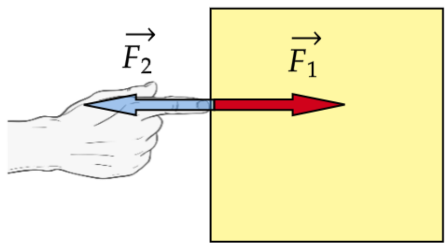
NEWTON'S THIRD LAW AND NORMAL FORCE

NOVEMBER 21, 2021

Theory recap

Newton's third law. Last time we learned Newton's first and second laws. We encountered the concept of force which describes strength of interaction between objects. Interaction always occurs between two objects but at our last class we ignored one of them. Today we'll 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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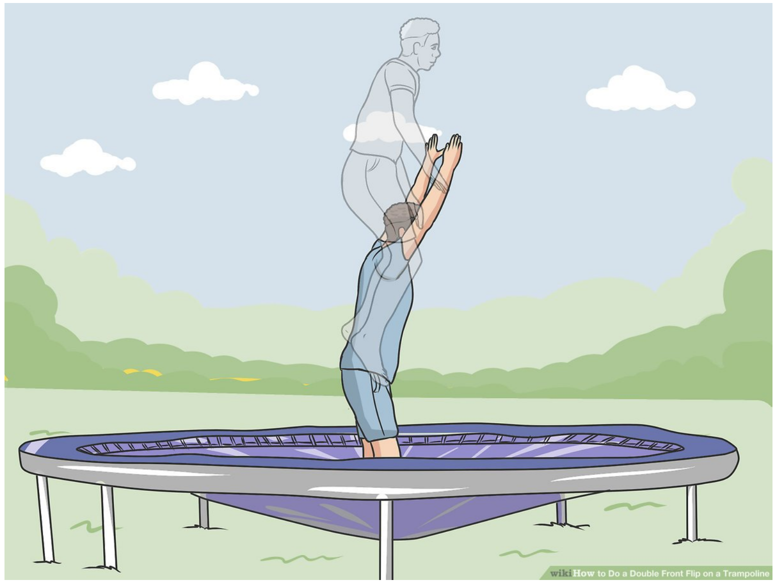
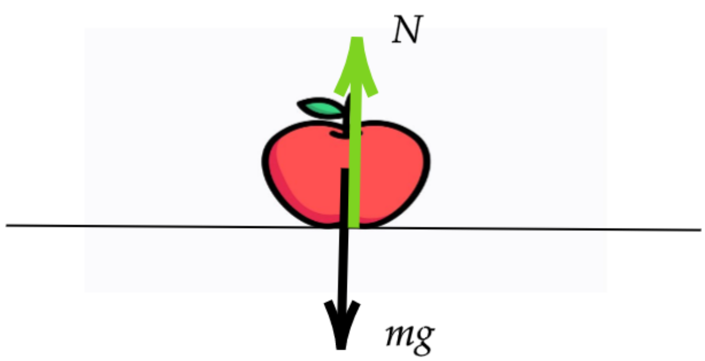
Let me remind that if one vector is equal to minus the other it means that they point in the opposite directions but their magnitudes are the same. This means that the block pushes your hand to the left with exactly the same force as your hand pushes the block to the right. Newton's third law is often 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. Last time we also mentioned that there are different kinds of forces. We have already considered gravitational force. Now let us discuss another 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 will 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.



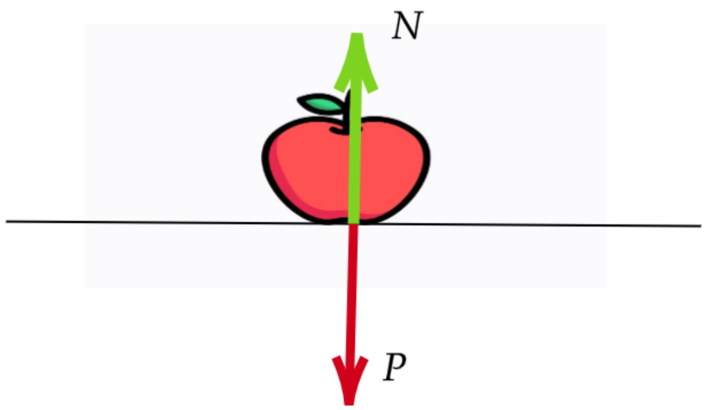
For the floor the situation is the same as for a very stiff trampoline. Floor bends very slightly under your weight and the resulting elastic force supports your weight and does not let you fall through the floor. For the same reason an apple doesn't fall through a plate, the plate does not fall through 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 obtain

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

Weight. As we have learned today, Newton's third law tells us that when the table acts with normal force $\vec{N}$ on the apple, the apple acts on the table with force $\vec{P} = -\vec{N}$. This force $\vec{P}$ is called **weight**. From the above equation we see that when the apple is at rest, its weight is equal to the gravitational force: $P = mg$. However, it is important not to confuse weight and gravitational force because they act on two different objects. Gravitational force mg acts on the apple. Weight P acts on the table. You need to always keep this distinction in mind in order to avoid confusion.



If an object is moving with acceleration, normal force (and therefore weight) change compared to when it is at rest. Let us assume that the same apple is in an elevator which is moving with acceleration a directed up. The net force up in terms of normal and gravitational forces is $F_{net} = N - mg$, and by Newton's second law for the apple:

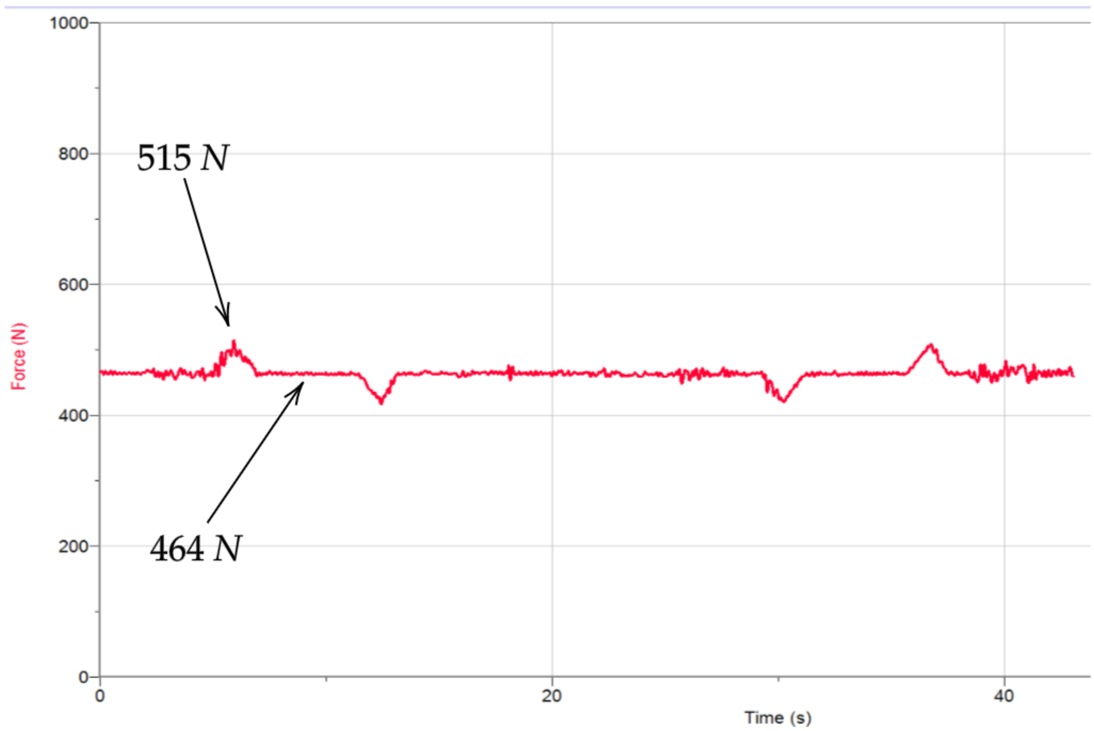
$$F_{net} = N - mg = ma \Longrightarrow N = mg + ma \Longrightarrow \boxed{P = mg + ma}$$

For the last equation we used Newton's third law relating absolute values of weight and normal force: $P = N$. We see that for positive a (acceleration up) weight is increased and for negative a (acceleration down) weight is decreased.

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. In this problem using the data obtained in our elevator experiment you will need to calculate the maximal upwards acceleration of the elevator. On the next page there is the plot (which is the result of our experiment) of how weight of a person riding an elevator changes with time. It has the relevant data points provided. In order to find person's mass, use the fact that when there is no acceleration, weight measured by the scales is equal to the gravitational force acting on the person. Knowing the mass and weight for the moment of maximal acceleration (which is provided), you

will **find the maximal upward acceleration**. You could use $10\frac{\text{m}}{\text{s}^2}$ for the free fall acceleration.



***4.** Find the force with which a 1 kg block gravitationally attracts the Earth. What is Earth's acceleration due to this force? Earth's mass is approximately $6 \cdot 10^{24}$ kg.