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# Guidelines to Antigravity\*

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(Received 12 September 1962)

This paper emphasizes certain little known aspects of Einstein's general theory of relativity. Although these features are of minor theoretical importance, their understanding and use can lead to the generation and control of gravitational forces. Three distinctly different non-Newtonian gravitational forces are described. The research areas which might lead to methods for the control of gravitation are pointed out and guidelines for initial investigation into these areas are given.

## INTRODUCTION

EINSTEIN'S general theory of relativity provides a number of ways to generate non-Newtonian gravitational forces. Theoretically, all of these forces could be used to counteract the gravitational field of the earth, thus acting as a form of antigravity. The three outlined here were probably known by Einstein before he published his paper on the principle of general relativity in 1916.<sup>1</sup> They were first specifically derived by Thirring<sup>2</sup> in 1918, and since then have been contained in nearly every text on general relativity.<sup>3-5</sup>

Although non-Newtonian forces are well known to the theorists in general relativity, they are little known to those outside the field, and it was for this reason that it was felt that a simplified discussion of these unusual gravitational effects would be of interest to the nonspecialist.

The equations of general relativity not only predict the usual radial Newtonian gravitational force behavior of a stationary mass on a stationary test body, but they also predict that a moving mass can create forces on a test body which are similar to the usual centrifugal and Coriolis forces, although much smaller. In addition, when the general relativity field equations are linearized, they result in a set of dynamic gravitational

field relations similar to the Maxwell relations. Thus one can use intuitive pictures from electromagnetic theory to design theoretical models. Whether the effects predicted by the linearized theory really exist, will, of course, have to be checked by repeating the calculations with the nonlinearized field equations.

The essential point is that all of these unusual forces create accelerations which are independent of the mass of the test body and the forces are, therefore, indistinguishable from the usual Newtonian gravitational force.

## NON-NEWTONIAN GRAVITATIONAL FORCES

### Effect of Rotating Masses on Stationary Bodies

By using Einstein's general theory of relativity for a rotating system of masses, it can be shown that in addition to the usual Newtonian term, the gravitational scalar potential contains terms which arise from the rotation of the body. One of the shapes which has been rigorously investigated is the rotating massive ring.<sup>3</sup>

For a massive ring rotating in the  $x$ - $y$  plane, the non-Newtonian acceleration on a stationary test body near the origin is approximately

$$\begin{aligned}\ddot{x} &= (MG\omega^2/2c^2R)x, \\ \ddot{y} &= (MG\omega^2/2c^2R)y, \end{aligned} \quad (1)$$

and

$$\ddot{z} = -(MG\omega^2/c^2R)z.$$

Where  $M$  and  $R$  are the mass and radius of the ring,  $\omega$  is the angular velocity,  $G = 6.67 \times 10^{-11}$  m<sup>3</sup>/kg-sec<sup>2</sup> is the Newtonian gravitational constant,  $c$  is the speed of light, and  $x$ ,  $y$ ,  $z$  are the coordinates of the test body with respect to the origin of the rotating mass. From these equations it is evident that the rotating mass not only

\* This paper was submitted as an essay to the Gravity Research Foundation in 1962 and received the Second Award.

<sup>1</sup> A. Einstein, *Ann. Phys.* (New York) **49**, 769 (1916); see also A. Einstein, *Principle of Relativity* (Dover Publications, Inc., New York, 1923).

<sup>2</sup> H. Thirring, *Z. Phys.* **19**, 33 (1918); and **22**, 29 (1921).

<sup>3</sup> C. Möller, *The Theory of Relativity* (Oxford University Press, London, 1952), pp. 317ff.

<sup>4</sup> J. Weber, *General Relativity and Gravitational Waves* (Interscience Publishers, Inc., New York, 1961), p. 160.

<sup>5</sup> J. Landau and E. Lifshitz, *The Classical Theory of Fields* (Addison-Wesley Publishing Company, Inc., Reading, Massachusetts, 1959).

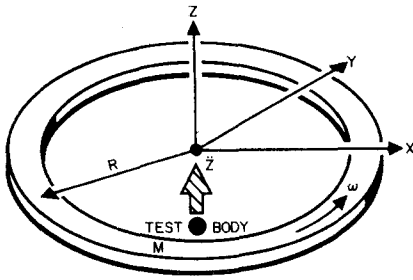


FIG. 1. Non-Newtonian component of acceleration on a test body below the center of a rotating massive ring.

forces the test body away from the axis in an imitation of centrifugal force, but also pulls it upward into the plane of rotation as shown in Fig. 1.

#### Effect of Rotating Masses on Moving Bodies

It has been pointed out that a rotating mass will exert a force similar to centrifugal force on a stationary test body; also, if the test body is moving at some constant velocity  $\mathbf{v}$ , it will experience an additional force which is proportional to the cross product of the angular velocity of the rotating mass and the linear velocity of the test body. The additional force can be compared with two others: mechanically, it acts like a very weak Coriolis force; electrically,<sup>4,6</sup> it acts like the gravitational equivalent of the Lorentz force on a charged particle moving through a magnetic field.

One of the shapes which has been investigated is the rotating massive spherical shell. The acceleration on a test body moving with a velocity  $\mathbf{v}$  inside the shell is approximately<sup>4</sup>

$$\begin{aligned}\ddot{x} &= (GM/3c^2R) \left[ \frac{4}{5}\omega^2x - 8\omega v_y \right], \\ \ddot{y} &= (GM/3c^2R) \left[ \frac{4}{5}\omega^2y + 8\omega v_x \right],\end{aligned}\quad (2)$$

and

$$\ddot{z} = -(8GM\omega^2z/15c^3R),$$

where  $v_x$  and  $v_y$  are the  $x$  and  $y$  components of the velocity of the test body and  $M$  and  $R$  are the mass and radius of the spherical shell. The first term in each expression is the centrifugal-type force on a stationary test body described in the previous section. The second term in the  $x$  and  $y$  components of the acceleration depends

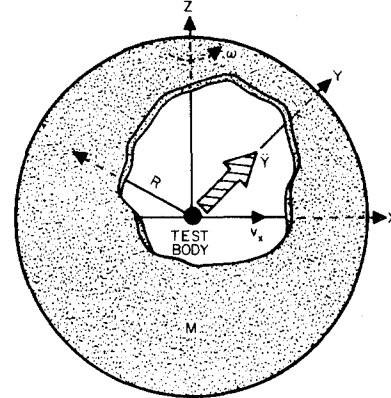


FIG. 2. Non-Newtonian component of acceleration on a test body with a velocity  $v_x$  at the center of a rotating massive sphere.

upon the velocity of the test body as shown in Fig. 2.

#### Effect of Accelerated Masses on Stationary Bodies

In employing Einstein's Theory to investigate the effect of a large accelerated mass on a small test body, it is found that the accelerated body drags the test body along with it. The exact equations are<sup>4</sup>

$$\begin{aligned}\ddot{\mathbf{r}} &= \nabla(GM/R) + (4GM/c^2R)\mathbf{a} \\ &\quad + (4GM/c^3)(\mathbf{a} \cdot \mathbf{R}/R^2)\mathbf{v}, \quad (3) \\ &= F_1/m + F_2/m + F_3/m,\end{aligned}$$

where  $M$ ,  $\mathbf{a}$ , and  $\mathbf{v}$  are the mass, acceleration, and velocity of the large body, respectively, and  $\mathbf{R}$  is the distance from the small body to the large body. In addition to the usual Newtonian attraction, the test body experiences forces in the direction of the acceleration and the velocity of the large body as shown in Fig. 3.

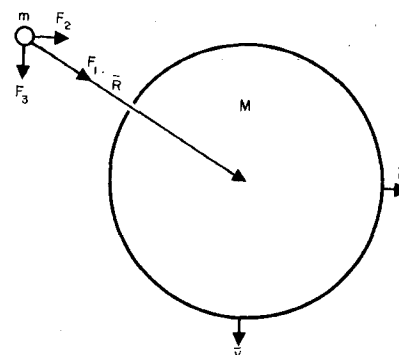


FIG. 3. Forces on a test body near a massive, accelerating, moving body.

<sup>6</sup> Robert L. Forward, Proc. IRE 49, 892 (1961).

## CREATING NON-NEWTONIAN GRAVITATIONAL FORCES

### Devices Using Moving Masses

The equations in the previous section contain two common factors. One is the Newtonian gravitational field,

$$GM/r^2 \approx (4\pi/3)G\rho r, \quad (4)$$

and the other is the ratio of the characteristic system velocity to the velocity of light such as

$$v^2/c^2 \text{ or } ar/c^2. \quad (5)$$

In order to obtain measurable amounts of gravitational force, these quantities must be as large as possible. To obtain a high gravitational field, either a large mass or a high density is required. The greater the density, the less total mass necessary to achieve the same gravitational field.

To obtain high rotational velocities, we cannot use the mechanical strength of materials since this limits the obtainable equatorial velocities to approximately the speed of sound.<sup>7</sup> Because of this, it will be necessary to use fields to hold the systems together under inertial stresses. One example would be the high gravitational fields obtainable with dense matter. However, any practical device which might be constructed would probably use electric or magnetic fields. By using electromagnetic forces to contain rotating systems, it would be possible for the masses to reach relativistic velocities; thus a comparatively small amount of matter, if dense enough and moving fast enough, could produce usable gravitational effects.

An example of a system held together by gravitational fields is a contact binary dwarf star system. The force equation describing the mutual rotation of the stars is

$$-(GMM/(2r)^2) = -M\omega^2 r = -(Mv^2/r). \quad (6)$$

A particle coming near the system will experience not only a radial acceleration<sup>4</sup>

$$\ddot{x}_r = -GM \left[ \frac{1}{(b-r)^2} + \frac{1}{(b+r)^2} \right] - \frac{4GMa}{c^2} \left[ \frac{1}{b-r} - \frac{1}{b+r} \right], \quad (7)$$

but also a tangential acceleration

$$\ddot{x}_t = -\frac{4GMva}{c^3} \left[ \frac{1}{b-r} + \frac{1}{b+r} \right] \approx \frac{1}{c^3 b} \left( \frac{GM}{r} \right)^{\frac{3}{2}}, \quad (8)$$

where  $b$  is the distance of the particle from the center of the system.

In applying these equations to a test object (such as a space vehicle) passing by this star system, it is evident that, in general, the radial acceleration will not introduce any net change in velocity, but that the tangential acceleration will transfer energy and momentum to the vehicle. For a neutron binary star, this acceleration can be greater than one million  $g$ 's; although these accelerations seem very high, there are no stresses on the human body because the forces are gravitational. Such systems could be used to accelerate space vehicles to nearly the speed of light.

### Devices Based on Analogies between Electromagnetic and Gravitational Fields

There are other types of devices for obtaining non-Newtonian gravitational forces which follow from the known electromagnetic analogies based on Einstein's general theory of relativity; however, these devices have not been analyzed using the complete field equations. For instance, two rotating gyroscopes should repel each other if oriented properly, and two pipes with massive liquid flowing through them should exhibit a pinch effect.

Although the rotating gyroscopes and flowing masses should exhibit non-Newtonian forces, the linearized theory does not predict an interaction with a stationary test body. A device which electromagnetic analogies predict might be able to create a non-Newtonian gravitational force that will accelerate a nonrotating, nonmoving body is one that contains accelerated masses whose mass flow is like the current flow in a wire wound torus.<sup>8</sup> If we look at the electromagnetic model, a current  $I$  through the wire causes a magnetic field in the torus. If the current constantly increases, then the magnetic field also increases with time. This time-varying magnetic field then creates a dipole electric field. (Fig. 4.)

<sup>7</sup> J. W. Beams, *Sci. Am.* **204**, No. 4, 134 (1961).

<sup>8</sup> Robert L. Forward, *Proc. IRE* **44**, 1402 (1961).

The value of the electric field at the center of the torus is

$$E = -\dot{B} = + (d/dt) (\mu N I r^2 / 4\pi R^2), \quad (9)$$

where  $R$  is radius of the torus,  $r$  is the radius of one of the loops of wire wound around it, and  $N$  is the total number of turns.

If we replace the wires with pipes carrying a massive liquid, then the known analogy between the electromagnetic and gravitational fields can now be used.<sup>6</sup> All the electromagnetic quantities are transformed to their equivalent gravitational quantities to obtain

$$G = -\dot{K} = -\frac{d}{dt} \left( \frac{\eta N T r^2}{4\pi R^2} \right), \quad (10)$$

where  $G$  is the gravitational field generated by the total mass current  $NT$ , and  $\eta = 3.73 \times 10^{-26}$  m/kg is the gravitational equivalent to the magnetic permeability.<sup>6</sup> (See Fig. 5.)

It is important to notice in the above equation that the time derivative operates on the entire quantity in the brackets. One would normally say that all quantities are independent of time except the mass flow  $T$ . If the amount of mass flow increases with time, then  $\dot{T} > 0$ , and thus a gravitational field  $G$  can be generated. However, in electromagnetism, the permeability of some materials such as iron is nonlinear, which allows the construction of highly efficient electromagnetic field generators. A material with a highly nonlinear  $\eta$  would also be useful in the construction of efficient gravitational field generators.

## RESEARCH AREAS

### Dense Materials

It has been emphasized that in order to achieve measurable gravitational effects with moderate amounts of mass, dense matter is required. Thus, the study of degenerate matter could lead to the generation and control of gravitation. Methods must be found to manufacture, contain, and control matter with densities from  $10^8$  to  $10^{15}$  g/cm<sup>3</sup>. The best starting point appears to be an investigation of the neutron-neutron interaction. By using extremely low temperatures and strong magnetic fields, one should be able to cool the thermal neutrons from a pile and concentrate

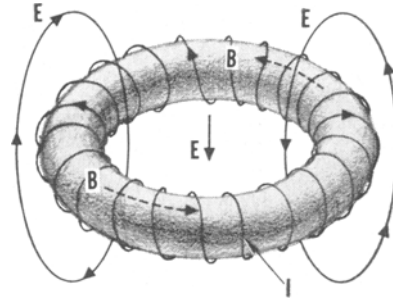


FIG. 4. Generator of a dipole electric field.

them into a small region through the interaction of the magnetic field with the magnetic moment of the neutron.<sup>9</sup> The Fermi energy will limit the density to about  $10^{-6}$  g/cm<sup>3</sup>, but the formation of tetra-neutrons ( $n^4$ ) or the existence of a superconductive-type phase space condensation will create bosons which do not have this limitation. The results of a more comprehensive study of the properties of a cold neutron gas and the methods for containment will be given in a future paper.

### Gravitational Properties of Matter

In studying analogies between electromagnetism and gravitation, it can be seen that one analogous quantity has not been investigated. This is the gravitational equivalent to the magnetic permeability. Electrical power distribution systems depend upon the anomalously large and nonlinear permeability of iron and other magnetic materials. Since all atoms have spin, all materials will have a gravitational permeability which is different from that of free space. Rough calculations show that this difference is very small, but experimental investigation may

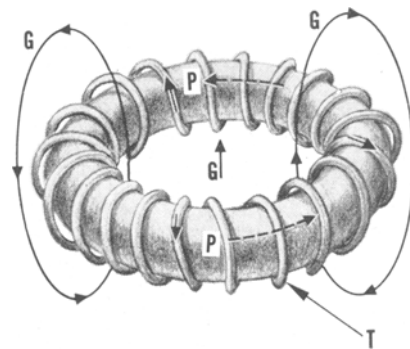


FIG. 5. Generator of a dipole gravitational field.

<sup>9</sup> V. V. Vladimirkii, Soviet Phys.—JETP **12**, 740 (1961).

find materials with anomalously large or non-linear properties that can be used to enhance time-varying gravitational fields. Also, since the magnetic moment and the inertial moment are combined in an atom, it may be possible to use this property to convert time-varying electromagnetic fields into time-varying gravitational fields. At present, the only way to search for such materials is to intersperse wedges of material between gravitational wave generators and detectors, such as those described by J. Weber,<sup>10</sup> and look for a change in amplitude or direction of propagation. The first efforts in this direction<sup>11</sup>

have been carried out by the Russian workers Braginsky, Rudenko, and Rukman with negative results.

It is obvious that research in the field of gravitation will be very difficult since even the most optimistic calculations indicate that very large devices will be required to create usable gravitational forces. Antigravity, like space travel, will probably have no direct effect on the daily life of the average person. Future progress in the control of gravitation, like all modern sciences, will require special projects involving large sums of money, men, and energy.

<sup>10</sup> J. Weber, *Phys. Rev.* **117**, 306 (1960).

<sup>11</sup> V. B. Braginsky, V. N. Rudenko, and G. I. Rukman,

*Zhur. Eksp. i Theoret. Fiz.* **43**, 51 (1962) (in Russian with English abstract).

## Lagrangian Solutions of the Equations of Motion in Fluid Mechanics by Integrating Certain Types of Nonlinear Ordinary Differential Equations

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(Received 16 July 1962)

The classical problems of the forced motion of a fluid particle induced by the motion of solid bodies immersed in an incompressible and nonviscous fluid of unbounded extent are solved by integrating nonlinear equations of the type:

$$(d^2r/dt^2) + P(r,t)(dr/dt)^3 + Q(r,t)(dr/dt)^2 + R(t)dr/dt = 0,$$

and

$$(d^2r/dt^2) + M(r)(dr/dt)^3 + N(r,t)dr/dt + S(r,t) = 0.$$

The solutions of the Lagrangian equations of motion instead of the usual Euler's equations furnish better physical insight. The second integrals are evaluated in terms of both elliptic integrals and series for the problem of cylinder, and hyperelliptic integrals and series for the sphere. A systematic method of integrating nonlinear equations of this type is discussed. The problem of a half-body is also discussed.

### I. INTRODUCTION

WE propose to investigate first a class of equations which are nonlinear in one coordinate frame formed by dependent and independent variables and integrated by choosing a new coordinate frame formed by new dependent and independent variables. That is to say, the nonintegrability of the original equation is due to an improperly chosen coordinate frame. We wish to study systematically the method of finding the right frame.

In this paper, we consider a class of equations having the forms:

$$(d^2r/dt^2) + P(r,t)(dr/dt)^3 + Q(r,t)(dr/dt)^2 + R(t)(dr/dt) = 0, \quad (I)$$

$$(d^2r/dt^2) + M(r)(dr/dt)^3 + N(r,t)dr/dt + S(r,t) = 0. \quad (II)$$

Equations (I) and (II) appear often in applied mechanics. We apply this method to the problem of the forced motion of fluid particles of a non-