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Space-Time Relationships and Thermal Effects in Centrifugal Field

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Abstract

Proceeding from the equivalence of gravitational and centrifugal fields, and using the findings of Einstein's theory of gravitation, there were calculated values of relative time dilation and thermal effects caused by compression of samples during centrifugation. The results obtained for the same experimental conditions have been compared, and there has been suggested an idea that there is some correlation between proper time and the thermal effects of the centrifuged samples. This correlation justifies the utilization of energy equivalent of the time. The relative time dilation also depends on other factors, such as the pressure and density of the liquid sample; this one has been substantiated by the respective formulas.

Keywords

Centrifugation, Centrifugal Field, Time Dilation, Thermal Effects, Energy-Time Equivalent

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1. Introduction

Centrifugation is now widely used both at industrial enterprises and laboratories, and in household [1-5]. The principle underlying the operation of the centrifuge is the emergence of centrifugal force at high speed movement of its rotor. In classical mechanics, centrifugal force is defined as the force acting on the moving body (regarded as material point), limiting freedom of movement, forcing it to move on a curve. This force is directed from the center of curvature perpendicular to the trajectory of the moving body. When rotating, or during curvilinear moving, centrifugal force is equal to the value of centripetal one, both forces being directed on the same line, in opposite directions, but applied to different bodies, as forces of action and reaction [6,7]. Maybe, currently such definition is already obsolete, since there may be other, alternative definitions, based on the phenomena that accompany such a move. It is known that during centrifugal separation processes, the centrifugal forces are very similar to the action of gravity, but its value exceeds the value of the gravitational one and decreases essentially duration of the separation process. The ratio of these forces (centrifugal and gravitational) is called relative centrifugal force (RCF), and for corresponding accelerations - relative centrifugal acceleration (or separation factor), and serves as a technical characteristic of the centrifuge [8]:

$$a/g = z \qquad (1).$$

The space, where the centrifugal force being manifested, is called centrifugal field, from the analogy of a gravitational one. However, between these two fields there are essential differences, both by nature and some specific properties. The gravitational field lines of force are considered as being parallel, their convergence toward the center of the Earth is insignificant due to the large size of the planet. Centrifugal force field lines are, however, divergent (radial) from the center of rotation of the body [9], and there are not comparable the distances where can be detected actions of these two types of forces. The need for a more serious approach to centrifugation phenomena is caused by the

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modern tendency to accelerate and direct physicochemical processes in industry. It is known that the conditions of a centrifugal field can influence the kinetics of the processes as well as their direction [10], and this is very important for the chemical, pharmaceutical and other industries. The chemical processes in centrifuge are performed at accelerations of hundreds and even tens of thousands higher than Earth's gravitational acceleration [9,10]. It should be mentioned here, that Jupiter′s gravitational acceleration is 24.92, and that of the Sun is 274 m / s^2, versus 9.81 of Earth [11]. There is a theory, according to which the space-time can be local-anisotropic [12], and considering the universal fractality phenomenon (symmetry of similarity) from atoms and cells to galaxies [13, 14], we can assume that we have the same situation in centrifuge. Fractality is understood here not only in space, but broadly, as well in energy, or generally, in space-time. It is clear that in centrifugal field local major perturbations in space-time occur, as a result we observe mechanic compressing and heating of the samples and other specific phenomena. For example, centrifugation also changes the properties of radioactive substances [15]. That is why the investigations of certain processes in centrifugal field are interesting for physicists and chemists.

2. Purpose and Theoretical Basis of the Paper

The aim of the study was to analyze the localized space-time relationships (in centrifuge), and their relation to thermal effects observed in recently centrifuged samples. As a theoretical basis used in this work there was published material on the phenomena accompanying the centrifugation and their similarity with the gravitational field phenomena and their explanation using equivalence principle and Einstein's theory of gravitation [16-18].

3. Results and Discussions Gravitational Field and the Centrifugal One. Principle of the Equivalence

According to the definition, the gravitational field is the physical field, in which the attraction between two massive bodies occurs. This field is potential, because in them the done mechanical work depends only on the initial and final points position of the moving body, and does not depends on the type of trajectory (the road) between these points [17]. Position of the points is characterized by the some gravitational potential in the field. This potential depends on the mass of a massive body (planet) and is expressed by the following formula:

$$U = G\frac{M}{R} \quad (2),$$

The gravitational acceleration corresponding to the same body mass is the following:

$$g = G\frac{M}{R^2} \quad (3),$$

where G is the universal gravitational constant (G = 6.7545· 10^{-11} $m^3 \cdot s^{-2} \cdot kg^{-1}$, or $N \cdot m^2 \cdot kg^{-2}$), M and R - massive body mass and radius. For Earth these sizes are: M = 5.9736 kg · 10^{26} kg and $R = 6.378 \cdot 10^6$ m [19].

In the General Theory of Relativity (GTR) the gravity phenomenon is explained by the deformation of spacetime, which is greater, where the more massive is the body surrounded by this space-time. In general, the gravitational field can be characterized by the equation:

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu} \quad (4),$$

where $R_{\mu\nu}$ is Ricci's tensor, $g_{\mu\nu}$ - metric tensor, Λ - cosmological constant, R - scalar curvature ($R = g^{\mu\nu} R_{\mu\nu}$), G - universal constant of gravitation, $T_{\mu\nu}$ - stress-energy tensor, and c - speed of light [19,20]. In the homogeneous and not too large regions of spacetime, the gravitational field is manifested similarly to a system moving uniformly-accelerated. The principle underlying such a statement is called Equivalence Principle [17-19]. Considering that the rotation movement of the body is uniform, we can say that this object there is both under a gravitational field and its gravitational acceleration (g_2) coincides by value of a centrifugal acceleration (a_c):

$$g_2 = a_c \quad (5).$$

3.1. Time Dilation in Gravitational and Centrifugal Fields

According to the same theory of Albert Einstein, the proper time of a material point located in the gravitational field of a massive body slows (dilates) [10], and can be expressed by relation:

$$\tau = \tau_1(1 - \frac{U}{c^2}), \text{ or: } \frac{\Delta\tau}{\tau_1} = -\frac{U}{c^2} \quad (6),$$

where $\Delta\tau / \tau_1$ - is relative time dilation of the material point, U - potential of gravitational field of the massive body and c - speed of light. In comparison with the course of time outside the centrifuge, the slowing of centrifuged samples time will be:

$$\frac{\Delta\tau}{\tau_1} = -\frac{U_2 - U_1}{c^2} \quad (7),$$

where U_2 - is the quasigravitaţional potential in centrifuge and U_1 - is Earth's gravitational potential (outside the centrifuge). From the formulas (2) and (3), we observe that $U = gR$, and therefore, equation (7) may be exposed in this way:

$$\frac{\Delta\tau}{\tau_1} = -\frac{(a_c - g_1)R}{c^2} \quad (8),$$

where a_c and g_1 are respectively centrifugal and gravitational (9.81 m/s^2) accelerations. Introducing in formula (8) relative centrifugal acceleration value z from (1), we obtain:

$$\frac{\Delta\tau}{\tau_1} = -\frac{(a_c - g_1)R}{c^2} = -\frac{(z-1)gR}{c^2} \quad (9).$$

The physical quantities g, R and c are constants; therefore, introducing their values in formula (9), we obtain another, more simple formula:

$$-\frac{\Delta\tau}{\tau_1} = \frac{(z-1)gR}{c^2} = \frac{(z-1)9.81\cdot 6.378\cdot 10^6}{9\cdot 10^{16}} = 6.952\cdot 10^{-10}\cdot (z-1) \quad (10)$$

Calculation using formula (10) shows that the relative time dilation in the centrifuge T 52.1 (Germany) having swing-out rotor, at the speeds from two and up to five thousands rpm (or min $^{-1}$) gives, respectively, values of the order of 10^{-6} conventional units. This means that for the motionless observer of centrifugation process, each unit of time, for example, a second centrifuge outside, inside it corresponds (in the end of the rotor arm, depending on the speed, and under studied conditions), " one dilated second ", respectively, with values from 0.466 and to 2.914 microseconds (Table 1).

Table 1. The values of some physical characteristics depending on centrifugation conditions

Rotation speed (thousands min^{-1})	2	3	4	5
Relative centrifugal acceleration (a_c/g)	671	1509	2683	4193
Temperature increasing (˚C)	0.05	0.11	0.19	0.30
Relative time dilation (n·10^{-6})	0.466	1.048	1.865	2.914

3.2. Thermal Effects Versus Time Dilation in the Some Conditions of Centrifugation

Centrifugation of the liquid samples at high speed of the rotor (2-4 thousands rpm, within 15-60 minutes) results in heating of these samples, depending on the speed, up 1 to 9 ℃ [21]. The samples′ heating is caused predominantly by rotor rubbing movement of air in the centrifuge chamber, and the phenomenon of heat transmission from the centrifuge engine. A small share in the heating process is caused by compression of samples under the action of centrifugal force. In the work already indicated [21], there was proposed a formula for evaluating the compression ratio in the thermal effects observed during centrifugation:

$$\Delta T = g(z-1)\frac{V}{c_p \cdot S}\left[1 - \frac{m\beta}{2S}\cdot g(z+1)\right] \quad (11),$$

where: ΔT, V, m, c_p are, respective: temperature increase, volume, mass, specific heat capacity of the sample ($^\circ K$, m^3, kg, $J/kg\cdot{}^\circ K$, respective), S - surface area (m^2) of the bottom of centrifuge glasses, β - compressibility coefficient (m^2 / N) of the liquid sample, g - gravitational acceleration (9.81 m/s^2), and z - relative centrifugal acceleration (or separation factor of the centrifuge). Calculation according to the formula (11) shows that the thermal effect caused by centrifugal compression of samples is small and in our experiment did not exceed decimal degrees value (Tab.1). The information on the thermal effects of the liquids under pressure can be found in literature [22], but they are not considered in connection with their proper time (present in Einstein's theory). Under accelerations of the order of tens of thousands higher than the gravitational one of Earth, the processes may arise otherwise, and therefore it is necessary to take into consideration the proper time of the system. In this paper it has been tried to make the connection between the time and thermal effect using, as a model, Joule's experiment (determining the mechanical equivalent of heat), but performed in the time, i.e. at different centrifugal accelerations. Centrifugal field has its proper local space-time curvature. Changing the rotation speed, and thus, centrifugal acceleration, we change "value" of this curvature being characterized by the ratio of space/time (both, space and time, as complementary parts of space-time unit). The emergence of "centrifugal compression" is accomplished by heating of the centrifuged samples, so, temperature (or ΔT, its change) may serve as the size that characterizes the "value" of a space-time curvature. Another size, which characterizes the "value" of this curvature, is "time dilation" Δτ/τ. It isn′t the cause of thermal effect during centrifugation, but both sizes (ΔT and Δτ/τ) characterize the ratio space/time. Hence, the change of this ratio videlicet is the cause of "time dilation" and thermal effect. Between these two sizes (ΔT and Δτ/τ), there is a formal mathematical correlation only. Using this correlation, we may evaluate the energy changes in the physically real time. This method is not the best, but at the moment we have no another one. Because the time dilation and thermal effects during centrifugation were analyzed for one and the same physical conditions, we can make a connection between these results. To do this, we take out the expression $g(z-1)$ from the formulas (9) and (11), common to both formulas:

$$g\,(z-1) = -\frac{\Delta\tau}{\tau_1}\cdot\frac{c^2}{R} \text{ and } g\,(z-1) = \frac{\Delta T\cdot c_p\cdot S}{V\left[1-\frac{m\beta}{2S}\cdot g(z+1)\right]} \quad (12).$$

Putting the values from the right site of the formulas (12) in equality, we can obtain:

$$-\frac{\Delta\tau}{\tau_1} = \frac{\Delta T\cdot c_p\cdot S\cdot k}{V\left[1-\frac{m\beta}{2S}g(z+1)\right]} \quad (13),$$

where $k = R\,/\,c^2 = 0.7087$ (s^2/m) is the ratio of radius of the Earth to the square speed of the light. From this formula (13), we see that the relative time dilation is proportional to the temperature increasing value of the samples. Here there appear the assumptions that in general case the changing of energy state of a body (system) leads to a change of his proper time (Table 1). In analogy with thermal equivalent of mechanical work there can be introduced in use the notion of heat (or energy) equivalent of the time - the amount of energy required to change the physical body's proper time by 1 second. Since the thermal effect depends on the mass and nature (substance) of the body, the notion of specific energy-temporal capacity (for the unit of mass) for this substance would be required. This feature physical quantity can be calculated from the formula for the amount of the heat received from the heating due to centrifugal compression:

$$Q = mc_p\cdot\Delta T \quad (14)$$

where ΔT is the temperature increasing calculated using the formula (11).

Dividing the expression (14) to $m\cdot\Delta\tau$, we obtain the value for specific energy-time capacity of substance:

$$q_\tau = c_p\cdot\frac{\Delta T}{\Delta\tau} \quad (15),$$

were c_p is specific thermal capacity ($J\,/\,kg\cdot{}^\circ K$), ΔT - temperature (°K) increasing caused by centrifugal compression and $\Delta\tau$ - time dilation (seconds) for concrete conditions of the experiment. The unit for the specific energy-time capacity q_τ will be $J\,/\,kg\cdot s$. It is possible that use of such concepts could contribute to understanding the nature (essence) of real physical time and evaluate the increasing (or descreasing) of energy in the body moving from one to another time-system. Also this would extend the area of traditional laws of thermodynamics and responds to question if a time travel is possible. Another aspect of the space-time problem is the relationships between the pressure and time dilation in centrifugation process. Chemical processes at high pressure differently occur than in "normal" conditions [10], so in other space-time relationships. As is well known [23], the pressure (N/m^2) in the liquid subjected to centrifugation can be expressed by the formula:

$$P = \frac{\rho\omega^2\,(R_2^2-R_1^2)}{2} \quad (16),$$

where ρ is the density of sample liquid (kg/m^3), ω - centrifugal acceleration (rad/s), R_2 and R_1 are the distances (m) of extremities of a horizontal liquid column (during centrifugation) from the rotation axis. Relative changing of the frequency (ν) of a cyclic process (effect Mössbauer on a rotating disc) [24] depending on centrifugal acceleration (ω) is the following:

$$\frac{\Delta\nu}{\nu_1} = \frac{\omega^2\,(R_2^2-R_1^2)}{2c^2} \quad (17),$$

where $\omega = 2\pi\cdot n$ in the rotation movement, n - rotation speed, and c - speed of light. Comparing (16) and (17), and taking into account results from [25, 26] as well as the equality

$$\frac{\Delta\nu}{\nu_1} = -\frac{\Delta\tau}{\tau_1} = \frac{\Delta U}{c^2} \quad (18),$$

we can obtain:

$$-\frac{\Delta\tau}{\tau_1} = \frac{P}{\rho c^2} \quad (19).$$

From (19) there can be observed that relative time dilation depends on the pressure P, exerted on the liquid sample and its density ρ.

4. Conclusions

1. Analyzing the physical conditions of centrifugation and comparing them with the same ones in gravitational field, and having as theoretical basis the principle of equivalence, and Einstein's theory of gravitation, it was assumed that centrifugal effects are due to the specific spatial-temporal relationships during centrifugation, different from the ones outside the centrifuge.

2. It was evaluated by calculation, the time dilation in a located space of the centrifugal field, limited only by the range of the centrifugal force in the concrete experimental conditions. It was also mentioned that this time dilation depends on temperature, pressure and density of the liquid sample.

3. Comparing the values of proper time dilation and thermal effects of the centrifuged samples under the same physical conditions, certain relationships between these interdependent quantities have been assumed and it was proposed to introduce the notion of energy equivalent of time, and, respectively, the specific energy-time capacity of the substances.

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