

# Physics of Ballet Dancing

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Dancing is one of the most difficult, disciplined, and beautiful art forms. Ballet is truly the foundation of all dance. Ballet teaches self-discipline, correct body placement, strength, and gracefulness. Who would guess that ballerinas are actually physicists in disguise. Not too many people, but in a way they are because they are showing us many fundamentals of this science, which allow them to produce breathtaking, dance masterpieces. They are performing physics at its best as they dance, leap and turn across the stage.

Dancing is a unique art form, which lets one express their feelings and use their body's capabilities to full extent. In order to use their body and withhold their own kinesphere, the fundamentals of mechanical physics are needed to ensure that the art form is definitely an amazing one.

The concepts of the following:

- [center of gravity and balance](#)
- [rotational mechanics and the pirouette](#)
- [friction and the glissade](#)
- [projectile motion and the grande jete](#)

all are part of physics that underlies the movements of ballet.

This article discusses how steps in Ballet are reliant and dependent on mechanical physics. Looking at dance from the mechanical physics point of view brings the art form of dance to a deeper level and shows the enormous amount of discipline needed to attain a beautiful, talented ballerina.



## Center of Gravity and Balance

Dance consists of movements of the body interspersed with motionless poses. Often these poses demonstrate balance of the body over a small area of support on the floor. Physically, a condition of balance exists if the dancer remains motionless above the area of support and does not fall. The balance condition will be achieved if and only if the center of gravity lies on a vertical line passing through the area of support at the floor.

If the dancer is motionless, the sum of all the forces and torques acting on the body must be zero. The force of gravity vertically downward will be balanced by the force upward from the floor to the foot (the Normal force), acting on the same vertical line.

This concept is derived from Newton's Third Law of Motion (the action-reaction law) which states: Whenever one body exerts a force on a second body, the second body exerts an oppositely directed force of equal magnitude on the first body.

**If the center of gravity is not in line with these other equilibrium state forces, the dancer will be unbalanced and experience an angular acceleration towards the ground (in other words the dancer will fall to one side.**

A dancer seldom achieves a true balance condition. If the center of gravity is close to that "balance area" that is if the forces are almost but not perfectly vertical, the acceleration away from vertical is initially quite small and the dancer appears to be balanced.

## Rotational Mechanics and the Pirouette

Turning movements are common in all forms of dance. One of the most common turns is the pirouette. The pirouette, in general, is a rotation where the dancer supports herself on one leg while the other leg is in retire position. Any pirouette must commence with some form of preparation position followed by a torque exerted against the floor. This torque of the floor against the dancer causes the angular acceleration that produces turning motion.

The torque to initiate a turn can be exerted against the floor by two feet with some distance  $l$ . In Ballet, pirouettes are commonly done from one of two positions, fourth position or fifth position. A turn from fifth position, which has a smaller distance ( $l$ ), will require more force to produce the same torque than a turn from fourth position, which has a larger distance ( $l$ ). This is because Torque ( $T$ ) is equal to the force ( $F$ ) multiplied by the distance of the lever arm ( $l$ ).

Another way to describe the torque used in a pirouette is to take into account the dancer's Moment of Inertia. The moment of inertia depends on the mass of a body and its distribution relative

to the axis of rotation. A body of given mass will have a larger moment of inertia if the mass is far from the axis of rotation than if it is close. An arabesque position has a larger moment of inertia than a retire position.

An arabesque turn is different than a pirouette because the leg is now stretched out behind the dancer (larger R) rather than close to the dancer at the knee (smaller R). The moment of inertia for the dancer in arabesque or pirouette position with the axis of rotation going vertically through the center of the body is  $I = \frac{1}{3} MR^2$ . Therefore, the larger the R, the larger the moment of inertia.

If we can determine the angular acceleration (a) of an arabesque turn or pirouette, then we can determine the torque used to produce it. If we know angular velocity (w) then we can take the change in the angular velocity divided by the time it takes to do the pirouette to find the angular acceleration.

**Using the equation:  $T = I\alpha$  which is analogous to Newton's second law of motion ( $F = ma$ ), we can calculate the T used for the turn.**

### Conservation of Angular Momentum

A powerful concept for dance analysis involves angular momentum. Analogous to linear momentum ( $p = mv$ ), angular momentum is given by  $L = I\omega$ . It is a conserved quantity and is a constant if there are no torques acting on a body. In other words, the total angular momentum L of a body can change only if there is an external torque acting on it. There is no way that changes in body position alone, representing changes in the configuration of mass within the rotating system, can change the total magnitude of L.

It is sometimes claimed that "spotting" the head one more time can squeeze and extra turn out of a multiple pirouette. But rotating the head relative to the rest of the body does not change the total angular momentum of the body as a whole, and therefore cannot contribute any extra turning motion.

The body may descend from turning position before completion of the turn, but the additional rotation of the head gives the appearance of a full additional turn. But once the initial torque against the floor has been exerted, and the dancer rises on the supporting foot, the angular momentum L is constant, decreasing only gradually because of friction with the floor.

### Friction and the Glissade

Friction involves the properties of surfaces, both chemical and mechanical. Chemical adhesion and roughness contribute to a frictional force that acts in a direction tangential to the interface between the surfaces. Each type of surface has its own coefficient of friction. This coefficient of friction multiplied by the vertical force

perpendicular to the floor (also called the normal force) will give the force of friction which acts against the motion of the dancer.

Friction is very important in dancing. To increase friction many ballet dancers use a substance called Rosin. Rosin has a high coefficient of kinetic friction but a significantly smaller dynamic coefficient. This means that if the foot is stationary on the floor a large horizontal frictional force is possible, but if the foot is moving that force is much smaller.

This difference is very useful for a dancer performing glissades, a step which needs this horizontal force only when the foot is not moving against the floor. A glissade is a gliding motion from fifth position to an open stretched position and then back to a fifth position.

Many dance movements involve sliding on the floor or rotating against it. Whether a dancer needs a change in linear horizontal motion as in a glissade, or an angular acceleration as in a pirouette, the floor must be able to supply the horizontal forces that provide for such accelerations. Too much friction may prevent these movements.

### Projectile Motion and the Grand Jete

All jumps involve vertical accelerations and forces. Because gravity acts vertically downward on our bodies at all times, we can only remain motionless if there is a vertical supporting force equal to our weight (the normal force). In order to jump off the ground we need to exert a force downward against the floor greater than our weight ( $mg = \text{mass} * \text{acceleration due to gravity}$  for long enough to achieve the vertical upward velocity desired).

The height of a jump depends on the downward vertical distance through which that force is exerted. In order to obtain enough force to jump off the ground a dancer is required to bend their knees, a position called plie.

Jumps combined with horizontal motions such as the grand jete (a leap in which the weight of the body is thrown from one foot to the other) produce trajectories or have projectile motion. Once the body loses contact with the floor, the center of gravity will follow a parabolic trajectory that is totally determined by the initial conditions starting on the ground.

**The trajectory will follow the path of a normal projectile- it will begin with an initial velocity ( $v_0$ ), which will decrease as the dancer rises into the air until it reaches zero. This is at the maximum height during the leap. Following this maximum is the descent to the floor which is an accelerating downward motion until the dancer reaches the ground again.**

In order to calculate the different parameters of this parabolic trajectory, we can employ two-dimensional kinematics. Both the “x” and the “y” component must be considered in this case. Also as in all projectile motions, the initial velocity in the x direction is equal to the final velocity in the x direction This means there is no horizontal acceleration. Finally the acceleration in the y or vertical direction is always due to gravity (-9.8 m/s<sup>2</sup>).

In conclusion dance is truly dependent on physical concepts such as momentum, Newton's laws of motion, rotational mechanics, and linear kinematics. Analysis of Ballet and correct Technique employs physics to maintain gracefulness, strength, and an overall sense of space required for all beautiful dancers.

**List of definitions**

<http://www.geocities.com/CapeCanaveral/Hangar/4421/definitions.html>

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