On the Geometrical Origin of Inertial Mass: A Heuristic Derivation

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Abstract

This brief paper proposes a physical model in which the phenomenon of inertial mass arises from a self-interaction effect. Specifically, it is suggested that the inertial resistance to acceleration is the work required to displace an object's own gravitational field. A heuristic derivation is presented, showing that this work is proportional to the object's gravitational potential, resulting in a quantity with the units of mass. This model provides an immediate physical explanation for the equivalence of inertial and gravitational mass.

1 The Core Premise

We begin with a single, non-standard postulate:

The Inertial Postulate: *The force required to accelerate a body from rest is equal to the work done per unit displacement to move the body* through *its own gravitational field.*

In essence, an object's gravitational field presents a kind of "drag" or potential well that the object itself must climb out of as it is accelerated.

2 A Heuristic Derivation

Let us consider a spherical object of gravitational mass M, at rest. Its gravitational field defines a gravitational potential $\phi(r)$ at a distance r from its center:

$$\phi(r) = -\frac{GM}{r}$$

Now, consider an instantaneous acceleration that moves the object a small displacement δx from its original position. From the object's new rest frame, its entire gravitational field has effectively shifted. The work δW required to effect this shift against the object's own gravity can be conceptualized as the energy needed to "move" the potential well.

A simple dimensional argument can be made. The work δW should be proportional to the gravitational self-energy of the object per unit length of displacement. The gravitational self-energy U_g is of the form:

$$U_g \propto -\frac{GM^2}{R}$$

where R is the radius of the object. The work per unit displacement, $\frac{\delta W}{\delta x}$, therefore has dimensions of force and is proportional to $\frac{GM^2}{R^2}$.

Let us now consider Newton's second law, $F = m_i a$, where m_i is the inertial mass. For a given acceleration a, the force F is proportional to m_i. In our model, this force F is identified with the work per unit displacement needed to move the gravitational field, $\frac{\delta W}{\delta x}$.

Let us define a dimensionless proportionality constant k that encapsulates the specific geometry of the field displacement. We can then write:

$$F = m_i a \propto \frac{\delta W}{\delta x} = k\frac{GM^2}{R^2}$$

Noting that the object's gravitational acceleration at its surface is $g_s = \frac{GM}{R^2}$, we can rewrite this as:

$$m_i a \propto k \cdot M \cdot \frac{GM}{R^2} = k \cdot M \cdot g_s$$

The term $M \cdot g_s$ has units of force. For the equation to be dimensionally consistent and for the inertial mass m_i to be proportional to the gravitational mass M, we find:

$$m_i \propto M$$

Choosing the proportionality constant to be 1 (which defines the units of our constant k), we arrive at the central conclusion of this heuristic argument:

$$m_i = M$$

3 Explaining the Equivalence Principle

The above derivation is strikingly simple. It directly identifies the inertial mass m_i with the gravitational mass M. This is a statement of the **Weak Equivalence Principle**, which is a foundational pillar of General Relativity. In this model, the equivalence is not a coincidental fact of nature but a necessary consequence of a deeper physical mechanism: **inertia is gravito-inertial self-interaction.**

4 A Testable Prediction

If this model has physical merit, it must make a falsifiable prediction that deviates from the standard model. The primary deviation arises from the assumption of an instantaneous field displacement. In General Relativity, gravitational changes propagate at the finite speed of light, c.

Therefore, this model predicts a non-linear correction to $F = m_i a$ for accelerations that are so rapid that the object moves a significant fraction of its own radius R in the time $\tau \sim R/c$ it takes for its gravitational field to reconfigure.

This would manifest as an **anomalous inertial resistance** for extremely high, rapid accelerations. A potential experimental signature could be sought in:

- Ultra-high-intensity laser-plasma interactions, where particles can be accelerated to extreme energies over sub-micron distances.
- High-frequency vibrations of dense, compact objects, where the acceleration a and jerk $\dot{a}$ are immense.

The predicted effect would be an additional, non-linear energy loss term proportional to the jerk $\dot{a}$ and the object's gravitational potential ϕ.

5 Conclusion and Further Work

This note has proposed a physical interpretation of inertia as a self-gravitational effect. The heuristic argument presented provides an intuitive pathway to the Equivalence Principle. The model's key strength is its conceptual simplicity and its direct physical mechanism for a fundamental law.

The critical next step is the formal derivation of this effect within the framework of General Relativity, particularly analyzing the transient dynamics of a body's gravitational field during acceleration. The predicted high-acceleration anomaly provides a clear target for experimental falsification.

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