Mechanics – Dynamics - Application of Newton's Laws

Force of gravity

It is our daily experience that there is gravitational force between the Earth and objects. This force acts not only when objects touch the Earth's surface directly. In Newton's days, physicists could not yet explain the nature of the forces acting between bodies that do not touch each other.

Let us investigate. Can we measure this force? Previously, we were talking about push or pull. When in contact with the ground, there is a push. For a body suspended from a hook, there is a pull. This pull is measured by the device we call a dynamometer or spring balance. Our task for you is to make your own spring balance.

<u>Project proposal -Spring balance</u>

Research: Find some projects on the Internet, make pictures of the one you decided to make.

Strategy and modelling:
1.Decide on the type you will make.
2.Prepare appropriate material.
Most probably you will need:

- Cardboard paper to make a scale, a marker, scissors, a ruler, a spring, or a hard rubber.
- The cylinder into which you insert the spring or rubber can be made from a smaller, regular-shaped bottle.
- You can use the cover to fasten the rubber or spring. And finally, some kind of hook that you can make from a wire clothes hanger from the dry cleaners, or you can buy one in a hardware store.

3.Make the spring balance.
4.Test it by using known weights and according to it make your scale.

5.This is a picture of the spring balance, done professionally, you might have one at school. It may help you to decide on your design.

Now let's take a look at what we can discover using our device.

Pin the spring balance at a certain height and attach various objects to the hook. You will observe that the force differs in magnitude. We refer to this as putting objects with different mass on the hook and measuring their weight. In order to proceed with our measurements, we need to understand the distinction between mass, weight, and density. You may have already covered this in your lessons, but a review can be beneficial.

Mass, weight, and density.

Please answer the questions and make predictions.
Q: Which one is right? You are on a diet, are you losing mass or weight?

Your comments, question, observations.

A: When using the same bathroom scale at the same place you are losing weight and mass as well. So where is the trick? Do you have any ideas?

Your comments, question, observations.

We will investigate using a thought experiment.

In our thought experiment, Arphy will be wearing a space suit and traveling to different planets in our solar system. The weight of the space suit will vary between 80-120 kg, but for our experiment, we will use a space suit weighing 100 kg. Arphy's own mass is 60 kg.

By comparing Arphy's weight on the different planets, we can observe why his weight changes despite his mass remaining the same.

Table with the data of the thought experiment.

Object and its mass in 10^{24}kg	Gravity acceleration in $m.s^{-2}$	Arphy’s weight in Newtons -N,
Mercury - 0.330	3,703	592,48
Venus - 4.87	8,872	1420
Earth - 5.97	**9,8**	**1568**
Mars- 0.642	3,728	596,48
Jupiter- 1898	25,93	4148,8
Saturn -568	11,19	1790,4
Uranus- 86.8	9,01	1441,6
Neptun- 102	11,28	1804,8
Pluto -0.0130	0,61	97,6
Moon- 0.073	1, 625	260
Sun - 1 989 000	274,1	43856

Based on the data what conclusion can we make?

In our calculation for Arphy on Earth we used gravity acceleration 9,8 m. s^{-2}. In most examples we can round up the value to 10 m. s^{-2}, but it is good to know that gravity acceleration changes slightly on Earth as well.

Weight changes on Earth.

Weight changes on Earth can be influenced by various factors. Let's consider two factors: changes in gravity acceleration with altitude and the effect of Earth's rotation.

1.Gravity acceleration changes with altitude: As you go higher in altitude, the gravitational acceleration decreases slightly. This means that you weigh slightly less at higher altitudes compared to sea level. However, the difference is very small. For example, if Arphy's weight at sea level is 588 N (Newtons), it would decrease to around 586 N at a higher altitude. This change in weight is approximately 0.3 percent.

2.Effect of Earth's rotation: Due to the rotation of the Earth, there is a slight difference in weight between the Equator and the Poles. The rotational speed of the Earth is higher at the Equator compared to other latitudes. For example, the speed of rotation at the Equator is approximately 465.8 m/s, while in a city like Bratislava it is around 297.6 m/s. The difference in weight is influenced by the centrifugal force caused by Earth's rotation. However, this difference is very small and typically not noticeable in everyday life. (To give you an idea, the speed of the fastest cyclones in an amusement parks is around 20 m/s, which is much lower than the rotational speeds involves).

It's important to note that these variations in weight due to altitude and Earth's rotation are relatively small and typically not significant in our daily experiences.

Lattitude	Gravity acceleration in m. s^{-2}	Arphy's weight in Newtons -N
Poles	9,832	589,92
45° (where most Earth's inhabitants live)	9,806	588,36
Equator	9,78	586,8

People sometimes describe things like heavy.

What do you imagine, when someone says, it is heavy?

Your comments, question, observations.

We have some examples where you can find the clue.

How heavy things are?

1.Let us take heavy log of firewood. We can hardly lift it up, then we take it to the lake, throw it in and it floats.

Fig. 1 Log of wood

2. Do you like cocoa with heavy cream (whipped cream)? (We suppose you know what the heavy cream is from. You skim the cream from the top of milk, that is why it is called skim milk.) This cream floats, it is lighter than milk.

Fig. 2 Cocoa with heavy cream

From the given examples follow that when we say that something is heavy, it means denser. When something is less dense than liquid, it floats.

Let's delve into the concept of floating a bit further. Through our experiences, we know that objects like logs can float in water, and this observation led to the invention of the first canoe. However, like some other inventions, the use of ships can be both beneficial and harmful. Throughout the history, ships have been utilized for conquest and warfare, where weapons like bullets and fire posed a threat to their integrity. To address this challenge, the idea of constructing ships out of steel emerged. Initially, there was concern that steel ships would sink due to their density, but a breakthrough came in the 19th century when it was recognized that it is not just the density of the material that matters, but rather the overall density of everything present below the waterline. As a result, steel hulls were constructed, while the interior was filled with air. It is crucial to remember that density is determined by dividing the total mass by the total volume of an object or substance.

Your comments, question, observations.

Fig. 3 From canoe to ship

You want to float, you need to have less density, more fat, no diets. Therefore, sea mammals are that fat.

Fig. 4 Sea lion

We will start this part with a poem.
It is said that falling apple, made Sir Isaac Newton think better.
Discover what makes all things fall, from the smallest feather to great cannon ball.
Gravity is a great big pull, it pulls things together,
the bigger they are, the stronger is the force,
the closer they are, the stronger is the force.
It pulls the ones on Earth, so they don't fly away,
It keeps orbiting the Moon and planets.
No matter whether close or far,
The physics is the same for all around.

Newton's law of universal gravitation says: "Every particle in the universe attracts every other particle with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them. The direction of this force line is along the line joining the particles."
Its magnitude is:

$$F = G\frac{m_1\ m_2}{r^2}$$

F is the gravitational force exerted on the mass m_2 by the particle of mass m_1, or the other way around, *r* is the distance between two masses, G ≈ 6,674 x 10^{-11} N·m^2 / kg^2 is the universal gravity constant.
So why did we use in our calculation $F = mg$? You can take it as a fact, but the explanation is not that complicated.

Firstly, whenever we talk about the force the equation $F = ma$ holds. Secondly, we were calculating the "push / pull" close to the surface of Earth and so we can do our math.

$$m_1\ a = G\frac{m_1\ m_2}{r^2}$$

Where $m_1 \ a$ is the force acting on Arphy, $G\frac{m_1 \ m_2}{r^2}$ is gravitational force between Arphy and Earth(m_2).

$$a = G\frac{m_2}{r^2}$$

We have described above the small changes in the value of gravity acceleration, but for our purposes it will be sufficient to use $g = 9{,}8 \, m.s^{-2} \ or \ even \ 10m.s^{-2}$

How it is with orbiting planets mentioned in the poem.
As the Moon orbits the Earth, the force of gravity acting upon the Moon provides the centripetal force required for circular motion.

There are two new terms. Centripetal force and circular motion.

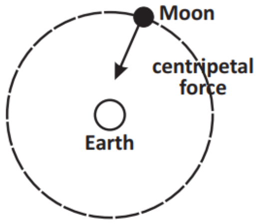


Fig. 5 Centripetal force

We start with the circular motion and an experiment.

There is a toy car in the video moving in a straight line with constant speed (this means constant velocity, as magnitude and direction are constant).

Watch the following video of the toy car moving in a straight line with constant speed.

https://youtu.be/LZBAITbhqMI

Now we would like to make it move in a circle. How can we make it? **You can see it in the next video** of the car moving in circular motion.

https://youtu.be/eRX0awa3Mwk

We applied force on the car using the spring balance. We held the spring balance steady, so that the force directs to the center of circular motion of the car. Car moved with constant speed, but holding it we had a constant force (watch the value on the dynamometer) directed to the center of the circle and it means that the direction of the speed was changing.

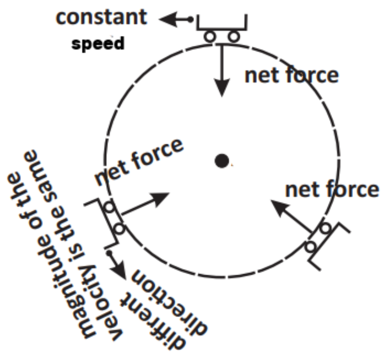


Fig.6 Force applied on the car using spring balance

There is one task for you. What would happen if the force suddenly disappeared?

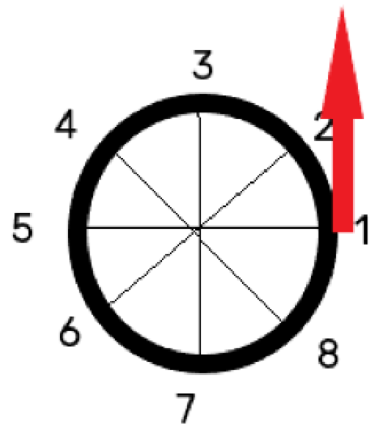
<u>Project proposal</u> – how you can test it.

1. Find or make a ball attached to a string. You definitely have at least one dog owner in your class, or you know someone, who has a dog. Such toys are made for dogs to train them.

   Fig.6 Ball attached to a string

2. Rotate the ball and release it at different places of the circle. The places are numbered. Then mark the direction in which the ball flew.
3. The best place for this activity is on the playground, where you can try also other experiments mentioned later in text.
4. Ask teacher or classmate to record the testing.
5. We answered the question for one point.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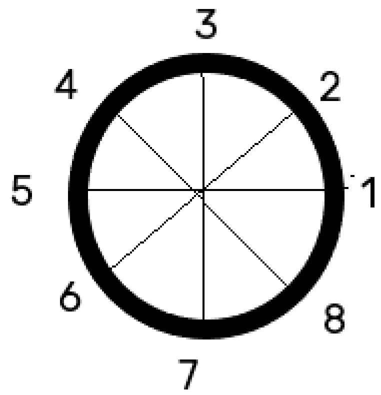
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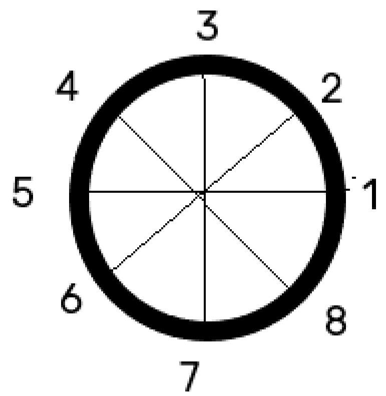
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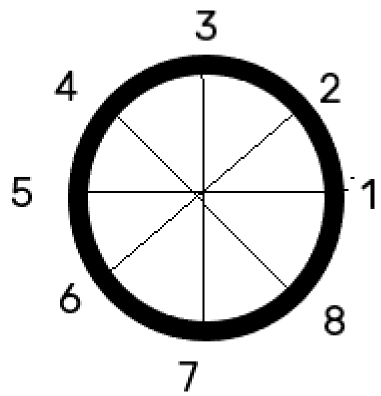
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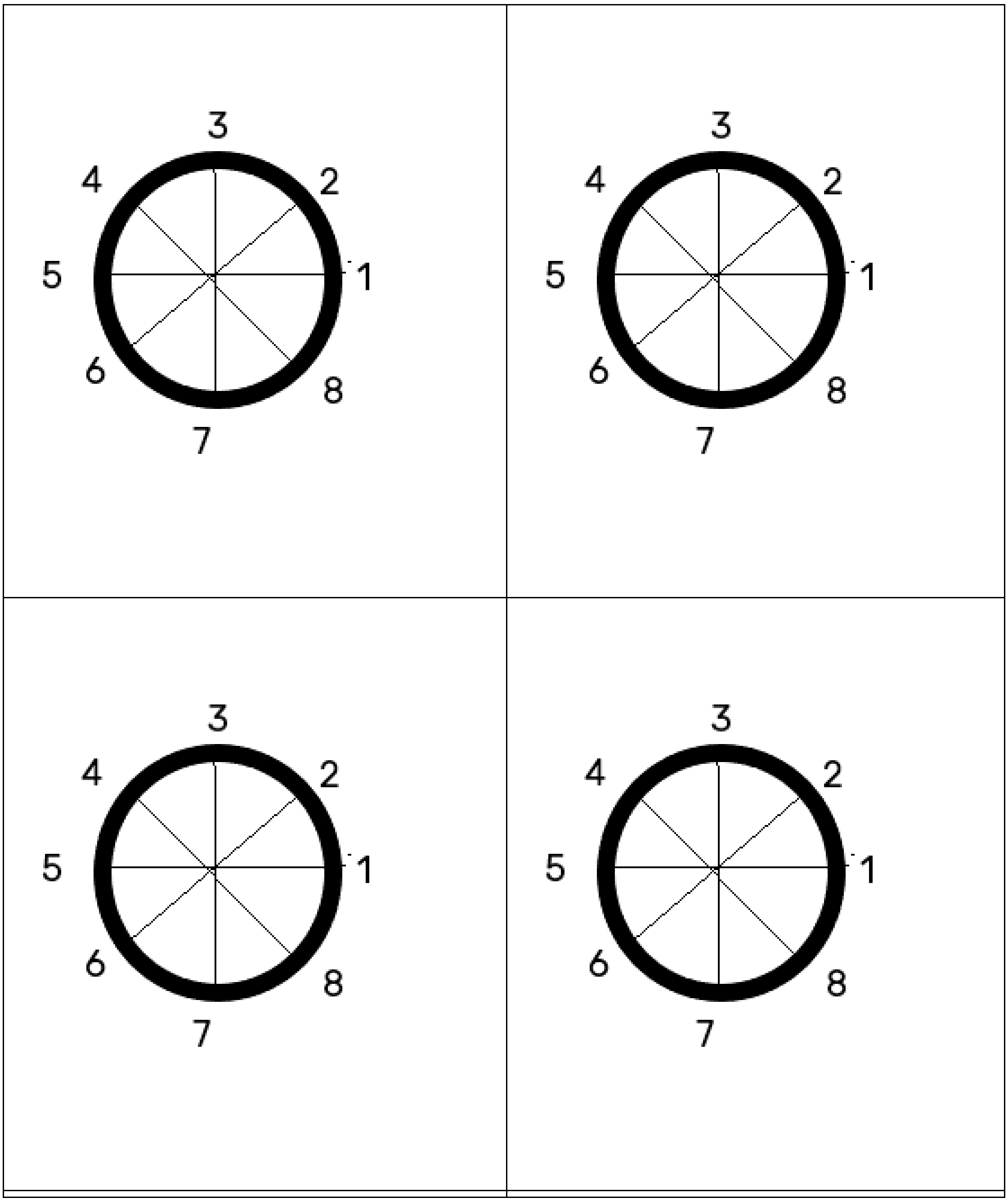


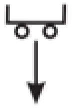
Fig.7 Releasing the ball

Doing the experiment carefully you realized that the direction the ball moves after releasing was always tangent to the point in which we released it.

To be able to fully understand uniform circular motion we need to answer another question. What would happen if the car would stand still and we will apply force towards us?

Now **watch the video** when we pull the car, but the wheels are standing still.

https://youtu.be/NirR_Gl1TLw



If car stands still it will just move towards us. With these experiments we can sum up.

After all the experiments with our toy car we can sum up the conditions for uniform circular motion:

1.There must be a constant **net force** always pointing to the center.

2. There must be a constant velocity perpendicular (90°) to the net force.

There is a name given to this net force – centripetal force. This can make us think that it is some kind of force, like gravity. **It is not true.** Centripetal force is **just net force (total force – the sum of all acting forces)** that always points to the center of motion and any force or the sum of forces can make it.

The last task, so that you can check your understanding.

In case of Moon orbiting the Earth, gravity is the centripetal force.

Do you know the direction of acceleration?

Your comments, question, observations.

(Where the net force is not zero, there is an acceleration.) Acceleration always points in the same direction as the net force (Second Newton's law -remember?)

The picture will help you.

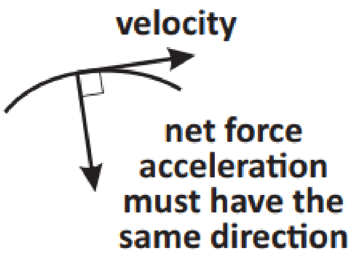


Fig.8 Acceleration and net force

Mechanics – Dynamics - Application of Newton's laws.

Friction.

We have already mentioned that in physics, we sometimes simplify the observed situation, and neglecting friction is one of those simplifications. However, if our predictions significantly differ from what we observe, we must revisit our initial assumptions and reflect on the role of friction. Many daily experiences cannot be explained without taking friction into account. Writing on a blackboard, for example, is closely related to friction. Let's consider the act of writing with chalk on the blackboard. As we move the chalk on the board, its particles remain on the surface, creating a visible trace. If we want the trace to be more pronounced, we can apply greater pressure while writing. If the board were very smooth or the chalk were very hard, there would be less rubbing off of chalk particles. Friction is encountered in various scenarios involving both machines and people. Professionals often view friction as a problem related to energy efficiency. Approximately twenty percent of gasoline consumption in automobiles is used to overcome the effects of friction in the engine and drivetrain. However, it's worth noting that without friction, a car would not be able to move. In the following sections, we will delve deeper into the topic of friction.

If you have ever observed people moving a wardrobe, you may have noticed something interesting: how does the necessary force change when the block starts to move? Visual illustrations will assist in understanding this phenomenon.

Your comments, question, observations.

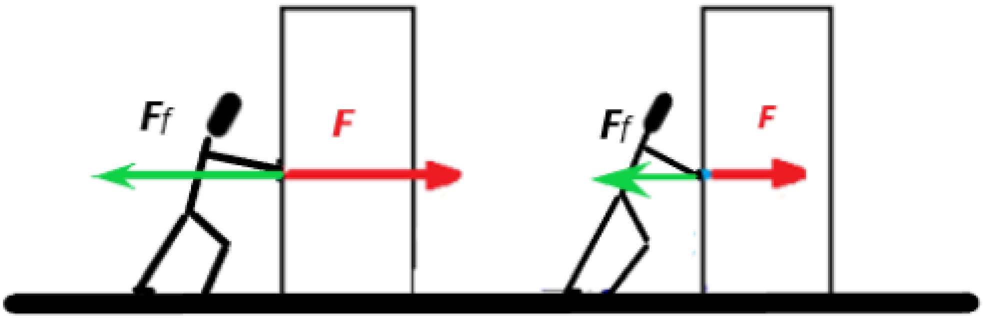


Fig.9 Pushing the wardrobe

Before the wardrobe starts moving. Wardrobe is in movement.

Got the clue? The hardest part by moving something heavy is to make it move. Then it is easier.
It is because we have different friction force with no motion and when moving.

Secrets of the power of friction will be revealed by the following experiments.
What does friction force depend on?

Your comments, question, observations.

Experiments involving the pulling of different objects on various surfaces using a dynamometer will help confirm the accuracy of our predictions. To conduct these experiments, you will need the following materials:

1.A bench or stable surface with the ability to attach strips made of different materials (such as polystyrene, aluminum foil, sandpaper, etc.).

2.Strips of the same length (approximately 50-70 cm).

3.Wooden blocks of the different weight, and with different sizes and each equipped with a hook at one end.

4.A dynamometer to measure forces.

Procedure:

1.Begin by attaching one of the wooden blocks to the dynamometer and observe the process as you attempt to pull the block.

2.In order to measure the force of friction accurately, you must apply a constant force that allows the block to move at a constant velocity.

3.When the block moves at a constant velocity, it indicates that the net force acting on it is zero.

4.The force acting in the opposite direction to your pulling force is the force of friction. Therefore, the pulling force and friction force combine to give a net force of zero.

By conducting these experiments and analyzing the results, you will gain a better understanding of the relationship between pulling force, friction, and the motion of objects on different surfaces.

Watch the videos. Carefully observe value showed on the dynamometer. We used three different materials. Compare the values of friction force in each situation.

Video with the first surface material:

https://youtu.be/ktHGOJ0aEQk

Video with the second surface material:

https://youtu.be/9XtKdJVrhyE

Video with the third surface material:

https://youtu.be/qwnC_VX_EKY

Following is the table for your own experiment.
How does the friction force depend on the surface material?
Change the surface material of the bench.
Put the results in the table
Block weight: [kg]

Measurement number	Surface material	Friction force at rest [N]	Friction force when moving [N]

Friction force at rest is the force shown on the dynamometer, just when the block starts moving.
Friction force when moving is the force shown on the dynamometer when block moves with constant speed, you will see that at that point the data changes only slightly.
Your observation according to the results of your measurement:

Try to think about how can we get the surface smoother?

Your comments, question, observations.

We can use some oil (or another lubricant, in some cases water is also a good lubricant), putting it on polystyrene track, the friction force will decrease.
So, it brings us to the possibility of decreasing the friction by making the surface smoother and smoother, but is it correct?

Your comments, question, observations.

Only to a certain extent. We cannot rely on this completely. This does not apply for touching two polished surfaces. This is because a force acting between the particles touching the surfaces begins to manifest. The science that deals with friction is called tribology and it is real “alchemy”.

Experiment 2.
Let us continue with our exploring. Do this experiment without the help of video.
How does the friction force depend on the weight of the object? Do the experiment on the horizontal plane.

Your comments, question, observations.

Put another block on the top of the first. Does the friction force change?
Put the data into the table.

Measurement number	Weight [N]	Friction force [N]
1 block		
2 blocks		
3 blocks		

The friction force increases with the weight of the blocks.

You can also make a graph of the friction force dependence on weight.

Another question:
Does the friction force depend on the size of contacting area? It is another experiment for you to do on your own.
Having a block with different size areas, you can test it.

Your comments, question, observations.

Measurement number		Surface area	Friction force [N]

There is no difference in friction force depending on the surface area.

Let us summarize:
Friction force is proportional to the weight (or part of weight perpendicular to the base) and material property called friction coefficient.

$$F_{fr} = f \cdot G$$

$$\text{Friction force} = \text{friction coefficient} \cdot \text{weight perpendicular to the base}$$

There is a difference in friction force when objects stand still and move, we have static and dynamic coefficient of friction.

All the above experiments were done with blocks. What if we move a barrel, the same weight as wardrobe?
There will be a big difference whether we push it or roll.

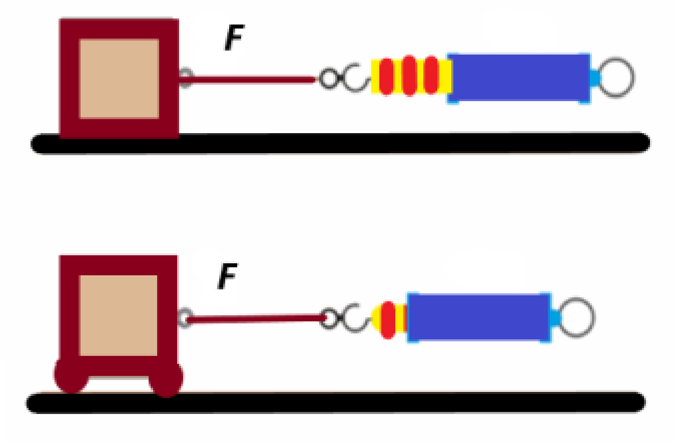


Fig.10 Static and dynamic friction

We can see this result in praxis. As it is easier to roll, we have trolley school bags and suitcases on wheels and people moving heavy furniture or transporting goods use platforms on wheels. We can also say that round bodies prefer roll to slide. But with friction, there are always some exceptions. Imagine football on ice. Very likely it would slide and not roll. The smooth surface of the ice reduces the contact and grip between the ball and the surface, resulting in sliding motion instead of rolling.

In the previous experiments, the movement took place on a plane. Will the friction force change for the same materials and weight if the measurement will be done on an incline?
When an object is placed on an incline, its weight can be divided into two components: one parallel to the incline and one perpendicular to the incline. The component perpendicular to the incline is the one that influences the friction force.

In the case of testing the dependence of friction force on the weight on an incline, it is observed that the friction force is proportional only to the weight component perpendicular to the base. As the angle of the incline increases, the weight component perpendicular to the base increases, resulting in a larger friction force.

Videos demonstrating the dependence of friction on the angle of incline provide the visual examples of how friction force changes as the incline angle varies. We have three different angles.

Video with the lowest angle.

https://youtu.be/ePt9kYCAVBs

Video with the higher angle.

https://youtu.be/Gz8xRQ1HuKQ

Video with the highest angle.

https://youtu.be/7aDL4FTZBwM

Mechanics – Dynamics - Physics on the playground and in space.

We were dealing with the circular motion explaining it with videos, but there is more exciting way how to learn physics. Let's go to the playground and learn about physics in a fun way! We'll discover how things can look different depending on how we look at them and how our senses can sometimes fool us. We'll also see how things that spin, like a merry-go-round, spaceship, or even a hurricane, have something in common. Remember, it's important to observe carefully and describe what we see, whether we're still or moving. So, let's read this part and then head to the playground to try it!

Fig. 10 Merry – go - round

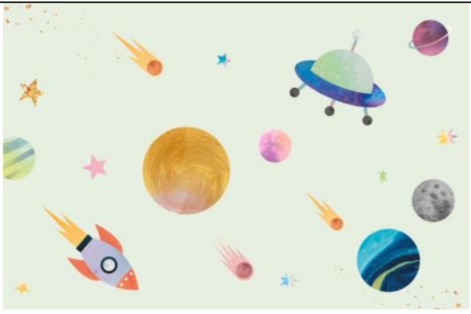


Fig. 11 Space ship

Let's talk about how things can appear strange when we're traveling and how our senses can trick us. Imagine you're in a car on a familiar route. When you look out the window, what do you see?

Your comments, question, observations.

Looking out of the car you observe that everything outside seems to be moving. The only reason we know that it is not true is that we have learned that trees, lamps, buildings do not move. It is our knowledge that brings us to that conclusion, not our senses.

When something moves in a circle, there has to be a force acting on it. Think about when you're in a car and it turns. You feel a push in the opposite direction of the turn. This is because your body wants to keep going in a straight line, but the car is making you turn. The force that makes you turn is directed towards the center of the circle.

This is similar to what happens when you swing a yo-yo. You have to keep pulling on the string to make the yo-yo go in a circle. If you let go of the string, the yo-yo would just keep moving in a straight line. The force from your hand pulls the yo-yo towards the center of the circle.

So, whenever something is moving in a circle, there is a force that keeps it going in that circle. Without this force, things would just keep moving in a straight line.

Project proposal.

Let us go to the playground. **But first watch the videos.**

We are going to observe what is going on from both perspectives:

1. Sitting on the merry – go – round and watching the happening.

Watch the video, observe the ball attached to the frame on the merry-go-round.

https://youtu.be/B1x7w94vM00

Your comments, question, observations.

When sitting on a merry-go-round, we observe the world around us rotating, and we notice that a ball attached to a string swings away from the center. It appears as though some force is pushing the ball outward. However, this force is fictitious, meaning it is not a real force acting on the ball. Despite that, we perceive it as a force because we do not have any other explanation for what we see. We also feel a push on our back due to this fictitious force.

2. Standing outside the merry – go – round and watching what is happening on the merry – go – round.

Watch the video, observe again the ball attached to the frame of merry-go-round from the different perspective.

https://youtu.be/5xvCgyU3Pp8

Your comments, question, observations.

When you're standing on the ground and you see a ball moving in a circle, you know that there must be a force making it move that way. It's like when you swing a yo-yo around in a circle, you have to keep pulling on the string to keep it going.

But sometimes things can feel weird when you're in a moving car. For example, when the car speeds up, slows down, or turns, you might feel like there's a force pushing or pulling you in different directions. It can be confusing because you know there's no physical force actually pushing or pulling you, but your body can still feel that way because of how it's moving.

So, just remember that when you're in a car and you feel these strange forces, it's just your body reacting to the changes in motion. It's not a real force like the one that makes a ball move in a circle. It's kind of like an illusion that your senses create.

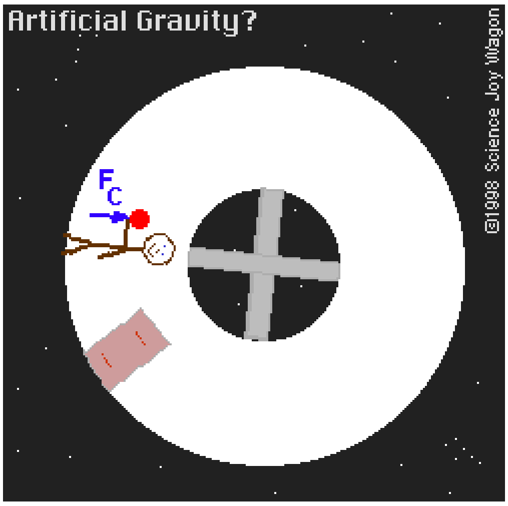
Now let's explore what merry-go-rounds and spaceships have in common. We've learned that our senses can sometimes mislead us, especially when we're in a car that speeds up, slows down, or turns. Our sense of weight, or the force of gravity, is often associated with feeling the floor pushing back on our feet.

But here's an interesting twist: When we're in free fall, like during a drop on a roller coaster or in an elevator moving downward (with an acceleration, which is only a short moment it starts moving), we feel weightless because there's no floor pushing against our feet. Conversely, when the elevator moves upward (with an acceleration, which is only a short moment it starts moving), we may feel heavier because the floor pushes harder against our feet.

Now, imagine hanging on a gymnastic ring. We feel the pull of gravity downward. But what happens if someone starts to rotate us?

Your comments, question, observations.

Who cares? We all, as there are still more and more discussions about the possibility of living in space for long periods of time (whether traveling or just staying in orbit around the Earth). We know that humans don't function well in weightless situations. We get upset stomachs and in general we need a floor to push against us so that we can move around. The question then arises, how do we create artificial gravity, or how do we simulate it? One idea is to build a spinning space station. By spinning it, we can create a force that feels like gravity. This way, astronauts can live and work in space more comfortably, just like on Earth. It's like something you might see in a movie, but scientists are actually working on making it a reality!



When the spaceship is spinning, the walls of the space station push towards the center, just like when a car turns and the door pushes you. It helps the person inside the station move in a circle instead of going in a straight line.

We can calculate the right speed of rotation so that the person in the space station feels the same amount of force pushing on their feet as if they were standing on Earth.
Fig.12 Spaceship spinning

Now to another question. What does merry – go – round and hurricane have in common?
It is even trickier for observing, therefore we suggest to look also for some videos on YouTube explaining Coriolis force. You will see scientists playing on the playground as you. (Some suggestions: https://www.youtube.com/watch?v=mPsLanVS1Q8, https://www.youtube.com/watch?v=dt_XJp77-mk)

For this observation, you'll need a ball and at least three of your classmates. First, **two of your classmates will sit on the merry-go-round and toss the ball back and forth to each other. You will be the observer standing off the merry-go-round.** Then, another classmate will start rotating the merry-go-round. Can your friends still catch the ball? **Watch the video to find out!**

https://youtu.be/lbmacYAeCt0

Your comments, question, observations.

When you watch your friends playing on the merry-go-round and throwing a ball to each other, it looks like the ball is going straight. But here's the tricky part: because the merry-go-round is spinning, the person trying to catch the ball keeps moving away from where the ball is going. So even though the ball is thrown in a straight line, it's hard to catch because the target keeps changing its position.

Do the same, only now, **watch the classmates play sitting with them on the merry – go – round. Watch the video.**

https://youtu.be/k2j9XkKr0i4

Your comments, question, observations.

When you're on the merry-go-round and you throw a ball to someone, it seems like the ball gets pulled away from them. This force is called the "Coriolis Force," but it only happens when you're on the merry-go-round. This force is similar to how the Earth's rotation affects the movement of air in a hurricane. It's not the whole story of hurricanes, but it's something you can see and understand on the playground.

Still not clear? Back in the classroom you can do the following.

Material you will need: a piece of cardboard, piece of paper, pencil, scissors and a pair of compasses.

Procedure:

Cut out a circle from the paper and pin it to the cardboard.

Draw a straight line across the circle.

Ask your classmate to rotate the circle while you draw another straight line.

Try rotating it clockwise and counterclockwise.

This activity will help you see how the lines change when the circle rotates. It's like the Coriolis effect we talked about earlier.

Your comments, question, observations.

On the paper, you will see a similar effect as with the ball on the merry-go-round. The purpose of this activity was to help you understand that our perception can sometimes be tricky. When you're at school, try to think from the perspective of no acceleration at all. And always remember to do experiments and play with physics whenever you can. It's a fun way to learn, even when things seem complicated. Keep exploring and enjoy the journey!

When on playground you can repeat the physics also sitting on a swing.

When you sit on a swing and start moving back and forth, you're actually experiencing some physics in action. Here are three important physics concepts that explain how swings work:

Gravity: When you sit on a swing, gravity is pulling you down toward the ground. That's why you don't float away. Gravity is what makes the swing come back down when you go up in the air.

Pendulum Motion: A swing moves in what's called a pendulum motion. Imagine a pendulum clock that swings back and forth. When you push a swing, it starts swinging like a pendulum. The reason it swings back and forth is because of gravity. Gravity pulls the swing downward when you're at the highest point, and that makes it start swinging downward.

Energy: Swinging back and forth involves energy. When you first start swinging, you use your muscles to give energy to swing. As you move back and forth, you convert this energy between two types: kinetic energy and potential energy. When you're swinging down low, you have lots of kinetic energy (the energy of motion). When you're at the highest point, you have lots of potential energy (the energy of position). So, you keep changing these two types of energy back and forth.

What was the hardest part when you first try swinging as a little child? If you do not remember try pushing the swing at different times during your swing. Notice how it affects your motion? If you push when you're at the highest point, you'll go higher. If you push when you're coming down, you won't go as high. This is all about understanding how to use the energy and timing to make the swing really fun.

Mechanics – Dynamics - Turning effect of force

There is one last effect of force we have mentioned in the beginning of this chapter– Arphy opening the door. The applied force caused the door to rotate around a fixed axis. We will begin our exploration remembering our playing with children's seesaw swing.

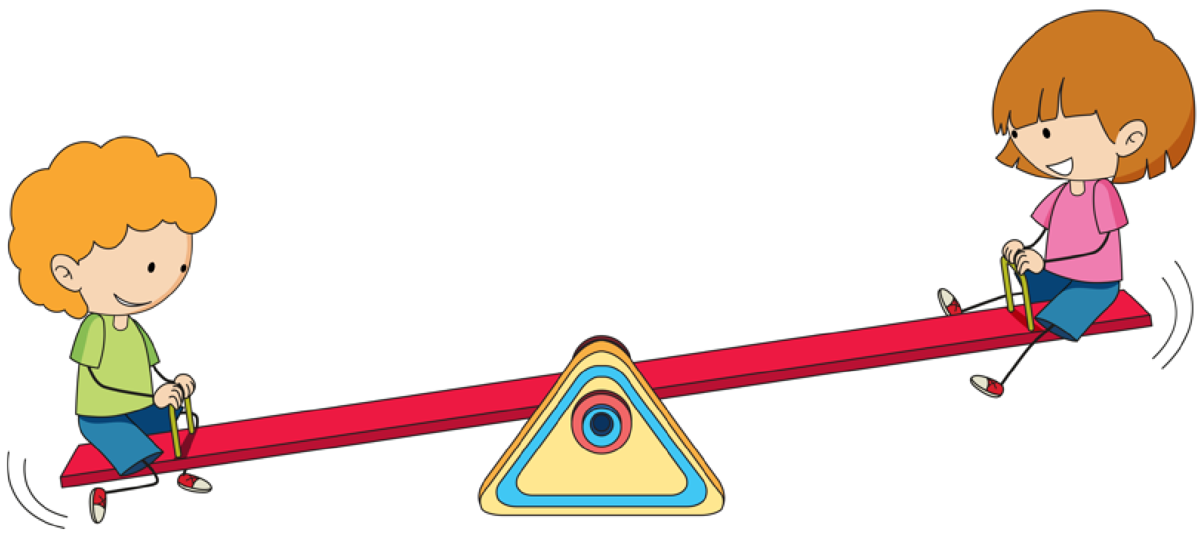


Fig.13 Seesaw

Imagine you and your friend are sitting on a seesaw, one on each end. The seesaw stays level and doesn't move when both of you are on the ground because your weights are balanced.

Now, let's discuss about what happens when one of you pushes off the ground with your legs. When you push, you're exerting a force. Because the seesaw can pivot in the middle, this force makes your end of the seesaw go up while the other end goes down.

This movement occurs due to something called torque. Torque is like a twisting force that causes objects to rotate. When you push down on your end of the seesaw, you generate more torque on your side, causing it to go down.

When one side goes down, the other side goes up because of the conservation of angular momentum. (You will deal with this law later, but it is good to mention it also now, because it is a crucial concept. For instance, think of a skilled ice skater doing a spin. When the skater pulls arms close to the body, he starts to spin faster, by stretching the arms he slows down.) This means that when one side of the seesaw goes down, the other side rises up to maintain balance.

From a physics perspective, a lever is characterized by an axis of rotation and arms, or can have only one arm, as seen in a mobile crane.

Let us describe the above situation. If we have two objects of the same weight and place them at the same distance from the axis of rotation, their rotational effects cancel out, and the lever remains balanced. We refer to the distance from the axis of rotation as the "force arm".

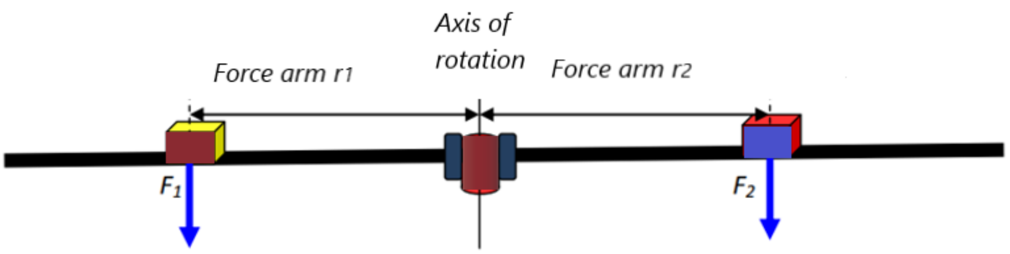


Fig. 14. Lever

The arm of a force relative to a given point is the shortest distance from the point, or center, to the line of action of the force. If a smaller force is to balance the rotating effects of a larger force, it must act at a greater distance from the axis of rotation, which means it must have a longer arm.

How can we use a lever with significantly different weights on each arm? See the picture.

Fig.15 Lever – different weights

When dealing with torque, it is essential to consider the direction of rotation of the body. If the force causes the body to rotate counterclockwise, the torque has a positive sign (+). Conversely, if the force induces clockwise rotation, the torque has a negative sign (-). This becomes important when multiple forces act on the body simultaneously.

Now, let's revisit Arphy closing the door. At which point does he have to exert the greatest force to close the door? We already knew the answer, but now we also understand why.

We also now understand, why the child with greater weight should sit closer to the axis od rotation.

<u>Do you know of an example from daily life?</u>

In practical situations, we often use a lever with a single force arm. A wrench is an example of a single-arm lever. By using a wrench, we can observe how the amount of force required to turn a nut changes when the length of the force arm is altered. If the force arm is shorter, we need to apply a greater amount of force to turn the nut.

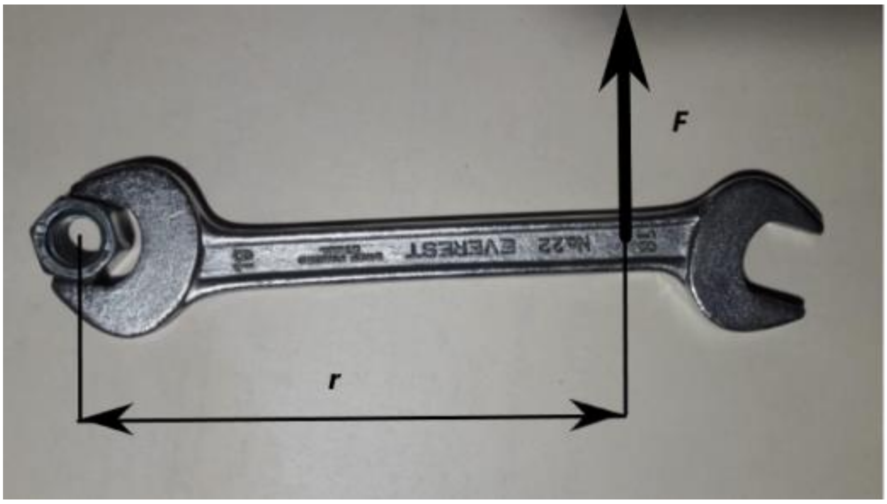


Fig.16 Wrench

Torque is a physical quantity denoted as T.

The formula used for its calculation is: $T = r F$

The unit of torque is N.m.

<u>One example for you.</u>

Measure the weight of different types of candies and then calculate how many of them you will have in a 100g pocket.

We will need a sheet of office paper (its mass is 5g), pin, candies, ruler.

We fold the paper first by half the width (Fig.1), then spread the paper and fold it three times in length (you will get a narrow, long strip Fig. 2).

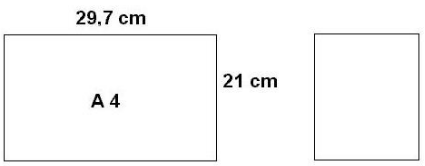


Fig.17 Paper folded in a half width

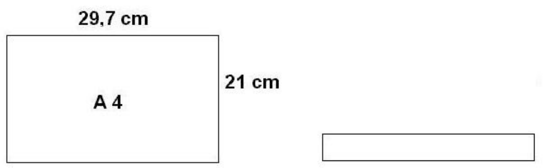


Fig. 18 Paper folded in a length

The center of gravity of the paper is located at its center. If we aim 5 cm to one side from the center and stick a pin in that spot, we can observe that the paper tilts to one side. Next, we create a groove by folding the paper and place a candy in it. We slide the candy along the groove until we find the point where the paper balances out (while still holding the scales with two fingers by the pin).

To determine the weight of candy we measure the distance A.

Torque equilibrium must hold and hence:

$F'.a = F.A$

$m.g.a = M.g.A$

$M = (m.a) : A$

O – axis of rotation

F – gravitational force acting on candy

M – mass of candy

F^* - gravitational force acting on the paper

m – mass of paper sheet

a – distance between the axis of rotation and center of gravity of the paper

A - distance between the axis of rotation and center of gravity of the candy

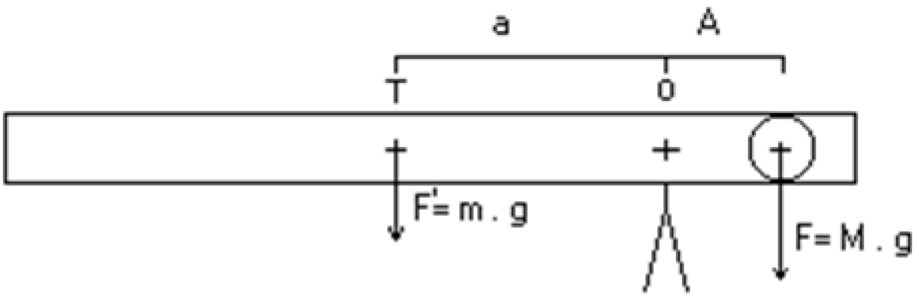


Fig.19 Weighing candies

Mechanics – Dynamics -Center of gravity.

So far, we have been discussing objects without considering their size and shape. We simplified the situation and worked with a concept called a mass point, which represents an object's mass concentrated at a single point. This approach works well when we neglect deformations and focus on translational motion. However, when dealing with a truck, we need to consider its size and shape. This raises the question: Which point should we choose as the mass point for the truck? To explore this further, we will conduct some experiments.

At circus performances, you may have seen artists who can balance trays of glass goblets on the point of a sword. Have you ever wondered how they do it? The secret lies in finding the point where they need to support the system of objects so that it doesn't fall. We can try a similar experiment using a broom. All you need is a broom and a little bit of patience. Here's what you do:

Hold the broom horizontally with your two index fingers.

Slowly slide your fingers together towards the center.

Eventually, your fingers will meet at a specific point. This point is known as the center of gravity, and it's the crucial point that keeps the broom balanced and prevents it from falling.

By finding the center of gravity, we can understand how objects balance and stay stable.

Fig. 20 Balancing broom

You can watch it on the video.

https://youtu.be/yMmwj2lKb8k

We will examine the center of gravity of homogeneous bodies first. Symmetrical objects and the ones with irregular shape.

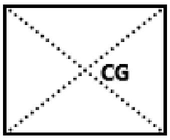
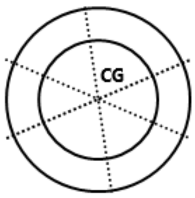
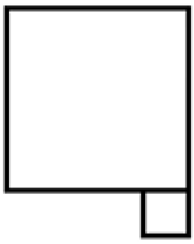
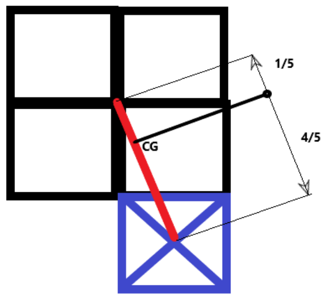
Symmetrical objects. 	The center of gravity lies in the geometric center (center of symmetry) of the body.
Clear? Try the following ones. 	The center of gravity can also lie outside the body.
	 The center of gravity of compound bodies can be found at the junction of the centers of the parts, closer to the larger body.

Fig.21 Gravity of different objects

What about irregular shapes of the same thickness? Cut some irregular shape from the cardboard, tie the string with one bolt to the material and follow the pictures. Did the picture reveal the secret?

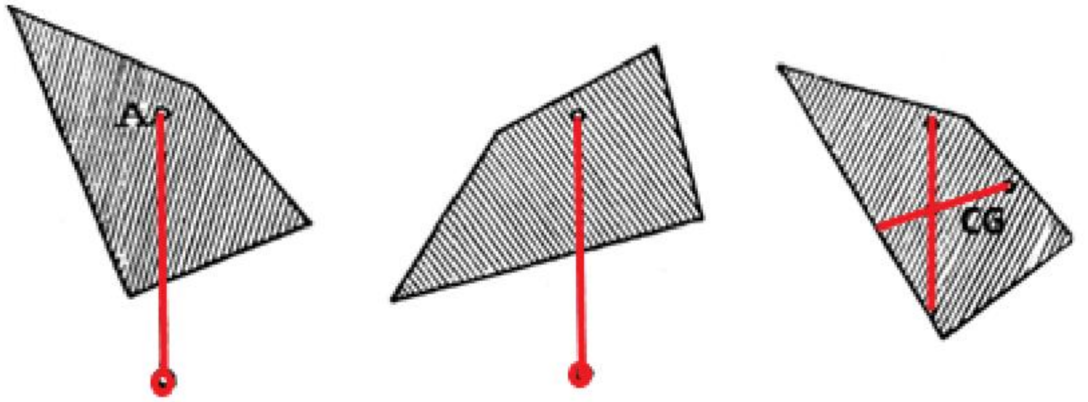


Fig. 22 Center of gravity of irregular shapes

Your comments, question, observations.

When dealing with objects of irregular shape but the same thickness, we can find their center of gravity in a simple way. All you need is some twine, a nut, and adhesive tape. Here's how you can do it:

Attach the twine with hanging nut to different points on the object using adhesive tape. Make sure the twine is securely attached to the nut.

Let the nut hang freely from each attachment point, pointing vertically downwards.

Draw a line along each twine to mark its direction.

Repeat the process for multiple attachment points on the object.

Once you have marked the lines for each attachment point, the center of gravity will be the point where the lines intersect.

So, what is the center of gravity, now when we can find it?

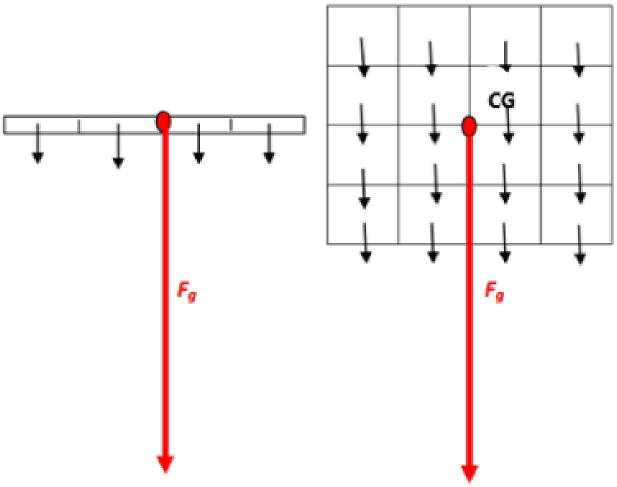


Fig.23 Understanding the center of gravity

Did the picture reveal the secret?

Your comments, question, observations.

A gravitational force acts on each particle of the body. If we have a body (square cut out of hard paper) divided into smaller parts, each of which is subjected to gravitational force. The effect of all these partial *gravitational forces on the body is the same as the effect the resulting gravitational force which would act at the center of gravity of the body.*

Let us play a bit and see how the center of gravity works.

The center of gravity helps us to follow up and describe the movement of a system of mass points. Best described by experiment with a system of two interconnected "mass points". We create it using three nuts and a thread. One material point will be represented by one nut, the other by a pair of the same nuts.

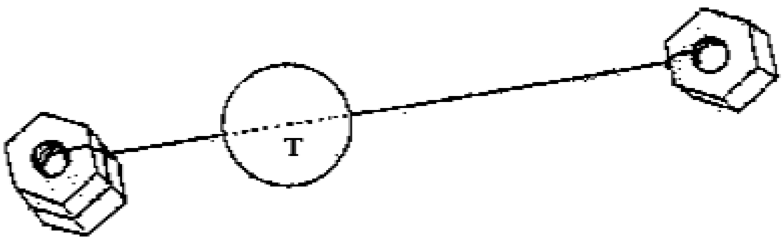


Fig. 24 Center of gravity with nuts

To verify this experimentally, we must first make the center of gravity of the system visible. We will do this by placing a ping - pong ball (or something similar) at the center of gravity. In our case, the center of gravity is one-third of the distance between the two mass points. We fix the ball on the thread by creating knots in close proximity to the holes we made before into the ball. We throw the system up by grabbing it by one end and trying to spin it as much as possible.

Watch the video and describe the movement of the nuts and the ping- pong ball in the center of gravity in your own words.

https://www.youtube.com/watch?v=20S0bgkFO0I

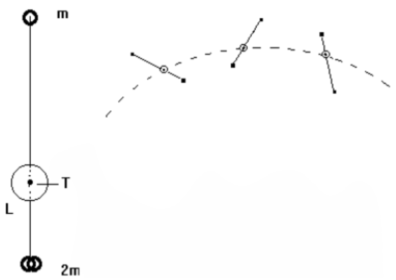


Fig. 25 Movement of the center of gravity

If we throw our configuration so that it also rotates, it will move in a complicated way. However, the center of gravity of the system will move similarly to a thrown stone. In that way the center of gravity allows us to predict the position of the whole object

We can also find toys using the center of gravity. You can find them in some science toys shops. **We bought one and made the video.**

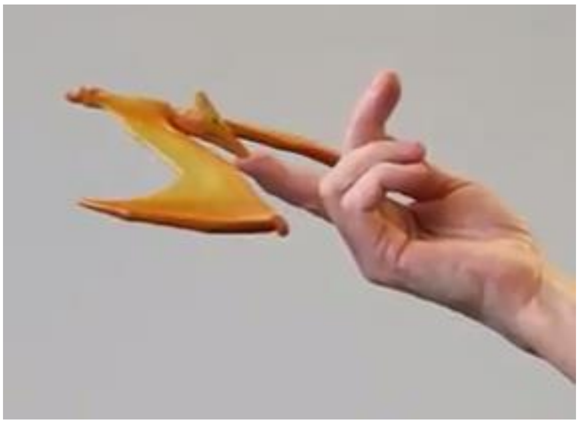


Fig. 26 Pterodactyl

https://youtu.be/EE9UiHrQk3I

Understanding the physics of the center of gravity we can move things up the hill.

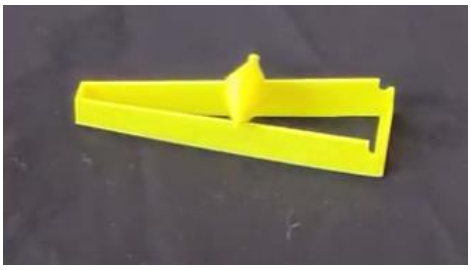
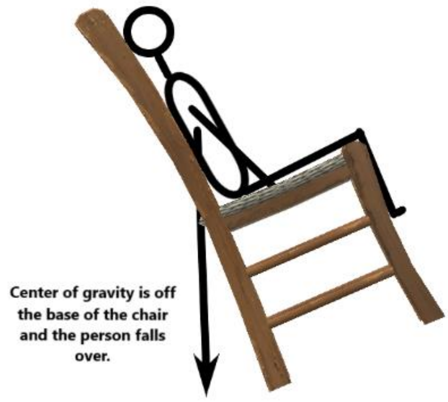


Fig. 27 Moving uphill

https://www.youtube.com/shorts/jkcDE9rokOY

The trick is that moving uphill in this configuration means that the center of gravity gets lower and it is in more stable position. The lower the center of gravity of an object is, the more stable object is. Objects with higher center of gravity are easier to topple than objects with lower center of gravity. If you tilt on a chair you will topple over when the vertical line from your center of gravity falls outside the base of a chair.



The same is true for improperly loaded cargo on a truck. It can then easily tip over in a turn. Find some pictures with such examples on the internet.

Fig. 28 Tilted chair

Your comments, question, observations.

Or you can trick your classmates with balancing can.

When you have 500 ml can, fill it with 100ml of water and you can make the trick.

A – an empty can, B – can with water, the center of gravity is lower.

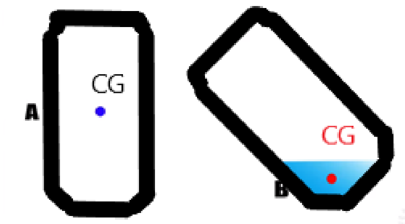


Fig. 29 Balancing can

Figures acknowledgements

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