Lesson 25: Newton's Third Law (Action-Reaction)

Newton came up with one more law when he started thinking about the ***interaction*** of objects.

- He had already talked about what happens when there is **no** net force (1st Law).
- He then talked about what happens when there **is** a net force (2nd Law).
- But what happens when you have objects interacting, affecting each other?

The 3rd Law (The Law of Action-Reaction)

"For every **action** force there is an equal and opposite **reaction** force."

Anytime something applies a force, there will be an equal and opposite force back in the opposite direction.

- Push on the handle of a lawnmower to make it go forward, and it will push back against you in the opposite direction with just as much force.
- This is the pressure that you feel of the handle against your hand.

There is one ultra important thing to remember when you are looking at **action-reaction** pairs.

- The two forces that you are looking at are each acting on different objects!
- If you are examining what you *think* are **action-reaction** forces, but the forces are both acting on the one object, it is not an **action-reaction** pair.
- In the above example, you exert a certain force on the **lawnmower**. The lawnmower exerts an equal force on **you**. Two objects, two forces.

Some examples of **action-reaction** forces depend on the objects being in direct contact, meaning that the two objects involved are actually touching each other to exert forces on each other. These are called "**contact forces**." The following examples explain two objects interacting according to Third Law.

1. A car driving forwards
   Action: the **tires** on a car push **backwards** on the **road**…
   Reaction: the **road** pushes **forwards** on the **tires**.

2. You swimming
   Action: **you** push the **water** **backwards**...
   Reaction: the **water** pushes **you** **forward**.

3. A rocket takes off from a launch pad
   Action: a **rocket** pushes out **exhaust** **backwards**...
   Reaction: the **exhaust** pushes the **rocket** **forward**.

   One of the original arguments that flight in the vacuum of space was impossible was that there would be nothing to push against. This **action-reaction** explains how a rocket can fly in space where there is no air to push against.

action-reaction pairs can also happen without friction, or even with the objects not touching each other, known as "**action at a distance**" forces …

Dropping an apple
Action: the **Earth** pulls **down** on an **apple**…
Reaction: the **apple** pulls **up** on the **Earth**.

How can this example be true?!?

Example 1: If the apple has a mass of 0.150 kg, **determine** the acceleration of the Earth.

- There is an action-reaction pair of forces given by $F_a = - F_E$
- We know that the apple will accelerate towards the earth at 9.81 m/s^2, but does the Earth accelerate towards the apple at the same rate?
    - If this were true you would expect the earth to be constantly jumping up towards falling objects.
    - Carefully remember Newton's Second Law (F = ma). In this example the ***forces*** are equal, but the ***mass of the earth*** is considerably larger than the apple!
    - The earth has more inertia than the apple, so the same force will only accelerate it a little bit.

The Force of the Earth on the Apple

$$_EF_a = ma = mg$$
$$_EF_a = 0.150(-9.81)$$
$$_EF_a = -1.4715\,N$$

This is the force of the Earth acting on the apple, but because of Newton's Third Law, it is also the force of the apple on the Earth, just in opposite directions.

$$_EF_a = -1.4715\text{ N}$$
$$_aF_E = 1.4715\text{ N}$$

The Acceleration of the Earth because of the Apple

$$_aF_E = ma$$
$$a = \frac{_aF_E}{m} = \frac{1.4715}{5.97e24}$$
$$a = 2.46482e\text{-}25 = 2.46e\text{-}25\,m/s^2$$

This is such a small acceleration of the Earth towards the apple that it can't even be measured. We can see that although the forces are equal, the accelerations do not have to be.

> DID YOU KNOW?
> Sir Isaac Newton was uncomfortable with his own theories about gravity being an "action at a distance" force. He believed so strongly that there must be some material that connects objects that have a gravitational pull on each other, that he was one of the first scientists to seriously suggest there was a mysterious substance called the aether (sometimes spelled ether) that connected all objects in the universe.

Example 2: When a rifle fires a bullet, the force the rifle exerts on the bullet is exactly the same (but in the opposite direction) as the force the bullet exerts on the rifle… so the rifle "kicks back". The bullet has a mass of 15 g and the rifle is 6.0 kg. The bullet leaves the 75 cm long rifle barrel moving at 270m/s.

a) **Determine** the acceleration of the bullet.

We will assume that the bullet is traveling forwards, while the rifle is moving backward.

$$v_f^2 = v_i^2 + 2ad$$

$$a = \frac{v_f^2 - v_i^2}{2d}$$

$$a = \frac{270^2 - 0}{2(0.75)}$$

$$a = 48600 = 4.9e4\, m/s^2$$

The positive acceleration shows that the bullet is speeding up while traveling forwards.

b) **Determine** the force of the rifle on the bullet.

$$F_b = m_b a_b = 0.015(48600) = 729\, N = 7.3e2\, N$$

c) **Determine** the acceleration of the rifle.

$$F_b = 7.3e2\, N$$

$$F_r = -7.3e2\, N$$

$$F_r = m_r a_r$$

$$a_r = \frac{F_r}{m_r} = \frac{-729}{6.0}$$

$$a_r = -121.6 = -1.2e2\, m/s^2$$

The negative acceleration shows the rifle is speeding up while going backwards.

d) **Explain** why the bullet accelerates more than the rifle if the forces are the same.

Although have the same amount of force acting on them, they each have a different mass (and therefore a different inertia).

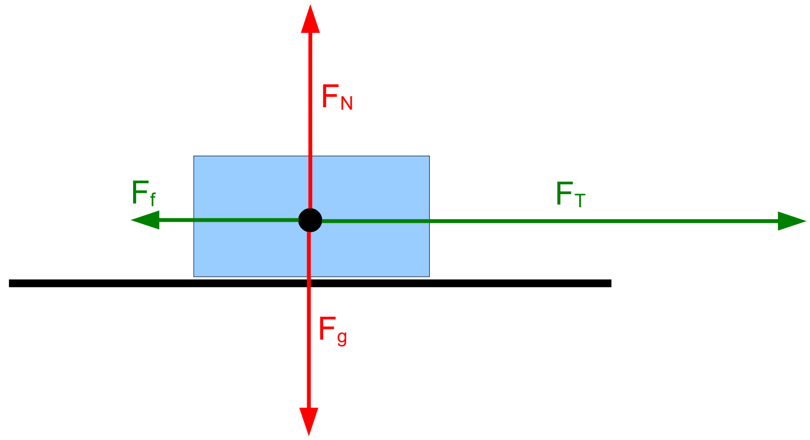
Example 3: You are planning to pull a trailer with your truck. You are a little worried about whether or not the hitch on your truck is strong enough to pull the trailer without snapping when you accelerate forwards, like accelerating hard from a red light. The hitch can handle up to 1 000 N of force exerted on it. Here are some numbers you collect…

- Mass of the truck = 1500 kg
- Mass of the trailer = 200 kg
- Force of air resistance (friction) acting on the trailer = 40 N
- Maximum speed you will accelerate up to = 80 km/h
- Time it takes you to get up to that speed from rest = 20 s

Determine the force the trailer exerts on your truck hitch.

We can use Newton's Third Law here, since if I can calculate the force the truck hitch exerts **forwards** on the trailer, the trailer must just be exerting the exact same force **backwards** on the truck hitch (the number I want). Start with a free body diagram of the trailer…

The force of gravity and normal force will cancel each other vertically ($F_{NET} = 0$), so we'll just ignore them. I do need to figure out some stuff about the horizontal forces ($F_{NET} \neq 0$).



$$F_{NET} = F_T + F_f$$

We are solving for the **tension**…

$$F_T = F_{NET} - F_f$$

$$F_T = ma - F_f$$

We do need to find the acceleration to use this F_{NET} formula, so let's calculate the acceleration of the trailer now (from the numbers given in the question), and then we can use it to find the tension.

$$a = \frac{v_f - v_i}{t}$$
$$a = \frac{22.22 - 0}{20}$$
$$a = 1.1\, m/s^2$$

$$F_T = ma - F_f$$
$$F_T = 200(1.1) - (-40)$$
$$F_T = 262.222 = 2.6e2\, N$$

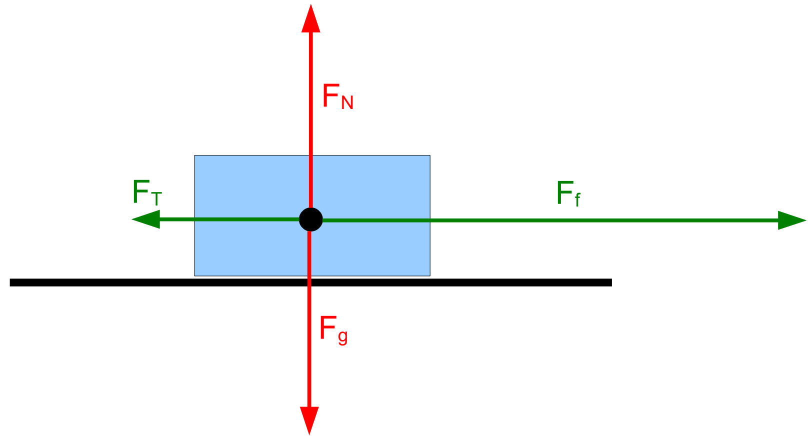
So, it requires 2.6e2 N of tension to pull the trailer **forward**. By Newton's Third Law, this means the trailer pulls **backwards** on the hitch with 2.6e2 N of force. **We would say the force on the trailer is -2.6e2 N or 2.6e2 N [backwards].**
The hitch will be fine, since this is well below 1 000 N.

Example 4: Still using the same numbers from the previous example, let's look at the truck. It's the reason that the whole system (truck and trailer) will be able to accelerate forwards. This is because of the motor running in the truck turns the tires, which have grip (***friction***) with the road surface. Because of this friction, the tires push the road **backwards**, so that the road pushes the tires **forwards** (**action-reaction**). **Determine** the force of friction with which the truck is pushing backwards against the road. Ignore air resistance acting on the truck.

Again, let's start with a free body diagram, but this time for the truck. This is going to look a lot like the diagram for the trailer, but it is different. Of note…

- The force of tension is pointing to the left, since the truck is being pulled back by the trailer.
- Friction is pointing forwards? Yup, because we are talking about what the road is doing to the tires. If the tires are pushing the road backwards, the road is pushing the tires forwards. That's *good* friction… traction.

The force of gravity and normal force will cancel each other vertically ($F_{NET} = 0$), so we'll just ignore them. We will concentrate on the horizontal forces again ($F_{NET} \neq 0$).



$$F_{NET} = F_T + F_f$$

We are solving for the **friction**…

$$F_f = F_{NET} - F_T$$

$$F_f = ma - F_T$$

We already have the acceleration from the previous example. The truck must be accelerating just as much as the trailer, since they are attached and doing the same things.

$$F_f = ma - F_T$$
$$F_f = 1500(1.1) - (-262.222)$$
$$F_f = 1928.888 = 1.9e3\,N$$

This is how hard the road pushes forwards on the truck. **The truck must push with a force of 1.9e3 N [backwards] on the road.**

Example 5: If I push on a lawn mower, it pushes back on me with an equal, but opposite force. **Explain** why we don't both just stay still.

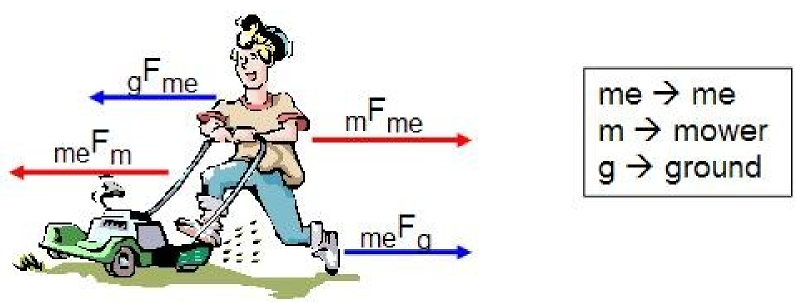


Illustration 4: The two sets of action-reaction pairs in this situation.

- The answer is that these forces are acting on different bodies (and there are other forces to consider).
- It doesn't matter to the lawn mower that there is a force on me… all that matters to the lawn mower is that there is a force on it, so it starts to move forward.
- Another action-reaction pair you need to consider is that I am pushing backwards on the ground, and it pushes forwards on me.

Homework

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