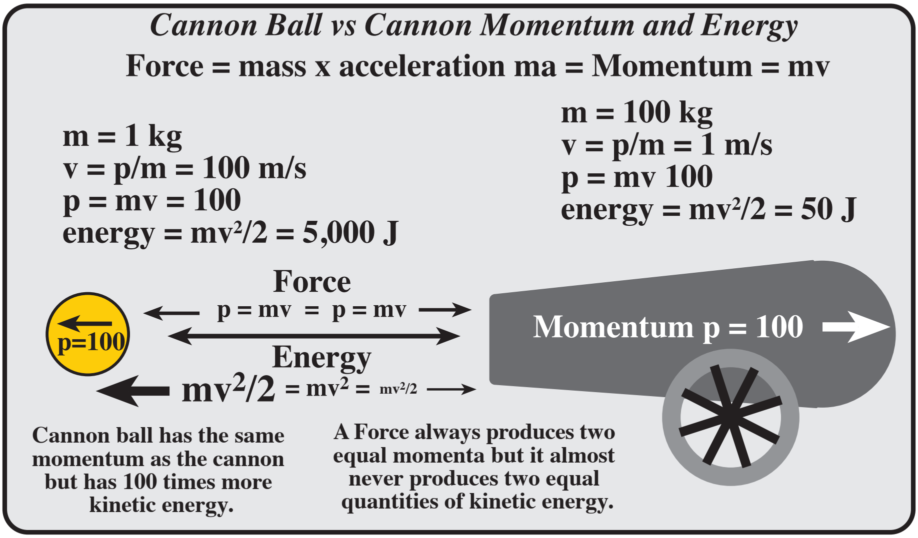
Measuring Inertial, Centrifugal, and Centripetal Forces and Motions

Many people are quite confused about the true nature and dynamics of centrifugal and centripetal forces. Some believe that centrifugal force is a fictitious radial force that can't be measured. Others claim it is a real force equal and opposite to measured centripetal force. It is sometimes thought to be a continuous positive acceleration like centripetal force. Crackpot theorists ignore all measurements and claim the centrifugal force comes out of the aether or spacetime continuum surrounding a spinning body. The true reality of centripetal and centrifugal forces can be easily determined by simply measuring them with accelerometers rather than by imagining metaphysical assumptions.

The Momentum and Energy of the Cannon versus a Cannonball



In the following thought experiment with a cannon and golden cannon ball, their individual momentum is easy to calculate because they are always equal. However, the recoil energy from the force of the gunpowder is much greater for the ball than the cannon. Momentum is measured from the acceleration produced by of a single quantity of force and energy is calculated from the opposite accelerations produced by force. In this sense, momentum is absolute and energy is relative even though they are both always equal. Momentum is measured as motion in a single absolute frame and energy divides the motion between two relative frames.

Since we are unable to measure the cannonball's momentum without changing it, we can calculate its exact velocity and energy by measuring the cannon's equal recoil momentum. If the cannon barrel is rifled, and causes the cannonball to spin, then calculating the total energy of the ball, when it hits the target, becomes more complicated. The cannonball's linear energy $e = mv^2/2$ is strictly relative to its motion with the target. However, its rotational energy $e = mvr^2/2$ is absolute and has the same value at all moving targets.

Measuring of Positive and Negative Centrifugal Forces

Centrifugal Forces are Momentary Transverse Pushes.
Centrifugal forces are measured as momentary transverse accelerations or decelerations. Whereas a linear force that changes momentum, is on a vector relative to the accelerometer's position of rest, centrifugal and centripetal forces that change angular momentum are perpendicular measurements relative to the center of a two-dimensional plane.

Centripetal Force is a Constant Radial Pull.
Centripetal force is a constant and equal balance of radial acceleration and deceleration. Centripetal force can be measured at anyplace on the table with two accelerometers set at 90˚ apart and aligned with the center. One measures a constant one-half transverse acceleration and the other measures the equal one-half of a transverse deceleration.

Both centrifugal force and centripetal force are measured with accelerometers attached to a rotating body. Centripetal force is a measure of the total positive centrifugal forces that have created the rotation. A free-wheeling rotating turntable produces a constant centripetal force at any location on the table. Transverse centrifugal forces produce either positive or negative changes in the turntable's angular momentum and rotational energy. Momentary centrifugal forces are equally added to or subtracted from the table's constant centripetal force.

The turntable measurements of force and momentum are done with two accelerometers. Centrifugal force accelerometers are aligned at 90˚ to the radius and centripetal force accelerometers are aligned at 45˚ to the radius. Centrifugal forces are measured as positive and negative one-dimensional pushes that are equal and opposite to the two-dimensional centripetal pulling force. These two forces are really just the same force aligned at 90˚ from one another. The momentum and linear energy produced by centrifugal forces are stored in the angular momentum and rotational energy of centripetal force.

Force Produces the Momentum that is a Measure of Energy

It is a common misconception of both scientists and laymen alike when they say, "To increase the rotation of the turntable we must add energy to it." This concept is true only in a relative sense. When we measure and change the rate of the turntable's rotation it is done by adding equal, consecutive units of centrifugal force. Each unit of force increases the table's centripetal force, angular momentum, and rotational energy. However, while each unit of centrifugal force does equally increase the table's angular momentum and centripetal force, equal units of force do not impart the same quantities of energy to it. The amount of energy transferred to the table by a given unit of centrifugal force is dependent on the accelerometer's location on its radius. A centrifugal force pushing at the table's outside edge increases energy far more than the same unit of force pushing near its center. Force is the cause of momentum change and energy is its result. It should be clear from this, that when we accelerate the table by using centrifugal force to equally increase its angular momentum and centripetal force, we are producing kinetic energy in the table that is not in proportion to force. Momentum can always be measured as energy but energy can never be measured as momentum.

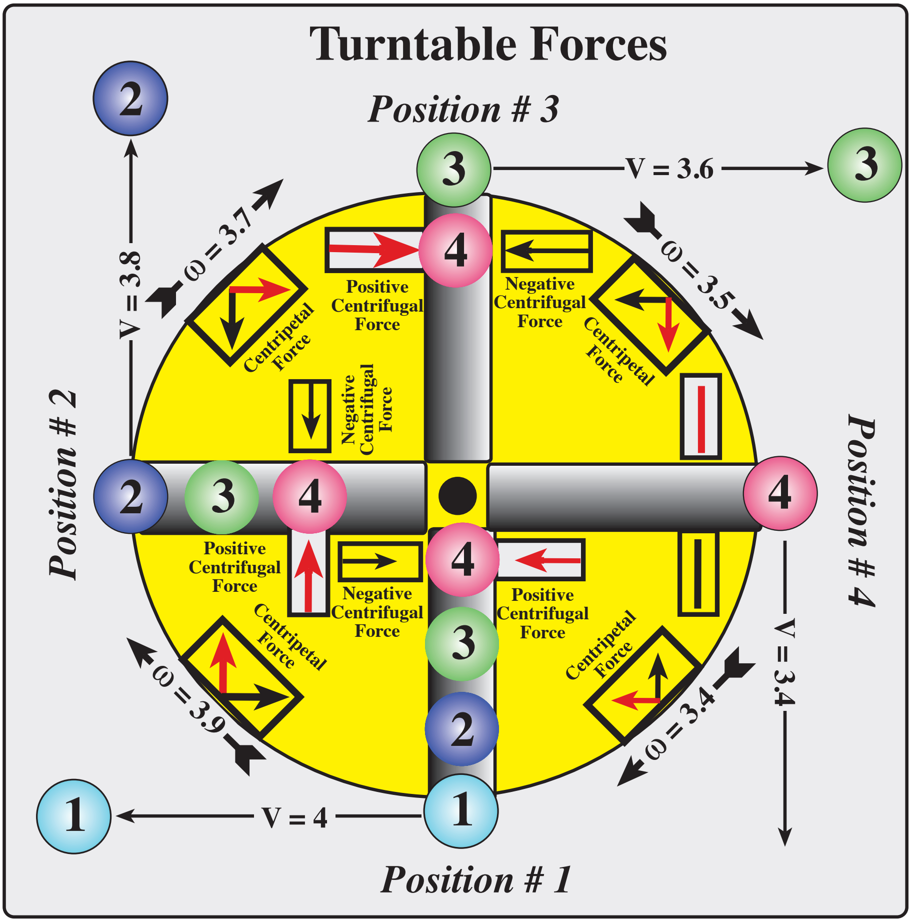
This rotating turntable experiment begins at Position 1 with the balls locked to the table. Ball #1 is just leaving the table at $v = 4$ and the table is spinning at $v = 4$. The total angular momentum and energy of the table and the balls is $I\omega = 1$. The table's centripetal force is $F = 1$ and its centrifugal force is $F = 0$.

When the balls are all released from the centripetal pulling force of the table, centrifugal pushing forces becomes active and begin pushing the balls down the groove and accelerating them to a higher velocity. As the balls move out to the edge of the table, their velocity and energy are increased by the centrifugal push from the edge of the groove. Accelerometers on the balls measure a positive centrifugal pushing force from the turntable and accelerometers mounted to the table measure an equal and opposite negative centrifugal pushing force that decreases its rotational velocity and energy.

As the balls roll out to Position #2, angular momentum is being transferred between the accelerating balls and the decelerating table. As the balls' velocity speeds up, their energy increases, and as the turntable's velocity slows its energy decreases by an equal amount. Total combined angular momentum and energy of the table and the balls remain constant. When the #2 ball leaves the table it carries away some of the momentum and energy that had been previously added to the turntable by centrifugal force.

In this experiment, accelerometers are used to measure the positive and negative centrifugal forces that change the angular momentum and energy of both the table and the balls. This is a passive measurement that involves no change in total angular momentum or kinetic energy. What is measured are the forces required to transfer angular momentum and energy from the table to the balls.

This experiment consists of measurements at eight positions on a single rotation of the table and balls. Four positions measure the table's decreasing centripetal force as the balls move along the grooves and the other four positions measure proportional decreases in positive and negative centrifugal forces. The arrows point in the direction of force, with their lengths indicating equal force, and their size indicating the amount of acceleration or deceleration being produced. Red arrows represent accelerations and black arrows are decelerations. All arrows are measurements of the forces that change the balance of angular momentum between the table and the balls. As the Balls leave their grooves, their angular momentum becomes linear momentum and kinetic energy. However, even after the balls leave the groove in the table and are far away, the total angular momentum and relative energy between the balls and table remains a constant value.



The Absolute Accelerometer Measurements

Accelerometers measure the force producing the acceleration or deceleration of mass. They are the only possible measuring devices for quantifying changes in a body's momentum or angular momentum. Modern experimental physicists have thousands of different measuring devices for determining all of the many different quantities in physics. However, at their most fundamental level, each of these instruments measures and calculates changes in momentum and angular momentum through the measurement of accelerations and decelerations produced by force. As an example, consider the radar gun used by police to measure the speed of cars. This device determines traffic speeds by measuring changes in the momentum of photons reflected from moving vehicles. The Hubble red shifts are measured as changes in the momentum of spectral photons. All of an experimental physicist's many measured and calculated values are based on accelerometer readings of either a linear force or centrifugal force that changes momentum and angular momentum.