

Figure skating and angular motion

Rotating during a jump

By changing the terminology, we can relate Newton's laws of motion to angular motion. Angular motion occurs as a result of torque (often called the moment). Torque is a turning force that causes an object to turn about its axis of rotation. Increasing the size of the force increases the torque. Applying the same force further away from the axis of rotation also increases the torque.

Let us look at how analogues of Newton's laws of motion can account for a figure skater's speed of rotation during a jump.

Spinning on the ice

Angular momentum is the quantity of rotation a body possesses or, more simply, angular momentum is spin. It depends upon the moment of inertia and angular velocity:

Angular momentum = moment of inertia $\times$ angular velocity

The moment of inertia is the resistance of a body to angular motion (rotation). Angular velocity refers to the speed of the rotation. These two are inversely proportional – if the moment of inertia increases, then angular velocity decreases and vice versa.

Angular momentum is a conserved quantity – it stays constant unless an external torque (force) acts upon it. In the context of figure skating, the figure skater will apply a torque through manipulating their moment of inertia to increase or decrease the speed of their spin. They do this by changing their body position so that they distribute their body mass either closer to or further away from the axis of rotation.

Newton's first law

A rotating body will continue to turn about its axis of rotation with constant angular momentum unless an external rotational force (torque) is exerted upon it.

When the ice skater is spinning in the air, they will continue to spin (rotate with constant angular momentum) until they land on the ice. Here an external force (torque) is exerted from the ice on their skates, which changes their state of angular momentum by slowing them down.

Newton's second law

The rate of change of angular momentum of a body is proportional to the force (torque) causing it and the change that takes place in the direction in which the force (torque) acts.

The greater the torque exerted as the ice skater pushes off the ice, the faster the rotation will be. This will allow them to complete their rotations before returning to the ice.

Newton's third law

When a force (torque) is applied by one body to another, the second body will exert an equal and opposite force (torque) on the other body.

When the ice skater takes off at the start of the spin, they apply a torque to the ice that generates a torque in the opposite direction, causing the ice skater to rotate. At the end of the spin when the rotating ice skater lands back on the ice, the torque exerted onto the ice is returned to slow the skater down.



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Starting the spin

At the start of the spin, the figure skater's arms and leg are stretched out. This increases their distance from the axis of rotation, resulting in a large moment of inertia and a large angular momentum in order to start the spin, so the speed of the rotation (angular velocity) is slow.

During the spin

When more speed is needed, the figure skater brings their arms and legs back in line with the rest of their body, significantly decreasing the distance of these body parts from the axis of rotation. This reduces the moment of inertia, meaning that angular momentum has to increase. The result is a very fast spin (increase in angular velocity).

Slowing down

To slow the spin down and gain more control, the figure skater adjusts their body position again by spreading their arms and legs back out to increase their moment of inertia. This decreases their angular velocity and the figure skater is able to control the slower spin and move onto the next phase of the routine.

