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A Dilemma in the Physics of Gravitational Fields

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It is shown that improper use of local quantities for nonlocal situations in fields leads to traditional errors. Nonlocal theoretical quantities referred to standards in a fixed field are defined in order to obtain reliable results. Nonlocal properties of gravitational fields and matter located in it are deduced with the help of physical principles and an electromagnetic model for matter. In spite of the fact that the local velocity of light should be constant, the field is a space of variable nonlocal velocity of light, which accounts for its properties. Matter and light virtually propagate themselves without exchanging energy with the external field, in disagreement with traditional assumptions. Matter becomes contracted by the field. The results are self-consistent and consistent with the observed facts. Bodies with $r < 2GM$ would be different from black holes and they may account for the peak of highest energy of cosmic radiation and other astronomical facts.

1. INTRODUCTION

The original purpose of this work was to look for a direct way of understanding the true physical nature of the gravitational field with the use of the most reliable physical principles and direct reasoning. But soon it was realized that there were two major problems: Most of the traditional local physical quantities are not well defined for nonlocal situations in strong fields; and the improper use of these quantities has lead to fundamental errors of concepts that are deeply embedded in the traditional physics.

On the other hand, the relatively weak tests done for the gravitational theories are not an absolute guarantee of the validity of all of their hypotheses and implicit assumptions.

For the above reason, it was thought that it would be better to start all over again from the most elementary basis with new quantities better defined for more general nonlocal situations in fields and by putting, as a

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principle, a reasonable doubt on any arbitrary identity that has not been previously demonstrated on the basis of some unquestionable physical principle.

The main purpose of the first sections of this article is to introduce the new definitions for the nonlocal (theoretical) quantities and to look for the answer to the basical problem, what supplies the energy for the conservation work?

For this problem there are two main alternatives: The traditional one, which assumes that the field transfers energy to the body, and the unconsidered one, that the body converts part of its own rest mass into relatively free energy. None of the two hypotheses has ever been seriously demonstrated before.

The most simple demonstrations have been done in Section 3 in order to show which one of the alternatives is consistent with unquestionable principles extensively used in physics. It may seem hard to believe that the result is in strong disagreement with the mainstream of currently accepted concepts in physics, for which reason some of the statements made in this article—if read independently from the main context—may look odd. But on the other hand, the new concepts greatly simplify both the understanding of the true physical nature of the gravitational phenomena and the straightforward derivation of the theoretical properties of gravitational fields. This is done later on with the help of a previously tested electromagnetic model for matter. Final tests of the theoretical values with the experimental facts are given in the last section, with the purpose of showing that the nonlocal masses defined here are the true source of the field, as is expected to be the case.

Unimportant details for each particular case have been omitted for reason of space and simplicity. For similar reasons, the obvious generalizations from the simplest cases to the more general ones are not even mentioned.

2. NONLOCAL QUANTITIES

Revision of Concepts. Since the properties of space in a conservative field change from point to point, it should be assumed—unless it is otherwise demonstrated—that the properties of matter located in it should also change from point to point. The rather evident influence of the gravitational field on real clocks and rods has also been pointed out by Rastall (1960), Dehnen et al. (1960), and Thirring (1961). For this reason, the effective properties of the standards of observers in fields of different magnitude are not supposed to be absolutely identical to each other regardless of the identical numbers arbitrarily assigned to them by the corresponding local observers. Then, the traditional physical quantities determined in fields of different magnitude are not strictly referred to identical standards, for which reason any quantity measured by a local observer is of no use for another observer in a different field unless some unquestionable relationship between the corresponding standards has been previously determined on the basis of basic principles of physics.

The traditional physical quantities, therefore, are not strictly well defined for "nonlocal" observers in fields, specially when there is an appreciable difference of field between the object and the observer. Then any attempt to establish "direct" physical comparisions or relationship between traditional quantities should, most probably, lead to wrong results.

In spite of this, it is usual to establish a direct physical relationship with quantities determined in fields of different magnitude. This is the case of classical physics in which the effects of the field on matter are neglected. But it should be understood that those relationships, unless it is otherwise demonstrated, do not correspond to well-defined physical concepts in the strict sense of the word. For example, the concept of potential energy of a body has classically been defined after assuming that there are not real changes of the mass of the test body nor of the standard rods along any integration line in the field. This is something that has not been proved. On the contrary it is simple to prove that the opposite alternative is the true one, as shown below. Indeed, in strong fields, the traditional concept of potential energy turns out to be as meaningless as the summation of the incomes of employees during a strong inflationary period in which the buying power of money changes with time.

Partly as a result of this classical way of reasoning, it is reasonable to expect that some wrong fundamental concepts based on presumed identities between quantities determined in fields of different magnitude have escaped a deep revision.

This is the case of one of the most common assumptions made in traditional physics: that the external field is supposed to exchange energy with the body doing conservation work. For example, when Einstein (1965) justifies his field equation, he uses the same statement twice: "...the gravitational field transfers energy and momentum to matter in that it exerts forces upon it and gives it energy." This hypothesis has never been demonstrated. The question is: why has the opposite alternative—that the field does not exchange energy with the body—been traditionally disregarded? There are at least two main reasons.

One of them is the usual tendency to conclude, without a fair demonstration, that the forces applied to a body accelerating by the effect of such forces are bound to transfer energy to the body. This statement is not always true, as follows from the next example. Assume a car accelerating on a horizontal road with the power of its own batteries. The road forces acting on the tires do not give up evergy to the car although they give up momentum to the car and the forces seem to travel with the car. This statement may be easily demonstrated according to two viewpoints: a direct one and an indirect one.

From the first viewpoint, the road forces are static ones. They have no real displacement because new forces are generated at different contact points of the road with the tires. This makes a strong difference with the case of a nonself-powered car pulled by a string. The application point of the external force in this last case is displaced with the car, whose relativistic mass should increase with time.

From the second viewpoint, the kinetic energy is not increased at the cost of an external source of energy but at the cost of its own internal energy. In other words, the increase of the kinetic energy of the car is automatically compensated for by the corresponding decrease of the energy of the batteries of the same car. Then, the main characteristic of a self-powered body is that its relativistic mass remains constant, in contrast to a body powered by an external source of energy.

Similarly to the above example, in the case of a body falling freely from rest in a gravitational field, it is possible, by using the second viewpoint, to determine which one of the two alternatives is the true one. For this purpose it is enough to find out if the effective mass of the body either increases or does not increase during the free fall. But unfortunately, only the final local relativistic mass of the body is the unique well-known piece of data available at the end of trajectory. The initial local value of the mass is referred to a standard different from the one of the final observer, who is in a different field. Therefore, the initial local value is of no use for the final observer unless the theoretical relation between the standards can be determined from reliable physical principles.

Here is where the second reason for traditional confusion enters in. The straightforward use of the initial and final local masses in order to determine the mass difference obviously gives a positive relativistic mass increase, thus favoring the traditional assumption. But this careless mass-energy balance is meaningless from the strict physical viewpoint because this is made with quantities referred to different standards. A reliable mass-energy balance should be made only when the initial mass is corrected for the difference of field between the two locations so that the two quantities become theoretically referred to a common standard.

It may be concluded that in order to establish true physical relationships between quantities determined in fields of different magnitude it is most important that all of the quantities are referred to the same standards. For this purpose, a new type of nonlocal, field-corrected, quantity is to be defined for a theoretical observer for which all of the quantities are, in one way or another, referred to his local set of standards even when the object is actually located in a field whose magnitude is different from the one at the observer's location. This type of quantity is unobservable and it should be determined theoretically according to reliable principles or laws. This differs from traditional physics, in which the influence of the field on basic quantities such as the mass, length, and time are often ignored to such a degree that the location of the observer is not even mentioned. Not a single additional symbol is normally used in order to show a difference between quantities in fields of different magnitudes.

As a result of the influence of the field on matter, it is to be expected that matter, instead of the space, may become contracted and curved by the effect of the field and its gradient. For this reason, the material reference frame of each local observer would be approximately flat only within an infinitesimal local volume in which the deformation produced by the field gradient on matter may be neglected. The traditional physical principles, such as special relativity, may be safely applied within this local volume. A flat theoretical reference frame tangent to this local volume may be used for the local observer for his nonlocal theoretical deductions taking into account that these units of measurement are not bound to be identical to the ones of the observers in different fields. In this way every theoretical observer should have the same picture—but a different scale for the same reality.

Definitions. The nonlocal quantities are defined here as the true quantity that should theoretically exist at a nonlocal object position in the field according to reliable principles or laws, but compared theoretically with the standards at the position of the theoretical observer who is in a well-defined and fixed field, or at infinity, at rest relative to the center of mass of the system.

This type of quantity is unobservable, but it is possible to find general theoretical relationships between local and nonlocal quantities according to reliable physical principles. These relationships are functions that convert local quantities determined by one observer to the system of units of the other nonlocal observer.

Because of the influence of the field on the properties of matter, the new nonlocal quantities should depend not only on the field at the object but also on the field at the observer's standards. This introduces new variables into the traditional physical quantities that normally depend only on the relative velocity. Then, the nonlocal quantities may be regarded as an extension of the relativistic quantities to the more general nonlocal case in fields. For this reason the term "relative" has also been used here for the nonlocal quantities, when more emphasis is to be placed on this character.

The terms "apparent" and "true" were also used before by the author (1977, 1978).

The term "local" is used here when there is no appreciable difference of field between the object and the observer, but in obvious cases these terms have been omitted.

In order to avoid distractive variables on the problem, the simplest type of field—a central static field—has been used here most of the time. The central field is assumed to be a point function so that the radial positions r and r' of the object and the observer, respectively, fix well-defined fields at these positions. For simplicity most of the times it is assumed that the test masses are infinitely small as compared with the central mass.

The notation used in this type of field and, for example, for the nonlocal mass of a test body traveling with a velocity β relative to that of the light is $m_{r'}(\beta, r)$. The value of r' is the constant value that fixes the true constant values of the reference standards. The velocity β of a body is dimentionless and, therefore, independent of the location of the observer:

$$\beta = V_{r'}(r)/c_{r'}(r) = V_r(r)/c_r(r) = V/c \tag{2.1}$$

When r', r, or β are unimportant they are omitted. When only r' is omitted, it is to be assumed that the observer is at ∞, which makes the relations look simpler. When both r and r' are omitted, it may be understood, except in special cases, that they are local values. In order to avoid unnecessary subindices, the ones for the variables in the parentheses are omitted, but it is to be understood that they are expressed in terms of the units of the observer at r'. But in special cases, some physical quantities are shown to be independent of the location of the observer. In these cases, values without subindices are used in the explicit functions even when the observer is not at ∞.

For photons, the place of β in this notation is sometimes used for the velocity β of its source.

Local Standards. Extremely simplified and idealized definitions are used here in order to both save space and avoid distractive variables. For example, it is assumed that when an atom is forced to stop in the field the kinetic energy is transformed into electromagnetic radiation that is radiated away, leaving the atom at rest in a free and unexcited state, i.e., at temperature of 0° K. No chemical bonds nor thermal energy would be ideally present. For this reason, the present definitions are just theoretical ones and they cannot be reproduced in practice. Many other variables should be clearly defined.

Inertial masses or mass-energies are used here. They obviously include any kind of energy—such as kinetic energy—that is bound to accelerate with the body. The local energy of photons and the local mass of bodies are ideally compared by inertial methods with the local standard of mass.

The local rest mass of some standard test atom in a free and unexcited state has been selected as a local unit of both mass and energy. For observers at r', r, or at ∞,

$$m_{r'}^0(0, r') = m_r^0(0, r) = m^0(0, \infty) = m^0 = E^0 = 1 \tag{2.2}$$

Since the structure of matter is fixed by well-defined numbers of wavelengths, the most elementary standard of length may be chosen in terms of wavelengths. According to the quantum theory of the structure of matter, the ratio between atomic diameters and the wavelengths of any of its spectrum lines is expected to be a constant number.

The local wavelength of some well-defined spectrum line emitted by the local standard atom at rest has been selected as the standard unit of local length. Its local period has also been selected as the standard unit of local time:

$$\lambda_{r'}^0(0, r') = \lambda_r^0(0, r) = \lambda^0(0, \infty) = \lambda^0 = 1 \tag{2.3}$$

$$T_{r'}^0(0, r') = T_r^0(0, r) = T^0(0, \infty) = T^0 = 1 \tag{2.4}$$

The local frequency thus becomes unity and the local velocity of light becomes constant because of the implicit normalization made by local observers when they assign arbitrary constant numbers to their standards:

$$f_{r'}^0(0, r') = f_r^0(0, r) = f^0(0, \infty) = f^0 = 1 \tag{2.5}$$

$$c_{r'}(r') = \lambda_{r'}^0(0, r')/T_{r'}^0(0, r') = c_r(r) = c = 1 \tag{2.6}$$

This fact does not preclude the possibility that the nonlocal velocity of light may be different from unity, since the observer in a different field would have different standards.

Some physical relationships may become clearer when the mass-energy of the standard atom is expressed as a multiple of the energy of the standard photon:

$$m^0 = E^0 = Nhf^0 = Nh = 1 \tag{2.7}$$

The Planck constant, for example, results just equal to the fraction $1/N$ of the standard atomic mass corresponding to the standard photon.

Because of the well-defined and quantized nature of matter and the proportional interaction of the gravitational field with every part of the atomic structure, it may be safely assumed that N does not change after a change of field. This is even more obvious when the standard body is an electron pair or a positronium atom. In this case, the standard photon is the gamma radiation resulting from its normal annihilation. $N=2$, in this case, is a whole number. This shows that h is the same for any observer.

3. CONSERVATION PRINCIPLES FOR NONLOCAL QUANTITIES

In order to find out the theoretical relationship between local and nonlocal quantities it is most important to have reliable principles. The author (1977, 1978) thought that the most elementary principle is the "mass-energy conservation," which has proved to hold nonlocally, i.e., even when the objects are in strong fields such as the ones existing in the nuclei of atoms while the observer is completely out of those fields. Later on, the author (1979) realized that this principle is the result of even more basic principles for photons.

Nonlocal Conservation Principles for Photons. Static conservative fields cannot change the net number of cyclic events observed by means of monochromatic radiation traveling through them along a well-defined trajectory. This rather trivial fact seems to be the most elementary conservation principle from which the basical relationships between local and nonlocal quantities may be established. This kind of principle is normally used in physics. Schild (1960), for example, uses it in order to show the curvature of the current space-time.

It is simple to show that if the net number of signals sent by means of electromagnetic radiation is conserved during its free trip in a static field, its nonlocal frequency should also be conserved. Assume for example that the static observer at r' sends a continuous wave train of n electromagnetic waves towards the observer at r. The first and the final wave of the train should travel through the same infinitesimal nonlocal displacement $ds_{r'}(r)$ with the same instantaneous nonlocal velocities $c_{r'}(r)$. Then they should take the same nonlocal time interval to travel between r' and r. If $t^1_{r'}(r')$ and $t^2_{r'}(r')$ are the local starting times of the first and last wave, respectively, the theoretical nonlocal time interval $t_{r'}(r)$ that it should take the waves to reach the point at r is

$$\Delta t_{r'}(r)=\left[t_{r'}^{2}(r')+\int_{r'}^{r}\frac{ds_{r'}(r)}{c_{r'}(r)}\right]-\left[t_{r'}^{1}(r')+\int_{r'}^{r}\frac{ds_{r'}(r)}{c_{r'}(r)}\right]$$

$$\Delta t_{r'}(r)=\Delta t_{r'}(r') \tag{3.1}$$

This nonlocal time interval should not be confused with the local one for the observer at r. This last observer should have his local clocks running at different rates than the ones at r' because they are in fields of different magnitude.

If both the number of waves and the nonlocal time interval of the wave train do not change during the trip, then the nonlocal frequency of the waves reaching r should not change either. From (3.1)

$$f_{r'}(r)=\frac{n}{\Delta t_{r'}(r)}=\frac{n}{\Delta t_{r'}(r')}=f_{r'}(r') \tag{3.2}$$

Since the energy of a photon depends only on its frequency, the nonlocal energy of a photon traveling freely in a field should also remain constant. From (3.2)

$$E_{r'}(r)=hf_{r'}(r)=hf_{r'}(r')=E_{r'}(r')$$

$$E_{r'}(r)=\text{const} \tag{3.3}$$

It may be concluded that three quantities, the net number of waves, the nonlocal or relative frequency, and the nonlocal or relative energy of photons traveling freely in conservative fields, should remain constant. In other words, no net exchange of signals or of nonlocal energy would exist between photons and static conservative fields. This is a rather obvious conclusion since once the temporary electromagnetic perturbation produced by the photon has gone away, the field should recover its original state.

Nonlocal Conservation Principle for Bodies. According to the equivalence between mass and energy, the same conclusions as above are expected to hold for the relative mass of bodies. This may be shown to be true in the following theoretical experiment.

Assume that the test body is a positronium atom or an electron pair that falls freely from r' in the gravitational field of a central nonlocal mass M. Assume that annihilation occurs during the free fall at the level r with the emission of two photons traveling in opposite directions symmetrically to the original path.

If the traditional hypotheses—namely, that the central field gives up energy to the body—is assumed to be true, the relative mass of the test body should increase during the fall by the amount of relative energy presumed to be added up by the central field:

$$m_{r'}(\beta, r) = m_{r'}(0, r') + \Delta M_{r'} = m^0 + \Delta M_{r'} \tag{3.4}$$

When the test body annihilates itself, the resulting radiation should conserve its relative energy according to (3.3):

$$m_{r'}(\beta, r) = 2E_{r'}(r) = 2E_{r'}(r') \tag{3.5}$$

From (3.4) and (3.5), the final energy $2E_{r'}(r')$ reaching to the level r' would be larger than the initial mass m^0 just by the amount $\Delta M_{r'}$ added up by the central field. It would be, then, theoretically possible to use only the part equivalent to m^0 of the resulting energy to regenerate the test body at r', which could repeat the above cycle rather indefinitely with the net result of converting the central mass into radiation. This is, obviously, absurd unless

$$\Delta M_{r'} = 0, \qquad m_{r'}(\beta, r) = m_{r'}(0, r') = \text{const}_{r'} \tag{3.6}$$

This result may be expressed in terms of the standards at r, which is equivalent to multiplying (3.6) by a suitable conversion constant:

$$\Delta M_r = 0, \qquad m_r(\beta, r) = m_r(0, r') = \text{const}_r \tag{3.7}$$

It may be concluded that no net exchange of relative energy should exist between the central field and test bodies or photons traveling freely through it. Bodies would keep their relative masses constant until some nonconservative interaction takes place.

If the nonlocal mass of each body of an isolated conservative system remains constant, the same should hold for the whole system, which is equivalent to the mass-energy conservation principle.

Nonlocal Mass-Energy Relations. The local application of special relativity at r to a standard test atom falling from r' to r and the use of (3.7) and (2.2) gives

$$\frac{m_r(0, r')}{m_r(0, r)} = \frac{m_r(\beta, r)}{m^0} = \frac{1}{(1-\beta^2)^{1/2}} = \text{const} \tag{3.8}$$

Observe that the larger relativistic mass $m_r(\beta, r)$ when compared with the local rest mass $m_r(0, r)$ is a particular case of a larger relative mass that comes constant even from the starting point at r'. From (3.8) the difference of relative rest mass between r' and r is equal to the kinetic energy released by the conservative work:

$$m_r(0, r') - m_r(0, r) = \Delta E_r = m^0\left[(1-\beta^2)^{-1/2} - 1\right] \tag{3.9}$$

Equation (3.9) may also be expressed in terms of the standards at r', which is equivalent to multiplying (3.9) by a well-defined conversion factor. Calling the change of nonlocal rest mass between r' and r $\Delta m_{r'}(0)$, we have

$$m_{r'}(0, r') - m_{r'}(0, r) = \Delta E_{r'} = -\Delta m_{r'}(0) \tag{3.10}$$

Then, the nonlocal potential energy of a body becomes well defined by its own nonlocal mass, according to (3.9) or (3.10). Observe that the gravitational work, or the energy released by it, is done at the cost of a decrease of the relative rest mass of the same test body. The gravitational work, therefore, is not done by the field, as is traditionally assumed, but by the body.

From (3.10) but for a free fall from r to $r + dr$ we have

$$dE_{r'} = -dm_{r'}(0, r) \tag{3.11}$$

The nonlocal rest mass of a body decreases just in the amount of energy released. It is smaller for stronger fields and it should be a well-defined point function.

Equation (3.10) may also be obtained directly from the mass-energy conservation principle in the next theoretical experiment carried out in a space free from the influence of external fields.

Assume that a large number N of standard atoms are initially at rest and evenly distributed in a massless spherical shell of initial radius r^i, each of them tied to massless strings whose opposite ends are connected to massless mechanisms at rest at r^i, which slowly transform the work into other forms of energy, which may be either stored at r^i or escape as radiation to infinity. When the atoms displace themselves quasistatically in the field of each other up to a radius $r^f < r^i$, the atoms would come to rest in a free and unexcited state, as originally, but in a stronger field.

The application of the mass-energy conservation principle to the whole system for an observer at $r' > r^i$ gives

$$Nm_{r'}(0, r^i) = Nm_{r'}(0, r^f) + N\Delta E_{r'} \tag{3.12}$$

Here $\Delta E_{r'}$ is the net relative energy released by each atom. Equation (3.12) divided by N gives an expression equivalent to (3.10), but for each atom. In spite of the fact that this theoretical experiment is done for a highly symmetrical case with any imaginable number $N \geqslant 2$, it is equivalent to highly unsymmetrical cases since for this particular geometry each atom displaces itself just as if the rest of the atoms were located at their mass center. Obviously, the same result should also be obtained if the atoms fall freely from r^i to r^f giving away the energy released by gravitational work in any imaginable way before coming to rest at r^f.

4. DETERMINATION OF NONLOCAL RELATIONSHIPS IN GRAVITATIONAL FIELDS

According to the mass-energy conservation principle, a box with perfectly reflecting surfaces cannot change its weight or its trajectory in a gravitational field if any fraction of matter contained in it is transformed into radiation, provided that no energy escapes from the box. Based in this fact and since the mass and the form of the walls are unimportant, the test body may be replaced by an idealized light-box model of any appropriate form with massless and perfectly reflecting walls containing either the simplest forms of neutral matter or, even better, the radiation resulting from the annihilation of the particles. For example, a particle–antiparticle pair or a positronium atom could theoretically be used. The radiation resulting from their annihilation into two gamma photons traveling in opposite directions will form, for simplicity, standing waves after the reflection in the walls of the model whose distances are also self-determined by a well-defined number of wavelengths. This simulates in part the well-defined (quantized) structure of matter. It is reasonable to expect that the size of matter and the size of its theoretical model should be related by a proportional constant. For similar reasons, it is assumed that the local rest mass of the model is just equal to the energy of an even number N of photons of equal energy $hf(0, r)$ each, which may be called the confined energy of matter. More complex models may, of course, be devised with sets of standing waves of different frequencies in order to study, for example, the effects of the field on the energy levels of matter.

In order to make the picture even simpler, only two main orientations of the traveling waves are considered here. The two different approaches should lead to consistent results.

Nonlocal Acceleration of Gravity. The light-box model cannot accelerate unless a gradient of the nonlocal velocity of light exists in the space. This may be shown by using either vertical waves or horizontal ones (Fig.1).

Assume two monochromatic wavefronts of light starting simultaneously from the center of the light box of height dr in opposite vertical directions. After reflections at $r+dr/2$ they will meet at a level below the original center only if the average relative velocity of light in the upper region is higher than that at the lower region. If $dc(r)=c(r+dr/2)-c(r-dr/2)$, the average difference of relative velocities of the two wavefronts is $dc(r)/2$. From Figure 1, the net displacement dy of the center of the box after a time $dt(r)=dr/c(r)$ is equal to $-\frac{1}{2}[dc(r)/2]dt(r)$ which should be equal to $\frac{1}{2}\,g(0,r)\,dt(r)^2$, from which

$$g(0,r)=-\tfrac{1}{2}c(r)\frac{dc(r)}{dr} \tag{4.1}$$

The nonlocal acceleration of gravity $g(0,r)$ is, therefore, a consequence of the gradient of the nonlocal velocity of light of the space and it is independent of the nonlocal mass of the body, in agreement with the experiments.

The acceleration of gravity may also be determined from a monochromatic wavefront emitted along a vertical source 00′ of length Δr (Figure 2) that starts its trip horizontally. The vertical displacement Δy of the wavefront after one wavelength of horizontal displacement occurring during the time $\Delta t(r)=\lambda(0,r)/c(r)$ may be determined according to Huygen's principle, from which $\theta\approx\lambda(0,r)/r$ and $\Delta y=(1/2)\lambda(0,r)\theta$. By equating Δy with $(1/2)g(0,r)\Delta t(r)^2$, Equation (4.2) results in the limit when $\Delta r\to 0$:

$$g(0,r)=-c(r)^2\frac{d\ln\lambda(0,r)}{dr} \tag{4.2}$$

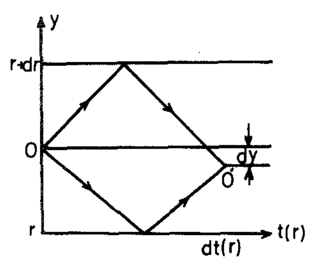

Fig. 1. Nonlocal space-time diagram for standing electromagnetic waves traveling vertically in a gravitational field within an infinitesimal light box of height *dr*. The larger nonlocal velocity of the light in the upper region as compared with that in the lower regions results in a net displacement *dy* accounting for the acceleration of gravity.

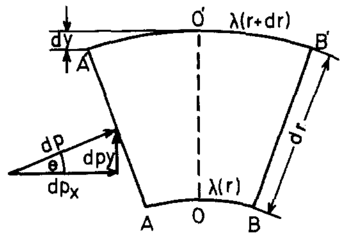

Fig. 2. Deviation of horizontal standing waves produced by a vertical source OO' in a gravitational field. The vertical displacement dy and the vertical momentum gain dp_y would account for the acceleration of gravity and weight, respectively.

From (4.1) and (4.2) the effect of the gradient of the nonlocal velocity of light on matter at rest may be deduced:

$$\frac{1}{2}\frac{dc(r)}{c(r)}=\frac{d\lambda(0,r)}{\lambda(0,r)} \tag{4.3}$$

The Nonlocal Weight. The nonlocal conservative force may be theoretically determined from the nonlocal energy released by the conservative work done when the theoretical model displaces itself from a rest at r to a rest at $r+dr$. Using (3.11) for the observer at infinity, we obtain

$$dW(r)=dE(r)=-dm(0,r)=F(0,r)\,dr \tag{4.4}$$

from which

$$F(0,r)=-\operatorname{grad} m(0,r) \tag{4.5}$$

Observe that the relative rest mass of a body replaces its potential energy in the traditional expression $F=-dU/dr$. From (3.9) and (4.5) for $\beta\to 0$

$$F(0,r)=\frac{(1/2)m(0,r)(d\beta)^2}{(1/2)\,dV(r)\,dt(r)}=m(0,r)g(0,r)/c(r)^2 \tag{4.6}$$

which is consistent with the observed facts.

The weight of the model may also be obtained directly from the waves traveling either vertically or horizontally in the light-box model after use of nonlocal momentum relationships.

The local momentum is well defined in its most elementary form for photons whose free trajectory is well determined by its wavelength. Then, the modulus of the nonlocal momentum of photons of relative wavelength

$\lambda(r)$ becomes well defined by

$$p(r)=h/\lambda(r)=hf(r)/c(r) \tag{4.7}$$

When the light box falls from a rest at r_0 down to r, the frequency of the waves traveling downward would be blue shifted by Δf due to the Doppler effect after successive reflections, while the waves traveling upward should be red shifted by the same value. This rearrangement of the internal energy does not change the relative frequency or energy within the box:

$$f(\beta, r)=\tfrac{1}{2}[f(0, r_0)+\Delta f]+\tfrac{1}{2}[f(0, r_0)-\Delta f]=f(0, r_0) \tag{4.8}$$

This makes a difference with the case of the light-box model accelerating not by a field but by the effect of a force doing effective work on it. In this last case the average relative frequency and energy of the standing waves are increased.

It is simple to show that the Doppler-shifted components of the free-falling model may be expressed in the following compact and dimensionless expression valid for any observer:

$$\frac{f_{r'}(\pm\beta, r)}{f_{r'}(0, r)}=\frac{f_{r'}(0, r_0)\pm\Delta f_{r'}}{f_{r'}(0, r)}=\frac{1\pm\beta}{(1-\beta^2)^{1/2}} \tag{4.9}$$

From (4.8) and (4.9), the average frequency for the observer at infinity is

$$\bar{f}(\beta, r)=f(0, r_0)=\frac{f(0, r)}{(1-\beta^2)^{1/2}} \tag{4.10}$$

Which multiplied by Nh is consistent with (3.8).

The net nonlocal momentum of the box may be obtained from the sum of nonlocal momenta of the confined photons. Using (4.7), (4.9), and (4.10), we obtain

$$p(\beta, r)=\frac{Nh\Delta f}{c(r)}=\frac{Nh\bar{f}(\beta, r)}{c(r)}\beta=\frac{m(\beta, r)}{c(r)}\beta=\frac{m(\beta, r)V(r)}{c(r)^2} \tag{4.11}$$

which is consistent with traditional forms. Observe that the nonlocal force (4.6) derived from (4.5) is equal to the one derived from (4.11) and

$$F(0, r)=\lim_{\beta\to 0}\frac{dp(\beta, r)}{dt(r)} \tag{4.12}$$

The weight may also be obtained directly from the vertical momentum gained by the waves traveling horizontally. Assume, for simplicity, that the wavelengths are almost infinitely small and that the horizontal displacement is just one wavelength (see Figure 2):

$$d_{p_y} = -p_x \frac{d\lambda(0,r)}{dr} = \frac{-Nh}{\lambda(0,r)} \frac{d\lambda(0,r)}{dr} \tag{4.13}$$

Using $dt(r) = \lambda(0,r)/c(r)$ and (4.13) we obtain

$$F(0,r) = dp_y / dt(r) = -nhf(0,r) \frac{d \ln \lambda(0,r)}{dr} \tag{4.14}$$

which is the same result obtained from (4.2) and (4.6).

Theoretical Nonlocal Properties of Matter at Rest in the Field. The relations between the fractional changes of nonlocal rest mass, frequencies, wavelengths, and the fractional changes of $c(r)$ may be derived from

$$m(0,r) = Nhf(0,r) \tag{4.15}$$

$$c(r) = f(0,r)\lambda(0,r) \tag{4.16}$$

And with the use of (4.3) or (4.5) and (4.14),

$$\frac{dm(0,r)}{m(0,r)} = \frac{df(0,r)}{f(0,r)} = \frac{d\lambda(0,r)}{\lambda(0,r)} = \frac{1}{2} \frac{dc(r)}{c(r)} = d\phi(r) \tag{4.17}$$

The first three members of (4.17) show that any ratio between relative masses, structural frequencies, or wavelengths should remain undistorted by the change of the field. The fourth member relates the fractional change of the physical properties of the space in the field.

The dimensionless function $\phi(r)$ defined in (4.17) is obviously independent of the location of the theoretical observer. Similarly to the traditional potential, $\phi(r)$ may be more completely defined by the integration of the fractional changes in the relative mass of the test body when it is displaced from a free and unexcited state at rest at infinity up to a free and unexcited state at rest at r. A similar but more fundamental definition may also be made in terms of $c(r)$:

$$\phi(r) = \int_\infty^r \frac{dm(0,r)}{m(0,r)} = \tfrac{1}{2} \int_\infty^r \frac{dc(r)}{c(r)} = \ln m^0(0,r) = \ln c(r)^{1/2} \tag{4.18}$$

Observe that in this very special case, since $d\phi(r)$ is independent of the location of the observer, the integration of (4.18) may also be done with local infinitesimal quantities. This makes the numerical values of (4.18) identical to the traditional field potential. In spite of this, the physical meaning of $\phi(r)$ is fundamentally different, for which reason it is meaningless to multiply $\phi(r)$ by the local mass, as is done in traditional physics. The traditional potential energy becomes undefined in strong fields since the relative rest mass of the test body changes along the integration path. The name "field magnitude," instead of "field potential," has been preferred here in order to avoid misinterpretations. For a central field, the best value of $\phi(r)$ found below is equal to $-GM/r$.

With the help of (1.1)–(1.5) the integration of the dimensionless equations (4.18) between r' and r gives the following theoretical properties of matter at rest in the field and of space.

(a) Nonlocal Gravitational Red Shift and Time Dilation

$$f_{r'}(0,r)/f_r(0,r)=\exp[\phi(r)-\phi(r')]=[c_{r'}(r)/c]^{1/2} \tag{4.19}$$

$$m_{r'}(0,r)/m_r(0,r)=\exp[\phi(r)-\phi(r')]=[c_{r'}(r)/c]^{1/2} \tag{4.20}$$

The relative frequencies, the relative energies, and the relative masses of each structural part of matter would be theoretically decreased by the same factor. The same fractional changes should occur in the relative frequencies of the photons emitted by atomic transitions between any two energy levels whose values would be effected by the same factor.

From (4.19), the theoretical relative time corresponding to a local time interval $t_r(r)=NT^0$, for example, would be

$$t_{r'}(r)=t_r(r)\exp[\phi(r')-\phi(r)]=t_r(r)[c_{r'}(r)/c]^{-1/2} \tag{4.21}$$

Everything would thus occur at slower rates in the field as compared with the same phenomenon occurring at infinity. But since local clocks would also run at slower rates, local observers in the field would not realize that this is actually happening.

(b) Nonlocal Gravitational Contraction

$$\lambda_{r'}(0,r)/\lambda_r(0,r)=\exp[\phi(r)-\phi(r')]=[c_{r'}(r)/c]^{1/2} \tag{4.22}$$

Every length in the body at rest should, therefore, be contracted by the same factor. For a local length $L_r(0, r) = n\lambda^0$

$$L_{r'}(0, r)/L_r(0, r) = \exp[\phi(r) - \phi(r')] = [c_{r'}(r)/c]^{1/2} \quad (4.23)$$

Local observers in the field should, therefore, have smaller units of length than the ones at infinity.

(c) Nonlocal Refraction and Relative Velocities. From (4.23) and (4.21), the nonlocal velocity of a body is contracted by the same factor as the nonlocal velocity of light:

$$V_{r'}(r)/V_r(r) = c_{r'}(r)/c = \exp[2\phi(r) - 2\phi(r')] \quad (4.24)$$

The nonlocal refraction index of the field thus becomes

$$n_{r'}(r) = c/c_{r'}(r) = \exp 2[\phi(r') - \phi(r)] \quad (4.25)$$

which accounts for the deviation of light and for the propagation of matter in the field, as shown below.

(d) Nonlocal Space-Time Contraction. The identical fractional changes of the relative frequencies and lengths that matter should have at rest in the field stand up even in the nonlocal space-time whose line element is defined by

$$ds_{r'}(0, r)^2 = [c_{r'}(r)\, dt_{r'}(r)]^2 - \sum_{i=1}^{3} dx^i_{r'}(0, r)^2 \quad (4.26)$$

From (4.23), (4.24), and (4.26)

$$ds_{r'}(0, r)/ds_r(0, r) = \exp[\phi(r) - \phi(r')] = [c_{r'}(r)/c]^{1/2} \quad (4.27)$$

Then, the nonlocal space-time interval undergoes the same changes of scale as each of the four coordinates.

For the observer at infinity and for a central field, the application of the value $\phi(r) = -GM/r$ found below to (4.27) and (4.26) gives

$$ds_r(0, r)^2 = \left[c(r)^2\, dt(r)^2 - dx(r)^2 - dy(r)^2 - dz(r)^2\right] e^{2GM/r} \quad (4.28)$$

With the use of (4.25) something like Yilmaz's metric results:

$$ds_r(0, r)^2 = c^2\, dt(r)^2 e^{-2GM/r} - \left[dx(r)^2 + dy(r)^2 + dz(r)^2\right] e^{2GM/r} \quad (4.29)$$

The first approximation of (4.29) looks like the Schwarzchild line element. But it seems necessary to point out here that the true nonlocal space-time should have all of its coordinates of nonlocal character as in (4.26) and (4.28). The product $c\,dt(r)$ in (4.29) is a product of a local quantity $c_r(r)$ and a nonlocal quantity $dt(r)$. It is doubtful that this hybrid product may have some physical meaning since the two quantities are referred to different standards whose ratio is not constant but depends on $\phi(r)$.

(e) Nonlocal Charge Depletion. From (4.5), (4.20), and (4.23) it is simple to prove that the nonlocal forces, the same as any ratio $m_{r'}(r)/L_{r'}(r)$, are independent of the gravitational field at both the observer and the object.

On the other hand, a force is to be used in order to define the local unit of charge. Assume, for example, that the centripetal force of an electron charge rotating around a proton is used for a natural definition of the charge unit. The same theoretical force is to be derived for an observer in a general nonlocal position:

$$F_{r'}(\beta, r) = \frac{m_{r'}(\beta, r)}{R_{r'}}\beta^2$$

$$F_{r'}(\beta, r) = k\frac{e_{r'}^{+}(0, r)}{M_{r'}(0, r)}\frac{e_{r'}^{-}(\beta, r)}{m_{r'}(\beta, r)}\frac{M_{r'}(0, r)}{R_{r'}}\frac{m_{r'}(\beta, r)}{R_{r'}}$$

in which $M_{r'}(0, r)$ and $m_{r'}(\beta, r)$ are the masses of the proton and of the electron, respectively, and $K = 1$ or a well-defined constant like the classical $\mu_0/4\pi$

Since the ratios m/R and M/R are independent of the gravitational field, the same should be true of the ratios e/M. Therefore, the nonlocal charges should change in identical proportion as nonlocal masses, after a change of gravitational field.[1]

[1]Most of the theoretical relationships between local and nonlocal parameters for electromagnetism in gravitational fields may be derived most simply, for example, by using the particular case of the nonlocal electromagnetic force between charges moving parallel:

$$F(\beta, r) = k\frac{q(\beta', r)q'(\beta', r')}{d^2}[1 - \beta(r)\beta'(r')]$$

taking into account that both nonlocal electric and nonlocal magnetic forces are independent of gravitational fields.

(f) Deformation of Matter. The curvature radius of a pseudohorizontal rule determined from Figure 2 and (4.22) is equal to $[d\phi(r)/dr]^{-1} = [F(0,r)/m(0,r)]^{-1}$.

(g) Nonlocal Forces. The relation between local and nonlocal momentum may be derived either from (4.7) and (4.22) or (4.11), (4.20), and (4.24):

$$p_{r'}(r) = p_r(r)\exp[\phi(r') - \phi(r)] \tag{4.30}$$

The relation between local and nonlocal forces may be derived either from (4.5) and (4.20) or from (4.12), (4.20), and (4.21):

$$F_{r'}(0,r) = F_r(0,r) = -\frac{\partial\phi(r)}{\partial r_{r'}} m_{r'}(0,r) \tag{4.31}$$

The forces are independent of the location of the observer because the rest masses, the energies, and the lengths change in the same proportion. Observe that for reason of symmetry in (4.31) the term $\partial\phi(r)/\partial r_{r'}$ should be proportional to the nonlocal mass $M_{r'}(0, r_0)$ causing the gravitational field.

(h) Nonlocal Mechanical Energy Conservation. From (3.8) and (4.20) the nonlocal mass-energy conservation is expressed by

$$m_{r'}(\beta, r) = \frac{m^0}{(1-\beta^2)^{1/2}}\exp[\phi(r) - \phi(r')] = \text{const} \tag{4.32}$$

since the nonlocal potential energy and the nonlocal kinetic energy are equal to

$$PE_{r'}(r) = m_{r'}(0,r) = m^0\exp[\phi(r) - \phi(r')] \tag{4.32a}$$

$$KE_{r'}(r) = m_{r'}(\beta, r) - m_{r'}(0,r)$$

$$KE_{r'}(r) = m^0\left[(1-\beta^2)^{-1/2} - 1\right]\exp[\phi(r) - \phi(r')] \tag{4.32b}$$

The summation of (4.32a) and (4.32b) gives

$$m_{r'}(\beta, r) = KE_{r'}(r) + PE_{r'}(r) = \text{const} \tag{4.32c}$$

The approximations of (4.32), (4.32a), (4.32b), and (4.32c) are consistent with the corresponding traditional expressions for weak fields.

From (4.32), we have

$$\beta^2 = 1 - K_{r'} \exp[2\phi(r) - 2\phi(r')] \tag{4.32d}$$

where $K_{r'} = m^0/m_{r'}(\beta, r)$ is a constant for each trajectory close to 1 for nonrelativistic bodies and equal to zero for photons.

(i) Nonlocal Angular Momentum Conservation. This may be derived directly from the theoretical trajectory of the light-box model. For this purpose assume, for simplicity, that the components of the standing waves are traveling back and forth along the line of movement. The interference of the Doppler-shifted standing waves, from (4.8) and (4.9) gives an amplitude proportional to

$$A = \sin\frac{2\pi}{\lambda(\beta, r)}[x - V(r)t(r)] \cos\frac{2\pi}{\lambda'(\beta, r)}[x - c'(r)t(r)] \tag{4.33}$$

$$\lambda(\beta, r) = c(r)/\bar{f}(\beta, r) \tag{4.34}$$

$$\lambda'(\beta, r) = \frac{c(r)}{\Delta f} = \frac{c(r)}{\beta \bar{f}(\beta, r)} = \frac{Nh}{p(\beta, r)} = \frac{\lambda(\beta, r)}{\beta} \tag{4.35}$$

$$c'(r) = c(r)/\beta \tag{4.36}$$

Use of (4.11) and (4.34) has been made in (4.35).

A is a product of two traveling wave functions. The amplitude of the first one is modulated by a kind of guide wave of effective wavelength $\lambda'(\beta, r)$ that determines the orientation of the wavefront of the packet of waves according to the interference laws or Huygens' principle. From Figure 3 and (4.35) these waves will be in phase when

$$\frac{d(\sin\theta)}{\sin\theta} = \frac{d\lambda'(\beta, r)}{\lambda'(\beta, r)} - \frac{dr}{r} = \frac{dp(\beta, r)}{p(\beta, r)} - \frac{dr}{r} \tag{4.37}$$

The integration of (4.37) gives the nonlocal angular momentum conservation law of the same form as the traditional one but with nonlocal parameters:

$$\frac{r\sin\theta}{\lambda'(\beta, r)} = \text{const} \tag{4.38}$$

$$r \times p(\beta, r) = \text{const} = L \tag{4.39}$$

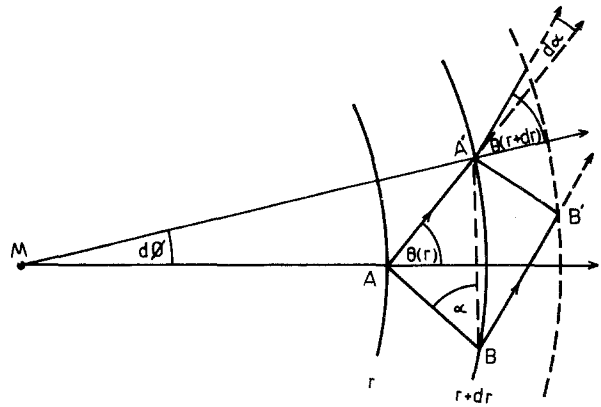

Fig. 3. Propagation of the monochromatic wavefront AB through successive layers of the central field produced by M according to electromagnetic principles.

The good agreement with the traditional expressions confirms, once more, the reliability of the light-box model for matter. More explicitly and from (4.39) and (4.11) for an observer at r' we have

$$L = \frac{m_{r'}(\beta, r) r_{r'} \times \beta}{c_{r'}(r)} \tag{4.40}$$

From (4.20), (4.23), and (4.24) it may be deduced that the numerical value of L is independent of the location of the observer.

Since $m(\beta, r)$ is a constant in a free trajectory in the field, it seems useful to define a constant density of angular momentum for a specific trajectory and for a well-defined observer:

$$j_\infty = \frac{L}{m(\beta, r)} = \frac{r \times \beta}{c(r)} = \text{const}_\infty \tag{4.41}$$

which is valid for bodies and for photons. In the last case, $m(1, r) = hf(r)$, the energy of the photon. The orbit of the photon in the field is determined by (4.41).

5. EXPERIMENTAL TESTS FOR CENTRAL FIELDS

According to the definitions, the nonlocal masses are the true or effective masses corrected for the difference of field between the object and the observer. Therefore, they should be the true source of the field.

This is also evident from (4.6) for reasons of symmetry. It should be expected, therefore, that the introduction of nonlocal quantities in the classical Poisson equation should greatly improve its results in the case of strong static fields, at least:

$$\nabla_{r'}^2\phi(r)=4\pi\rho_{r'}(0,r) \tag{5.1}$$

The integration of (5.1) for a central body of relative mass $M_{r'}(0,r_0)$ gives

$$\phi(r)=-G_{r'}\frac{M_{r'}(0,r_0)}{r_{r'}}=-\frac{GM}{r} \tag{5.2}$$

The third member of (5.2) results from the fact that the ratio $M_{r'}(0,r_0)/r_{r'}$ and the value of $\phi(r)$ are independent of the location of the observer, for which reason the values for the observer at infinity may also be used for it. In this case, $M=M(0,r_0)$. For the same reason it may be deduced that $G_{r'}=G$, a universal constant, equal to the classical ratio G/c^2.

Since the relationships of the last sections have been deduced according to well-proved principles and laws of physics, it seems unnecessary to show further consistency with ordinary physics; several self-consistency tests have already been done during the deductions.

Beside others, the following tests may be worth mentioning in more detail in order to show that the nonlocal field equation (5.1), which is the simplest one that may be imagined, is the one that gives the best fit with the observed facts.

(a) Agreement with the Standard Newtonian Theory. From (4.5), (4.20), and (5.2), for the observer at infinity

$$F(0,r)=-\frac{GMm(0,r)}{r^2}=-\frac{GMm^0}{r^2}e^{-GM/r} \tag{5.3}$$

which resembles Newton's law, but with nonlocal quantities instead of local ones. In contrast to Newton's law, $F(0,r)$ is maximum at $r=GM/2$, and decreases to zero for $r=0$. No singularity is obtained for $r=0$ nor for $r=2GM$, in contrast to general relativistic results.

From (4.1), (4.25), and (5.2), we obtain

$$g(0,r)=-c(r)^2GM/r^2 \tag{5.4}$$

consistent with classical laws in weak fields.

The use of (5.1) for the case of one body in the field of several discrete bodies would give a net contribution of the latter to the field magnitude at the location of the former equal to

$$\phi^i(r) = \sum_{j \neq i} \frac{GM^j}{r^{ij}} \tag{5.5}$$

M^j is the nonlocal mass of the body j and r^{ij} is the distance between the body i and the body j. Each body would thus contribute to the fractional depletion of the nonlocal mass of the rest of the bodies of the system. The use of (4.5), (4.20), and (5.5) leads to gravitational forces in agreement with traditional physics.

(b) Gravitational Red Shift and Time Dilation. The approximations of (4.19) after use of (5.2) agree with experiments made by Pound and Snider (1965).

The lower nonlocal velocity of light in a gravitational field should affect in the same proportion every standing wave representing the energy levels in a more elaborate model of atoms. The emission spectrum resulting from the difference between energy levels should, therefore, be red-shifted in the same proportion as each individual frequency or the total mass of the atom, according to (4.19) or (4.20). It is simple to prove—after use of classical electromagnetism and (4.23) and (4.25)—that even the nonlocal frequency of an LC resonant circuit should also change according to (4.19). It seems trivial to show that some similar relationship holds for any kind of frequency or energy, such as the nuclear one, whose values depend linearly on the mass.

(c) Gravitational Refraction. Light emitted by atoms of a vertical source in the field is not strictly monochromatic because of the gravitational red shift. The lower part of the wavefront traveling horizontally has lower nonlocal frequencies, according to (4.19), and travels with lower nonlocal frequencies, according to (4.25). The net result is a smaller nonlocal wavelength, according to (4.22), of the lower part of the wavefront. The wavefront would deviate, according to Huygens' principle, proportionally to $d\lambda(0, r)/dr \approx GM/r^2$, thus accounting for the weight and acceleration of gravity determined from (4.3), (4.22), (4.14), and (5.2).

A strictly monochromatic wavefront, on the other hand, would have a wavelength determined from (4.24), (5.2), and (4.19):

$$\lambda(r) = c(r)/f(r) = \lambda^0 \exp(-2GM/r) \tag{5.6}$$

Its deviation is roughly proportional to $d\lambda(r)/dr \approx 2GM/r^2$, i.e., the double of the deviation of the internal waves of matter at rest. The integrated deviation of light from stars produced by the gravitational field of the sun is thus approximately equal to $4GM/r_i$, where r_i is the impact parameter. This is in agreement with the experiments of Bertotti et al. (1962).

From (4.41) and (5.2) the trajectory of photons in central fields is well determined. The inclination angle, θ, is determined by

$$\sin\theta = (x_i/x)\exp(-2/x) \tag{5.7}$$

where $x = r/GM$, $x_i = r_i/GM$, and r_i is the impact parameter.

Figure 4 gives x vs θ for some special cases. In curve ABC for $x_i = 3e$, light is only deviated. Curve DE is for the critical case when light may either be deviated according to curve EF, may stay orbiting at E, or may be captured according to curve $E0$. Curve IJK represents a photon escaping from the surface (LL') at an angle of about 45°, but later captured at the same surface.

The limiting escape angle, θ_e, of photons is determined by

$$\sin\theta_e = (2eGM/r)\exp(-2GM/r), \qquad r \leqslant 2GM \tag{5.8}$$

Superdense bodies with $r < 2GM$ would capture anything traveling with $x_i < 2e$, regardless of its energy, but they would let escape only

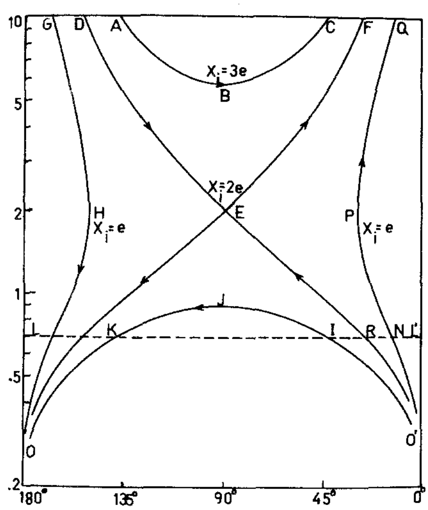

Fig. 4. Inclination angles θ of monochromatic light beams for several impact parameters r_i and critical escape angles for a semiblack body with $r < 2GM$. The values of x are equal to the ratio r/GM, and $x_i = r_i/GM$.

photons or relativistic particles emitted with an angle lower than θ_e. Therefore, they let photons escape with lower probabilities than a black body, for which reason they have been called semiblack bodies. They could capture more energy than they may emit due to both the lower escape probability and the strong gravitational red shift, which may go beyond the limits generally assumed from the theory of general relativity. In spite of high local temperatures at their surfaces, they should look, as observed from infinity, as if they had temperatures close to 0° K with the characteristics of cavity radiation. Some evidence of the existence of these bodies is given below.

(d) Time Delay of Radar Echo from Planets and Mariners. From (4.24) and (5.2), the theoretical time of radar echo from a planet is determined by

$$ct = 2(x_e + x_p) + 4GM\ln(r_p + x_p)/(r_e - x_e) \tag{5.9}$$

x_e and x_p are the distances along the line of flight from the earth and the planet, respectively, to the point of closest approach to the sun. r_e and r_p are the distances from the sun to the earth and from the sun to the planet, respectively. Equation (5.9) is in agreement with the experiments published by Shapiro et al. (1971) and Anderson et al. (1971).

(e) The Perihelium Shift of Planets. The application of (4.32d) and (4.41) to free orbits gives

$$\left(\frac{dz}{d\alpha}\right)^2 + z^2 = A^2\left[1 - K^2\exp 2\phi(r)\right]\exp\left[-4\phi(r)\right] \tag{5.10}$$

where α is the angular position, $z = GM/r$, $A = GM/jc$, and j is the density of angular momentum.

For $\phi(r) = -z$, the second-order approximation of (5.10) gives a perihelium shift of

$$\Delta\alpha = 6\pi A^2 = 6GM/a(1-e^2) \tag{5.11}$$

in agreement with the results of the observations given by Shapiro et al. (1971).

It is interesting to know how much experimental errors of the perihelium shift would allow that the ratio $F(0,r)/m(0,r)$ may deviate from the theoretical value (5.3):

$$\frac{F(0,r)}{m(0,r)} = -\frac{\partial\phi(r)}{\partial r} = -\frac{GM}{r^2} \tag{5.12}$$

For this purpose it may be assumed that the ratio $F(0,r)/m(0,r)$ has the form suggested from the results of general relativity,

$$\frac{F(0,r)}{m(0,r)} = -\frac{GM}{r(r-xGM)} \approx -\frac{GM}{r^2}(1+xGM/r) \tag{5.13}$$

$x=2$ for general relativity. Here x is the maximum factor that may produce results in agreement, within experimental errors, with the observed facts. If $\phi^d(r)$ is the new field magnitude defined by (5.13), its value may be obtained by equating (5.13) with $d\phi^d/dr$ and integrating. Its approximate value is $(GM/r)(1+xGM/2r)$. The substitution of this value into (5.10) gives a shift of

$$\Delta\alpha = \pi(6+x)A^2 \tag{5.14}$$

The experiments deviate from (5.11) by about $\pm 1\%$, for which reason x must be smaller than 0.06, i.e., much smaller than the value of 2 suggested from general relativity.

(f) Relativistic Cosmic Radiation. The nonexchange principle for nonlocal mass-energies turned out to be just a consequence of well-proved principles such as the mass-energy conservation, which does hold for any type of conservative field. It may be expected, therefore, that this principle would hold for other conservative fields or for a combination of them.

The rough application of the principle of nonexchange to the case of a He nuclei falling freely into a superdense star permits a fairly good estimation of the maximum energy of the particles that would result from the capture of neutrons and from the pseudoreflection of the protons by the core.

Even when the intermediate processes are unimportant for the present purposes, it may be expected that, for example, a combination of attractive and repulsive fields should produce different effects on both types of particles. Under dynamical conditions, for example, it is reasonable to expect that the core becomes positively charged so that protons are likely to be reflected with more probability than neutrons under the combined effect of nuclear, electrostatic, and gravitational fields. While the two particles are bound together, the nonlocal mass of the repelled particles (protons) would grow at the cost of the decrease of the nonlocal mass of the attracted particles (neutrons), thus keeping constant the total mass of the He nuclei, according to the nonexchange principle, up to the point of rupture of the nuclear binding.

Neglecting some probable nonconservative loss of energy on the whole process, the sum of the final nonlocal masses of the particles should be equal to the initial nonlocal mass of the He nuclei. From (4.20) and (5.2), the final relative rest mass of the neutrons at rest at the core of high GM/r should be negligible as compared to the final relative masses of the protons escaping towards infinity. This simple mass-energy balance of nonlocal masses leads to a final relative mass of the two protons just equal to the initial relative mass of the He atom. The magnetic rigidity equivalent to this excess of mass is equal to 1.6×10^9 V, which is in excellent agreement with the last peak of the primary cosmic ray spectrum observed by McDonald and Webber (1959) in periods of minimum perturbations due to solar flares.

6. CONCLUSIONS

The introduction of nonlocal theoretical quantities referred to standards in a fixed field at the position of the observer provides a firm basis on which true physical relations may be established between quantities in fields of different magnitude. The gravitational phenomena may be understood in terms of quantities previously corrected for the unavoidable effects of the field on matter.

The basic theoretical relationships between local and nonlocal quantities have been deduced with the help of either the mass-energy conservation principle or the equivalent fact that static conservative fields do not change the net number of electromagnetic waves traveling through them. From them it was deduced that the nonlocal frequency and energy of radiation and the nonlocal mass of bodies should remain constant during their free propagation in gravitational fields. This is equivalent to a nonexchange principle according to which there is no net exchange of mass-energy between the static conservative field and matter or radiation traveling freely through it.

This result is in clear disagreement with the traditional assumptions that the conserving fields should transfer energy to the bodies doing conserving work. On the contrary, the energy released comes from the conversion of the equivalent fraction of the rest mass of the same test body into rather free forms of energy. The gravitational work is more properly done by the body, not by the field as is commonly stated.

As a result of this, the nonlocal rest mass of the body becomes a measure of its absolute potential energy.

The explanation for the above result and for the gravitational phenomenon becomes clearer after use of the light-box model for matter. The gravitational field turns out to be a space of variable nonlocal velocity of light, which accounts for all of its properties. The local velocity of light, nevertheless, is a constant for any observer because of the constant values assigned to their local standards.

Similarly to the case of light, the standing wave packets of the model for matter propagate themselves in the field without changing their average nonlocal frequencies or energies. They deviate toward regions of lower nonlocal velocities. Their theoretical trajectories are consistent with the most rigorous experiments.

When a free-falling body is forced to stop in the field, each elementary part of it releases a well-defined fractional part of its own energy which, in one way or another, may go away from the body. As a result of both the lower nonlocal residual mass-energy of the body and the lower nonlocal velocity of light of the space, the new body, neglecting the small deformation produced by the field gradient, would be of identical proportions to the original one, but every part of it would have smaller nonlocal rest mass, lengths, wavelengths, and electric charges. The nonlocal energy levels and the emitted wavelengths would also change in the same proportion as the wavelengths defining the structure of matter. The percentage of gravitational red shift observed is just a direct measure of the percentage of the mass difference between the atoms of the object and the observer's atoms.

The good agreement of the tests done in the last section prove that the nonlocal field equation (5.1) is the one most consistent with both the observed facts and the physical principles involved in the deductions. They also prove that the nonlocal mass of a body is the true source of its gravitational field. The field itself is not a secondary source of gravitational field.

If both the test body and the source are replaced by light-box models, it is simple to conclude that the most elementary gravitation phenomenon is just a photon–photon interaction in which each one modifies the electromagnetic properties of the space around it.

The theoretical semiblack body resulting here for $r<2GM$ would have different properties from both plain black bodies and black holes. Radiation may escape from semiblack bodies but with lower probabilities than in a black body. They, therefore, may emit both strongly red-shifted cavity radiation of nonlocal temperature close to 0° K and relativistic cosmic radiation close to the theoretical maximum at magnetic rigidity of 1.6 GV. Both types of radiation have been detected. In the primary cosmic ray spectrum observed by McDonald and Webber (1959) there is a sharp decrease of cosmic radiation just after the last peak at 1.6 GV, just as is expected. This seems to prove both that the nonexchange principle derived here holds for the other types of conservative fields involved in the generation of cosmic radiation and that a relatively large fraction of matter in the universe exists in the form of semiblack bodies. This is also consistent with the very much larger mass of the clusters of galaxies when this mass is determined by dynamical methods as compared with the sum of the masses of their luminous galaxies. On the other hand, it seems reasonable to expect that black galaxies would be the natural result of galactic evolution and that their most massive bodies would have reached the state of semiblack bodies. This is also consistent with the well-known fact that the density of galaxies observed beyond clusters of galaxies is smaller than the average found in other regions of the sky. Black galaxies would not let see what is behind them.

The absence of a singularity at $r=2GM$ would open the way for nontraditional alternatives for stellar evolution and for new explanations of many astronomical phenomena (Vera, 1974, 1977). For example, the quasar red shifts can be interpreted as gravitational red shifts rather than cosmological ones. This is in agreement with the work of Clapp (1973) based on the Yilmaz (1958) exponential metric.

It seems possible to make a direct comparison of the present results with the ones of general relativity after use of the work of Thirring (1961).

In his original pseudo-Euclidean metric, the unrenormalized quantities are unobservable, the same as the nonlocal quantities used here. On the other hand, the renormalized metric is directly defined by observable (local) quantities that are in agreement with the Riemannian metric of general relativity.

The unrenormalized lengths, time, electric charges, and the velocity of light are equal to the respective approximations of the nonlocal values obtained here. The renormalized mass increases with the increase of the field. The nonlocal mass decreases in stronger fields.

The present results are more consistent with the results of Yilmaz's theories (1958, 1971) than with the ones of Einstein's general relativity. We need not be concerned with the objections made by Will and Nordvedt (1972) because the nonlocal quantities are not dependent on the velocity of the system relative to the space. Any possible anisotropic phenomena produced by such a relative displacement should affect in the same proportions and in the same relative orientations both the local structure of the atoms of the standard and the nonlocal structure of the system. Since every nonlocal quantity is a ratio between quantities that are affected by the same kind of changes, their ratio should be independent of such a change, unless the changes were nonlinear, which is unlikely. Then, it would be impossible to detect such a linear phenomenon. For practical purposes, therefore, a theoretical observer at rest relative to the mass center of the system may safely assume an idealized working space at rest relative to him.

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