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The Direction of Gravity

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Abstract How much do we really know about gravity? Though our knowledge is sufficient to send people to the Moon, there is a large and fundamental gap in our empirical data; and there are basic questions about gravity that are rarely even asked, and so remain unanswered. The gap concerns the falling of test objects near the centers of larger gravitating bodies. Newton's theory of gravity and Einstein's theory, General Relativity, though giving essentially the same answers, describe the problem quite differently. A discussion of this difference—which emphasizes the role of *clock rates* in Einstein's theory—evokes a question concerning the most basic characteristic of any theory of gravity: Is the motion due to gravity primarily downward or upward; i.e., inward or outward? Have our accepted theories of gravity determined this direction correctly? The answer to this question may seem obvious. We will find, however, that we don't really know. And most importantly, it is emphasized that we can get an unequivocal answer by performing a relatively simple laboratory experiment.

1 Introduction

We don't know the first thing about gravity. Our empirical knowledge of gravity suffers from a large gap that cuts through the middle of every body of matter. What we do know about gravity derives primarily from centuries of observations of moving objects over and beyond the surfaces of astronomical bodies like the Earth and Sun. The question is, how do small bodies fall through the *centers* of larger bodies?

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Suppose, for example, that a ball of matter falls into a hole drilled through the center of a larger massive sphere. (See Figure 1.) Presently, nobody knows the fate of the falling object because gravity-induced motion through $r = 0$ (as in the figure) has never been observed. Since zero is the natural starting point of any investigation, this is arguably the first, or at least one of the first things we should like to know. We simply want to complete the graph in Figure 1 with empirical data.

Customarily, physicists assume that they already do know the falling object's fate. The curves in the figure are routinely extended through $r = 0$ by *extrapolation.* The extrapolation is based on certain deeply held assumptions concerning the essential nature of matter and gravity. An actual empirical observation of motion through $r = 0$ would thus serve to test the validity of these assumptions. The purpose of this article is to begin questioning these assumptions and to propose a laboratory experiment whereby they would in fact be tested; and the corresponding gap in our empirical knowledge of gravity would be filled in.

In case further affirmation is desired to assure that this is a worthwhile inquiry, consider the advice of Herman Bondi:

> It is a dangerous habit of the human mind to generalize and to extrapolate without noticing that it is doing so. The physicist should therefore attempt to counter this habit by unceasing vigilance in order to detect any such extrapolation. Most of the great advances in physics have been concerned with showing up the fallacy of such extrapolations, which were supposed to be so self-evident that they were not considered hypotheses. These extrapolations constitute a far

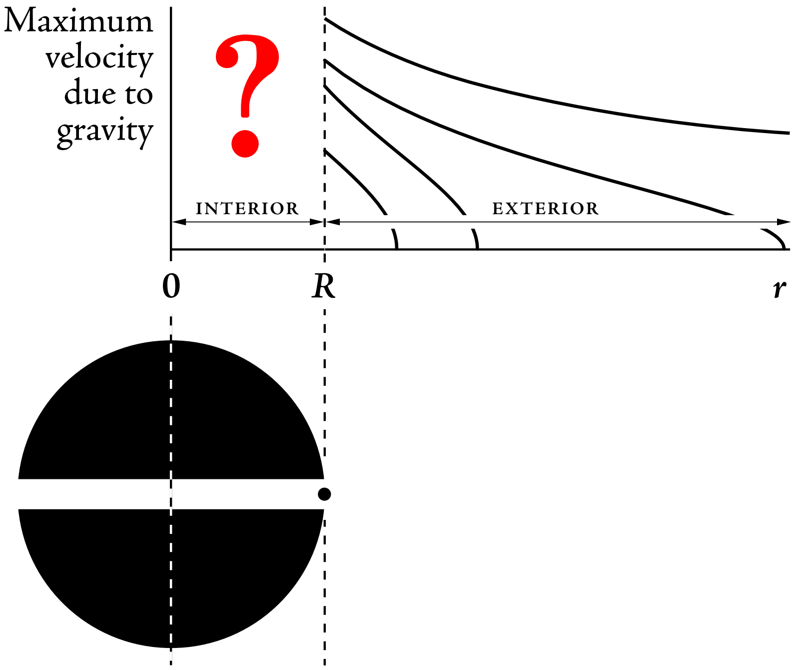

Fig. 1 How should the curves be drawn for the interior region? We dont know because we have no empirical evidence of bodies falling through $r = 0$.

greater danger to the progress of physics than so-called speculation. [1]

The example of extrapolation before us now could, of course, be correct. But it could be a fallacy. We cannot be certain either way until we've conducted the empirical test. Whatever we find, doing the test will contribute substantially to our knowledge of gravity.

2 Newtonian Gravity vs. General Relativity

Though both Newton's theory of gravity and Einstein's theory, General Relativity (GR) make essentially the same prediction for how the graph of Figure 1 should be completed, their respective explanations are curiously different. Consider the most common example, which is found in many freshman physics texts. A ball is dropped into a hole through a large sphere. If the density of the sphere is uniform, then the ball is supposed to oscillate between opposite sides of the sphere (simple harmonic motion). In Newtonian terms, this is due to the attractive force of gravity varying directly as the distance from the center.

By contrast, according to GR there is no force of gravity. Instead the ball's trajectory is determined by the *curvature of spacetime*. What does this mean? A commonly found answer is that it means "matter tells spacetime how to curve and spacetime tells matter how to move." What is rarely, if ever pointed out in the context of this description is how very much is hiding behind the word, "tells." How exactly are the orders conveyed from one to the other? What exactly does matter do to cause spacetime curvature? And how exactly does curved spacetime make material bodies move? Rather than address these unanswered questions, physicists typically retreat into the mathematics, saying, "gravitation is geometry," as though the universe and the enterprise of physics were constrained to obey the dictates of Einstein's geometrical equations.

Before taking a closer look at the *physical* clues bearing on these questions, let's consider a peculiarity in GR's prediction for the motion of the test object inside our spherical mass. Since there is no force of attraction in GR, to what is the predicted motion attributed? It's the rates of clocks. Clocks inside the sphere are supposed to have slower rates (i.e., lower frequencies) toward the center, with the one at the center having a local minimum. This is supposed to cause the falling ball to oscillate in the hole. But nobody knows for sure that the rate of the central clock is in fact a local minimum. A direct comparison of clock rates is impossible for bodies large enough to reveal a measurable difference. So the best we can do is carry out an indirect test. If an experiment revealed that the object oscillates in the hole, this would be evidence that the rate of the central clock is indeed a local minimum.

Since the experiment has not yet been done, we are left with the question: what could possibly cause the central clock to tick slow? What must matter be doing to make it so? Intuitively, we may expect instead that the clock's rate should be a local *maximum.* If the matter causing the change in rate is concentrically arrayed around the clock, then how could the effect propagate inwardly from all directions without canceling because of symmetry?

3 Rotation Analogy

This question becomes all the more poignant in light of an analogy that Einstein used to help illustrate the meaning of spacetime curvature. The analogy involves the similarity between a gravitating body and a body undergoing uniform rotation. On a rotating body we find four interrelated effects. The first two have been known for hundreds or thousands of years: velocity and acceleration, both of which vary directly as the distance to the axis. The velocity is tangential and the acceleration is inward, toward the axis. The remaining two (more subtle) effects are predicted by relativity: time dilation and length contraction, both of which depend on velocity—not acceleration. The rates of clocks on the rotating body are a minimum at its periphery, where the velocity is greatest; toward the axis the rates increase, reaching a maximum at the axis, where the velocity is zero. This effect has been abundantly confirmed by observations. Finally, the lengths of rods oriented in the direction of the velocity (tangentially) are shortened by the same magnitude as that of the effect on clock rate. This effect has not been directly observed, but there is no compelling reason to doubt that it exists and various reasons to expect that it does exist.

It is this combination of slow clocks and shortened rods occurring together on a body that moves in a stationary way—showing always the same (or periodic) appearance over time—that motivated Einstein to describe the system in terms of non-Euclidean geometry, i.e., curved spacetime. Einstein's contemplation of the description of uniform rotation in terms of curved spacetime coincided with his contemplation of the description of gravitating bodies in similar terms. Since Einstein regarded gravitating bodies as static things, he used the analogy to argue that rotating bodies may also be regarded as being *at rest.* To Einstein the effects of motion experienced on a rotating body were to be interpreted as the effects of a particular kind of gravitational field. Einstein consistently eschewed the significance of motion in favor of his geometrical theory of the gravitational field, with respect to which anyone can claim to be at rest—even if undergoing rotation.

4 Gravitational Stationary Motion

In our assumption-questioning spirit we may reasonably ask if perhaps Einstein had it backwards. It is not really logical to deny that a rotating body moves. If you spin in place, it's absurd to insist that the universe is really revolving around you. What is undeniably true is that the effects on a rotating body are the same as the effects on a gravitating body. An alternative to Einstein's conclusions springs from a straightforward application of a standard strategy of scientific reasoning (known as *Occam's razor* or *Newton's Rules of Reasoning in Philosophy*): "To the same natural effects one must, as far as possible, assign the same causes."

If evidence of spacetime curvature (slow clocks and shortened rods) arises on a rotating body because it moves, perhaps this is also true of a gravitating body. Perhaps gravitating bodies are similarly in a state of stationary motion; and this motion is the cause of spacetime curvature. Another potent clue in support of this deduction will be given momentarily. First note, however, that if we apply the idea to the gravitational interior question raised earlier, we find support for the intuitive guess that the rate of the central clock should be a local maximum—not a local minimum. On a rotating body the clocks furthest from the axis, the ones in the most asymmetrical position, experience the greatest time dilation. The one at the center (axis) ticks the fastest. If stationary motion can be attributed to a gravitating body and this motion is the cause of spacetime curvature (as it is in the case of rotation) then we should expect the effect to exhibit a similar kind of symmetry, which suggests that the rate of the central clock would be a local maximum.

5 Equivalence Principle

We have so far neglected the most prominent effect of both uniform rotation and gravitation. The effect that we would most readily feel in both circumstances is *acceleration.* This effect is often discussed in terms of another of Einstein's heuristic inventions: the Equivalence Principle. This principle was originally proposed to explain the empirical fact that all falling bodies—whether they are heavy, light, or composed of any chemical species of matter—appear to have the same downward acceleration. The principle's essence is often illustrated by inverting the apparent direction of motion. The equal falling of all bodies is explained not as a consequence of equal accelerations of the falling bodies but as the upward acceleration of the ground.

L. C. Epstein expressed the idea this way: “Einstein’s view of gravity is that things don’t fall; the floor comes up!” [2] J. Richard Gott similarly explains:

> Einstein proposed something very bold—if the two situations [accelerating in a rocket ship and a state of rest on a gravitating body] looked the same, they must be the same. Gravity [is] nothing more than an accelerating frame of reference... Earth’s surface [is] simply accelerating upward. [3]

Gott argued that “The only way [this] assertion could make sense is by considering spacetime to be curved.”

But is this enough? Even admitting the curvature of spacetime leaves us with a conceptual contradiction. It is well known that the field of a spherical body like the Earth or Sun is represented in GR by an equation (the *Schwarzschild solution*) corresponding to a *static* system. So we have various states of acceleration attributed to a system that is also static, i.e., completely at rest, completely void of motion. The usual meaning of these words surely prohibits referring to one body as being in both states at once. Does admitting the existence of spacetime curvature mean that we must scramble the terminology of motion? Must we really mix up that which is *static* and *at rest* with that which *accelerates*? Is this not a recipe for confusion?

We have before us the same ingredients, the same clues pondered over by Einstein and Gott. Einstein’s solution, described by Gott, leaves not only an intuitively contradictory account of motion, it still leaves us with the puzzle of how a static chunk of matter produces spacetime curvature. By contrast, the present interpretation of the rotation analogy, whereby gravitating bodies are regarded as being in a state of stationary motion, not only assembles the puzzle pieces without contradiction, we also get an explanation for spacetime curvature. (For a more rigorous defense of this hypothesis, see [4].) Speculative though it may be, we can find out whether or not this idea is correct by performing the interior falling experiment.

6 The Direction of Gravity Determined by Laboratory Experiment

If material bodies are static, then gravity will cause the falling test object to have a maximum velocity at the center and to oscillate in the hole because the direction of gravity is essentially inward. The motion caused by gravity is ascribed to the *falling* object. But if material bodies are in a state of stationary motion and this motion is the cause of spacetime curvature, then the falling test object will not pass the center because it would mean the direction of gravity is essentially outward. The motion caused by gravity is ascribed to the large gravitating body and its surrounding space. The evidence we have from observations over and beyond the surfaces of gravitating bodies does not allow deciding between these possibilities. Performing the interior solution experiment would provide an unequivocal answer.

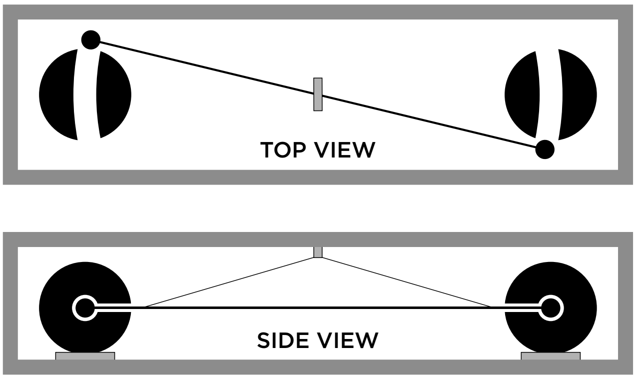

Fig. 2 Schematic of modified Cavendish balance.

One way of doing the experiment would be to use a modified Cavendish balance. Since Cavendish’s original experiment in 1798, dozens or hundreds of gravity experiments have been done with similar devices. But in no case has the arm of the balance been allowed to move inside the larger body to its center. The modification would thus involve excavating the large masses and adapting the arm’s support system to allow motion inside the large spheres. (See Figure 2.) Though challenging, this modification is certainly possible with modern technology.

Performing the experiment would finally allow replacing a seemingly self-evident extrapolation with a concrete physical fact. Are material bodies static things? Is the direction of gravity inward? Why settle for presumed self-evidence inherited from antiquity when these questions can be answered with physical facts gathered by conducting a simple experiment?

7 Conclusion

In the course of inquiring as to the *first* thing about gravity—i.e., how test objects move near $r = 0$—we’ve uncovered an even more fundamental question. What may be called the *zeroth* thing about gravity is its direction. Until we do the interior falling experiment we cannot be certain whether it is inward and refers to falling bodies, or outward and refers to gravitating bodies and their surrounding space. Our empirical knowledge of gravity and our understanding of its most essential characteristics will take a big step forward when we finally undertake to do the experiment, when we finally resolve to complete the curves in Figure 1 with empirical data. Possibly, we will discover that saying "the ground comes up" brings us closer to the truth than Epstein, Gott, or Einstein ever imagined.

References

1. Bondi, H., *Cosmology* (Cambridge University Press, Cambridge, 1952) p. 6.
2. Epstein, L. C., *Relativity Visualized* (Insight, San Francisco, 1988) p. 152.
3. Gott, J. Richard, *Time Travel in Einstein's Universe* (Houghton Mifflin, New York, 2001) p. 86.
4. Benish, Richard, *Maximum Force Derived from Special Relativity, the Equivalence Principle and the Inverse Square Law* <http://www.scribd.com/doc/19248407/Maximum-Force-Derived-from-Basic-Physical-Principles> accessed May 18, 2011.