



SCIENCE / PHYSICS

Rotational Motion (Physics): What Is It & Why It Matters

By [Kevin Beck](#) / Updated Aug 30, 2022

Perhaps you think of your movements in the world, and the motion of objects in general, in terms of a series of mostly straight lines: You walk in straight lines or curved paths to get from place to place, and rain and other things fall from the sky; much of the world's critical geometry in architecture, infrastructure and elsewhere is predicated on angles and carefully arranged lines. At a glance, life may seem far more rich in linear (or translational) motion than in angular (or rotational) motion.

As with a lot of human perceptions, this one, to the extent each person experiences it, is hugely misleading. Thanks to how your senses are structured to interpret the world, it is natural for you to navigate that world in terms of *forward* and *back* and *right* and *left* and *up* and *down*. But were it not for **rotational motion** – that is, motion about a fixed axis – there would be no universe or at least not one hospitable or recognizable to physics buffs.

Okay, so things spin around as well as shift about generally. What of it? Well, the big takeaways about rotational motion are that: 1) It has mathematical analogs in the world of **linear** or **translational motion** that make studying either one in the context of the other extremely useful, as it shows how physics itself is "set up"; and 2) the things that set rotational motion apart are very important to learn.



What Is Rotational Motion?

Rotational motion refers to anything spinning or moving in a circular path. It is also called angular motion or circular motion. The motion may be uniform (i.e., the velocity $\mathbf{v}$ doesn't change) or non-uniform, but it has to be circular.

- The revolution of the Earth and other planets around the sun may be treated as circular for simplicity, but planetary orbits are actually elliptical (slightly oval) and therefore not an example of rotational motion.

An object can be rotating while also experiencing linear motion; just consider a football spinning like a top as it also arcs through the air, or a wheel rolling down the street. Scientists consider these kinds of motion separately because separate equations (but again, tightly analogous) are required to interpret and explain them.

It's actually useful to have a special set of measurements and calculations to describe rotational motion of those objects as opposed to their translational or linear motion, because you often get a brief refresher in things like geometry and trigonometry, subjects it is always good for the science-minded to have a firm handle on.

Why Studying Rotational Motion Matters



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While the ultimate non-acknowledgment of rotational motion might be "Flat Earthism," it is actually pretty easy to miss even when you're looking, perhaps because many people's minds are trained to equate "circular motion" with "circle." Even the tiniest slice of the path of an object in rotational motion around a very distant axis – which would look like a straight line at a glance – represents circular motion.

Such motion is all around us, with examples including rolling balls and wheels, merry-go-rounds, spinning planets and elegantly twirling ice-skaters. Examples of motions that may not seem like rotational motion, but in fact are, include see-saws, opening doors and the turn of a wrench. As noted above, because in these cases the angles of rotation that are involved are often small, it's easy to not filter this in your mind as angular motion.

Think for a moment about the motion of a cyclist with respect to the "fixed" ground. While it's obvious that the wheels of the bike are moving in a circle, consider what it means for the cyclist's feet to be fixed to the pedals while the hips remain stationary atop the seat.

The "levers" in between are executing a form of complex rotational motion, with the knees and ankles tracing out invisible circles with different radii. Meanwhile, the whole package might be moving at 60 km/hr through the Alps during the Tour de France.

Newton's Laws of Motion

Newton's Laws of Motion



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Camel. Since you are studying motion formally, you might as well be familiar with the "ground rules" governing all motion and who discovered them.

Newton's first law, the law of inertia, states that an object moving with constant velocity continues to do so unless disturbed by an external force. **Newton's second law** proposes that if a net force $\mathbf{F}$ acts on a mass m , it will accelerate (change the velocity of) that mass in some way: $\mathbf{F} = m\mathbf{a}$. **Newton's third law** states that for every force $\mathbf{F}$ there exists a force $-\mathbf{F}$, equal in magnitude but opposite in direction, so that the sum of the forces in nature is zero.

Rotational Motion vs. Translational Motion

Rotational Motion vs. Translational Motion

In physics, any quantity that can be described in linear terms can also be described in angular terms. The most important of these are:

****Displacement.**** Usually, kinematics problems involve two linear dimensions to specify position, x and y . Rotational motion involves a particle at a distance r from the axis of rotation, with an angle specified in reference to a zero point if needed.

****Velocity.**** Instead of velocity v in m/s , rotational motion has angular velocity ω (the Greek letter omega) in radians per second (rad/s). Importantly, however, *a particle moving with constant ω also has a tangential velocity v_t* in a direction perpendicular to $\mathbf{r}$. Even if constant in magnitude, v_t is always changing because the direction of its vector continually changes. Its value is found simply from $\mathbf{v}_t = \omega \mathbf{r}$.



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As noted above, is always changing; there exists a centripetal acceleration a_c directed inward toward the rotation axis and with a magnitude of

$$a_c = \frac{v_t^2}{r}$$

Force. Forces that act about an axis of rotation, or "twisting" (torsional) forces, are called torques, and are a product of the force F and the distance of its action from the axis of rotation (i.e., the length of the *lever arm*):

$$\tau = F \times r$$

Note that the units of torque are Newton-meters, and the " $\times$ " here signifies a vector cross product, indicating that the direction of τ is perpendicular to the plane formed by F and r .

Mass. While mass, m , factors into rotational problems, it is usually incorporated into a special quantity called the moment of inertia (or second moment of area) I . You'll learn more about this actor, along with the more fundamental quantity angular momentum L , soon.



Radians and Degrees

Because rotational motion involves studying circular paths, rather than using meters to describe the angular displacement of an object, physicists use radians or degrees. A radian is convenient because it naturally expresses angles in terms of π , since one complete turn of a circle **(360 degrees) equals 2π radians**.

- Commonly encountered angles in physics are 30 degrees ($\pi/6$ rad), 45 degrees ($\pi/4$ rad), 60 degrees ($\pi/3$ rad) and 90 degrees ($\pi/2$ rad).

Axis of Rotation

Axis of Rotation

Being able to identify the **axis of rotation** is essential in understanding rotational motions and solving associated problems. Sometimes this is straightforward, but consider what happens when a frustrated golfer sends a five-iron twirling high into the air toward a lake.

A single rigid body can rotate in a surprising number of ways: end-over-end (like a gymnast doing 360-degree vertical spins while holding a horizontal bar), along the length (like the drive shaft of a car), or spinning from a central fixed point (like the wheel of that same car).



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axis of rotation were chosen through its long axis, the distribution of mass around this axis would be symmetrical, though not uniform, so you can imagine it spinning smoothly. But what if the axis were chosen through the heavy end? The hollow end? The middle?

Moment of Inertia

Moment of Inertia

As you just learned, spinning the *same* object around a *different* axis of rotation, or changing the radius, can make the motion more or less difficult. A natural extension of this concept is that similarly shaped objects with different distributions of mass have different rotational properties.

This is captured by a quantity called the **moment of inertia I** , which is a measure of how hard it is to change an object's angular velocity. It is analogous to mass in linear motion in terms of its general effects on rotational motion. As with elements in the periodic table in chemistry, it's not cheating to look up the formula for I for any object; a handy table is found in the Resources. But *for all objects, I is proportional to both mass (m) and the square of the radius (r^2).*

The biggest role of I in computational physics is that it offers a platform for computing angular momentum L :



Conservation of Angular Momentum

Conservation of Angular Momentum

The **law of conservation of angular momentum** in rotational motion is analogous to the law of conservation of linear momentum and is a critical concept in rotational motion. Torque, for example, is just a name for the rate of change of angular momentum. This law states that the total momentum L in any system of rotating particles or objects never changes.

This explains why an ice skater spins so much faster as she pulls in her arms, and why she spreads them out to slow herself to a strategic stop. Recall that L is proportional to both m and r^2 (because I is, and $L = I\omega$). Because L must remain constant, and the value of m (the skater's mass doesn't change during the problem, if r increases, then the final angular velocity ω must decrease and conversely.

Centripetal Force

Centripetal Force



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centripetal force. A classic example: The tension (force per unit length) on a string holding a tether ball is directed toward the center of the pole and makes the ball keep moving around the pole.

This causes centripetal acceleration toward the center of the path. As noted above, even at constant angular velocity, an object has centripetal acceleration because the direction of the linear (tangential) velocity v_t is continually changing.

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Cite This Article

MLA



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APA

Beck, Kevin. (2020, December 28). Rotational Motion (Physics): What Is It & Why It Matters. *sciencing.com*. Retrieved from <https://www.sciencing.com/rotational-motion-physics-what-is-it-why-it-matters-13721033/>

CHICAGO

Beck, Kevin. Rotational Motion (Physics): What Is It & Why It Matters last modified August 30, 2022. <https://www.sciencing.com/rotational-motion-physics-what-is-it-why-it-matters-13721033/>

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