ABOUT POSSIBLE EXPERIMENTAL EFFECT CHECK LIGHT FREQUENCY TRANSFORMATION WITH SOURCE ACCELERATION

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One of the urgent problems of physics is to discover new ways of transforming optical radiation into other frequency ranges with the possibility of smooth tuning of the radiation frequency. Usually, such a transformation is carried out by means of nonlinear effects in a medium, which imposes serious restrictions on the degree and efficiency of conversion of the frequency of light, on the maximum power and duration of the output signal (from absorption and optical breakdown of the medium). Here we propose a new method for smooth transformation of the duration of laser pulses and tuning of the frequency of optical radiation in any other range of electromagnetic waves traveling in a vacuum and without such restrictions.

The effect of transformation of the duration of electromagnetic influences from an accelerating source was predicted a century ago in 1908 by the Swiss physicist W. Ritz on the basis of the ballistic theory of light [1]. According to it, the source additionally imparts its speed **v** to the emitted light moving relative to the source with the standard speed **c** (speed of light), and relative to the receiver - with the speed **c** + **v**, like a moving weapon giving additional speed to projectiles [2]. Then, if the source is rapidly moving towards the receiver, then the wave fronts, acquiring ever greater velocities at the moments of emission, will catch up with each other, reducing the wavelength and the period of light oscillations perceived by the receiver. If a is the acceleration of the source, then the first light signal (or front) emitted at the speed of light c will reach the receiver located at a distance L in time $t_1=L/c$. The second signal (or front), emitted after a period dt, when the source picks up speed $dv=adt$ and begins to emit light at a speed $c'=c+dv$, will reach the receiver in time $t_2=dt+L/c'$ after the emission of the first. As a result, the signals will arrive at the receiver with a smaller time gap.

$$dt' = t_2 - t_1 \approx dt\left(1 - \frac{La}{c^2}\right). \tag{1}$$

If the acceleration a of the source is directed from the receiver, then the crests of light waves will diverge, increasing the period of light oscillations perceived by the receiver $dt' \approx dt(1+La/c^2)$ and the wavelength $\lambda'=cdt'=\lambda(1+La/c^2)$ along compared to the source wavelength $\lambda=cdt$. From the kinematics follows the general law of changing the duration, wavelength and frequency of light, respectively:

$$\Delta t' = \Delta t\left(1 + \frac{La_r}{c^2}\right),\ \ \lambda' = \lambda\left(1 + \frac{La_r}{c^2}\right),\ \ f' = f\left(1 + \frac{La_r}{c^2}\right)^{-1}, \tag{2}$$

where a_r is the radial acceleration of the source (the projection of the acceleration on the line of sight r), f is the frequency of the source. In what follows, effect (2) will be called the Ritz effect. It is similar to the nonlinear self-phase modulation effect, which changes the frequency and wavelength in proportion to the path traveled by light from the inequality of the speed of light in the medium. The Ritz effect compares favorably with the fact that it changes the frequency of light in a vacuum. But until now, the effect has remained unnoticed, due to its smallness, since the denominator (2) contains the square of the speed of light.

However, the effect would manifest itself at distances L of the order of several light years. The American physicist D.F. Comstock [3], having considered possible distortions in the motion of binary stars from periodic compression-stretching of the visible intervals (2) of motion of stars in orbit with a variable projection a_r of centripetal acceleration a. The uniform motion of stars in a circular orbit will seem uneven, going along an ellipse elongated to the Earth (an imaginary eccentricity of the orbit $\varepsilon = La/c^2$ arises). Such distortions, as noted in 1913 by astronomers Guthnick [4] and Freundlich [5], were actually discovered in spectroscopic binaries in the form of the Barr effect [2, 6], which has not yet found an unambiguous explanation. Then La Rosa [7] and Zurhellen [8] showed that the Ritz effect would also appear in regular variations in the brightness and spectrum of binary stars. According to the energy conservation law of light emitted by a star in the interval Δt and perceived in the interval $\Delta t'$ (2), a star that would radiate power P into the telescope aperture without acceleration will be received with the radiation power

$$P' = P\frac{\Delta t}{\Delta t'} = P\left(1 + \frac{La_r}{c^2}\right)^{-1}. \tag{3}$$

Similar periodic variations in the brightness and wavelength λ_{max} of the spectral maximum were actually discovered in Cepheids and other physically variable stars, but were interpreted according to Wien's displacement law $T_c\lambda_{max}=b=\text{const}$ as fluctuations in their temperature T_c. Thus, the ballistic theory and the Ritz effect do not contradict the observations of binary stars, contrary to the well-known argument of De Sitter [9], and allow one to explain a number of anomalies in stellar systems, including the Barr effect and excess eccentricities of exoplanet orbits. As noted by J. Fox [10], when testing the ballistic theory in space, one should also take into account the re-emission of light by interstellar gas, so that the main part of the path the light beams move with the same speed c, losing the excess speed received from the stars. As a result, the effective length L_{ef}~$\lambda/(n-1)$ (where n is the refractive index of the medium) at which light is converted according to the Ritz effect (2) and which Fox is based on the concentration of hydrogen atoms in the Galaxy (N~1 см$^{-3}$) estimates in one light year, it turns out to be less than the real distances L of stars (hundreds and thousands of light years), thereby reducing distortions hundreds of times - in proportion to L_{ef}/L. That is, the smallness of the observed distortions [8-11] does not contradict the Ritz effect.

The Ritz effect would be more noticeable at intergalactic distances L, where the concentration of neutral hydrogen atoms is much lower, namely $N \leq 6 \cdot 10^{-11}$ [12], and since L_{ef} is proportional to $1/N$, then $L_{ef} \geq 2 \cdot 10^{10}$ light years >> L, and there is practically no re-emission. In particular, according to the Ritz effect $\lambda' = \lambda(1+La_r/c^2)$, the wavelength λ of light emitted by the visible regions of bright galactic bulges, which give the most intense spectral lines and have accelerations directed from us ($a_r>0$) to the centers of galaxies, should grow in proportion to the distance L to the galaxies. The effect resembles the redshift in the spectra of galaxies $\lambda' = \lambda(1+LH/c)$, discovered by E. Hubble, who denied its cosmological nature [13]. The proportionality coefficient H = 74 km s^{-1} Mpc^{-1} (the Hubble constant) is close to the a_r/c coefficient calculated from the known accelerations $a_r = V_b^2/R_b$ in galaxies. Taking our Galaxy as a sample, the characteristics of which are typical for spiral galaxies, and the bulge has a radius of R_b=0.002 Mpc and a peripheral velocity V_b=205 km / s and [14], we obtain the calculated value of the Hubble constant $H_c = a_r/c \approx 70$ km s^{-1} Mpc^{-1}, close to the measured value H. That is, the ballistic theory and the Ritz effect do not contradict the data of extragalactic astronomy, explaining the redshift and its anomalies without hypotheses about the expansion of the Universe, about dark matter and dark energy. For example, the anomalously high redshifts of quasars and a strong difference in redshifts for linked, equally distant galaxies [15] can be explained by the Ritz effect by the difference in accelerations a_r in them, giving different $H_c = a_r/c$ and different redshifts. And the redshift deficit in the most distant galaxies [16] may be a consequence of re-emission by intergalactic gas, which becomes noticeable when the distances L are comparable to L_{ef}~$2 \cdot 10^{10}$ light years, after which the Ritz effect redshift would grow more and more slowly. Approximately at such distances (L~10^{10} light years, which corresponds to a redshift z~0.8), when L~L_{ef}, and deviations from the Hubble law in the form of a redshift deficit, interpreted as an accelerated expansion of the Universe, were revealed [16].

At laboratory distances L and accelerations a_r, the frequency shift according to the Ritz effect is so small that it could be recorded only by the Mössbauer effect. Indeed, in the experiment of Bömmel (1962) with the translational accelerated motion of a γ-ray source, a shift in the radiation frequency at the absorber $\Delta f/f=(f'-f)/f=La_r/c^2$ was observed, proportional to the distance L and the acceleration of the source a_r [17] ... The frequency shift was also recorded when the emitter with the absorber was placed on a rotating disk, which imparted centripetal acceleration to the γ-source. The frequency shift according to the Ritz effect, calculated taking into account the re-emission in the disk, coincides with the result of these experiments. Thus, laboratory experiments do not contradict the existence of the Ritz effect, although they are interpreted according to the general theory of relativity. Also, so far there are no experiments that confidently prove the absence of dependence of the speed of light on the speed of the source, since in all such experiments, including recent ones, either the effect of re-emission is not taken into account, or the speed of the source is not measured directly [10, 18].

For an unambiguous verification of the Ritz effect and a strong transformation of the frequency of light, it is necessary to provide in the formula (2) La_r/c^2~1. Therefore, for laboratory distances L~1 m, $a_r=c^2/L$~10^{17} m / s^2 is required. This acceleration is unattainable for light-emitting devices, but it is easy to communicate it to electrons or ions, which can either emit light themselves (when the ions are excited), or serve as re-emitting centers. In an electric field E, the acceleration $a=Ee/m$ of an electron (where $e/m=1.76 \cdot 10^{11}$ C / kg is its specific charge) will reach 10^{17} m / s^2 at a field strength of E~10^6 V / m. For ions, the field should be thousands of times higher: E~10^9 V / m. Such fields are easily attainable, and even $E=10^{12}$ V / m at the focus of laser beams has been achieved.

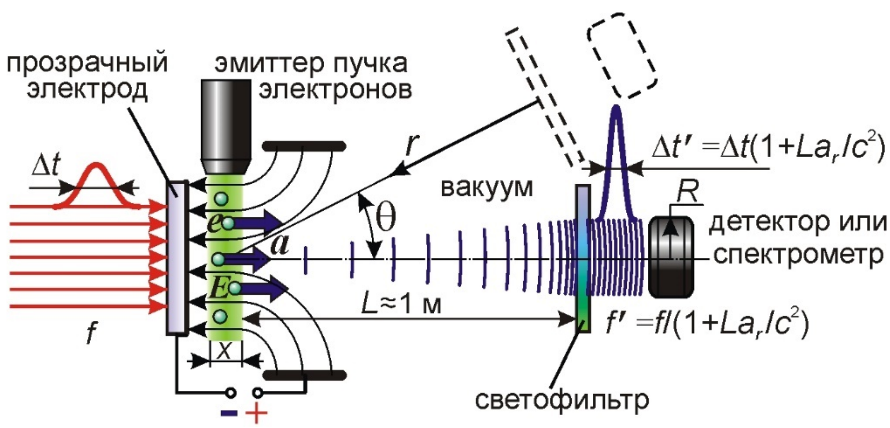

Fig. 1. Schematic of the setup for testing the Ritz effect, which converts the frequency of light and the duration of laser pulses scattered by accelerating electrons.

The installation for checking the Ritz effect and transformation of the frequency of light (Fig. 1) is a vacuum chamber, where a beam of electrons or ions acquires an acceleration of ~10^{17} m / s^2 in an electric field. Laser pulsed radiation with a frequency f and a pulse duration Δt~1 ps is focused on the beam and undergoes Thomson scattering on electrons (or ions), which become secondary sources of radiation of frequency f. Their light freely flies in a vacuum for a distance L~1 m to a light filter (which does not transmit radiation of frequency), enters a spectrometer or detector, which, if the Ritz effect is valid, will record a signal with a changed duration and frequency (2). The dependence of this frequency f' and the frequency transformation coefficient $k=f'/f$ on the radial acceleration of electrons a_r and the accelerating field E is shown in Fig. 2. It can be seen that at $a_r=-c^2/L$, the transformation ratio tends to infinity and a small variation in a_r caused by a change in E or L causes a strong change in the frequency f', which opens up a simple way of tuning the frequency of light from optical to UV, X-ray and gamma range. With the opposite sign of the field and acceleration, the frequency will decrease, which makes it possible to transform optical radiation into infrared and terahertz radiation. Note that general relativity does not predict such frequency shifts (Fig. 2), since the radiation receiver is not accelerated with the source.

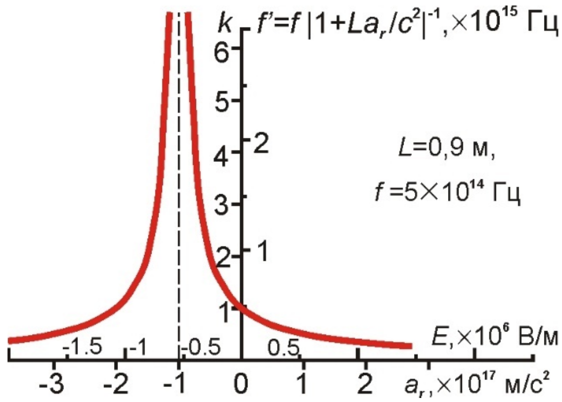

Fig. 2. Conversion of the source frequency by the Ritz effect depending on on the magnitude of the accelerating field and the acceleration of the scattering centers.

The Ritz effect is also different from the Doppler effect, which does not change the frequency when re-emitted in the forward direction. In addition, the velocities acquired by the particles during a picosecond laser pulse $t\sim10^{-12}$ s will amount to $V=a_r t\sim10^5$ m / s, which is insufficient for Doppler conversion of the light frequency by several times or for generating quanta of high-energy bremsstrahlung radiation. Generation of an electron beam and an electric field by short pulses synchronous with laser pulses will also make it possible to reduce energy consumption for emission, particle acceleration, and to simplify the high voltage generator circuit. An important feature of the Ritz effect is that the frequency, wavelength and duration of the converted light pulse depends on the distance L traveled by the light (Fig. 3). Analysis of this dependence with variation in the distance L to the detector is the main criterion for testing the Ritz effect.

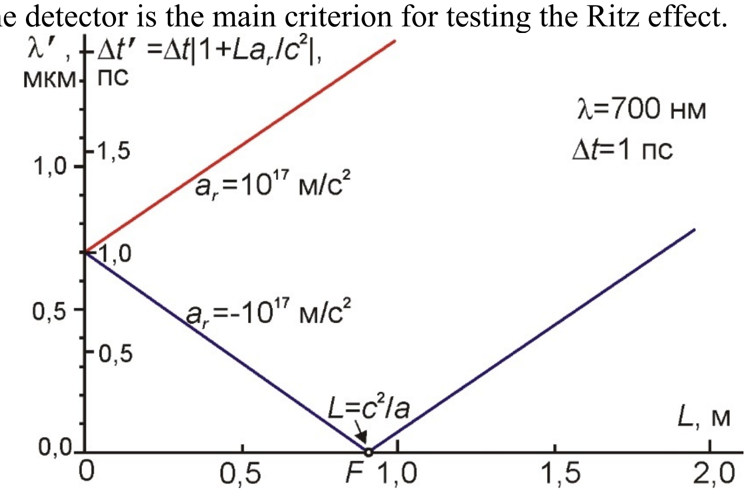

Fig. 3. Change in wavelength λ' and duration expected from the Ritz effect pulse Δt depending on the distance to the receiver at a given acceleration.

Another criterion is the study of the dependence of f' on the angle θ, at which the radiation is recorded. Since the Ritz effect (2) depends not on the absolute value of the acceleration a, but on its projection a_r=-$a$cosθ onto the line of sight r, then the dependence

$$f' = \frac{f}{1 - \frac{La}{c^2}\cos\theta}. \quad (4)$$

In polar coordinates, the angular dependence (4) corresponds to an ellipse (Fig. 4) with a focus at the pole, and the parameter $\varepsilon=La/c^2<1$ characterizes the eccentricity of this ellipse. At a critical value of the eccentricity parameter ε =1, the ellipse turns into a parabola - the maximum frequency f' becomes infinite. For ε>1, the angular dependence has the form of a branch of the hyperbola (ε>1) and the frequency tends to infinity in the direction $\theta_0=\arccos(c^2/La)$ of the hyperbola asymptotes. Within the angle $|\theta|<\theta_0$, where the denominator is negative (since the trailing edges overtake the leading ones), the frequency modulus should be taken: the dependence is depicted by the second, but mirrored, branch of the hyperbola. Since the Thomson scattered radiation is linearly polarized, the radiation transformed from it according to the Ritz effect and observed at large angles θ should also be linearly polarized. This opens the way for the generation of polarized X-ray and gamma beams.

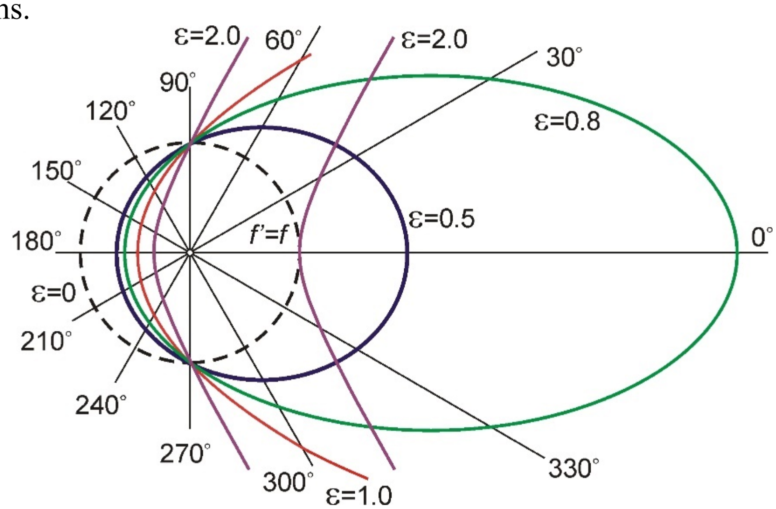

Fig. 4. Angular dependence of the frequency $f'(\theta)$ transformed the Ritz effect for different values of the parameter $\varepsilon=La/c^2$.

The main advantage of the Ritz effect is the possibility of unlimited compression of the pulse duration $\Delta t'$ (2) and an unlimited increase in the peak power P' of the pulse (3). This possibility opens up a simultaneous reduction in the pulse duration and wavelength, the period of light oscillations (Fig. 3). Therefore, the pulse duration, which is limited from below only by the oscillation period, can become arbitrarily small, and the intensity arbitrarily high. In fact, at the point F, where $L=c^2/a$ (i.e., ε=1), absolute phase focusing is realized, when the wavefronts emitted at different times arrive at the receiver simultaneously.

Let us estimate the power of the transformed pulses. If the initial laser radiation has a power P_0, then the power of radiation scattered by electrons will be $P=P_0(1-e^{-\tau})\approx P_0\tau=P_0N\sigma_T x$, where $\tau=N\sigma_T x<<1$ is the optical thickness of the electron beam layer, N is the concentration of electrons in it, x≈0.001 m is the beam thickness, $\sigma_T=(8\pi/3)r_e^2\approx 6.65\cdot 10^{-29}$ m^2 is the effective cross section of Thomson scattering, and r_e is the classical radius of the electron. At an electron concentration $N=10^{26}$ m^{-3} [19], attainable in beams of explosive electron emission (giving pulses with a duration of ~100 ps), we obtain $P\sim P_0\cdot 10^{-5}$. But provided that the pulses are compressed by a factor of 10^5

or more, formula (3) implies the possibility of generating gamma-radiation pulses with a power equal to or higher than the initial one: $P'\sim P\cdot 10^5\sim P_0$. That is, it becomes possible to generate monochromatic X-ray or gamma radiation of a continuously tunable frequency with a peak power of about 10^{15} W (peak power of a petawatt laser), but of an extremely short duration $\Delta t'\sim 10^{-17}$ s. It also opens up the possibility of creating beams of coherent X-ray and gamma radiation with the properties of laser radiation.

The signal power entering the solid angle $\Omega=\pi R^2/L^2$ (into the detector aperture of radius R) will be $P_\Omega=P_0 N x\Omega d\sigma/d\Omega$, where $d\sigma/d\Omega=\sigma_T(3/16\pi)(1+\cos^2\theta)$ is the differential Thomson scattering cross section. Then at $\theta=0$ and $R/L\sim 0.05$ with the same parameters, we get $P_\Omega\sim P_0\cdot 10^{-8}$. And the signal power recorded by the detector after conversion by the Ritz effect, according to formula (3), will be

$$P_\Omega' = \frac{P_\Omega}{1+La_r c^{-2}} = P_0\frac{3N\sigma_T x\Omega}{16\pi}\cdot\frac{1+\cos^2\theta}{1-\varepsilon\cos\theta}. \quad (5)$$

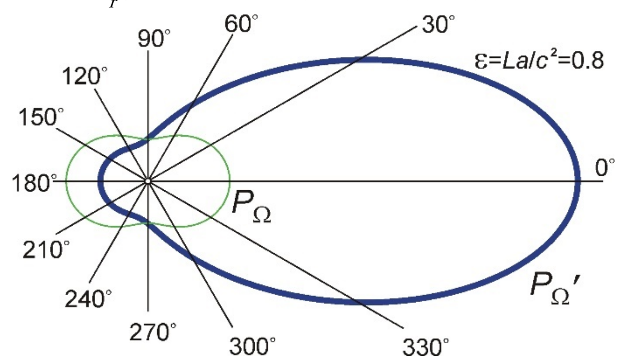

Fig. 5. Angular dependence of the energy of the scattered radiation pulses (peak power P_Ω at the instant of scattering) and their peak power P_Ω' converted by the Ritz effect.

In Fig. 5 shows the directional diagrams of the scattered radiation by the pulse energy (proportional to P_Ω), and by the peak pulse power P_Ω' (5). It can be seen that for $\varepsilon<1$, the maximum peak power is expected in the forward direction ($\theta = 0$), where the frequency is maximized.

The acceleration of electrons or ions can also be caused by light pressure from the side of a focused laser beam. In this case, the laser light would simultaneously accelerate the particles and, after being re-emitted by them, would transform according to the Ritz effect. A similar effect is actually observed in generators of attosecond pulses, where in a focused beam of a femtosecond laser, atoms of inert gases acquire giant accelerations under the action of light pressure, up to 10^{23} m / s^2. It turns out that attosecond X-ray pulses recorded in these generators can partly be femtosecond optical pulses converted by the Ritz effect (2). The main mechanism of pulse generation can be determined by checking the main criteria of the Ritz effect (2–5): the angular dependence of the spectrum and peak power, the dependence of the maximum frequency in the spectrum on distance and on acceleration (ie, on the value of light pressure proportional to the intensity).

Thus, modern laser physics opens up a number of new possibilities for testing the ballistic theory and the Ritz effect, which, if confirmed, will make it possible to smoothly transform the light frequency, duration and intensity of laser pulses over the entire range of frequencies, times, and intensities. At the very least, the restrictions here will be purely technical, not fundamental.

In conclusion, I would like to express my gratitude to my supervisor, Professor of Nizhny Novgorod State University M.I. Bakunov for valuable comments, additions and advice on the analysis of the effect and the scheme for its experimental verification.

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