Kingdom of Cambodia

Nation - Religion - King

Low-Cost Experiments for Physics Education

Part 1

Chapter 1: Mechanics

Chapter 2: Sound

Chapter 3: Heat

Teacher Training Department 2012

Physics Experiment Manual: Part 1

Chapter 1: Mechanics

Chapter 2: Sound

Chapter 3: Heat

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Prologue

The main objective of this manual is to enable science teacher trainers and teachers to introduce practical activities to their students, thus improving their critical thinking and problem solving skills. All experiments are designed with low-cost and easy-to-find materials.

This manual is complementary with other learning materials developed by the Ministry of Education, Youth and Sport, in cooperation with VVOB. These include a manual on student centred approaches for science education, science posters and boxes with low-cost learning materials for all science subjects.

To ensure an effective use of the experiments in this manual, we suggest the following procedure:

1. Prepare all the material for the experiment before the start of the lesson.
2. Allow students to think, to predict, to observe and to explain during the practical activity. In this way, they will grow familiar with the scientific method.
3. Allow as much as possible hands-on time for students.
4. Revise student understanding after doing the experiment and adjust your lesson plan if necessary.

The Ministry hopes that you all will make the best use of the materials to improve the quality of science education.

Phnom Penh, 21 September 2012

HE Nath Bunroeun

Secretary of State

For Minister

Preface

This manual was developed by the Ministry of Education, Youth and Sport, in cooperation with VVOB. Its objective is to improve science teacher training by introducing student centred approaches.

This manual consists of a set of science experiments that will help students to understand the main concepts outlined in the RTTC curriculum. All experiments have been tested by teacher trainers and teachers. Complementary to the manual is a set of DVD's with short movie clips of all experiments in order to help teacher trainers with integrating experiments in their lessons.

For each experiment we include a set of objectives, a link to the relevant lesson in the curriculum, the material needed to do the experiment, a detailed description of the procedure, observations, an explanation and additional questions. Where appropriate we add ideas for variations.

We are convinced that this manual will contribute to an improvement of science education in Cambodia. However, do not hesitate to communicate us your comments and suggestions.

We are looking forward to receiving your comments. We wish you an inspiring experience and many satisfying science lessons with this manual.

The authors,

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Chapter 1: Mechanics

Introduction

This manual consists of a set of experiments that will help students to understand the main concepts of mechanics. All experiments have been tested. For each experiment we included a link to the curriculum, a list of the material needed, a detailed description of the procedure, observations and an explanation. Where appropriate we added ideas for variations and questions to probe for deeper understanding. The videos can also be found on YouTube and **http://krou.moeys.gov.kh**

We are convinced that you will enjoy using this manual. However, do keep in mind that this version may contain mistakes. Do not hesitate to communicate us your comments and suggestions.

Main concepts

1. First law of Newton – Inertia

Mass is the quantity of matter in an object. It is also the measure of inertia that an object has in response to any effort made to start it, stop it or change its state of motion in any way. **Weight** is the force upon an object due to gravity.

Newton's first law, the law of **inertia**:

- an object at rest remains at rest, as long as no net force is acting on the object.
- an object in motion remains in motion at constant speed along a straight-line path, as long as no net force is acting on the object.

This property of objects to resist change in motion is called *inertia*. *Mass* is a measure of inertia. Objects will undergo changes in motion only in the presence of a *net force*.

2. Second Law of Newton – Acceleration

Newton's second law, the law of **acceleration**: when a net force acts on an object, the object will accelerate. The acceleration is proportional to the net force and inversely proportional to the mass (i.e. $a = F/m$ or $F = ma$).

Some examples: when objects fall in vacuum, the net force is simply the weight, and the acceleration is g. When objects fall in air, the net force is equal to the weight minus the force of air resistance, and the acceleration is less than g.

3. Third law of Newton – Action and reaction pairs

Newton’s third law, the law of **action-reaction**: whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first. Forces occur in pairs, one action and the other reaction, which together constitute the interaction between one object and the other.

4. **Momentum and impulse**

Momentum is inertia in motion and is defined as the product of mass and velocity. A moving object can have a large momentum if either its mass or its velocity is large. The momentum of an object changes when either its mass or (usually) its velocity changes (and acceleration occurs). To change the velocity of an object a force is required (second law of Newton). When you apply a force over a longer period of time the change in momentum will be greater. The impulse is the change in momentum and is the quantity force x time interval ($F.t = \Delta m.v$).

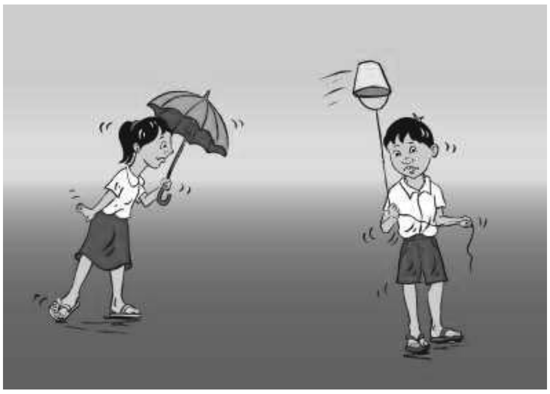
5. **Rotation**

The effect of a force (by rotation) depends on the distance to the centre of rotation.

Torque is the rotational counterpart of force.

Torque = lever arm x force (the lever arm is the distance from the axis to the line along which the force acts)

If the net torque is zero, no rotation is produced. What we win in **force**, we lose in distance.



6. **Equilibrium**

How many times have you walked along a curb with your arms out at your sides to help keep your balance? Even as a small child you understood that to keep your balance you had to have as much weight on one side of you as on the other. You knew this instinctively. You also discovered how easy it was to lose your balance when you walked on any wall or narrow line. Instead of stepping off the wall or falling, you bent and twisted and waved your arms a bit. When you did these things your body was regaining its balance by getting its centre of gravity right over the curb.

Everyone knows how gravity works. Gravity is that invisible force that keeps us from flying off into space. But what is the centre of the gravity? And what does it have to do with keeping your balance?

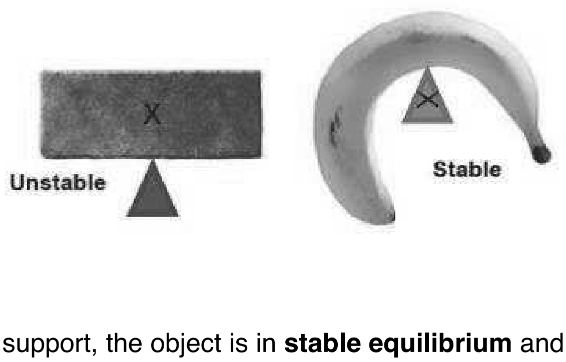
The **centre of gravity** is that point in an object where there is as many weight on one side as on the other. When you're walking along a curb, your centre of gravity is right on the line where you place your feet. If you stand up straight with your feet spread, your centre of gravity is between your feet and straight down in a line from your nose. The average position of an object's weight distribution is called the centre of gravity (CG).

When we locate the centre of gravity in an object we can get that object to balance. You can balance a pencil on your finger, can't you? Its centre of gravity is halfway from the eraser to the point. For simple, solid objects, such as a football or a brick, the centre of gravity is located at the geometric centre. If an object does not have a uniform weight distribution then the centre of gravity will be closer to where most of the weight is located.

For example, the centre of gravity for a hammer is located close to where the head connects to the handle.

The centre of gravity can be located at an empty point in space, such as the centre of a hollow ball.

The centre of gravity can even be completely outside of an object, such as for a donut or a curved banana.



When the centre of gravity (CG) is under the point of support, the object is in **stable equilibrium** and a slight rotation makes the object just swing back and forth.

When the CG is perpendicular above the point of support (pivot), the object is in **unstable equilibrium**. Any slight rotation causes the object to tip and fall off the pivot.

1. *Newton's First Law - Inertia*

1.1 Experiment to illustrate inertia #1

Objectives

- Students can explain the difference between mass and weight (and impulse).
- Students can apply Newton's first law to situations in daily life.

Material needed

- A tablecloth (or a strip of paper and one object)
- a bottle filled with water
- some tableware

Link with curriculum

Physics textbook: Grade 10, chapter 1, lesson 2 (2008)

Procedure

- Put the tablecloth on the table and make it hang down.

- Put the other objects on the tablecloth. It is important that both the cloth and the table top be smooth and low-friction. If the table surface slows them too quickly, tall objects like glasses and candlesticks can topple forward.
- Ask your students how they can “clean the table” as quickly as possible.
- Draw the cloth from the table with a quick jerk; make sure you pull the cloth <u>downward.</u> It is best to practice a few times before. It helps to roll up the edge you are pulling all the way to the edge of the table before pulling it, helping to ensure that the cloth doesn't "bunch up" anywhere during the pull.

Observation

Does the tableware fall down, or does it remain upright?

Explanation

If you really give a quick jerk downward, the objects remain upright, due to their inertia and the first part of the law of inertia. The net force is working too short to let the objects start moving.

An alternative explanation is to relate it to the impulse of the objects. The impulse given by the cloth to an object on it is F t, where F is the tension in the cloth and t is the duration of application of the force. The impulse changes the momentum of the objects on the cloth. F depends on the friction force, and this is nearly independent of the speed of movement of the cloth. Since the friction is proportional to the normal force (equal to the weight of the object), which is constant in all cases, the impulse depends only on the time, and if the time is short enough the impulse is small. The impulse is so small that the cloth is removed in a time shorter than that required for the objects to accelerate enough to fall.

Conclusion

Inertia is a property of mass, causing the objects on the table to remain in place when the cloth is pulled away suddenly.

Questions

What happens if you pull the tablecloth slowly? Why does the experiment work only when you give a sudden jerk? (A slow pull allows the tableware to overcome inertia.)

1.2 Experiment to illustrate inertia #2

Objectives

- Students can explain the difference between mass and weight (and impulse).
- Students can apply Newton's first law to situations in daily life.

Material needed

- Large drinking glass
- Plastic plate or piece of cardboard
- Small stone (or something similar such as a coin)
- Empty matchbox

Link with curriculum

Physics textbook: Grade 8, chapter 2, lesson 3, published 2008
Physics textbook: Grade 10, chapter 1, lesson 2, published 2008

Procedure

Start by asking your students if they can get the stone into the glass without touching it.

Put the glass on the table with the rim upwards. Put a plastic plate (or the piece of cardboard) on top of the glass. Next, put a small stone on top of an empty matchbox on top of the plate. Get a firm grip on the glass with one hand. Strike the edge of the plate or cardboard with your other hand. Make the blow hard and fast.

Observations

The plate flies into the air. The matchbox tumbles off and the stone falls into the glass.

Why will the stone drop into the glass when a force accelerates the card?

Explanation

Inertia again! Explanation is similar to the previous experiment.

Conclusion

Inertia is a property of mass, causing the ball on the bottle to fall inside the bottle when the cloth is pulled away suddenly.

1.3 Experiment to illustrate inertia #3

Objectives

- Students can explain the difference between mass and weight (and impulse).
- Students can apply Newton's first law to situations in daily life.

Link with curriculum

Physics textbook: Grade 8, chapter 2, lesson 3 (2008)
Physics textbook: Grade 10, chapter 1, lesson 2 (2008)

Material needed

- a few coins or similar

Procedure

Place one coin on your elbow. Hold your arm parallel to the floor or the coin will fall off. You are now going to catch the coin that is on your elbow. That wouldn't be much of a trick except for one thing: you are going to catch the coin in the hand of the same arm. Here's how to do it. In one sudden, very quick move you will drop your arm. This will cause your open hand to snap forward. At the same time, your elbow will fall away from under the coin.

After you have learned to catch one coin, add a second on top of the first. Then add three or four and catch them all at once!

Observations

As your elbow moves from under the coin your hand will come down from it. When you get the timing right, you will catch the coin every time.

Explanation

Since the coin is still, it tends to remain in that position. This is inertia working again! When your elbow moves rapidly, it just drops out from under the coin. This leaves the coin hanging in the air. Gravity pulls the coin toward the ground, but inertia gives it a slow start. Your hand is faster than the coin because your hand is already moving.

Conclusion

Inertia is a property of mass, causing the coin to fall more slowly allowing people to catch the coin with their hand.

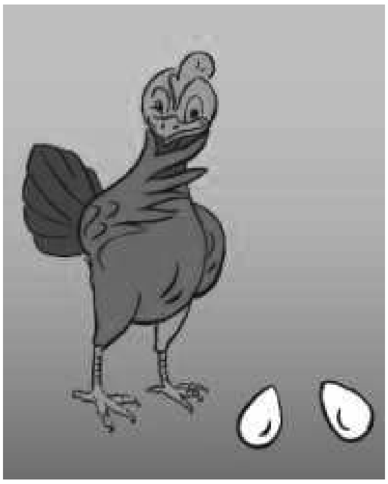
Question

Does the experiment work better with a heavy coin than with a light object? Why (not)?

1.4 Experiment to illustrate inertia #4

Objectives

- Students can explain the difference between mass and weight (and impulse).
- Students can apply Newton's first law to situations in daily life.



Material needed

- 2 eggs of the same size, one boiled, the other one raw.

Link with curriculum

Physics textbook: Grade 8, chapter 2, lesson 3 (2008)
Physics textbook: Grade 10, chapter 1, lesson 2 (2008)

Procedure

Show students the two eggs. Ask students how they could distinguish a boiled egg from a raw one. Collect some ideas.

Put both eggs on the table and have them rotate in giving them a short turn. Take the eggs and rotate them. The students mustn't know the difference between the two eggs beforehand. It's better to let them look for an explanation themselves. Once the eggs are turning, try to stop them by shortly touching them.

Observations

Do both eggs rotate in the same way? Which egg rotates more fluently? Which egg stops most easily? It looks like one of the eggs is drunk!

Explanation

The boiled egg rotates more fluently, because it is compact. The whole egg spins at the same speed as the shell. In the raw egg the yolk will remain at rest (inertia law, part 1), and resist the rotation. You have another situation when you get the raw egg rotating. Since the yolk is rotating, it will remain rotating (inertia law, part 2) even when the surrounding shell is stopped. Because of this the raw egg will starts moving again.

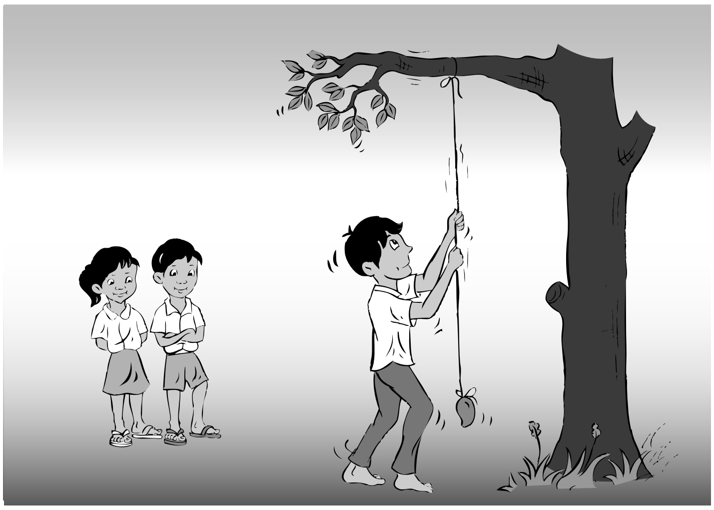
Conclusion

Inertia is a property of mass, causing the raw egg to resist rotation more strongly than the boiled egg.

1.5 Breaking threads and the difference between mass and weight

Objectives

- Students can explain the difference between mass and weight (and impulse).
- Students can apply Newton's first law to situations in daily life.



Material needed

- Hammer (or other heavy object)
- Approx. 1 m of cotton thread
- Short piece of string

Link with curriculum

Physics textbook: Grade 8, chapter 2, lesson 3, published 2008
Physics textbook: Grade 10, chapter 1, lesson 2, published 208

Procedure

This is a good experiment to review Newton's First Law with the students. Stimulate students to apply what they have learned and explain the experiment themselves (in groups).

Choose a hammer or other object that won't break if it's dropped. A heavy piece of wood will work just fine. Tie a loop of string around the hammer. Next cut the sewing thread in half. Make sure to use cotton thread because the experiment will not work with nylon thread. Tie the end of one piece of thread to the top of the string loop. Then tie the second piece of thread to the bottom of the loop.

Tie the loose end of the top thread to something solid so the hammer hangs below it. A tree branch is great, any strong support will work. Without a support, you can also ask a pupil to hold the setup at the loose end. Be sure there is nothing you can break or hurt below the hammer! After you have set up the experiment, get a firm grip on the bottom string. Then give a sudden hard pull downward.

Afterwards, repeat the experiment, but start pulling gently at the thread and gradually increase the pull.

Observations

The thread breaks somewhere between your hand and the hammer. The hammer will continue to hang from the top thread. In the second experiment the upper thread will break and the hammer will fall on the ground.

Why is it that a slow continuous increase in the downward force breaks the string above the weight but a sudden increase breaks the lower string?

Explanation

Note that only the top string bears the weight of the hammer. So, when the lower string is gradually pulled, the tension supplied by the pull is gradually transmitted to the top string. The total tension in the top string is caused by the pull plus the weight of the hammer. The top string breaks when the breaking point is reached.

However when the bottom string is pulled down suddenly the tension on the lower string increases to the breaking point in a very short time. As a consequence the hammer hasn't moved far enough to stretch the upper string enough to break it. The mass of the hammer, its tendency to remain at rest, is then responsible for the bottom string breaking. Although the hammer doesn't weigh much, it takes a lot of energy to get it moving when it is at rest. The big but very short force of the downward pull causes the lower thread to break.

Conclusion

Inertia is a property of mass. Objects will resist changes in movement in correspondence to their mass.

Questions

Why will a slow, continuous increase in downward force break the string above the hammer, while a sudden increase would break the lower string? (With a pull the hammer will tend to stay at rest – inertia part 1 – so it doesn't pull down and break the upper thread. With a gradual pull the hammer will be pulled downwards and the upper thread will break since it supports a greater weight.)

Which of the two cases illustrates the weight of the hammer, and which illustrates the mass of the hammer? (The sudden pull illustrates the mass and the gradual pull the weight.)

Does a 2-kg brick have twice as much inertia as a 1-kg iron brick? (yes) Twice as much mass? (yes) Twice as much volume? (yes) Twice as much weight? (yes).

1.6 Experiment to illustrate inertia #5

Objectives

- Students can explain the difference between mass and weight (and impulse).
- Students can apply Newton's first law to situations in daily life.

Material needed

- 5 small plastic bottles (from soda drinks)
- Sand
- Water
- Table

Link with curriculum

Physics textbook: Grade 8, chapter 2, lesson 3, published 2008
Physics textbook: Grade 10, chapter 1, lesson 2, published 2008

Procedure

Fill the first bottle with water, the second with sand, the third bottle half with sand and the fourth one half with water. The last bottle remains empty. Let the table slope. Let the two bottles with sand roll down the table at the same time. Then try the two bottles with water. Also compare the speed with which a bottle with sand and one with water run down the table. Finally, do the races again with the empty bottle.

Observations

Some bottles have a slow start and accelerate; other ones start faster, but are overtaken later. Which bottle wins the race depends on the length of the table.

Explanation

This is a good experiment to review Newton's First Law with the students. Stimulate students to apply what they have learned and explain the experiment themselves (in groups).

All this has to do with inertia. An object that is at rest, wants to stay at rest. (And an object that is moving wants to keep moving.) A heavier object (e.g. a full bottle) has a larger inertia than a lighter object (e.g. a half filled bottle). This means it has more difficulties coming out of rest and it will start more slowly.

There isn't only a difference between a filled bottle and a half filled bottle. There is also a difference in movement between the bottle that is half filled with water and the bottle that is half filled with sand. The water moves along the sides of the bottle while it is rolling, while most of the sand stays on one side of the bottle. So, the sand is sometimes in the top part of the bottle, sometimes in the lower part. In fact, the sand makes a rolling movement along with the bottle. The water doesn't have to be swirled around, it kind of slides down the table. The movement of the sand means a huge loss of energy which results in losing the bottle race.

Conclusion

The different bottles have a different inertia, causing them to roll down the slope at different speeds.

2. Newton's second law: acceleration and friction

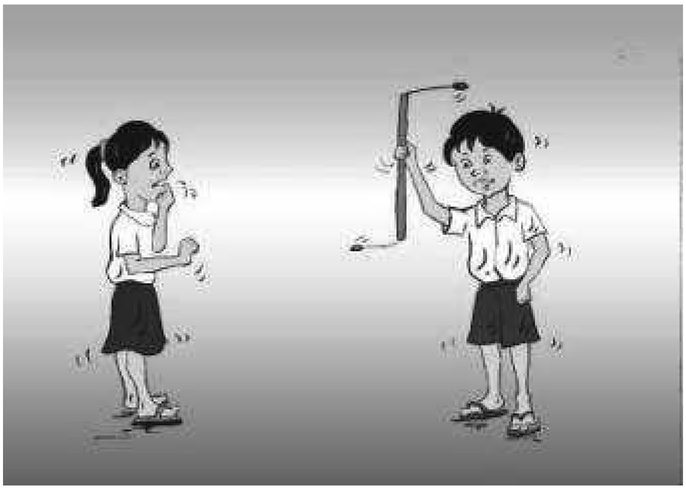
2.1 Centripetal force #1

Objectives

- Students can explain Newton's Second Law, including the existence of centripetal and centrifugal forces.
- Students can apply Newton's Second Law to situations in daily life.

Material needed

- A plastic tube (or a spool)
- A rope
- Two weights and one weight has to be approx. twice as heavy as the other one.



Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 2, published 2009

Procedure

- Pull the rope through the tube and attach a weight on each side.

- Hold the tube vertically with the heaviest weight at the bottom. Hold the tube in the middle with one hand and turn the upper weight round so it starts to move in circles. Whirl the spool around so both weights move as fast as possible. Gradually let go of the string below the tube.

Observation

The rope will become longer on the top side. The upper weight starts to make bigger circles. The heavy weight at the bottom is pulled up.

Explanation

The upper weight makes circles, therefore it needs a centripetal force ($F_{cp} \sim r$). This force is executed by the hanging weight. When there is equilibrium, the centripetal force is equal to the hanging weight. By increasing the speed, the lower weight is pulled up because the upper one asks more and more rope. Slowing down the motion gives again a new equilibrium. Following relations can be examined qualitatively:

- the bigger the radius of the circles, the bigger the centripetal force ($F_{cp} \sim r$),
- the faster the rotational speed (ω), the bigger the force ($F_{cp} \sim \omega^2$),

Conclusion

The centripetal force depends on the radius of the circle described and on the rotational speed.

2.2 Centripetal and Centrifugal force

Objectives

- Students can explain Newton's Second Law, including the existence of centripetal and centrifugal forces.
- Students can apply Newton's Second Law to situations in daily life.

Material needed

- Bucket or water bottle filled 1/3th with water (or can)

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 2, published 2009

Procedure

Be sure that the area above and around you is clear. Water will slosh out if your bucket gets bumped in mid-swing. Practice (outside!) before you do this experiment in front of an audience.
Start the bucket swinging gently from side to side, gathering speed. When you feel confident, swing the bucket up and over your head, and keep swinging it in circles in front of you, quickly enough that it makes it over the top of the swing without wobbling.

Observation

The water won't fall out at the top, as long as you swing

Explanation

If you were to let go of the rope at any point in the swinging arc, the bucket and the water would start traveling in a straight line *in the direction as it is released*. This is due to the inertia of the bucket and the water. Essentially, the bucket (and water) would travel off in a direction that is *tangential* to the circle at the point is released (see diagram). If the bucket was released, at the top it would start traveling along a horizontal line (see ‘path of water’ on the figure) (This can easily be visualized experimentally (but best without the water and a light object so nobody gets wet or hurt).

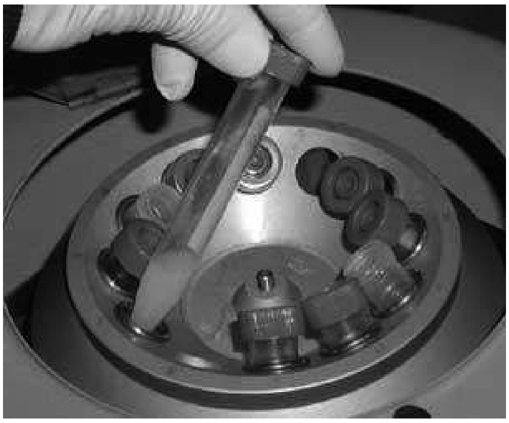
So at any point in the circle, the water is forced in the circular motion because of the sides of the buckets. The water is not long enough at the top of the movement to let the water fall out the bucket. However, when the water is at the top, the water is actually in the state of falling down pulled down by gravity. If you don’t believe this, just stop the movement of the bucket on the top and notice what will happen. During a normal swinging the bucket is moving fast enough to prevent the falling from really starting, keeping the water in a circular motion.

Conclusion

The water is kept in the bucket by the centripetal force ,which depends on the radius of the described circle and the rotational speed.

Application

A centrifuge works by swinging its contents around in a circle and using their inertias to make them separate. The various items in the centrifuge have different densities that affect their paths as they revolve around the centre of the centrifuge. Inertia tends to make each item go straight while the centrifuge makes them bend inward. There's a tendency for the denser items in the centrifuge to travel straighter than the less dense items. As a result, the denser items are found near the outside of the circular path while the less dense ones are found near the centre of that path.



Source: Wikipedia

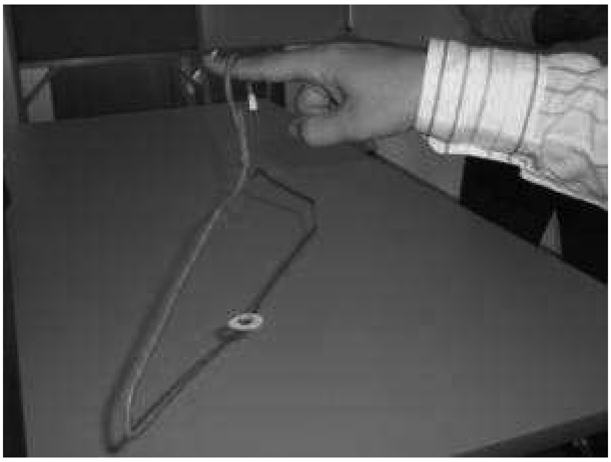
Questions

Can you explain this experiment using the centrifugal force? Do not forget to change from reference frame. Start moving around together with the water.

2.3 Centripetal force #2

Objectives

- Students can explain Newton’s Second Law, including the existence of centripetal and centrifugal forces.
- Students can apply Newton’s Second Law to situations in daily life.



Material needed

- a hook from a wire coat
- a coin
- a hammer or tape to flatten the wire

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 2, published 2009

Procedure

- Place the hook of a wire coat hanger over your finger

- Carefully balance a coin on the straight wire on the bottom directly under the hook. You may have to flatten the wire with a hammer or make a tiny platform with tape.

- Try to swing the hanger with the coin back and forth and then in a circle.

Observation

With a surprisingly small amount of practice you can swing the hanger and the balanced coin back and forth and then in a circle without falling down.

Explanation

The centripetal force holds the coin in place. This explanation is analogous to the previous two experiments.

Conclusion

The coin is kept in place by the centripetal force, which depends on the radius of the described circle and the rotational speed.

Questions

Make a drawing in which you explain why the coin doesn't fall down.

2.4 Rotating wheels to illustrate friction and Newton's Second Law

Objectives

- Students can explain Newton's Second Law, including the existence of centripetal and centrifugal forces.
- Students can apply Newton's Second Law to situations in daily life.

Material needed

- See picture
- Two wheels of equal size (from a bicycle) assembled next to each other on a wooden board, being able to rotate.
- Small wooden plank or plastic pipe

Link with Curriculum

Physics textbook: Grade 10, chapter 1, lesson 2, published 2008

Procedure

- Turn the wheels in the opposite direction (to each other).
- Repeat the action turning the other way round.

Observation

Ask the students to predict the movement of the tube before your start turning the wheels
In which direction will the pipe move?

a. The pipe alternatively moves to the right and to the left
b. The pipe falls down to one side

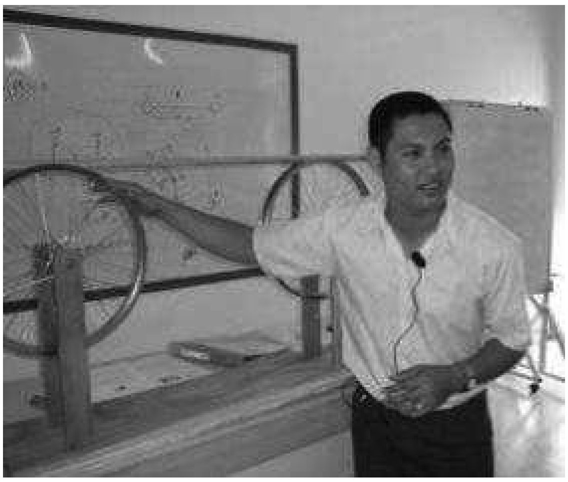
Explanation

The pipe is not exactly in the middle. Most of the weight will be on one wheel, so the friction force on that wheel will be the biggest and this wheel will have the best grip on the tube. This wheel makes the pipe move. Because of this movement the friction on the other wheel gets larger, so this wheel now generates motion.

The larger friction remains on the same wheel, so this wheel makes the pipe fall

Conclusion

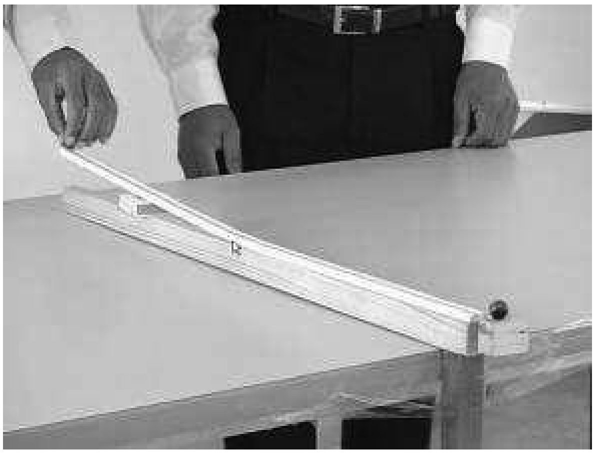
The back-and-forth movement of the tube is explained by varying sizes of the friction force and Newton's second law of motion.



2.5 Forces as Vectors

Objectives

- Students can apply the concepts of vectors and gravitational force.
- Students can explain why the two marbles hit the ground simultaneously.



Link with curriculum

Physics textbook: Grade 8, chapter 2, lesson 1, published 2008

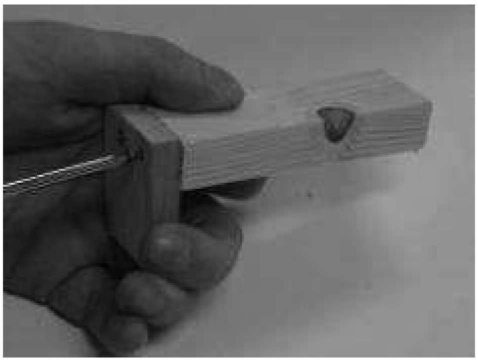
Material needed

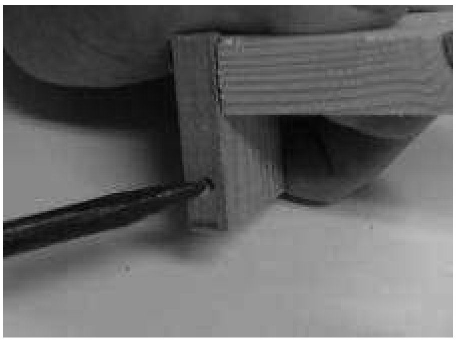
- 4 slats of wood (4cm, 5cm, 20cm, 60cm)
- a piece of curtain rail
- two marbles
- 6 screws
- a large nail
- a screwdriver

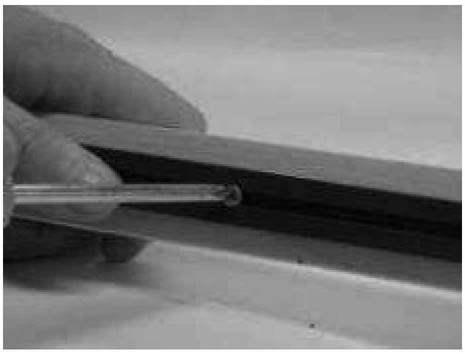
How to make the inclined plane:

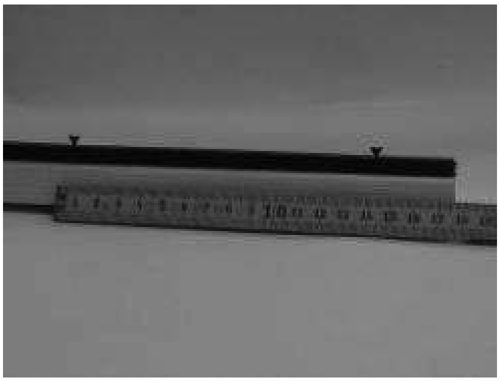
1. Fasten the small slat (4cm) onto the other slat (20cm) with two screws as shown.
2. Use the awl to make a hole in the upper part of the small slat, where you can put your marble.
3. Use the two remaining screws to fasten the curtain rail onto the long slat. Leave a distance of about 15cm between the screws.
4. Make sure that the end of the curtain rail corresponds with the end of the slat.
5. Make sure that there is just enough space for a marble to pass between the end of the long slat and the short slat.
6. Fasten the slat with the curtain rail to the 20cm slat.
7. Push the remaining slat under the curtain rail so as to obtain an inclined plane.
8. Put the marble on the hole that you have made for it.
9. Make a set-up as shown in the picture.


Picture 1

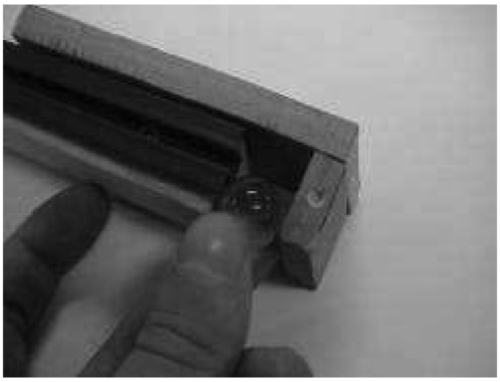

Picture 2


Picture 3

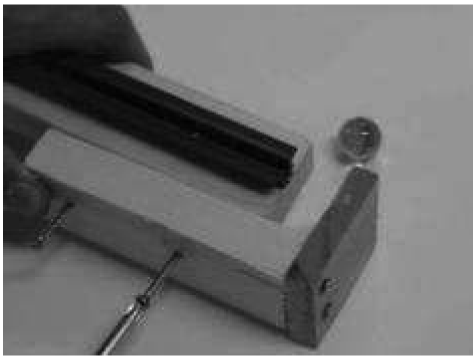

Picture 4



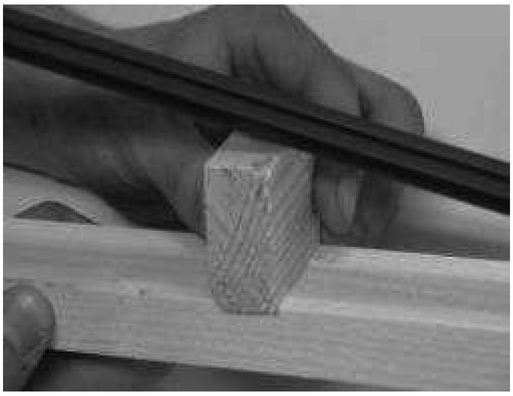
Picture 5



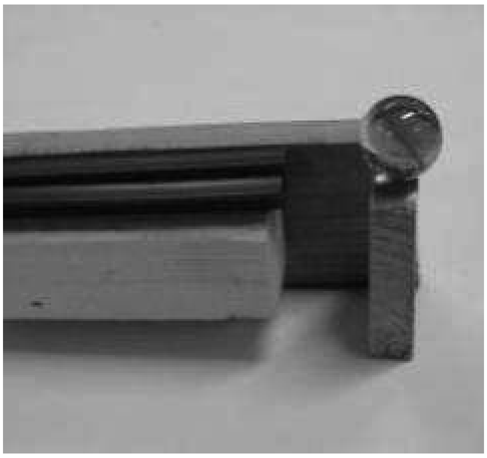
Picture 6



Picture 7



Picture 8



Picture 9

Picture 10

Procedure

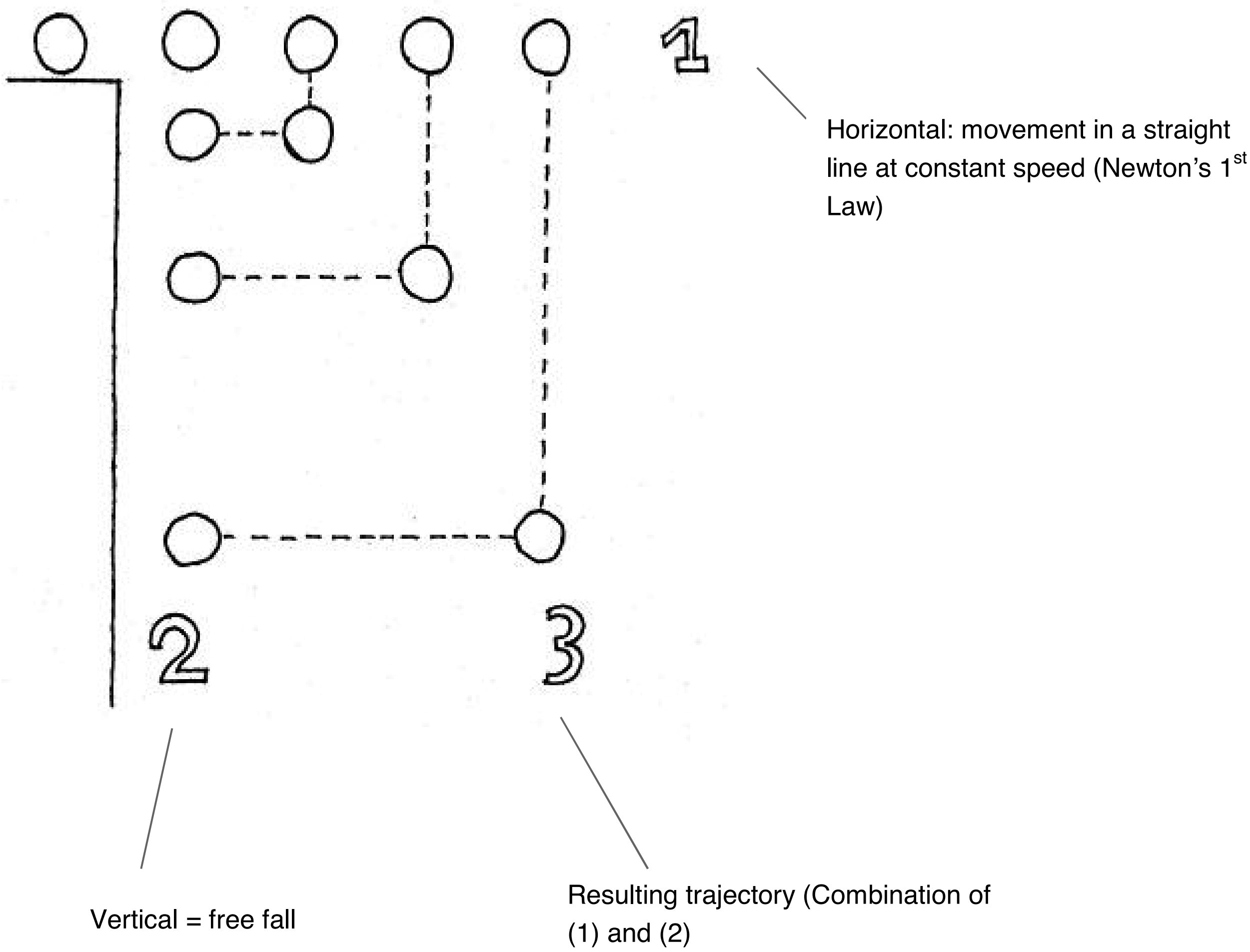
Ask students which marble will hit the ground first.

Observation

The two balls hit the ground simultaneously. Try to listen to the sound they make when they hit the ground.

Explanation

The marble that is shot away horizontally describes a *parabolic curve*, which can be subdivided into two parts (see picture):



The two components are independent of each other. The ball that falls vertically is subjected to a free fall only. This is the same movement as the vertical component of the first ball. They will therefore hit the ground simultaneously.

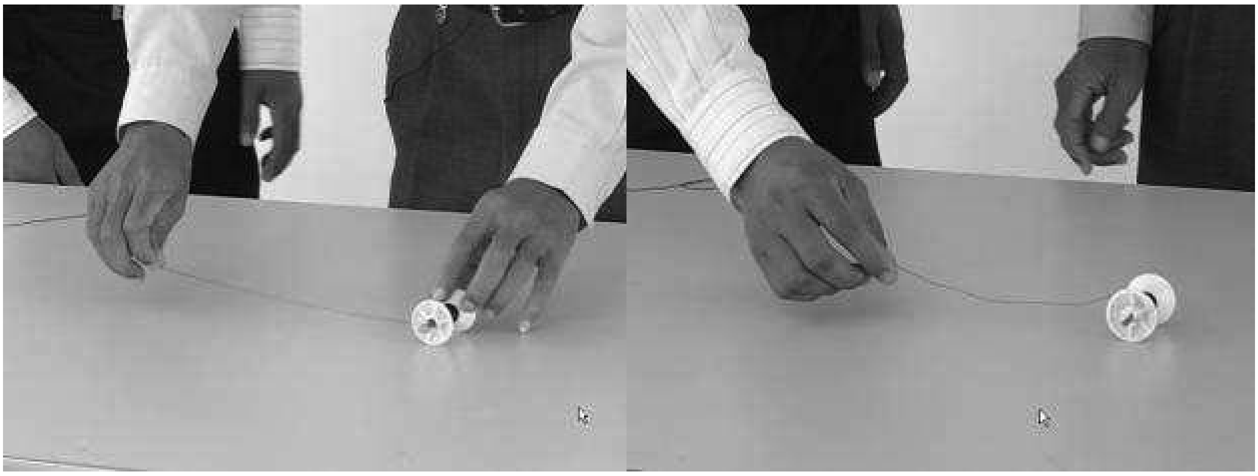
Conclusion

With an inclined plane the horizontal and vertical component of a force acting on a moving object can be investigated.

2.6 The Rolling Spool: Forces as Vectors

Objectives

- Students can apply the concepts of force vectors, friction and torque.
- Students can explain how torque causes the spool to rotate.



Material needed

- A spool with cotton thread or cord.

Link with Curriculum

Physics textbook: Grade 11, chapter 1, lesson 2, published 2009

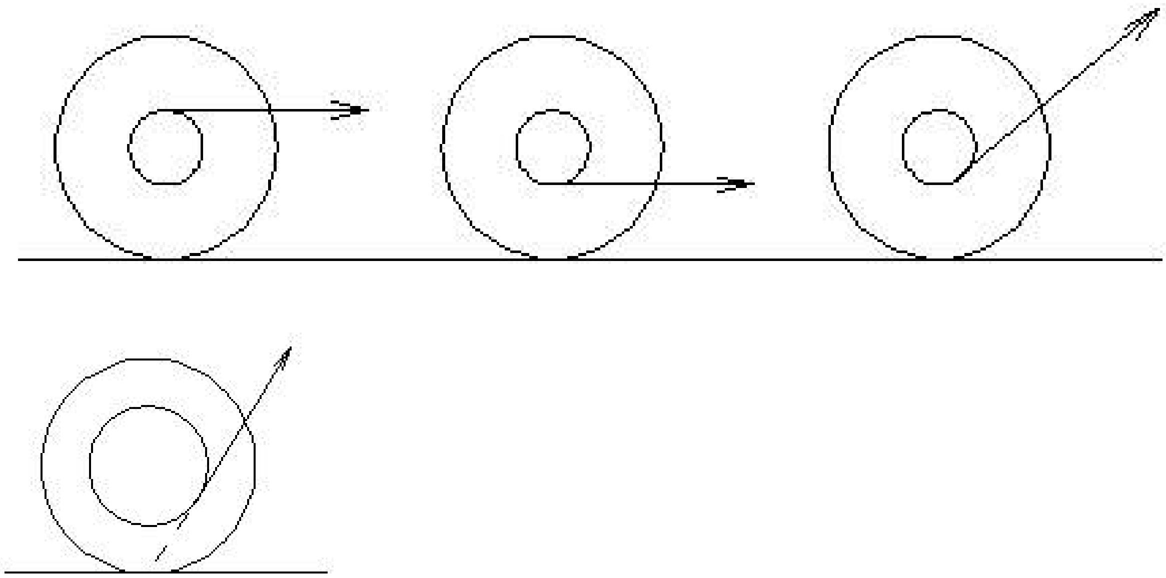
Procedure

Select a large spool and wrap several turns of ribbon or cord around it. Place the spool on a table so it can roll when the free end of the ribbon is pulled out from the spool bottom.

First put the spool on the table with the thread on the upside. Pull it.

Then put the spool on the table with the thread on the downside. Pull again.

Observe the direction that the spool rolls when the ribbon is pulled straight up and when it is pulled at other angles closer to the horizontal. (see picture below).



Observation

The spool will come rolling towards you in both cases. For non-horizontal angles and with a little practice, the spool can be made to roll in either direction as the ribbon angle is changed.

Explanation

The point of support for the spool is the spot where it touches the table. This can also be called the turning point. The effect of the force with which you pull, depends on the spot where you pull. In both cases, this point lies above the turning point. So, the force is the same in both cases: same direction (horizontally), same sense (towards you).

At a particular angle of pull the spool slides without rolling, if the angle is maintained as it moves. Ask students to determine, from physics principles (forces and torques), precisely how that angle can be predicted from the nature of the spool. Answer: The angle is such that a line extended along the ribbon passes exactly through the point of contact of the spool with the table, therefore the ribbon exerts no torque about that point. The force due to friction and the gravitational force mg also pass through that point, so the net torque about that point is zero, and no rotation can occur around that point.

Conclusion

Rotation is caused by torque, which depends on three quantities: the force applied, the length of the lever arm connecting the axis to the point of force application, and the angle between the force vector and the lever arm.

Questions

Encourage students to explain the phenomena using terms such as torque, friction, and vector direction of force.

3. Newton’s third law – action and reaction pairs

3.1 Experiment to illustrate Newton’s Third Law #1

Objectives

- Students understand that forces are interactions between different bodies
- Students can apply Newton’s Third Law to situations in daily life.
- Students can identify the resultant vector and net force that applies on an object.

Material needed

- Two equally long pieces of strong sewing thread

Link with curriculum

Physics textbook: Grade 10, chapter 1, lesson 2, published 2008

Procedure

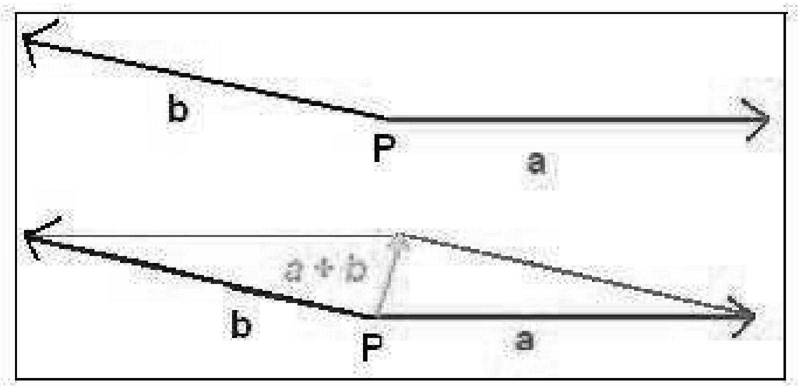
Each person holds a piece of thread with both hands and tightens it. The two threads should be crossed. The person who holds the upper thread now pulls it down fast. His or her aim is to break the lower thread which is firmly held tight.

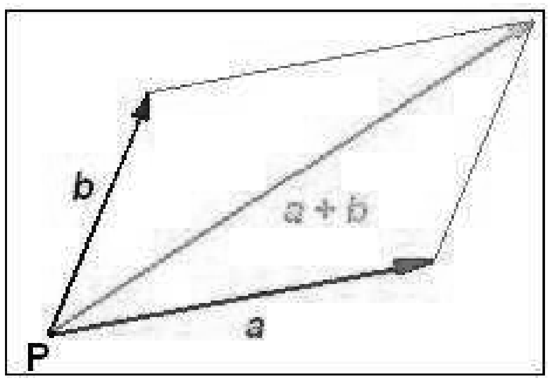
Observation

The upper thread breaks.

Explanation

Think about the net force that is exercised onto the point of contact between the two threads. The thread that has to put up with the largest net force will break. In fact, each thread experiences two forces, because it is pulled or held by two hands. Between these two forces there is an angle depending on the direction of the pulling forces of the hands. The sum of two forces is larger when this angle is smaller (see figure). The upper thread (of the person who pulls), has a significant smaller angle than the other thread (that has an angle of 180 degrees). This is why it will break.





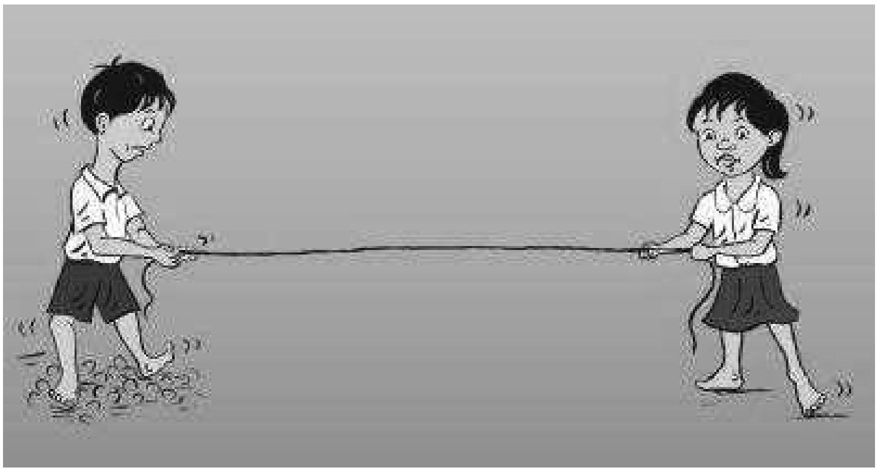
Conclusion

The strength of a force is determined by the resultant vector of the different force vectors.

3.2 Experiment to illustrate Newton’s Third Law #2

Objectives

- Students understand that forces are interactions between different bodies
- Students can apply Newton’s Third Law to situations in daily life.
- Students can identify the action and reaction force in a force system.



Material needed

- strong cord
- slippery floor (make the floor wet)
- 2 groups of at least one person. One group wears shoes, the other only socks.
- (balloon)

Link with curriculum

Physics textbook: Grade 10, chapter 1, lesson 2, published 2008

Procedure

- perform a tug-of-war

Observation

The group that wears shoes will win moving the other group to their side.

Explanation

Newton’s third law is necessary to understand this experiment.

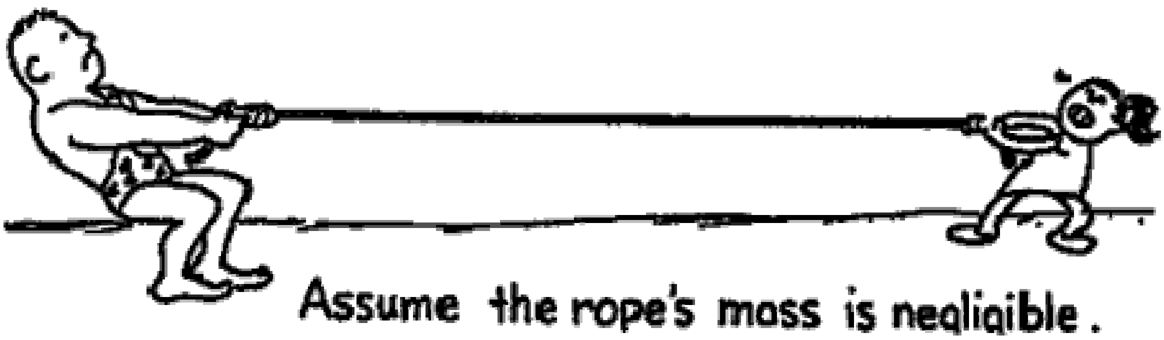
To win the game one group of students must pull harder to the rope than their opponents. The experiment proves that the students can only pull the rope effectively using the friction with the floor. How does this work? The students exert a horizontal force to the ground (in the opposite direction of the pulling) and as a reaction force they get the pulling force of the ground that they transmit to the rope. In reality it is the floor that is pulling (they are just pushing the floor to get the reaction force). Of course when the students do not have enough friction, they cannot push horizontally to the floor and they lose the game.

Conclusion

According to Newton’s Third Law of Motion an action force on an object generates an equal but inversely directed reaction force by that object. The force exerted by pulling the rope is equal to a friction force with the ground.

Questions

1. Who wins a tug-of-war, those that pull harder on the rope or those who push harder against the floor?



©Hewitt, 2005

The person on the left side can pull no harder on the rope than the person on the right. Rope tension is the same all along the rope, including the ends. Just as a wheel on ice can exert no more force on the ice than the ice exerts on the wheel, and just as one cannot punch an empty paper bag with any more force than the bag can exert on the puncher, Arnold can exert no more force on his end of the rope than Suzie exerts on her end. However, the person on the left can push harder against the ground, so he will likely win this tug-of-war.

Draw a scheme of the tug-of-war in which you indicate the action-reaction pairs that take place.

Take an inflated balloon. What happens if you deflate the balloon? Can you explain this using Newton's third law?

3.3 Make a rocket to illustrate Newton’s Third Law

Objectives

- Students understand that forces are interactions between different bodies
- Students can apply Newton’s Third Law to situations in daily life.
- Students can identify the action and reaction force .

Material needed

- A plastic bottle
- A cork with the valve of the tire of a bicycle in it
- A bicycle pump

Link with curriculum

Physics textbook: Grade 10, chapter 1, lesson 2, published 2008

Procedure

Close the bottle with the cork. Blow air into the bottle using the pump and valve.

Observation

The bottle flies away.

Explanation

More and more air is pushed into the bottle. The pressure inside becomes too big. The cork is pushed out of the bottle. A stream of air comes out which launches the bottle like a rocket.

Extra: Fill the rocket partly with water. Will the rocket go higher?

Conclusion

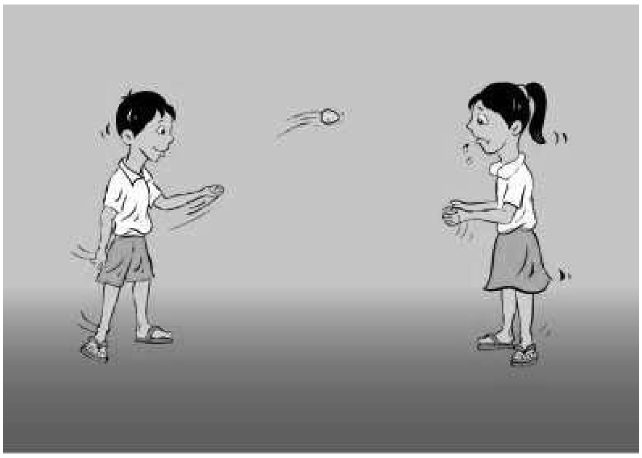
The experiment illustrates Newton's Third Law of Motion. Exerting a force in one direction, generates an equal but opposite force in the other direction.

4. Momentum and impulse

4.1 Experiment on Momentum and Impulse #1

Objectives

- Students can explain the difference between momentum and impulse in their own words.
- Students can apply the concepts of momentum and impulse to situations from daily life



Material needed

- Egg (can be a boiled one to avoid a mess when it's dropped)

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 4, published 2009

Procedure

- Throw an egg to a student from a distance of a few meters.

Observation

- Observe how the student catches the egg. Which technique is used to prevent breaking the egg?

Explanation

By moving the hands down when catching the egg you increase the time period to bring the momentum to zero. A longer time period means a lower impact force, preventing thus the egg from breaking.

Conclusion

Impulse is a change in momentum over time. A small force applied for a long time can produce the same momentum change as a large force applied briefly, because it is the product of the force and the time for which it is applied that is important.

Questions

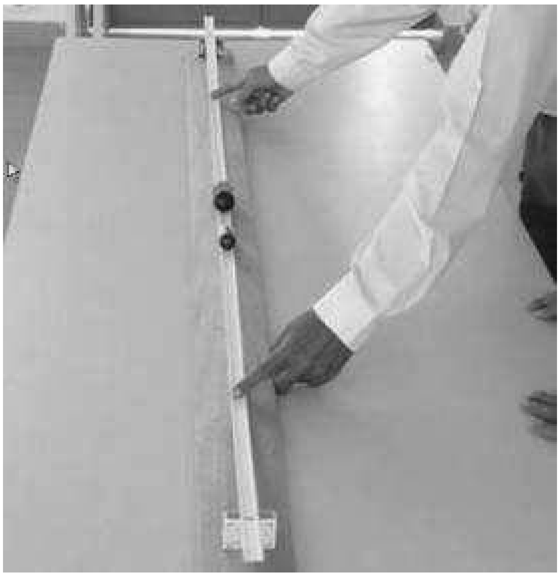
If you throw an egg against a wall, you'll break it, but, if you throw it with the same speed into a sagging sheet, it won't break. Explain using physics.

4.2 Experiment on Law of Conservation of Momentum

Objectives

- Students can explain the law of conservation of momentum in their own words.

- Students can apply the concepts of momentum and impulse to situations from daily life



Material needed

- marbles (different sizes)
- smooth (table) surface

Link with curriculum

Physics textbook: Grade 10, chapter 1, lesson 4, published 2009

Procedure

- Try out the following collisions:
    - 2 marbles of the same size and speed collide from opposite directions
    - 2 marbles of different size and speed collide from opposite directions
    - 2 marbles of the same size. The first one moves slowly and the second one moves faster.
    - 2 marbles of the same size. One strikes the other at rest head-on.

- 2 marbles of the same size. The small one strikes the big one at rest.

- Predict what will happen using the conservation law.

Observations

Observe each collision and try to explain your observations using the law of conservation of momentum.

Explanation

$(\text{Total momentum})_{\text{before the collision}} = (\text{Total momentum})_{\text{after the collision}}$

Conclusion

In an (almost) elastic collision between marbles the total amount of momentum is conserved, in accordance with the Law of Conservation of (Linear) Momentum.

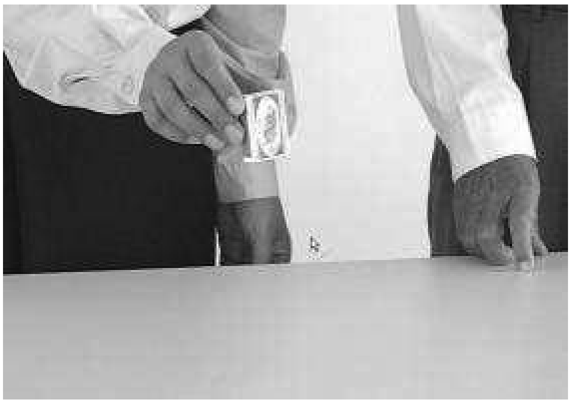
Questions

Can you determine for each collision the action and reaction pair?
Explain each collision using the mass and velocity of the balls.

4.3 Using a matchbox to explain momentum and impulse

Objectives

- Students can explain the difference between momentum and impulse in their own words.
- Students can apply the concepts of momentum and impulse to situations from daily life



Material needed

A matchbox

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 4, published 2009

Procedure

Start with asking your students to find a way to drop the matchbox in such a way that it doesn't turn over. Hold the box up above a table. Keep the distance between the box and the table at about 15 centimetres. Drop the box.

Observation

When you close the box before you drop it, the chance is large that the box won't stand straight up on the table. It will fall over. You have a better chance of succeeding at keeping it straight when you open it (upwards) a little before dropping it.

Explanation

This experiment demonstrates the notions of impulse and momentum. Momentum is inertia in motion.

The fundamental law is that the impulse (Force x time interval) = change in momentum

During both experiments the change in momentum is the same, giving rise to the same impulse.

With a closed box, the time interval of the collision is small, so a large force is created when the box lands. It is quite a shock. The box tumbles down. The time of collision is stretched when the box is slightly open. The outside of the box lands first and then the box closes, so the inside lands too. Although the impulse is the same as before, the force will be much smaller. A long shock is less heavy than a short shock with the same force. It takes the same impulse to decrease your momentum to zero. A longer time interval reduces the force and decreases the resulting deceleration.

By opening the matchbox the time of impact is increased and the force is reduced. For example, if the time interval is extended 100 times, the force is reduced to a hundredth. Whenever we wish the force to be small, we extend the time of contact.

When jumping from an elevated position, you bend your knees when your feet make contact with the ground. By doing so you extend the time during which your momentum decreases by 10 to 20 times that of a stiff-legged abrupt landing.

Similarly, if you want to catch a high-speed ball, you'll extend your hand forward so you'll have plenty of room to let your hand move backward after you make contact with the ball. You extend the time of impact and thereby reduce the force of impact. Another example is the crushable zone of a car. By extending the impact time during an accident the force on the car (and the passengers) is decreased.

Conclusion

Impulse is a change in momentum over time. By increasing the total time of impact, the force is reduced.

Questions

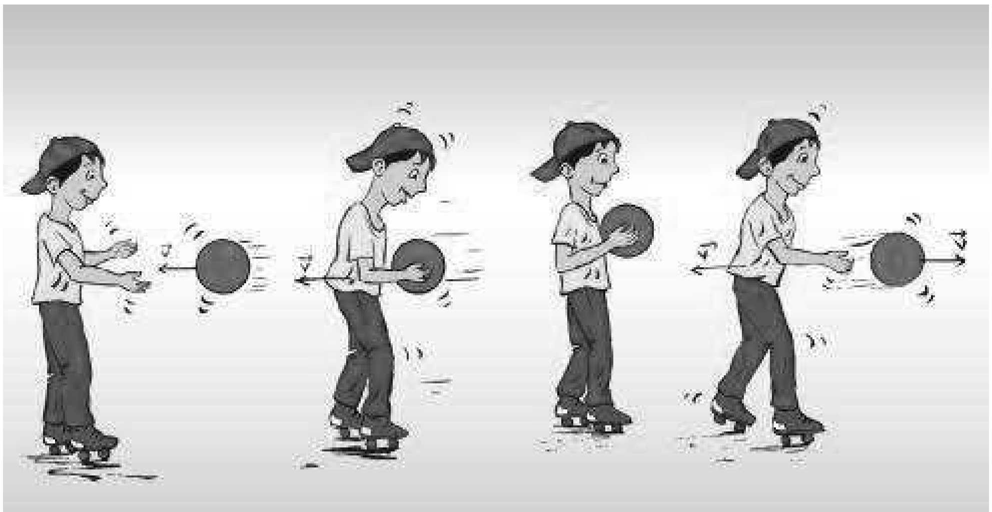
- When you jump from a 2-m high ladder, what do you prefer? A concrete floor or a haystack? Explain your answer using impulse and momentum. (The haystack allows you to spread your momentum change over a larger period of time, thus reducing the impact force.)

- When you jump from an elevated position down to the ground, you bend your knees when your feet make contact with the ground. Explain why you do this. (Bent knees will allow more time for momentum to decrease, therefore reducing the force of the landing.)

4.4 Experiment on Law of Conservation of Momentum

Objectives

- Students can explain Newton’s third law and the law of conservation of momentum in their own words.
- Students can apply Newton’s third law and the concept of momentum to situations from daily life



Material needed

- wooden rod with wheels attached underneath
- heavy ball

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 4, published 2009

Procedure

- a person standing on the rod throws a ball to a second person.
- The second person throws a ball to the person on the rod

Observation

The person on the rod will move backwards.

Explanation

According to Newton's third law, whatever forces you exert on the ball, they are balanced by equal forces that the ball exerts on you. In terms of momentum, when you give momentum to the ball, you will receive the same amount of momentum according to the law of conservation of momentum. The harder you throw the ball and the higher the mass of the ball, the faster you will move backwards.

Conclusion

In a closed system the total amount of momentum will remain constant in absence of external forces.

Questions

Why do you need a heavy ball? Does the experiment work with a light ball as well?

5. Equilibrium

5.1 Experiment on stable equilibrium

Objectives

- Students can explain the concepts of stable equilibrium, point of support and centre of gravity.
- Students can identify a situation of stable equilibrium
- Students can apply physics concepts on equilibrium to situations in daily life.

Material needed

- a ballpoint with clip
- a belt

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 6, published 2009

Procedure

Take the belt and shove the clip over the belt, about in the middle. Now have the ballpoint balance on one finger.
Put the ballpoint over the border of the table so that the belt is hanging at the side of it.

Observations

Does the ballpoint fall from your finger? From the table? No, the ballpoint won't fall.

Although one side of the belt is much heavier than the other side, the ballpoint doesn't fall.

Explanation

The buckle is the heaviest part of the belt so it's near the centre of gravity; the point of support is your finger. When the centre of gravity is under the point of support, there is a stable equilibrium.

Conclusion

A stable equilibrium is created when the centre of gravity lies below the point of support.

Application

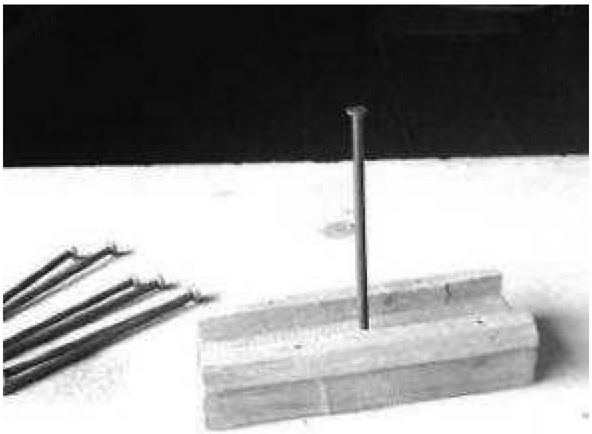
Cycling over a wire (see figure above).

There is a heavy weight under the wire, so the centre of gravity is lower than its point of support (here it is actually a support line formed by the line between the 2 contact points of the wheels with the cable). This makes it a lot easier for the person to maintain equilibrium. The cyclist can even move a little bit to the right and the left, it's a stable equilibrium so the bike always corrects its position.

5.2 Experiment with nails on stable equilibrium

Objectives

- Students can explain the concepts of stable equilibrium, point of support and centre of gravity.
- Students can identify a situation of stable equilibrium
- Students can apply physics concepts on equilibrium to situations in daily life.



Material needed

- a small wooden board
- a nail which is one cm driven into the rod (perpendicular),
- another 6 nails

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 6, published 2009

Procedure

Exercise this experiment a couple of times before doing in front of a class.

Give students the problem and let them try. Then the teacher takes over.

Try first to bring 6 nails into equilibrium on a table and put them afterwards on the 7th nail. Otherwise you will be short in hands!

In this way it should work: put one nail on the table. Put a nail on each end of this nail in a perpendicular direction, so the head supports on the nail below and the long end points at you. Now you repeat this but with the long ends pointing away from you. The last nail is put in the same direction as the first nail, on top of the others

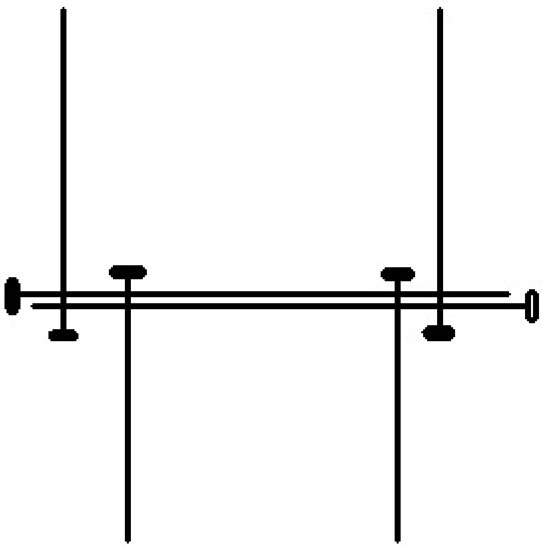
Now take the 6 nails and put them in the middle on the nail that is in the rod. If you do this in the middle then the nails are in equilibrium. You can even give it a slight touch, they won't fall.

Observations

Do the nails stay in equilibrium? What happens when you give a slight touch to the nails?

Explanation

The centre of gravity of the construction is under the point of support, meaning there is stable equilibrium.



Conclusion

A stable equilibrium is created when the centre of gravity lies below the point of support.

5.3 Experiment with tableware on stable equilibrium

Objectives

- Students can explain the concepts of stable equilibrium, point of support and centre of gravity.
- Students can identify a situation of stable equilibrium
- Students can apply physics concepts on equilibrium to situations in daily life.

Material needed

- a cork
- 2 forks
- a match
- a bottle

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 6, published 2009

Procedure

- push the forks and the match into the cork
- put the match on your finger
- put the match over the border of the bottle
- light the match

Observations

In situations a) and b) the construction is in equilibrium. In situation c) the match will stop burning when it has reached the border of the bottle and the construction remains in equilibrium.

Explanation

In either way the centre of gravity is under the point of support, so there is stable equilibrium. The point of support is the point where the 2 forks rest on your finger. Try to determine the gravity point of one fork by balancing it on your finger. If it's not falling, then the gravity point is just at your finger.

Conclusion

A stable equilibrium is created when the centre of gravity lies below the point of support.

5.4 Experiment on point of support and centre of gravity

Objectives

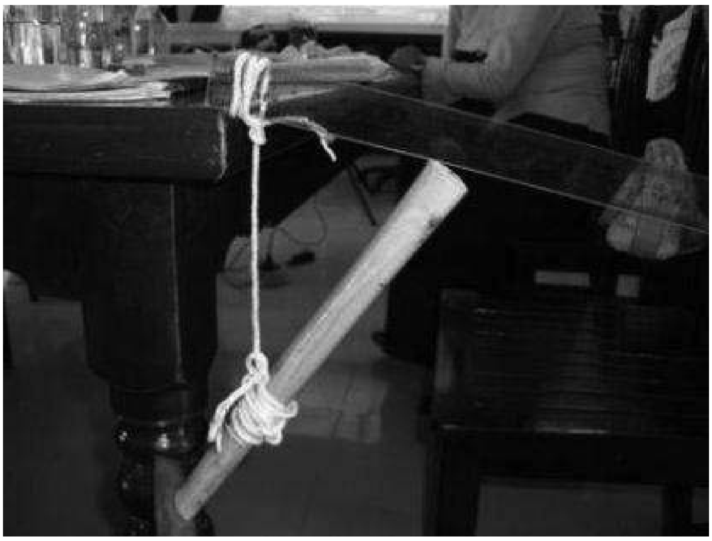
- Students can explain the concepts of stable equilibrium, point of support and centre of gravity.
- Students can identify a situation of stable equilibrium
- Students can apply physics concepts on equilibrium to situations in daily life.

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 4, published 2009

Material needed

- Hammer
- Piece of thread
- Table
- Ruler



Procedure

- Tie the end of the string around the ruler. Tie the other end of the string around the hammer handle. Tie it tightly so it won't slip up and down the handle. Now try to make things balance.
- Be sure the end of the hammer handle touches the ruler. Position the ruler so that a few cm of it are on top of the table. Carefully test the ruler and hammer to see if they are in balance.

- You may have to adjust the string to get the hammer to hang correctly. If you have problems getting things to balance, shorten the string between the hammer and the ruler. Don't give up if things don't balance first. They will when you adjust the string to the perfect length.

Observations

The hammer and the ruler are in equilibrium.

Explanation

You positioned the hammer and the ruler so that the centre of gravity is right at the edge of the table. If you look at things from one side, you'll see that the head of the hammer is on one side of the centre of gravity and the handle and most of the ruler is on the other.

Conclusion

A stable equilibrium is created when the centre of gravity lies below the point of support. The centre of gravity should be underneath the point of support.

Questions

Is this an example of stable or unstable equilibrium? Explain. (Stable since the centre of gravity is below the point of support.)

5.5 Experiment on unstable equilibrium #1

Objectives

- Students can explain the concepts of unstable equilibrium, point of support and centre of gravity.
- Students can identify a situation of unstable equilibrium
- Students can apply physics concepts on equilibrium to situations in daily life.

Material needed

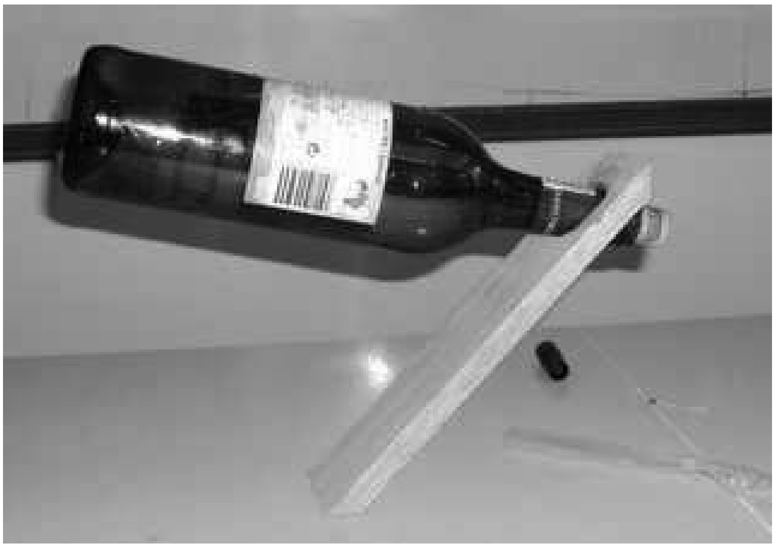
- an nearly full bottle (closed)
- a rod (approx. 45 cm long and 10 cm wide) the bottom of which has been sawn off obliquely (45°), with a hole (oblique in the same direction) in the upper part (approx. 11 cm from the top).

Link with curriculum

Grade 11, chapter 1, lesson 6

Procedure

- Put the rod obliquely on the table and shove the bottleneck through the hole
- Try to keep equilibrium.



Observations

- Are you able to keep the bottle in equilibrium?
- What happens if you disturb the equilibrium?
- Is it hard to get this equilibrium?

Explanation

Yes, you are. In this case the CG isn't under the point of support, but it is above it. When the CG is above the point of support perpendicularly, the construction is in unstable equilibrium.

When going over from experiments of stable equilibrium to those of unstable equilibrium, it's important to take the time to point out the differences:

- difference in reacting of a slight touch,
- difference on the position of the CG and the point of support.

Conclusion

When the centre of gravity lies above the point of support, there is unstable equilibrium.

5.6 Experiment on unstable equilibrium #2

Objectives

- Students can explain the concepts of unstable equilibrium, point of support and centre of gravity.
- Students can identify a situation of unstable equilibrium
- Students can apply physics concepts on equilibrium to situations in daily life.

Material needed

- a glass with some water
- a little fine salt or sand

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 6

Procedure

Exercise this experiment a couple of times before doing in front of a class.

Pile up the salt and put the glass on it obliquely. When the glass stands, try blowing away the grains.

Observations

Is the glass able to stand on its side? How can the glass stand oblique and why doesn't it fall?

Explanation

The point where the glass touches the table is the point of support. The centre of gravity is in the glass. Even now equilibrium remains because the CG is perpendicular above the point of support. There is unstable equilibrium. The grains of salt may help to set up the construction, but they aren't necessary. That's why you can blow them away, without making the glass fall.

Conclusion

When the centre of gravity lies above the point or plane of support, there is unstable equilibrium.

5.7 Experiment to illustrate concept of "Support Plane"

Objectives

- Students can explain the concepts of stable equilibrium, support plane and centre of gravity.
- Students can identify a situation of stable equilibrium
- Students can apply physics concepts on equilibrium to situations in daily life.

Material needed

- a man
- a woman
- a match box

Link with curriculum

Physics experiment: Grade 11, chapter 1, lesson 6, 2009

Procedure

Both persons sit on their knees and put the match box on its side in front of them at a distance of one forearm (from the contact point knee-elbow to the top of the fingers). Now the persons try to topple the match box on its side with their nose. They are not allowed to use their hands or move their knees.

Observations

Who is able to do this: the man, the woman or both? Look for the plane of support and the centre of gravity follow it during the movement. Once its position is not above the plane of support, the person can not keep his balance.

Explanation

A man has heavier shoulders and a woman has heavier hips. This means that the centre of gravity is positioned lower in the body of a woman. That's why women are able to do this experiment, while men aren't.

The centre of gravity does not move outside the base of support (past knees) as she bends with hands clasped behind her back. There is equilibrium as long as the perpendicular from the gravity centre crosses the support plane. Compare this law with the law "there is equilibrium as long as the centre of gravity is perpendicular to the support point." Both laws are basically the same, only here there is a plane of support.

Person will fall if CG moves outside the plane of the feet.

Conclusion

There is equilibrium as long as the perpendicular from the gravity centre crosses the support plane.

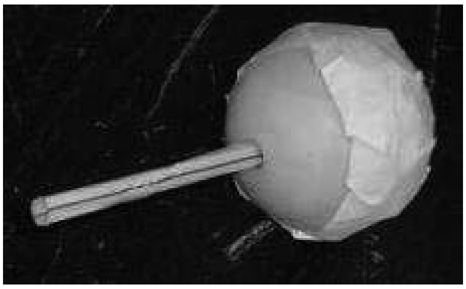
Alternative activity

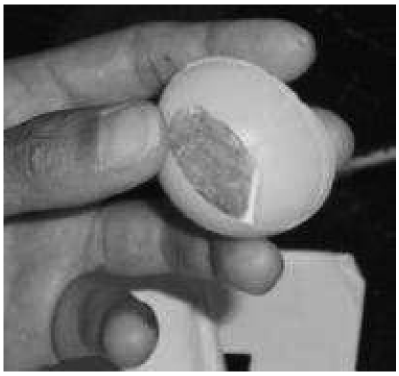
Stand with your heels and back against a wall and try to bend over and touch your toes.
You'll find that you have to stand away from the wall to do so without toppling over. Compare the minimum distance of your heels from the wall with that of a friend of the opposite sex.

5.8 Experiment on centre of gravity

Objectives

- Students can explain the concepts of stable and unstable equilibrium, point of support and centre of gravity.
- Students can identify a situation of stable and unstable equilibrium
- Students can apply physics concepts on equilibrium to situations in daily life.





Material needed

- A ping-pong ball cut into 2 halves; fill one half with clay or a little stone. If you use a stone, make sure it can‘t move anymore.
- Make a hole in the other half and put in a straw.
- Stick both halves to each other again.
- A small nail fitting in the straw. It’s nice when students cannot see the nail in the straw. This allows you to ask them to find an explanation themselves first.

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 6, published 2009

Procedure

- try to put the ball on the table with the straw vertically

- repeat the previous step with the nail in the straw
- repeat this, but with the straw resting on the table
- repeat the previous step with the nail in the straw

Observations

- success
- no success, the ball falls to a horizontal position
- no success, the ball returns to an upright position
- success

Explanation

When ball and straw are standing vertically, the centre of gravity is near the point of support (the point where the ball touches the table) because of the clay. In this way the ball is able to balance. The equilibrium is stable. With the nail in the straw, equilibrium is unstable.
When you hold the straw slanting, the ball without nail will overturn. The lower the centre of gravity, the more stable the equilibrium.

Conclusion

The closer the centre of gravity is to the point of support, the more stable the equilibrium.

Application

Racing cars are lowered in order to make them more stable.
Drinking cups for little children have a heavy bottom so they can wobble without falling over.

5.9 Experiment on friction and equilibrium

Objectives

- Students can apply physics concepts on equilibrium and friction to situations in daily life.

Material needed

Wooden meter stick (approx. 1m)

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 6, published 2009

Procedure

Hold the yardstick between two outstretched fingers as shown above.

Try to move one finger toward the centre of the yardstick. Move your finger slowly and steadily. It isn't correct to suddenly move your finger to the centre of the yardstick. Try to keep the other finger still.

What is the point where the two fingers meet?

Observations

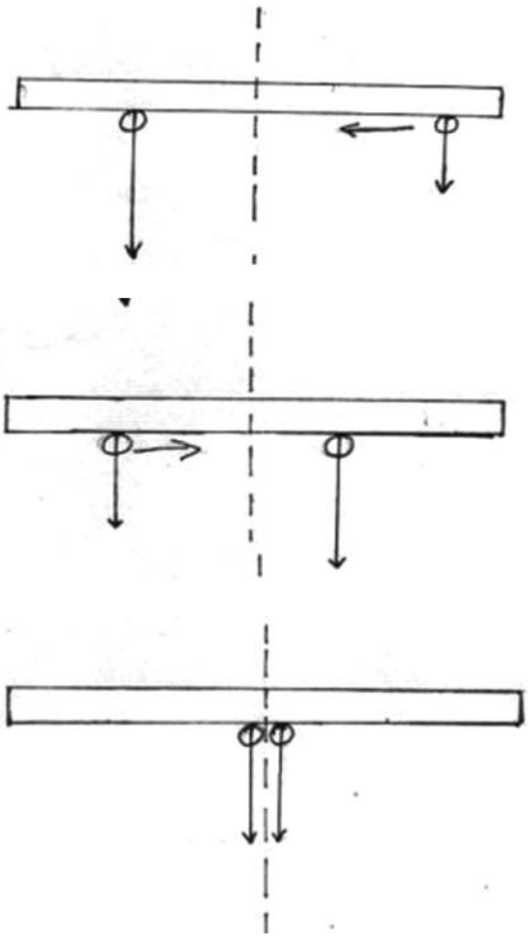
A strange thing happens as you move your finger towards the centre of the yardstick. You only move one finger along the yardstick, but the other finger moves along the stick too. Actually, it's the stick that starts to move over the finger at a certain point. Eventually you find yourself with both fingers side by side and the yardstick still balanced. Your fingers will meet at the centre of gravity.

Explanation

The yardstick's centre of gravity is right in the middle. When you slowly move one finger towards the centre of gravity the yardstick begins to tip towards that finger because that finger is nearer the centre of gravity.

When it tips, even slightly, it reduces the weight on the finger that isn't moving. When less weight presses on the unmoving finger, the yardstick begins to slide along that finger. This is because there is less friction on the still finger. The moving finger has more friction because more weight is on it.

The yardstick keeps rebalancing itself as your fingers slowly move toward one another.



Conclusion

Using friction and weight you can determine the centre of gravity of a stick.

Alternative activities

Repeat this experiment with a stick with a centre of gravity that’s not in the middle, e.g. with a weight

5.10 Experiment on centre of gravity #2

Objectives

- Students can explain the concepts of stable and unstable equilibrium and centre of gravity.
- Students can identify a situation of stable and unstable equilibrium
- Students can apply physics concepts on equilibrium to situations in daily life.

Material needed

- Small wheel or an empty can
- A weight (coin, stone…)
- Tape or glue
- Cardboard

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 6, published 2009

Procedure

- attach the weight inside the wheel or can
- It's best to close the wheel or can so the students do not see that it is tampered with.
- make a small inclined plane with the cardboard

- put the wheel or can in the middle of the slope, making sure that the weight is on top and a little to the higher part of the plane.
- let the students predict what will happen if you let go
- let go and be amazed

Observations

The wheel appears to be rolling towards the upper side.

Explanation

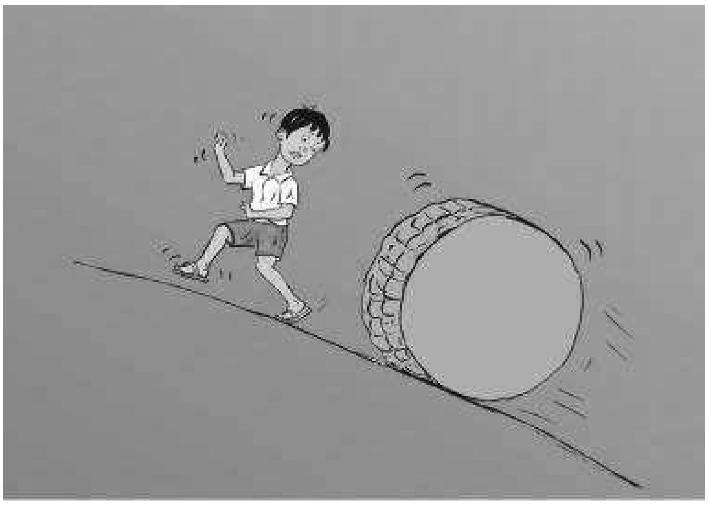
The centre of gravity of an object always moves downwards.

By adding a weight, we move the centre of gravity to the top right.

Although the wheel (apparently) rolls towards the upper side, the centre of gravity moves downwards.

Conclusion

The centre of gravity of an object always moves downwards, but this can mean that a wheel rolls upwards.



6. Rotation

6.1 Torque and force

Objectives

- Students can explain the difference between torque (related to rotation) and force.
- Students can apply torque and force in situations from daily life.

Material needed

- a wooden or metal ruler (30 cm or 50 cm)
- a movable weight attached to the ruler

Link with curriculum

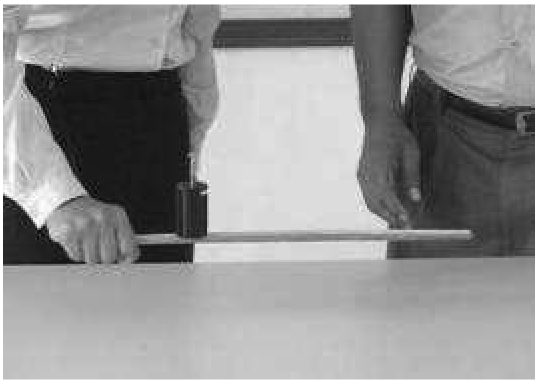
Physics textbook: Grade 11, chapter 1, lesson 2, published 2009

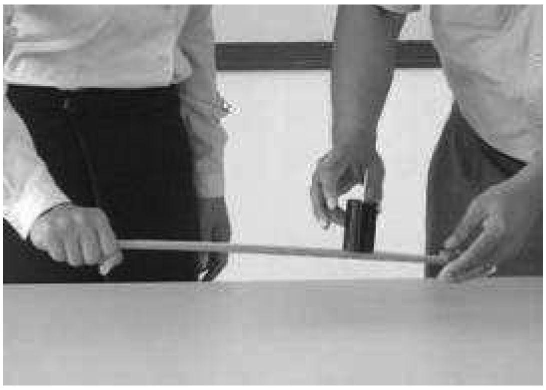
Procedure

- hold the ruler with the weight attached
- move the weight away from your hand. What do you notice?

Observations

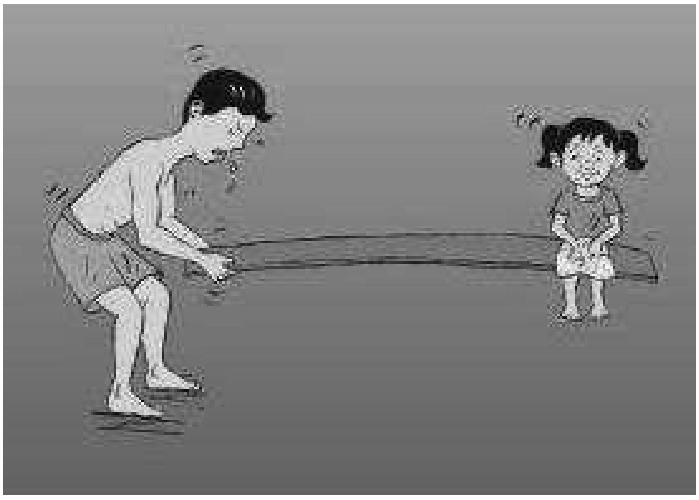
When you move the weight away, you can feel the twist is greater.





Explanation

The force acting on your hand is the same. What's different is the torque, since the lever arm has increased. Torque is the product of the lever arm and the force.



Conclusion

Torque is the product of the lever arm and force. The longer the lever arm the higher the torque exerted on your arm and the more difficult to carry the weight.

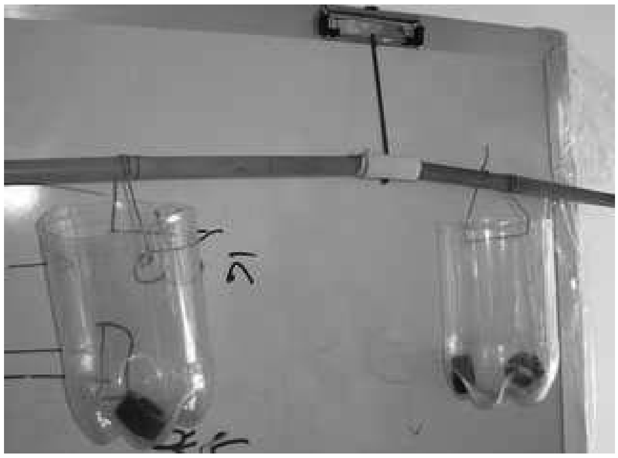
Questions

- What happens with the force when you move away the weight?
- Why do you have more difficulty holding the ruler?

6.2 Balancing weights

Objectives

- Students can explain the difference between torque (related to rotation) and force.
- Students can apply torque and force in situations from daily life.



Material needed

- a wooden stick with a length of over 1 meter
- a thread or hook
- two baskets (cut off plastic bottles), with a rope attached so that they can hang.
- some equal weights (e.g. marbles, nails)

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 6, published 2009

Physics textbook: Grade 8, chapter 4, lesson 1, published 2008

Procedure

Before the experiment

Mark the exact middle of the stick and attach a thread or hook at that point, so that the hook can not easily move.

Draw a line on the stick every 10 centimetres, starting from the middle, *During the lesson:*

Fill the baskets or sacks with an equal amount of weights and hang them on the stick at an equal distance from the middle, on both sides (e.g. 30 centimetres from the middle).

Pick up the stick using the thread or hook that is attached to the middle.

Now add a weight to the right basket.

Let the students think about how they should hang the baskets when the two baskets are filled with an equal amount of weights and then when one is only filled with half the amount than the other.

Observations

In the beginning, the stick has reached a balance. This balance is lost when the extra weight is added. The stick goes down on the side with more weight. Try to restore equilibrium <u>without</u> removing weights.

Explanation

When the weight and the distance to the point of support are equal on both side there is balance. When weight is added to one side, the balance is lost. There is a way to restore it without adding or removing weight into the lightest basket.

The construction will be in balance when the products of the weight and the distance to the point of support are equal on both sides. So, if you move the lightest basket or sack away from the middle (you make the distance to the point of support larger), balance can be restored.

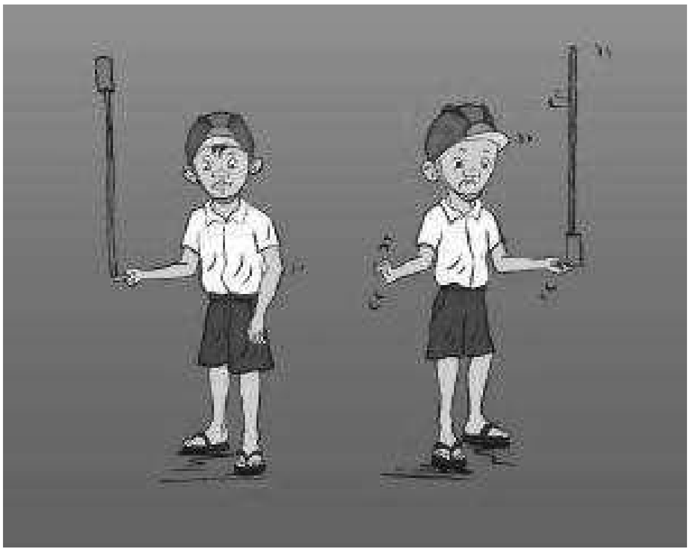
Conclusion

Weight x weight-arm = force x force-arm. A lighter object can be in balance with a heavier object if its distance to the point of support is higher.

6.3 Experiment with a broomstick on centre of gravity and rotational inertia

Objectives

- Students can explain the relation between the gravity centre and the rotational inertia of an object.
- Students can apply torque and rotational inertia in situations from daily life.



Material needed

A long stick (e.g. from a broom) with a wooden board or a weight attached. It can also be done with a hammer, but the longer the object the clearer your observations.

Link with curriculum

Physics textbook: Grade 11, chapter 3, lesson 2, published 2009

Procedure

Let students predict which will be easier: balancing the stick (or the hammer) with the weight on top or with the weight at the bottom.

Try to hold the stick vertically on your finger:

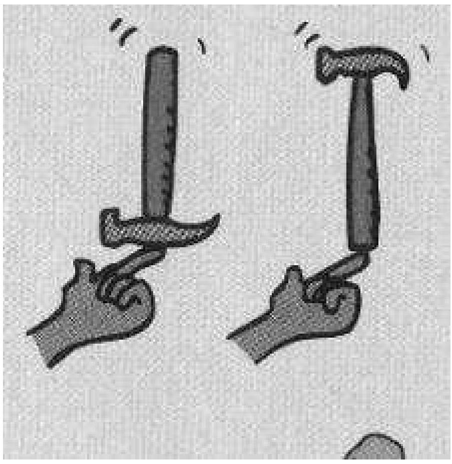
- with the weight at the top
- with the weight at the bottom

Observations

Are you able to keep the stick in equilibrium? In which situation is it easier?

Explanation

It is best to keep the weight at the top. The rotational movement of the sticks is the best explained using the rotational inertia. When the gravity centre is at the top the distance to the rotation point (the point where you finger touches the stick) is greatest, then the stick has a bigger rotational inertia so it resists more a rotational change. This means you have more time to restore the balance. So, the rotational inertia is higher when the gravity point is far from the rotation point.



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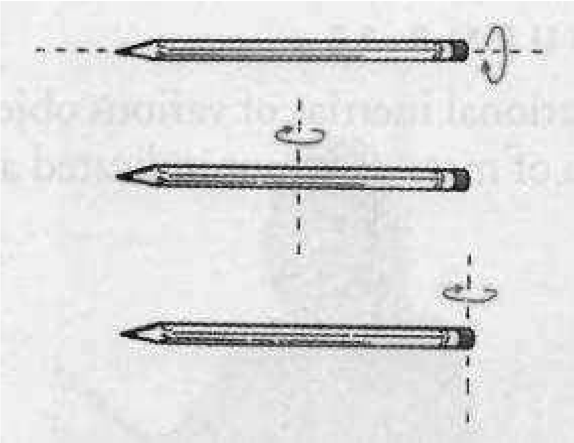
An artist walking on a rope uses the same principle. Often he will use a long stick or at least spread his arms out. By doing this, more of his mass is far from the axis of rotation, its midpoint, so increasing his or her rotational inertia. If the artist starts to topple over, a tight grip on the pole rotates the pole. But the rotational inertia of the pole resists, giving the artist time to readjust his or her balance. The longer the stick, the better.

Conclusion

Attaching the weight to the top of stick increases the distance between point of support (or axis of rotation) and the centre of gravity. The higher this distance the bigger the rotational inertia.



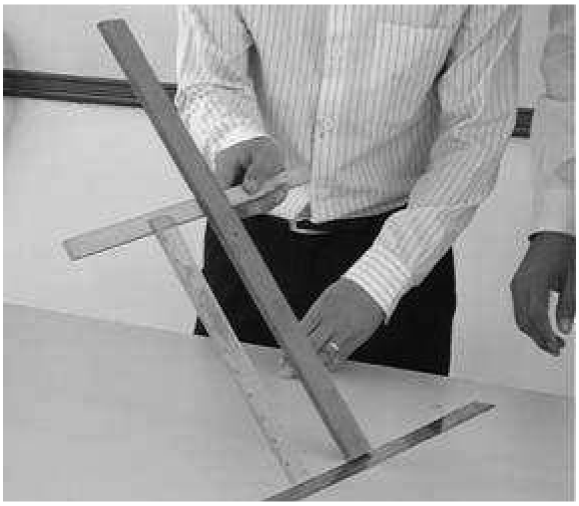
Questions

Compare the different rotations of a pencil (see figure below). Which is easiest to rotate? Determine for each one the axis of rotation and assess the rotational inertia. Where the inertia is highest and where is it lowest?
(Rotational inertia is very small about the first position. It's very easy to rotate the pencil between your fingertips, because most of the mass is very close to the axis. With the second axis, the rotational inertia is greater. With the third axis, most of the mass is far from the axis so the rotational inertia is greatest.)

6.4 Experiment with ruler and yardstick on centre of gravity and rotational inertia

Objectives

- Students can explain the relation between the position of the centre of gravity and the rotational inertia of an object.
- Students can apply the relation between the distance between point of support (or axis of rotation) and the centre of gravity to situations from daily life.



Material needed

- Yardstick (approx. 1m)
- Ruler (approx. 30 cm)

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 2, published 2009

Procedure

- Begin by standing a ruler and a yardstick side by side with a few centimetres between them. Steady each of them with just the tip of your finger. If you don't have a ruler and a yardstick, two straight pieces of wood will work perfectly.
- Lean the ruler and the yardstick forward just a tiny bit to make sure both of them will fall in the same direction. Be sure they both have the same amount of forward lean. Then let go.

Observations

The ruler will win the race to the ground every time!

Explanation

The centre of the balance for the yardstick is higher than it is for the ruler. The farther that centre of balance is from the ground the higher the rotational inertia (is proportional with the square of this distance). Therefore, the yardstick will take longer to complete its fall because it resists more the rotational change.

That does not mean that a high centre of gravity makes an object steadier than one with a low centre of gravity. Just the opposite! Automobile and motorbike manufacturers try to keep the centre of gravity as low as possible so that cars are less likely to tip over.

Conclusion

The higher the distance between point of support (or axis of rotation) and the centre of gravity. the bigger the rotational inertia.

6.5 Game on Equilibrium and Torque

Objectives

- Students can explain the difference between torque (related to rotation) and force.
- Students can apply torque and force in situations from daily life.

Material needed

- a bottle (filled with sand)
- a round, flat plate
- some small unbreakable objects (e.g. some small stones) to put on the plate
- a small ball (e.g. ping pong ball) to be put on the bottleneck

Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 6, published 2009

Procedure

- put the ball on the bottleneck
- distribute the objects on the plate and put it on the bottle in equilibrium
- now carefully take the objects from the plate one by one and try not to make the plate fall down

The person, who causes the plate to fall, loses the game.

Observations

Does the plate immediately lose its balance or does it depend on the object you take away? Try to identify a rule to predict when the plate loses its balance or not.

Explanation

Torque = lever arm (here: distance between stone and support point) x force (here: the weight of the stones)

Stones far away from the support point have a higher torque and thus cause a bigger change in the torque of the system. To keep equilibrium you have to take the lightest object closest to the middle away.

Conclusion

You have equilibrium when the <u>net torque on a system is zero</u>.

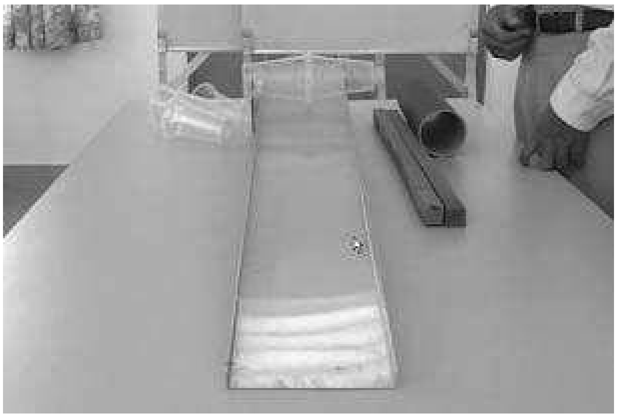
Question

Take 2 stones with the same weight. Use physics concepts to explain why taking one stone close to the support centre affects the equilibrium less than taking one far from the centre.

6.6 Experiment on Rotational Motion

Objectives

- Students can explain the difference between tangential and rotational speed.
- Students can apply principles of rotational motion in situations from daily life.



Link with curriculum

Physics textbook: Grade 11, chapter 1, lesson 7, published 2009

Material needed

- Two paper or plastic cups. The diameter of the bottom should be smaller than the diameter of the top.
- Two identical wooden sticks, for example rulers that can be placed on their side.

Procedure

Start the experiment with asking students why a moving railroad-bounded train stays on the tracks? Tell them to use the principles of rotational motion. Collect answers and then do the experiment.

- Fasten a pair of cups together at their wide ends by taping them together.
- Roll the pair along a pair of parallel tracks
- Try to roll them off centre

Observations

The cups will remain on the track and centre themselves whenever they roll off.

Explanation

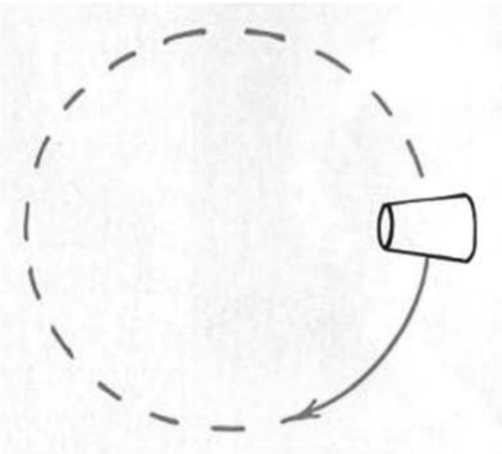
The wider part of the cup experiences a higher tangential speed than the smaller part. This causes the cup to roll in a curve (picture 1). For example, when the pair rolls to the left of centre, the wider part of the left cup rides on the left track, whereas the narrow part of the right cup rides on the right track. The wider part of the cup has a greater radius, rolls at a greater distance per revolution and therefore has a bigger tangential speed. This difference in velocity steers the pair back towards the centre. So, it is the difference in tangential speeds that causes the pair to self-correct toward the centre of the track.

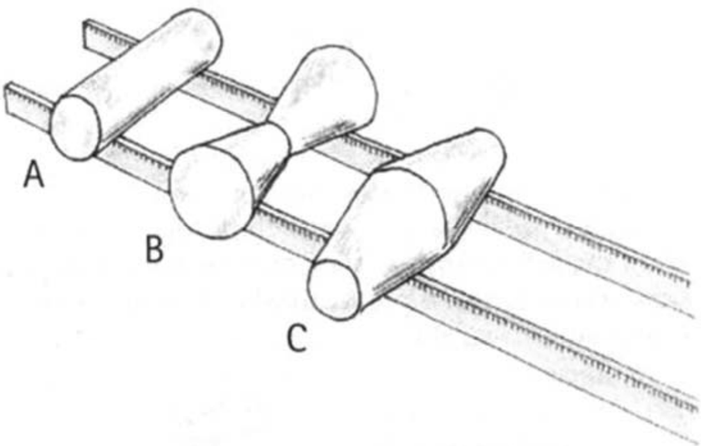
Conclusion

The higher the diameter, the higher the tangential speed, which is determined by the distance covered per revolution. This is the difference between tangential speed and rotational speed, which is independent of distance covered per revolution.

Questions

Railroad train wheels have a shape similar to the paper cups: wider toward the middle. Try to explain why this is important. The shape also allows the train to ride along curves. Explain.



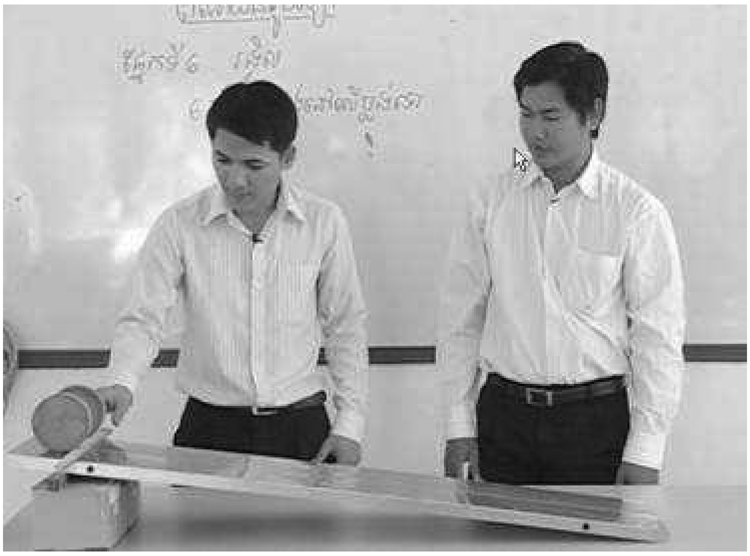


If you would tape the cups together at their narrow ends, would the pair of cups self-correct or not, when rolling slightly off centre (option B in the picture above)?

6.7 Experiment on rotational inertia

Objectives

- Students can explain why the hollow cylinder rolls down the inclined plane more slowly.
- Students can apply the concepts of rotational inertia and its dependence on the distribution of the mass around the axis of rotation to situations in daily life.



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Link with curriculum

Physics textbook: Grade 11, Chapter 1, Lesson 7, published 2009

Material needed

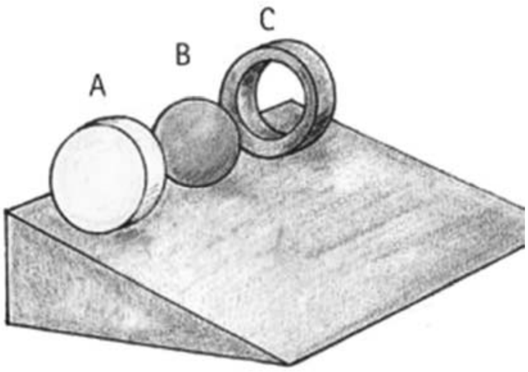
- 2 wooden cylinders: one hollow cylinder and one solid cylinder (weight and diameter can be different)

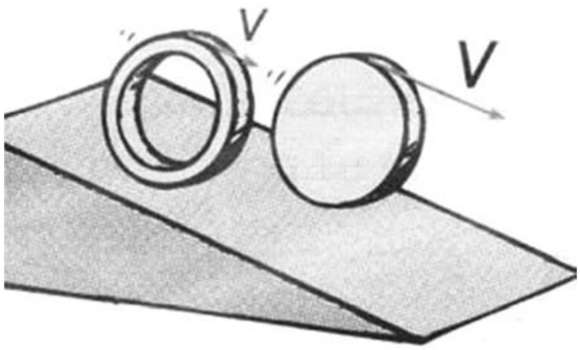
Procedure

Let the cylinders roll down a slope.

Observations

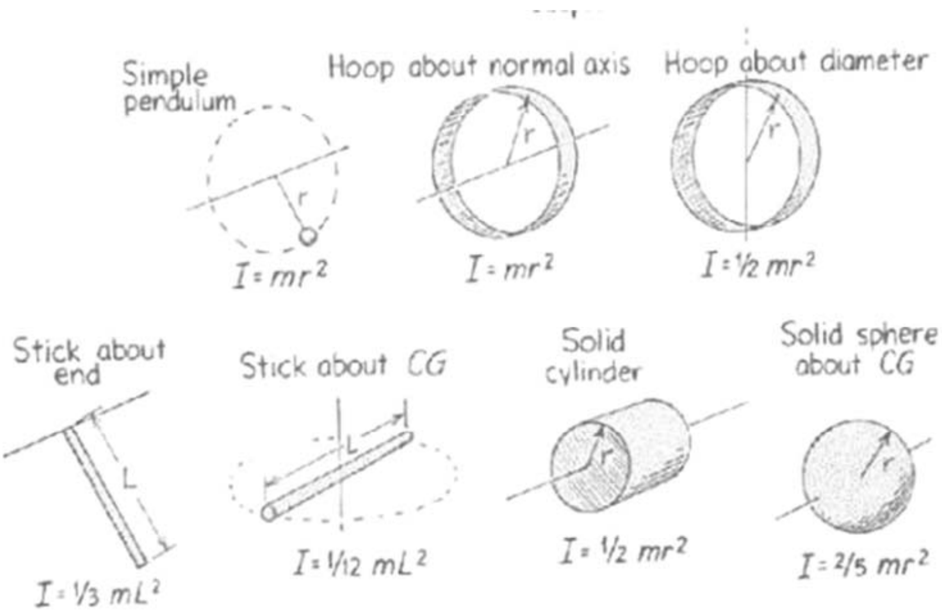
The hollow cylinder rolls down slower.





Explanation

The rotational inertia is dependent on the distribution of the mass around the axis of rotation. The greater the distance between an object's mass concentration and the axis of rotation, the greater the rotational inertia.



Conclusion

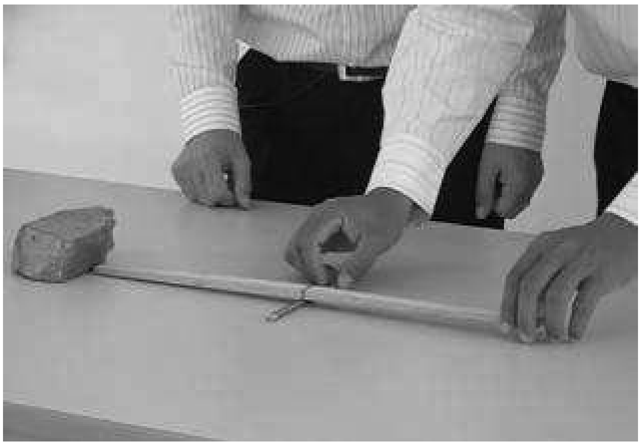
The greater the distance between an object's mass concentration and the axis of rotation, the greater the rotational inertia.

7. Energy and simple machines

7.1 Simple Machines: Lever

Objectives

- Students can apply concepts of work, energy and the conservation of energy to a lever.
- Students can recognize examples of levers in daily life.
- Students can draw force diagrams to explain how levers work.



Material needed

- ruler (30 cm or 50 cm, wood or hard plastic, not flexible)
- Stone or similar heavy object
- Pencil

Link with curriculum

Physics textbook: Grade 8, chapter 4, lesson 1, published 2008

Procedure

1. Lift the rock to get a feeling how big a force you need to lift it.

2. Place the pencil on a flat surface with the ruler on top so that the pencil is at the centre of the ruler.
3. Put the rock on top of the ruler at one end
4. Push down the free end of the ruler so the rock rises up. Compare the force you need with the force you needed to lift the rock directly. Also compare the distance you push the ruler down with the distance the rock is lifted.
5. Reposition the ruler and pencil so the pencil is closer to the rock and repeat the same steps.

Observations

1. Each time you use the ruler to lift the rock; the ruler changed the direction of the force you exerted. You pushed down, the rock went up. This is one thing simple machines can do, they can change the direction of the force you apply.

2. When the pencil is near the rock end of the ruler, it’s much easier than when the pencil is near the other end. When the pencil is in the middle of the ruler, you have to push about as hard as you would have to in order to lift the rock directly.

Explanation

By lifting the rock you did work on the system (consisting of the pencil, the ruler and the rock). This work was mainly used to increase the gravitational potential energy of the rock (a minor percentage went into the kinetic energy of the ruler and thermal energy of the system).

Because of energy conservation one can state that:

the work input = work output

or

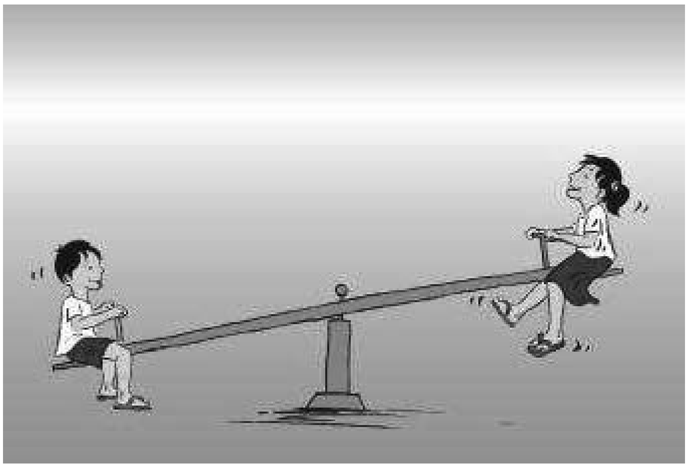
$F_1.d_1 = F_2.d_2$

F_1 equals the force exerted by you on the ruler, d_1 is the distance your end of the ruler moves, F_2 is the force exerted by the ruler on the stone and d_2 is the distance the rock moves. Notice that the distance moved in each case is in the direction of the applied force.

Unfortunately, though, you don’t get something for nothing. In order to get that increase in force, there is a trade-off in the distance. You had to push the ruler down further than the rock went up. A trade-off between force and distance is the basis for the operation of all simple machines.

Application

A pair of *scissors* is actually two levers that move in opposite directions. The place where the two parts are joined takes the place of the pencil. We call this point the fulcrum. When cutting paper, you want the force exerted on the paper to be bigger than the force you exert on the scissor. To achieve this, you need to place the paper close to the fulcrum of the scissors. At this position you move the handles much farther than the parts of the lever near the fulcrum.



Conclusion

Levers can be used to exert a large force over a small distance at one end by exerting only a small force over a greater distance at the other.

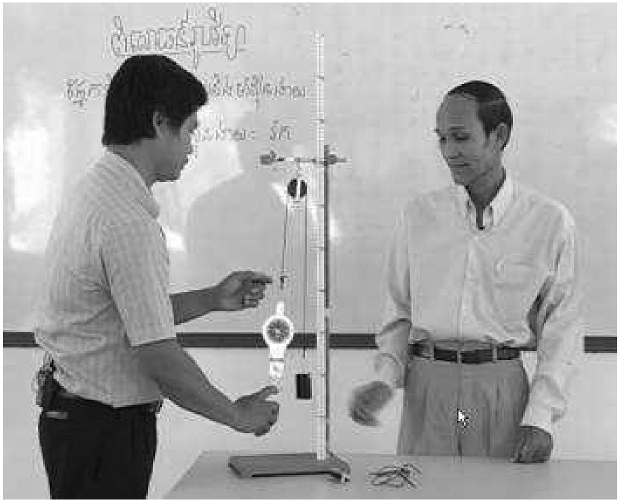
Questions

Other examples of levers are fingernail cutters, bottle openers and lock cutters. Can you explain now how they work?

7.2 Simple Machines: Pulley

Objectives

- Students can apply concepts of work, energy and the conservation of energy to a pulley.
- Students can recognize examples of pulleys in daily life.
- Students can draw force diagrams to explain how pulleys work.



Background knowledge

A pulley is a device for multiplying forces or simply changing the direction of forces. The principle underlying the pulley is the conservation of energy concept.

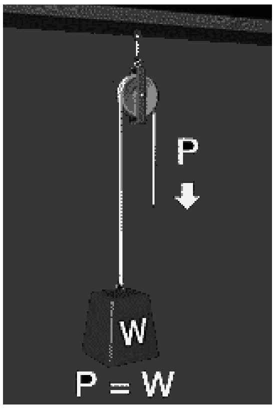
Work input = work output

$$(\text{Force x Distance})_{\text{input}} = (\text{Force x Distance})_{\text{output}}$$

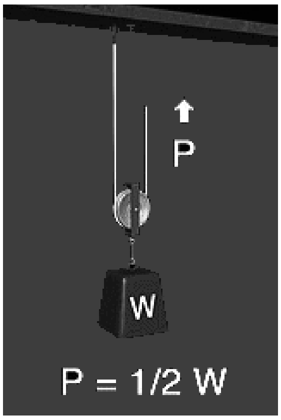
Forces and distances can change while work input and work output stay the same.

There are two basic types of pulleys. When the wheel is attached to a surface it forms a fixed pulley. The *fixed pulley* changes the direction of the required force. For example, to lift an object from the ground, the effort would be applied downward instead of pulling up on the object. The same amount of force is still required, but just applied in another direction.

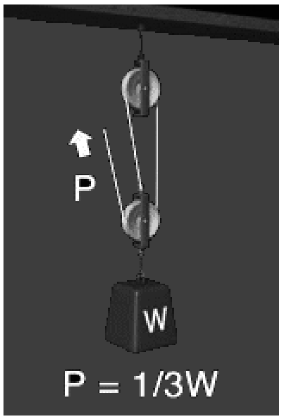
Another type of pulley, the *loose pulley*, consists of a rope attached to some surface. The wheel directly supports the load, and the effort comes from the same direction as the rope attachment. A movable pulley reduces the effort required to lift a load. Force is increased and distance moved is decreased.



This figure shows a single pulley with a weight on one end of the rope. The other end is held by a person who must apply a force equal to the weight of the object to keep it hanging in the air (in equilibrium).



In the second figure, the pulley is moveable. As the rope is pulled up, it can also move up. The weight is attached to this moveable pulley. The weight is supported by two sections of string, effectively halving the force you have to apply.



This figure has the same two pulleys, but the rope is applied differently and it is pulled upwards. The weight is supported by 3 strings. The mechanical advantage is 3, and the force to hold the weight in equilibrium is 1/3 the weight.

Any machine that multiplies force does so at the expense of distance.

Material needed

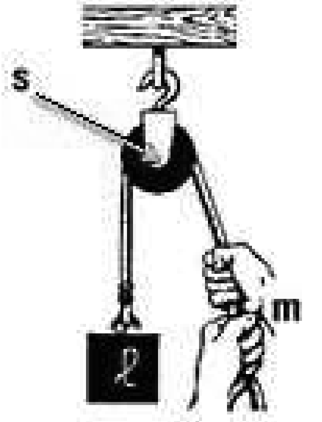
- 2 pulleys
- cord
- supporting point to hang the pulley on (a coat hook),
- weight
- spring scale

Link with curriculum

Physics textbook: Grade 8, Chapter 4, lesson 3, published 2008

Procedure

- prepare the constructions below
- first, compare the force you need to lift the weight in the three situations
- second, use a spring to measure the forces

<table>
<tr>
<td>
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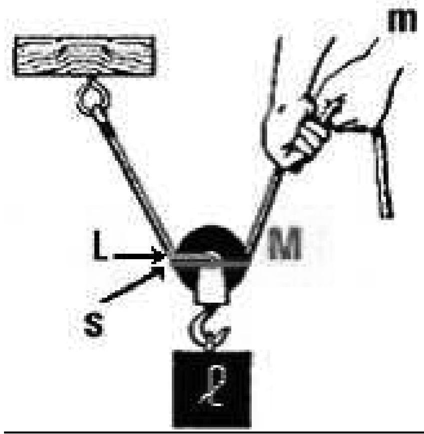
<td>
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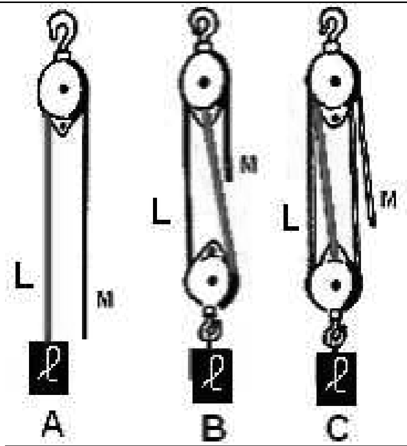
<td>
</td>
</tr>
<tr>
<td colspan="3">s: point of support

m: force

ℓ: weight

M: Force arm

L: weight arm</td>
</tr>
<tr>
<td>The fixed pulley
Hang the pulley as is shown in the picture and attach the weight to the cord. First let the weight rest on a table. Then pull it up about 30 centimetres.</td>
<td>The loose pulley
Hang the pulley as is shown in the picture and attach the weight to the cord. First let the weight rest on a table. Then pull it up about 30 centimetres.</td>
<td>Combination of a fixed and a loose pulley
Make the combination you find in the picture. Try to pull the weight up with this pulley.

A: weight arm = force arm ;
B: weight arm is half of the length of force arm;
C: force arm is three times longer than the weight arm.</td>
</tr>
</table>

Observations

It is easier to lift the weight with the loose pulley than with the fixed pulley. Even easier is using the combination, but it takes more time.

Explanation

1) With a fixed pulley you only change the direction of the force, the weights and the arms are equal. By the loose pulley the weight-arm is the half diameter of the wheel and the force-arm the diameter. So the force is the half of the weight.
2. Yes, with a factor of 2.

Remember: what we win at force, we lose in distance. Simple machines are devices that allow someone to trade an increase in distance moved for an increase in applied force, or vice versa.

Questions

1. Is there a difference in the effort required to lift a load when using a fixed pulley and a movable pulley?
2. Did the effort distance differ when using the two types of pulleys? Why or why not?

Application

Auto mechanics use pulleys to lift an entire engine out of a car.

Conclusion

A pulley is a device for multiplying forces or simply changing the direction of forces. The principle underlying the pulley is the conservation of energy concept. The total amount of work remains constant.

$$\text{Work} = (\text{Force x Distance})_{input} = (\text{Force x Distance})_{output}$$

Forces and distances can change while work input and work output stay the same.

7.3 Experiment on Pulleys

Objectives

- Students can apply concepts of work, energy and the conservation of energy to a pulley.
- Students can recognize examples of pulleys in daily life.
- Students can draw force diagrams to explain how pulleys work.

Material needed

- Two solid wooden sticks
- Long rope

Link with curriculum

Physics textbook: Grade 8, Chapter 4, lesson 3, published 2008

Procedure

Invite students to find the explanation themselves, when they are familiar with the working of pulleys. You can introduce the experiment with the question “who is the strongest?”

The rope is attached to one of the sticks. Wind it a few times around the two sticks. Let two persons hold the sticks at about a meter from each other. They have to try to keep them apart. Now pull the loose end of the rope.

Observations

It is a lot easier to pull the sticks together than to keep them apart. One person wins and two lose. No matter how hard the two persons try to keep the sticks apart, you can pull them together.

Explanation

This experiment works according to the same principle as the pulley. The work done by a force does not only depend on the magnitude of the force. Distance is important too. Remember that:

$(\text{Force x Distance})_{input} = (\text{Force x Distance})_{output}$

If you have to pull a long distance, you don't have to pull very hard. If the rope is wound around the sticks three times, this means six meters of rope. You have to move six meters of rope in order to bring the sticks together. The two other persons together move only one meter. If these persons pull as hard as you, they will lose. They would both have to pull more than six times as hard as you to win. When you pull on the end of the rope, you exert a small force, but over a long distance. The resulting force is far greater than the force the two persons can exert over a small distance.

Conclusion

As the total amount of work remains constant, you can achieve the same amount of work with a smaller force by increasing the distance.

Chapter 2: Sound

Introduction & Main Concepts

We provide an outline first of the main physics concepts of physics related to sound that are necessary to understand the experiments. For more detailed information we refer to handbooks of physics.

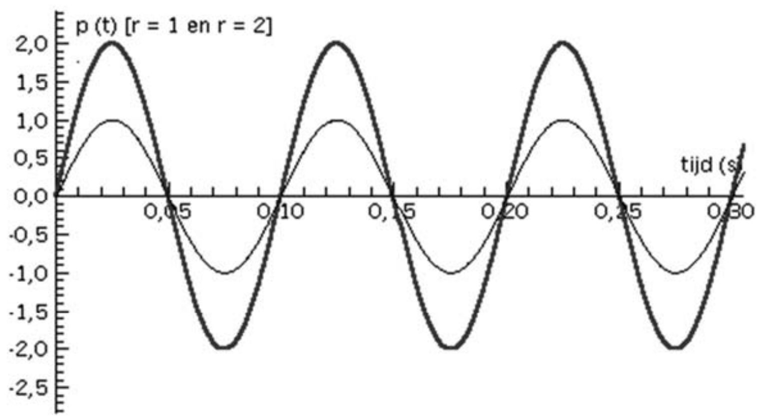
For every sound we distinguish between three aspects. First, to produce sound, there must be a *source*, which is a *vibrating* object. Second, the energy is transferred from the source in the form of longitudinal sound *waves*. And third, the sound is detected by an ear or an instrument.

The important characteristics of sound are:

- *Period* T: time to complete 1 oscillation (expressed in seconds)
- *Frequency* f: the number of oscillations over 1 second (expressed in ***Hertz*** = 1/s). This means that the relation between period and frequency is described as f = 1/T.
- *Intensity*: the amplitude of the vibration.

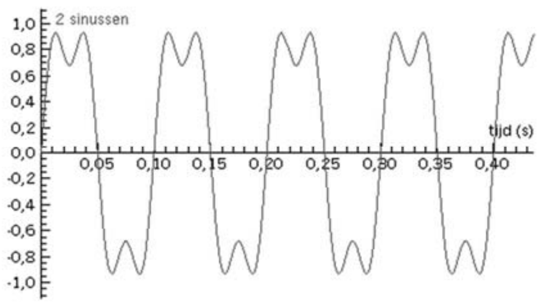
When we hear sound, we have a subjective interpretation of these characteristics. The frequency (or frequencies) of any sound is described in common language as 'pitch' (high and low tones). The human ear has a limited interval (20 Hz – 20 000 Hz). We cannot hear every frequency. Sounds below 20 Hz are called ***infrasonic***, above 20 000 Hz are called ***ultrasonic***. The intensity is related to the loudness of the sound.

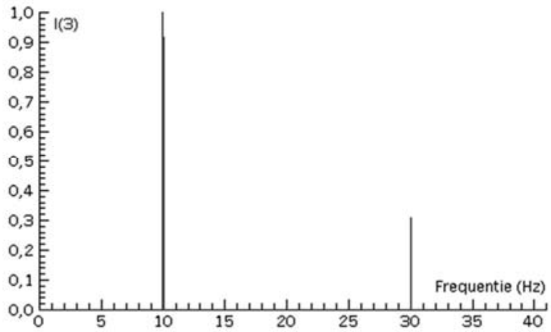
Sound can be mathematically represented through a *graph*. Here you can see a (perfect) sine curve of a sound produced with a frequency of 10 Hz (or period of 0,1 seconds).



This is a very monotonous (and noisy) sound with only 1 frequency. In daily life sounds do not have 1 frequency, but lots of frequencies. Each of them has a specific intensity. This is called the ***principle of superposition***.

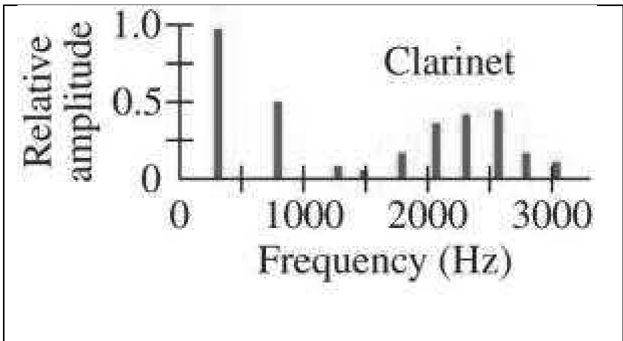
This can be analysed by the ***frequency spectrum*** of sound. In this spectrum all frequencies are displayed according to its intensity. The graphs below show two representations of a sound with 2 frequencies.

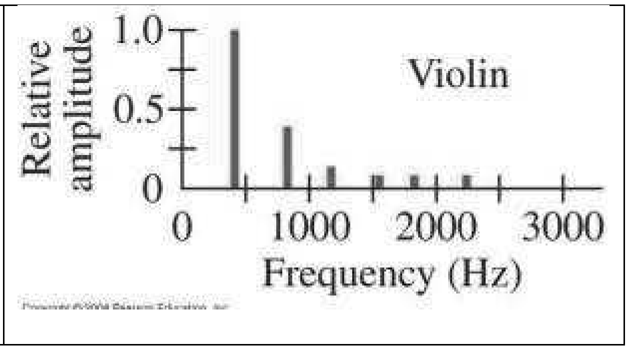




This is also the reason why different music instruments sound differently, even when they play the same 'tone'.

If, for example, a clarinet or a violin plays a do (246 Hz), you will have the same dominating frequency but there will be a difference in *overtones*, as shown is the following spectra.





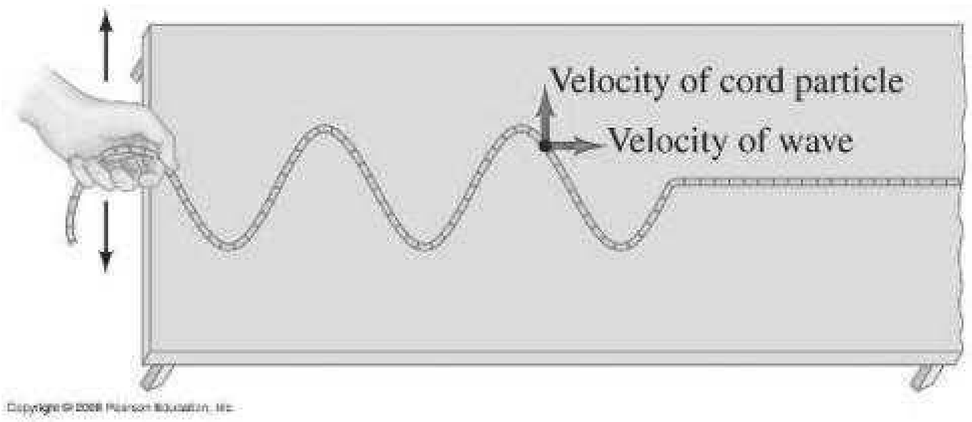
The second aspect of sound is the principle of ***propagation*** through a sound wave.

The vibrating object (source) creates a disturbance. This disturbance is transmitted in an elastic medium. The propagation of this disturbance is called a wave.

Sound waves however not only have time characteristics (such as period and frequency) but also characteristics in space[1]. These are:

- ***Speed*** v of the wave (m/s) in an elastic medium. The speed of sound through air is 343 m/s (20 ° C), through water 1440 m/s and through aluminium 5100 m/s. An important remark: not the medium itself moves, but the disturbance!
- We distinguish two kinds of waves: transverse and longitudinal waves.

  Transverse: when the vibration of the medium is perpendicular to the motion (see example of rope)



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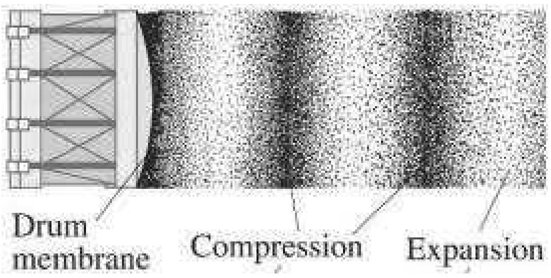
  Longitudinal: when the vibration of the medium is in the same direction of the motion. Sound waves are always longitudinal waves.



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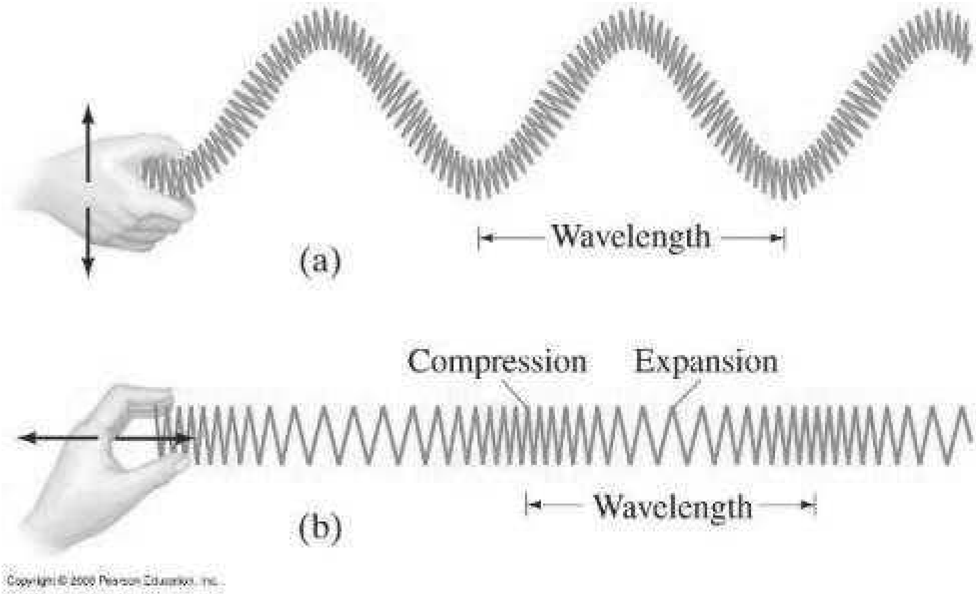
- ***Wavelength*** λ (m): distance between two successive maxima (or minima)/compressions (or expansions). In the same manner as before we can define the frequency as the number of vibrations that pass a given point.

[1] Graphs of a vibrations (amplitude over time) are often confused with wave projections, which are time and space related. The distance between two maxima in a graph is the period (time!), the distance between two maxima in a wave projection is the wavelength (distance!).

The relationship between frequency, wavelength and speed is described as follows:

$v = \lambda . v$



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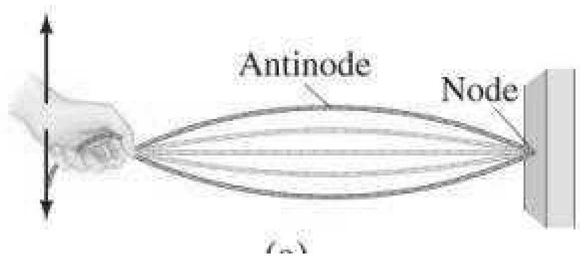
If you shake one end of a cord and the other end is kept fixed, the continuous wave will travel down to the fixed end and be reflected back, inverted. As you continue to vibrate the cord, there will be wave travelling in both directions. They will interfere and there will be quite a jumble. The waves will easily 'drop dead'. But if you vibrate the cord a just the right frequency, the two travelling waves will interfere in such a way that a *standing wave* will be produced.



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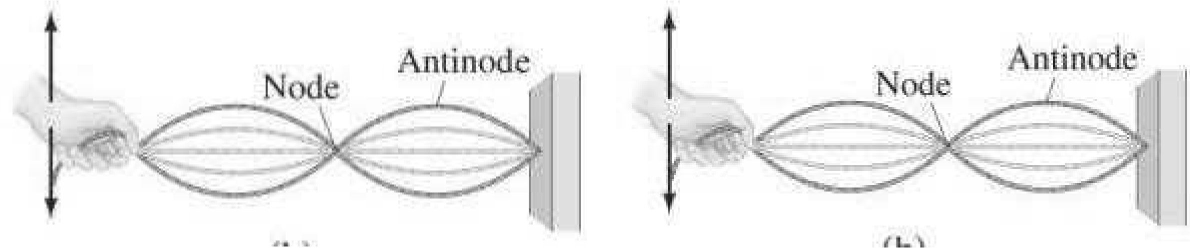
The points of destructive interference, where the cord remains still at all times, are called nodes. Points of constructive interference, where the cord oscillates with maximum amplitude, are called antinodes.

The standing wave can occur at more than one frequency. The picture below shows standing waves, produced at twice and three times the lowest frequency. These frequencies are called the natural frequencies or resonant frequency.



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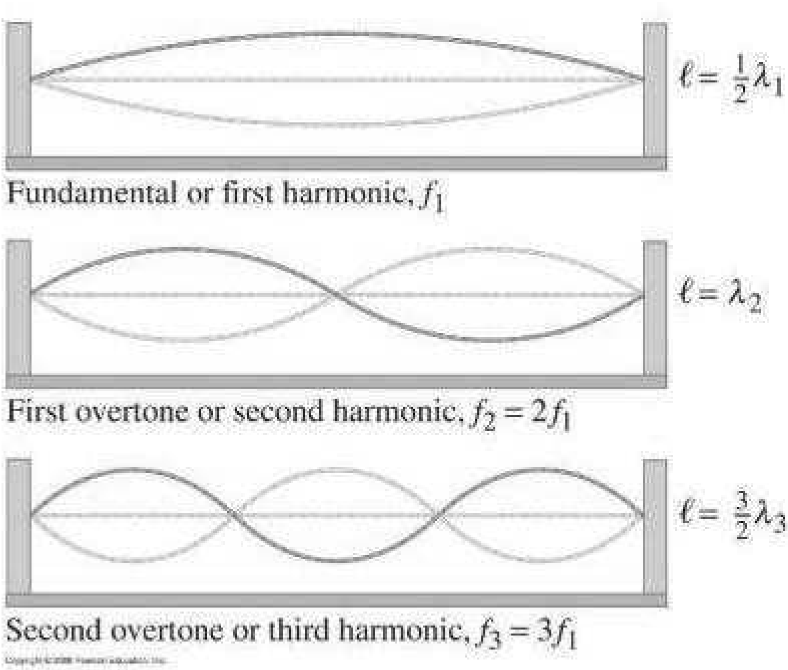
The same thing happens with music instruments, for example a string of a guitar. If you know the length of the string you can easily determine the wavelength of the standing wave.



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You have a resonant frequency when the wavelengths of the standing waves bear a simple relationship to the length L of the string. The wavelength of the lowest frequency, called the fundamental frequency, corresponds to the length L as follows: L = ½ λ and so on. The other natural frequencies are called overtones. There is always an easy connection between wavelength and length of the string.

If you know how fast the wave is moving in the elastic medium (metal string), then you can easily determine the frequencies (f = v/λ).

On the other hand, if can measure the frequency (through microphone), you can easily determine the speed of the wave in the medium.

Other examples of standing waves in music instruments are wind instruments such as pipes.

These phenomena of standing waves will occur often in the experiments about sound.

1. Capturing sound with ICT

Measuring and analysing sound is a very useful and powerful tool in understanding basic concepts of sound. When we want to register sound during the lessons physics or science and to make sound visible then we can use simple material such as:

- Computer or laptop with soundcard
- Headset or simple microphone
- Software (freeware, available on the internet or on cd 'sound capture') such as **Visual analyser** & **Audacity**

With these programs you can:

- Make a sound wave visible (as on a normal scope)
  - Capturing scope
  - Capturing spectrum of any sound (see different frequencies with spectrum)
- Production of sound wave
- Measuring frequencies

During some experiments in this manual the sound can be measured, analysed and investigated. In this way, scientific investigation can be easily stimulated.

2. Experiments creating sound

2.1 The singing bar

Objectives

- Students understand the nature of sound
- Students can explain the conditions needed to produce sound.
- Students can correctly use scientific terms such as wavelength, frequency and standing wave
- Students can perform a simple experiment to demonstrate the nature of sound

Link with curriculum

Physics textbook: Grade 8, Chapter 6, Lesson 1-3, published 2010

Material needed

- metal aluminium bar length 1 meter
- a sponge
- computer, microphone and software to measure the frequency

Procedure

Take with one hand the metal (aluminium) bar (length 1 meter) between the thumb and index finger tightly, exactly in the middle! You can easily find the middle by placing the bar on the two index fingers and then slide your two index fingers to each other. They will meet each other right in the middle of the bar (see also experiment 5.9 in the mechanics manual).

Moisten (wet) the fingers of the other hand and slightly rub with the wet fingers across one side of the bar (do not wet the sponge!). Fold the sponge around the bar and rub from the middle to the end of the bar. Make sure only the soft part of the sponge has contact with the metal bar. Rub it a few times and you should create a very loud and penetrating sound.

This needs some practice. Make sure you hold the bar in the middle (only with thumb and index finger).

To demonstrate the vibration of the metal, just let the end of the metal bar make contact with a table or glass (while the bar produces sound). You will hear the vibration through the table or glass.

Now try to do the same experiment while holding the bar not in the middle (but a few centimetres from the middle).

Observations

The result is a very loud, monotonous and penetrating sound. This experiment works even better with a larger bar.

If you do not hold the bar in the middle, you will hear no sound.

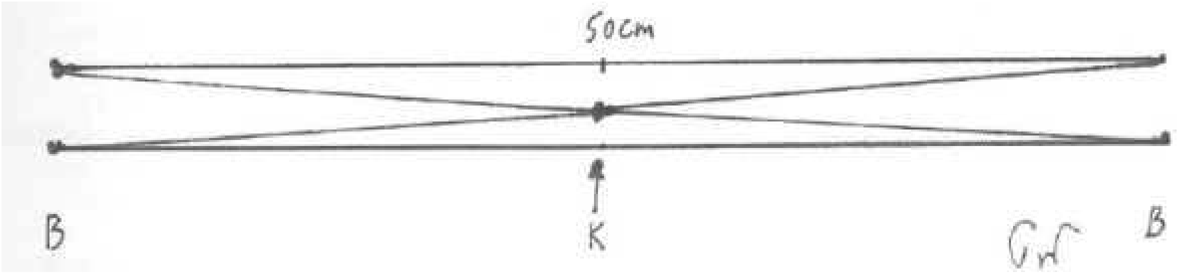
Explanation

By rubbing the bar you create a vibration which moves along the metal bar and produces a wave in the bar. Most often the sound will either end very quickly or you will hear almost nothing.

But, when you hold the bar right in the middle, a standing wave will be produced! The bar can vibrate freely at the end, but not in the middle[2]. This means that there is a node in the middle of the bar, and

2

two antinodes on at the end of each side of the bar. It's like a pipe instrument: a tube with both ends open. In this example, not the metal, but the air inside the tube is vibrating and producing sound.



In this particular case, you can easily determine the wavelength: **$\lambda = 2L$** (L = length of bar).

There is also a clear relationship between frequency, wavelength and speed: **$\lambda f = v$**.

This means that the frequency is $v/\lambda = v/2L$. In physics books you will find that the speed of sound in aluminium is 5 080 m/s. So the frequency is 2 540 Hz.

If you measure the frequency of this penetrating sound (by Virtual Analyser), the results will be confirmed!

Conclusion

The standing wave inside the metal bar creates a sound. A standing wave is a wave that remains in a constant position as a result of interference between two waves traveling in opposite directions. Many sounds we hear are caused by brief resonant vibrations in the object.

Questions

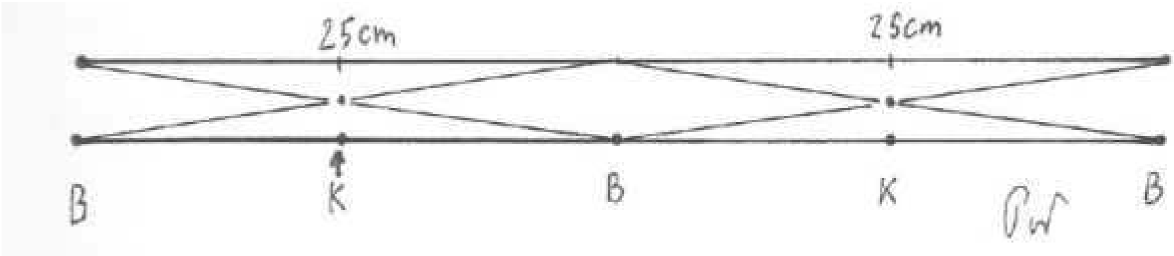
- *What happens if you use a copper bar instead of an aluminium bar?*

  Since the speed of sound in copper is lower (3 500 m/s), the frequency will also be lower.

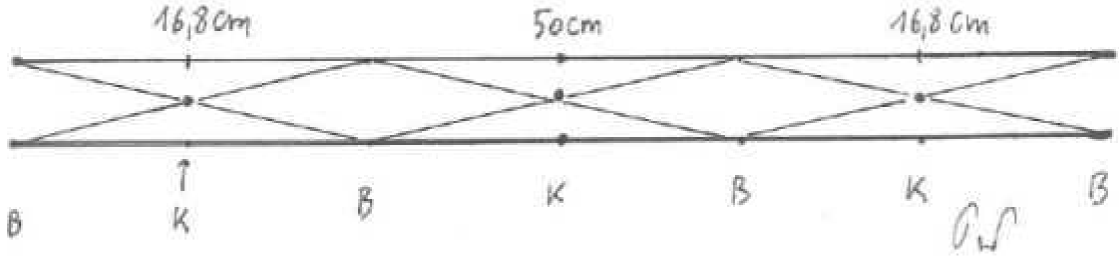
  f = v/2L = 3 500 m/s / 2 . 1 m = 1 750 Hz.

- *Where do you have to hold the bar to create overtones?*

  See waves of the 1st and 2nd overtone:



1st overtone: L = λ → f = v/L



2nd overtone: L = 3 λ /2 → f = 3v/2L

2.2 The singing glass

Objectives

- Students understand the nature of sound
- Students can explain the conditions needed to produce sound.
- Students can correctly use scientific terms such as wavelength, frequency and standing wave
- Students can perform a simple experiment to demonstrate the nature of sound

Material needed

A wide glass made of thin glass.

This experiment will not work with every glass, but you don't need the expansive crystal glasses (the thinner, the better). Just try some different glasses…

Link with curriculum

Physics textbook: Grade 8, Chapter 6, lesson 1, published 2010

Procedure

1. Pass your wet finger over the border of the glass,
2. Repeat the action with a glass half empty.
3. Add a small piece of paper to the water inside the glass and repeat the action

Observations

1. You hear a monotonous sound
2. Your hear a lower pitch and the water seems to be turning
3. The piece of paper stays at the same place!

Explanation

The friction of the finger over the glass generates vibrations of the glass. The thinner the glass, the higher the resulting pitch.

It may seem that the water is moving, but, in fact, standing waves are created in the water. This means that the piece of paper is vibrating at the same place and not moving around.

Conclusion

The sound is created by a standing wave. A slower vibration will result in a lower sound. Many sounds we hear are caused by brief resonant vibrations in the object.

Questions

What happens if we add more water?

You will hear a lower pitch… But why?

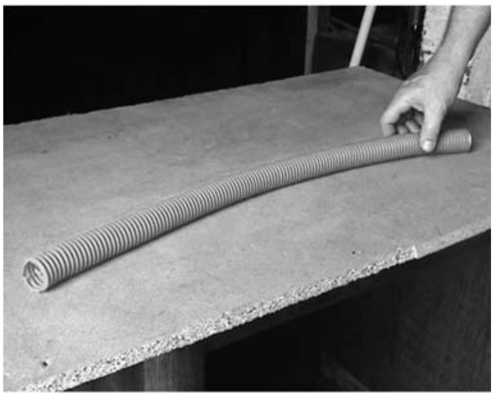
When we put more water in the glass, we add more mass that needs to vibrate in order to create sound. You can compare this with a vibrating slat (or a strip of wood) that is held on one side at a table. If you now add a piece mass (for example a piece of clay) at the vibrating part of the slat, the vibration will be slower and the frequency lower.

The same thing happens with the glass of water. The more mass, the lower the natural frequency of glass and water!

2.3 The singing tube

Objectives

- Students understand the nature of sound
- Students can explain the sound produced by the tube, using Bernoulli's Law
- Students can correctly use scientific terms such as wavelength, frequency and standing wave
- Students can perform a simple experiment to demonstrate the nature of sound



Link with curriculum

Physics textbook: Grade 8, Chapter 6, Lesson 1-3, published 2010

Material needed

A ribbed plastic flexible tube or pipe (The ribs must not be spirals!)

Procedure

1. Sing the pipe around slowly and faster
2. Close off one end with your hand or some tissue

Observations

1. You will hear a monotonous tone. If you swing faster, you will hear an overtone.
2. If you close off the tube, you don't hear anything.

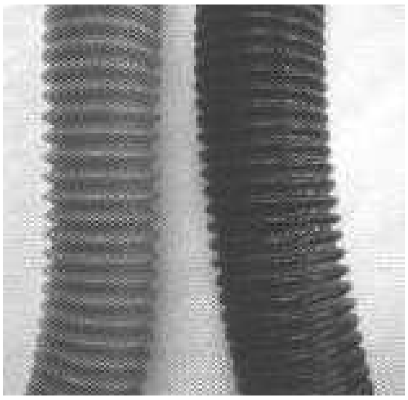
Explanation

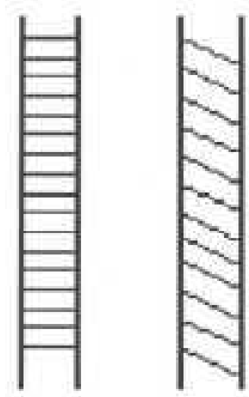
This sound can only be produced because air is going through the tube while swinging! When you put a tissue inside the tube, air cannot move inside the tube so there will be no sound. You can demonstrate this by placing little pieces of polystyrene foam (or pieces of paper) on the table. Now swing the tube while holding one end above the foam. The pieces of foam will rise and enter in the tube. Eventually they fly out of the tube on the rotating end. This implies an air movement inside the tube while swinging.

The explanation lies with the Law of Bernoulli (see experiment manual on Pressure). At the end of the swinging part, the air particles move very fast and generate a lower air pressure. At your hand, there is less air movement and a higher pressure. Because of this difference in air pressure, air (together with the foam particles) will move inside the tube.

But why is a tone produced?

The collision of air particles against the ribs of the tube generates vibrations. So at regular distances air molecules collide with the obstacles (ribs) so air is periodically compressed. These compressions create a standing wave and produce the tone.





Conclusion

A sound is created by the collision of air particles against the ribs of the tube at regular distances. These compressions of air molecules create a standing wave and produce the tone.

Questions

What happens when you use a tube with spiral ribs (for instance from a vacuum cleaner)?

How hard you try, no sound will be created! Because of the spiral ribs, air cannot collide on regular periodic base (like before), so there cannot be a standing wave!

2.4 The buzzing slat

Objectives

- Students understand the nature of sound
- Students can explain the sound produced by the slat
- Students can correctly use scientific terms such as wavelength and frequency
- Students can perform a simple experiment to demonstrate the nature of sound

Link with curriculum

Physics textbook: Grade 8, Chapter 6, lesson 1-3, published 2010

Material needed

- A piece of rope
- A slat with a small hole at one end (to attach the rope).

Procedure

Make a loop at the end of the rope and slide it through the hole of the slat. Make sure you tighten it strongly and, if necessary, attach with tape.

Produce sound by taking the end of the rope and turn the slat in a wide vertical circle.

Observations

This may need some practice (if it does not work, try swinging it the other way), but after a while you should hear a monotonous low tone (a kind of buzzing sound).

Explanation

By turning, the slat starts to rotate. The air close to the rotating slat will vibrate and in this way starts producing a sound.

Conclusion

Sound is produced by the vibration of air molecules, caused by rotating the slat.

2.5 Another singing pipe (horn principle)

Objectives

- Students understand the nature of sound
- Students can explain the role of heat in producing a sound in the experiment
- Students can correctly calculate the frequency of the sound using length and the speed of sound in air.
- Students can perform a simple experiment to demonstrate the nature of sound

Material needed

- A metal or cardboard pipe (if possible 2 samples with different lengths)
- Bunsen burner (or other kind of burner)
- A small mesh-wire netting

Link with curriculum

Physics textbook: Grade 8, Chapter 6, Lesson 1-3, published 2010

Procedure

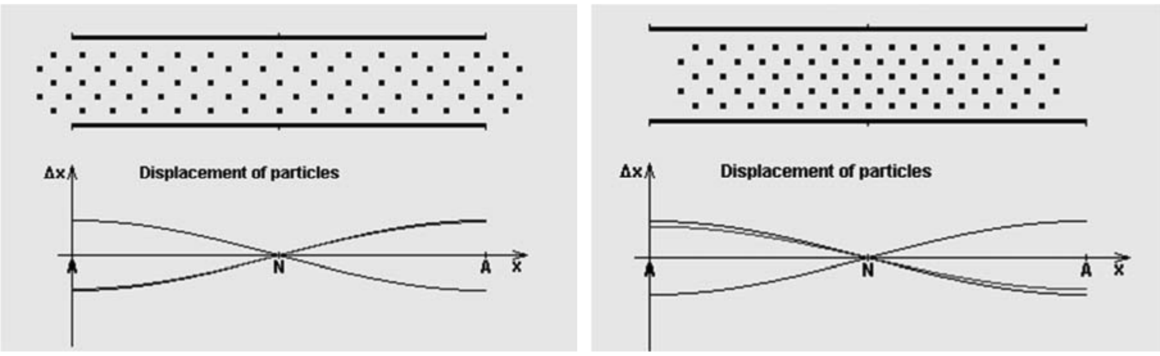
1. Put the small mesh-wire netting at the end of the burner & light up the burner until the netting gets hot.
2. Now place the tube vertical above the burning end (with the netting!) and slowly slide it inside the tube.
3. Try with other tubes of different lengths.

Observations

1. You will hear a loud monotonous sound.
2. The longer the pipe, the lower the tone.

Explanation

The hot wire-netting warms up the air which rises into the pipe. There it will collide with the cold air generating vibrations. This sound will continue for a while because a standing wave is created is this pipe with both ends open. In the picture below you see a standing wave with the node in the middle and antinodes at the ends.



A similar thing happened during the experiment of the ‘singing bar’, except it was not air that was vibrating but metal.

This implies a relationship between the wavelength and the length of the tube: $L = \lambda / 2$. The speed of the sound waves through the air is about 340 m/s.

You can do two kinds of calculations:

- Starting from the length L, you can calculate frequency: $f = v / \lambda = v / 2L = 283$ Hz (for a length of 60 cm).

- But, like the experiment of the singing bar, you can calculate the speed of the sound wave through air if you measure the frequency (by ICT sound capturing using Virtual Analyser). $v = f \; \lambda = 280$ Hz 2 L = 340 m/s.

Conclusion

The sound is created by a standing wave, caused by the collision of hot and cold air molecules at regular distances.

Questions

Why are horns used to communicate over large distances?

To make sure that a sound can be heard from a large distance, it is best that tones with a low frequency are emitted. Sound waves with low frequencies have long wavelengths. In this way the sound waves can easily pass through obstacles like buildings, mountains …

This is also used by radio stations. Signals with long wavelengths (or short frequency) such as international radio communications are transmitted over a longer distance. Local radio stations often use a communication signal with smaller wave length (or bigger frequency).

Elephants communicate with very low tones (that cannot be heard by humans, 10 Hz) over a very large distance (several kilometres).

2.6 Talking strips

Introduction

A talkie tape is a plastic ribbed strip less than 1/8 inch wide and about 24 inches long. Just like an old gramophone, the ribs can produce a recorded sound by rubbing it!

Find out what your talking strip says.

Objectives

- Students understand the nature of sound
- Students can explain how sound is produced by the strips
- Students can perform a simple experiment to demonstrate the nature of sound

Link with curriculum

Physics textbook: Grade 8, Chapter 6, lesson 1-3, published 2010

Material needed

- A talkie tape (see www.talkietapes.com)
- Some ‘amplifying’ material such as piece of paper (different sizes, different thickness), a balloon, a plastic cup, etcetera.

Procedure

One side of the strip is smooth (no ribs), the other side is rough, the 'talk side'. One end of the strip is pointed or rounded, the other end is squared.

1. Put the pointed end between your teeth and place the rough side downwards. Now slide the nail of your thumb (like on the picture) with a constant speed towards the squared end.
2. Now try it with different items like a plastic of cardboard cup (always start from the pointed end). If necessary use some plastic tape to attach it.
3. Now you can do some research by placing the strip on different kind of materials; for example thin paper, thick paper, large piece of thick paper, piece of metal, plastic, …

Observations

You need to listen very carefully, but the talking strips says '*Science is fun!*'. On the website of talking strips, you can buy other strips saying 'happy birthday', …

1. While holding it between your teeth, you will be the only one who can hear it.
2. Everyone can hear it.
3. The sound will be louder when you use a larger piece of paper, but will be more silent when using thick paper.

Explanation

Talkie tapes contain messages or sounds on a piece of plastic, just like on a gramophone record. The nail of your thumb is like the gramophone needle. The ribs, put on different positions on the strip, make your thumb vibrating and producing a sound. When using ‘amplifying’ objects like a balloon, piece of paper, …, not only your thumb will vibrate but also this object. These talkie tapes are based on an invention of Thomas Edison.

Conclusion

The sound is created by your thumb moving over the particular groove pattern of the strips.

2.7 How a loudspeaker works

Objectives

- Students understand the nature of sound
- Students can explain in their own words how a loudspeaker works
- Students can make a simple loudspeaker

Link with curriculum

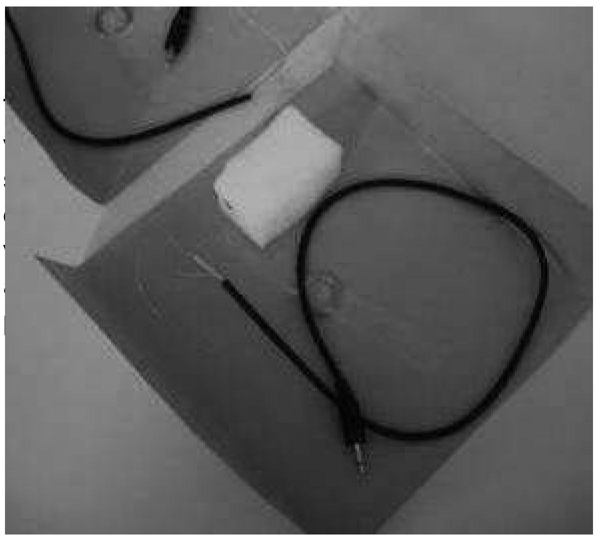
Physics textbook: Grade 8, Chapter 6, lesson 1-3, published 2010

Material needed

- Strong magnet + nail
- Isolated copper wire to make a copper coil
- Piece of strong paper
- Junction or connection wire to connect to a computer, mp3-player or a radio (audio signal). You can easily use a broken headphone or microphone and cut off the connection (with to wires).

Procedure

1. The homemade speaker can be constructed as follows:



You can easily wind the copper wire into a copper coil with a small tube (see picture). Make sure you have on both ends still 10 cm of copper wire. Now attach the ends of the copper coil with the connection device. Make sure they are strongly connected (wind the ends firmly and use plastic tape). Now attach the copper coil to a piece of paper or another object with tape. This object will amplify the sound (see previous experiment 'Talking strips'). This picture shows our homemade speaker.

2. Connect the speaker with a headset connection of a computer or a simple radio.

3. Take the strong magnet and place it (with the nail) very close to the copper coil.

During both actions listen close to the piece of paper!

Observations

1. During the first experiment (without the magnet), you will hear no sound.
2. When the magnet is placed nearby the copper coil, a sound will be heard!

Explanation

Also see experiment guide on electromagnetism.

The copper coil is a current-carrying wire so it behaves like a magnet. This means that this electromagnet can be attracted or repelled (Lorentz force) by another magnet. The current in the coil is an alternating current so the poles of the electromagnet will change rapidly. There will be alternatively attraction and repulsion. Because the coil is connected to an amplifying object (piece of paper or a membrane), this will also vibrates. The air particles close to this object will start to vibrate and creates a sound wave.

The alternating electric current is carrying the music from the radio or computer.

Conclusion

A loudspeaker is based on the principles of an electromagnet and sound waves. An electromagnet creates vibrations in a coil, which are passed on to an amplifier and the surrounding air particles.

Questions

How you can make a better loud speaker? What are the influences of producing a better sound?

- The length of the copper wire: When the wire is longer, you can make more windings in the copper coil. This implies a stronger magnetic field so the vibration and the sound will be heard better.
- Thickness of the copper wire: When the wire is thicker, there will also be a stronger magnetic field.
- A stronger magnet will produce better vibration of the copper coil.
- The object to amplify the sound: You can use different kind of object to amplify the sound (another piece of paper, a balloon, …).

Use an old speaker and open it! You will notice that magnet, copper coil and an electric audio signal are always present!

3. Experiments on sound waves

3.1 Principle of sound waves

Objectives

- Students understand that only the sound wave is moving, not the medium itself.
- Students can perform a simple demonstration to illustrate the difference between the sound wave and the medium through which it moves.

Link with curriculum

Physics textbook: Grade 8, Chapter 6, Lesson 1-3, published 2010

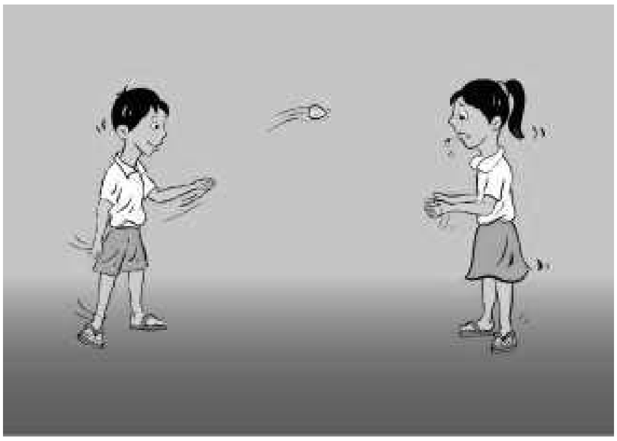
Material needed

- A plastic cup
- A whistle or a small flute
- A dish with soap bubble liquid
- Domino blocks

Make a hole in the bottom of the plastic cup, just big enough to but the flute or whistle in it. Make sure it is firmly connected.

Procedure

Fill a dish with the soap liquid and sop the plastic cup so you can blow soap bubbles. Then blow…



Observations

You see a big soap bubble appearing and you can hear a tone from the whistle.

Explanation

This seems a very simple and even stupid experiment, but in fact this experiment demonstrates a very important insight about how sound waves propagate!

The air, that you are using to produce sound, remains inside the soap bubble and does not move to the listeners around you. The sound wave (the whistle tone) on the other hand does reach the listeners (otherwise they wouldn't hear it).

This implies the following: <u>It is not the medium that is moving towards you ears, but the only the sound wave!</u> Of course, when a wave passes, the air particles must vibrate (but only locally, at a very small distance) but the particle itself does not move along the wave. Only the disturbance of the medium (air) is moving. You can compare this with a Mexican wave in a big stadium: the crowd only goes up and down, but they all stay at the same place.

Questions

How is a set of falling domino blocks similar to a sound wave?

To illustrate this more clearly and lively, you can use domino blocks (see picture). If the first one falls, all the others will follow. The falling of these blocks (= wave) will continue along the row with a certain speed, but the blocks (= medium) remain at the same position.

How does the spacing of the domino blocks resemble the propagation of sound waves in a medium?

If you place the blocks close to each other (like solid material), the disturbance (falling of the blocks) will propagate fast. When the blocks are placed further from each other (like a gas), the speed will be much slower. Because of this reason, the speed of sound waves in solid is much bigger than in a gas (iron: 5100 m/s; air: 340 m/s). The disturbance (oscillating of particles) can be passed on much faster when particles are closer to each other.

Conclusion

In a sound wave, it is not the medium that is moving, but the only the sound wave.

3.2 Types of waves

Objectives

- Students understand the difference between longitudinal and transverse waves
- Students can perform a simple demonstration to illustrate the difference between longitudinal and transverse waves.

Link with curriculum

Physics textbook: Grade 8, Chapter 6, Lesson 1-3, published 2010

Material needed

- Plastic bottle
- Balloon
- Candle
- Large spring

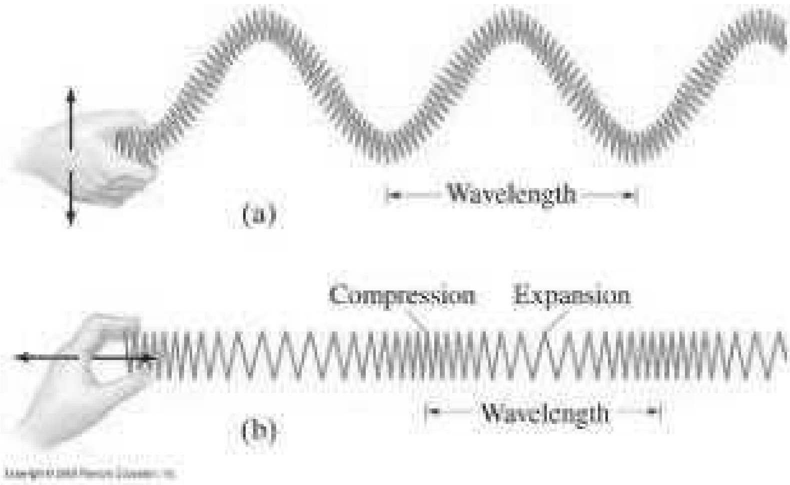
Cut off the bottom to the plastic bottle and stretch the membrane (piece of balloon) around it.

Procedure

1. Propagation of a disturbance through air: hold the plastic bottle with the membrane of the balloon with the opening close to a burning candle. Push a few times against the membrane.
2. Now place the candle about half a metre from the opening of the bottle. Take the membrane between thumb and index finger, pull and let go.
3. Take the spring and make sure there is some tension (attach the other side of spring). Now move the spring perpendicular and in the same direction of the spring.

Observations

1. You see the flame of the candle moving along with the membrane.
2. If you aim well, you will be able to blow out the flame from a distance of half a meter.
3. With some practice, you can see the following:



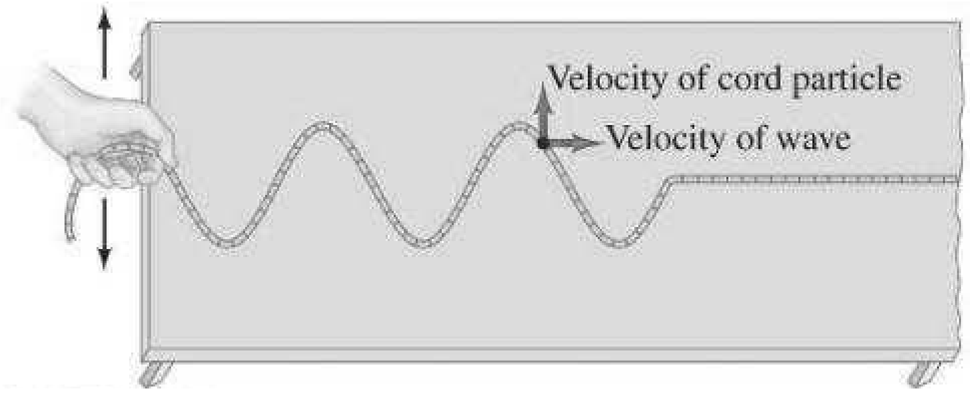
Copyright: Pearson, 2008

Explanation

Sound is created by a disturbance in the medium. Air particles are being compressed and decompressed by a vibrating membrane or another object. This produces locally a change in pressure by vibrating air particles.

Sound waves are longitudinal waves: the vibration of the air particles is in the same direction of the motion of the wave.

Other waves, like waves on water or disturbance on a cord, a transverse waves: the vibration is perpendicular to the motion. The experiment with the spring clearly shows these two kinds of waves.



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Conclusion

In longitudinal waves, like sound waves, the vibration of the air particles is in the same direction of the motion of the wave. In transverse waves the vibration is perpendicular to the motion.

3.3 Swinging sticks (resonance)

Objectives

- Students can explain resonance and natural frequency with examples from daily life
- Students can perform a simple experiment to demonstrate resonance

Link with curriculum

Physics textbook: Grade 8, Chapter 6, Lesson 1-3, published 2010

Material needed

- 2 identical sticks threaded to a rope
- Stretch the rope between two points

Source: Arteveldehogeschool

Procedure

1. Let one stick swing (by giving it a little push).
2. Repeat, but make one stick heavier.

Observations

1. After a short time also the second stick starts swinging and the first one stops.
2. The experiment doesn't succeed.

Explanation

The vibration of the first stick propagates over the rope to the second stick. This is only possible when both objects have the same natural frequency.

This phenomenon is called resonance.

If there were no friction, the movement would continue. Each object has a natural frequency and will vibrate to this frequency.

Conclusion

Each object has a natural frequency and will vibrate to this frequency. Objects tend to absorb more energy when the frequency of oscillations in the environment match with the objects' natural frequency.

Questions

Can you give some examples of resonance by transmitting sound waves?

Sometimes well-trained singers can break glasses just by singing. Therefore they need to sing at a loud monotonous tone at the same natural frequency of the glass. If enough energy is being transmitted, the glass will vibrate very heavy until it breaks.

If you have a computer and a strong loudspeaker, you can produce a monotonous tone (with software program virtual analyser) to try it yourself.

4. Experiments about the speed of sound waves

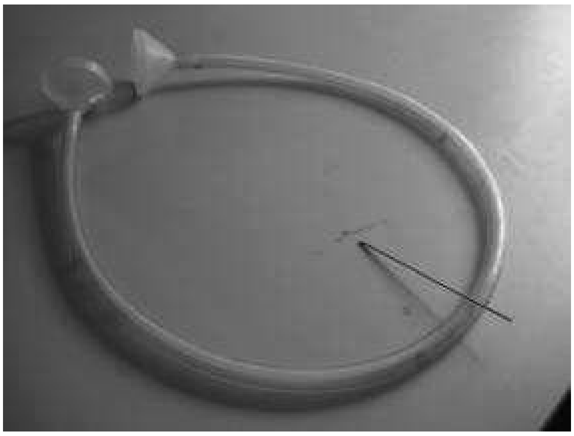
4.1 Propagation of sound

Objectives

- Students understand that the speed of sound is limited to 340 m/s in air at average temperature.
- Students can explain why we hear the sound slightly faster in one ear than in the other ear.
- Students can perform a simple experiment to demonstrate the constant speed of sound.

Link with curriculum

Physics textbook: Grade 8, Chapter 6, Lesson 1-3, published 2010



Material needed

- A flexible plastic tube with a funnel on both ends. Mark the middle of the tube.

Procedure

1. Ask someone a pupil to put the funnels over his ears. Tap on the tube in the middle & ask if he or she can hear the sound.

2. While the pupil is closing his/her eyes, tab alternatively in the middle, more to the left and once more to the right. Can the pupil here where exactly the tube was tapped?

Observations

1. The pupil will hear clearly a sound.
2. Yes, he or she can.

Explanation

Sound propagates in the tube and reaches the nearest ear first. The speed of sound in air is 340 m per second. This seems very fast but even a short difference in distance (because you tap the tube not in the middle) will be noticed by your ears.

Conclusion

Sound propagates through air at a speed of 340 m/s. In solids and liquids the speed is higher.

Questions

What about the speed of sound in other materials like liquids or solids?

In solids and liquids the speed is higher. The disturbance (oscillating of particles) can be passed on much faster when particles are closer to each other. See experiment 4.1: falling domino blocks.

4.2 Determining the speed of sound

Objectives

- Students understand that the speed of sound is limited to 340 m/s in air at average temperature.
- Students can explain how the speed of sound in air can be calculated using the concepts of resonance and standing waves.
- Students can perform a simple experiment to calculate the speed of sound

Link with curriculum

Physics textbook: Grade 8, Chapter 6, Lesson 1-3, published 2010

Material needed

- A jar filled with 4/5 with water
- Tuning fork 440 Hz
- Tube with a length indicator on the side


.

Procedure

1. Put the tube in the water with the 0 cm – unit upwards.
2. With your other hand, tap the tuning fork on the table and keep it close to the opening of the tube.
3. Now move gently the tube along with the tuning fork up or down until you hear amplification! If necessary, tap the tuning fork and try again.
4. If you have found the right length for amplification, measure the length of the air column.

Observations

With some practice you should be able to hear amplification at a certain length of the air column. Make you measure the length of the air column correctly!

This should be about 18 cm.

Now we can make some calculations:

The amplification is only possible when a standing wave occurs inside the air column. See explanation.

This means that the length L equals ¼ of the wavelength λ. So $\lambda = 4$ L.

The speed of the sound in the air column $v = \lambda f$.

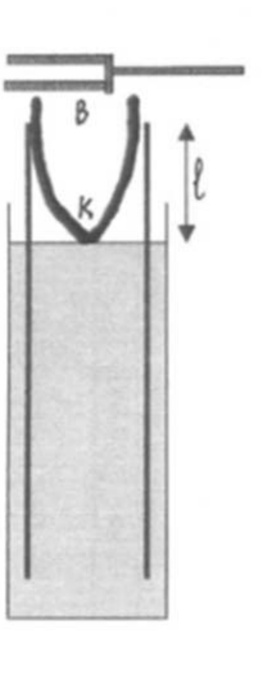
For a length of 18 cm and a frequency of 440 Hz (tuning fork), we should get $v = \lambda f = 4 L f = 4 .18$ cm . 440 Hz = 317 m/s.

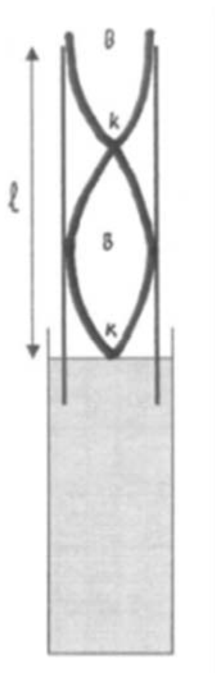
The actual speed of sound in air is 330 m/s so this is quite a good calculation! The small error in this calculation must be ascribed to the diameter of the tube. It is best to use small diameters but then this experiment will be hard to perform

Explanation

Sound propagates like waves. If a wave enters the one side open tube it collides with the bottom (surface water) and will be reflected. In a normal case the sound will extinguish quickly and you won't hear much. But under specific circumstances the reflected wave and the first wave will strengthen each other and you will surprisingly hear an amplified sound.

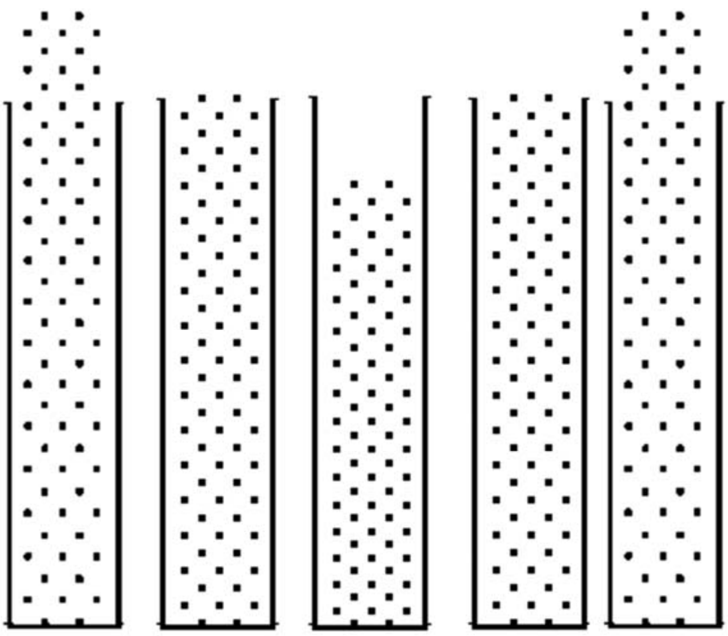
The speed of sound through air is constant, which means that sound with a certain frequency must have constant wavelength λ (= v / f). A standing wave can only be created when the tube has a certain length L, so that the wave at the bottom, sc the closed end, is standing still and at the top, sc the open end, is moving. The bottom will be the node and the opening the antinode of the standing wave. If you look at this picture, you will notice this only occurs at a length L = ¼ λ.





Standing wave at L = ¼ λ   Standing wave at L = 5/4 λ

In these pictures you see the movement of the sound wave (moving air particles) during one cycle (1/440 of a second).



Conclusion

You can measure the speed of sound in air by creating standing waves (resonance) in a - one side open – tube with a tuning fork.

Questions

Is it possible to make standing waves at other lengths of the tube?

Yes, remember what the conditions are to have a standing wave in an one side open tube: It can only be created when the wave at the bottom, or the closed end, is standing still (node) and at the top, or the open end, is moving (antinode).

This means also occurs at other lengths $L = \frac{3}{4} \lambda$, $5/4\ \lambda$, …

If the tube is long enough you can also have amplification at a length L = 54 cm.

What happens when we use a sound with another frequency (for example a tuning fork of 880 Hz)?

Then of course we will measure a different length of the tube! With a different frequency the wavelength will be different: $\lambda = v \, . \, f$ → the bigger the frequency, the bigger the wavelength.

4.3 Factors influencing the speed of sound

Objectives

- Students understand that the speed of sound is limited to 340 m/s in air at average temperature.
- Students can explain which factors affect the speed of sound in a medium
- Students can perform a simple experiment to demonstrate the effect of temperature and presence of CO_2 on the speed of sound.

Link with curriculum

Physics textbook: Grade 8, Chapter 6, lessons 1-3, published 2010

Material needed

- Same as the previous experiment 5.2 (jar, tuning fork, tube)
- Candle (to heat up the air)
- Effervescent tablet (aspirin, vitamin, …) & a small plastic bottle (50 cl) to produce CO_2

Procedure

1. To investigate the influence of the temperature:
    - Light up a candle and place it on the water surface in the jar.
    - Carefully put the tube over the candle (again with the 0 cm –unit upwards) and wait until the air inside the tube is heated.

- Now perform this experiment like experiment 5.2.

2. To investigate the influence of CO_2:

   - Put the tube in the water.
   - Now fill the plastic bottle with a bit of water (2 cm is enough) and put the tablet inside. Wait until the tablet is fully vanished. Now the bottle is filled with non-visible CO_2 gas. Because CO_2 is heavier than air, it will stay inside the bottle.
   - Make sure you have an air column of 20 cm and gently pour the CO_2 gas inside the tube. This may look strange because you cannot see the gas.
   - Now perform this experiment like experiment 5.2.

Observations

If you have performed well, you should measure a length of the column as follows:

1. Hot air: L = 19 cm → $v = \lambda.f = 4\ L.f = 4\ .\ 19\ cm\ .\ 440\ Hz = 334\ m/s$.

   The speed of sound in hot air is faster!

2. CO_2 – gas: L = 16 cm → v = 281 m/s.

   The speed of sound in CO_2 – gas is slower!

These calculations are not completely correct, but these results show that there is a clear influence if you use other kind of gasses!

Explanation

1. In hot air the speed will increase! Remember experiment 4.1 with the domino blocks. It the particles are closer the each other the speed of the disturbance (= sound wave) will increase. The particles in hot air will move faster and they will be able to pass on the wave quicker.
2. In CO_2 – gas the speed will decrease! It looks like the particles of CO_2 are not so close to each other. They cannot succeed fast in passing on the disturbance of the sound wave.

Conclusion

The speed of sound is affected by the temperature and the chemical composition of the air. In hot air the speed will increase and in CO2 gas the speed will decrease.

Questions

How you are sure that you have produced CO_2 gas in the bottle?

Because you cannot see the gas, you are not sure whether you have produced CO_2 gas. An easy experiment to find out is pouring this non-visible gas above a burning candle. The gas is heavier than air and will drop onto the flame. It will extinguish (a magic trick)!

Is it possible to use other gasses?

Of course, you can use propane or butane gas from a Bunsen burner!

5. Experiments on pitch

5.1 Producing different tones

Objectives

- Students can explain how the length of the air column affects the pitch (or frequency) of the sound you hear.
- Students can perform a simple experiment to illustrate the pitch of a sound.

Link with curriculum

Physics textbook: Grade 8, Chapter 6, Lesson 1-3, published 2010

Material needed

- Plastic bottle (50 cl)
- PVC – tube
- Straw and scissors

Procedure

2 short experiments:

1. Fill the plastic bottle (50 cl) 3 cm from the top edge with water & put the PVC – tube inside the water. Now take bottle with your left hand while holding the tube with your right hand. Try to whistle over the opening of the tube, like you play the panpipes (put the lower lip against the edge of the tube & blow over the pipe). This may need some practice. With your hands you can change the length of the tube. Listen carefully.
2. Take a straw and flatten out the end (you can do this with your teeth). If the end is flat, cut off two pieces on the bias so you have a V-shaped end (about 1 cm). Make sure that the shape is not to slanting. Otherwise the end won't vibrate because the lips are too long and flexible. Now take the straw in your mouth (beyond the V-shape) and blow. A new straw needs some practice to start vibrating.

   If you hear a tone, now extend the straw by sliding a new straw inside the first one.

If you perform well, try to do this: While blowing, take the scissors and cut off pieces (about 2 cm) from the straw!

Observations

1. Depending on the length of the air column, you hear low tones (long air column) and high tones (smaller air column).

2. You hear again a tone, because the lips start vibrating. You can easily feel this by touching them with your tongue (feeling of little electrical shocks).

   When you extend the length of the straw, this tone becomes lower.

   While cutting off the straw, the pitch becomes higher!

Explanation

1. While the air column becomes smaller, the tone becomes higher, which means a higher frequency. Similar to experiment 5.2 the tube is a – one side open – tube. Every specific length of the tube corresponds to a specific frequency (and a specific tone).

2. When blowing in the V-shaped opening of the straw, the pressure between the lips drops a little bit[3]. The lips are pretty elastic so they repel again. Eventually their will be a vibration… A lot of music instruments (like a saxophone, clarinet, …) are based on this physical principle.

   By changing the length of the air column you can change the frequency or pitch of the sound.

Conclusion

The longer the air column the lower the tones that are produced.

[3] This can be explained by Bernoulli’s law (see experiments of pressure): fast air creates low pressure.

5.2 Experiment on the Doppler Effect

Objectives

- Students can explain what the Doppler Effect is, using examples from daily life.
- Students can explain the change in pitch when a sound source is moving towards or away from them.
- Students can illustrate the Doppler Effect with a low-cost experiment.

Link with curriculum

Physics textbook: Grade 8, Chapter 6, Lesson 1-3, published 2010

Material needed

- A buzzer (connection of 9 V battery with the buzzer)
- A rope
- (the large spring)

Make sure you connect the buzzer properly with the rope.

Procedure

1. Connect the wire with the battery. Listen to the tone while the buzzer is not moving.
2. Have the buzzer swing in a horizontal, circular way so that it moves nearer and father from a spectator.

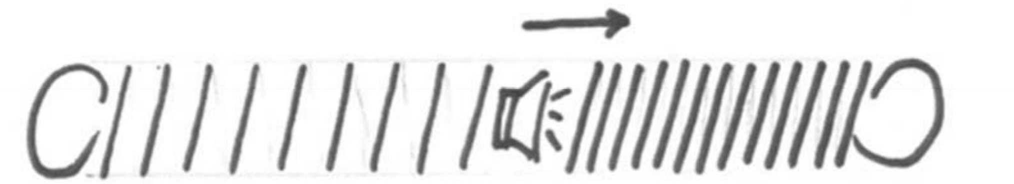
Observations

1. There is no difference in tone or pitch noticeable.
2. The spectator notices a change of pitch: a higher pitch when the buzzer comes closer and a lower pitch when the buzzer is going away from the spectator.

Explanation

This change in pitch or tone is called the Doppler Effect and occurs while a source (or receiver) is moving towards or away from sound waves. When a source is moving towards you, it seems like he is overtaking its own sound waves. The waves are huddled together, so that the frequency, that reaches the spectators ears, is higher than the originally produced tone. The effect is reversed when the source is moving away from the spectator.

You can use a spring as a model to illustrate what happens. Take one end of the spring with your left hand, while a pupil is holding the other end. With your right hand you take the middle of the spring (this can be modelled as the source) and move this hand to your pupil.



You can clearly see that the ‘waves’ before the source (going to the pupil) are much closer to each other (more huddled together). At that place the frequency will be higher.

Conclusion

The Doppler Effect is present when the source, medium or receiver are moving relatively to each other. If the source moves toward us we perceive a higher pitch due to the Doppler Effect. When the source moves away from us, we perceive a lower tone.

Questions

Can you hear this ‘Doppler’ effect in daily life?

Yes, you can! Listen at night (when there are not so many cars and motors) carefully to cars coming to you and going away from you. The effect is best noticeable when you hear the siren of a police car, because this siren has a monotonous pitch.

Chapter 3: Heat

Introduction

This manual introduces 9 experiments on heat. The experiments have all been tried out and can be done with low-cost materials.

Some of the experiments are short, providing an engaging introduction to your lesson. Other experiments are longer and can be useful for creating an inquiry-based lesson.

The earth science activity manual contains many experiments on the expansion of gases, which you may also find useful to teach about heat.

Main concepts addressed

The experiments in this manual focus on the following concepts of heat and heat transfer.

- Materials that are heated expand and get a lower density.
- Heated air takes up more place than cold air.
- Heated air had a lower density than cold air and rises.
- Evaporation makes colder.
- Some materials expand more than other ones.
- Metals are good heat <u>conductors</u>.
- Other materials almost don't conduct heat. They are <u>insulators</u>.
- Heat energy can be transferred by conduction, convection and radiation.

3. Experiments

3.1 Experiment on Conduction

Objectives

- Students can explain in their own words the difference between a conductor and an insulator
- Students can give examples of conductors and insulators from their daily life.

Link with curriculum

Physics textbook: Grade 7, Chapter 2, Lesson 1, published 2009

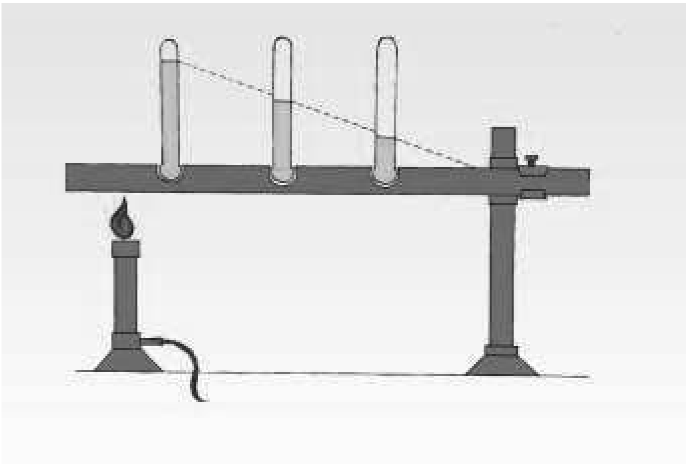
Material needed

- Gas fire or cooking plate
- Wooden stick or spoon
- Metal stick or spoon
- Plastic stick or spoon

Procedure

- Boil some water and put it in a glass or Erlenmeyer. Make sure the glass can withstand boiling water!

- Take two different objects. For example a spoon or stick made out of plastic or wood and the other one made out of metal.
- Hand the two objects over to two students and make them feel the temperature when they put it in the boiling water.
- Let the students switch spoons, so they can feel the actual difference.



Observations

The metal object will heat up more quickly than the wooden or plastic object.

Explanation

One material will conduct heat better than the other, because of the different properties of material, like the presence of free electrons. Metals conduct heat better than wood, because there are a lot of free electrons in metal.

Heat can be transferred through metal a lot faster than through wood. We say that metal is a good conductor, while wood is a good insulator.

Conclusion

Conduction is a mode of transfer of heat energy within and between bodies of matter, due to a temperature gradient. Heat spontaneously tends to flow from a body at a higher temperature to a body at a lower temperature. Metals are usually the best conductors of thermal energy, due to the presence of free electrons.

Questions

Why do we sense a difference in heat between the two materials?

(One material will conduct heat better than the other, because of the different properties of material, like free electrons.)

3.2 Experiment on Convection

Objectives

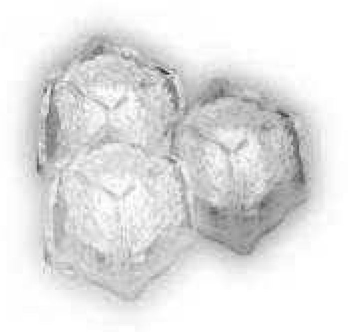
- Students can explain how convection transports heat energy within a liquid
- Students can give examples of convection from their daily life
- Students can perform a low-cost experiment to illustrate convection to pupils

Link with curriculum

Physics textbook: Grade 7, Chapter 2, Lesson 2, published 2009

Material needed

- Glass of water
- Colouring liquid
- Ice cube holder
- Freezer



Procedure

- Colour some water with red or green food colouring. Use the amount of water that fits into an ice cube holder.
- Place the ice cube holder with the coloured water in the freezer for some time until you have ice cubes.
- Place the coloured ice cube in the glass of water.
- Let students observe the melting of the ice cube in the water thoroughly. Give them some time to think about the process.

Observations

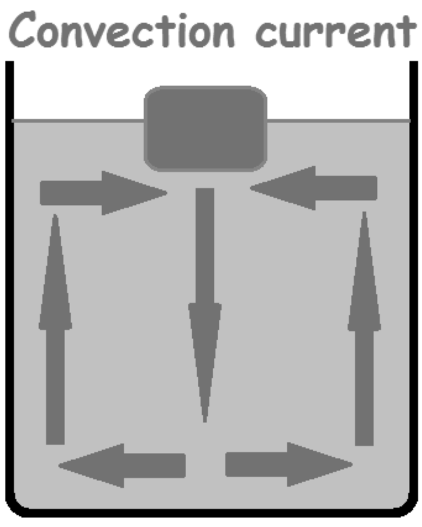
The coloured ice cube floats on the water. The coloured cold water from the ice cube sinks to the bottom. There it heats up and rises to the surface, where it cools and goes downwards again. You can see the cycle of the coloured water.

Explanation

When we put the coloured ice cubes in a glass of water, the coloured cold water from the ice cube will sink to the bottom. That's because cold water has a higher density than hot water.

At the bottom it will heat up and rise to the surface, where it will get cold again. So we will get a cycle. Hot water has a lower density than cold water (due to the faster movement of molecules) so it will rise while cold water has a higher density and will sink.

We call this convection and it is very visible with this experiment.



Conclusion

Convection is the movement of molecules within fluids (liquids and gases). The fluid motion is caused by buoyancy forces that result from the density variations due to variations of temperature in the fluid.

Questions

Can you give an explanation for the movement of the coloured water in the glass?

See Observations and Explanation for the answers on these questions.

3.3 Experiment on heat transfer: creating a heat shield

Objectives

- Students can apply their knowledge on heat transfer to construct an effective heat shield
- Students learn to work together to solve a scientific problem

Link with curriculum

Physics textbook: Grade 7, Chapter 2, Lesson 1-3, published 2009

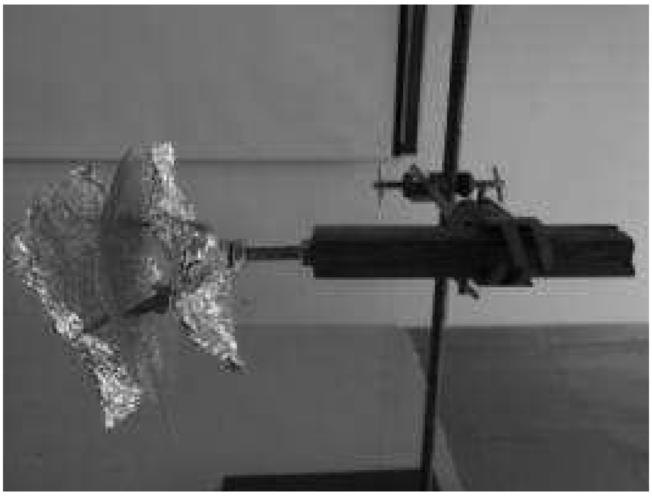
Material needed

- Wooden sticks
- Bolts and nuts
- Metal nets
- Aluminium foil
- Iron wires
- Some tape (not necessary)
- Gas flame
- Liquid glue

Procedure

- Glue the bolts to the wooden sticks in advance. Use for example one drop of glue ***(the same amount to all the sticks)***. Too much or too little glue will boycott the experiment. The glue has to be dry before you start.
- Hand out all the material to the students. Make sure every group has the same amount of material. Allow 15 to 20 minutes for the teams to prepare their heat shield. You may let them choose an original name for their heat shield prototype.
- You can add a "teacher prototype" (a heat shield that you prepared yourself before the lesson) to the competition.
- Students are only allowed to attach materials **to the metal part**, not to the wooden part of the heat shield.
- After they created their heat shield, it is time to test them! Therefore you attach them horizontally to the stand. You start timing when you put the gas flame in front of the rocket. When the glue is

melted and the bolt falls of the wooden stick, you stop timing. The heat shield that survives the longest, wins the competition!



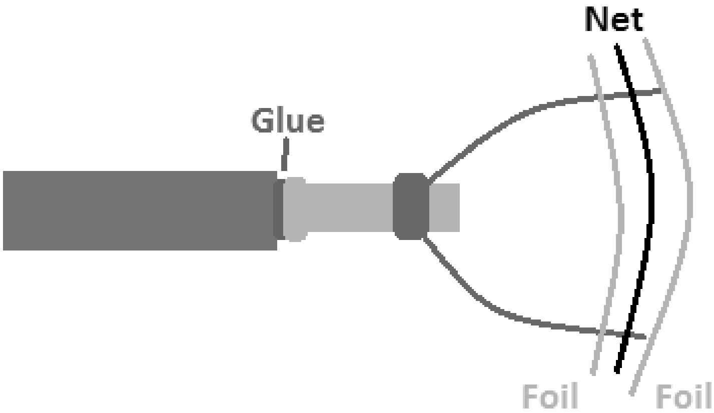
Observations

At first you can observe the change of some of the material due to the heat. In some cases you can even see how the gas flame gets blocked or swept away by the heat shield!

The bolt and the heat shield, attached to the bolt, of some of the prototypes will eventually loosen from the wood, because the glue in between starts to melt. In that case the entire construction falls down. Not every construction falls down. If they do, they don’t fall down at the same time.

Explanation

The heat shield needs to have different layers. Some air between them is good, because air is a good isolator. The aluminium foil will melt very quickly in front of the fire, but if you put some aluminium foil after the net, you can prevent it for melting for a long time. And aluminium foil is a very good material against radiation. When you add some isolating material between the bolt and the iron wires, you can prevent the conduction of the heat through the iron.



Conclusion

An effective heat shield protects against heat energy from radiation, conduction and convection. Air is a good isolator and aluminium protects well against radiation. Materials have particular heat transfer characteristics.

Questions

Organize a short **class discussion** after the experiment.

The group with the best heat shield can explain their way of thinking and explain how they made the rocket to the whole class. Try to encourage them to involve the three ways of heat transfer in their explanation.

3.4 Experiment on heat transfer: making a thermos bottle

Objectives

- Students can explain how a thermos bottle prevents heat transfer.
- Students can build a low-cost thermos bottle, using heat transfer concepts.
- Students learn to work together in a constructive and respectful way.

Link with curriculum

Physics textbook: Grade 7, Chapter 2, Lesson 1-3, published 2009

Material needed

- Small bottles (without the top) and big plastic bottles (cut in half)
- Bubble plastic
- Aluminium foil
- Black and white paint
- Tape
- Old newspaper or textile… or any other material that you can find to insulate a bottle
- Thermometers

Procedure

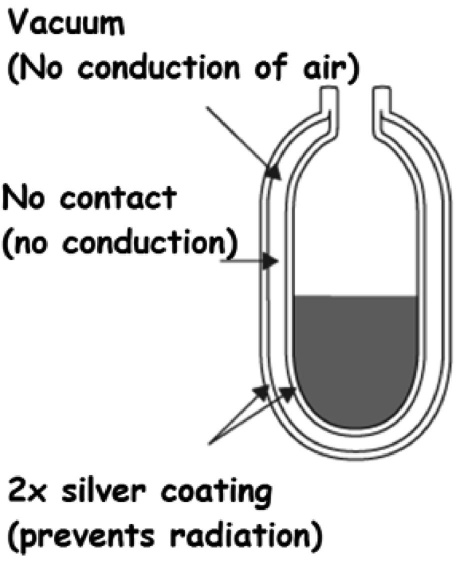
- Decide whether the students have to build a thermos bottle to keep cold water cool or to keep hot water warm.
- Divide the class into teams. The team that keeps the water the coolest/hottest (depending on the instruction) wins.
- Hand out equal amounts of material to each team.
- Give the students time (10 to 15 minutes) to make an original thermos bottle.
- Measure the temperature of the water before putting it in the bottles.
- Place the thermos bottles with cold water in the sun and the thermos bottles with hot water in the shade or fridge for a while (at least 20 to 30 minutes).
- You can also place a non-isolated bottle in the sun or fridge, as a control for your experiment.
- Evaluate the isolating capacity of each bottle by measuring the temperature of the water.

Observations

In most thermos bottles the temperature of the water has changed remarkably. If you put cold water in the sun, the temperature will rise. If you put hot water in the shade or fridge, the temperature will drop. Some bottles will isolate better than others.

Explanation

The thermos bottle is built in such a way that it prevents heat transfer in its three ways. There are 2 layers of silver which prevent heat loss through radiation. The vacuum between these two prevents any form of convection. (Convection requires a liquid or gas)
Also there is no contact between the layers so this will prevent heat transfer through conduction.



Conclusion

The vacuum between the two layers of a thermos bottle prevents heat transfer through convection, whereas silver protects against radiation.

Questions

Let the winning team come to the front of the class and explain how they built their thermos bottle to prevent heat transfer.

Some questions that you can ask the team members:

- *Why did you use aluminium foil?*
- *Why is there air inside the bubble plastic?*
- *How did you prevent the water cooling/heating up through radiation?*
- *How did you prevent the water cooling/heating up through convection?*
- *How did you prevent the water cooling/heating up through conduction?*
- *Which material would you liked to use that was not available?*

3.5 Experiment on Heat Conduction: Fire

Objectives

- students can explain the observations of the experiment in their own words
- students can perform a low-cost experiment to illustrate heat conduction to their pupils

Link with curriculum

Physics textbook: Grade 7, Chapter 2, Lesson 1, published 2009

Material needed

- piece of polystyrene
- a sheet of metal (cupper or iron)
- two pieces of paper
- matches

Procedure

Put a piece of paper on the thin plate of metal. The other piece of paper is put on the polystyrene. Put a burning match on each piece of paper.

Observations

The piece of paper on the polystyrene will catch fire, but the one on the metal plate will not.

Explanation

Metal is a heat conductor. The metal takes up the heat from the match, so the paper won't become very hot. Meanwhile, the polystyrene nearly doesn't take up any heat. The material contains a lot of air, which is a bad heat conductor. The piece of paper on the polystyrene heats up and catches fire.

Conclusion

Metals are good conductors of thermal energy.

3.6 Experiment on Heat Conduction: Burning sticks

Objectives

- students can explain the observations of the experiment in their own words
- students can perform a low-cost experiment to illustrate heat conduction to their pupils

Link with curriculum

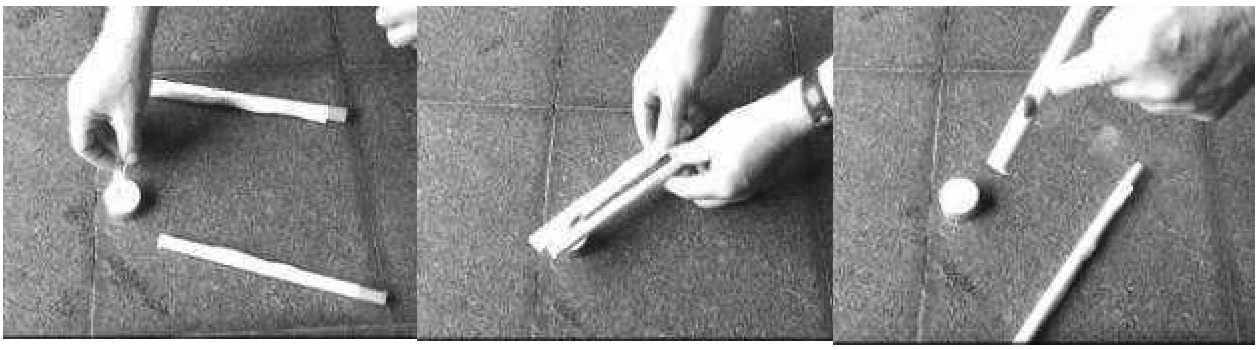
Physics textbook: Grade 7, Chapter 2, Lesson 1, published 2009

Material needed

- A wooden stick, wrapped up in paper
- A metal stick, as long and thick as the wooden one, also wrapped up in paper
- A burning candle

Procedure

Hold both sticks in the flame of the candle.



Observations

The paper around the wooden stick will catch fire first.

Explanation

The heat conductivity of metal is higher than that of wood. The metal picks up the heat, so the paper around it doesn't get heated so quickly.

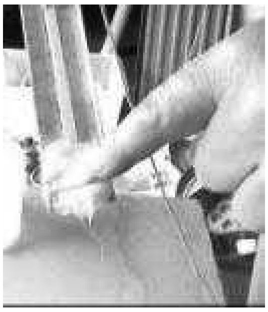
Conclusion

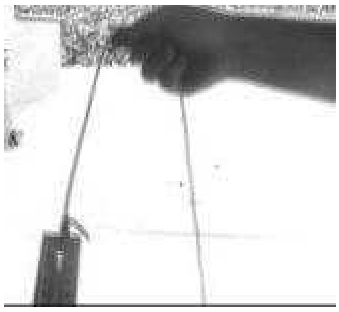
Metals are better conductors of thermal energy than wood.

3.7 Effect of Evaporation on Temperature

Objectives

- Students can explain that evaporation is a cooling process, using examples from their daily life
- Students can perform a low-cost experiment to illustrate evaporation as a cooling process to their pupils





Link with curriculum

Physics textbook: Grade 9, Chapter 4, Lesson 4, published 2008

Material needed

- a thermometer
- a thread
- some cotton wool
- ether (or water)

Procedure

- Read the temperature on the thermometer and note it down.
- Fasten a piece of cotton-wool on the reservoir at the bottom of the thermometer and put some ether (or water) on it.
- Whirl the thermometer about while holding the thread.
- Now read the temperature again.

Observations

Whirling the thermometer around helps the cotton wool to dry. The ether (or water) evaporates faster because of this movement. The temperature will drop.

Explanation

In order to evaporate, a fluid needs heat. This heat is subtracted from the near environment. In this case, heat is subtracted from the fluid in the thermometer. When we sweat, our body cools down. The sweat subtracts heat from our body to evaporate.

Conclusion

Evaporation is a cooling process. This means that during evaporation, heat energy is taken from the environment to realize the phase change, causing the temperature to decrease.

3.8 The balloon that doesn't melt

Objectives

- Students apply what they have learned about heat transfer to a practical situation.
- Students learn to work together to solve a scientific problem

Link to curriculum

Physics textbook: Grade 7, Chapter 2, Lesson 1, published 2009

Material needed

- Two balloons
- a candle
- some water

Procedure

1. Put some water in a balloon and blow it up further. Hold the balloon above the burning candle.

2. Blow up the second balloon without putting water in it. Now also hold it above the burning candle.

Observations

Does the balloon melt or not?

1. The balloon doesn't melt.

2. The balloon melts and explodes.

Explanation

1. The balloon can pass on the heat to the water. By doing this, the balloon itself doesn't get so hot.

2. The balloon becomes very hot and melts. It pops.

3.9 The solar cooker

Objectives

- Students apply what they have learned about heat transfer to a practical situation.
- Students learn to work together to solve a scientific problem

Link with curriculum

Physics textbook: Grade 7, Chapter 2, Lesson 1-3, published 2009

Material needed

You can use whatever material you want. It's important to use common-or-garden materials and to provide loads of (different) material. Some suggestions:

- Lenses, mirrors, magnifying glass, sun glasses...
- Aluminium foil, clean wrap, cardboard, shoe boxes...
- Cans, cups, jugs, glasses...
- Scissors, knife, measuring rod, glue, tape, paintbrush, black paint or paper...
- Newspaper, cloths, wool...
- Barbeque stick, marshmallow or sausage...

Procedure

Divide the pupils in groups and give them the necessary information and material. Make them built their own original solar cooker. If they finish they can present their creation.

To test their creations, put a cup of water in it and place the solar cookers in the sun. The cup of water that reaches the highest temperature after a given time wins the contest!

Observations

The water (or the sausage) inside the solar cooker will start to warm up quickly. You can measure the temperature every 5 minutes or so, to visualise the increase in temperature.

Explanation

The solar cooker absorbs a lot of heat because it is painted black. The water (or sausage) will absorb even more heat because the sun rays are reflected to it by the aluminium foil (mirror or lenses) If your solar cooker is insulated well and has some clean wrap on top of it (~greenhouse effect), most of the heat will stay inside.

The more you can implement the principles of heat transfer (and of course the better the material), the better the solar cooker will be.

Conclusion

A solar cooker applies the principles of heat transfer to maximize the heat energy inside the cooker.

References

- Churchill, E.R., Loeschnig, L.V. and Mandell, M. (1997) 365 Simple Science Experiments with Everyday Materials, Unk. Black Dog & Leventhal Publishers.
- Giancoli, D.C. (2008) Physics for Scientists & Engineers with Modern Physics, 4th ed. Prentice Hall.
- Govaert, M. (2005) De Proefjeskoffer, vzw Winadoe
- Hewitt, P.G. (2006) Conceptual Physics, 10th Edition, 10th ed. Addison Wesley Publishing Company.
- Muller, R.A. (2009) Physics for Future Presidents: The Science Behind the Headlines, Reprint. W. W. Norton & Company.
- Robertson, W.C. (2004) Electricity And Magnetism: Stop Faking It! Finally Understanding Science So You Can Teach It, illustrated ed. National Science Teachers Association.
- Robertson, W.C. (2002a) Energy, National Science Teachers Association.
- Robertson, W.C. (2002b) Force and Motion: Stop Faking It! Finally Understanding Science So You Can Teach It, 1st ed. National Science Teachers Association.
- Robertson, W.C. (2003) Light, Stop Faking It! Finally Understanding Science So You Can Teach It, 1st ed. National Science Teachers Association.
- Robertson, W.C. and Diskin, B. (2004) Sound: Stop Faking It! Finally Understanding Science So You Can Teach It, illustrated ed. Natl Science Teachers Assn.
- Walravens, P. (nd) 50 Experimenten, Deel 1, Zavophysics
- Walravens, P. (nd) 50 Experimenten, Deel 2, Zavophysics
- Walravens, P. (nd) 50 Experimenten, Deel 3, Zavophysics

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