Technical Comments

Comment on "Negative Matter Propulsion"

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FORWARD'S discussion of negative matter propulsion[1] is interesting and worth some additional comments. A discussion of negative mass would be incomplete without a reference to the work of Paul Dirac,[2] who developed a theory of elementary particles which included negative energy solutions in 1928. Dirac's theory has been remarkably successful in explaining physical phenomena and is now considered a part of the "standard model" of physics. Dirac's discussion of negative energy states predates the work of Bondi[3] by several decades. Although "bare" Dirac negative mass particles are not actually seen, if they *could* be seen their properties would presumably be much like those of the negative matter Forward discusses.

There is no physical distinction between Dirac's negative energy solutions and the negative mass objects described by Bondi and Forward. Given $m = E/c^2$, a negative energy state is identical to a negative mass state. For example, the standard text on quantum mechanics by Messiah notes about Dirac negative energy states: "it would be more correct to call them negative mass solutions; however, when the field is null, the distinction between mass and energy is illusory."[4] The Dirac theory does predict antiparticles, but the antiparticles themselves are *not* the negative energy states (at least not in the conventional way of interpreting the Dirac theory); the antiparticles are holes where negative energy particles *are not*.

Dirac's negative energy states, if they could be observed alone, have exactly the properties Forward supposes for negative mass particles [5]:

1) The momentum is opposite in direction to the motion of the center of mass [$< v > = < (p/E) >$, where E is negative, in units where $c = 1$].

2) The acceleration is opposite in direction to the applied (electrostatic) force.

3) The gravitational mass is negative.

The last point assumes that the gravitational mass of an antiparticle is positive—a fact that will soon be experimentally verified but which is not usually doubted. Since the antiparticle is the absence of the negative energy particle, if the antiparticle has positive gravitational mass the particle itself must have negative gravitational mass. By Newton's law of reaction, then, both active and passive gravitational mass must be negative.

One may argue that Forward has also defined rest mass m_0 as negative, but in Dirac's usage rest mass is a scalar, and the sign is a matter of convention.

It is interesting to note that, in the spaceship consisting of positive and negative mass elements discussed by Forward, as the total mass of the spaceship approaches zero ($M_- \rightarrow M_+$) the Brownian motion of the ship due to impact of various particles will buffet it around at increasingly large velocities. Even in a perfect vacuum, photons of cosmic background radiation will become important if the mass is low enough. At $M_- = M_+$ the mass of the ship equals zero and any impact will apparently send it moving off at the speed of light. (Actually M will never precisely equal zero, as the ship will be constantly absorbing and emitting thermal photons.)

A particle hitting a zero mass spaceship would, of course, actually hit either the positive or negative mass portion. In a ship consisting of nearly equal amounts of positive and negative mass, the center of mass can move faster than either of the constituent masses and will do so whenever the distance between the two masses changes. Unless the ship is allowed to come apart, the true motion of the ship must eventually reconcile with the motion of the center of mass. This occurs due to the force on the link connecting the masses. The force on the link will cause the masses to move as described by Forward, so that even a small initial impulse will cause very large change in velocity if the positive and negative masses are nearly equal. This fact is of use in propulsion: a very nearly zero mass spaceship could be propelled by a flashlight.

Finally, Forward notes that bulk negative matter repels itself. This is true only if gravity is the only force considered. Gravity has the unusual property that like-charged particles attract, leading to the fact that gravity is not self-neutralizing. Thus, even though it is an extraordinarily weak force, gravity is still significant for large amounts of matter, while the much stronger coulomb force between electrically charged particles tends to neutralize itself. For negative matter, though, gravity repels like-charged particles. In essence, for negative mass, gravity and charge exchange roles. Because electrostatic forces are enormously stronger than gravitational forces, the effect is that charged bulk negative matter *attracts* itself and does so much more strongly than ordinary matter.

Thus, the large voids between galaxies noted by Forward, if they are to be accounted for as regions of negative mass, must be places where the negative mass has collected into huge, electrically-bound antiblack holes.

This tends to justify the initial assumption made by Forward, that negative matter can exist in bulk if it is charged, even though negative matter would not hold together by gravitational or molecular binding forces. While negative matter would indeed not form neutral atoms, it would form highly charged, tightly bound masses very much like the point particles assumed.

References

[1]Forward, R. L., "Negative Matter Propulsion," *Journal of Propulsion and Power,* Vol. 6, No. 1, 1990, pp. 28–37.

[2]Dirac, P. A. M., *Proceedings of the Royal Society of London,* A 117, 1928, p. 610, and A 118, 1928, p. 351.

[3]Bondi, H., "Negative Mass in General Relativity," *Review of Modern Physics,* Vol. 29, No. 3, 1957, pp. 423–428.

[4]Messiah, A., *Quantum Mechanics Vol. II,* Wiley, New York, 1966, p. 888.

[5]Messiah, A., *Quantum Mechanics Vol. II,* Wiley, New York, 1966, pp. 950–953.

Received April 30, 1990; revision received June 15, 1990; accepted for publication June 18, 1990.

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