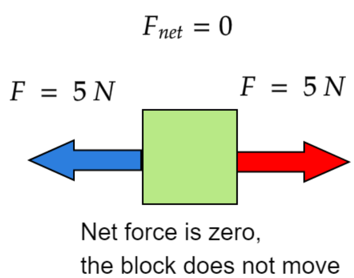
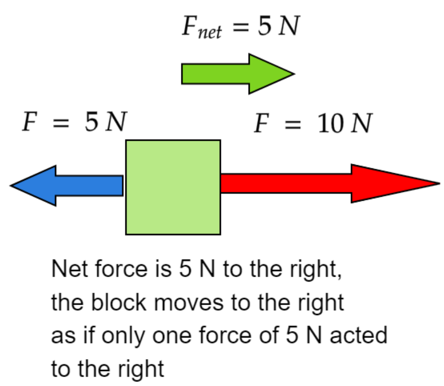
NEWTON'S LAWS CONTINUED. GRAVITY FORCE.
NOVEMBER 13, 2023

Theory recap

Net force. So far we have only discussed how does an object move when only one force acts upon it. What happens if there are several forces? It is not much more complicated: we have to add forces as vectors. For example, if you and your friend pull a block in the opposite directions with the same force 5 N, the block will not move: force vectors add up to zero. But if you were to pull stronger, say 10 N and your friend would still pull with 5 N, the block will move towards you as if a single force of 5 N was pulling it in your direction.





Net force is the sum of all the forces acting on an object: we can replace multiple forces with just one net force to describe its motion. The ind the net force in general, we add all the forces acting on an object as vectors:

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + ...$$

Net force then is what really enters Newton's second law:

$$\vec{F}_{net} = m\vec{a}$$

It is highlighted here that force and acceleration are both vectors and this equation means that their directions are the same.

Gravity force. The first particular kind of force we consider is gravity force. All objects around us are pulled down to the Earth with a gravity force, which is also called weight. Weight is usually denoted by letter W. The formula to calculate it is

$$W = mg$$

Mass m in this equation is the same mass entering Newton's second law. So actually, the mass of an object not only determines how it is accelerated by any force, but also what will be the gravity force acting on this object. g is the free fall acceleration.

For an object in free fall the only force acting on it is weight, so we can find its acceleration using Newton's second law:

$$F_{net} = W = mg = ma$$

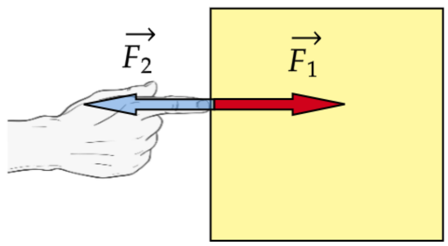
and canceling the same factor of m we obtain

$$a = g$$

In other words, we rediscover that objects in free fall move with a free fall acceleration. But this time we derived it from Newton's laws.

Newton's third law. Any interaction always occurs between two objects but so far we have completely ignored one of them. Now we will learn what happens to the second object as well.

For example assume that your hand and a block are in contact. You are pushing the block to the right, so you are acting on the block with a force $\vec{F_1}$ directed to the right. At the same time you feel that block is pushing you as well. Force $\vec{F_2}$ which the block exerts on your hand is directed to the left. What is the magnitude of this force compared to the one you push the block with? In other words, what is the magnitude of $\vec{F_2}$ compared to $\vec{F_1}$?



The answer to this question is given by **Newton's third law**:

$$\vec{F_2} = -\vec{F_1}$$

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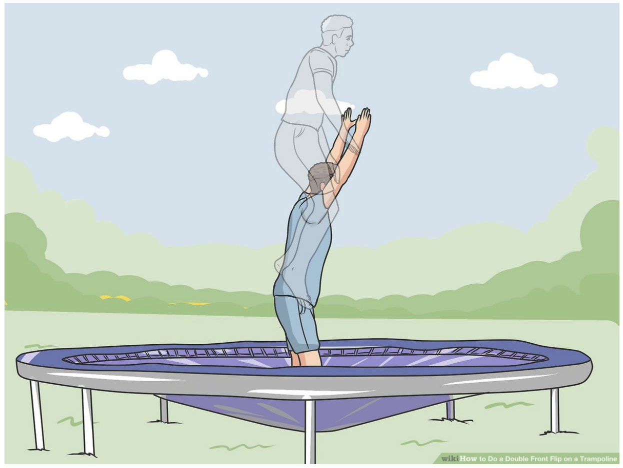
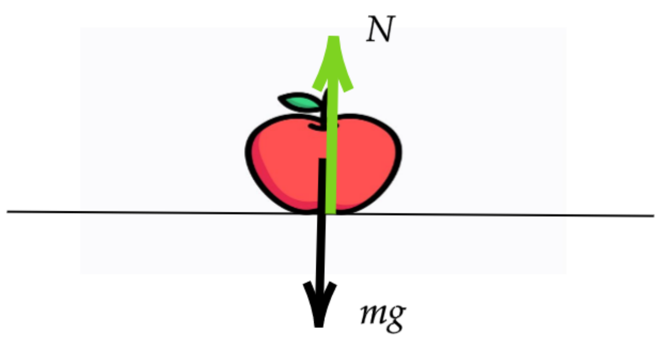
As a reminder, if one vector is equal to minus the other it means that they point in the opposite directions but their magnitudes are the same. This means that the block pushes your hand to the left with exactly the same force as your hand pushes the block to the right. Newton's third law is often stated as follows: **for any action there is an equal and opposite reaction**. Action here means force with which object 1 acts on object 2 and reaction - force with which object 2 acts on object 1.

Normal force. Now let us discuss another example of force - normal force. When you stand on the floor gravity pulls you down but you don't fall through the floor. What does not let you fall? Of course it is the floor, you can feel that it pushes you feet up supporting the whole weight of your body.

Where does this force come from? To understand this, let us take a look at a trampoline. When you stand on a trampoline, it bends under your weight in order to support it. The force with which the trampoline acts on you is due to its elastic properties. Now if you imagine trampoline being stiffer, it will bend less. You could think of a trampoline so stiff, that you can not see its deformation under your weight with a naked eye. But you know it is still there - elastic forces are supporting your weight even if you don't see the deformation.



For the floor the situation is the same as for a very stiff trampoline. Floor bends very slightly under your weight and the resulting elastic force supports your weight and does not let you fall through the floor. For the same reason an apple doesn't fall through a plate, the plate does not fall through a table, the table does not fall through the floor and a house does not fall through the ground. In all these cases the normal force counteracts against gravity force and as a result an object rests.



The fact that normal force plays against gravity allows us to calculate it in many situations. Assume an apple of mass m rests on a table. There are two forces acting on the apple - gravitational force mg and normal force from the table N. Since the apple is at rest, its' acceleration is zero. So net force must be zero. Gravitational force is directed down while normal force is directed up. So to find the net force down we subtract normal force from gravitational force and find

$$mg - N = 0 \;\Rightarrow\; N = mg$$

Homework

1. Why can you exert greater force on the pedals of a bicycle if you pull up on the handlebars?

2. The gravity force on the surface of the Moon is about 6 times less than this on the Earth. What will happen with your weight and mass on the Moon?

3. You pull upwards a 2 kg brick with a force of 30 N. Find the acceleration of the brick.

The problem below is a bonus problem.

***4.** A block is attached to the cart using four ropes, as shown in the picture. Force of tension in the horizontal ropes is $T_1 = 21\ N$ and $T_2 = 36\ N$, and in vertical ones - $T_3 = 30\ N$ and $T_4 = 60\ N$, free fall acceleration is $g = 10\frac{m}{s^2}$. What is the acceleration of the cart?