

«New dispersion formula and results of its application»

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«New dispersion formula and results of its application»

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25 **Abstract.**

26 The aim of the study was to obtain a new physical formula for determining
27 the refractive indices of light as a function of wavelength, which can be applied to
28 a wide range of transparent substances. In the process of research on the basis of
29 Einstein's relativistic formula, such a dispersion formula was obtained.
30 Comparison of the obtained indicators with laboratory indicators showed the high
31 accuracy of the new dispersion formula, which was $\pm 10^{-7} - 10^{-5}$ in the calculated
32 wavelength ranges **of more than 100 nm.**

33 The new dispersion formula is obtained on the basis of the mathematical
34 dependence of the speed of propagation of photons in a transparent substance on
35 the energy density of electron clouds of atoms of the substance. Energy is a
36 universal category, therefore, it is possible to apply the basic version of the new
37 formula (where instead of the wavelength there is the energy density of electron
38 clouds) when conducting research in all areas of light generation, manipulation and
39 detection.

40 And, finally, the very fact of applying the adapted relativistic Einstein's
41 formula to physical processes occurring at the atomic level allows us to look at the
42 nature of the interaction of light and matter from a new angle.

43

44 **Keywords.** New physical dispersion formula, empirical dispersion
45 formulas, a formula for determining the total energy of a moving body, the
46 energy density index of electron clouds, the calculation of the refractive indices
47 of light.

48 **Introduction.**

49 Currently, there are no physical formulas that can be applied to a wide
50 range of transparent substances. For example, the well-known physical formula
51 of Lorentz-Lorentz, which is based on the dependence of the refractive index
52 of light **on the density of a substance**, is valid only for isotropic media (gases,
53 non-polar liquids, cubic crystals) and is not applicable for most transparent
54 substances. Therefore, in practice, to calculate the refractive indices, empirical
55 dispersion formulas (Cauchy, Hartmann, etc.) are usually used. These formulas
56 are quite accurate, but at the same time they are not physical formulas.

57 A new physical dispersion formula was obtained on the basis of the
58 assumption that the speed of propagation v_γ of photons in a transparent
59 substance depends on **the energy density of electron clouds Q_e** of atoms of
60 the substance: the higher the density of the electron clouds, the lower the speed
61 of the photons. In this case, the greater the energy of the photons propagating
62 in the substance, the more the electron clouds of the atoms of the substance are
63 "condensed" by the energy. This leads to the fact that different wavelengths in
64 the same transparent substance propagate at different speeds. Thus, there is a
65 physical relationship between the energy density Q_e of electron clouds of
66 atoms of matter and the speed of propagation v_γ of photons in matter. This
67 dependence, as it turned out in the study, is regulated by Einstein's relativistic
68 formula for determining the total energy of a moving body. As a result of the

69 transformation of this formula, the author obtained a new dispersion formula,
70 which showed very good results.

71

72 **Methods.**

73 Now let us describe in detail the method of obtaining a new dispersion
74 formula. To do this, we first write down Einstein's relativistic formula for
75 determining the total energy of a moving body:

$$76 \quad E_{total} = \frac{m_0 c^2}{\sqrt{1 - \frac{v^2}{c^2}}} \quad \text{or} \quad E_{total} = \frac{E_0}{\sqrt{1 - \frac{v^2}{c^2}}} \quad (1-1)$$

77 Where E_{total} is the total energy of a moving body.

78 E_0 – energy of a body at rest.

79 v is the speed of the body.

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

$$81 \quad v = c \sqrt{1 - \frac{E_0^2}{E_{\text{полн.}}^2}} \quad \text{или} \quad v = c \sqrt{1 - Q_b^2} \quad (1-2)$$

82 Where Q_b is an indicator of the ratio of the energy of a body at rest to the total
83 energy of a moving body, $0 < Q_b < 1$.

84 Now we apply formula (1-2) to the speed of propagation of photons in a
85 transparent substance:

$$86 \quad v_\gamma = c \sqrt{1 - Q_e^2} \quad (1-3)$$

87 Where v_γ is the speed of propagation of photons in the electron clouds of atoms of
88 a transparent substance.

89 Q_e is a dimensionless indicator of the energy density of electron clouds of a
90 transparent substance, $0 < Q_e < 1$.

91 Let's transform the formula (1-3) and get:

$$92 \quad \frac{c}{v_\gamma} = \frac{1}{\sqrt{1-Q_e^2}} \quad \text{or} \quad n = \frac{1}{\sqrt{1-Q_e^2}} \quad (1-4)$$

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

94 Let's reveal the value of Q_e in the formula (1-4):

$$95 \quad n = \frac{1}{\sqrt{1-(Q_0+\Delta Q_\lambda)^2}} \quad (1-5)$$

96 Where Q_0 is a dimensionless basic indicator of the energy density of electron
97 clouds of a transparent substance.

98 ΔQ_λ is a dimensionless indicator of the increase in the energy density of electron
99 clouds of a transparent substance.

100 The Q_0 index is constant (at constant temperature and pressure). The
101 exponent ΔQ_λ is a variable. It depends on the energy e of the electromagnetic
102 wave, where $e = h\gamma = hc/\lambda$. From here we get the formula:

$$103 \quad n = \frac{1}{\sqrt{1-(Q_0+k_\gamma hc/\lambda)^2}} \quad (1-6)$$

104 Where k_γ is the coefficient of proportionality, J^{-1} .

105 Replace $k_\gamma hc$ with a single coefficient k_λ and obtain a new dispersion formula:

$$106 \quad n = \frac{1}{\sqrt{1-(Q_0+k_\lambda/\lambda)^2}} \quad (1-7)$$

107 Where k_λ is the coefficient of proportionality, nm.

108 λ – wavelength, nm.

109 The coefficient k_λ is individual for each substance and depends on the
110 absorption of electromagnetic waves by atoms. It is relatively stable in the visible
111 range of the electromagnetic spectrum. But in the ultraviolet and infrared ranges,
112 the coefficient k_λ can significantly change its value due to changes in the
113 absorption of electromagnetic waves by matter. For this reason, according to f. (1-
114 7), the value of the refractive index n can change sharply up to the adoption of
115 anomalous values. This circumstance introduces a limitation on the use of formula
116 (1-7) in these wave ranges.

117 Let us check the accuracy of the new dispersion formula. Table 1 presents 39
118 laboratory indices of refraction of light in the visible range of the spectrum in five
119 transparent substances. 13 conventionally known indices of refraction of light are
120 highlighted in bold, 26 conventionally unknown indices, which must be
121 determined using a new formula, knowing the wavelength, are highlighted in
122 regular font. (These refractive indices are commonly known and readily available
123 on the Internet. To be able to verify with the table data, they will be sent to the
124 editor in a separate file). The first column of the table contains the basic indicators
125 Q_0 (they were determined by solving a system of equations and subsequent
126 selection of the optimal value Q_0). The wavelengths are highlighted in bold in the
127 table, where the proportionality coefficients were calculated using the formula

128 $k_{\lambda 1,2} = \lambda_n \left(\sqrt{\frac{n^2-1}{n^2}} - Q_0 \right)$ (1-8), which will be used for interpolation. As can be

129 seen from the table, for an inert gas the number of such coefficients was unity for

130 the entire wavelength range, for other substances - 3. (This is due to different
131 amplitudes of fluctuations in the magnitude of the proportionality coefficients in
132 these substances). Then, using the formula $k_{\lambda} = \frac{k_{\lambda 1}(\lambda_n - \lambda_2) + k_{\lambda 2}(\lambda_1 - \lambda_n)}{(\lambda_1 - \lambda_2)}$ (1-9), the
133 coefficients k_{λ} (they are presented in the table in regular font) and then the
134 refractive indices of light are determined by the formula (1-7).

135 After that, the calculated indices were rounded off in accordance with the
136 number of digits after the decimal point in laboratory refractive indices. Therefore,
137 for an inert gas, the refractive indices of light were rounded up to 7 decimal places,
138 for water - up to 5 decimal places, for solids - up to 4 decimal places. It should be
139 noted that in those cases when the rounding of the numbers led to a complete
140 coincidence of the refractive indices, then the accuracy was taken to be one order
141 of magnitude greater than that of the other refractive indices. For example, in glass,
142 after rounding, two refractive indices completely coincided for wavelengths of
143 670, 8, and 643.8 nm. The accuracy here was taken as 10^{-6} . An order of magnitude
144 higher than the rest of the refractive indices in glass, where the accuracy was 10^{-5} .
145 The same method was applied to the rest of the indicators in other substances. The
146 author believes that this approach is the most correct, because the known
147 laboratory parameters, after being obtained experimentally, were also rounded to a
148 certain sign. From this it follows that when comparing the refractive indices, the
149 equality of the commas after zero must be observed, because otherwise, the
150 calculation accuracy indices may increase unreasonably or, conversely, decrease.

151 After rounding off the calculated indices, they were compared with
152 laboratory refractive indices and the discrepancy between them was determined.
153 The results were tabulated.

154

155 **Results and discussion.**

156 Table 1 shows the 26 calculated refractive indices of light in 5 transparent
157 substances, which were calculated using the new dispersion formula.

158 Comparison of the indicators calculated by the new physical formula with
159 laboratory indicators showed the following: in an inert gas the discrepancy was 10^{-7} ,
160 in water and solids $\pm 10^{-6} - 10^{-5}$. In this case, **the calculated range was more**
161 **than 100 nm.**

162 For comparison, the very exact empirical formula of Hartmann has four
163 constants and shows an accuracy of $\pm 10^{-6} - 10^{-5}$ in the sections of the wavelength
164 ranges **that do not exceed several tens of nm.**

165 If we compare the new formula with the physical Lorentz-Lorentz formula,
166 then the advantage of the new formula is obvious. This is a much wider range of
167 action among transparent substances, which is equal to the range of known
168 empirical formulas.

169

170 **Conclusions.** In this study, on the basis of Einstein's relativistic formula, a
171 new dispersion formula was obtained. This physical formula was used to calculate
172 26 refractive indices of light in 5 transparent substances in three states of

173 aggregation. The accuracy of the new dispersion formula was $\pm 10^{-7} - 10^{-5}$ in the
174 calculated wavelength ranges **of more than 100 nm**. This physical formula can be
175 applied, as well as empirical formulas, to almost all transparent substances.

176 The new formula is obtained on the basis of the mathematical dependence of
177 the speed of propagation of photons in a transparent substance on the energy
178 density of electron clouds of atoms of the substance. Energy is a universal
179 category, therefore, it is possible to apply the basic version of the new formula
180 (where instead of the wavelength there is the energy density of electron clouds)
181 when conducting research in all areas of light generation, manipulation and
182 detection.

183 And, finally, the very fact of applying the adapted relativistic Einstein's
184 formula to physical processes occurring at the atomic level allows us to look at the
185 nature of the interaction of light and matter from a new angle.

186

187 *See Table1 on the following page*

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Table 1

202

Substance	λ nm	k_λ nm	Calculated refractive index	Laboratory refractive index	Divergence
Krypton $Q_0 = 0,0228741$	450,4		1,0002750	1,0002752	10^{-7}
	556,4	0,2573906	-	1,0002724	
	565,1		1,0002723	1,0002722	
	587,3		1,0002719	1,0002719	
	605,8		1,0002715	1,0002716	
	645,8		1,0002709	1,0002711	
Water $Q_0 = 0,648752$ $t = 20\text{ }^\circ\text{C}$	447,1	7,3594178	1,33931	1,33942	$10^{-6} - 10^{-5}$
	471,3	7,3504891	-	1,33793	
	486,1	7,3450358	1,33716	1,33712	
	501,6	7,3393246	1,33640	1,33635	
	546,1	7,322928	-	1,33447	
	577,0	7,3469439	1,33342	1,33338	
	587,6	7,3551824	1,33308	1,33304	
	656,3	7,4085769	-	1,33115	
	670,8	7,4198465	1,33080	1,33080	
706,5	7,447593	1,32999	1,33002		
Sylvin $Q_0 = 0,727035$ $t = 18\text{ }^\circ\text{C}$	480,0	8,5850021	1,4989	1,4990	$10^{-6} - 10^{-5}$
	486,1	8,5766026	-	1,4983	
	508,6	8,5456209	1,4962	1,4961	
	546,1	8,4939848	-	1,4931	
	589,3	8,5471312	1,4905	1,4904	
	643,8	8,6141794	1,4876	1,4877	
	656,3	8,6295574	-	1,4872	
670,8	8,6473959	1,4866	1,4866		
Light crown glass $Q_0 = 0,741579$ $t = 15\text{ }^\circ\text{C}$	480,0	6,1563048	1,5234	1,5235	$10^{-6} - 10^{-5}$
	486,1	6,1545121	-	1,5230	
	546,1	6,1372274	1,5192	1,5191	
	589,3	6,1241824	-	1,5170	
	643,8	6,1806235	1,5149	1,5149	
	656,3	6,1935687	-	1,5145	
670,8	6,2085851	1,5140	1,5140		
Rock salt $Q_0 = 0,747572$ $t = 18\text{ }^\circ\text{C}$	480,0	8,5940181	1,5541	1,5541	$10^{-6} - 10^{-5}$
	486,1	8,5867621	-	1,5534	
	508,6	8,5599976	1,5510	1,5509	
	546,1	8,5153919	-	1,5475	
	589,3	8,5653435	1,5445	1,5443	
	643,8	8,6283611	1,5413	1,5412	
	656,3	8,6428147	-	1,5407	
670,8	8,6360523	1,5399	1,5400		

203

204

Declarations

205

206

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

208 All data obtained and analyzed in the course of this study is included in this article
209 (and file with additional information.)

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

211 **3. Funding.** Not applicable.

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

213 **5. Acknowledgements.** Not applicable

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