THE PHYSICS OF IN-LINE SKATING

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In-line skating, or rollerblading, is a popular mode of transportation and a fun pastime. As an avid rollerblader, I have always been interested in the physics behind the exercise. The behavior that governs rollerblading and the person wearing the skates can be explained through the application of classical mechanics or Newton's laws of motion. The concepts involved in the behavior of rollerblading are: various forces, friction and drag, potential and kinetic energy, the conservation of energy, acceleration and linear and angular momentum.

These concepts can be applied to the behavior of the person and the skates under the general conditions involved in starting from rest, continuous motion, or turning and stopping. Because no two people are created exactly alike, one must also consider that the behavior explained by the laws of mechanics is dependent upon how the mass and body shape of the given individual affects her momentum and the air resistance she will encounter while skating. The design of the rollerblades, too, may play a role.

What causes a person wearing rollerblades to start forward when she is at rest? In order for the in-line skater to begin moving, he or she must experience a force in the direction of motion which causes her to accelerate from rest to some velocity. An in-line skater at rest is only exerting a force down upon the ground (gravity) and the ground is exerting an opposite but equal force up on the skater. This is a simple application of Newton's third law. However, to begin to accelerate, the body itself needs a force. The acceleration of an object is directly proportional to the force applied to it. The skater uses her leg muscles to apply this force. The skater converts potential energy in the form of stored chemical energy (provided by the food a person consumes) into kinetic energy. The rollerblader shifts her center of gravity over one leg and pushes off that leg while the other leg is thrust forward and the process is continually repeated. All four wheels of the rollerblade are in contact with the surface. The wheels rotate due to the frictional force (static friction) between the area of the wheels that are in contact with the surface. The static friction exerts torques on the wheels which makes them spin. The force of static friction prevents the two surfaces from starting to slide across each other. The force of friction between the area of the wheel touching the ground is opposite the applied force.

The amount of friction between the two surfaces depends on the characteristics of the surface. The main reason for friction between two solids is that any surface, no matter how smooth, is actually jagged when examined with high magnification. When two surfaces are in contact, they actually touch only at specific points which provide resistance to relative motion. The frictional force is complicated and involves electrostatic forces between atoms or molecules where the surfaces are in contact.

Because static friction produces no thermal energy, all of the work the rollerblader does should become kinetic energy in the skater's forward motion. In order to eliminate any sliding friction, the rollerblade wheels rotate using a ball bearing system. The wheel is positioned between two raceways which hold the ball bearings. The axle is fitted in place between the two and locked in a lot on the shoe using Allen screws. The hub of the wheel does not touch the axle directly. Instead, the two are separated by the set of balls that turn with the hub. The points of contact between the ball bearings and the hub and the axle experience only static friction. Therefore, the possibility of transferring some kinetic energy to thermal energy is reduced.

The sliding friction problem is also reduced by the use of lubrication. Oil added around the parts fills the holes and forms a thin layer of liquid between the pieces of solid. Then each solid part rubs only on liquid, thereby greatly reducing friction.

As the wheels turn, angular momentum is transferred from the surface to the wheels. The wheels spin in one direction and the surface's (or earth's) rotation changes in the other direction, but because the earth has such a huge moment of inertia, its minimal change in rotation is unnoticeable.

An in-line skater who ceases to use her muscles to keep her body going and coasts instead, relies on momentum to keep moving. Newton's first law states that a body tends to continue in motion in the direction it is going unless acted on by an outside force. Linear momentum is a product of mass and velocity. The faster a rollerblader is moving or the more mass she has, the more momentum she has in the direction of motion. A skater with greater mass must exert more force to achieve the same velocity (momentum) as a smaller skater.

Coasting along a road or down a hill, a rollerblader's speed is limited by static friction between the contact point of the wheels and the surface and aerodynamic drag due to the skater passing through air (due to the viscosity of air). It may also be the case that the wheels do not rotate perfectly and they skip on the surface microscopically resulting in kinetic or sliding friction. Also internally, the ball bearing do not eliminate all of the friction.

Collisions are taking place between the skater and molecules of air and a transfer of momentum is occurring. If the object is small and moves at a low speed, the drag force is proportional to the velocity. However for larger objects moving at high speeds through air, as is the case of a person rollerblading, the drag force is approximately proportional to the square of the velocity.

Aerodynamic drag on the skater is determined by the size and shape of the body area the rollerblader presents to the wind stream. The larger the cross- sectional area of the person facing the wind, the greater the resistive force and the greater the slowing effect. The most significant drag effects result from a difference in air pressure across the skater's body due to turbulent air flow. The rush of air around the rollerblader exerts far more pressure on the person's front than on her back. An in-line skater can reduce the size of her wake and the associated pressure drag by wearing aerodynamic clothing (such as spandex) and leaning down to her waist.

In order for the skater to continue to move forward and not slow down, she must continue to convey stored chemical energy into kinetic energy by using her muscles to apply a force, which results in forward progress. The speed and distance a person can attain is determined by her physical fitness and body type, as well as by the efficiency of the chemical to kinetic energy conversion process.

How does the person rollerblading decelerate and eventually stop? Rollerblades have hard, rubberized brake pad located at the heel of the right skate. A person brakes by tilting the heel of the rollerblade so that the rubberized brake surface comes into contact with the ground surface. The two surfaces experience sliding (dynamic) friction as opposed to static friction. The force of sliding friction is opposite to the direction of motion. The rubberized material is "skidding" across the surface. Thermal energy is produced as the rubber heats up due to the aforementioned friction. The smell of "burnt rubber" is noticeable if one follows closely an in-line skater who has come to an abrupt stop. The two surfaces are exchanging energy as a result of having done work on each other. The two surfaces are pushing on one another and moving relative to one another in the direction of their forces and exchanging energy as an outcome. Eventually, the skater comes to a stop because all of her mechanical energy is converted to thermal energy. Brake pads on rollerblades must be replaced very frequently due to the wear and tear from frictional forces. Particles from the brake pad come flying off due to the forces at the two surfaces' contact points.

The fundamental physics of in-line skating and in line skates is best described by Newton's laws of motion. Further, it is evident that forces of friction are very relevant in the behavior of rollerblades. Forces of friction allow people to walk and run and are necessary for the motion of all wheeled vehicles, such as my in- line skates.

References

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