"New results in Ives experiment"

Lev A. Pobedonostsev^{+} and Pavel F. Parshin^{++}

$^{+)}$ V.G. Khlopin Radium Institute, USSR
$^{++)}$ Dept. of Physics, Leningrad Academy of Civil Aviation, USSR

ABSTRACT

Analysis of previous experimental works concerning verification of the relativistic Doppler effect is performed. New results have been obtained in the modern Ives experiment with the canal rays. The beam of excited hydrogen atoms is produced by accelerating H_2^+ ions with voltages from 150 keV up to 2.000 keV.

There is a systematic deviation in the results obtained from those according to the special theory of relativity. The classical approach to understand experimental data is offered. Both theories are compared.

1. INTRODUCTION

102 years have passed since the first results of the Michelson-Morley famous experiment appeared in the press. As you remember this experiment was performed to observe the orbital motion of the Earth with the measurements to prove the null effect. The attempt to explain the null effect theoretically led to Fitzgerald-Lorenz contraction and the alteration of a moving clock rate hypothesis. It is commonly known that the further theory development of the alteration of clock rate in a moving frame of reference resulted in the special relativity created by Einstein where both phenomena originally introduced as hypotheses are treated as mere consequences of the special theory of relativity. The first phenomenon has not been observed yet, but as many scientists believe, the discovery of increasing the lifetime of fast mesons and observations of "the transverse Doppler effect" in canal rays say in favour of the latter.

Ives and Stilwell are pioneers in holding the experiment with canal rays and their first results were published in 1938 [1]. But it is worth mentioning that before this paper, four other articles written by Ives [2-5] with the theoretical investigation concerning the analysis of the null effect reason in the Michelson-Morley experiment and other problems involved appeared in the same journal. Here it's interesting to remark that Ives called the observation of the transverse Doppler effect in canal rays as the positive effect in the Michelson-Morley experiment. The last article of those mentioned, Ives entitled "The Doppler Effect Considered in Relation to the Michelson-Morley Experiment". The headline itself says that while holding the experiment with canal rays Ives considered it to be an analogue of the Michelson-Morley experiment and namely so we should treat this experiment nowadays.

That's why we believe that Ives' experiment and its modern development entirely correspond to the present conference schedule.

Now before dealing with the real results of our work I'd like to make some general remarks.

Any physical theory actually is merely modulating features of nature and some processes taking place in it. We think with models but with the progress of science some features of previous models become modified in opposition to the religion. In this evolution the main judge is an experiment, establishing real boundaries of the theory application. The consequence of it is considered to be of value after the repetition of fundamental experiments with a new apparatus and a higher accuracy. And if there are considerable deviations from the previous data it' necessary to analyse these deviations and try to explain them.

The present report offers the results obtained by us recently during the Ives modern experiment with a higher energy in the canal beam, up to 2 Mev.

2. EXPERIMENTAL FOUNDATION

As it is well known, in the special relativity a wavelenght radiated by a moving atom in the laboratory frame is calculated with the help of the following formula :

$$\lambda = \lambda_o \frac{1 - \beta \cos \Theta}{\sqrt{1 - \beta^2}}, \qquad (1)$$

where λ is a wavelength, emmited by the motionless atom, is the angle between the photon path and the direction of the velocity of a moving atom in a beam, $\beta = v/C$, and C is the speed of light.

If $\beta \ll 1$ instead of (1) we have approximately

$$\lambda \simeq \lambda_o - \lambda_o \beta \cos \Theta + 0{,}5\, \lambda_o \beta^2 \qquad (2)$$

In the general case the alteration of clock rate and frequency of a moving atom is the equivalence to appearance of the term $(1 - \beta^2)^{1/2}$ in the denominator of (1) or the same as the quadratic term in (2).

Due to the apparatus arrangement shown schematically in Fig. 1A, after some repetition and equipment modernisation Ives and Stilwell performed the experiment with the results published in papers [6-7]. It is commonly considered that they, by means of this experiment, verified the special relativity. During the observation H_2^+ ions were accelerating in the canal-ray tube with voltages ranging up to 28 kv. There was a special apparatus for the production of the ion beam and an observation chamber where the high-velocity ions were being converted into excited atoms emitting H_β line with the previous speed of ions. In the Ives experiment one could observe three spectral lines simultaneously. In each observation there was a central, undisplaced line accompanied at both sides by two companions corresponding to an angle Θ (blue line) and $180° + \Theta$ (red line). Then it is possible to compare the spectral shifts received with the theoreti-

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 08/26/2015 Terms of Use: http://spiedigitallibrary.org/ss/TermsOfUse.aspx

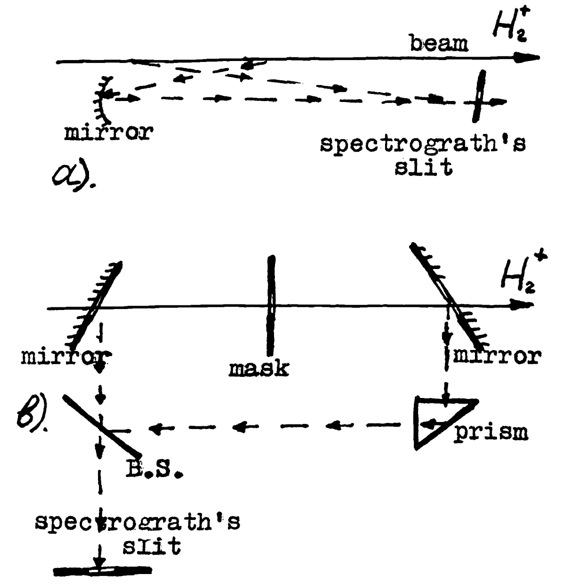

Fig. 1. Principal scheme of apparatus to obtain radiation into a canal-tube
A – used by Ives and Stiwell
B – by Mandelberg

cal prediction $\Delta\lambda_B = \lambda_0(\beta\cos\theta - 0{,}5\beta^2)$ and
$\Delta\lambda_R = \lambda_0(\beta\cos\theta + 0{,}5\beta^2)$

Using those expressions we obtain :

$$\left.\begin{aligned}\Delta\lambda_B + \Delta\lambda_R &= 2\lambda_0\beta\cos\theta\\ \Delta\lambda_R - \Delta\lambda_B &= \lambda_0\beta^2\end{aligned}\right\} \qquad (3)$$

As a consequence; we can calculate the quadratic Doppler shift and compare it with the predicted one. In the repeated experiment Ives and Stilwell [6] increased the energy range of ions H $_2^+$ up to 40 keV and received approximately the verification of previous results.

They dealt with a particular H 4862A line, using an angle $\theta = 7°$ to obtain quite considerable values $\Delta\lambda_B$ and $\Delta\lambda_R$ followed by computation of the quadratic shift.

In 1962 Mandelberg and Witten, using the improved technique achieved the energy of ions up to 78 keV. A principle scheme of their experiment is given in Fig. 1B.

We could tell you about a number of other works in which the expectation of the term $(1-\beta^2)^{1/2}$ in (1) is fulfilled with a higher accuracy. However, in our opinion, they exhibit no direct confirmation of this theory.

In spite of the fact that at present it is very difficult to doubt the truth of the relativistic theory, we are sure that the direct test of the transverse Doppler effect in canal rays, performed in papers [1,6,7] exhibit no convincing feasibility due to a number of reasons :

The apparatus arrangement in the investigation referred to is such that wavelength of lines, emmited near zero and 180°, belong to different parts of space and as a consequence it leads to previous unsimmetry in the position of accompanying spectral lines, the details of it can be found in paper [9]. Moreover, in the real process there may exist another dependence of a wavelength on the angle θ.

In this approach by means of the calculation of the Doppler shift at an angle θ closed to zero we cannot be sure that the shift obtained corresponds to $\theta = 90°$.

3. EXPERIMENT FOUNDATION

In the previous observation the ion energy was too low, not sufficient for reliable obtaining a useful signal from the background. Moreover the spectrogram had many other spurious spectral lines interfering with useful hydrogen lines. The reasons stated and the opportunity to apply new powerful techniques made us repeat the Ives experiment.

As a source of H $_2^+$ ions we applied the accelerator of the V.G. Khlopin Radium Institute Hr – 400 with the energy up to 300 keV and as well as with that up to 2 MeV.

The magnetic analisator gives the necessary component of ions H $_2^+$ from the directed ions beam. In a special chamber there occurred collisions of fast ions with stationary H $_2$ molecules.

The radiation of excited atoms was observed at the angles of 77° and 257°.

For increasing light flow we used a special design collimator, consisting of plain parallel plates, the scheme of which is represented in Fig. 2.

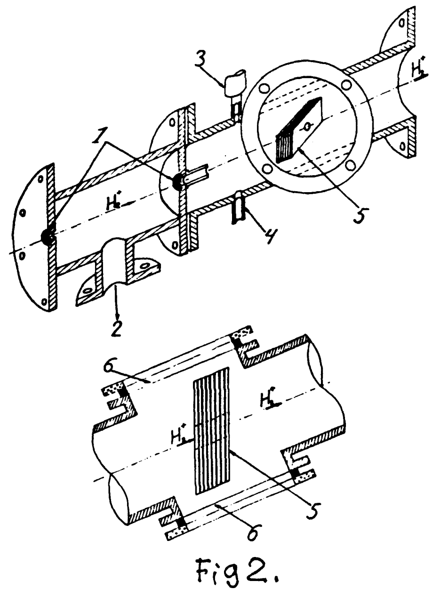

Fig. 2. Arrangement applied by us[8,9].

1 – way of ion's beam, 2 – exit to pump,
3 – thermopair's lamp, 4 – entrance to hydrogen, 5 – collector of light beam,
6 – looking window.

A more detailed description of the apparatus is given in papers [8,9]. Radiation at the angle of 257° with the help of the collimator lens was focused on the spectrograph slit. Radiation at the angle of 77° with the help

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 08/26/2015 Terms of Use: http://spiedigitallibrary.org/ss/TermsOfUse.aspx

of the similar system was focused at the entrance by the flexible optical fiber. Then the radiation was transmitted into the grating spectrograph entry slit. Only three spectral lines appeared in the spectrogram on the light-sensitive photo-plates or films. The observation was carried out on the hydrogen H_α 6563A° line. In the photos one could see and measure the two companions of various intensity, deviated from the central one at considerably various distances. The line corresponding to the observation angle of 77° is less strong since the fiber was used for the observation. Exposition time with the energy of ions ranging from 1.500 to 2.000 keV was about 48 hours, in other cases from 6 to 8 hours.

While processing the plates received, the height of the microphotometer slit was less than that of the lines obtained. For every photo 10 photomeasurings were performed in different spectral sections from the height point of view. The distance between places of spectral lines on the plate or film corrected by means of the method of least squares.

4. MEASUREMENTS AND CALCULATIONS

For excepting a weak unlining of spectrograph dispersion, the approximate polynomial was calculated with the help of 5 lines of neon. Then by using it the exact values of three wavelengths λ_0, λ_R, and λ_B were found.

The transverse Doppler Effect $\Delta'\lambda$ for the fixed angle Θ was determined by two methods. Besides formular (3) $\Delta'\lambda$ value can be measured by the following equation :

$$\Delta'\lambda = \frac{\lambda_B + \lambda_R}{2} - \lambda_0 \qquad (4)$$

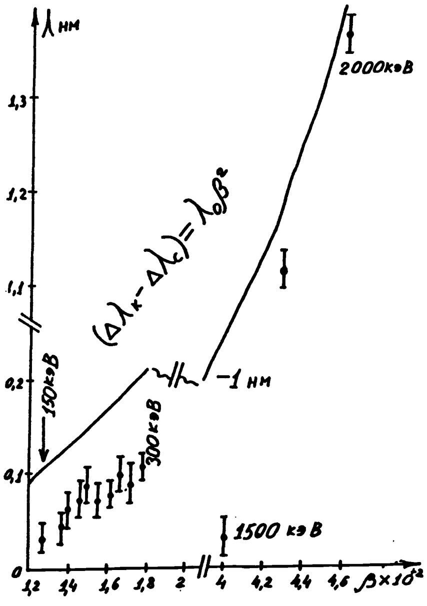

Fig. 3. Observation of the transverse Doppler effect $\Delta'\lambda$ in our experiments[8,9]

To verify the Θ angle we used the formula :

$$\cos\Theta = \frac{\lambda_R - \lambda_B}{2\lambda_0\beta} \qquad (5)$$

The experiment results are represented in Table and Fig. 3.

Table and Fig. 3 show especially considerable deviation of the observation results from the relativistic theory within the range of 150-300 keV.

4.1. Theoretical interpretation of the experimental results. Special theory of relativity.

In order to understand better the results obtained, let us refer to Fig. 4, 5, 6, which show wavelength changes due to increasing.

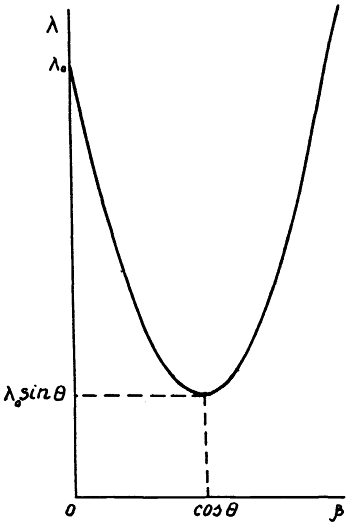

Fig. 4. The Doppler wavelength change into short-side.

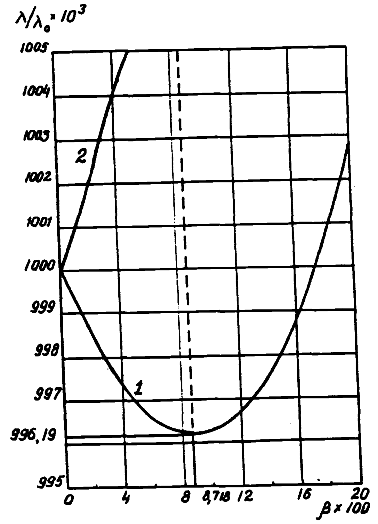

Fig. 5. The computed Doppler wavelength change for H_α line, 1 - blue shift at $\Theta = 85°$ 2 - red shift at $\Theta = 85° + 180°$.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 08/26/2015 Terms of Use: http://spiedigitallibrary.org/ss/TermsOfUse.aspx

Table Experimental Results

VкB	β	Obs. λ_B, A°	Relat. λ_B, A°	Obs. λ_R, A°	relat. λ_R, A°	relat. $\Delta'\lambda_r$	obs. $\Delta'\lambda_{obs}$	$\Delta'\lambda_{obs} - \Delta'\lambda obs.$ $\Delta'\lambda_r$
150	.01263	6545.96$^+$	6546.42	6580.06$^+$	6580.23	.52	.21^{++}	.60
175	.01364	44.16	45.15	81.83	81.67	.61	.19	.69
180	.01384	44.69	44.91	81.14	81.95	.63	.11	.82
200	.01459	43.78	43.98	82.66	83.02	.70	.42	.40
210	.01495	43.09	43.53	83.26	83.54	.73	.37	.49
225	.01547	42.35	42.88	83.94	84.29	.78	.34	.56
250	.01631	41.83	41.85	84.60	85.50	.87	.41	.53
260	.01663	40.70	41.45	85.46	85.97	.91	.28	.69
275	.01711	40.01	40.87	86.49	86.65	.96	.45	.53
300	.01789	39.80	39.94	87.01	87.76	1.05	.61	.42
1500	.03996	6509.01	9.78	6625.72	6625.81	4.99	4.56	.09
1750	.04316	5.64	5.97	32.05	31.34	5.85	6.04	−.03
2000	.04614	3.66	2.49	36.78	36.55	6.72	7.42	−.10

Experimental uncertainty : $\begin{cases} (+) & 0{,}04\ \text{A}^\circ \\ (++) & 0{,}08\ \text{Å} \end{cases}$

Table. Comparison of the results obtained with the theory prediction.

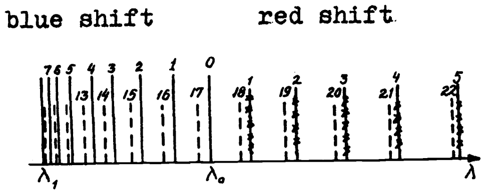

Fig. 6. The spectral H_α line changed due to the step velocity increasing of an atom : (——) blue common shift, (– – –) reflected, (+++) red shift. Numbers indicate value β × 100.

β = β_i when the λ reaches the minimum value, and we call a wavelength $\lambda = \lambda_i$ a short-wave boundary. Fig. 4 and 5 show how λ changes near β_i as a function of β.

4.2. Correlation between the theory and observation results. Fig. 7 and 8 show theoretical and experimental curves calculated with the application of the least squares method. As it can be seen in Fig. 8 a place of min. is considerable shifted from the theoretical prediction. Hence, we consider that this distinction needs mere careful studying in future.

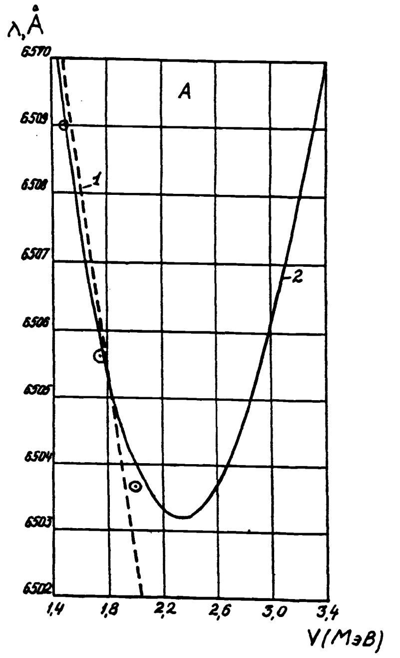

Fig. 7. The blue side shift of the wavelength H_α line due to moving of atoms excited in canal-ray beam.

1 (– – –) is the special relativity curve,
2 (——) is an approximate polynomial.

Experimental points are noted by circles, θ = 1.3469 rad (≈ 77°)
λ min = 6503.22 ± 0.08 Å (V = 2.325 MV, β = 0.0497) instead of λ' min (relat.) = 6403.48 Å (V' = 44.694 MV, β' = 0.2184).

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 08/26/2015 Terms of Use: http://spiedigitallibrary.org/ss/TermsOfUse.aspx

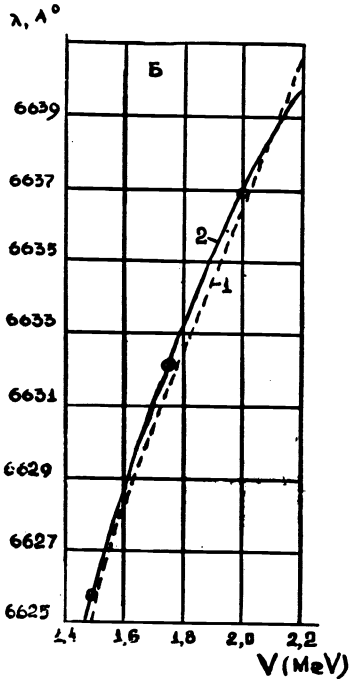

Fig. 8. The same as in Fig. 7, with radiating into the opposite side at the angle of $\theta + 180°$ (red side shift).

3.3. <u>Theoretical interpretation. Classical mechanical approach</u>. Let's consider a moving excited atom, which emits a photon at an angle θ to its direction. Then we can find the λ using the inertia of energy and momentum. In consequence of it we receive the Marinov's [10] formula for the wavelength λ :

$$\lambda = \frac{\lambda_0}{(1 - \beta^2 \sin^2\theta)^{1/2} + \beta\cos\theta} \qquad (6)$$

But the latter can be obtained only in the case if the „rest" photon mass "m" is computed by the formula : $m = 2h\nu_0/c^2$,

where $h\nu_0$ is photon rest energy.

Fig. 9 gives two diagrams of the wavelength dependence as a function of an angle θ . The first of them refers to special relativity, the second one is computed by the Marinov's formula. You can see that the transverse Doppler effect is treated equally as a consequence either of the special relativity or a classical description of breaking down of an excited atom into two particles. To understand the general distinction between both theories instead of (6) it is convenient to use an approximate equation

$$\lambda \approx \lambda_0 (1 - \beta\cos\theta) + 0{,}5\,(1 + \cos^2\theta)\,\beta^2, \qquad (7)$$

taking into opinion (7) we have :

$$\Delta'\lambda = 0{,}5\,(1 + \cos^2\theta)\,\beta^2 \qquad (8)$$

(8) shows a great dependence of the quadratic Doppler effect on the angle θ of observation.

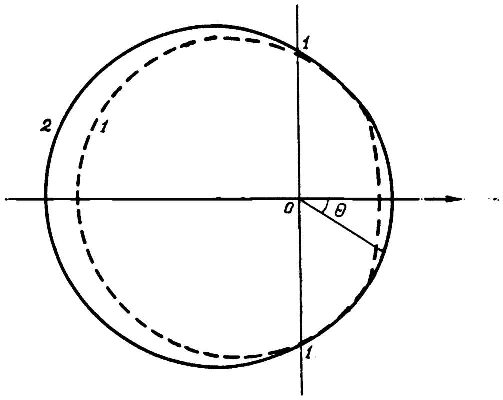

Fig. 9. Diagram of the wavelength dependence as a function of an angle θ . 1 (---) is special relativity, 2 (—) is computed by Marinov's formula [10] . ($\beta = 0,5$)

5. CONCLUSION

1. New experimental results are obtained on the optical Doppler effect in canal rays in the field of energy within the range of 150 - 2.000 keV.
2. The results received by us do not confirm the relativistic theory. Especially considerable deviations (more than twice) are available within the range of 150-300 keV.
3. At an approximate angle of 90° we offer to conduct experiments for finding a real value of short-wave boundary in the Doppler effect.
4. The transverse Doppler effect can be explained at least by two theories : relativistic and classical. Under the experiment conditions chosen by us both theories expect coinciding results. However, it is possible that observation results are substantially effected by other factors unknown before.
5. The principal differences of both theories mentioned lies in the fact that according to the relativistic theory the quadratic shift does not depend on the angle between the photon and direction of the beam, whereas in accordance with the classical theory this dependence is quite obvious.

Thus it is of great interest to conduct in future a special experimental analysis of dependence $\Delta'\lambda$ upon θ.

6. REFERENCES

1. H.E. Ives and G.R. Stiwell, "An Experimental Study of the Rate of a Moving Clock", J. Opt. Soc. Am. v. 28, N°7, 215-226 (1938).
2. H.E. Ives, "Graphical Exposition of the Michelson-Morley Experiment", J. Opt. Soc. Am. 27, N°5, 177-180 (1937).
3. H.E. Ives, "Light Signals on Moving Bodies as Measured by transported Rods and Clocks", J. Opt. Soc. Am. 27, N°7, 263-273 (1937).
4. H.E. Ives, "The Aberration of Clocks and the Clock Paradox", J. Opt. Soc. Am. 27, N° 9, 305-309 (1937).

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 08/26/2015 Terms of Use: http://spiedigitallibrary.org/ss/TermsOfUse.aspx

5. H.E. Ives, "The Doppler Effect Considered in Relation to the Michelson-Morley Experiment", J. Opt. Soc. Am. 27, 389-392 (1937).

6. H.E. Ives and G.R. Stilwell, J. Opt. Am. 28, N°7, 215-226 (1938), 31, 369 (1941).

7. H.I. Mandelberg and L. Witten, "Experimental Verification of the Relativistic Doppler Effect", J. Opt. Soc. Am. 52, N°5, 529-536 (1962).

8. L.A. Pobedonostsev, Ya.M. Kramarovskii, A.B. Berezin, Y.P. Ostrovsky, P.F. Parshin, B.K. Seleznev, "Experimental determination of Doppler shift for hydrogen lines of H_2^+ -ions beams in the energy range 150-2.000 keV., Preprint PU-199/L (V.G. Khlopin Radium Institute), Moscow - 1966.

9. Д.А.Победоносцев, Я.М.Краморовский, П.Ф.Паршин, В.К.Селезнев, А.Б.Березин.
Экспериментальное определение Доплеровского смещения линий водорода на пучках ионов H_2^+ в диапазоне энергий I50-2000 кэВ.
Журнал технической физики, вы.3, стр.84-99, 1989

10. S. Marinov, Phys. Lett., 40A, N°1, pp. 73-74 (1972).

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 08/26/2015 Terms of Use: http://spiedigitallibrary.org/ss/TermsOfUse.aspx