*arXiv:physics/0006040 16 Jun 2000*

# Dark matter and the origin of mass: a simplified semiclassical approach

**C. L. Herzenberg**

---

**Abstract**

*The pervasive presence in space of a flux of high-speed, electrically uncharged dark matter particles is examined here for potential consequences. Dark matter interactions with ordinary matter are considered, and a model of the dark matter flux is developed. In this model, the property of matter that we designate as mass is a measure of the interaction cross section of ordinary matter with the flux of dark matter. From this model emerge effects similar to certain quantum phenomena, and also a flux-mediated attractive inverse-square force between particles of ordinary matter. The occurrence of effects resembling both quantum phenomena and effects resembling gravitational phenomena in this model may enable a straightforward examination of convergence of gravitational physics and quantum mechanics.*

---

---

**Key words:** dark matter, dark energy, mass, gravitation, quantum mechanics, Planck length, spacetime, physical vacuum, quantum fluctuations

## 1. INTRODUCTION

The presence of large amounts of non-luminous matter in the universe has been inferred to account for certain observed large-scale gravitational effects such as the rotational motion of galaxies and the motion of galaxies in clusters.[(1)] More recently, further evidence has been forcing consideration of the possibility that some cosmic dark energy exists that opposes the self-attraction of matter and causes the expansion of the universe to accelerate.[(2)] The identity of non-luminous matter and energy responsible for these various astrophysical effects remains at least in part unknown. However, the importance of these issues has led to considerable interest in examining dark matter and dark energy candidates of various types, including new and exotic types of matter. Among the numerous dark matter candidates that have been considered are high-speed particles of low mass without electrical charge.

We wish to explore here some potential consequences of the presence of a high-speed uncharged particle flux that is pervasive in what we call empty space or vacuum. That is, the explanatory capability for other phenomena of a flux of so far undetected particles permeating the vacuum will be investigated. We will limit our attention to a particular model; as will be seen, such a dark matter flux can under certain circumstances play a role somewhat analogous to a Higgs field[(3,4)], in that it can lead to the origin of mass from the coupling of ordinary matter to the particle flux.

Let us suppose that space is permeated by a type of non-luminous matter which consists of an omnidirectional flux of particles moving at very high speed that do not interact with eachother appreciably, and interact with ordinary matter primarily by exchange of momentum in collisions. This dark matter may be expected to exhibit some properties distinctively different from those of ordinary matter. Such dark matter particles could be expected to impact individually upon particles of ordinary matter, causing recoils. As a result, if there is continuing bombardment of an ordinary matter particle

by dark matter particles, the trajectory of the ordinary matter particle could be expected to be very irregular. If the dark matter flux is adequately large and the bombardment sufficiently intense, the impacts could be sufficiently frequent to cause particles of ordinary matter to undergo bombardment-induced erratic, agitated motion. This fluctuating, jittery motion of particles of ordinary matter induced by incessant bombardment by particles of the dark matter medium would correspond to zitterbewegung and be analogous to the Brownian motion or pedesis due to thermal agitation of the suspending medium which is observed for microscopic particles suspended in fluids. However, in this model it is ascribed to impact by real, long-lived dark matter particles rather than to short-lived local virtual particles.

In the absence of ordinary matter to interact with, these dark matter particles could be expected to travel undeflected through empty space. But such a flux would impact on massive macroscopic objects through their constituent particles, imparting momentum impulses to them. Any shadowing effect of ordinary massive objects on eachother could lead to a force between massive objects mediated by directional flux differences. As a consequence of the geometry, such a flux-mediated force could turn out to exhibit the distinctive characteristics of gravitational attraction. A directional excess of flux impacting against an object could lead to an acceleration in conformity with Newton's second law, as would any other source of momentum transfer. We will now examine how such effects can come about, and take an initial look to see how the presence of such a particle flux in space could accomodate and account for some of the quantum and classical properties of ordinary matter.

## 2. INTERACTION OF DARK MATTER FLUX WITH ORDINARY MATTER

Let us examine initially the case in which this flux of dark matter particles is macroscopically omnidirectional, isotropic, and uniform. The incidence of interactions of the flux with an individual particle of ordinary matter could be evaluated in terms of an interaction cross section which is a measure of the probability of occurrence of a collision or interaction. The cross section is the reaction rate per unit incident flux of dark matter particles per target particle of ordinary matter. Accordingly, the number of interactions per second of the flux with an individual object of ordinary matter will be given by:

$$n = fs \quad (1)$$

where f is the flux (in dark matter particles per square centimeter per second) and s is the interaction cross section (in square centimeters). (In numerical evaluations later we will switch to MKS units.) The quantity is a characteristic property of the particle or object of ordinary matter subjected to bombardment by the flux of dark matter particles.

## 3. INDIVIDUAL PARTICLE INTERACTIONS AND THE ROLE OF MASS

Eqn. (1) gives the number of interactions per second or frequency of interaction of a particle of ordinary matter with the flux of dark matter. This frequency may be regarded as the inverse of a coherence time, during which (on average) the ordinary matter particle continues propagating locally before undergoing the next stochastic impact with the dark matter flux.

Let us recall that in quantum theory every particle of ordinary matter can be regarded as having a characteristic frequency which is given by the de Broglie relation[5,6]:

$$n_q = mc^2/h \quad (2)$$

Here, h is Planck's constant, m is the (inertial) mass of the particle, and c is the velocity of light.

If impacts of dark matter flux particles on ordinary matter were associated with and involved in the quantum behavior of ordinary matter, it would appear that these two frequencies might be simply related or correspond to eachother. If these two frequencies are taken to be equal, combining Eqn. (1) with Eqn. (2) relates the mass m of a particle of ordinary matter to the cross section for interaction of that particle with the flux of dark matter particles, as follows:

$m = (sfh)/c^2$ (3)

Thus, this approach would lead to the conclusion that the cross section for interaction of an individual particle of ordinary matter with a flux of dark matter particles would be proportional to the mass of the particle of ordinary matter, and suggests that an object's inertial mass could be regarded as a measure of the probability of interaction of ordinary matter with a flux of dark matter particles. Our assumptions would imply that the average time interval between impacts would correspond to the time period corresponding to the de Broglie quantum frequency of the ordinary matter particle.

We will examine other aspects of interactions of individual dark matter particles with ordinary matter particles further in subsequent sections. Next, however, let us see how the idea of interaction of ordinary objects with a dark matter flux may be able to contribute to further insight into another physical phenomenon in which mass plays a role: namely, gravitation.

## 4. FORCE FROM DIRECTIONAL ANISOTROPY IN FLUX

If circumstances lead to a directional imbalance of dark matter flux on an ordinary matter object, the transfer of momentum during individual impacts would be expected to lead to an excess net rate of transfer of momentum to the impacted object along the direction of the flux imbalance, and hence the appearance of a net force on the object.

As we will see, such a mechanism can enable a flux of dark matter to produce forces between objects of ordinary matter, which, because of their geometry, are attractive inverse square law forces. Somewhat similar ideas for producing an attractive inverse square law force have been examined by others at varying levels of sophistication, dating back to Newton, who "... at times thought universal gravity might be caused by the impulses of a stream of ether particles bombarding an object ..."[(7)].

If only a single object of ordinary matter is present in an omnidirectional flux of high-speed particles of dark matter, it will on average be impacted uniformly from all directions. If more than one such object is present, these objects may shield eachother from the dark matter flux by their individual interactions with this flux. If, from the point of view of one object, the flux from the direction of another object is lowered by the presence of the other object, there will be an imbalance of flux along that direction, with more impacts coming from the direction opposite that of the other object, so as to impel the initial object toward the direction of the shielding object. This leads to an attractive force between objects of ordinary matter, mediated by the dark matter flux. Furthermore, the effective solid angle presented by one ordinary matter object to another will give rise geometrically to a $1/r^2$ force.

The total number of impacts per second on a single object of ordinary matter by the dark matter flux will be given by the product fs in accordance with Equation (1). These impacts come from all directions; the fraction f of the impacts coming from a particular solid angle in steradians would be given by:

$f = W/4p(4)$

Let us assume that each incident dark matter flux particle interacting with the ordinary matter object transfers a momentum of average magnitude $p_i$. (In the case of scattering, the recoil direction may differ from the original direction of the incident dark matter particle, so a geometrical correction may need to be considered and incorporated into the average magnitude of momentum transfer.) If the flux is omnidirectional, then the combined effect of these directed impacts will be to cancel eachother out on average over time, and there will be no net momentum transfer to and hence no net force on the impacted object. However, if an excess fraction f (or decrement - f) of the impacts occur from a particular direction, then the ordinary matter object will experience a net momentum transfer and hence a net force from the excess impacts. The net force produced by this net momentum transfer per unit time will be given by the product of the average momentum transfer per interaction with the net number of interactions per unit time effectively transferring that momentum:

$F = p_i fsf(5)$

Next, let us examine a situation in which we have present two objects composed of ordinary matter, a and b. Each object will shield the other from a portion of the otherwise omnidirectional uniform flux. Therefore there will be an imbalance of flux on each object, with the usual flux impacting on it from all directions except from the direction of the other object, where some fraction of the flux has been absorbed or scattered by the other object. This will result in a net force between the objects as the remaining impacts on each object preferentially impel each object toward the other one.

We will associate with ordinary matter objects a and b the interaction cross sections $s_a$ and $s_b$ respectively. A cross section has the dimensions of area, and at a distance r will determine an effective solid angle:

$W = s/r^2(6)$

Let the effective area of absorption or scattering of the flux by a massive object b be designated by $s_b$. The solid angle corresponding to this area from a distance r will then be given by:

$W_b = s_b/r^2(7)$

Then the effective solid angle of flux eliminated by the presence of an object b from the flux otherwise impinging from all other directions surrounding an object a will be given by the expression above, Eqn. (7).

Thus, we can evaluate the fraction f as:

$f = s_b/(4pr^2)$ (8)

Hence, using equations (4) - (8), we find for the force on an object a due to shielding effects of an object b:

$F_s = p_i fs_a s_b/(4pr^2)(9)$

It can be seen that this shielding force will vary inversely with the square of the distance between the two objects, and will depend directly on the product of the cross-sections of the two objects for interaction with the dark matter flux. Because of the symmetry of the expression with respect to the two objects, equal and opposite forces will be exerted on the two objects by the flux.

Equation (9), which gives the attractive force between two objects produced by their interaction with the dark matter flux, can be compared with the familiar expression for the gravitational force between two objects:

$$F_{grav} = Gm_a m_b/r^2 \quad (10)$$

Here $m_a$ and $m_b$ are the masses of the objects a and b, and G is the gravitational constant.

If we compare the equation for the attractive force mediated by the flux with the familiar equation for gravitational force, we can equate the coefficients of $r^{-2}$ in the equations (9) and (10) and obtain the equation:

$$Gm_a m_b = p_i f s_a s_b/4p \quad (11)$$

Comparison of the left-hand and right-hand sides of this equation suggests that the cross-section for interaction of a given particle of ordinary matter with a flux of dark matter particles would be proportional to the (gravitational) mass of the particle of ordinary matter; and that an object's (gravitational) mass can be regarded as a measure of the probability of interaction of ordinary matter with a flux of dark matter particles.

We see that an attractive inverse square force law follows from this flux impact model, and that the masses (in this case gravitational masses) appear proportional to interaction cross sections.

## 5. INERTIAL AND GRAVITATIONAL MASS: COMBINING RELATIONSHIPS

We can simplify Eqn. (11) mathematically to the case of objects having identical properties, so that the masses are of equal magnitude and the cross-sections are of equal magnitude. This would lead to an equation:

$$4pGm^2 = p_i f s^2 \quad (12)$$

On the left hand side of this equation, we have known physical quantities, and on the right hand side, parameters characterizing the model involving dark matter flux. We see that the (gravitational) mass enters the left hand side of the equation quadratically while the cross section enters the right hand side of the equation quadratically; the other parameters (gravitational constant, flux, and average momentum transfer) enter it linearly. This again supports the idea that the cross section associated with an object of ordinary matter would be proportional to the object's mass, as we have already conjectured.

Eqn. (12) informs us that the square of the (gravitational) mass is proportional to the square of the interaction cross-section. Squaring Eqn. (3) informs us that the square of the (inertial) mass is proportional to the square of the interaction cross-section. If we want to assure the equivalence of the gravitational mass to the inertial mass, the proportionality factors in the two relationships must be equal; this leads to the requirement:

$$p_i/f = (4pGh^2)/c^4 \quad (13)$$

so we see that the ratio of the average momentum transfer to the flux is wholly determined by known constants of nature.

Another relationship among the newly introduced model parameters and the known physical constants will be required in order to evaluate the new parameters individually in terms of known physical constants.

## 6. FORCE TO MASS RATIO

We have seen that in the context of this model the mass of a particle depends upon the product of its interaction cross section with the magnitude of the dark matter flux; and that, similarly, the inverse square force originating from flux imbalance on a particle also depends on the product of the flux and the cross section. These common factors will be eliminated in evaluating a ratio of force to mass. Equation (5) provides a general expression of the force on an object originating from a directional excess of dark matter flux. If we combine this with Eqn. (3) which expresses the particle's mass in terms of its interaction cross section and the dark matter flux, we obtain an expression for the ratio of force to mass:

$F/m = (p_i c^2/h)f$ (14)

This equation informs us that in this model the ratio of the flux-mediated force on an object to the object's mass is a quantity with the dimensions of an acceleration which is independent of the mass of the material object. It can be seen that this ratio depends only upon several natural constants, and on the fraction f corresponding to the excess or deficit of impacts coming from a particular direction. As a result of relationships derived later in this paper, the maximum acceleration, $(p_i c^2/h)$, turns out to be related to a maximum force, $(c^4/4pG)$, recently discussed in the literature[8].

Thus we find that the flux-mediated inverse-square force that originates in this model obeys an equation of the form:

$F = ma$ (15)

Where a is the quantity on the right-hand side of Equation (14), which has the dimensions of acceleration.

More generally speaking, it might be possible to cast other forces into a similar form, and express them in terms of equivalent fractions of impacts coming from a given direction in space.

## 7. DARK MATTER FLUX NUMBER DENSITY

So far, we have examined the interaction of a flux of dark matter with ordinary matter, but we have not characterized the distribution and motion of the dark matter itself sufficiently. Let us look in more detail at the ensemble of dark matter particles and their trajectories through space.

To obtain a measure of the average distance between flux particles, we can evaluate the number of flux particles per unit volume (that is, the number density of dark matter). We can obtain a value for the number density of dark matter particles by taking the value of the flux, , measured in particles per square centimeter per second, and dividing it by the average speed of these flux particles, $v_{dm}$, which would be measured in cm/sec. That would give a quantity with units particles per cubic centimeter. The number density would then be:

$N = f/v_{dm}$ (16)

Argonne ILL 60439
Telephone: 630-252-5021 FAX: 630-252-4979
e-mail: herzenbc@anl.gov, herzenberg@compuserve.com

Submitted for publication in Physics Essays.

Examination of possible consequences of the presence of an intense flux of dark matter particles shows that certain aspects of various familiar physical phenomena, including both macroscopic (gravitational interactions) and microscopic phenomena (some quantum effects) may result. In this view, some aspects of quantum phenomena may be regarded as medium-induced behavior, and gravitational forces may be regarded as medium-induced forces, the medium being the dark-matter flux. "Mass without mass", that is, the origin of mass as a secondary property of matter, comes as a result of interaction of ordinary matter with this dark matter flux. The parameters characterizing this model turn out to be closely related to the corresponding Planck scale, which is usually regarded as the characteristic scale of quantum fluctuations in the geometry of space. It is hoped that this simple semiclassical approach may help to contribute some insight into the transition between classical and quantum physics.

La présence dominante dans l'espace d'un flux de particules neutre et rapide de la matière sombre est examinée ici pour des conséquences potentielles. Des interactions de matière sombre avec la matière ordinaire sont considérées, et un modèle du flux de matière sombre est développé. Dans ce modèle, la propriété de la matière que nous indiquons comme masse est une mesure de la section efficace d'interaction de la matière ordinaire avec le flux de matière sombre. L'occurrence des effets ressemblant à des phénomènes de la mécanique quantique et les effets ressemblant à des phénomènes de la gravité dans ce modèle peut permettra un examen franc de la transition de la mécanique classique à la mécanique quantique.

## 1. INTRODUCTION

We consider here the possibility that both the classical gravitational force and certain quantum phenomena may be interpretable as effects of high-energy impacts of an intense dark matter particulate flux upon ordinary matter. While a dark matter particle flux of the type considered here would not necessarily be a likely candidate for the dark matter needed to supply the missing mass needed to account for certain astrophysical conundra such as the characteristics of the rotation of galaxies, it might constitute a medium that has useful explanatory capabilities relating to the fundamental properties of matter.

## 2. DARK MATTER PARTICLE FLUX

Let us assume that there is a flux of dark matter particles, and that these particles are neutral and have a velocity that is very high, relative to the velocity of matter in our vicinity. Let us further assume that the particles have a velocity that is very much greater than the escape velocity from the solar system, so that we may regard the particles as coming from outside the solar system and moving through it on straight-line paths. Let us assume for the time being that the velocity of the dark matter flux particles is given by the velocity of light, c. Then the last equation becomes:

$$\rho c = \Phi_{dm} \quad (18)$$

We can interpret this quantity as a measure of the average distance between dark matter flux particles.

## 8. MOMENTUM AND ANGULAR MOMENTUM IN INDIVIDUAL INTERACTIONS

We based our initial considerations in this discussion on the hypothesis that the frequency of impacts of the dark matter flux particles on an ordinary matter particle, as given by Eqn. (19), would be related to the de Broglie frequency associated with that particle's mass or energy, as given by Eqn. (2). Analogous considerations might be applied to the macroscopic motion of an ordinary matter particle, using the momentum and wavelength in the corresponding de Broglie relation[5,6]:

$$\lambda = h/(mv) \quad (19)$$

However, for present purposes we shall consider application of this de Broglie relationship to the instantaneous momentum associated with the stochastic motion of the particle. (As we shall see subsequently, this motion may be expected to be highly relativistic.) Let us now examine the implications of relating the momentum that appears in the model with an associated distance, in accordance with the above de Broglie relation for momentum and wavelength. If in Eqn. (19) we insert the magnitude of the average momentum transfer per impact, $p_s$, as given by Eqn. (17), we find:

$$\lambda = h/p_s \quad (20)$$

Just as in an earlier section the de Broglie frequency was interpreted as a measure of the frequency of impacts of the dark matter flux on the particle, here the de Broglie wavelength given by the distance $\lambda_{dB}$ can be interpreted as a measure of a distance between impacts.

Now, from Eqn. (17), $p_s = 2mv$, so we can also write Eqn. (20) as:

$$\lambda = h/(2mv) \quad (21)$$

Let us now eliminate $p_f$ between Eqn. (13) and Eqn. (22), so as to find a relationship between $f$ and $\lambda$:

$$f = \lambda c f \quad (22)$$

From Eqn. (22) into Eqn. (21), we can also evaluate the interaction cross section of a particle of ordinary matter in terms of its mass:

$$\sigma = m^2 [(64\pi^2 G^2)/(h^2 c^4)] \quad (23)$$

## References

1. S.N. Shore, in Encyclopedia of Physical Science and Technology, Second Edition, Vol. 4, edited by R.A. Meyers (Academic Press, New York, 1992).

2. N.A. Bahcall, J.P. Ostriker, S. Perlmutter, and P.J. Steinhardt, Science 284, 1481 (1999).

3. F. Wilczek, Phys. Today 52, 11 (1999).

4. F. Wilczek, Phys. Today 53, 13 (2000).

5. L. de Broglie, An Introduction to the Study of Wave Mechanics (Methuen, London, 1930).

6. L. de Broglie, Theorie Generale des Particules a Spin (Gauthier-Villars, Paris, 1943).

7. I.B. Cohen, Sci. Am. 244, 166 (1981).

8. L. Kostro and B. Lange, Phys. Essays 12, 182 (1999).

9. J. Baez, Length scales in physics, [URL http://math.ucr.edu/home/baez/lengths.html] (accessed 14 May 1998).

10. F.K. Richtmyer and E.H. Kennard, Introduction to Modern Physics (McGraw-Hill, New York, 1947).

11. K. Huang, American Journal of Physics 20, 479 (1952).

12. W. Weitzel, Zeit. für Physik 134, 264 (1953).

13. F. Hoyle, Proc. Roy. Soc. A 273, 1 (1963).

14. F. Hoyle, Proc. Roy. Soc. A 282, 191 (1964).

15. F. Hoyle, Proc. Roy. Soc. A 290, 162 (1966).

C. L. Herzenberg

Argonne National Laboratory