AP Physics - Newton's Laws

This is where the ***real*** physics begins. Physics is more than equations and math problems -- it is the laws of the universe and, most importantly, ***understanding*** these laws. The laws, of course, determine how everything works.

The first of these laws we will study were developed by Sir Isaac Newton while he camped out on a farm having fled the London plague of 1665. An interesting thing about all of it is that he didn't publish them until 1687. Wonder why? Anyway, twenty-two years later in 1687 he finally got around to publishing them in his book, *Philosophiaie Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*) which is usually known as the *Principia*. It was written in Latin and wasn't translated into English until 1729. Other trivia bits on the thing? Okay. The *Principia* is perhaps the greatest scientific work ever written. In it Newton set out how the universe operates. He explained how the planets orbit the sun, how the moon orbits the earth, and how objects behave on earth. It basically founded the science of physics.

So let us get into the physics.

Inertia: Inertia is an important property of matter.

Inertia ≡ property of matter that resists changes in its motion.

Basically, because of inertia, objects want to maintain whatever motion they have. This was described initially by Galileo, later Sir Isaac Newton formulated it into one of his basic laws of motion.

Inertia is proportional to mass. The more mass something has, the more inertia it has.

Mass ≡ measurement of inertia

The unit for mass is the kilogram (kg). Mass is also defined as the amount of matter something has. Mass is different than weight, which is the gravitational force of attraction between the earth and an object.

More important definitions:

Force ≡ push or pull

Contact Force ≡ physical contact exists between the object and source of the force

Field Forces ≡ No contact exists between the source of the force and the body being acted upon: gravity, magnetic force, &tc.

Friction ≡ A force that resists the motion between two objects in contact with one another

The First Law:

Newton's First Law: An object at rest remains at rest, and an object in motion remains in motion with constant velocity unless it is acted upon by an outside force.

This law really deals with inertia. It is because of its inertia that matter behaves according to this law. The idea that something would keep moving at a constant velocity for like forever is something that we don't see happen very often on the earth, because when something is moving, there is almost always an outside force acting on it – usually friction. This is why a ball rolling along a straight section of road will come to a stop all on its own. Friction slows it down and makes it stop.

When the net external force acting on an object is zero, the acceleration on the object is zero and it moves with a constant velocity. Of course if it is at rest, it will remain at rest. (Unless and outside force blah blah blah….)

If $\sum F = 0$ Then $a = 0$ And v is constant

The Second Law:

Second Law ≡ The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

This is usually written as a simple formula, $F = ma$

More properly, however, it should be thought of as:

$$\sum F = ma$$

This means that the acceleration of an object is a function of the ***sum of all forces*** acting on it. The sum of these forces is known as the ***net force***.

Force is a vector!

The unit for force is the Newton (N)

$$1\ N = 1\frac{kg \cdot m}{s^2}$$

In the USA, the unit for force is the pound (lb). 1 N = 0.225 lb

Newton's second law is responsible for weight. Weight is a force, the force of gravity acting on something. Using the second law, we see that the weight of an object is:

$$w = mg$$

Here, ***w*** is the weight.

Weight ≡ force exerted by gravity on an object's with mass.

The weight of an object depends on the acceleration of gravity. If the acceleration brought about by gravity changes, then the weight can change. This does not happen with mass - the mass of an object is a constant and has the same value everywhere. If you were to travel to the moon, your weight would be only 1/6 of its value on earth, but your mass would be the same. This is because the gravity on the moon is much smaller than the earth's gravity.

- An object has a mass of 10.0 kg, find its weight.

$$w = mg \quad = 10.0\ kg\left(9.8\frac{m}{s^2}\right) \quad = \quad \boxed{98.0\ N}$$

Recall that accelerations change velocities. Therefore, the net force is the thing that causes accelerations.

- A 450 kg mass is accelerated at 2.5 m/s^2. What is the net force causing this acceleration?

$$\sum F = ma \qquad F = 450\ kg\left(2.5\frac{m}{s^2}\right) \quad = \quad \boxed{1100\ N}$$

- A 2500 kg car is pushed with a net force of 250 N force, what is the acceleration acting on the car?

$$\sum F = ma \qquad a = \frac{F}{m} \qquad a = \frac{250\ N}{2500.0\ kg}$$

$$a = \frac{250\ \cancel{kg}\ m}{s^2}\left(\frac{1}{2500.0\ \cancel{kg}}\right) \quad = \quad \boxed{0.10\frac{m}{s^2}}$$

- Now same problem, same 250 N force and all, but the mass of the car is twice as big, 5000.0 kg. Let's find the acceleration once again.

$$a = \frac{250\ \cancel{kg}\ m}{s^2}\left(\frac{1}{5\,000.0\ \cancel{kg}}\right) \quad = \quad \boxed{0.050\frac{m}{s^2}}$$

The acceleration is only one half the value of the first problem.

- An artillery shell has a mass of 55 kg. The projectile is fired from the piece and has a velocity of 770 m/s when it leaves the barrel. The gun barrel is 1.5 m long. Assuming the force and therefore the acceleration is constant while the projectile is in the barrel, what is the force that acted on the projectile?

Find *a:* $v^2 = v_o^{\ 2} + 2ax \qquad v^2 = 0 + 2ax \qquad a = \frac{v^2}{2x}$

$$a = \left(770\,\frac{m}{s}\right)^2 \frac{1}{2(1.5\,m)} = 197\,600\,\frac{m}{s^2} \quad = \quad 2.0\,x\,10^5\,\frac{m}{s^2}$$

Find the force:

$$F = ma \quad = 55\,kg\left(2.0\,x\,10^5\,\frac{m}{s^2}\right) \quad = 110\,x\,10^5\,N \quad = \quad \boxed{1.1\,x\,10^7\,N}$$

The Third Law:

> ***Third Law ≡ If two objects interact, the force exerted on object 1 by object 2 is equal in magnitude but opposite in direction to the force exerted on object 2 by object 1.***

The classic way of saying this is, "For every action there is an equal and opposite reaction".

Newton's third law simply says that forces come in pairs. You push on a wall and the wall pushes on you. We call these ***action/reaction force pairs***.

One of the skills most people master is walking. We rarely think about the act of walking – you don't have to concentrate on it, it's just something that you can do. It turns out, however, that walking is a fairly sophisticated application of Newton's laws of motion.

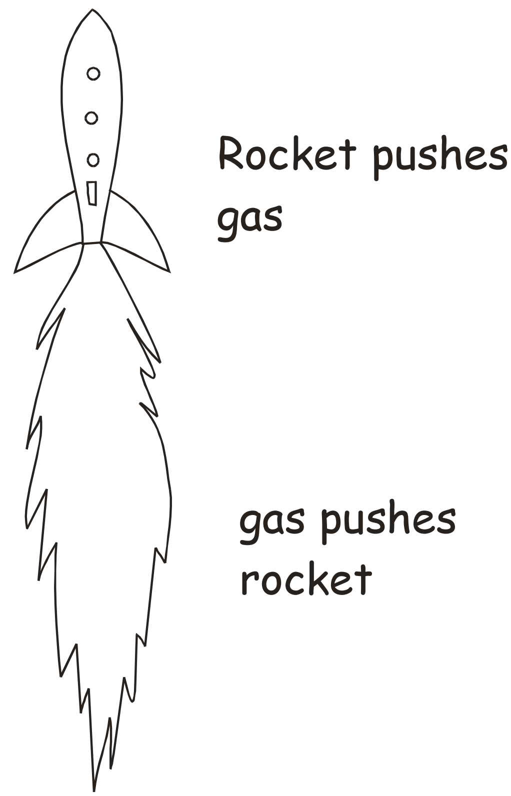
The key to walking is the third law. You push against the ground and the ground pushes you. All there is to it. But how does that make you move? Okay, you takes your basic second law. It goes like this; you exert a force on the ground and it exerts a force on you. The two forces are equal and opposite. The force exerted on you by the earth causes you to accelerate. The size of the acceleration depends on the force and your mass. $\boldsymbol{F = ma}$. Because your mass isn't very big compared to the earth, you end up with a pretty good acceleration – enough to make you move.

What about the earth? It also had a force exerted on it – the one from your foot pushing on it. Does it also get accelerated? Well, yes, it has to. The same magnitude force is acting on it. Why then don't you notice the earth moving away from you? The second law is involved here. $\boldsymbol{F = ma}$, but this time the mass of the earth is huge (6.0 x 10^{24} kg) compared to your mass. If your mass is 60 kg, the earth is 10^{23} times more massive than you. That means that the acceleration acting on the earth is 10^{23} times smaller than your acceleration. It is so small that it cannot be measured. But it is real.

Because the forces are the same, the mass times the acceleration has to equal the same thing. So we get:

$$m_{earth}\,a_{earth} = m_{you}\,a_{you}$$

Rockets work because of the third law. A common misconception is that a rocket works by pushing against air. We know this is not true because rockets work in outer space where there is no air to push against. The way a rocket works is like this: hot gases, the products of combustion, are blasted out of the end of the rocket. They are pushed away from the rocket, but according to the third law if the rocket pushes the exhaust gases away, the exhaust gases must push the rocket in the opposite direction. So the rocket goes.

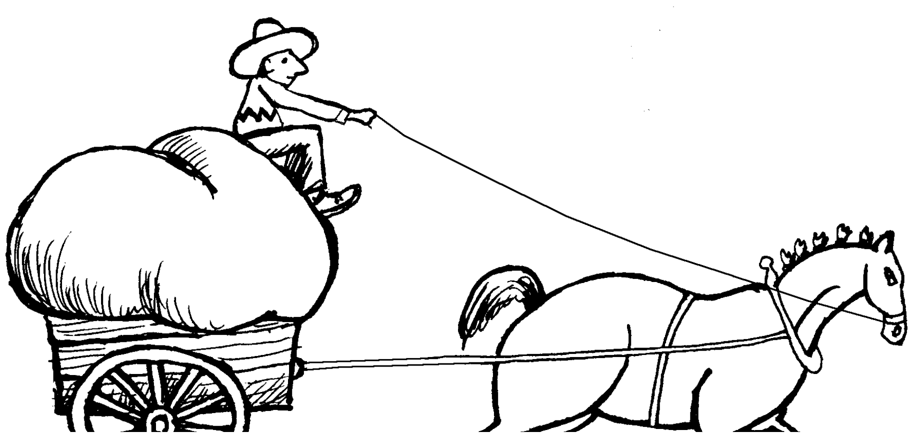


Here is the classic third law conundrum. An acquaintance tells you, “There’s no way a horse can pull a wagon.”

You say, “No way that’s true because horses pull wagons all the time!” (You’ve been around, you see, and no one can fool with you.)

“No, I’m right. The horse can’t pull a wagon. See, if the horse pulls on a wagon, then according to the third law the wagon has to pull on the horse with an equal and opposite force. Since the two forces are equal and opposite, they cancel out, so the horse can’t pull the cart!”

The argument sort of makes sense, but you know that it has to be flawed because it is clearly not true. So what’s the deal?



Action/reaction force pairs never cancel each other out – they can't because they are partners in the same action force. Can you touch your mother without being touched by her? Does your mother touching your finger when your finger touches her cancel out the touch? Can a single-hand clap?

Pretty heavy stuff.

In order to have forces cancel out; they have to be different forces. An example of this would be if we had two horses hitched to the same wagon pulling in opposite directions. The forces the horses exert would then cancel out and the wagon wouldn't move. These would be two separate forces that ***do*** cancel out.

The horse does indeed pull on the wagon and the wagon pulls on the horse in accordance with the third law. The wagon pulling on the horse results in keeping the horse from running off really fast – the horse is slowed down by the extra mass of the cart, so its acceleration is much smaller than if it were not hitched to the wagon.

The horse moves, dragging the wagon with it, by pushing the earth away from it. The earth pushes back on the horse, so the horse and wagon move. The earth moves away as well, but, because its mass is so huge (as previously discussed), we can't measure its acceleration.

The horse and wagon move because the horse pushes against the earth. What would happen if you tried to make you car move by sitting in it and pushing on the dashboard? Would the car move?

What does this picture show about Newton's laws?

Newton's Second Thought Laws:

1) A body at rest tends to watch television.
2) A body acted upon by a force usually breaks.
3) For every human action there is an overreaction.