Photon Thrust

Horace Heffner September, 1998

The following is in regard to the concept of interstellar vehicles driven by sails using photon pressure from a solar system based laser. It also deals with photon thrust in general, and with the false notion that free energy can be derived by driving masses using lasers.

Some starting point equations relating to photons and waves:

E = h nu (Planck) (1)

E = m c^2 (Einstein) (2)

lambda = c/nu (3)

p = E/c = (h)(nu)/c = h/lambda (4)

Assume the sail is 100 percent black, albedo zero. If photons are absorbed at rate n photons per second for time t, then the total reaction force is given by:

F = (n p)/t (5)

and the power absorbed by the sail is given by:

P = (E n)/t (6)

It is of interest the amount of energy absorbed by the sail per unit of momentum supplied to the rocket is obtained by substituting (4) into E/p:

E/p = E/(E/c) = c (7)

Notice that the amount of energy per unit of momentum imparted to the sail is *independent of the wavelength* of the photon. In fact, it is independent of anything else, as it is constant. I suppose this is self evident, especially considering equation (4), but it is important to the basic issues at hand. As energy per photon goes up, so does momentum, and vice versa. They have a linear relationship.

To determine the power absorbed by the sail per unit of thrust we divide (6) by (5) to obtain:

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$$P/F = (n\ E)/(n\ p) = E/p \qquad (8)$$

but from (7) E/p = c, so:

$$P/F = c \qquad (9)$$

and we immediately see:

$$P = c\ F \qquad (10)$$

We know that one kg-force is equal to 9.807 newtons, or 9.807 kg-m/s^2. So we now see that to produce thrust using photons of any energy we need the sail to absorb a photonic power per kg of thrust of at least:

$$P = (3x10^8\ m/s)(9.807\ kg\text{-}m/s^2) = 2.94x10^9\ kg\text{-}m^2/s^3 \qquad (11)$$

$$P = 2.94x10^9\ watts \qquad (12)$$

This is why photonic rockets are not so great. It's the same process in reverse, as is the case where photons are reflected from the sail.

Unlike particles, the photons leave the sun (or other light source,like a laser) with constant velocity c, yet arrive at the moving sail at the same velocity c, regardless of the sail's velocity. If nonzero rest mass particles did this it would be obvious that free energy were gained somehow by the reacting particles accelerating between the time launched and the time absorbed by the sail. If, with expenditure of a fixed amount of energy, you can add the same momentum to a departing mass being at any velocity, independent of the energy initially supplied, you have free energy.

The photon arrives at the same velocity regardless of the energy cost of emitting it. It would appear on the surface, when looked at as a particle, to have the requisite characteristics for providing free energy. However, nature extracts her toll even with the photon, and even at low velocities, though the effect is easier to understand when considered in context of near light speed events. The energy toll is extracted by nature in the form of the red shift, a result of the Doppler effect. The amount of change in wavelength of light, delta lambda, is proportional to the ratio of Vr/c,

where Vr is the recession speed of the departing sail relative to the light source, the rate at which it departs. If lambda0 is the wavelength emitted, and lambda is the wavelength absorbed at the sail then:

lambda0 = lambda + (delta lambda) (13)

(delta lambda)/lambda0 = Vr/c. (14)

So:

(delta lambed) = (lambda0)(Vr)/c (15)

As the recession velocity increases, lambda decreases. Equation (4) provides in general:

(p)(lambda) = h (4)

and, substituting (15) into (13):

lambda = lambda0 - (lambda0)(Vr/c) (16)

If p0 is the energy imparted when Vr is zero, and p1 is the energy imparted at Vr, we have:

(p0)(lambda0) = h (17)

and:

(p1)(lambda0 - (lambda0)(Vr/c)) = h (18)

so:

p1 = (1-Vr/c)P0 (19)

and we can see that p1 is diminished as Vr increases. Further the amount deltap is diminished is given by:

deltap = p1 - p0 = (1-Vr/c)P0 - p0 (20)

deltap = (-Vr/c)p0 (21)

so the incremental momentum, mother natures' tax, is proportional to the velocity of recession. Since E is proportional to p, the same can be said of deltaE. Energy is conserved.