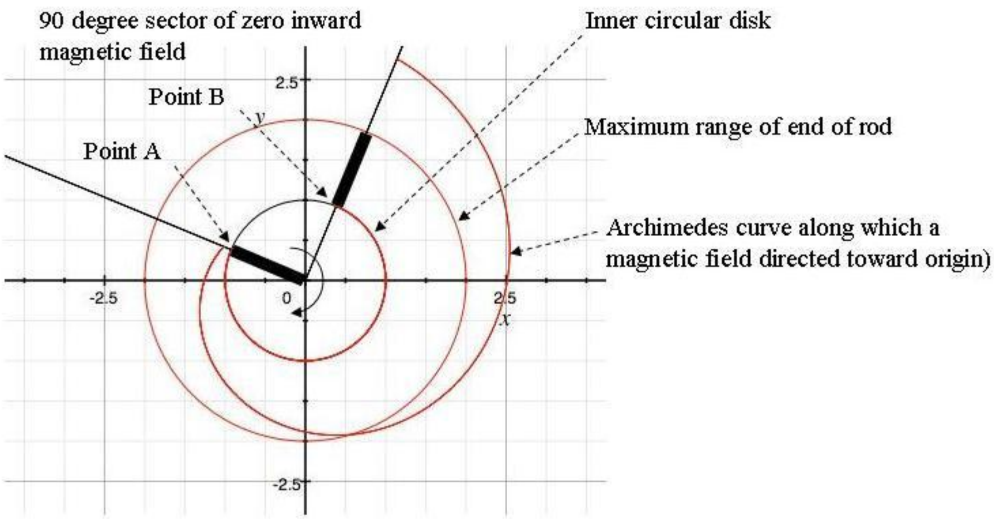
A brief description of the physics behind the unidirectional and self-contained, i.e., no propellant, linear motion device (Written for Paul Sprain and Bob Taylor; Author: Bobby Nichols, rnroot@gmail.com, August 2011)

Qualitative Description. As shown in Figure 1 below the device consists of an inner circular disk that is rotated by a motor (not shown) in a clockwise direction. A radial hole in the disk contains a single (black) rod that is free to move back and forth continuously from an inner position (*Point A*) to an outer position (*Point B*). The rod has a magnet attached to its outer end with the magnetic field pointing away from the origin. An array of magnets with magnetic fields pointing toward the origin are situated along the outer curve (Archimedes function, $r(\theta) = \theta + \theta_0$ in polar coordinates), whose radius decreases from *Point B* to *Point A* and which is not present in the 90° sector indicated as the "*Zero Magnetic Field Region*". At *Point B* the rod is fully extended and, as the disk rotates, is pushed into the disk as the rod location moves to *Point A*. From *Point A* to *Point B*, the rod is accelerated outward due to centripetal acceleration (and absence of an inward magnetic field). At some point between *Point A* and *Point B*, the stops at the inner end of the rod impact the disk (and rest of device), imparting a force or transfer of momentum to the device, causing a unidirectional transfer of momentum from the rod to the disk.

Figure 1. Geometry of a unidirectional linear motion device (Bobby Nichols)



Physics Description. Several basic laws of physics may be used to represent the situation described above including a force-impulse, conservation of energy, and conservation of linear momentum. The equations of kinematics (relating position, velocity, acceleration and time) are also employed. Gravity may or may not be included depending on the physical alignment of the device with respect to the gravitational field. For this analysis, the forces and energies associated with the magnetic fields need not be considered, as long as the disk is driven by a motor that rotates at an approximately constant rate and as long as the rod follows the path described above.

1. Conservation of Linear Momentum. We'll first consider conservation of linear momentum for an inelastic impact, analogous to one ice skater impacting (and sticking to) another skater that is initially stationary. The initial calculation does not include the effects of gravity, as would be the case if the device were placed on its side with the gravitational field directed along the motor shaft. Thus, the equations in this section are approximate for horizontal collisions on a frictionless surface.

Each impact between the rod of mass *m* and the rest of the device of mass *M* may be described as an *inelastic* collision, for purposes herein we take along y-axis without gravity. Such an impact (while not conserving energy) obeys

$$mv_{m1} = (m+M)v_2 \approx Mv_2 \qquad (1)$$

where v_{m1} is the velocity of the rod immediately prior to impact in the positive y-axis direction, v_2 is the velocity of the entire device in the positive y-axis direction, and the approximation may be made if *m* is much less than *M*. Thus, after each impact the velocity of the entire device is increased by v_2 in the positive y-axis direction. Note that Newton's Third Law (every action has an equal and opposite reaction) does not apply here as a similar impact does not occur anywhere else (even at the shaft) during a single revolution of the disk, hence unidirectional. The collision is likely *inelastic* (implying that the two objects stick together briefly after impact as noted above) due to the centripetal acceleration of the rod. Rearranging, we thus have

$$v_2 = \left(\frac{m}{m+M}\right)v_{m1} \approx \left(\frac{m}{M}\right)v_{m1} \qquad (2)$$

The radial velocity of the rod (the velocity away from the origin) immediately prior to impact may be calculated using centripetal acceleration. At *Point A* as the rod enters the magnetic field free region, the rod experiences a radial acceleration outward given by

$$a_{CM} = \frac{v_t^2}{r_{CM}} \qquad (3)$$

where v_t is the tangential velocity (the velocity perpendicular to the origin) of the rod and r_{CM} is the distance from the origin to the center of mass (CM) of the rod. The tangential velocity v_t is related to the angular velocity ω of the disk via $v_t = \omega r_{CM}$ implying that

$$a_{CM} = \omega^2 r_{CM} \qquad (4)$$

The radial velocity of rod immediately prior to impact may be calculated using kinematics with the initial radial velocity at *Point A* equal to zero (it was held fixed by the magnetic field), the distance R that the center of mass of the rod moves, i.e., the radius of the disk, and Eqn. (4), yielding

$$v_{m1} = \sqrt{2a_{CM}R} = \omega\sqrt{2r_{CM}R} \qquad (5)$$

Thus, combining all equations yields

$$\boxed{v_2 = \left(\frac{m}{m+M}\right)\omega\sqrt{2r_{cm}R}} \qquad (6)$$

for the velocity increase of the entire device after each impact with mass in units of kilograms [kg], radii in units of meters [m], and with $\omega = 2\pi f$ where f is the frequency of revolution in inverse seconds [1/s] or [Hz].

For example, if f = 600 rpm = 10 revolutions per second = 10 Hz, then $\omega=20\pi$ Hz. Approximating M = 15 kg, $m = (1\%)M$, and $R = 2r_{cm}$ = 0.20 m yields an imparted velocity to the device *after each impact* of 0.25 m/s. Thus, in the absence of friction after 100 s, the device would achieve a speed of 25 m/s (or about 60 mph). In many laboratory situations frictional losses could significantly limit the speed, but not alter direction of movement.

2. Force-Impulse and Conservation of Energy. In order to incorporate the effects of gravity, we'll perform a preliminary analysis of the demonstration whereby a sheet of paper is pulled out from under the device. Independent of mass, an object fired vertically with a velocity of 0.25 m/s will reach a maximum height of 3 mm in 0.025 s or 25 ms, and return to the ground in 50 ms. At 600 rpm, the device is impacted 10 times per second or once every 0.1 s or 100 ms, implying that the device will rise and fall between impacts. If the maximum height were reduced the thickness of a typical sheet of paper (1 micron), then the initial velocity would be about 0.005 m/s or 50 times less than the velocity estimated above (which is reasonable). Mass does not play a role in the preceding calculations. The power required to lift a 15 kg object 1 micron every 0.1 s is approximately 15 mW, much less than that required to rotated a heavy disk against the friction of its bearings.

Summary. The physical process is analogous to rapidly firing BBs at a larger object, or suspending a ping pong ball in air with a blow dryer (where the more numerous air molecules act like BBs against the much heavier ping pong ball). The analogy is not exact in that the entire device, affixed within a closed "black box", would move in one direction in the absence of friction: no external force would be required due to the devices design.

Final Note. While the above analysis is far from complete this author emphasizes that no conservation laws of physics are violated. Some of the energy supplied by the motor is ultimately transferred to creating the unidirectional impact.

Addendum 1. It is interesting to note that if the number of impacts per second were increased by increasing the rotation rate by a significant, but achievable factor, then the device could levitate or even rise in the presence of gravity on the earth. (It would still oscillate up and down at any rotation rate.) Further, the device, affixed to an object, would effectively reduce the weight of the object or, equivalently, reduce the net acceleration of the object toward the center of the earth.