

The Relation between the Speed of Electromagnetic Waves and Gravity

Pahal Bhatti¹ and Himanshu K Patel²

¹DPS Monarch Intl School, Doha, Qatar
Email: pahal.bhatti11@gmail.com

²Nirma University, Ahmedabad, INDIA
Email: hkpatel@nirmauni.ac.in

Abstract—This research is aimed to experimentally investigate the connection between the speed of electromagnetic waves and the strength of gravitational fields. This can be accomplished by utilizing Maxwell's equations and measuring the variations in permittivity and permeability across different gravitational field strengths. Although no significant changes in permittivity are observed under varying gravitational conditions using standard equipment, a relationship is established between permeability and gravitational field strength. These two factors are directly proportional, suggesting that the speed of electromagnetic waves is inversely proportional to gravity. The implications of these findings are discussed, particularly the potential for developing a theory that could link electromagnetism and gravity, as well as the impact of these findings on the special theory of relativity, which assumes the constancy of the speed of light.

Index Terms— electromagnetic waves, gravitational field strength, permittivity, permeability, capacitor, magnetic field.

I. INTRODUCTION

Since the formulation of Maxwell's equations, it has been understood that the speed of electromagnetic waves in a vacuum is a universal constant¹. There is no direct indication of a relationship between the speed of electromagnetic waves and gravity within the framework of classical electromagnetism. Maxwell's equations are based on four fundamental laws of electromagnetism: Gauss's law for electric fields, Gauss's law for magnetism, Faraday's law of electromagnetic induction, and Ampere's law with Maxwell's addition². Since these laws describe electromagnetic phenomena without incorporating gravitational effects, the speed of electromagnetic waves, as derived from Maxwell's equations, is independent of gravity in classical physics. For example, the speed of light in a vacuum c is given by:

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \quad (1)$$

Where: c = speed of light = 299,792,458 m/s

μ_0 = Permeability of free space = $4\pi * 10^{-7}$ H/m

ϵ_0 = Permittivity of free space = $8.85 * 10^{-12}$ F/m

The widespread consensus at the turn of the 20th century and the lack of scientific temperament led to the absence of a trial to find a link between the speed of light and gravity experimentally. Further, leading to Einstein's special theory of relativity's initial assumptions:

"We will raise this conjecture (the purport of which will hereafter be called the "Principle of Relativity") to the status of a postulate, and also introduce another postulate, which is only apparently irreconcilable with the former, namely, that light is always propagated in space with a definite velocity " c " which is independent of the state of motion of the emitting body" ³

A conjecture is defined by the Cambridge dictionary as "a guess about something based on how it seems and not on proof".

As Einstein used the idea of a constant speed of light in a vacuum, it was less challenged in the years to come. On the other hand, in 1911, Einstein's paper predicted a change in the path of electromagnetic waves, such as light, by gravity.

"From the proposition which has just been proved, that the velocity of light in the gravitational field is a function of the place, we may easily infer, using Huygens's principle, that light rays propagated across a gravitational field undergo deflexion⁴."

The term velocity as a function of place in a gravitational field in this context does not refer to the magnitude of the velocity, but rather the direction.

Even though Einstein did not explicitly state in his paper that the speed of light changes with gravity, from his above statements and numerous proofs of the phenomena of bending of light by gravity, such as the blue horseshoe galaxy or Einstein's rings, we can infer that light does get affected by gravity (a change in velocity). Several other theories, such as the string theory, also predict a link between the speed of light and gravity, although these theories lack formal experimental evidence^{5–15}.

Therefore, the main focus of the paper is to experimentally determine whether there exists a link between the speed of light and gravity. The goal is not to establish a precise mathematical relationship but rather to assess whether they are connected. It is emphasized that the speed of electromagnetic waves referred to throughout the paper is the actual speed of these waves, rather than an apparent or observed speed in a gravitational field. Further details on why this is a matter of discussion will be provided in subsequent sections.

A. Permittivity and Permeability Under Varying Gravitational Field Strengths

While experimenting, the speed of electromagnetic waves will not be directly measured; instead, a more sophisticated method will be employed to simplify the experiment's complexity. By utilizing equation (1), it is understood that the speed of electromagnetic waves depends on the permittivity and permeability of the medium through which they travel. If it can be demonstrated that both permittivity and permeability change as the gravitational field strength varies, it may be concluded that the speed of light also changes with fluctuations in gravitational field strength. This approach could also help determine whether the electromagnetic and gravitational forces can be unified, a topic of significant interest among theoretical physicists. To achieve this, two experiments will be conducted. The first will focus on measuring permittivity under varying gravitational field strengths, while the second will assess permeability under the same conditions.

Permittivity as a Function of Gravitational Field Strength

A capacitor will be used to measure permittivity as a function of gravitational field strength. A capacitance meter will be employed to measure the capacitance of the capacitor under different gravitational field strengths. Given that other variables, such as the area of the plates and the distance between them, are known, permittivity within the capacitor will be calculated. By measuring permittivity at different gravitational field strengths, it will be possible to determine whether a relationship exists between changes in permittivity and variations in gravitational field strength, suggesting that these two factors are not independent.

Permeability as a Function of Gravitational Field Strength

For measuring permeability as a function of gravitational field strength, a bar magnet will be used in conjunction with an Arduino circuit. The bar magnet generates a magnetic field influenced by its magnetic moment, the distance from the point where the field is measured, its length, and the medium's permeability. The Arduino circuit, which includes a magnetometer sensor and an Arduino Uno board powered by a battery, will measure the magnetic field strength.

By accounting for parameters such as magnetic moment, length of the magnet, and the distance between the bar magnet's centre and the magnetometer sensor, permeability across varying gravitational field strengths can be effectively monitored. If a specific relationship between permeability and gravitational field strength is observed, it can be concluded that these two factors are also not independent.

B. Change in Gravitational Field Strength

To calculate changes in gravitational field strength, the equivalence principle will be utilized, which states, "From this correspondence, it follows that it is impossible to discover by experiment whether a given system of coordinates is accelerated, or whether... the observed effects are due to a gravitational field¹⁰." Thus, if the setup used—a closed system—is accelerated, the net gravitational force experienced within it will be equivalent to that acceleration. Free fall is considered the most effective method to achieve maximum acceleration and the greatest change in acceleration. In a free fall scenario, the forces acting on the system include gravitational force and air resistance. Although free fall involves some air resistance, it results in non-uniformly accelerated motion, meaning that the acceleration will vary at different moments. This leads to diverse gravitational forces within the system, allowing for the creation of varying gravitational field strengths at multiple times.

Drawing the free-body diagram would be as shown in Fig. 1,

Thus, applying Newton's second law,

$$F_{net} = m_{total} a_{centre\ of\ mass} \text{ (Where } m \text{ is the mass of the object)}$$

$$F_{grav} + F_{air} = m_{total} a_{centre\ of\ mass}^{11}$$

Here m_{total} will be represented as m

$$mg - kv = ma_{centre\ of\ mass} \text{ (Where } g \text{ is the gravitational field strength, } k \text{ is the air resistance constant; } v \text{ is the velocity of the system)}$$

The drag is assumed to be linear because the velocity would be relatively small¹².

$$a_{centre\ of\ mass} = \frac{mg - kv}{m}$$

As acceleration can be written as $\frac{dv}{dt}$,

$$\frac{dv}{dt} = \frac{mg - kv}{m}$$

Solving the above differential equation will yield velocity as a function of time,

$$v(t) = mgk(1 - e^{-\frac{kt}{m}})$$

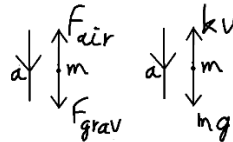


Fig. 1: Free Body Diagram of the box in free fall

Differentiating to time yields acceleration as a function of time,

$$a(t) = ge^{-\frac{kt}{m}}$$

By the equivalence principle,

$$a(t) = g(t)$$

$$\text{Thereby, } g(t) = ge^{-\frac{kt}{m}}$$

Differentiating $g(t)$ to time gives the change in gravity to time,

$$\frac{dg}{dt} = \frac{-gke^{-\frac{kt}{m}}}{m} \quad (2)$$

II. METHODS

A. Experiment for Change in Permittivity

In the experimental procedure, the first step involved measuring a change in permittivity. A plastic box with dimensions of 24.5 cm in length, 17.5 cm in breadth, and 11.7 cm in height was prepared. At the centre of the

box, a standard capacitance meter was installed and connected to a capacitor. The box was sealed at both ends, and a phone was placed on top to capture a slow-motion video of the capacitance meter's readings while the entire system was in free fall. The area of the side of the box that experienced air resistance was 428.75 cm², with the air density at sea level generally around 1.23 kgs per cubic meter. The drag coefficient for a flat plastic plate was noted to be approximately 1.4. The mass of the box was measured at 0.1 kgs, which suggested that air resistance would be 0.0369 times the square of the velocity²¹. The change in gravity was expressed as

$$-3.6199e^{0.369t}$$

This is based on an earlier equation. This indicated that after one second, the change in gravity would amount to -2.5, resulting in a percentage change in gravity of 25.514 %.

To mitigate the impulsive normal force from the ground that could potentially damage the system, a couple of individuals were tasked with holding a mattress at the bottom of the free fall. The experiment was conducted with capacitors of various capacitance values, ranging from 11 nF to 900 µF, and included other dielectrics such as electrolytic and ceramic. The entire setup was made to free fall from various heights, specifically between 2.4 m and 4.9 m.

B. Experiments for change in permeability

The same plastic box from the first experiment was used to measure the change in permeability. A bar magnet with a magnetic moment of 8,294.11 Am⁻² and a length of 7.5 cm was secured to one end of the box using electrical tape. At the opposite end of the box, aligned with the axis of the magnet to minimize magnetic effects on the electrons flowing through the Arduino circuit²², an Arduino Uno R3 board, a HMC5883L magnetometer sensor, and a Nippo GOLD 6F22 9 V battery were attached for power. The magnetometer sensor was positioned at a distance of 14.15±0.1 cm. (as shown in Fig. 2)

The Arduino was programmed to take ten readings, each spaced 300 ms apart. These data were stored in the EEPROM of the Arduino board and retrieved after each free fall²³⁻²⁴. With the approximate duration of free fall being one second, the Arduino recorded three different readings for the X, Y, and Z components of the magnetic field. Since the difference between the two readings was 0.3 seconds, the usual change in gravity was approximately

$$-3.6199 * e^{0.369t}$$

This equals about -3.24 and is translated to a 33.033 % change in gravity after each subsequent 300 ms interval

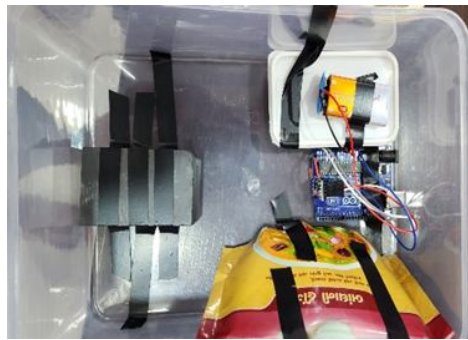


Fig.2 the setup of the experiment on permeability and gravity

III. RESULTS

A. Results for Change in Permittivity

This experiment was repeated multiple times with capacitors of different capacitance values. Interestingly, no change was observed in the capacitance readings recorded by the standard capacitance meter. However, fluctuations in the capacitance readings that occurred when the setup was at rest did not happen during free fall or in an accelerated frame of reference. This observation suggests that the internal fluctuations and the change in permittivity were balanced, resulting in the capacitance meter displaying a constant net reading throughout the free fall.

These findings were based on a standard capacitance meter, which indicated lower sensitivity and, consequently, reduced accuracy in measuring smaller values. Therefore, a change in capacitance may be observable if more sensitive capacitance meters were used. Even if a relationship between permittivity and gravitational field

strength could be established using high-sensitivity materials, it would likely be a very weak correlation, which explains the difficulty in observing this effect in real life.

B. Results for the Change in Permeability

The experiment was conducted 10 times. The data was obtained is displayed in Table 1

The magnetic field range is about 9500, due to a 0.1 cm error in the distance between the magnetometer sensor and the centre of the bar magnet.

The graphs drawn from the data obtained during each free fall, all have a pattern similar to the one shown in Fig. 3

It can be observed that during each free fall, whenever the acceleration decreases, the magnetic field value also decreases. Thus, it hints at a relationship between permeability and gravitational field strength to be directly proportional to each other.

As the box itself wasn't covered with a magnetic shield, it can mean that the earth's magnetic field must have played a role in displaying these changes.

But despite those interventions, the earth's magnetic field cannot change this drastically during a 5m change in height. Even if it did play a role, it would increase the overall magnetic field reading sensed by the sensor rather than decrease it.

TABLE I. RECORDED MEASUREMENTS OF MAGNETIC FIELD VALUES (IN MT) EACH TIME THE SYSTEM WAS IN FREE FALL

Sr. No.	1 st value	2 nd value	3 rd value	4 th value (after impact)
1	6668.968	6653.190	6652.955	6666.8227
2	10200.461	10012.257	9916.97	10,174.54
3	2569.235	2542.643	2522.615	2565.867
4	737.127	723.446	719.537	721.838
5	1587.986	1550.593	1524.868	Not recorded
6	1570.531	1557.9505	1539.397	1561.643
7	1457.098	1442.328	1426.159	1426.131
8	742.690	730.726	717.425	Not recorded
9	4855.039	4852.005	4850.0315	4857.008
10	2200.017	2195.015	2181.097	2197.041

Notes:

The “Not recorded” readings denote that the 3rd value was the 10th measurement taken by the program, and the 11th measurement, after impact, was not recorded as the Arduino circuit was programmed to take only 10 readings.

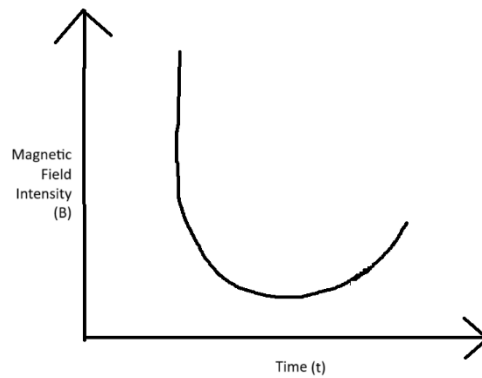


Fig. 3, Graph of magnetic field intensity as a function of time, as a result of the experiments.

C. The relation between the speed of electromagnetic waves and gravity

As a direct relation between permeability and gravitational field, strength was observed (section 3.2). A mathematical modification of equation (1) can be done as follows:

$$\mu \propto g \quad (3)$$

The proportionality from the above equation can be removed by introducing a constant, which will be referred to as the gravitomagnetic constant, and will be denoted as α

The dimensional formula of magnetic permeability is $M^1L^1T^{-2}A^{-2}$ and gravitational field strength (g) is L^1T^{-2} . Thus removing the proportionality sign from the above equation would yield a proportionality constant of the dimensional formula M^1A^{-2} . If we refer to this proportionality constant as α , then the above equation becomes :

$$\mu = \alpha g$$

Putting this value of permeability in equation (1) yields,

$$c = \frac{1}{\sqrt{\epsilon_0 \alpha g}}$$

However, this suggests that in a gravity-less system, the speed of light would become infinite, which seems less likely according to the lack of experimental evidence.

Thus, a better mathematical formulation of the relation - which is in correspondence to Maxwell's equations, would be,

$$\mu = \mu_0(1 + \alpha g)$$

Further yielding,

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0(1 + \alpha g)}} \quad (4)$$

By this potential equation, it would mean that the speed of light is the definite velocity c for a gravity-less system and would be approximately 0 for a large magnitude of gravitational field strength (which could be the reason why light cannot escape a black hole)

This would also mean modifying the gravitomagnetic constant's dimensional formula to $L^{-1}T^2$ instead of M^1A^{-2} .

The above equation is not the final formula for the speed of electromagnetic waves in differing gravitational field strengths. Further investigation into the matter would result in a more profound equation and the value of the gravitomagnetic constant.

D. Concern of the Actual Speed of Light and Not the Observed Speed of Light

In the introduction, it has been mentioned that the experiment deals with the actual speed of electromagnetic waves and not the observed speed of electromagnetic waves. This was done because of the established notion that the speed of light is always observed to be constant (according to Einstein's special theory of relativity's initial assumptions).

If we consider the belief correct and the experimental evidence of a person ageing faster at a hill station, then our experimental results and the special theory of relativity go hand in hand. This explains that gravity acting on our body and electromagnetic waves proportionally slow down our time perception and the speed of light, such that we always observe a constant speed.

However, if the actual and the observed speed of light were changing by a gravitational field, then the theory of special relativity would be contradicted for the first time, in a century, and would translate to the need for a new theory to replace it. The non-observance of this contradiction can also be attributed to the earth's gravity. As it is relatively low, the change in speed of light might not be observable by the precision of our age, which is the precision of only 10^6 in the Global Positioning System.

IV. CONCLUSION

Based on the above experiments, while trying to find a relation between permittivity and gravity and trying to find a relation between permeability and gravity, the following conclusions can be deduced:

- No observable difference was found in the capacitance of various capacitors tested using a standard capacitance meter.
- An observable difference was found in the permeability with changing gravitational field strengths. Based on the results, it was found that permeability and gravitational field strength are directly proportional.
- As permittivity does not appear to change in varying gravitational field strengths, while permeability is observed to change, Maxwell's equations suggest that the speed of electromagnetic waves changes with a variation in gravity.
- This experimental evidence of a direct relation between permeability and gravity can also pave the way for a theoretical framework to merge electromagnetism and gravity, thus fuelling the existing idea among the scientific community of a unified theory of all four fundamental forces of nature.

- The potential formula for the speed of electromagnetic waves in differing gravitational fields can be $c = \frac{1}{\sqrt{\epsilon_0 \mu_0 (1 + \alpha g)}}$ where α is the gravitomagnetic constant.

ENDNOTES

- The relativistic effects such as length contraction were neglected due to the relatively low velocity.
- No magnetic shielding was done, but care was taken to ensure that no devices played a role in the changing magnetic fields were nearby.
- Maxwell's equations like the localness of space (add the other assumptions) were assumed.
- In the "Coriolis Effect", tidal forces were neglected due to a small change in height. There can be other effects too that can possibly hinder the results of the experiment 19, but none of them seem plausible in the environment the experiments were conducted in.
- According to Maxwell's electromagnetic theory, it is understood that charged bodies in an accelerated frame of reference produce alternating electric and magnetic fields. However, this would not hinder the results because the measurement device was also in the same frame of reference. Thus it would be In a local inertial frame. 20

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REFERENCES

- [1] Maxwell, J. C. A Dynamical Theory of the Electromagnetic Field (The Royal Society Publishing, 1865).
- [2] Ellingson, S. W. Electromagnetics, Volume I (VT. Publishing, 2018).
- [3] Einstein, A. On the electrodynamics of moving bodies. Ann. Phys. 17, 891–921 (1905).
- [4] Einstein, A. On the Influence of gravitation on the propagation of light. (Ann. Phys. 35, 1911).
- [5] Greene, B. The Elegant Universe (Random House, 1999).
- [6] Snyder, D. M. A connection between gravitation and electromagnetism. arXiv:physics/0002028 (2000).
- [7] Beach, R. J. Geometric unification of electromagnetism and gravitation. <http://dx.doi.org/10.20944/preprints201711.0022.v1> (2017).
- [8] Tajmar, M., Kölling, M. & Neunzig, O. In-depth experimental search for a coupling between gravity and electromagnetism with steady fields. Sci. Rep. 14, 19427 (2024).
- [9] Montgomery, G. Relativistic variations in the permittivity and permeability of free space = gravitation. J. Sci. Explor. 26, 111–116 (2012).
- [10] Zhu, Y. Gravitational-magnetic-electric field interaction. Results Phys. 10, 794–798 (2018).
- [11] Hawking, S. A Brief History of Time, 2017 edition (Bantam Books, 2017)
- [12] Goenner, H. F. M. On the history of unified field theories. Living Rev. Relativ. 7, 2 (2004).
- [13] Beach, R. J. A classical field theory of gravity and electromagnetism. J. Mod. Phys. 5, 928–939 (2014)
- [14] Li, L.-X. A new unified theory of electromagnetic and gravitational interactions. Front. Phys. 11, 110402 (2016).
- [15] Assis, A. K. T. Deriving gravitation from electromagnetism. Can. J. Phys. 70, 330–340 (1992).
- [16] Einstein, A. On the Relativity Principle and the Conclusions Drawn from It (Volume 2: The Swiss years, 1907).
- [17] Taylor, J. R. Classical Mechanics (2015).
- [18] Sanny, J. & Ling, S. University Physics Volume I (OPENSTAX, 2016).
- [19] Ivanov, B. On the gravitational field induced by static electromagnetic sources. (2004).
- [20] Maluf, J. W. & Ulhoa, S. C. Electrodynamics in accelerated frames revisited. Ann. Phys. 522, 766–775 (2010).
- [21] Munson, B. R., Young, D. F. & Okiishi, T. H. Fundamentals of Fluid Mechanics, 4th Edition (Wiley, 2003).
- [22] Arora, S. L. Physics Class 12 Volume I, 13th Edition (2022).
- [23] Monk, S. & McCabe, M. Programming Arduino: Getting Started with Sketches (McGraw-Hill, 2016).
- [24] Banzi, M. & Shiloh, M. Getting Started with Arduino (Maker Media, Inc., 2022).