Transactions on Computer Science and Intelligent Systems Research
ISSN: 2960-1800, eISSN: 2960-2238 | Volume 11
TPCEE 2025

Quantitative Verification of Newton's Gravity and Einstein's Equivalence Principle

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Abstract. This research will focus on understanding gravity, which governs everything from falling apples to orbiting planets. Newton described gravity as a force that pulls on objects, while Einstein later revealed that gravity is the curvature of space itself. Most experiments proving these theories require advanced laboratory equipment, making it difficult for students to test these revolutionary ideas firsthand. My research addresses this problem by creating a simple method that anyone can use to verify Newton's and Einstein's theories of how gravity works. The experiment has two stages, where the measurement will be different. The first stage is before the free-fall, where the phone will be held still, and the app will show data. The second stage is during the free-fall, where the phone will experience a free-fall while the app and the phone will be screen recording. It will show a data when the phone reaches the maximum velocity. As a result, when the phone is at rest, the acceleration is about 9.8 m s^{-2}, which is exactly what Newton predicted for Earth's gravity. When the phone is in free-fall, the acceleration decreases to nearly zero. This proves Einstein's breakthrough idea that gravity "vanishes" during free-fall.

Keywords: Gravity; Free-fall experiment; Newton and Einstein theories.

1. Introduction

Humans have always looked up at the stars and wondered about the universe. The researcher has raised numerous questions, like what holds the planets up and why objects fall to the ground. This curiosity and desire to understand our place in the universe drove the study of gravity. Two of the giants in this area were Isaac Newton and Albert Einstein. Testing Newton's laws and Einstein's equivalence principle can be a way for science to answer our biggest questions about how the universe works.

This study investigates how gravity affects objects during free-fall by using a simple smartphone-based experiment to verify Newton's law of gravitation and Einstein's equivalence principle. The purpose of this research is to provide an accessible method for demonstrating fundamental gravitational theories without the need for advanced laboratory equipment.

2. Background Information

2.1. Basic Knowledge

Newton has provided the first clear mathematical rules for gravity. His laws state that every object attracts every other object with some force. The more massive the object, the stronger this force is, and the farther away the objects are, the weaker this force is. This law can be written as [1]:

$$F = \frac{Gm_1m_2}{r^2} \tag{1}$$

Where F is the gravitational force in newtons. G is the gravitational constant, 6.67×10-11 N m^2 kg^{-2}. m_1 and m_2 are the masses of the two objects in kilograms. r is the distance between the centre of the two masses in metres.

This explains why planets orbit the sun and why apples fall from trees. But Newton's laws depend on a strange coincidence that the weight of an object due to gravity is always exactly equal to the resistance it has when it's pushed. When Einstein realized that gravity feels like acceleration, he solved the question of why these two different things could be the same. If one person is in a closed elevator and the elevator is located on Earth, gravity will pull him to the floor. If the elevator is in space, being pulled upward by a rocket at just the right speed, he will also be pushed to the floor. In the elevator, he can't tell the difference [2]. Einstein said that this equivalence principle is fundamental. This means that gravity isn't a “force” pulling on an object, but rather the effect of massive objects warping spacetime itself. Objects simply follow the straightest possible paths through this curved spacetime (Table 1) [3].

Table 1. Terms and definitions from the equations

Term	Definition
F / N	Gravitational force
m / kg	Phone’s gravitational mass
g / m s^{-2}	Earth’s gravitational acceleration
G / N m^2 kg^{-2}	Gravitational constant
M / kg	Earth’s mass
r / m	Earth’s radius

2.2. Experiment Brief

The researcher’s experiment will focus on ideas about gravity, such as the relationship between the force we feel standing on Earth and the feeling of weightlessness experienced by astronauts in orbit. The researcher will be using an APP called Phyphox from my phone to record the acceleration due to gravity before and during it experience of a free-fall. The researcher’s aim in this experiment is to prove Einstein’s equivalence principle, which connects Newton’s description of gravity as a force to Einstein’s idea that gravity is the curvature of spacetime.

Before the researcher let go of the phone, it was held still. Newton’s law of universal gravitation can provide a clear theoretical expectation that when the researcher holds the phone, Earth’s gravity exerts a downward force, which can be calculated using the equation that represents the force of gravity acting on an object [4]:

$$F = mg \tag{2}$$

Where, F is the gravitational force in Newtons. m is the phone’s gravitational mass in kilograms. g is Earth’s gravitational acceleration, approximately 9.8 m s^{-2}.

The accelerometer in the app will measure the forces acting on a tiny mass inside the sensor. Newton’s framework predicts the sensor will show a reading of approximately 9.8 m s^{-2} downwards. This represents the upward force exerted by the researcher’s hand against gravity. So, this value is consistent with the prediction of Newton’s law of universal gravitation, which is expressed as [4]:

$$g = \frac{GM}{r^2} \tag{3}$$

Where g is Earth’s gravitational acceleration in m s^{-2}. G is Gravitational constant, 6.67×10^{-11} N m^2 kg^{-2}. M is Earth’s mass in kilograms. r is Earth’s radius in metres.

When the researcher releases the phone, it will begin to free-fall, and both the device and every component within it will accelerate downward at g. There will be no relative forces acting on the test mass inside the sensor since it floats freely inside the phone. This is just like an experiment where people can float inside the plane during parabolic flights [5]. Einstein's principle thus predicts a specific quantitative outcome that the accelerometer should show approximately 0 m s^{-2} during free-fall. This measurable state of "weightlessness" is the experimental signature of equivalence.

This experiment can directly verify the fundamental theories of gravity. This change of 9.8 m s^{-2} gravitational acceleration to 0 m s^{-2} acceleration revealed two key ideas. First, it confirmed the equivalence of gravitational mass and inertial mass. Gravitational mass defines how much gravity pulls on the phone, and inertial mass defines how much the phone resists acceleration. This equivalence ensures that all objects accelerate the same in a gravitational field. Second, it can show the physical experience within the free-falling reference frame, which is that weightlessness is indistinguishable from true zero gravity. This means that the effects of gravity can vanish due to free-fall motion, as Einstein hypothesized.

3. Experiment

Table 2 shows the measured accelerations before free-fall across five experimental trials.

Table 2. Acceleration before free-fall

	Acceleration / m s^{-2}
Trial 1	9.88
Trial 2	9.68
Trial 3	9.79
Trial 4	9.86
Trial 5	9.83

These are the values of gravitational accelerations shown in the app before free-fall where the phone is not in any motion. This shows this app, Phyphox, is accurate enough since all the downward acceleration is approximately 9.81 m s^{-2}.

Table 3 presents the measured accelerations during free-fall across five experimental trials.

Table 3. Acceleration during free-fall

	Acceleration / m s^{-2}
Trial 1	0.19
Trial 2	0.10
Trial 3	0.18
Trial 4	0.13
Trial 5	0.11

The results show that the recorded accelerations are significantly lower than the expected gravitational acceleration of approximately 9.8 m s^{-2}. This discrepancy suggests the presence of systematic errors, likely due to limitations in the measurement method, such as sensor sensitivity, reaction delays, or external disturbances. Despite these deviations, the data qualitatively support the occurrence of free-fall motion, though they highlight the need for improved experimental precision

These are the values of gravitational accelerations during free-fall. They all show an acceleration of almost 0 m $s^{-2,}$ which proves the previous theories. There are three main reasons why the acceleration is not exactly 0 m s^{-2}.

The existence of air resistance opposes free-fall motion, which generates an upward drag force that reduces net acceleration. Moreover, the phone also might experience a slight release-induced rotation, cause centripetal acceleration, and increase the net acceleration. Also, the sensor in the phone could create fluctuations even under ideal conditions, which also affect the measurements of the acceleration before free-fall in Table 2.

The acceleration of about 9.8 m s^{-2} measured before the free-fall verified Newton's description of gravity as a force that acts predictably on mass. It confirmed the existence and strength of the Earth's gravitational field on Earth. The acceleration dropped dramatically to about 0 m s^{-2} during free fall, quantitatively proving Einstein's equivalence principle.

4. Conclusion

This experiment quantitatively proved Newton's gravitational law and Einstein's equivalence principle by using a smartphone accelerometer app. The measured accelerations before free-fall from Table 2 strongly support Newton's gravitational equation, $F = mg$, which demonstrates the consistency of Earth's gravitational field strength and confirms the predictions of Newton's universal law.

The accelerations during free fall from Table 3, which are close to 0 m s^{-2}, directly proved Einstein's insight that gravity will “vanish” in the reference frame of a falling object. This important change physically demonstrates the equivalence of gravitational mass and inertial mass and further confirms that all objects accelerate at the same rate under the influence of gravity, which is 9.81 m s^{-2} on Earth.

The limitations that occurred in the experiment could be improved by using the following methods and tools. The use of a vacuum chamber could eliminate aerodynamic effects that exert an upward force; An electromagnetic release machine could minimize the rotational errors that create a centripetal force; repeating the experiment multiple times can balance the outcome. These improvements would further bring gravitational phenomena closer to the theory.

This research captured the change from 9.8 m s^{-2} to near-zero acceleration during free fall. The experiment demonstrates how simple tools can answer questions about the universe.

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