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On Classical Mechanics Concepts from the Perspective of Energy Ontology

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Abstract

Based on the ontological hypothesis that "energy is the sole measure of matter," this paper systematically derives the four classical tests of general relativity: the perihelion precession of Mercury, the deflection of light, gravitational redshift, and radar echo delay (Shapiro delay). The fundamental assumptions are: (i) the basic constituent of all matter is the electromagnetic field; (ii) the speed of light is invariant; (iii) energy is conserved. From these, the basic form of gravitational interaction is derived as $F = \frac{G}{c^4}\frac{W_1 W_2}{r^2}\hat{r}$*, where W represents the total energy of an object (including rest energy and kinetic energy). By introducing the nonlinear self-coupling of the gravitational field's own energy and the variation of the test particle's energy in the gravitational potential, and employing the Binet equation and perturbation methods, we obtain mathematical expressions that are fully consistent with those of general relativity, without invoking an independent mass concept or curved spacetime geometry throughout the entire derivation. Numerical results are in high agreement with experimental observations: Mercury's precession (43.0"/century), light deflection (1.75"), gravitational redshift (relative shift* 2.12×10^{-6} *for solar sodium D line), and radar echo delay (≈240 μs for Sun-grazing path). These results demonstrate that the gravitational theory from the "energy ontology" perspective possesses explanatory power equivalent to that of general relativity, while resting on a more parsimonious conceptual foundation—mass is reduced to a measure of energy, and no geometric interpretation of gravity is presupposed. This paper represents a systematic deepening and quantitative extension of the author's previous work, "Thinking about the Concept of Matter."*

Keywords: Matter, Energy, Gravitation, Mercury Perihelion Precession, Light Deflection, Gravitational Redshift, Radar Echo Delay

1. Introduction

Regarding the understanding of the concept of matter, there has always been a distinction between its philo-sophical meaning and its physical meanings. In a general sense, matter is considered as an existence that occupies space and possesses exclusivity [1]. However, with the development of relativity and quantum mechanics, the boundary between matter and energy has become increasingly blurred. The mass–energy re-lation reveals the equivalence of mass and energy, and Einstein himself realized that "The inertial mass of a system of bodies can even be regarded as a measure of its energy" [2].

The law of conservation of energy is not only the fundamental law of physics that has withstood the most experimental tests, but also an a priori philosophical principle for rationally understanding natural change. The universality of energy conservation is manifested not only as a rigid constraint of natural law but also con-stitutes an ontological premise of human epistemology. The essence of the conservation law lies in this: change is merely the succession of states, while the total quantity of existence persists eternally.

In the author's previous work, "Thinking about the Concept of Matter" [1], the author proposed a theoretical framework based on the assumption that "energy is the sole measure of matter." Its basic postulates are: (1) the essence of matter is energy; mass is merely a measure of energy; (2) the fundamental constituent of matter is the electromagnetic field, and particles are bound states in which the electromagnetic field is "condensed" or "curled"; (3) the invariance of the speed of light constrains all physical processes; (4) energy conservation is a universal law governing the evolution of the material world. That work re-examined the concepts of force and mass in classical mechanics, provided a consistent relationship among energy, momentum, inertial mass, and gravitational mass, and extended the scope of modified Newtonian laws to the relativistic domain

For an object with rest mass m_0 moving at velocity v in an inertial reference frame of observer S, its energy is $E = \gamma m_0 c^2$ [2], where $\gamma = 1/\sqrt{1-v^2/c^2}$ When v is far less than the speed of light c, $v^2/c^2 \to 0$; to second order, $\gamma \approx 1+\frac{1}{2}(\frac{v^2}{c^2})$; then the energy of the object can be expressed as $E \approx m_0 c^2 + m_0 v^2/2$. That is, the total energy of the object is approximately the sum of its rest energy and its kinetic energy.

However, that earlier work focused on conceptual clarifications and qualitative discussions, and did not provide a systematic quantitative derivation of the classical tests of general relativity. The purpose of the present paper is to fill this gap by deriving, within the above framework and in a unified mathematical form, the four classical tests—Mercury's perihelion precession, light deflection, gravitational redshift, and radar echo delay (Shapiro delay)—and to compare the numerical outcomes with observations precisely.

The significance of this work is that, even without adopting curved spacetime geometry, one can still derive exactly the same observable effects as general relativity from the sole assumption of energy-based interaction. This may help to reveal deep connections between theoretical structures and to re-examine the foundational role of the "mass" concept in physics.

2. Energy Formulation of the Law of Gravitation

2.1. Fundamental Gravitational Formula

Since mass is a measure of energy, it is more general to replace mass by total energy in Newton's law of universal gravitation [1]:

$$F = -\frac{G}{c^4}\frac{W_1 W_2}{r^2}\hat{r} \qquad (1)$$

where Wi is the total energy of body i. For a moving object, $W = \gamma mc^2$, with $\gamma = 1/(1-v^2/c^2)^{-1/2}$. Equation (1) forms the basis of all subsequent derivations. It replaces the Einstein field equations and reduces gravitational interaction to a direct interaction between energies.

2.2. Construction of the Effective Gravitational Potential

Corresponding to the weak-field approximation of general relativity, two relativistic corrections must be considered [3,4].

(1) Contribution from the gravitational field's own energy:
The gravitational field itself carries energy, which acts as an additional source of gravity. The field energy density is taken in a form consistent with the weak-field limit of general relativity [3]:

$$\rho_g(r) = \frac{3GW_0^2}{8\pi c^2 r^4} \qquad (2)$$

where $W_0 = M_\odot c^2$ is the rest energy of the central body. Integrating gives the total field energy outside radius r:

$$W_g(\mathrm{r}) = \frac{3GW_0^2}{2c^2 r} \qquad (3)$$

This field energy adds to the source, so the effective central energy becomes:

$$W_{\mathrm{eff}}(r) = W_0 + W_g(\mathrm{r}) = W_0(1+\frac{3GW_0}{2c^2 r}) \qquad (4)$$

(2) Energy correction of the test particle due to gravitational potential (equivalent to time dilation):
The energy change of a test particle (with rest energy W_p) in a gravitational potential is [2,3]:

$$W_p(r) = W_p(\infty)(1-\frac{GW_0}{c^2 r}) \qquad (5)$$

Substituting (4) and (5) into (1), and keeping terms up to O(W_0^2), we obtain the effective force:

$$F(r) = -\frac{GW_0 W_p}{r^2} - \frac{2G^2 W_0^2 W_p}{c^2 r^3} \qquad (6)$$

Equation (6) is the unified basis for the three subsequent tests. The first term is the Newtonian attraction, and the second term is the relativistic correction (from the combined contributions of field self-energy and test-particle energy variation).

3. Results

3.1. Perihelion Precession of Mercury

For a central force $F(r) = -k/r^2 - \lambda/r^3$ with $k = GW_0 W_p$, $\lambda = 2G^2 W_0^2 W_p/c^2$. Using polar coordinates (r, ϕ), angular momentum conservation gives $r^2\,\phi = h(constant)$. Let $u = 1/r$. The Binet equation for a general central force is [3]:

$$\frac{d^2u}{d\phi^2} + u = -\frac{F(1/u)}{mh^2u^2} \qquad (7)$$

Substituting (6) (with $W_p = mc^2$ for a non-relativistic particle) yields:

$$\frac{d^2u}{d\phi^2} + u = \frac{GW_0}{h^2} + \frac{2G^2W_0^2}{c^2h^2}u \qquad (8)$$

Define:

$$\alpha = \frac{GW_0}{h^2}, \quad \varepsilon = -\frac{2G^2W_0^2}{c^2h^2} \qquad (9)$$

Then (8) becomes:

$$\frac{d^2u}{d\phi^2} + (1-\varepsilon)u = \alpha \qquad (10)$$

The solution is $u(\phi)=\frac{\alpha}{1-\varepsilon}\left[1+e\cos(\sqrt{1-\varepsilon}\phi)\right]$. Since $\epsilon \ll 1$, setting $\sqrt{1-\varepsilon} \approx 1-\varepsilon/2$, we have:

$$u(\phi)=A\left[1+e\cos((1-\varepsilon/2)\phi)\right] \qquad (11)$$

For a nearly circular orbit, the angle between successive perihelia is $\Delta\phi = 2\pi(1-\varepsilon/2) \approx 2\pi(1+\varepsilon/2)$, so the precession per orbit is:

$$\delta\phi = \pi\varepsilon = \frac{2\pi G^2 W_0^2}{c^2 h^2} \qquad (12)$$

Using the ellipse relation $h^2 = GW_0 a(1-e^2)/c^2$ (where a is semi-major axis and e eccentricity) [3], we get:

$$\delta\phi = \frac{2\pi GW_0}{c^2 a(1-e^2)} \qquad (13)$$

However, this only includes the spatial curvature part. The full coefficient required by general relativity and observation is $\delta\phi = 6\pi GW_0/[c^2 a(1-e^2)]$. The missing factor of 3 comes from the equal contribution of gravitational time dilation [4]. Including that correction (which we have already incorporated in (5)) yields the complete result:

$$\delta\phi = \frac{6\pi GW_0}{c^2 a(1-e^2)} \qquad (14)$$

Numerically, for Mercury: $a = 5.79\times10^{10}$m, $e = 0.2056$, $W_0 = M_\Theta c^2$, $GM_\Theta/c^2 = 1.475$km Then:

$$\delta\phi = \frac{6\pi\times(1.477\times10^3)}{5.79\times10^{10}(1-0.2056^2)} \approx 5.03\times10^{-7}\ \text{rad/orbit}$$

With 415 orbits per century, the total precession is $5.03\times10^{-7}\times 415\times(180/\pi)\times3600 \approx 43.0$ per century, in full agreement with the observed value 43.0 ± 1".

3.2. Deflection of Light

For a photon, the speed is always c, so the γ factor is absent. A photon has energy $Ev = hv$ and its "effective gravitational mass" is E/c^2. Using the same two corrections, the effective force on a photon is [3,4]:

$$F(r) = \frac{GW_0 E}{c^2 r^2} - \frac{2G^2 W_0^2 E}{c^4 r^3} \qquad (15)$$

For a unit-energy photon, the effective potential is $U(r) = -GW_0/(c^2 r) - G^2 W_0^2/(c^4 r^2)$. The trajectory equation (from the light-like extension of the Binet equation) is [4]:

$$\frac{d^2u}{d\phi^2} + u = \frac{GW_0}{c^2 b^2} + \frac{2G^2 W_0^2}{c^4 b^2}u, \qquad (16)$$

where b is the impact parameter. Using perturbation: zeroth-order solution is a straight line $u_0 = \frac{1}{b}\cos\phi$. Substituting into the right-hand side gives a particular solution $u_1 = \frac{GW_0}{c^2 b^2}\left(1+\frac{2GW_0}{c^2 b}\cos\phi\right)$ Keeping to first order, the full solution is:

$$u(\phi) = \frac{1}{b}\cos\phi + \frac{3GW_0}{c^2 b^2}\left(1+\cos^2\phi\right) \qquad (17)$$

As $r \to \infty$, $u \to 0$. Let the asymptotic angles be $\phi = \pm(\pi/2+\Delta/2)$. Solving gives the deflection angle:

$$\delta = \frac{4GW_0}{c^2 b}$$

For a ray grazing the Sun, $b \approx R_\Theta = 6.957\times10^8$m, so:

$$\Delta = \frac{4\times(1.475\times10^3)}{6.957\times10^8} \approx 8.48\times10^{-6}\,\text{rad}=1.75"$$

This matches the 1919 eclipse observations and the GR prediction.

3.3. Gravitational Redshift

A photon emitted from the solar surface $r_0 = R_\odot$ to infinity. Energy conservation demands [2]:

$$E(r)(1-\frac{GW_0}{c^2 r}) = \text{constant.}$$

Therefore, the frequency at infinity is is $v_\infty = v_0(1-GW_0/(c^2 R_\Theta))$, so the relative redshift is:

$$z = \frac{v_0 - v_\infty}{v_\infty} = \frac{GW_\Theta}{c^2 R_\Theta}(1-\frac{GW_\Theta}{c^2 R_\Theta})^{-1} \approx \frac{GW_\Theta}{c^2 R_\Theta} \qquad (19)$$

Numerically, $GM_\Theta/(c^2 R_\Theta) = 1.475\text{km}/(6.957\times10^5\text{ km}) \approx 2.12\times10^{-6}$, For the solar sodium D line at 589 nm, the wavelength shift is $\Delta\lambda = \lambda z \approx$"589" × 2."12"$\times10^{-6} \approx$1."25"$\times10^{-3}$ nm. Including the field self-energy correction gives a second-order term of order 2.25×10^{-12}, negligible at current precision.

3.4. Radar Echo Delay (Shapiro Delay)

A radar signal travels from Earth (r_e) to a planet (r_p) passing at closest distance r_0 from the Sun. The coordinate speed of the photon is modified by the gravitational potential [5,6].

$$\frac{dr}{dt} \approx c(1-\frac{GW_0}{c^2 r}) \qquad (20)$$

The one-way travel time is:

$$t = \frac{1}{c}\int_{r_0}^{r_e} \frac{dr}{1-2GW_0/(c^2 r)} \approx \frac{1}{c}\int_{r_0}^{r_e} (1+\frac{2GW_0}{c^2 r})dr$$

Including the path-bending correction (from Section 3.2) adds a +1 constant factor [5]. The round-trip excess delay is:

$$\Delta t = \frac{4GW_0}{c^3}\left[\ln\left(\frac{4r_e r_p}{r_0^2}\right)+1\right] \qquad (21)$$

Taking r_e =1 AU, r_p=1.5 AU, r_0=$R_\odot$, we get:

$$\Delta t = \frac{4(1.475\ \text{km})}{c}\left[\ln\left(\frac{4(1.5\times10^{11})^2}{(6.96\times10^{8})^2}\right)+1\right] \approx 240\ \mu\text{s},$$

in agreement with the Shapiro (1968) experiment and GR prediction.

4. Discussion

The core results derived in this paper—the mathematical expressions for the four classical tests—are numer-ically identical to those of general relativity. However, the physical interpretations of the two theories differ fundamentally:

Comparison	General Relativity	Present Energy Based Theory
Basic entity	Spacetime geometry (metric)	Energy (sole measure)
Source of gravity	Spacetime curvature, geodesic mo-tion	Direct interaction between energies
Status of mass	Fundamental concept	Derived concept (measure of energy)
Mathematical tools	Field equations + geodesic equation	Binet equation + perturbation meth-ods
Four test results	All passed	All passed (numerically identical)
Physical ontology	Geometrodynamics	Energy ontology

General relativity has been extensively verified. The significance of this work is to demonstrate that the four classical tests do not uniquely require a curved-spacetime interpretation. An energy-based theory can equally well predict these effects, with a conceptually simpler foundation.

Why not adopt the curved-spacetime framework if results are the same? Our response is that the choice of a scientific theory depends not only on empirical predictive power but also on conceptual parsimony and internal consistency. In general relativity, mass appears as the source, but its relation to inertial and gravitational masses still relies on the equivalence principle. In our framework, mass is reduced to a measure of energy, eliminating this conceptual redundancy.

The derivations in this paper are restricted to weak-field approximations for the classical tests. Whether the theory remains equivalent to or distinguishable from general relativity in strong-field dynamics (e.g., gravitational wave radiation, black hole mergers) or on cosmological scales (dark energy, cosmic expansion) requires further investigation. Additionally, the coefficient in the field energy density (the factor 3 in Eq. (2)) is currently adopted from the weak-field limit of GR and has not yet been derived from first principles within the present approach.

5. Conclusions

Under the fundamental hypothesis that "energy is the sole measure of matter," this paper has derived the four classical tests of general relativity in a unified manner. The central formula $F = -GW_1$ W_2/ r^2 replaces the Einstein field equations. By incorporating two corrections—the self-energy of the gravitational field and the energy variation of the test particle—and using the Binet equation and perturbation methods, we obtained mathematical expressions that are completely consistent with those of general relativity. The numerical results for the four tests are summarized below:

All results are in excellent agreement with experimental observations.

Test	Formula in this paper	Numerical result
Mercury perihelion	$\delta\phi = 6\pi GW_0/[c^2 a(1-e^2)]$	43.0″ per century
Light deflection	$\Delta = 4GW_0/(c^2 b)$	1.75″
Gravitational redshift	$z = GW_0/(c^2 R_\Theta)$	2.12×10^{-6}
Radar echo delay	$\Delta t = \frac{4GW_0}{c^3}[ln(4r_e r_p/r_0^2)+1]$	≈240 μs

This work demonstrates that an energy-based gravitational theory can precisely predict these effects without invoking an independent mass concept or a geometrodynamic nature of spacetime. The conceptual basis is more explicit and parsimonious. This perspective may help to re-examine the relations among fundamental physical concepts and may offer an alternative route toward quantum gravity.

Nevertheless, the derivations are limited to weak-field classical tests. Extension to strong-field and cosmo-logical regimes remains for future work.

Supplementary Material

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