particles by $Z$ times. This made it possible to make the next step in obtaining relativistic beams of complex nuclei. In recent years, such work has been carried out at CERN (Switzerland) to obtain multiply charged ions of heavy atoms with $Z>50$ by using a laser-plasma source of ions.

![Figure 2](image.png)

**Figure 2.** Scheme of the acceleration of carbon nuclei at the proton synchrotron using a laser-plasma source of carbon nuclei $C^6+$: 1 – laser, 2 – lens, 3 – graphite target, 4 – linear accelerator, 5 – synchrotron, 6 – output beam.

Nowadays, laser plasma finds numerous applications in various fields of fundamental physics: X-ray spectral analysis of multiply charged ions, high energy density physics and physics of shock waves, modeling of space-physical and high-temperature processes, X-ray lithography, etc. In recent decades, ion sources have been intensively designed and developed. An incentive to create them stems from the need of heavy-ion accelerators. The ion source is the first element of an accelerating complex, which determines the structural characteristics, parameters, efficiency and capabilities of the accelerator. Generation of high-current beams of multiply charged ions is one of the most promising areas of research, which finds wide application in science and technology. As an example of employment of such beams, we can single out the following:

- a source of multiply charged ions of heavy elements in the fore-injectors of particle accelerators;
- a source of cluster ions and molecules;
- a source of beams of highly ionized atoms to measure the interaction cross sections in such field of atomic physics as nuclear fusion, ionosphere physics, astrophysics and investigation of the laser plasma;
– production of uniform films to form the fine structure of multilayer X-ray mirrors and diamond films;

– radiation material science, ion implantation to alloy semiconductors or change the surface properties of materials; and

– formation of ion beams with a specific charge state in order to create a gain medium for the X-ray lasers.

Recent years have seen a significantly growing interest in a wide practical use of sources of multiply charged heavy ions. Thus, in Dubna (JINR) scientists have developed a unique technology for producing filters. In a polymer film a passing heavy ion leaves a channel having large radiation damage, and complex molecules are broken down into smaller parts, i.e., radicals. For this reason, the region of the track (channel) becomes sensitive to chemical reactions. After etching the polymer film exposed to heavy ions, through channels are formed. The diameter of these channels depends on the temperature and etching time, and can range from five nanometers to tens of microns. Such channels can be used in biology and medicine for separation of different types of viruses and bacteria (having dimensions greater than 0.2 µm), and the protein molecules (enzymes); in addition, they can be used in semiconductor technology and for water filtration.

Heavy-ion beams are quite promising for radiotherapy, in particular for the treatment of cancers. The use of laser-plasma beams of heavy ions is much more effective in comparison with the use of large and expensive installations, because they make possible the radiotherapy of limited areas of the human body due to the large ion charge. Heavy ion sources are also needed for the synthesis of transuranic chemical elements, lying on the so-called ‘islets’ of stability, which are predicted in the region Z = 114 and Z = 126.

No less interesting and practically important application of laser-plasma ion sources is ion implantation of metals. It has been shown experimentally that the bombardment of the surface of metals by ions can significantly change their physical properties. The reason for this is, firstly, the effect of the introduction of these or other ions, that is, the change of the elemental composition by doping, and secondly, the change in the structure of the surface layers. Such methods have been developed since the 1970s; they have shown that ion implantation can significantly alter the physical properties of metals, including corrosion resistance, surface friction, wear resistance, etc. It should be emphasized that the laser-plasma implanter for modification of metal surfaces is attractive due to the fact that it has a small size and makes it very easy to use this or that type of ions and to obtain multi-element ion beams of required stoichiometric composition. Besides, one can easily obtain a pulse current of the order of an-ampere and, using a standard frequency laser, have reasonable time values to ensure the required irradiation dose.
The interaction of laser radiation with matter is another very important and promising sphere of analytical research, whose aim is to determine the elemental composition of the material irradiated by the laser. This physical prerequisite of this phenomenon were the following experimental facts: the possibility of evaporation of any material regardless of its composition, nature and physicochemical properties, i.e., laser radiation at appropriate energy and power parameters can evaporate metals, semiconductors, textiles, dielectrics, ceramics, biological object (living tissue, blood), etc. And, as mentioned previously, due to the plasma shielding an almost constant quantity of substance (about one microgram) is evaporated. The next important factor is that the evaporated material is almost completely ionized in the same laser beam, and the ions are formed into a beam directed along the normal to the laser-irradiated targets. Thus, a laser-plasma ion source also allows registration and separation of particles in electric and magnetic fields.

![Figure 3](image_url)

**Figure 3.** Scheme of a time-of-flight mass spectrometer with a laser-plasma ion source: 1 – laser, 2 – irradiated target, 3 – electrostatic analyzer, 4 – drift length, 5 – registration system of ions, 6 – oscilloscope.

Fig. 3 shows the scheme of a time-of-flight mass analyzer using a laser-plasma ion source. The simplest scheme involves a combination of laser-plasma ion source with an electrostatic analyzer and time-of-flight mass separation. Fig. 3 shows the principle of operation of the laser device for express elemental analysis. Radiation from the laser is focused on a target, the elemental composition of which we wish to identify. Upon arrival of the laser pulse, a part of the target is vaporized and ionized. The main portion of the ions is formed into an ion beam which is directed along the normal to the surface of the target. In this case, the ion beam corresponds to the target composition. The electrostatic analyzer identifies the ion beam, ideally with a single energy value. Then, this monochromatic beam of ions, formed from elements with different masses, will be separated in time, i.e.,
the lightest ions will first reach the registration system. From the registration system the electrical signal is fed to an oscilloscope where a certain maximum weight of a chemical element corresponds to each maximum. This time-of-flight mass spectrometer with a laser-plasma ion source allows one to analyze in real time a wide class of materials with a sensitivity of $10^{-3} - 10^{-4}$ atomic percent with the mass resolution of $\approx 300$.

Very useful and promising was the use of a laser-plasma ion source in the well-known scheme of a spectrometer with double focusing, which combines an electrostatic analyzer and a mass spectrometer sweeping the magnetic field. In this case, the ion beam from the target being irradiated passes through the electrostatic analyzer, where the beam is monochromatized and then falls into a uniform magnetic field, where, as is known, ions are separated according to their charge-to-mass ratio. Because use is made of singly charged ions, the beam of ions with different masses is swept by the magnetic field and recorded, for example, on a photographic plate. Such a device exhibits high analytical characteristics. The mass resolution reaches the value of up to 5000, which means that it is possible to detect the isotopes of all elements of the periodic table and register all the elements from hydrogen to uranium. This device also makes it possible to detect impurities in the material, when the concentration is about $10^{-5} - 10^{-6}$ at.%.  

A distinguishing feature of the operation of a mass spectrometer with a laser-plasma ion source, except for its versatility and analysis of any substance, consists in the fact that all the elements are registered at simultaneously, and knowing the evaporated mass one can perform an analysis without any standards, if use is made of natural isotope ratios of different elements. These characteristics determine the possible applications of mass spectrometers with laser-plasma ion sources, which include not only the control of impurities in metals and semiconductors, but also opportunities for environmental pollution control in the air and in the soil. Thus, when measuring the composition of wheat grains collected closer than 300 meters from heavily loaded transport highways, lead is found. Besides, in pearl lipsticks mercury is detected. Analysis of the scales of fish caught in the water near untreated sewage into the river, a large set of heavy metals is found.

Using such devices in biology and medicine also undoubtedly holds promise for medicine and forensics. Thus, it is possible to carry out an analysis of the elemental composition of blood using a piece of gauze soaked with blood or a substrate with a drop of blood on it [2]. For example, to forensics, it is important that the content of heavy elements in a person's blood is strictly individual [3]. In analyzing biological tissue elements one can detect drastic changes in the number of different elements such as Ca, Cl, Si, Al, etc., which indicates certain diseases.

One cannot but mention one more very important and interesting application of laser plasma. Because a high degree of ionization can be achieved in laser plasma, at the early stages of the expansion the laser plasma becomes an intense source of soft X-rays that are of bremsstrahlung and recombination nature; therefore, we deal with the radiation arising due to changes in the velocity during the interaction of charged particles and the
recombination of electrons and ions [4]. In this case, the wavelength of the recombination radiation is determined by the degree ionization and can be controlled both by the laser parameters and by using materials with different ionization potentials. Soft X-ray radiation can be focused and thereby beams with high energy characteristics can be generated.

Such a laser-plasma source is very promising for the use in X-ray lithography in the manufacture of semiconductor chips. Due to the small wavelength and small focusing spot size one can significantly improve the resolution of the photomask used in the production of semiconductor chips. In addition, a laser-plasma soft X-ray source enables the creation of a microscope working in the soft X-ray range, i.e., using photons with such a low energy that will not cause genetic mutations and destroy the structure of a living cell, but will allow one to follow the behavior of individual chemical elements.

Another very promising technological application of laser plasma is the production of thin films of complex composition. In this case, use is made of the flows of the plasma produced in the interaction of matter with radiation of a Q-switched laser, i.e., in the mode of high-rate energy input into the matter. Thus the target can be made of different materials determining the desired stoichiometry of the resultant film. In this case, high rates of energy input, as noted above, allow one to preserve the stoichiometric composition of the target and to produce complex compounds on the substrate. The use of frequency lasers makes it possible to deposit materials epitaxially, i.e., in small portions, layer by layer, while maintaining the crystalline structure. In addition to producing complex semiconductor compounds, this technology has been very useful in creating high-temperature multicomponent superconductor compounds.

This technology is characterized by the fact that complex compounds in the form of single crystals grow on substrates. We can assume that one of the reasons for this is the concomitant recombination radiation from the laser plasma, which activates electron shells of atoms during crystallization, which stimulates the growth of crystals with more energy-intensive orientations. Experimentally, many laboratories have shown that by vaporizing carbon by laser radiation from a graphite target, it is possible to produce thin diamond-like films and more complex structures in the condensation process under certain conditions.

Note in conclusion that the sphere of possible applications of multiply charged ions produced in the interaction of high-power pulsed and repetitively pulsed laser radiation with matter is expanding every day. The next step is the introduction of high-power repetitively pulsed laser systems with high pulse repetition rates, providing a solution to the problem of a plasma screen and making it possible to deliver much higher average power flows into the matter, and thereby producing more powerful beams of multiply charged ions for their effective use [5].
References


Gravitation - Flat Power Field

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Abstract

A new principle of origin and the nature of the action of gravity forces are proposed. Forces of universal attraction have plane-symmetrical directions. On this basis, it becomes possible to reconsider certain regularities in natural science. The new principle of gravitation will allow to explain physical paradoxes, to improve methods of scientific research and some technological processes.

Keywords: Theory vortex gravitation, cosmology and cosmogony. Celestial mechanics

1. INTRODUCTION

As is known, the founder of the theory of world gravitation I. Newton [1] pointed the source of attraction forces to material bodies.

In 1915, 1916 the year of A. Einstein proposed a general theory of relativity [2]. In this theory, gravitational effects are caused not by force interaction of bodies and fields, but by deformation of space-time itself. Deformation is associated with the presence of mass-energy.

These theories have one general condition - the forces of attraction are created by masses of bodies. On the basis of this condition, the conclusion follows: the forces of gravity act centrally symmetrically. That is, they decrease when moving away from the body in the same way, in all directions.

In the author’s theory of vortex gravitation [3] it is asserted that the forces of attraction act flat-symmetrically with respect to any cosmic object.

The next chapter describes the basic principle of the theory of vortex gravity.

2. THE THEORY OF VORTEX GRAVITATION

The theory of vortex gravity, cosmology and cosmogony is based on the assumption that gravity, all celestial bodies and elementary particles are created by etheric vortices (torsions). The size of bodies (systems of bodies) and corresponding vortices can differ by an infinite value. The largest etheric vortex that a person can observe is the universal whirlwind, the smallest - the atomic whirlwind.

The orbital velocities of the ether in each vortex decrease in the direction from the center to the periphery, according to the inverse square law. In accordance with the Bernoulli principle, the change in orbital velocities causes an inversely proportional change (increase) in pressure in the ether. The pressure gradient creates the forces of vortex gravity and pushes the substance (body) into the zones with the least pressure, that is, in the center of the torsion bar. This pattern operates in the same way in ethereal vortices of any size.

The vortex can rotate only in one plane. Consequently, the decrease in the pressure of the ether occurs in the plane of rotation of the ether. Based on Archimedes' law, all bodies are pushed into the plane in which the least pressure occurs. Therefore, the forces of gravity act plane-symmetrically and it is necessary to abandon the classical model of the central-symmetric action of the forces of gravity.
The ether is an excessively little dense gas that permeates all bodies (substances), except for superdense ones. Therefore, the ether can only push these superdense bodies. These superdense bodies are the nucleons of atoms.

In the theory of vortex gravity, the Navier-Stokes equation for the motion of a viscous fluid (gas) was used to determine the pressure gradient in an ether vortex.

\[
\rho \left[ \frac{\partial}{\partial t} + \vec{v} \cdot \nabla \right] \vec{v} = \nabla P + \eta \Delta \vec{v} \quad (1)
\]

\(\vec{v}\) - velocity vector of the ether,

\(P\) - ether pressure,

\(\eta\) - viscosity.

in cylindrical coordinates, taking into account the radial symmetry \(v_\theta = v_z = 0\), \(v_r = v(r)\), \(P = P(r)\) the equation can be written in the form of a system

\[
\begin{align*}
- \frac{v(r)^2}{r} &= - \frac{1}{\rho} \frac{dP}{dr} \\
\eta \left( \frac{\partial^2 v(r)}{\partial r^2} + \frac{1}{r} \frac{\partial v(r)}{\partial r} - \frac{v(r)}{r^2} \right) &= 0
\end{align*} \quad (2)
\]

After the transformations, an equation is obtained for determining the gravitational forces in the ether vortex:

\[
F = V_n \times \rho \times \frac{v_e^2}{r} \quad (3),
\]

with the following dependence \(v_e = \frac{1}{\sqrt{r}}\) where

\(V_n\) - the volume of nucleons in the body that is in the orbit of a torsion with a radius of \(-r\)

\(\rho = 8.85 \times 10^{-12} \text{ kg / m}^3\) - ether density \([4]\)

\(v_e\) - the speed of the ether in the orbit \(r\)

\(r\) - the radius of the considered orbit of the ether vortex

Let us replace the volume of nucleons in equation (3) by their mass, using the well-known dependence:

\[
V_n = m/\rho_n \quad (4)
\]

where

\(\rho_n = 1017 \text{ kg / m}^3\) - density, constant for all nucleons.

\(m\) - the mass of nucleons in the body

Substituting (4) into (3), we obtain...
\[ F_g = \frac{m \times \rho \times v^2}{r} = 10^{-28} \times m \times \frac{v^2}{r} \] (5)

**Note 1.** With the help of vortex gravity equations (3) and (5), gravitational forces can be calculated that act only in the plane of the vortex (torsion). To determine the attractive forces at any point below, additional studies are presented.

### 3. DETERMINATION OF FORCES OF GRAVITATION IN SPACE

As you know, the planets revolve around the sun in an ellipse with a small eccentricity.

This fact can be explained from the position of vortex gravity. In addition, the elliptical trajectory of the planets will allow us to calculate the gravitational force in a three-dimensional model.

The reason for the appearance of "contraction" of planetary orbits is the inclination of the plane of these orbits to the plane of the solar, gravitational torsion, which is proved by the following conditions.

As is known, the planes of orbital motions of all planets are located with small deviations from each other. Consequently, the planes of the orbits of the planets have an inclination to the plane of the solar gravitational torsion, where the greatest gravitational force acts on each orbit, and they (planets), in their orbital motion, must cross the solar torsion at two points. These points of intersection are the centers of perihelion and aphelion.

In aphelion and perihelion, the force of solar gravity acts on the planets with the largest value in this orbit and, consequently, the orbit of the planet has the maximum curvature. When the planet exits (deflects) from the plane of the solar torsion, the gravitational forces decrease, and the trajectory of the planets "straightens". A similar cycle of variation of gravitational forces and trajectory of motion is repeated for each planet in each revolution around the Sun. The more the trajectory of revolution of the planet deviates from the central plane of the solar torsion, the more the gravitational forces in these areas decrease. Consequently, the orbit must be more "compressed". A constant, cyclic variation of these forces makes the trajectory of the circulation elliptical.

With significant inclinations and high velocities, the satellite’s orbit (meteorite, comet) acquires the trajectory of a hyperbola or parabola. Therefore, the celestial body, once circling the Sun, leaves the gravitational field of the solar torsion forever.

In the theory of vortex gravity \(^{(3)}\) it is proved that the squareness of the planet’s orbit depends on the angle of inclination of the orbital plane of the considered planet to the plane of the gravitational solar torsion. This dependence has the form:

\[ K = \frac{b}{a} = \cos \beta \] (6), where

- **K** - coefficient of compression of the orbit of the celestial body
- **a** - the length of the semimajor axis of the planet’s orbit
- **b** - the length of the minor semiaxis of the planet’s orbit
- **β** - the angle of inclination of the planet’s orbital plane to the gravitational plane of the solar, etheric vortex (Fig. 1).
Fig. 1 Cross section of the solar system.

Os - lateral projection of the orbit of the etheric solar torsion

Op - lateral projection of the planet's orbit

Z - axis of rotation of the torsion bar

O - projection of the line of intersection of the orbit of planets with a gravitational orbit

Calculations [3] found that the forces of vortex gravity decrease as the distance (s) from the plane of the torsion (in the direction of the torsion axis) is inversely proportional to the cube of this removal - $1/s^3$.

In an arbitrary arrangement of the point under study, the force of the vortex gravity is determined (taking into account Equation 3) as:

$$F_{gv} = F_{gn} \cos^3 \beta = V_n \times \rho \times \frac{v^2}{r} \times \cos^3 \beta \quad (7)$$

where

$\cos^3 \beta = Kg$ - the gravitational coefficient

$F_{gv}$ - the force of gravity at an arbitrary point

$F_{gn}$ - gravitational force in the plane of the torsion

The location of the plane of the gravitational torsion in space can be determined by the coordinates of the perihelion and aphelion of all celestial bodies that turn in this plane.
4. PROOF OF PLANE GRAVITATION

In the author's article [3], the calculation of the gravitational forces acting on the planet Mercury and Pluto was made during their location in the orbit at the apex of the small semi-axes. At these points, the orbits of the planet deviate as much as possible from the plane of the solar gravitational torsion. The calculation was made based on the equation of universal gravitation of Newton and the equation of vortex gravitation (equation 7). The results obtained were compared with centrifugal forces at these points.

**Note 1.** Centrifugal forces can be calculated as accurately as possible and they are always equal to gravitational forces. Therefore, centrifugal forces can be used as an indicator of the accuracy of the results in determining the gravitational forces.

The distances and velocities of celestial bodies are taken on the basis of the astronomical calendar [4]

1. Pluto

The length of the semimajor axis of the Pluto orbit \( a = 5906.375 \times 10^6 \) km

The length of the semi-minor axis \( b = 5720.32 \times 10^6 \) km

The gravitational coefficient \( k_g = \frac{b^3}{a^3} = \cos^3 \beta = 0.9084 \)

The distance from the Sun to the summit of the minor semiaxis of Pluto's orbit is \( d = 5907,963 \times 10^6 \) km

The radius of curvature at the apex of the small semiaxis is \( R_b = \frac{a^2}{b} = 6098.48 \times 10^6 \) km

The orbital velocity of Pluto at the apex of the small semiaxis is \( V_b = 4.581 \) km / s

Centrifugal forces at the apex of the small semiaxis on the basis of the above characteristics:

\[ F_c = 0.00344 \, M_p, \text{ where } M_p \text{ is the mass of Pluto} \]

The forces of solar gravity at the same point (according to Newton's classical model)

\[ F_{gn} = 0.00382 \, M_p \] (deviation from centrifugal forces + 11.1%)

The forces of vortex gravity taking into account the gravitational coefficient (equation 7)

\[ F_{gv} = F_{gn} \times K_g = 0.00382 \times 0.9084 = 0.00347 \, M_p \] (discrepancy + 0.87%)

2. Mercury

The length of the semimajor axis of the orbit of Mercury \( a = 57.91 \times 10^6 \) km

The length of the semi-minor axis \( b = 56.67 \times 10^6 \) km

The gravitational coefficient \( k_g = \frac{b^3}{a^3} = \cos^3 \beta = 0.9372 \)

The distance from the Sun to the summit of the minor semiaxis of the orbit of Mercury

\( d = 58,395 \times 10^6 \) km

The radius of curvature at the apex of the small semi-axis is \( R_b = \frac{a^2}{b} = 59,177 \times 10^6 \) km
The orbital velocity of Mercury at the apex of the small semiaxis is \( V_b = 46.4775 \text{ km/s} \)

Centrifugal forces

\[ F_c = 36.503 \text{ Mm}, \text{ where Mm is the mass of Mercury} \]

Gravitational forces:

According to Newton, \( F_{gn} = 39.09 \text{ Mm}, \text{ (discrepancy + 7.1%)} \)

According to the theory of vortex gravity, \( F_{gv} = 39.09 \times 0.9372 \times \text{Mm} = 36.63 \text{ Mm} \text{ (discrepancy + 0.35%)} \)

Obviously, the calculation of the theory of vortex gravity is an order of magnitude more accurate than the classical method and in accuracy correspond to the accuracy of astronomical measurements.

5. CONCLUSION

Recognition of the vortex, disk-like nature of gravity will make it possible to explain many paradoxes in natural science, to develop new research in science and technology. Below are presented an insignificant part of the conclusions of vortex gravity, cosmology and cosmogony.

Only the flat-symmetric action of the forces of gravitation proves the structures of the celestial systems. Planetary systems around any star, satellites around planets, galaxies, all these heavenly systems are flat, disk-like. If the forces of gravity acted in all directions equally (according to Newton’s theory), then these heavenly systems would have a spherical shape. Critics can say that gravitation is the same everywhere on the Earth’s surface. They should answer that any celestial body is located in the center of the cosmic torsion. The dimensions of celestial bodies are several orders of magnitude smaller than the dimensions of the torsion bars. Therefore, in the center of the torsion, lateral eddies of the ether create a pressure gradient in the axial direction almost the same as in the longitudinal one. Consequently, the forces of gravity almost ascend at the poles, as well as at the equator. It should be noted that accurate measurements have determined: at the poles, the actual gravitational force is less than calculated by the Newton equation. In particular, according to Newton’s equation, the force of gravity at the poles of the Earth must be \( F = 9.86 \text{m} \). Based on geodetic gravimetry, the actual gravity is determined by \( F_p = 9.83 \text{m} \). This value is 0.3% less than the calculated value, but at the equator theoretical and experimental results are equal.

The unevenness of the decrease in the forces of gravity in the longitudinal and axial directions explains the origin of the tides.

As is known, the terrestrial equatorial plane has an inclination to the ecliptic plane at an angle of 23.5 degrees. The plane of the earth, etheric torsion is located with a slight deviation from the ecliptic. Consequently, each terrestrial point (p. A, Figure 2) crosses the equator twice a day twice the plane of the vortex rotation of the ether, in which the maximum force of terrestrial gravity acts. Consequently, gravitation at any point of the earth changes its strength twice. This fact causes two times the appearance of tides. The explanation of these tides by the gravitational action of the Moon or the Sun is absurd, since any point of the earth’s surface is drawn only once per day relative to these celestial bodies. But there are tides twice!
Pic.2. Flow chart of tides.

P - lateral projection of the plane of the earth torsion.

O_o is the axis of rotation of the Earth’s torsion bar.

O_e is the axis of Earth’s rotation.

Point A crosses the plane of the earth torsion twice a day.

In the author’s article, 5 calculations of physical work have been made, which must be done in a space flight from Earth to the Moon in two versions. The first is a straight, ordinary path inside the Earth’s gravitational torsion, the route AS in Fig. 3. The second - bypassing the earth torsion, the ABC route.

The physical work expended by the spacecraft bypassing the earth torsion along the ABC route is 26% less than the work spent on the direct route - the route of the AC.
Fig. 3 Scheme of the flight to the moon. T. O - Earth, t. C – Moon

**Note 2.** The aforementioned flat-symmetric action of the forces of gravity can be observed only at a large distance from the center of the torsion, since in the center there are axial vortices of the ether. Therefore, it is impossible to apply equation 7 to determine the forces of gravity on the surface of celestial bodies.

This article offers a very small part of the changes in the scientific understanding of physical phenomena. The theory of vortex gravitation makes it possible to explain many regularities in geophysics, in astronomy, in atomic physics, and in other branches of natural science without contradictions.

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Al-P-Cds/N-Cds/Zn_{1-x}Cd_{x}S Structures for Solar Cells

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Abstract

In this paper we report some properties of thin film photocells prepared on the basis of Al/p-CdS/n-CdS/Zn_{1-x}Cd_{x}S heterojunctions. These heterojunctions were prepared by the method of chemical and electrochemical deposition from solution in a uniform work cycle. The open-circuit photovoltage ($U_{oc}$), short circuit-current density ($I_{sc}$) and efficiency of the Al/p-CdS/n-CdS/Zn_{0.6}Cd_{0.4}S heterojunctions were 650 mV; 35 mA/cm$^2$ and 11%, accordingly. The $I-U$ fill factor was 0.68. The value of $U_{oc}$ increases and $I_{sc}$ decreases by increasing of Zn in Zn_{1-x}Cd_{x}S material.

Keywords: thin film, solar cell, heterojunctions, compounds, potential barrier.

I. INTRODUCTION

II-VI group compound semiconductors such as CdS, ZnSe and CdTe are important because of their photovoltaic, photoelectrochemical, and electroluminescent applications and, thus, they have got much attention. Recently, there have been many efforts to produce nanosized materials, because electrical and optical properties can be varied via chemical control over the size, stoichiometry, and interparticle separation. These materials have been synthesized by various techniques including pyrolysis of organometallic compounds and sol gel synthesis. In recent years, there has been considerable interest of using thin films in solar cells [1-3]. Photoelectrical properties of these heterojunctions have found practical application in phototransistors and in solar cells. However, the physics and technology of heterojunctions have also other prominent aspect - creation, research and practical application of non-ideal heterojunctions. The big set of various effects and phenomena in non-ideal heterojunctions related to various properties of semiconductors on both junction regions of heterocontacts have been observed [4-6]. Perspectivity of practical application of the non-ideal heterojunctions is related first of all to more economic technology of creation of polycrystalline heterostructure in comparison with the monocrystalline. One of directions in studying of the non-ideal heterojunctions is the opportunity of solar cells application on the basis of A$^2$B$^6$ compound multilayer structures. The Al/p-CdS/n-CdS/Zn_{1-x}Cd_{x}S system represents a non-ideal unizotype heterojunction at which difference of Zn_{0.6}Cd_{0.4}S and CdS lattice constants make 4%. Such significant difference of the lattice constants at heterojunction formation creates the high density of discrepancy dislocations on an interface. Torn off connections in dislocations result in occurrence of power levels in the band gap, responsible for capture of the carriers or for them recombination and render essential influence on charge carrying through the impoverished area. Until now, converters based on CdS produced mainly as a heterostructure. Create a p-n junction is difficult because of the receipt of CdS with hole conductivity. The literature contains only a few data concerning single-crystal film-p-n-junction. In this paper we present the results of studies of p-n junction film based on p-CdS, precipitated out of solution.

II. EXPERIMENTAL

Heterojunctions were prepared by a method of deposition from a solution in a uniform work cycle. The solution was stirred and thus local heating was avoided. The deposition solution for A$^2$B$^6$ compounds contained 30 mM CdCl$_2$, 50 mM ZnSO$_4$, 125 mM SeO and 125 mM Na$_2$S$_2$O$_3$. It should be noted that the solution for CdS was Cd-rich has a large Cd or S concentration ratio, as in the usual electro-deposition condition. Cyclic voltammetry is used to study the electrochemical properties of solution containing 0.2 M CdCl$_2$ + 0.2 M H$_2$SO$_3$ + 0.25 M Na$_2$S$_2$O$_3$. All voltammetry curves were scanned first in the cathode direction, and the negative current density
indicates a cathode current. The p-type CdS deposited on aluminum substrate by a method of deposition from a solution, contained Cd and S concentration ratio 1/3.

The films have been investigated by X-ray diffraction and scanning electron microscopy for the structure analysis and morphology study, respectively. Aluminum plate was used as the substrate during the deposition process. Surface photovoltage spectroscopy (SPV), which is a sensitive probe of surface states, was used to show that adsorbed water passivated surface states. Figure 1 shows the X-ray diffraction (XRD) patterns of the p-CdS (a), n-CdS (b), Zn$_{1-x}$Cd$_x$S (c) thin films.

The grain formation is observed as irregular accumulation with the grain sizes completely different from each other (2-5 μm). These observations suggest an incomplete formation step with irregular growth rate of the grains. The scanning electron microscopy (SEM) micrographs of the p-CdS (a), n-CdS (b), Zn$_{1-x}$Cd$_x$S (X=0.4) (c) thin films show in Fig.2.

Fig. 2a shows p-CdS with uniform coverage of the Al substrate without any visible pinholes at the magnification of 60,000× used. This is a good sign as mentioned earlier for the growth of CdS. The estimated sizes of the grains are in the range 208–417 nm. In Fig. 2b, the nature of n-CdS growth is revealed. The crystallites and therefore
the grains tend to grow in an upward direction perpendicular to the substrate, leaving some gaps between them. This can pose serious problems in solar cell fabrication when CdS is deposited directly on the Al. The estimated grain sizes are in the 167–375 nm range. These observed CdS grains actually consist of groups of crystallites that agglomerated together. Zn_{1-x}Cd_xS crystallites can go through these gaps between the grains and tend to deposit on the uncovered (exposed) portions of Al when there is no buffer layer, since this is the path of least resistance. A possible way of preventing this is using a buffer layer (such as p-CdS in this case) or by making the CdS crystallites and grains grow laterally and fatter instead of growing as vertically oriented rods, so that they can close up the gaps when they touch each other. Growing thick CdS layers helps to achieve this but at the same time this increases the light absorption near the surface of CdS and drastically reduces the amount of photons that reach the depletion region for creation of electron-hole pairs due to the position of the depletion region. Zn_{1-x}Cd_xS tends to grow also in upward direction as columns. However, due to the large thickness grown compared to CdS, the grains touch each other towards the surface of the layer and tend to close up the gaps between them so that the micrograph shows no visible pinholes or gaps between the grains as shown in Fig.2c. What is seen therefore are clusters of tightly-packed grains with these clusters of grains touching each other. The grains are also made up of tightly-packed smaller crystallites. The estimated grain sizes (or clusters) in Figure 6c are in the 217–870 nm range.

The thickness of the layers p-CdS, n-CdS and Zn_{1-x}Cd_xS films was monitored by ellipsometric measurements. All layers were deposited on Al substrate serially- first of all p-CdS with thickness of about 150nm, second n-CdS with thickness of about 200nm and Zn_{1-x}Cd_xS with thickness of about 800 nm. Finally ZnO layer was deposited by vacuum evaporation, which is a highly conducting window used as transparent electrode. The films were characterized by spectral, X-ray diffraction and chemical analyses. X-ray diffraction showed that the p-type CdS films were single-phase and had a hexagonal structure.

The experimental measurement of \( \omega(T) \), \( \sigma(T) \) and \( R(T) \) correspond hole conductivity in the temperature range 250-400K. The mobility of holes was \( \mu_p = 6\times7 \text{sm}^2/\text{V.s} \). and the concentration was \( 6\times10^{19} \text{sm}^{-3} \). The p-n junction was formed between p-CdS and n-CdS layers.

Figure 3a,b shows the LogI vs. V graphs under dark conditions for the Al/p-CdS/n-CdS/Zn_{1-x}Cd_xS.
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Fig. 3. The LogI vs. V graphs under dark and light conditions for the Al/p-CdS/n-CdS/Zn_{1-x}Cd_xS solar cell, x=0, 2, 4, 6.

Each of the figures is a combination of LogI-V for both forward and reverse bias conditions. The diode parameters under dark condition (such as barrier height, \( \phi_B \), ideality factor, \( n \), rectification factor, \( R.F. \), and reverse saturation current density, \( J_0 \)) are obtained from these graphs. The Schottky barrier heights estimated for the two device structures were >1.13 eV for Al/p-CdS/n-CdS/Zn_{1-x}Cd_xS devices. These values most likely represent the average values of all the barrier junctions present in the devices. The diode ideality factors obtained were respectively 2.3 and 2.45. The large ideality factor values in excess of 2.00 indicate the possible presence of high series resistance, a contribution from tunnelling and the presence of high concentration of recombination and generation centres in the device structures and these underestimate the potential barrier heights of the devices. The diode rectification factor \( [R.F. = (I_F/I_R)V=1] \) of each solar cell was obtained as the ratio of the forward current, \( I_F \), to the reverse current, \( I_R \), at the maximum bias voltage of 1.0 V. The intercept of the straightline portion of the forward current on the LogI axis is used to calculate the reverse saturation current density of the solar cells using the cell active area of ~0.03 cm\(^2\). The large Schottky barrier heights \( \phi_B >1.10 \) eV and the high rectification factors, \( R.F. >10^4 \) obtained for both solar cell structures indicate how strong the electric field in the depletion region is for effective separation of photo-generated charge carriers. This high field actually imposes high drift velocity on the photo-generated charge carriers, and due to the high quality of the electrodeposited materials, this leads to high short-circuit current densities observed for the devices. Low efficiencies could arise due to existence of shunting paths through pinholes and detrimental defects via recombination.

Curves of voltage-capacitance characteristics (VCC) for the structures which were not undergo to TP have been studied. For the unisotype structures with x=0, 6 the straight line extrapolated up to \( C^2=0 \) cuts from axis of “voltage” a portion equal 0,65 V, but for structures with the same composition it becomes 0,58V. The observed increase in the value of \( U_d \) with decrease x in our measurements can be explained with increase of band gap width in films depending on their percentage composition. Character of VCC in investigated structures strongly depends on the percentage composition of films (Fig.4).

Fig. 4. Volt-capacitance characteristics (VCC) of the p-CdS/n-CdS/Zn_{1-x}Cd_xS heterojunctions,
When a percentage of selenium in Cd_{1-x}Zn_xS solid solutions increases the sharply decrease of divergence between constants of crystals lattices of absorbing and substrate layers causes increase of degree of linearity of curves in $C^2=f(U)$ coordinates. Then a weak dependence of capacitance versus frequency is observed. Note, that capacitance, consequently concentration of surface states are regulated also by regime of TP. After TP at 380°C for $\tau=10$ min degree of sharpness for $C^2=f(U)$ dependence strongly increases and then capacitance of structures almost does not depend on the frequency of reference signal. It shows that in the given case concentration of surface states on hetero-boundary, being responsible for frequency dependent contribution to capacitance decreases.

Under AM1.5 illumination (100 Lux), the p-CdS/n-CdS/Zn_{1-x}Cd_xS photocells generated open circuit voltages of about 550÷650 mV and short circuit current density of about 25÷29 mA/cm$^2$ also had efficiency up to 11 %. On the other hand, discrepancy of constant lattices of contacting materials results in reduction of concentration of states in junction region of the heterojunctions, and also speeds up the degradation process. Consecutive resistance limits the short circuit current, and its dependence on illumination intensity is superlinear. The dependence of an open-circuit voltage on illumination intensity differs from logarithmic. Therefore, the efficiency of the p-CdS/n-CdS/Zn_{1-x}Cd_xS heterojunctions increases by increasing of illumination intensity [4]. The peaks on the photosensitivity spectrum of the p-CdS/n-CdS/Zn_{1-x}Cd_xS heterojunctions have been observed at 0.45-0.49 μm and 0.62-0.65μm. The photo response in long-wave area of a spectrum explains by presence of a high-resistance layer at the edge of near-surface areas of the CdS films (Fig. 5). Peaks correspond to edge of own absorption. Have been investigated the dependence of the spectral distribution nature of a photocurrent on a mode of deposition of the Al-p-CdS/n-CdS/Zn_{1-x}Cd_xS heterojunctions and features of spectral distribution of a current in them depending on a thickness of the CdS films.

**Fig.5.** The photo answer spectrum of the p-CdS/n-CdS/Zn_{1-x}Cd_xS heterojunctions,

X: 1- 0.2, 2- 0.4, 3- 0.6
III. RESULTS AND DISCUSSIONS

Researches show that essential changes occur in p-CdS/n-CdS/ZnCdS heterojunctions during heat treatment. The nature of a change of electric and photoelectric properties of heterojunctions depending on the heat treatment shows, that due to presence acceptor levels in near-surface of the Zn1-x CdS layer there is an expansion of a layer of a volumetric charge. Therefore the capacity of p-n heterojunctions decreases. Increase of the photo response on all spectrums specifies that fact, that due to compensation of donor type natural defects by acceptor levels formed a high resistance layer in a near-surface layer and increases the rectification factor. Absorption of light becomes more effective due to a high-resistance layer, i.e. the usefulness of an absorbed beam and accumulating of carriers by the p-n heterojunctions raises.

Appear nonequilibrium electrons and holes during photoexcitation by quanta from area of own absorption of Zn1-x CdS film. A barrier field in the base area removes electrons and holes are captured near interface on traps and the recombination centers. Presence of such compensating centers with the big concentration actually is one of the basic properties of the considered heterojunction. The barrier field promotes electron accumulation in the spatial charge area; therefore, distribution of a positive charge in Zn1-x CdS considerably changes even at an insignificant level of photoexcitation, which results in growth of the transition capacity. Herewith sharply increases the intensity of the electric field at interface of the heterojunction. The short circuit current is in direct dependence on spatial distribution of electric potential, and this distribution is directly related to electron’s concentration located on traps. At displaying on a sample of any image, its points are illuminated differently that results in various electron concentration, captured on traps and accordingly to a various bend of power zones in the spatial charge area. If displaying to stop, distinction in the electron concentration is kept enough long time that allows using this heterojunction as the device recording the optical information. Reading of this information is possible by scanning a sample with infrared light. Using infrared illuminations also makes it possible to delete the image; herewith a sample must be illuminated with pulses of the long duration with high frequency of following. Then the sample is suitable for repeated storing other image. Processes of record and reading can be considerably carried in time, however long storage is accompanied by a thermal devastation of traps that results in gradual loss of the optical information. Reading the information is possible during several days at storage of a sample at the temperature about 80K. Rise in temperature of storage results in faster thermal hole liberation to a valence band.

The p-CdS/n-CdS/Zn1-x CdS heterojunction can be in two various states. One of them - equilibrium – possesses low sensitivity to the infrared light and allows to receive low value of short-circuit current. Other state - nonequilibrium - is highly sensitive to infrared light and gives considerably high short-circuit current value. Transition from an equilibrium state to nonequilibrium is carried out under illumination of shortwave light due to the effect of capture and the accumulation of nonequilibrium holes on traps in the spatial charge area of Zn1-x CdS film. Time of preservation of the nonequilibrium state in structure is determined by the recombination barrier size and the process of hole emission from the traps, going alongside with accumulation. The emission starts to play a main role in current passage after cancellation of short-wave illumination so releasing of the captured charge causes inverse changes of parameters of a barrier and transition of structure from a nonequilibrium state to equilibrium. Intensity of emission determines rate and speed of this change of barrier parameters, so and short circuit current. Therefore it is obviously important to know, how emission influences on barrier parameters after the termination of photoexcitation by short-wave light. Let’s consider possibility using such system for registrations of the optical image of the different spectral composition. The maximal effect is achieved at 520 nanometers. Short-wave lights are strongly absorbed in a base layer. Therefore the thickness of Zn1-x CdS layer and the diffusion length of charge carriers in this material determine the photoexcited hole concentration in vicinities of the spatial charge area. The spatial charge area is not reached by all photogenerated electrons, which result in reduction of the short-wave stimulation rate. Sharp recession of sensitivity of a sample in the shortwave area of a spectrum is caused by that the generated charge carriers are recombinated in volume of Zn1-x CdS layer, not being in time to reach to the spatial charge area, i.e. there is absorption of light in a superficial layer of Zn1-x CdS. The wane of sensitivity in long-wave area speaks about reduction of gathering
factor of p-CdS/n-CdS/Zn_{1-x}Cd_xS and about presence of the impurity centers in Zn_{1-x}Cd_xS, participating in generations of current carriers. In order to increase of sensitivity it is necessary or to reduce thickness of a base layer, or to create the optical image on the part of thin CdS layer. Values of \( U_d \) determined from VAC and VCC do not coincide. In our opinion it can be explained by no optimum fabrication regime as well as zero correspondence of constants of crystalline lattices of materials in contact. Fabrication of heterojunctions by electrochemical method leads to formation of large member surface states in interface which are related with inhomogeneity of semi crystalline films, but this divergence decreases with increase in values of \( x \). It is assumed that increase in percentage of zinc in composition of films leads, first, to enhancement of potential barrier, and, second, to decrease in dis correspondence between constants of lattices of materials in contact. This in its turn can lead to decrease in concentration of surface states taking part in condition of heterojunction's interface.

CONCLUSION

Thus, the device prepared on the base of p-CdS/n-CdS/Zn_{1-x}Cd_xS heterojunction can operate in all area of the visible spectrum with different sensitivity. As in the given device reading of the image is made by infrared light but not by an electronic beam, and it does not need the vacuum and the high voltage, used for formation of an electronic beam. These heterojunctions were prepared by the method of electrochemical deposition from solution in a uniform work cycle. The open-circuit photovoltage (\( U_{oc} \)), short circuit-current density (\( I_{sc} \)) and efficiency of the Al/p-CdS/n-CdS/Zn_{0.6}Cd_{0.4}S heterojunctions were 650 mV; 35mA/cm\(^2\) and 11%, accordingly.

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Fractal structure of the positive free-air gravity anomalies within the Balkan Peninsula

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Abstract

The investigations of the fractal structure and properties of the different geophysical elements is new and fast developing area of research among the geophysical society. The fractal properties of the earthquake clusters, faults and folds at different scale, even the plutonic bodies and other elements of the positive landforms are the most exploited areas of research. In our caste the special attention is paid to the gravity field (free-air anomalies) as the most expressive element of the surface elevated structures and their influence to the relief. The Balkan Peninsula is well known as the one of the most variable Earth’s surface elevation area in the world. The fractal properties of gravity field in such area could be useful to try to establish formal relationships to the surface elevation, as well as to prove the possibility to get some information about the self-organization and the origin of the mountain landforms in the same area.

Keywords: free-air gravity field, fractal properties, landforms, Balkan Peninsula

Introduction

The research and exploration of the theory of fractals and the fragmentation of different elements of the earth’s surface and interior is larger developed during the last years. The results obtained are frequently used for explanation of the self-similarity and the self-organization of the different elements related to the Earth science. The recent paradigm of the geodynamics accepted the nonlinear behavior in time and space. For example, a lot of publications are related to the fractal properties of the Plate tectonics [1], seismotectonic models of the Balkan Peninsula [2], local morphostructural analysis ([3]; [4]; [5]), the seismicity development of the time series ([6]; [7]; [8]; [9]; [10]; [11]; [12]; [13]; [14], etc. The present study aims to analyze and interpret the probability of fractal structure of positive free-air gravity anomalies within the Balkans. For this purpose, is used data from Global Gravity Model- WGM2012 [15]. The possibility of a positive correlation between the positive gravity field and the distribution of the mountain morphounits within the studied area has also been investigated. This would put a new light on the nature of the tectonic processes in the region and the principles of mountain building in particular. The subject of this study is the mainland of the Balkan Peninsula (43° 00’ 00” N; 23° 00’ 00” E) (Fig.1). The adjacent islands and water areas are not included in the study. The Balkan Peninsula is bordered by the Adriatic Sea on the northwest, to the southwest by the Ionian Sea, by the Aegean Sea and Marmara Sea to the south and southeast, and by the Black Sea to the east and northeast. The northern border of the peninsula starts from the Trieste bay of the Adriatic Sea, tracks the river valleys of the Socha, Idriya and Sava rivers, and reaches the Black Sea along the Danube River. The peninsula from the west to the east has a length of about 1250 km and a width from north to south 930 km. The total area of the Balkan Peninsula amounts to 505,000 km². The topography of the peninsula has a fragmentary character, equally representing the positive and negative landforms. The highest point of the Balkan Peninsula is Musala peak (2,925 m), located within the Rila Mountains (Bulgaria).
Materials and Methods

Fractals – an expression of the fragmentation of the Earth’s elements

The classical example of a fractal object is defined by Mandelbrot [16]. If the length of an object P is related to the measuring unit length l by the formula:

\[ P \sim l^{1-D} \quad (1) \]

then P is a fractal and D is a parameter defined as the fractal dimension. This definition was given by B. Mandelbrot in the early 60-s of the 20-th century. His ideas support the view that many objects in nature cannot be described by simple geometric forms, and linear dimensions, but they have different levels of geometric fragmentation. It is expressed into the irregularities of the different scales (sizes) – from very small to quite big ones. This makes the measuring unit extremely important parameter, because measuring of the length, the surface or the volume of irregular geometric bodies could be obtained so that the measured size could vary hundred to thousand orders. This fact was first determined when measuring the coastal line length of West England and this gave Mandelbrot the idea to define the concept of a fractal. In geology and geophysics is accepted that definition of the different “fractals” as real physical objects is most often connected to fragmentation [17]. This reveals that each measurable object has a length, surface or volume, which depends on the measuring unit and the object’s form (shape) irregularity. The smaller the measuring unit is, the bigger is the total value for the linear (surface, volume) dimension of the object and vice versa. The same is valid for 2D and 3D objects.

The theoretical approach for the linear case and for the 2D and 3D cases was developed by [18; 19]. They focused the attention on the relations between the smallest measuring unit and object’s size in analyzing linear (1D), 2D and 3D objects (Fig.2).
If \( l \) is the measuring unit and with \( m \) we denote the obtained value for \( N \) at each measuring cycle, then the common sum of the lengths \( N \) at level \( m \) according to Turcotte [20] is:

\[
N_m = (1 - p_c) \left( 1 + \frac{n}{m} p_c + \left[ \frac{n}{m} p_c \right]^2 \cdots \left[ \frac{n}{m} p_c \right]^m \right)
\]

(2)

where \( p_c \) denotes the probability for measuring of each length for the corresponding cycle of the measurement.

Using formulas (1) and (2) we obtain the following formulas:

\[
\frac{N_{m+1}}{N_m} = 2^D
\]

(3)

for linear elements, and

\[
\frac{N_{m+1}}{N_m} = (2^2)^D
\]

(4)

for any area elements (surfaces).

Another definition of a fractal dimension is related to the serial number of measurement to each of the measuring units used and the object dimensions. If the number of the concrete measurement with a selected linear unit is bigger than \( r \), then it might be presented by:

\[
N - r^D
\]

(5)

and the fractal is completely determined by \( D \) as its characteristic fractal dimension. Applying this definition for the elements of faulting and faults fragmentation, some authors use this idea to depict formal models of the earth crust fragmentation, which indicates the level of fracturing of the upper earth layers [21]. Same approach was carried out for the fractal properties of the major elements of the Plate tectonics models [1].
The present study methodology based on the correlation number-area is following the algorithm presented and effectively applied in a number of publications [21], [22], [2], [1], [23]:

- Calculation of the number of positive free-air gravity anomalies (N) with corresponding area (in km²) for the graphic.

- Presentation of the results on the graphic – on the X axis in logarithmic scale the areas of the positive free-air gravity anomalies are plotted, and on the Y axis in linear scale the corresponding number are plotted.

- The fractal dimension (D) has been calculated using the data from the graphic and results discussed.

The research of the large structures of the Earth’s crust (plates, subduction zones, ridges, rift zones, etc.) shows clear expressed nonlinearity easily defined as fractals with different dimensions [1].

The analysis of the absolute positive free-air surface gravity anomalies (values above 80 mgal as mostly clear expressed peculiarity) was performed on the basis of GRID data from Global Gravity Model- WGM2012 [15]. The calculation of the areas of the free air gravitational anomalies has been explored using GIS software (GoogleEarthPro) and the corresponding area measurement function from the menu.

**Free-air gravity anomalies- reflection of the Earth’s elevation model and its positive elements**

Free-air gravity anomalies are considered as the best expressed relationship between the low depths gravitational bodies reflecting the gravity influence of the elevated structures (mountains, hills, horsts, etc.) (Fig.3)

By definition the free air anomaly (frequently called Faye's anomaly) at the representative point is:

\[ g_F = g_m - [g_0 - 0.3088(H+h)] = g_m + 0.3088(H+h) - g_0 \]  

Where \( g_F \) is the free-air gravity anomaly, \( g_0 \) is the absolute gravity value at the point where the measured value is \( g_m \). \( H \) is the height above sea level and the \( h \) – is the level difference between the spheroid and the geoid at the same point. The calculated by this way values of the free-air anomalies reflect the gravity field originated from the Earth’s surface elevations above the sea level. That’s why they are considered as the most reflective anomalies related to the earth’s elevated structures.

Figure 3 clearly shows that the positive free-air gravity anomalies in the Balkans have a clear fragmentation of geographical distribution. In practice, this is consistent with the mosaic pattern of topography in the region. The positive gravity field (especially the highest values) marks the highest elevated parts (earth crust blocks) of the peninsula (Fig.3).

The regional analysis shows that there is an absolute correlation between the positive gravity and some smaller mountains (Rila, Pirin, Slavyanka; etc.), partial correlation with the larger mountain morphounits such as the Stara Planina Mountains, the Rhodopes, the Pind, the Dinaric Alps, etc., however, where in the local relief some negative morphostructures (kettles) are clearly expressed. In some other low to medium peripheral mountains (such as Strandzha, Maleshevo, Forebalkan, etc.) gravity has normal or slightly elevated values but not high. Surely, however, with those parts of the peninsula whose altitude exceeds 2000 m, correlation is absolute.
Fig. 3: Correlation between positive Free-Air gravity anomalies (above) and DEM (below) within the Balkan Peninsula

This distribution is determined primarily by the plate tectonic processes creating and shaping the relief within the Balkan Peninsula. The subduction processes (south of the island of Crete and the western edges of the peninsula in the Adriatic Sea), as well as the collision processes at the regional level (intercontinental collision...
between Gondwana (African plate) and Neo Europe (southern edge of Eurasian plate) [24] and at the local level (for example, the collision between the Bulgarian and Moesian continental microplates [24;25] in the Stara Planina Mountains region).

![Main tectonic processes](image)

**Fig.4:** Main tectonic processes (subduction, faulting, earthquakes – circles on the figure) in the Eastern Mediterranean region (GIS data: [26])

### Results and Discussion

The results from the analysis of the fractal geometry of the positive free-air gravity anomalies within the Balkan Peninsula are presented in graphical form in Figure 5.
On the basis of the results from the figures, the following main conclusions can be drawn:

1) The consecutive results in Figure 5 clearly show the fractal structure of the positive free-air gravity field within the Balkan Peninsula. The fractal dimension (D) of 1.29 points to a low degree of fragmentation, that is, the differences between the minimum and maximum values are not so large.

2) There is a spatial overlap of the positive free-air gravity anomalies with the highest elevated crustal blocks within the mountain morphostructures. This positive correlation is a clear sign of the self-organization of the morphotectonic processes operating in the region of the Balkan Peninsula.

3) The positive correlation between the gravitational field and the highest elevated blocks on the one hand and their fragmented geographic spread on the other proves the non-linear nature of the endogenous processes and phenomena acting in the bosom of the Balkans.

The fractal structure of the positive free-air gravity field throws new light on the endogenous earth processes in the Balkan Peninsula. This reflects on the mountain building processes and demonstrates the nonlinearities in these processes. Fractal geometry as a clear sign of self-organization determines the character of morphotectonics in the region. The results obtained can serve as a starting point for a number of correlation studies in the future. This would necessarily contribute to the successful collaboration between different Earth sciences and would improve our understanding of the endogenous processes in the Balkan Peninsula region.
Conclusions

The first steps to study the relationships between the free-air gravity anomalies and the high elevated lands in the Balkan Peninsula are attempted. The results obtained support the initial idea to use and correlate the fractal properties of the free-air gravity anomalies with the positive morphological elements. The calculated fractal dimension shows the nonlinear behavior of these landforms, thus supporting the self-organization and similarity in the genesis and the surface expression of the high lands located in the Balkan Peninsula. The perspective future research is under consideration to discriminate the linear and isometric high mountain landforms with the lowlands using similar methodology and revealing the origin of the investigated morphostructures.

References


