Physics Lecture 1a - Lets Put Car Weight in Proper Perspective - Part 1

Many years ago the Greek philosopher Aristotle thought that the heavier of two objects dropped simultaneously would hit the ground first. Makes sense, sort of, because the heavier object has more force pulling it down. That's what makes it heavier. If one object was twice the weight of another, then it should hit the ground maybe twice as fast. Almost everybody believed him, except one gentleman named Galileo. Galileo did a lot of experiments with a pendulum and he also rolled objects down an inclined plane to study their motion (kind of an ancient pinewood derby). And then late in life (around 1630) he had one of his students drop a large cannonball and a smaller ball from the leaning tower of Pisa. Both objects hit the ground at very close to the same time. But still, a lot of parents believe Aristotle's philosophy, and they will cluster around the official race balance arguing to add that last iota of mass to their pinewood derby car. They won't be happy until they see 4.9999 ounces of weight. So Aristotle was wrong, but why? How do you explain what Galileo found to these parents? Why isn't weight super important? Read on.

Here is the short answer: It starts with these 2 parts.

1) Yes, the more matter you have in an object, the larger is its mass, and the greater is the force that tries to pull it to the ground. We call this force gravity and when we measure a mass using this force (called weight) we refer to the mass involved as a gravitational mass.

2) But, the more matter you have in an object, and the larger is its mass, then the greater is its resistance to being accelerated by a force. We call this resistance inertia, and when we measure a mass using its resistance to an acceleration we refer to the mass involved as an inertial mass.

These two natural laws of the universe above were first shown by Isaac Newton about 1670. Law 1) follows from his theory of universal gravitation and law 2) follows from his first and second laws of motion.

Still, how do we know that this inertial resistance to accelerated motion 2) is related to the acceleration caused by gravity 1)?

Einstein thought about Newton's laws and said something to the effect that I paraphrase as "You know what, there is no experiment that anybody—anywhere—anytime—anyway—can do that can tell the difference between gravitational mass and inertial mass of an object...case closed." The masses are therefore the same and will exactly cancel out. A few simple equations will show this.

In equation form, Newton's law of gravitation 1) reads for just the earth pulling on a general object of mass M, a force F proportional to M, where the constant of proportionality for the earth is g. Thus

$$F = Mg$$

In equation form, Newton's second law 2) reads for a general object of mass m, a force f required to accelerate m is proportional to m, where the constant of proportionality is the acceleration a. Thus

$$f = ma$$

So in cases where the force that causes the acceleration on a piece of matter is the gravitational force, we have $f = F$, whereupon

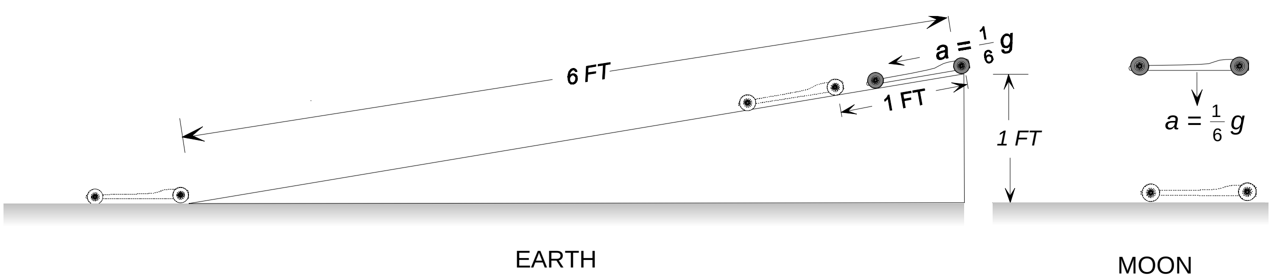
$$ma = Mg$$

But Einstein said we can never tell the difference between *m* and *M* so they must be the same and we can divide them out of the equation, giving

$$a = g$$

Thus it doesn't matter how large *M* and its equivalent *m* are, they just don't enter into the gravitational acceleration picture at all. Everything has an acceleration *a* that is constant and is equal to *g* on the earth. Now Newton and Einstein figured it out (mostly) mathematically and with thought experiments. And Galileo verified experimentally that all objects have the same acceleration because they cover equal distances in equal times when dropped. And he noted that objects rolling down an inclined plane (like pinewood derby cars) behaved just as if they were dropped, the only difference being that the acceleration he observed that they were given by gravity was slowed down some by the inclined plane. For example, if the inclined plane was 6 ft long and the start end was at 1 ft above the level ground, the acceleration of any car would be reduced to 1/6 of *g*. No matter what they weighed. And the time it would take them to go 1 ft down the plane would be close to the same as if they had been dropped to the ground on the moon from 1 ft high, because the moon's gravitational constant is 1/6 earth's *g* constant.

In conclusion we can restate what Newton and Einstein found. The force of gravity acts just the same as the force you apply when you steadily push on a mass and gravity isn't involved. The



mass resists your pushing to accelerate it and it resists exactly the same when gravity pulls to accelerate it. Since the resistance force is the same as the pushing or pulling force for any given mass, then the resulting motion is exactly the same for any given mass.

In **Lecture 1b** we will discuss the effects of air resistance and why it can make *some* difference that must be considered even at slow pinewood derby speeds—especially if the object's density is rather small like wood. A small air resistance effect was observed in Galileo's experiment, when the heavier object and lighter object hit the ground at "very close" to the same time. But Galileo didn't have a stopwatch to see air resistence effects on descent time. All he really found was that an object's weight didn't make the huge difference that Aristotle thought. So read on into **Lecture 1b** and see that although car mass is not super important, its just about as important as several other things that can affect car speed.