**The Physics of Roller Coasters**

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Hurtling around tight curves and plunging down steep hills, you might expect the physics of roller coasters to throw you for a loop. Indeed, an entire roller coaster ride is an engineering marvel, and requires a great deal of math to design especially with safety in mind. The basic physical principles of the roller coaster are quite simple, however concepts that a new physics students learns in their first semester.

The biggest concept behind roller coasters is the interconversion between kinetic and potential energy. Think that was a mouthful? Let’s break it down. Kinetic energy is the energy of motion. Anything that is moving has kinetic energy, determined by the object’s mass (closely related to weight) and the velocity (speed) the object is moving at.

In mathematical terms, K = 1/2 \* m \* v2 (K=kinetic energy, m=mass, v= velocity)

Potential energy is often thought of as stored energy. It is called “potential” because it has the potential to do work like speeding up a roller coaster car. In a roller coaster, potential energy is the result of gravity. You are probably already aware of this if you were going to fall off a roof, you’d much rather that you fell off the roof of a one-story ranch house than from atop a twenty story office building. In each case, gravity works to speed you towards the ground, but it does more work on the longer trip, making you go faster. Gravitational potential energy is calculated using an object’s mass, its height above the ground, and the acceleration of gravity (9.81 m/s2). In the language of math,

U = m \* g \* h . . . (U=potential energy, m=mass, g=gravity, h=height)

What makes roller coasters so fun is that these two forms of energy change back and forth readily. At the top of a large hill, the roller coaster is moving slowly, so it has a lot of potential energy, but very little kinetic. By the time it gets to the bottom of that hill, very little potential energy is left, but the kinetic energy has skyrocketed as you go zooming past. The key to making the roller coaster work is to ensure that there is enough kinetic energy that some will always be left at the top of any hill or loop (more is needed at the top of loops, but that comes later). This is why many roller coasters start off by dragging the cars by a chain to the top of the largest hill. At this point, you have more potential energy than you will need at any other point along the track. Other roller coasters add in a boost of kinetic energy propelling the cars forward to start them off with that velocity to help them up the next rise.

Energy can be converted to other forms besides kinetic and potential. Most people know that friction is caused when two things rub against one another. Most will also know that this generates heat. Heat is a form of energy, so wherever there is friction, heat energy is produced. That energy comes from kinetic energy. Some of the energy of motion is lost to produce the heat, meaning that any time there is friction a moving object loses energy and slows down. A roller coaster wouldn’t be much fun if it ground to a halt halfway through the ride, so designers work to minimize friction. Wheels are designed to minimize contact with the track, and both wheels and tracks are made from materials that reduce friction. (You might imagine that a sand-paper track would be a bad idea, for instance.) Air resistance is another form of friction, so roller coasters are often also designed to be aerodynamic, giving them that bulleted appearance.

The next topic in roller coastering is the forces involved. A roller coaster car is quite massive, and changing its direction requires a large force. The roller coaster track itself must supply that force called a normal force. [The normal force is the force that any surface applies against an object pushing on it you leaning on the wall, for example. The wall pushes against you with a force equal to the force you exert against it. Any less and you would fall through the wall, any more and you'd be shoved off the wall.] Because these forces must be quite large to execute tight turns and loops, the rollercoaster must be built with enough strength to supply and withstand the required forces. This is why roller coasters have extensive support structures.

Finally, there is inertia. Inertia, for our purposes, is the physical property that any moving object will continue to move along in a straight line unless acted on by an outside force. We just discussed the very large forces needed to overcome this inertia when making the roller coaster turn. This is why you feel yourself “pushed” against your seat or the harness when you make turns or navigate sudden hills inertia causes your body to move in a straight line until your seat or harness forces you to change directions. It might be tempting to think of inertia as a bad thing, but it also lets you experience the joys of looping the loops. When the roller coaster goes through a loop, you aren’t dropped on your head, nor do you even fall from your seat against the harness. This is again because of inertia, which causes your body to press onward in its upward motion until it is forced to turn downwards by both the force of gravity and the normal force supplied by your seat. The roller coaster experiences a similar circumstance, pushed back downwards by gravity and the track, so together both you and the roller coaster are turned, and plummet down the other side of the loop together, with your forward inertia still pressing you against your seat, and the car against the track (with the track and your seat pushing back).

All in all, every roller coaster is a complex masterpiece, built upon the concepts of energy and force. Master these, and the gates to roller coaster design are open to you. And don’t worry understanding roller coasters doesn’t make them any less exhilarating. (Only the long lines do that.)