Gravity between moving masses

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In this paper, a previously unknown form of gravity is presented what has been named by "dynamic gravity". Under dynamic gravity, we mean the phenomenon of gravitation between moving masses. The nearly 300-year success of the Newtonian gravitation theory has always been based on the implicit assumption that the gravitational force is the same size between standing and moving masses in non-relativistic cases. In the 1990s, gravitational experiments were carried out in Hungary in which the gravitational effects were studied between moving masses. Surprisingly, the moving source masses generated more powerful gravitational force than expected by the Newtonian gravity. In addition, in these experiments gravitational repulsion also appeared with the same strength as the attraction, depending on the moving directions of the interactive masses. The theoretical investigations have shown that the newly explored gravitational phenomenon is direct consequence of the special relativity.

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I. INTRODUCTION

In this paper, a previously unknown form of gravity is presented what has been named by "dynamic gravity". Under dynamic gravity, we mean the phenomenon of gravitation between moving masses. The nearly 300-year success of the Newtonian gravitation theory has always been based on the implicit assumption that the gravitational force is the same size between standing and moving masses in non-relativistic cases. In the Newton's gravitational theory has central role of the universal gravitational constant G, whose numerical determination since the birth of the Newtonian theory has been of paramount importance in physics. The first laboratory, surprisingly accurate G determination is connected to the name of H. Cavendish [1]. Over the past centuries, many gravitational constant determinations have been made, in a wide range of measurement methods, in laboratories and beyond. In each of the gravitational experiments, the so-called "source masses" that created the measuring gravitational field were static (standing) masses. No one designed gravity measurement at which the source mass (or masses) perform slow, periodic movements. In the 1990s, gravitational experiments were carried out in Hungary in which the gravitational effects were studied between moving masses. Surprisingly, the moving source masses generated more powerful gravitational force than expected by the Newtonian gravity. In addition, in these experiments gravitational repulsion also appeared with the same strength as the attraction, depending on the relative velocity of the interactive masses. Finally, the experienced strong gravitational force has been named dynamic gravity.

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II. GRAVITY AND SPECIAL RELATIVITY

The one of the most important equation of the *special relativity* can be written into the next form

$$E^2 = m^2c^4 + c^2\mathbf{p}^2 = c^2\left(p_0^2 + \mathbf{p}^2\right), \qquad (1)$$

where E is the energy, c is the speed of light, m is the rest mass, $\mathbf{p}$ is the mechanical impulse vector and p_0 is the "static" impulse associated with the rest mass of a point-like object. Let $E_{g,tot}$ be the total relativistic gravitational energy of the multi-body point-like masses

$$E_{g,tot} \propto (\sum_{i,j=1}^{n} p_{0,i}p_{0,j} + \sum_{i,j=1}^{n} p_ip_j). \qquad (2)$$

According to our present knowledge, the gravitational interaction energy is

$$E_g \propto \sum_{i\neq j=1}^{n} p_{0,i}p_{0,j} = -\frac{G}{2\hat{r}}\sum_{i\neq j=1}^{n} m_im_j, \qquad (3)$$

where $\hat{r}$ is an averaged distance value depending on the distribution of the point-like masses, G is the Newtonian constant of gravity. The Eq. (3) supposes that the gravitational energy is the same for static and moving masses in the frame of the Newtonian gravity theory. The reason for this is simply that in the gravitational interactions studied so far, the second member of Eq. (2) was in all cases constant (in most situations it is zero)

$$\sum_{i,j=1}^{n} p_ip_j = const. \qquad (4)$$

That is why the impulse- (speed-) dependence of the gravitational force has not appeared in the Newtonian law of gravity.

III. THE DYNAMIC GRAVITY PHENOMENON

The tacit attitude has remained so far is that the gravitational interaction is independent of the speeds of the interactive masses. It is factual that Newton's gravitational force explicit does not include the speeds of the interactive masses. According to the Eq.(2) the relativistic gravitational energy formula contains the impulse dependence of the interacting masses, including their speed-dependence. The question arises, why does ordinary experience not show the speed dependence of gravity (i.e. dynamic gravity)? We have gave the answer with the Eq. (4) in the previous chapter.

Nevertheless, there is exist a theoretical possibility when the gravitational interaction includes the impulse-dependent gravitational interaction by the relativistic Eq. (2), i.e. for the existence of the dynamic gravitation. This can be occurred when the equation Eq. (4) is not fulfilled. In this general case the energy of gravitational interaction may be the following

$$E_g = -\frac{G_{stat}}{2\hat{r}} \sum_{i \neq j=1}^{n} m_i m_j - \frac{G_{dyn}}{2\hat{r}} \sum_{i \neq j=1}^{n} p_i p_j, \quad (5)$$

where

$$G_{stat} = G \quad (6)$$

is the static gravitational constant which is equal to Newtonian gravitational constant and G_{dyn} is an unknown dynamic gravitational constant.

Probably for the first time in the world, in Hungary in the 1990s, successful gravitational experiments were carried out, where both the source masses and detector masses were in continuous periodical motion. In these experiments, the detector masses were the constituent masses of a relatively large size, vertical, dumbbell-shaped physical pendulum having about 60 - 80 second period. The periodic movement of the source masses continuously increased the amplitude of the pendulum swing by a mysterious strong gravitational effect. By these experiments the presence of the dynamic gravitational effect was clearly demonstrated, what was magnitudes stronger than Newtonian static gravity and what the relatively weak-sensing physical pendulum was able to detect.

The purpose of this paper is to determine the dynamic gravity constant G_{dyn} as precise as possible. In the first step we define this supposed constant theoretically with the investigation of the relativistic *impulse-four vector*. In the second step, we try to reconstruct the measurement data of our gravity experiment with mathematical simulation. This program defines the dynamic gravity constant by comparison with the experimental data.

IV. THE THEORETICAL BACKGROUND OF DYNAMIC DRAVITY

In those gravitational experiments in which the interacting masses are in motion, must be taken account of the second term of Eq. (2) if the Eq. (4) is not fulfilled. The question has long persisted in how to interpret the dynamic gravitational constant G_{dyn} theoretically. In Eq. (1) one can see that the mechanical impulse $\mathbf{p}$ is harmonizes to the "static" impulse $p_0 = mc$. The gravitational interaction, similarly to the electromagnetic interaction, is a product of two factors: the vector of the gravitational force multiplied by the sample mass at the given point of the force field. In case of Newtonian gravity the gravitation field strength is

$$\mathbf{\Gamma}_{stat} = \frac{\gamma}{c}\frac{p_0}{r^2}\frac{\mathbf{r}}{r} = -G_{stat}\frac{m}{r^2}\frac{\mathbf{r}}{r}. \quad (7)$$

where m is the source mass of the static gravity field. Similarly, the field strength vector of the dynamic gravity can be specified

$$\mathbf{\Gamma}_{dyn} = \gamma\frac{\mathbf{p},}{r^2}\frac{\mathbf{r}}{r} = -G_{dyn}\frac{\mathbf{p},}{r^2}\frac{\mathbf{r}}{r}, \quad (8)$$

where $\mathbf{p}$ is the source impulse of the dynamic gravity. According to the last two statements, the numerical value of the dynamic gravitational constant is equal to the static (Newtonian) gravitational constant numerical value multiplied by the numerical value of the light speed

$$\{G_{dyn}\} = \{c\}\{G\}. \quad (9)$$

This means that the theoretically obtained dynamic gravity constant is (in SI system)

$$G_{dyn} = 2.0008... \times 10^{-2}\ m/kg. \quad (10)$$

V. THE DYNAMIC GRAVITY EXPERIMENT

Our unconventional gravity measuring method is illustrated in FIG. 1. The m_s source mass is periodically moved by outer force which causes modulation in the movement of the physical pendulum through an unknown (suspected gravitational) interaction with the lower mass m_p of the pendulum.

Some of the technical features of the realised physical pendulum are

Pendulum arms: 2.5 + 2.5 m
Upper and lower masses: 24 - 24 kg, (cubic lead)
Pendulum frame: made of aluminum
Total mass with frame: 54.7 kg
Support of pendulum: two "in-line" hard steel wedges
Damping: hydraulic damper
Pendulum period: 60 - 80 s
Position detector: optoelectronic

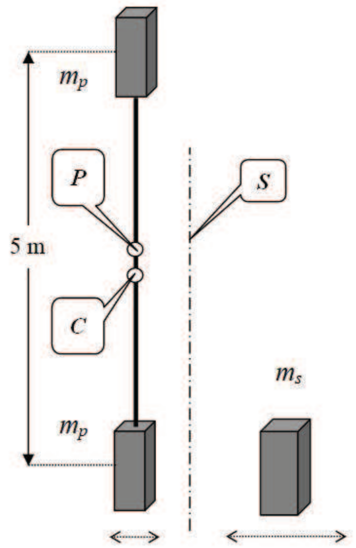

FIG. 1: Setup for gravity measurement. (P: pivot point, C: mass-center, S: iron isolation plate, m_p: pendulum masses, m_s: source mass).

Due to the relatively large dimensions, the period adjustment of the pendulum is relatively easy. The small pendulum amplitude results an acceptable low level of the friction. The test masses used were made of lead cubes. During the control tests, we put an iron isolation plate into the gap between roundtable and pendulum to prevent magnetic and air-draft disturbances. Reliable grounding of the apparatus is necessary for protecting it against the electrostatic disturbances.

The pendulum movement was recorded on-line by a personal computer, and was displayed in zoomed graphic form on computer screen. For the recording of the pendulum movement, an optical measuring system was developed. The sampling period of pendulum position is adjustable between 0.2 and 2.0 s; the resolution of the position detector is about 5 - 10 microns. Our laboratory is situated at about 500 meters from the nearest traffic road, in an environment of low gravitational and mechanical noise. The building of the laboratory is hermetically closed against the outer air draft. Nevertheless, on the floor of the laboratory continuous small mechanical vibrations could be observed, and the coupled vibration energy was transferred to the pendulum. This is a finally not eliminable background noise source of the minimal pendulum movement.

An important part is not shown on FIG. 1, a plastic container filled with water, in which rides a light plastic damping sheet of about 500 cm^2 surface area connected to the lower arm of the pendulum. This works as a hydraulic damper that minimizes the high frequency disturbances of the pendulum. The remaining low frequency components of the background noise cause permanent swinging of the pendulum with amplitude about 2 - 3 mm. To avoid any gravitational noises, no persons should be present in or near the laboratory during measurements.

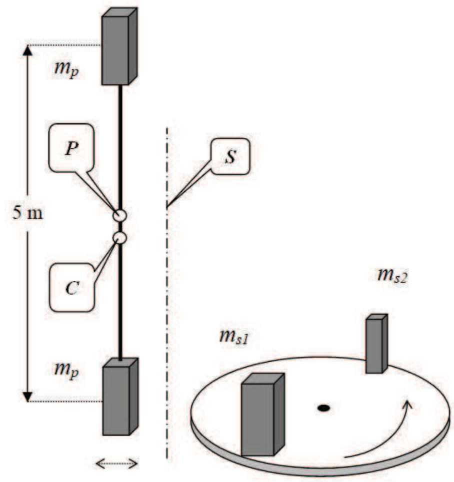

FIG. 2: Setup for a resonance measurement of the dynamic gravity (P = pivot of pendulum; C= mass center of pendulum, S: iron isolation plate, m_p: pendulum masses, $m_{s1,s2}$: source masses).

VI. THE RESONANCE MEASURING METHOD

For the purpose of detailed investigation of the dynamic gravity we have realized a resonance measurement method [2] using the physical pendulum introduced above. The experimental setup of our measurement is shown in FIG. 2.

The two source masses (m_{s1} = 24 kg, m_{s2} = 12 kg,) placed diametrically on a rotating table driven by a small electromotor. The turntable is made of hard wood in our particular case, but generally any non-magnetic material could be used for this purpose. The turntable and its driver system are placed on the floor, while the suspension of the pendulum is fixed to the ceiling of the laboratory. This solution gives a good isolation against the coupled vibrations of the whole instrument.

The preliminary control tests proved that there was no measurable mechanical coupling between the turntable and the pendulum. It has also been shown that the automatic driver system for the source masses movement did not affect the pendulum movement. The radius of the turntable was 0.5 meter; the minimum distance between the source masses and the pendulum lower mass was about 0.25 meter.

In our most successful measurement, the period of the pendulum was about 72 s, and the rotation period of the turntable was about 4 x 72 s = 288 s. The pendulum amplitude increased up to 10 mm from the background noise amplitude (2 - 3 mm). The rotating source masses produced energy transfer to the pendulum amplitude by the dynamic gravity effect.

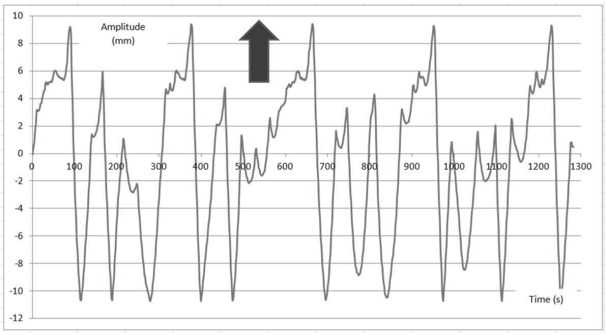

FIG. 3: A part of gravity measure with resonance method. The pendulum movement in "plan view". The black arrow shows the direction of the source masses.

VII. THE SIMULATION OF THE DYNAMIC GRAVITY EXPERIMENT

The motivation of our computer simulation was to prove the validity of the force law of the experienced dynamic gravity. It was supposed that the free pendulum movement is nearly harmonic, considering the relatively very small amplitude of its motion. The dynamic gravity effect acts on the pendulum as excitation force. From the theory of the mechanics, the movement of the pendulum is determined with an inhomogeneous second order differential equation

$$\ddot{x} = -\omega^2 x - 2\lambda\dot{x} + f, \;\; (f = F/m_{eff})\,. \tag{11}$$

Here ω is the natural frequency of the pendulum, λ is the damping factor, F is the acting force to the pendulum, m_{eff} is the effective mass of the pendulum. In optimal circumstances, the pendulum has a sharp resonance curve and the outer excitation force rigorously affects to the pendulum with the same pendulum frequency. In a real situation, these conditions are far from fulfilled. The pendulum behaves as a *broadband radio receiver* in a certain frequency domain. The two rotating source masses act to the pendulum gravitationally with different frequencies. From an approximately periodic part of measured pendulum movement (FIG. 3.) we calculated the dominant pendulum frequencies and their intensities with *Fast Fourier Transformation* (FFT). In the FFT calculation, to the natural pendulum period 72 seconds, the 36 and 18 seconds periods (harmonics) also occurred. In addition, the 144 and 288 seconds periods mainly dominated in the motion movement, which are from the 288 seconds period of the roundtable. Thus for all five harmonics has to solve the motion equation of the pendulum, and then the solutions has to be "super-positioned" with appropriate weight factors. To summarize, the following periods were involved into the computer simulation of the pendulum motion

$$T_n \Rightarrow 288\ s,\ 144\ s,\ 72\ s,\ 36\ s,\ 18\ s, \tag{12}$$

which means that in the movement of the pendulum only the even harmonics are the major ones. For calculation, the speed harmonics of the pendulum motion is required

$$\begin{gathered} v_n = a_n\omega_n \sin\omega_n t; \\ \omega_n = 2^n\omega_0,\ \omega_0 = 2\pi/288s,\ n = 0,1,2,3,4. \end{gathered} \tag{13}$$

At the first stage of the simulation process, the pendulum amplitude was set for a small value, and after the periodic excitation the pendulum amplitude was continuously growing, which was feed backed to the input of the computer program. The reachable maximum amplitude was limited by the damping factor of the pendulum. The excitation of the pendulum movement harmonics

$$\ddot{x}_n = -\omega_n^2 x_n - 2\lambda\dot{x}_n + f_{dyn},\ (n = 0,1,...4), \tag{14}$$

where

$$f_{dyn} = -\frac{G_{dyn}}{m_{eff}}\left(\frac{p_{s1}p_p}{r_1^2} + \frac{p_{s2}p_p}{r_2^2}\right). \tag{15}$$

The given dynamic gravity force density contains the impulses of source masses and pendulum mass, and the distance-squares between them. The solutions of these second-order equations

$$x_n(t) = \int_0^t e^{-\lambda t}\sin\omega_n(t) f_{dyn}(t-\tau)d\tau,\ (n = 0,1,...4). \tag{16}$$

Instead of this convolution integration, *Verlet* integration method [3] was chosen to solve these equations.

The pendulum movement is described by the superposition of the harmonics

$$x(t) = \sum c_n x_n(t) \approx \sum_{n=0}^{4} c_n x_n(t),\ \sum c_n = 1. \tag{17}$$

The amplitudes of the harmonics increase in proportion to the frequency, that is, the power of two, so the superposition weight factors are the following

$$c_n = 2^n / \sum_{k=0}^{4} 2^k,\ (n = 0,1,..4). \tag{18}$$

FIG. 4 shows the final result of the pendulum movement simulation.

VIII. ERROR ANALYSIS

The finally realized simulation program of our gravity experiment contains error calculation. The computer program contains two important parameters; the dynamic gravity constant G_{dyn} and the pendulum damping factor λ. These parameters depend on each other in the final result of the simulation program. Our intention was to determine the dynamic gravity constant with the using of measured data, so the primary condition was to define

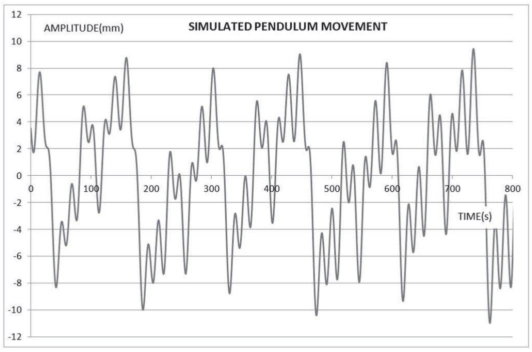

FIG. 4: The simulation of the dynamic gravity measure corresponding to FIG. 3. The calculated pendulum movement vs. time.

the damping factor of the pendulum. Regrettably, the damping factor in this experiment cannot be considered constant. The damping factor of the high swing-period physical pendulum depends on the actual state of the wedges providing the pendulum suspension. According to the experimental tests, the pendulum damping factor can be determined with a relative precision of 4%

$$\lambda = (5.45 \pm 0.22) \times 10^{-4} s^{-1};\ \Delta\lambda/\lambda = \pm 4\%. \quad (19)$$

The relative precision of the sizes of the measuring masses is about

$$\Delta m/m = \pm 2\%. \quad (20)$$

In the simulation program the interactive masses were taking account as a point-like objects, having effect for the G_{dyn} calculation relative error about 3%. This error has been represented simply by mass density error

$$\Delta\rho/\rho = \pm 3\%. \quad (21)$$

In addition, the final result of the simulation program is determined by the continuous distant measures between the moving masses, having about relative error

$$\Delta r/r = \pm 2\%. \quad (22)$$

Finally, the relative standard deviation of the dynamic gravity constant G_{dyn} can be calculated by the Gaussian error propagation law

$$\sigma_{Gdyn} = 6.7\%. \quad (23)$$

The result of the simulation model for the dynamic gravity constant is

$$G_{dyn} = (1.92 \pm 0.13) \times 10^{-2} m/kg, \quad (24)$$

which is considered as the experimental value of G_{dyn}.

IX. CONCLUSION

Based on the experiments carried out so far and by theoretical investigation, it can now safely assert that the strong gravitational effect, i.e. the here described dynamic gravitational interaction really exists between the moving objects (masses) in the nature. The condition for the appearance of dynamic gravity is that the sum of the impulses of the gravitationally interacting objects is not constant, which presupposes the effect of time-depending external force (forces).

The expression of the dynamic gravity force differs significantly from the known formula of the Newtonian gravity force. We have shown in both theoretically and experimentally that the dynamic gravity is proportional to the scalar product of the impulses of the interacting masses. The dynamic gravitational constant G_{dyn} (in numerical value) is the product of the Newtonian constant of gravity multiplied by the speed of light.

The phenomenon of dynamic gravity does not appear in the ordinary experience as spectacularly as Newtonian gravity. The simple reason for this is that, in everyday gravitational phenomena, the big masses being practically in rest state, dominate the static gravitational fields.

Actually, this newly discovered speed dependent gravitational interaction is still unknown in physics and requires further proofs and certifications.

Finally it is important to mention the currently strongly investigated problem regarding with the dark energy and dark matter of the Universe [4]. It seems the dynamic gravity explored in our experiment will help to solve this complicated problem in the future.

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