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# ANTIGRAVITY EFFECTS IN GENERAL RELATIVITY*

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The strong antigravity effects following from the Mathisson–Papapetrou equations for a highly relativistic spinning particle are discussed.

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## 1. Introduction

An important stage in the general relativistic investigations is connected with the equations which describe motions of a spinning test body (particle) in a gravitational field. Mathisson was the first who derived these equations [1] and later the same equations were obtained by many other authors [2]. Some correspondence between the Dirac and Mathisson–Papapetrou (MP) equations is studied [3].

It follows from the MP equations that there is a significant dependence of the spin–gravity coupling on the velocity of a spinning particle relative to a source of the gravitational field. In [4], the spin–spin and spin–orbit gravitational interactions in Kerr's background were considered when the particle's velocity is not high. New situations which arise at highly relativistic velocity were under investigations in [5–8]. Below, we shall consider some examples which show the strong antigravity action caused by the spin–gravity coupling in Schwarzschild's background.

## 2. Spin in gravitational field of a fast moving mass

Why the high value of the spinning particle velocity is important in the spin–gravity effects? To answer this question, let us consider a situation that is similar to the one known in electrodynamics, when the electromagnetic

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field of a moving electric charge is under consideration. Now, we are interested in the gravitational field of a moving mass. Following many papers where the deeper analogies between gravitation and electromagnetism are under investigation, we consider the gravitoelectric $E^{(i)}_{(k)}$ and gravitomagnetic $B^{(i)}_{(k)}$ components of the gravitational field [9]

$$E^{(i)}_{(k)} = R^{(i)(4)}{}_{(k)(4)}\,, \tag{1}$$

$$B^{(i)}_{(k)} = -\frac{1}{2}R^{(i)(4)}{}_{(m)(n)}\varepsilon^{(m)(n)}{}_{(k)}\,, \tag{2}$$

where the local (tetrad) components of the Riemann tensor are present.

There is a relationship following from the MP equations in the linear spin approximation for Schwarzschild's background with the mass $M$ [6]

$$a_{(i)} = \frac{s_{(1)}}{M}B^{(1)}_{(i)}\,, \tag{3}$$

where $a_{(i)}$ are the local components of the particle 3-acceleration relative to geodesic free fall as measured by the comoving observer; $s_{(1)}$ is the single nonzero component of the particle spin. The important point is that the nonzero values of $B^{(1)}_{(i)}$ at high velocity essentially depend on the relativistic Lorentz $\gamma$ factor and, as a result, the absolute value of the 3-acceleration is proportional to $\gamma^2$ [6]. That is, from the point of view of the observer comoving with a spinning particle in Schwarzschild's background, the spin–gravity interaction becomes much greater at high velocity.

## 3. Examples of strong antigravity effects with spinning particle

Let us consider some simple cases of highly relativistic motions of a spinning particle in Schwarzschild's background which starts from $r = 3M$. By the geodesic equations, a spinless particle with nonzero mass of any velocity close to the velocity of light, starting in the tangential direction from the position $r = 3M$, will fall on the horizon surface withing a finite proper time. According to the MP equations, a spinning particle can remain indefinitely on the circular orbit with $r = 3M$ due to the highly relativistic spin–gravity coupling, *i.e.*, here this coupling acts on the particle as a strong repulsive force which compensates the usual (geodesic) attraction [7].

Figure 1 corresponds to the highly relativistic noncircular equatorial motions of a spinning particle in Schwarzschild's background with different initial values of the tangential velocity and some fixed small initial value of the radial velocity directed to the Schwarzschild source. In all cases, the particle starts clockwise from the position $r = 3M$ and $\varphi = 0$, in the polar

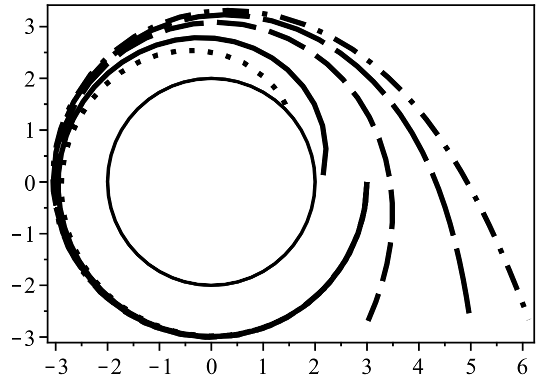


Fig. 1. Noncircular trajectories of a spinning particle at different initial values of the tangential velocity. The circle corresponds to the horizon line.

coordinates. The solid line corresponds to the tangential velocity on the circular orbit with $r = 3M$, and the dashed line, long-dashed and dash-dotted lines illustrate the cases when this velocity is multiplied by 2, 4 and 6 correspondingly. According to the solid line, the spinning particle falls on the horizon due to the nonzero radial velocity (for comparison, the dotted line in Fig. 1 shows the trajectory of the spinless particle which begins to move with the same initial conditions). The three other curves show that the spinning particle goes away from the Schwarzschild source, whereas by the properties of the geodesic lines in Schwarzschild's metric, the spinless particle in all these cases falls on the horizon. Figure 1 illustrates how the spin–gravity repulsive action increases with the tangential velocity.

More general significantly nongeodesic motions of a spinning particle in Schwarzschild' and Kerr's background caused by the highly relativistic spin–gravity coupling are considered in [8]. In some partial situations, these motions are described by the solutions of the MP equations which are close both to the Mathisson–Pirani and Tulczyjew–Dixon supplementary conditions. However, in general, the second condition has the concrete restrictions in the highly relativistic region of the particle motions [8].

Note that dependently on the correlation between the spin and orbital velocity, the spin–gravity coupling acts as a repulsive or an additional attractive force [5–8].

## 4. The concluding remarks

It follows from the MP equations that general relativity is both the theory of gravity as a generalization of the Newtonian description of gravity and, in the certain sense, predicts the effects of strong antigravity in some extremal situations which is impossible in the Newtonian theory. By the numerical estimates, some particles in cosmic rays posses a sufficiently high $\gamma$ factor for motions on the significantly nongeodesic orbits near black holes [8].

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