Relativistic effect inside matter. Obtaining a new dispersion formula.

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Research Article

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Content

1. Abstract.

In this study, the dependence of the refraction of light in matter on the energy density of electron clouds was studied. Therefore, one of the goals of this study was to obtain a dispersion formula based on this dependence. Einstein's relativistic formula was taken as the basis for obtaining this formula. After the transformations carried out, a new dispersion formula was obtained from this formula.

According to the new formula, **42** refractive indices of light were determined in **12** transparent substances in three states of aggregation. Comparison of the obtained indicators with the laboratory refractive indices of light showed the high accuracy of the dispersion formula, which amounted to $\pm\mathbf{10^{-6}}\ -\mathbf{10^{-5}}$ in the calculated sections of the **70-90 nm** wavelength ranges. This formula can be applied to the same wide range of transparent substances as the empirical formulas of Hartmann, Cauchy, etc.

The successful application of the new dispersion formula made it possible to apply the analogy method to the energy density of electron clouds. As a result, the formula for the density of electron clouds of transparent substances was obtained. Sample calculations were made using this formula. These calculations showed a high energy density of electron clouds in matter, which amounted to $\mathbf{10^{24}} - \mathbf{10^{25}}$ J/m^3.

Keywords. New dispersion formula, energy density of electron clouds of matter, formula for the density of electron clouds, calculation of refractive indices of light.

2. Methods.

Before proceeding to the study, we give brief information about the currently existing dispersion formulas. These formulas can be divided into two types: physical and empirical formulas. At the same time, the scope of physical formulas is significantly limited. For example, the Lorentz-Lorentz physical formula, which is based on the dependence of the refractive index of light on **the**

density of a substance, is valid only for isotropic media and is not applicable to most transparent substances. Therefore, in practice, empirical dispersion formulas are usually used to calculate the refractive indices of light. These formulas apply to a wide range of transparent substances and give fairly accurate results. For example, the most accurate empirical Hartmann formula determines the refractive indices of light with an accuracy of $\pm 10^{-6} - 10^{-5}$ **for the calculated sections of the wave ranges of several tens of nanometers.**

This study suggests that the propagation velocity $\mathbf{v_\gamma}$ of photons in a transparent substance depends on the energy density of electron clouds: the greater the energy density of electron clouds, the lower the photon velocity and vice versa. At the same time, the greater the energy of photons entering the substance, the more the electron clouds of atoms of the substance are "compacted" by this energy. As a result of this circumstance, electromagnetic waves having different energies propagate at different speeds in the same transparent substance. Thus, there is a relationship between the energy density of electron clouds and the propagation velocity $\mathbf{v_\gamma}$ of photons in matter. To find this dependence, we use the relativistic formula of Einstein:

$$\mathbf{E_{total}} = \frac{\mathbf{m_0\, c^2}}{\sqrt{1-\frac{v^2}{c^2}}} \quad \text{or} \quad \mathbf{E_{total}} = \frac{\mathbf{E_0}}{\sqrt{1-\frac{v^2}{c^2}}} \quad \mathbf{(1\text{-}1)}$$

Where $\mathbf{E_{total}}$ is the total energy of a moving body.

$\mathbf{E_0}$ – energy of a body at rest.

$\mathbf{v}$ is the speed of the body.

Let's transform the formula (1-1) and as a result we get:

$$\mathbf{v = c\sqrt{1 - \frac{{E_0}^2}{E^2_{полн.}}}} \quad \text{or} \quad \mathbf{v = c\sqrt{1 - Q_b^2}} \quad \mathbf{(1\text{-}2)}$$

Where $\mathbf{Q_b}$ is an indicator of the ratio of the energy of a body at rest to the total energy of a moving body, $\mathbf{0 < Q_b} < 1$.

Now let's apply formula (1-2) to the propagation speed of photons in electron clouds of transparent substances.

$$\mathbf{v_\gamma = c\sqrt{1 - Q_e^2}} \quad \textbf{(1-3)}$$

Where $\mathbf{v_\gamma}$ is the speed of propagation of photons in the electron clouds.

$\mathbf{Q_e}$ is a dimensionless indicator of the density of electron clouds of a transparent substance, $\mathbf{0 < Q_e < 1}$.

Let's transform the formula (1-3) and get: $\frac{\mathbf{c}}{\mathbf{v_\gamma}} = \frac{\mathbf{1}}{\sqrt{\mathbf{1-Q_e^2}}}$

In this formula, the expression $\mathbf{c/v_\gamma}$ is the refractive index of light in a substance $\mathbf{n = c/v}$ (where $\mathbf{c}$ is the speed of light in vacuum, $\mathbf{v}$ is the speed of light in matter). From here we get the formula:

$$\mathbf{n = \frac{1}{\sqrt{1-Q_e^2}}} \quad \textbf{(1-4)}$$

Where $\mathbf{n}$ is the refractive index of light in the substance ($\mathbf{n = c/v_\gamma}$).

Let's reveal the value of $\mathbf{Q_e}$ in the formula (1-4):

$$\mathbf{n = \frac{1}{\sqrt{1-(Q_0+\Delta Q_\lambda)^2}}} \quad \textbf{(1-5)}$$

where $\mathbf{Q_0}$ is the dimensionless basic indicator of the energy density of electron clouds.

$\mathbf{\Delta Q_\lambda}$ is a dimensionless indicator of the increase in the energy density of electron clouds.

The $\mathbf{Q_0}$ index is constant (at constant temperature and pressure). The exponent $\mathbf{\Delta Q_\lambda}$ is a variable. It depends on the energy $\mathbf{e}$ of the electromagnetic wave, where $\mathbf{e = h\gamma = h\,c/\lambda}$. From here we get the formula:

$$\mathbf{n = \frac{1}{\sqrt{1-(Q_0+k_\gamma\, e\ )^2}} = \frac{1}{\sqrt{1-(Q_0+k_\gamma h\, c/\lambda\ )^2}}} \quad \textbf{(1-6)}$$

Where $\mathbf{k_\gamma}$ is the coefficient of proportionality, $\mathbf{J^{-1}}$.

$\mathbf{e}$ is the energy of the electromagnetic wave, J.

Replace $\mathbf{k_\gamma\, h\, c}$ with a single coefficient $\mathbf{k_\lambda}$. As a result, we obtain the dispersion formula:

$$\mathbf{n} = \frac{\mathbf{1}}{\sqrt{\mathbf{1}-(\mathbf{Q_0}+\mathbf{k_\lambda}/\boldsymbol{\lambda})^2}} \qquad \textbf{(1-7)}$$

Where $\mathbf{k_\lambda}$ is the coefficient of proportionality, nm.

$\boldsymbol{\lambda}$ – wavelength, nm.

The coefficient $\mathbf{k_\lambda}$ is individual for each substance and depends on the absorption of electromagnetic waves by atoms. It is relatively stable in the visible range of the electromagnetic spectrum. But in the ultraviolet and infrared ranges, the coefficient $\mathbf{k_\lambda}$ can significantly change its value due to changes in the absorption of electromagnetic waves by matter. For this reason, according to f. (1-7), the value of the refractive index **n** can change sharply up to the adoption of anomalous values. This circumstance introduces a limitation on the use of formula (1-7) in these wave ranges.

Let's test the resulting formula. Table 1 shows the laboratory refractive indices of light in the visible range in 12 transparent substances in three states of aggregation. Refractive indices are widely available on the Internet. The sixth section of this article provides literary sources for this information.

Table 1

	$\boldsymbol{\lambda}$ nm	$\mathbf{k_\lambda}$ nm	**Calculated refractive index**	**Laboratory refractive index**	**Divergence**
Krypton	450,4		1,0002752	1,0002752	
	556,4		1,0002724	1,0002724	
$\boldsymbol{Q_0}$ **= 0,0228285**	**565,1**	**0,2827625**	**1,0002722**	**1,0002722**	$\mathbf{10^{-7}}$
	587,3		1,0002718	1,0002719	
	605,8		1,0002715	1,0002716	
	645,8		1,0002708	1,0002711	
	447,3		1,0002752	1,0002753	
Helium	471,5		1,0002745	1,0002745	
	492,3	**0,2804503**	**1,0002739**	**1,0002738**	$\mathbf{10^{-7}}$
$\mathbf{Q_0}$ **= 0,022829**	501,7		1,0002736	1,0002736	
	587,7		1,0002717	1,0002719	
	447,1	**7,197 863**	**1,33942**	**1,33942**	
Water	471,3	7,151 601	1,33795	1,33793	
	486,1	**7,123 309**	**1,33712**	**1,33712**	
$\mathbf{Q_0}$ **= 0,649184**	501,6	7,114 003	1,33637	1,33635	$\mathbf{10^{-6}-10^{-5}}$
	546,1	**7,087 286**	**1,33447**	**1,33447**	
t= 20 °C	577,0	7,097 803	1,33341	1,33338	
	587,6	7,101 769	1,33307	1,33304	

	656,3	**7,124 793**	**1,33115**	**1,33115**	
	670,8	7,129 728	1,33080	1,33080	
	706,5	7,141 879	1,32999	1,33002	
Trimethylpentane	**486,1**	**4,960 651**	**1,39639**	**1,39639**	
	501,6	4,877 871	1,39547	1,39544	
Q_0 = 0,687760	**546,1**	**4,640 212**	**1,39316**	**1,39316**	**10^{-5}**
t= 20 °C	589,3	4,497 612	1,39153	1,39145	
	656,3	**4,276 451**	**1,38945**	**1,38945**	
Methyleylohexan	**486,1**	**4,556 701**	**1,42847**	**1,42847**	
	501,6	4,460 476	1,42751	1,42744	
Q_0 = 0,704 742	**546,1**	**4,184 218**	**1,42497**	**1,42497**	**10^{-5}**
t= 20 °C	589,3	4,009 663	1,42320	1,42312	
	656,3	**3,738 941**	**1,42094**	**1,42094**	
Tolnene	**486,1**	**11,844 313**	**1,50847**	**1,50847**	
	501,6	11,800 169	1,50634	1,50620	
Q_0 = 0,724 322	**546,1**	**11,673 434**	**1,50086**	**1,50086**	**10^{-5}**
t= 20 °C	589,3	11,727 017	1,49718	1,49693	
	656,3	**11,810 119**	**1,49243**	**1,49243**	
Heptane	**486,1**	**5,967 364**	**1,39241**	**1,39241**	
	501,6	5,923 033	1,39153	1,39149	
Q_0 = 0,683 582	**546,1**	**5,795 759**	**1,38930**	**1,38930**	**10^{-5}**
t= 20 °C	589,3	5,756 92	1,38773	1,38764	
	656,3	**5,696 684**	**1,38572**	**1,38572**	
Sylvin	**486,1**	**8,283 144**	**1,4983**	**1,4983**	
	508,6	8,238 743	1,4962	1,4961	
Q_0 = 0,727638	**546,1**	**8,164 741**	**1,4931**	**1,4931**	
	589,3	8,191 868	1,4905	1,4904	
t= 18 °C	643,8	8,226 091	1,4878	1,4877	**$10^{-6} - 10^{-5}$**
	656,3	**8,233 94**	**1,4872**	**1,4872**	
	670,8	8,243045	1,4866	1,4866	
	480,0	8,541 438	1,5541	1,5541	
Rock salt	**486,1**	**8,533 486**	**1,5534**	**1,5534**	
	508,6	8,504 154	1,5510	1,5509	
Q_0 = 0,747 682	**546,1**	**8,455 266**	**1,5475**	**1,5475**	
	589,3	8,485 05	1,5444	1,5443	**$10^{-6} - 10^{-5}$**
t=18 °C	**643,8**	**8,522 624**	**1,5412**	**1,5412**	
	656,3	8,554 25	1,5406	**1,5407**	
	670,8	**8,590 936**	**1,5400**	**1,5400**	
Fused quartz	**467,8**	**5,850681**	**1,46435**	**1,46435**	
	480,0	5,8377307	1,46356	1,46355	
	486,1	**5,8312556**	**1,46318**	**1,46318**	
Q_0 = 0,718008	508,6	5,8238666	1,46193	1,46191	**$10^{-6} - 10^{-5}$**
	533,8	**5,8155909**	**1,46067**	**1,46067**	
t=18 °C	546,1	5,82158	1,46014	1,46013	
	589,3	**5,8426149**	**1,45845**	**1,45845**	
	643,8	5,8969853	1,45675	1,45674	
	656,3	**5,9094565**	**1,45640**	**1,45640**	
Fluorite (fluorspar)	**486,1**	**3,462 004**	**1,4369**	**1,4369**	
	508,6	3,421 062	1,4361	1,4362	
	540,1	**3,363 743**	**1,4350**	**1,4350**	

Q_0 =0,710975	589,3	3,337 833	1,4338	1,4339	**$10^{-6}-10^{-5}$**
	643,8	**3,309 132**	**1,4327**	**1,4327**	
t=18 °C	656,3	3,314 376	1,4325	1,4325	
	670,8	**3,320 46**	**1,4323**	**1,4323**	
	486,1	**6,626 515**	**1,6678**	**1,6678**	
Calcareous	508,6	6,588 783	1,6653	1,6653	
	546,1	**6,525 895**	**1,6616**	**1,6616**	
Q_0 = 0,786 674	589,3	6,526 03	1,6584	1,6584	**10^{-6}**
	643,8	**6,526 201**	**1,6550**	**1,6550**	
t=18 °C	656,3	6,540 803	1,6544	1,6544	
	670,8	**6,557 741**	**1,6537**	**1,6537**	

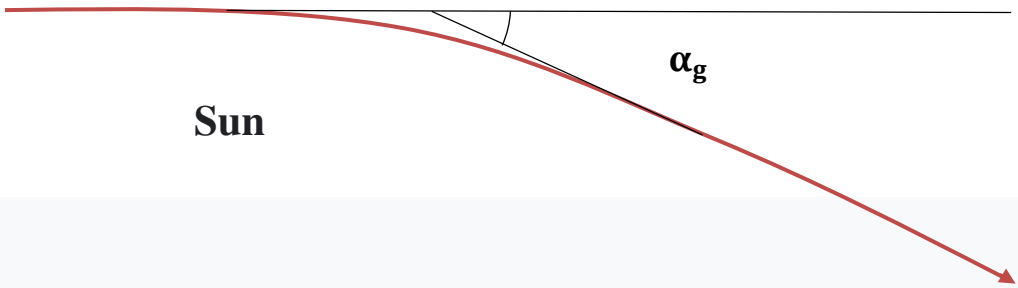
Bold type indicates known refractive indices of light, regular type indicates conditionally unknown indices that need to be determined. The first column of the table contains the $\mathbf{Q_0}$ indicators for each substance. The indicators $\mathbf{Q_0}$ are determined by the method of selection among the wavelengths taken in the middle of the entire wavelength range, taking into account the fact that $\mathbf{Q_0} = \sqrt{\frac{n^2-1}{n^2}} - \frac{k_\lambda}{\lambda_{1,2}}$. After determining $\mathbf{Q_0}$, reference coefficients $\mathbf{k_\lambda}$ are calculated for the calculated wave ranges. These reference coefficients are determined by the formula: $\mathbf{k_\lambda = \lambda_n \left(\sqrt{\frac{n^2-1}{n^2}} - Q_0\right)}$ **(1-8)** ($\mathbf{k_\lambda}$ are in bold in the table).

As can be seen from the table, for inert gases, the number of such coefficients was one for the entire wavelength range, for other substances this number is greater. This is due to different amplitudes of fluctuations in the values of the $\mathbf{k_\lambda}$ coefficients in substances. Further, using the formula $\mathbf{k_\lambda = \frac{k_1(\lambda_n-\lambda_2)+k_2(\lambda_1-\lambda_n)}{(\lambda_1-\lambda_2)}}$ **(1-10),** the $\mathbf{k_\lambda}$ coefficients were calculated for conditionally unknown light refractive indices (these coefficients are presented in the table in regular type). As a result, according to the formula $\mathbf{n = \frac{1}{\sqrt{1-(Q_0+k_\lambda/\lambda)^2}}}$ (1-7), the refractive indices $\mathbf{n}$ were calculated and entered in the table. After that, the calculated indicators were rounded, which was carried out in accordance with the number of digits after the decimal point in the laboratory refractive indices. In cases where the rounding of numbers led to a complete agreement with laboratory

indicators, the discrepancy was take n as $\mathbf{10^{-6}}$ (with the exception of an inert gases, where there were originally 7 decimal places).

2.2. The successful application of the new dispersion formula, which is based on the relativistic formula of Einstein, **suggests that space-time curvature occurs in electron clouds.** Therefore, the refraction of light in matter can be compared with the deflection of light in the gravitational field of massive bodies as a result of space-time curvature. The curvature of space-time in matter is associated **with the high energy density of electron clouds.**

In this study, the determination of the energy density of electron clouds in matter will be carried out by analogy. To do this, we use the well-known GR formula, according to which Einstein calculated the angle of deflection of light by the Sun: $\boldsymbol{\alpha_g = \arcsin \frac{4GM}{Rc^2} = 1{,}75''}$.



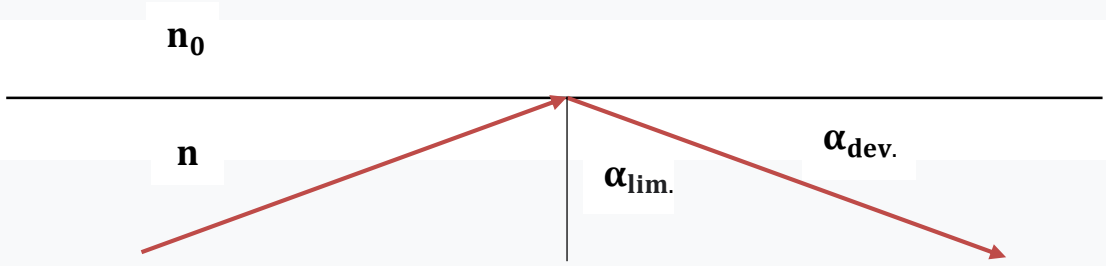
Where $\mathbf{G} = 6{,}6743 \cdot 10^{-11}$ is the gravitational constant, $\mathbf{M= 1{,}989 \cdot 10^{30}}$ kg is the mass of the Sun, $\mathbf{R= 6{,}957 \cdot 10^{8}}$ m is the radius of the Sun, **c** is the speed of light, $2{,}9979 \cdot 10^{8}$ m/s.

It follows from the formula that the deflection angle $\boldsymbol{\alpha_g = 1{,}75''}$ **(**$\boldsymbol{\sin \alpha_g =}$ **0,00000849245)** corresponds to the **"mass-radius"** ratio equal to:

$$\mathbf{M/R= \frac{1{,}989 \cdot 10^{30}}{6{,}957 \cdot 10^{8}}\ kg/m} \quad \mathbf{(1\text{-}11)}$$

The deflection angle $\boldsymbol{\alpha_g = 1{,}75''}$ is formed as a result of the fact that light, having got from the vacuum into the gravitational field of the Sun, is bent for some time in this field before going back into the vacuum**.** In optics, this phenomenon

can be compared **with the limiting total internal reflection of light** at the boundary of two media with different optical densities.



At the same time, at the boundary of the transition **from a denser medium to a less dense medium**, an angle of deviation $\alpha_{dev.}$ is also formed **between the transition boundary and the beam reflected from it.** In optics, this angle $\alpha_{dev.}$ can be determined by subtracting the limiting angle of internal reflection from 90°: $\alpha_{dev.} = 90° - \alpha_{lim.}$. The limiting angle of internal reflection, as is known, is determined by the formula: $\arcsin \alpha_{lim.} = n_0/n = 1/n$, where n is the refractive index of the medium, n_0 is the refractive index of light in vacuum. Next, we determine $\alpha_{dev.}$ and then $\alpha_{dev.}$. Note that taking into account the main trigonometric identity ($\sin\alpha^2 + \cos\alpha^2 = 1$), all the above calculations can be reduced to one formula: $\sin \alpha_{dev.} = \sqrt{1 - \frac{1}{n^2}}$.

Now back to **1-11.** The dimension **"kg/m"** present in this expression is suitable for the scale of general relativity, but is unacceptable for the scale of the atomic world. Therefore, the expression (1-11) for the possibility of its use inside the substance must be translated into **"J /m^3 "**. As a result, we get: $\rho_g = \frac{Mc^2}{R^3} = 5,955 \cdot 10^{20}$ J/m^3, where ρ_g is the energy density index. This energy density corresponds to the deflection angle $\arcsin \alpha_g = 0,00000849245$.

Now, through the analogy method, on the basis of proportional equality, we obtain a formula for determining the energy density of electron clouds in matter:

$$\rho = \rho_g \frac{\sin \alpha_{dev.}}{\sin \alpha_g} = \frac{\rho_g}{\sin \alpha_g} \sqrt{1 - \frac{1}{n^2}} \qquad \textbf{(1-12)}$$

where $\rho_g = 5{,}955 \cdot 10^{20}$ J /m^3, $\sin\alpha_g = 0{,}00000849245$.

(For the production of working calculations, the expression $\frac{\rho_g}{\sin \alpha_g}$ must be reduced to one value: $\mathbf{7,01 \cdot 10^{25}}$ J /m^3.

For an approximate calculation, take from the table.1 refractive index of krypton, where **n=1, 0002711** (λ = 645,8 nm). We get: $\boldsymbol{\rho = 1,63 \cdot 10^{24}}$ J /m^3.

For water, where **n=1, 33002** (λ = 706,5 nm): $\boldsymbol{\rho = 4,62 \cdot 10^{25}}$ J /m^3.

For rock salt, where **n=1,5400** ($\lambda = 670$ nm): $\boldsymbol{\rho = 5,33 \cdot 10^{25}}$J /m^3.

This is a very high energy density. (Similar calculations of the energy density of electron clouds can be made for all transparent substances, but this will be redundant within a single study).

3. Results.

The dispersion formula obtained in this study showed good results. According to the new formula, 42 refractive indices of light were determined. Comparison of the obtained indicators with laboratory indicators showed the following: **in an inert gases the discrepancy was 10^{-7}, in liquid and solid substances $\pm 10^{-6}$ -10^{-5}.** In this case, the calculated sections of the wave range were **70-90 nm** (see Table 1).

For comparison. The most accurate empirical Hartmann formula: $\mathbf{n = n_\infty + C/(\lambda - \lambda_0)^a}$, determines the refractive indices of light with an accuracy of $\pm 10^{-6}$ -10^{-5}. In this case, the calculated sections of **the wave range should not exceed several tens of nm: $(\lambda - \lambda_0) < 30 - 40$ nm.** If this range is exceeded, it will be necessary to recalculate the empirical constants, otherwise the accuracy of the formula may be significantly reduced.

The new dispersion formula is a physical formula because it is based on the **energy density of electron clouds.**

The essential results of this study include the determination by analogy of **the energy density of electron clouds**. The energy density was $\mathbf{10^{24} - 10^{25}}$J/m^3 (the energy density varies depending on the refractive index of the substance).

4. Conclusions.

In this study, based on the relativistic formula of Einstein, a new dispersion formula was obtained. This formula showed high accuracy: $\pm\mathbf{10^{-6}-10^{-5}}$ in the calculated sections of the **70-90 nm** wavelength range. The new physical formula can be applied to the same wide range of transparent substances as the well-known empirical formulas of Hartmann and Cauchy.

In this study, by analogy, a formula was obtained for determining the energy density of electron clouds of transparent substances. According to this formula, the indicators of the energy density of electron clouds in three substances in different aggregate states were selectively determined. The electron cloud energy density was $\mathbf{10^{24}-10^{25}}$ J/m^3.

5. Reference section.

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6. Declarations

1. **Availability of data and materials.**

All data obtained and analyzed in the course of this study is included in this article.

2. **Competing interests.** Not applicable (there are no competing interests).

3. **Funding.** Not applicable.

4. **Authors' contributions**. Not applicable.

5. **Acknowledgements.** Not applicable.