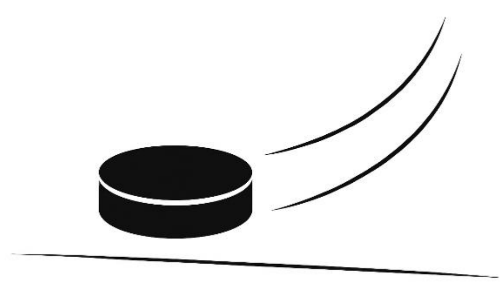
Inertia and Newton's laws

Our last class concluded our exploration of **kinematics**. Kinematics is a branch of physics that tells us how to describe motion geometrically: in space and time. We have learned about distance, displacement, speed, velocity, acceleration and relative motion. But we did not ask the question: what caused the motion?

Today we start considering **dynamics**. Dynamics is another branch of physics and, as opposed to kinematics, it is concerned with reasons causing motion. These reasons are interactions with other objects.

We have learned that any physical body being in motion tends to stay in motion (if the body is at rest it tends to stay at rest). This sentence is called "**the law of inertia**". It means the following: ***velocity*** **of an object does not change unless the object will interact with other objects**. Nothing starts moving by itself and stops by itself. We need another object to change velocity, or, in other words, to create acceleration. The interaction which causes acceleration of an object is called *force*. Force is a vector: it has both magnitude and direction. Examples of the force are: gravity force, electric and magnetic forces, elastic force, friction force.

It makes perfect sense that if a body at rest does not interact with anything**,** it will stay at rest. It takes a little bit more effort to understand that the same principle applies to motion with constant velocity. Imagine a puck on very smooth ice. After being hit, it will go at almost constant velocity (almost because there is still a tiny leftover friction). If the ice is even smoother, the velocity will change even less. We conclude that if there was no friction at all, the velocity would just stay constant indefinitely.



We have learned that **force can be determined as interaction which makes the interacting object accelerate**. Force and acceleration are connected by a simple formula:

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

Here *F* is a force applied to an object, *m* is the mass of the object and *a* is the acceleration of the object. **Force is measured in newtons** (N). 1N is the force required to provide an acceleration of 1m/s^2 to an object with a mass of 1kg. The unit of force is named after Sir Isaac Newton (1643-1727)– one of the brightest genii in human history.

Let us consider the following imaginary experiment: if you push with the same way an empty shopping cart and a heavily loaded shopping cart. A physical quantity which expresses the property of an object to resist acceleration is called **mass**. The mass is measured in kilograms (kg) and grams (g). 1 kg = 1000 g

Example: Suppose an empty shopping cart has a mass m_1 = 10 kg. After you load it with groceries you need for the next week total mass of the cart becomes m_2 = 30 kg. If you push the cart with the same effort (same force), say 30 N, the heavier cart will have a smaller acceleration than the lighter cart. How much smaller? Denote accelerations of the carts by a_1 and a_2 respectively. Let us use Newton's second law:

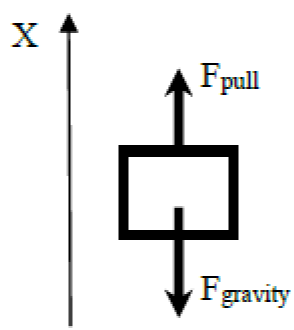
$$F = m_1 a_1 \Rightarrow a_1 = \frac{F}{m_1} = \frac{30\ \mathrm{N}}{10\ \mathrm{kg}} = 3\ \frac{\mathrm{N}}{\mathrm{kg}} = 3\ \frac{\mathrm{m}}{\mathrm{s}^2}$$
$$F = m_2 a_2 \Rightarrow a_2 = \frac{F}{m_2} = \frac{30\ \mathrm{N}}{30\ \mathrm{kg}} = 1\ \frac{\mathrm{N}}{\mathrm{kg}} = 1\ \frac{\mathrm{m}}{\mathrm{s}^2}$$

It is very important not to mix mass and weight. The weight (in common, “everyday” meaning of this word) depends on how strong an object presses to the surface supporting the object. Weight of the same object is different on different planets. The mass expresses the fundamental property of an object to resist acceleration.

However, if an object is not accelerating it does not mean that no forces applied to the object. In most cases it just means that forces applied to the object compensate each other. In other words, the sum of all forces applied to the object is zero. So, the **force *F* in the formula above is the sum of all the forces applied to the object**. We will call this sum as *total net force*. How can we sum up forces?

***Example*:** You pull up a 10kg load with a force of 150N. Is this force enough to lift the load? What is acceleration of the load?

First, let us make a picture:



Let us choose “positive” direction as “down to up”. So the “pulling” force is positive because it looks up and the gravity force is negative because it looks down:

$$F_{pull} - F_{gravity} = ma$$

or

$$F_{pull} - mg = ma$$

We do not know yet what the acceleration (magnitude and sign) is. Let us calculate it:

$$150N - 10kg \cdot 9.8\frac{m}{s^2} = 10kg \cdot a$$

$$a = \left(150N - 10kg \cdot 9.8\frac{m}{s^2}\right) \div 10kg = 5.2\frac{m}{s^2}$$

The acceleration is positive. It means that it is directed up, along our ”positive” axis. It also means that the applied force is enough to lift the load.

Homework:

1) Why do we need seatbelts in a car?

2) If an elephant were chasing you it's enormous mass would be the most threatening. But if you zigzagged, its mass would be your advantage. Why?

3) An accelerating airplane takes 30 seconds to reach the takeoff speed of 100 m/s. Mass of the airplane is 60 tons (1 ton is 1000 kilograms). Find the force acting on the airplane during the acceleration process. Express it in N; use scientific notation.

4)Two pirates have found a treasure chest. Both want it for themselves, so they start pulling it in the opposite directions with forces 400 N and 250 N. In what direction will the chest move? What is the mass of the chest with the treasures if acceleration of the chest is 5 m/s^2?