European Science and Technology in Action
Building Links with Industry, Schools and Home

VOLUME 1 | PHYSICS

ESTABLISH IBSE
Teaching & Learning Units:

Light
Sound
Heating & Cooling
Direct Current Electricity

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Teaching & Learning Units

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Light
Sound
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SEVENTH FRAMEWORK PROGRAMME | SCIENCE IN SOCEITY
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ABOUT ESTABLISH

ESTABLISH is a pan-European project funded by the European Union's Seventh Framework Programme (FP7) involving fourteen partners from across eleven countries (Ireland, Sweden, Poland, Czech Republic, Malta, Slovakia, Estonia, Italy, Germany, Netherlands, Cyprus). The aim of the ESTABLISH project is to promote and facilitate the use of inquiry-based approaches in the teaching and learning of science and technology across Europe with second level students (ages 12-18 years).

Through the collaborative efforts of these partners, a series of 18 inquiry-based science education (IBSE) teaching and learning units have been developed through piloting and trialling with teachers in the classroom. These units form the core resource for the implementation of ESTABLISH teacher education programmes.

These booklets provide background information for teachers on the ESTABLISH approach to IBSE and presents several of these units which focus on particular physics-related themes selected to be appropriate for the second level science curriculum.

Participating Institution	Country
Dublin City University	Ireland
AG Education Services	Ireland
Umea Universitet	Sweden
Uniwersytet Jagiellonski	Poland
Univerzita Karlova v Praze	Czech Republic
Acrosslimits Limited	Malta
Univerzita Pavla Jozefa Safárika v Košiciach	Slovakia
Tartu Ulikool	Estonia
Universita degli Studi di Palermo	Italy
Malmö University	Sweden
Leibniz-Institut fuer die Paedagogik der Naturwissenschaften und Mathematik an der Universitat Kiel	Germany
Centre for Microcomputer Applications	Netherlands
Martin Luther Universitaet Halle-Wittenberg	Germany
Frederick University	Cyprus

These materials serve as exemplary materials for science teachers and instructors of teacher professional development to experience the benefits of inquiry-based science education approach and are offered openly to inspire, guide and stimulate the further development of IBSE resources and practices. Electronic versions of these units and associated classroom materials are available openly for download from the project website at www.establish-fp7.eu and at www.castel.ie/establish.

The ESTABLISH project (2010-2014) is coordinated by Dr. Eilish McLoughlin, Dr. Odilla Finlayson, Dr. Sarah Brady and Dr. Deirdre McCabe from the Centre for the Advancement of Science and Mathematics Teaching and Learning (CASTeL) at Dublin City University (DCU).

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LIGHT

The development of this unit has been led by the ESTABLISH partners:

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Dublin City University (DCU), Ireland

UNIT CONTENTS

I. Unit Description

The Light Unit is divided into two subunits that can be used independently or sequentially, and within a hierarchical curriculum. The subunits follow the natural divide typically employed in relation to the topic of Light: Subunit 1 is aimed at an introductory level and takes a 'ray-based' approach, whereas Subunit 2 is more appropriate for the higher stages of secondary school and incorporates 'wave-based' phenomena. Light is a subject area that often involves curriculum-prescribed demonstrations and experiments, for example the dispersion of white light by a prism and image formation by lenses. The activities presented in this unit are suitable for demonstrations / experiments in a format consistent with an IBSE approach.

Subunit 1: Introducing Light

In this subunit, students examine the basic physical properties of light and its interaction with materials in a predominately qualitative fashion. They learn that sources of light have specific physical characteristics and these can determine properties of light, such as its colour and intensity. They investigate the interaction of light with matter and explore phenomena such as reflection and refraction.

- **Student level:** Lower secondary school level, ages 11 – 15
- Discipline(s) involved: Physics
- **Estimated duration:** 5-6 class periods

Subunit 2: Investigating Light

In this subunit, students re-examine a number of the concepts of Subunit 1 in a more quantitative way. They investigate refraction, the refractive index of materials, and the formation of images by mirrors and lenses. Additional topics such as polarization, diffraction, and scattering of light are introduced. Students also learn that, through an understanding of its behaviour, light can be manipulated for technological goals.

- **Student level:** Higher secondary school level, ages 15+
- Discipline(s) involved: Physics
- Estimated duration: 5-6 class periods

II. IBSE Character

Subunit 1: Introducing Light

As an introductory course on Light, the main IBSE approaches employed here are interactive discussion/demonstration, guided discovery and guided inquiry. Through the activities the students develop basic skills to perform and plan scientific inquiry:

- Asking and answering appropriate questions
- Planning and conducting simple scientific investigations
- Giving priority to empirical evidence
- Using empirical evidence as the basis for their explanations of phenomena
- Communicating and discussing their observations and explanations
- Revising explanations based on further investigations

Although light is a subject with which students have familiarity, questioning their conceptual understanding can quickly reveal gaps that can be exploited to form the basis of the subsequent investigations. The difficulty for the teacher lies in balancing the requirement that students (re)evaluate and (re)develop their own concepts, while simultaneously guiding them away from misconceptions and misguided interpretations. Therefore a key part of the IBSE character of this unit is to allow discussion between students of the pros and cons of particular lines of thought, interpretation of data, and conclusions drawn.

Subunit 2: Investigating Light

As this subunit is aimed at the higher levels of secondary education, the main IBSE approaches are guided discovery, guided inquiry, and bounded inquiry. Skills developed by students include:

- Performing experiments
- Analysing results
- Communicating results with the use of graphs
- Comparing experimental results to theoretical models
- Deciding if results support or falsify previous hypotheses

The difficulty for the teacher in this case arises if experimental errors are large and students reach incorrect conclusions. An important part of maintaining the IBSE nature of the investigations is to examine these results in the context of the wider opinion, i.e. how one set of results compare to those of other students. The aim should be to establish that a single experiment is insufficient to draw conclusions, that the results from multiple experiments should be analysed as a whole, and to promote discussion on why certain methodologies employed by the students were less error-prone than others.

III. Science Content Knowledge

Subunit 1: Introducing Light

In this subunit it is assumed that students have no prior formal knowledge of the subject beyond their existing own conceptions. The activities introduce students to the following ideas and concepts:

- Objects may be classified by their optical characteristics
- Light has physical properties such as colour and intensity
- Shadows are caused by the absence of light
- Light may not necessarily be visible to the naked eye
- Light is emitted as a wave
- The direction of propagation of these waves may be represented as rays
- Mirrors reflect light and, for a plane mirror, the angle of incidence is equal to the angle of reflection
- The direction of light can change as it passes from one medium to another
- White light is the combination of lots of different colours of light
- White light can be produced using just red, green, and blue primary colours
- Filters pass certain colours of light and absorb others
- Lenses alter the direction of light and can be used to form images

Subunit 2: Investigating Light

In this subunit it is assumed that students have studied basic trigonometry and are familiar with graphing data. The activities introduce students to the following concepts and ideas:

- An image is formed in a plane mirror and this image is located on the opposite side of the mirror to the observer
- Snell's Law describes how the direction of light changes as it passes from one medium to another
- At a particular angle, light will be reflected from an interface rather than transmitted as it passes from a high refractive index material to a low refractive index material
- When light travels from some medium to air, comparing the actual position or width of an object to its apparent position or width allows one to determine the refractive index of the medium

- The position and magnification of the image created by a lens depends on the focal length and the distance of the object to the lens
- Light can be polarised, and the intensity of light through two polarisers can be described by Malus's Law
- Light can be diffracted by small objects and the width of the diffraction pattern depends on the size of the objects
- Different wavelengths of light can be scattered by varying amounts

IV. Pedagogical Content Knowledge

Light is a topic that exposes students to a fundamental aspect of science – different models are employed depending on the information one wishes to obtain about a physical system.

- The properties of visible light (~400 – 700 nm) examined through the activities are representative of electromagnetic waves (EM) in general.
- EM waves are transverse, which can be demonstrated through polarization.
- The 'ray model' can be used to understand the formation of shadows, reflection and refraction. This model simplifies the analysis of situations where the direction of light is altered.
- The 'wave model' can also be used to understand shadows, reflection, and refraction, but is required to understand phenomena such as polarization, diffraction and interference.
- Phenomena such as the decrease in measured intensity of light as a function of distance, or partial absorption/transmission through neutral density filters, are difficult to explain on the basis of the 'ray model'. These can readily be explained by the 'wave model' as changes in the amplitude.
- The concept of energy is useful in explaining absorption/transmission, with the energy loss occurring as a result of the interaction of light with materials.
- It is the interaction with materials that result in reflection, refraction, shadows, polarization, absorption, and diffraction.

Science Education research has revealed a number of student misconceptions around the topic of Light:

- A recurring theme in studies is that light is said by students to illuminate objects and once 'lit up' these objects can then be seen. Students conceptualise light as a 'local brightness' and the act of seeing is often not considered to require that light travel directly to the eye.
- Students often ask questions of the form: 'If I can see light and it travels as a ray, then why don't I see bright rays crossing the room?' This type of question demonstrates that, although students may accept that light is present in the

space around them, they fail to understand the relationship between the image they see and the spatial-distribution of light in their environment (thereby altering their view of objects depending on their position).

- Students tend to classify light sources into those that are ‘natural’ and those that are ‘artificial’ and, accordingly, can attribute unique properties to the light produced in each case. Although the classification into ‘natural’ and ‘artificial’ sources is somewhat flawed (is a burning candle producing light through natural or artificial means?), it nevertheless demonstrates that students have actively attempted to distinguish between the properties of different light sources and the properties of the light produced. This can form the basis for a more scientific approach at classifying the optical properties of objects.
- Students tend to relate the reflection of light specifically to mirrors and ‘shiny surfaces’. They often fail to see the relevance of reflection in relation to the visible objects within their environment that are not ‘sources’ of light.
- Students often conceptualise that the image formed in a mirror is located on the surface of the mirror rather than behind it.
- Students often fail to understand the role of filters, even having studied the dispersion of white light by a prism. Many students consider that filters ‘alter the colour of light’ rather than allowing or preventing certain colours from passing through them.

Further reading:

‘Student Conceptions of Light: A Case Study’, D. M. Watts, Phys. Educ. 20, 183 (1985)

‘Exploring Students’ Concepts of Light’, B. F. Stead and R. J. Osborne, Australian Science Teacher’s Journal 26(3), 84 (1980)

‘Student Misconceptions about Light in Algeria’, D. Blizak, F. Chafiqi, and D. Kendil, http://spie.org/etop/2009/etop2009_4.7.35.pdf (Proceedings of the 2009 Conference on Education and Training in Optics and Photonics).

SPIE is the International Society for Optics and Photonics (www.spie.org) and maintains many excellent resources and tools for teachers and educators.

With regard to the features of an inquiry approach, teachers especially need to gain pedagogical content knowledge enabling them to “engage students in asking and answering scientific questions, designing and conducting investigations, collecting and analysing data, developing explanations based on evidence, and communicating and justifying findings”. This mainly involves teachers being able to:

- Provide questions to frame unit and questions for discussion
- Suggest approaches for using technology as laboratory and cognitive tools.
- Suggest approaches for collecting and analysing data.

- Support students in designing their own investigations.
- Suggest approaches to help students construct explanations based on Evidence
- Provide approaches for communicating science knowledge.

V. Industrial Content Knowledge

There are numerous industrial applications of light, from communications systems to laser-guided drilling equipment, but a particularly interesting and, from the students' perspective, contemporary area is display and image-capture technology. Examples of industry links to the activities within the unit are:

Activity	Relevance to Industry
1.1 Sources of light	Solids and gases are used in LCD and plasma screens to produce white/coloured light
1.2 How does light travel?	Altering the direction of light so each eye sees a different image is the basis of 3D lenticular displays such as those used in the Nintendo 3DS
1.4 Exploring white light and filters	Some LCD TVs use white light sources and filters to produce red, green, and blue pixels
1.5 Exploring primary colours	RGB pixels are used in virtually all display technology to produce coloured images. Conversely, RGB sensors are used in cameras to record colour images.
1.7 Exploring refraction 2.2 Investigating Snell's law	The refractive index of screens must be relatively constant across visible wavelengths or distortion of the image/colours would occur depending on viewing angle
1.8 Exploring lenses 2.4 Investigating lenses	Lenticular lenses are used in 3D displays that do not require glasses, and are obviously a key part of camera systems
2.5 Optical Storage	Interference patterns form the basis of holography, and holographic 3D TVs are expected to move from development to production stage in the next few years.
2.6 How do sunglasses work?	Polarization of light and acceptance/rejection by polarization filters is the method by which current-generation 3D movies (eg. Avatar, Tintin, etc) display different images to each eye

The activities within the Light unit can be readily shown to have ‘practical’ and ‘technological’ applications beyond the classroom. Professions requiring an understanding of the behaviour of light with regard to imaging technology is not limited to the production of screens and cameras, but includes such areas as computer animation (where scenes are ‘rendered’ or ‘ray-traced’ to provide realistic images), photography and cinematography (the use of filters, lenses, and lighting to achieve a distinctive ‘look’ in films), and in special effects.

VI. Learning Path(s)

Since the Light unit is divided into activity subunits, each of which is largely independent, different directions and emphasis can be taken depending on the requirements of the curriculum or learning aims of the teacher. For example, Activity 1.6 (Exploring Mirrors) replaces the traditional 'parallax and pins' method of determining the relationship between the angle of incidence and reflection from a plane mirror with a method involving straws that students must look through. Although the experiment yields the same end result, the use of straws reinforces the 'ray model' of light since only light travelling through the straws (i.e. in a straight line) is used. Activity 1.6 could therefore be used as a precursor to Activity 1.3 involving the formation of shadows.

Subunit 1: Introducing Light

Activity	Inquiry Type	E-emphasis
1.1 Sources of light	Interactive discussion	Engagement
1.2 How does light travel?	Interactive discussion/demonstration, guided discovery	Engagement, Exploration, Explanation, Elaborate
1.3 Understanding shadows	Guided inquiry	Exploration, Explanation, Elaborate
1.4 Exploring white light and filters	Guided discovery	Exploration, Explanation, Elaborate
1.5 Exploring primary colours	Interactive discussion/demonstration	Engagement, Exploration, Explanation, Elaborate
1.6 Exploring mirrors	Guided discovery	Exploration, Explanation, Elaborate
1.7 Exploring refraction	Interactive discussion/demonstration	Engagement, Exploration, Explanation, Elaborate
1.8 Exploring lenses	Guided discovery	Exploration, Explanation

Subunit 2: Exploring Light

Activity	Inquiry Type	E-emphasis
2.1 Investigating mirror images	Guided discovery	Exploration, Explanation, Elaborate
2.2 Investigating Snell's law	Guided inquiry	Exploration, Explanation, Elaborate
2.3 Studying real and apparent depths	Interactive discussion/demonstration, guided discovery	Engagement, Exploration, Explanation
2.4 Investigating lenses	Guided inquiry	Engagement, Exploration, Explanation, Elaborate
2.5 Optical Storage	Guided discovery	Exploration, Explanation, Elaborate
2.6 How do sunglasses work?	Guided inquiry	Engagement, Exploration, Explanation, Elaborate
2.7 Why are sunsets red?	Interactive discussion/demonstration	Engagement, Exploration, Explanation

VII. Assessment

Although the assessment strategy will ultimately depend on the nature of the curriculum, it is preferable that such strategies would employ both a theoretical test and a practical assignment. Some form of research project might also be considered.

For younger students (Subunit 1) a research project might involve examining a particular piece of technology, such as a Plasma/LCD TV screen or digital camera. The assessment in this case might be based on how well students are able to link aspects of their physics course to its construction and operation. For older students (Subunit 2) a research project might involve a comparison of different technologies, for example CRT and LCD displays, digital and film cameras, different strategies of producing a 3D image (lenticular displays versus polarized glasses), or the differences between CD and Blu-ray read heads.

A practical assignment could be based on any of the activities in the subunits, or experiments on the curriculum that are not specifically covered but related to these activities.

An example of a theoretical test is given at the end of this document. It can be modified for either the younger or older student groupings, and could involve either qualitatively or quantitatively determining the behaviour of light after interaction with a number of optical components. In the case of the older groups, values could be added, for example the wavelength of light or refractive index of the materials.

VIII. Student Learning Activities

Activity 1.1: What are sources of light?

Learning aims:

- Triggering the students' interest in light
- Differentiating between objects that are sources of light and those that are not
- Understanding that sources of light have different properties
- Understanding that light may not necessarily be visible to the human eye

Materials:

Candle, Torch, Infrared TV remote control, Overhead projector/acetate or Whiteboard/marker, Mobile phones (with cameras)

Suggestions for use:

Hand out Worksheet 1.1. The students should be asked to consider what objects they can see in the classroom, and a (brief!) list made of their choices. The discussion should then turn to whether these objects are 'sources of light'.

Next, the students should subsequently attempt to describe the differences between the candle and the torch on the basis of physical characteristics (i.e. is the intensity of light constant, what colour does the source produce, is the source hot, does the source require a battery, etc.). Having developed a list of criteria and expanded this to a number of different light sources, the students should then discuss whether objects that are sources of light have similar properties to those that are not.

This is undoubtedly a difficult exercise and intentionally so! The problem students will face is that other than the obvious 'light sources emit light' it is difficult to find a unifying principle that distinguishes light sources from other objects. This is a relatively robust way of challenging any preconceptions students may have: for example, that light sources need to be electrical in nature or that all objects are sources of visible light because we can see them.

Finally, the IR remote control should be introduced. The students can examine whether this is a source of light using mobile phone cameras and imaging the remote control LED while the teacher presses a button. Although invisible to the naked eye, the sensors used in mobile phones are typically sensitive to the IR light produced.

Possible questions:

- Which of the light sources are also hot? Are all light sources hot?

- Which of the light sources are solids, liquids, or gases?
- Which of the light sources involve chemical reactions?
- If we can see walls, tables, and chairs, are they also sources of light? If not, why can we see them?
- Is there a single physical characteristic that explains why some objects are sources of light and some are not? Does energy play a role in some way?

Activity 1.2: How does light travel?

Learning aims:

- Understanding that light is present in the space around a light source
- Understanding that the direction light travels to an observer may be modelled as a straight line ray

Materials:

Cardboard box with a hole cut in one side, Incandescent light bulb (~40 W), Overhead projector/acetate or Whiteboard/marker

Suggestions for use:

The incandescent bulb is placed in the centre of a darkened classroom and switched on. The students gather close to the bulb and, if they can see light from the bulb, should be asked to raise their hands. They then line up around the walls of the classroom with a large space between each of them and the process repeated. The teacher should then ask whether they would be able to see light from the bulb if they stood in the gaps that were deliberately left between each of them. Finally, the students should face the wall of the classroom and asked to raise their hands if they can still see light from the bulb. The bulb should be turned off for a moment, and then turned back on, and the students asked if they wish to reconsider whether they can see light from the bulb when not facing it. Using the acetate and overhead projector, the bulb is represented by a dot in the centre and the relative positions of the students and their direction of view marked on the acetate with arrows for the three cases. This forms roughly-concentric rings of different diameters. The students should then discuss how they think the light reached them and the teacher should guide this discussion towards conclusions that involve light ‘spreading out’ from the bulb. This can be directly compared to sound waves. They should then discuss how they think light reached their eyes when facing the wall and consider the direction that light appears to travel from the bulb to each observer. The teacher can guide the discussion towards conclusions involving straight line paths or ‘rays’ from the bulb.

The aim of this exercise is to establish in the students' minds that light is a wave, that light exists in the space around them, that light reflects from the wall, and that light can be modelled using rays. These concepts are reinforced in Worksheet 1.2.

As an additional component, the students could be asked to consider where they would need to stand to see the light from the bulb after a box (with a small hole in the side) is placed over it. They can then test their ideas by performing a similar 'hands-up' experiment to that at the beginning of the activity, and can map the positions from which they can see the light from the bulb. This can be used to show the validity of the 'ray' model in predicting where the students need to stand to see the light exiting the box.

Possible questions:

- If you changed the size of the hole in the box, would this change where in the room you could see the bulb?
- What happens to the light that doesn't come out of the hole in the box?

Activity 1.3: Understanding shadows

Learning aims:

- Understanding that a shadow is the absence of light
- Understanding what determines the size of the shadow on a screen

Materials:

Small torches or small incandescent bulbs, Small cardboard squares that are a few cm on each side (to cast the shadow), Retort stands to hold the torch, White sheet to use as a screen

Suggestions for use:

The students begin by drawing the arrangement of apparatus they would require to observe a shadow on a screen. They, then, qualitatively investigate the formation of shadows in an attempt to deduce what parameters affect its size, with the teacher guiding them towards providing answers to the following questions:

1. If the projection screen and torch are fixed in place, how does the size of the shadow change as the cardboard square is moved towards or away from the torch?
2. If the torch and cardboard square are fixed in place, how does the size of the shadow change as the projection screen is moved towards or away from the cardboard square?
3. If the screen and cardboard square are fixed in place, how would the size of the shadow change as the torch is moved towards or away from the

cardboard square?

The challenge for the students is then to try and explain their observations based on what they know about the propagation properties of light.

Possible questions:

- If I place a green bottle in front of the bulb, I see a green 'silhouette' cast on the wall. This grows in size and decreases in size depending on the bottle's distance from the screen and torch. Is this also a shadow?

Activity 1.4: Exploring white light and filters

Learning aims:

- Understanding that white light is composed of many different colours
- Understanding that filters only allow some colours through

Materials:

Torches with a narrow cardboard slit attached, glass prisms, good quality (i.e. theatre quality) red, green, or blue transmission filters, coloured cardboard 'screens'

Suggestions for use:

Hand out Worksheet 1.4.

Each student will project light from the narrow cardboard slit on their torch through a prism and onto a white sheet of paper. They will see the familiar red, orange, yellow, green, blue, indigo and violet rainbow colours. The students are then presented with two alternative explanations for this phenomena: either the prism 'converts' white light into coloured light or white light is a mixture of colours that are subsequently 'separated' by the prism through different angles.

Although students may already know the correct interpretation, they cannot distinguish between these alternatives on the basis of their observations. They should then be asked to suggest an experiment that could resolve this problem. One experiment often suggested is the use of two prisms to show that the spectrum of colours can be recombined to give back white light. This should be done as a demonstration although it does not resolve the problem as presented – even with two prisms it is still not clear whether the spectrum of colours is present in the white light before the interaction with the prisms.

The students should then investigate the use of coloured filters. By placing a red, green, or blue transmission filter between the prism and screen they will observe that only the corresponding colour is transmitted. If they now place this filter between the torch and prism, they will observe that red light is transmitted through the filter, passes through the prism, and arrives at the screen. The students can

repeat this process with different filters, hence proving that white light is a mixture of different colours and these are spatially dispersed by the prism.
The key to this experiment is the quality of the filters. If this poses a problem in terms of quantity, then the activity could be run as an interactive demonstration with students invited to place filters in the appropriate positions and record the results.
A suitable resource for this activity is freezeray.com/physics.htm which gives an interactive applet to investigate the effect of different coloured filters.

Possible questions:

- If the sun produces white light, then what must happen to the light to make leaves appear green in summer?
- In autumn, why do leaves then appear red and orange?
- How are rainbows formed?

Activity 1.5: Exploring primary colours

Learning aims:

- Understanding that white light can be produced by mixing red, green and blue light

Materials:

Overhead projector, sheet of card ~300 x 300 mm with three identical holes approximately 15 x 30 mm in dimension, red, green and blue filters, 3 small plane mirrors, Neutral Density filters with low optical density, magnifying glass

Suggestions for use:

Tape the red, green and blue filters over each of the holes in the sheet of card and position this on the overhead projector to produce three distinct beams of coloured light. Invite students to intercept each primary colour with a mirror, deflect it onto the ceiling or whiteboard and hence observe and note the colour that results when any two beams are mixed and when all three are mixed.
Next, the students should be asked to consider what would happen if the red, green, or blue beam was not as intense as the others – for example, if red was weaker than green, what colour would be produced by mixing them? The students can then test their ideas by placing the neutral density filters on top of each of the coloured filters and mixing the light.
Finally, the students should discuss whether any devices they know of produce different colours by mixing just red, green, and blue light of different intensities. They can verify that a TV, laptop or mobile phone screen does exactly this by examining the pixels with a magnifying glass.

Additional experiment: Using a single red, green, or blue filter and an OHP, project a small coloured spot onto a screen and have the students stare at it for at least 1 minute. Once the filter is removed (and the OHP left on), the students will see a small spot that persists for a moment in their vision that is a different colour to the spot that was projected – most people see red where it was green and vice versa.
The human retina contains cone cells that are sensitive to red, green and blue primary colours. Staring at a red spot breaks down the pigment in the red-sensitive cone cells and when the filter is removed these 'bleached' cells will be less sensitive than the green- and blue-sensitive cones, subsequently leading to the persistence of a spot of different colour. This can be used as a demonstration that the eye is sensitive to primary colours and that our perception of colour is due to red, green, and blue mixing.

Possible questions:

- Is it possible to create white light without using the seven colours of the rainbow?
- If you can create all visible colours by mixing red, green, and blue, then can you detect all colours by just measuring how much red, green, and blue arrives at a sensor?
- Is this how the eye sees colour?

Activity 1.6: Exploring plane mirrors

Learning aims:

- Understanding that light rays travel in straight lines
- Understanding that plane mirrors reflect light
- Understanding that the angle of incidence equals the angle of reflection

Materials:

White sheets of paper, plane mirrors, retort stands, straight drinking straws, pencils, protractors, rulers

Suggestions for use:

The activity begins with students being posed a question of the form: 'If you look through a straw at an object, what direction must the light travel from the object to your eye in order for you to see it?'

The students are then asked to consider the same question but for two straws forming a V-shape. What might one use to get light to alter its direction so that light passing into the first straw could be seen through the second straw? The teacher should guide the discussion towards the notion of 'reflection' from a mirror.

The students can then use Worksheet 1.6 and clamp a mirror at one edge so it is held vertically by a retort stand. The bottom edge of the mirror should be in contact with the mark on the paper. They can then position a drinking straw at some random angle in front of the mirror and attempt to position a second straw so that when they look through it, they will see the reflected light that passed through the first straw.

The students should then be asked how they would need to alter the setup if they changed the angle of one of the straws, or the angle of the mirror.

Possible questions:

- Do you notice anything about the angles the straws have to be in order for light to pass from one to the other?
- Does this relationship hold when the mirror is angled?
- What would happen to light at different points on the mirror if the surface of the mirror was curved inwards or outwards?

Activity 1.7: Exploring refraction

Learning aims:

- Understanding that light is refracted when it travels from one medium to another
- Understanding that light can be reflected from and transmitted through an interface

Materials:

Laser pointers (red, low wattage), large plastic lunch boxes with transparent/semi-transparent walls, salt or milk, water, plastic sheets (e.g. bin bags), plastic spoons, green or blue laser pointer

Suggestions for use:

The plastic sheets are placed on the desks in case of spillage. Students fill a plastic lunch box with water and add salt or milk until the water appears cloudy. Plastic spoons can be used in the case of salt to agitate the water during the investigations. The lunch box should be positioned close to the edge of the desk to allow for a wide range of possible angles.

The students begin by shining the laser pointers from air into the water and investigating how the path of light alters as they change the angle. They should draw a diagram to illustrate what they observe.

Next they investigate how the path of light changes if they shine the laser pointer through the side of the lunch box, through the water, and into the air. Again, they should draw a diagram to illustrate what they observe.

The teacher should then use the green or blue pointer side-by-side with a red pointer to illustrate that light of different colours will refract by different amounts.

Possible questions:

- How does the direction of light change when it travels from air into water?
- How does the direction of light change when it travels from water into air?
- Is it possible to pick an angle so that light travelling from water into air is reflected from the interface between the media?
- Why is not possible to see the beam of laser light passing through the air when it can be seen passing through the water?
- Why does a prism disperse white light into its constituent colours?

Activity 1.8: Exploring lenses

Learning aims:

- Understanding that lenses produce images
- Understanding that lenses do not necessarily ‘magnify’ objects

Materials:

Incandescent bulbs, short focal-length bi-convex lenses, paper ‘screens’

Suggestions for use:

The students should take a bi-convex lens and attempt to form an image of their bulb on their paper ‘screens’. This should take the form of a challenge to see how small they can make their image by changing the relative positions of the bulb and screen.

The students should then be asked to describe what they needed to do to minimise the size of their images and whether the lens ‘magnifies’ the object. Next the students should consider what must happen to the direction of light when it passes through the lens if the image is smaller than the object.

Next the students remove the screen and look through the lens in an attempt to ‘magnify’ the bulb (i.e. in a magnifying glass configuration when the object is inside the focal length). They should then be asked to describe where their eye and the bi-convex lens need to be positioned to produce this ‘magnified’ image. If they now place a screen where their eye was, is an image formed?

The students should consider what must happen to the direction of the light through the lens in order to produce this ‘magnified’ image.

A suitable resource for this activity is freezeray.com/physics.htm which gives an interactive applet to investigate the effect of different types of lenses.

This activity can lead on to discussing how the human eye works and how we can correct for long- and short-sightedness. Again freezeray.com/physics.htm gives an interactive applet to investigate the effect of different types of lenses on the human eye.

Possible questions:

- Why is the image upside-down when it is small? Does this fact change the conclusion as to what happens to the direction of light when it passes through the lens?
- Why is no image formed on the sheet of paper when your eyes can see a magnified image?
- What is the purpose of wearing glasses?

Activity 2.1: Investigating mirror images

Learning aims:

- Understanding that the image in a plane mirror is not located at the mirror surface

Materials:

Three thick whiteboard markers, Plane mirror, Retort stand, Paper, Pencil, Cocktail sticks, Shiny metal tin

Suggestions for use:

The students should initially investigate the phenomenon of parallax by placing one of the markers vertically on their desk and lining up the other two behind it. They should describe what they observe when they look along this line of markers, with one eye closed, and move their head sideways:

- Does the nearest marker appear to move a greater or lesser distance than the farthest marker?
- Where would the markers need to be placed so they appear to move together?

The students should then be asked to determine how they might use this method of parallax to determine where the image in a plane mirror is formed. They can hold the mirror vertically and use the paper to mark the locations of the object pen, the mirror plane, and the image itself. The students should plot the path the light takes to the eye, and the path to the image.

Finally, the students should set their tin on the sheet of paper and attempt to angle a number of cocktail sticks on the paper so that they appear to lie parallel in the tin. They should then attempt to explain how the image is formed in this convex mirror based on their understanding of ray optics.

Possible questions:

- Does the angle of incidence equal the angle of reflection for a curved mirror?
- How does the curve affect the direction of light reflected from different points?
- Where is the image formed in the convex mirror? What if it was concave?

Activity 2.2: Investigating Snell's Law

Learning aims:

- Understanding that Snell's Law describes the change in direction of light moving from one medium to another
- Understanding that at some angle, light will totally reflect from the interface when travelling from high to low refractive index

Materials:

Red laser pointer, Block of glass, White paper, Pencil, Protractor

Suggestions for use:

The students should be given the materials and asked to discuss how they might go about studying what happens to the direction of light when a laser passes from air into glass and back into air. The students should examine questions such as:

- How will I determine the direction that light takes through the glass?
- How will I measure and quantify the direction into and through the glass?
- How will the measurement be standardised so that the results from different people can be compared and combined?
- Which parameters of the experiment should I keep constant and which should I alter?
- Once I take my data, how will I tabulate and graph it to investigate the relationship between the direction of light into and through the glass?

Next, the students perform the experiment they have devised and report their results in **Worksheet 2.2**. If they have standardised their measurements, the data can be entered into a software package such as Excel and projected on a screen for the students to see. A plot of 'angle of incidence' versus 'angle of refraction' will not yield a straight-line graph and the teacher should then show the students how this changes if the Sine (or Cosine, depending on whether the students have measured the angle from the normal or surface of the glass) of the angles are plotted. The students can then use the slope of this line to extract the 'refractive index of glass' (assuming the refractive index of air is 1) and hence extract Snell's Law. Finally the teacher should check if the data contains evidence that at some angle the light did not escape from the block of glass, and whether any student reports this observation. If not then the students should be instructed to check this, and discuss why they failed to discover this phenomenon.

Possible questions:

- What property of the light changes to cause the change in angle as it passes from one medium to another?
- Is light reflected from the surface of the glass when the beam travels from air to glass? Does this reflected beam change in intensity as the angle of light onto the surface changes?
- How might we use the total internal reflection of light to transmit a laser beam?

Activity 2.3: Studying real and apparent depths

Learning aims:

- Understanding that the refraction of light alters its direction
- Understanding that refraction can affect the appearance and apparent depth of objects
- Understanding that comparing the real and apparent depths gives a measure of refractive index

Materials:

Graduated cylinders of different volumes, Coin, thin circle of Cork with a diameter equal to that of the coin, Mobile phones (with cameras)

Suggestions for use:

The students should drop the thin slice of cork into the graduated cylinder. Placing their mobile phone on the top of the cylinder, they take a photograph of the cork. It is important that the same optical/digital zoom settings are used throughout the experiment. They then add some water and measure its height inside the cylinder before photographing the now-floating piece of cork. The students should repeat the process at least six times for different water levels and finally should measure the height of the cylinder itself.

The purpose of this exercise is to allow the creation of a 'calibration graph' that relates the diameter of the cork circle in image pixels to its distance from the camera (obtained by subtracting the height of the water in the cylinder from the height of the cylinder).

The students then empty the cylinder and drop a coin to its base. They photograph the coin in the absence of water, then completely fill the cylinder and photograph the coin through the water. By comparing the diameter of the coin (in pixels) when imaged through the water to their calibration graph, they can determine the apparent depth of the coin. This analysis can be performed by the students at home. Since each student will have used different levels of water, a graph of real depth versus apparent depth can be created in Excel that includes data from each

of the students. The slope of this graph then gives the refractive index of water.
One simple method of analysing the images is to load them into software such as Microsoft Picture Manager (found in Office tools) and crop the photo so that only the coin remains. Since the coin is circular, the image dimensions then give the diameter in pixels. The experiment provides a good introduction to a number of topics. Firstly, the calibration graph will not be linear and so students must draw 'best fit curves'. Secondly, it provides a good example of experimental errors – cameras with a higher megapixel count will be more accurate than those with lower counts, and the apparent diameter of the coin is related to both the height of the cylinder (i.e. the distance of the camera from the base of the cylinder) and the height of water added.

Possible questions:

- Why does a swimming pool look shallower than it actually is?

Activity 2.4: Investigating lenses

Learning aims:

- Understanding that the lens equation describes the position of the image, given the object position and focal length
- Understanding that the magnification of a lens is given by the ratio of image to object distance

Materials:

Stands to hold (1) Bulb, (2) Short focal-length convex lens, (3) Paper screen, Metre rule, Pencil

Suggestions for use:

The activity can progress in one of two directions: either the students have previously studied the lens equation and the experiment will subsequently test the law, or the students have not studied the equation and will derive it on the basis of their results.
Firstly, the students should determine the focal length of their lens or verify the value given. This can be achieved by focusing light from a distant object (the ceiling lights are a good source) onto the desk and measuring the height of the lens from the table. The students should then discuss the method by which they will investigate the relationship between object and image distance using the equipment supplied, and how they will graphically show the relationship. The teacher should guide this discussion so that students will standardise all

measurements of distance to be relative to the lens.

The students can then conduct an experiment by which they fix the screen in place, adjust the position of the bulb relative to the screen, and subsequently move the lens to produce an image. They should record and tabulate their data into columns corresponding to object distance, image distance, and focal lengths. To investigate the magnification, students should also measure the width of the bulb filament they observe on the screen for each combination of image/object distance and compare this to the actual width.

The students should then plot a graph of the relationship between image and object distance. For students who have not covered the lens equation, the natural tendency will be to plot object distance versus image distance (or vice versa) which will generate a curved graph. The teacher should discuss with the students what this shape might indicate in terms of the relationship, and the students can subsequently plot the reciprocal of object distance versus the reciprocal of image distance to yield a straight line.

Possible questions:

- If you examine the x and y intercepts of the graph, what does this relate to? (1/f)
- What is the equation of the line if M is the slope? (M=v/u)
- How does this slope relate to the width of the filament at each object/image combination?

Activity 2.5: Optical Storage

Learning aims:

- Understanding that light can be diffracted by small objects
- Understanding that examining the diffraction pattern can tell us the dimension of those objects
- Understanding that the diffraction pattern depends on wavelength

Materials:

CD, DVD and/or Blu-ray discs, Red laser pointer, Retort stand, Graph paper 'screen', adjustable slits

Suggestions for use:

The students should be asked to consider the differences between a CD and DVD/Blu-ray disc with the discussion being guided towards the amount of information each disc can store (CD: 740 MB, DVD: 4.7 GB, Blu-ray: 25 GB for

single sided discs). They should then be asked to compare the physical size of each disc (120 mm diameter x 1.2 mm thick) and discuss why, if the discs are the same physical dimensions, the information content is different. Hand out Worksheet 2.5. The students then set up their laser so it is incident at some angle on the CD surface and should observe and sketch the diffraction pattern observed on the screen. If the students have not previously covered the topic of diffraction, they are likely to explain this pattern in terms of reflections from multiple objects. This observation will conform to their knowledge of CDs having 'pits' on the surface. They then replace the CD with a DVD and should note that the pattern is now broader. These observations should now be related to the amount of information stored on each disc. The conceptual difficulty students may encounter is that the pattern obtained from a DVD seems broader, which they may attribute to larger features on the DVD. However, the storage capacity of the DVD is larger than a CD, which suggests the features should be smaller! The students should then investigate how the diffraction pattern changes as laser light is passed through a slit that is made progressively narrower. This serves to reconcile the broad pattern obtained from the DVD and the smaller features on that disc. The exercise can be used as an introduction to diffraction, with the teacher providing the subsequent theory.
Possible questions:
• What does the size of the pits mean in relation to the amount of information that can be stored on the discs? • Why are red lasers used to read CDs but blue lasers are needed for Blu-ray discs? • Why do optical microscopes have a limit on their magnification?

Activity 2.6: How do sunglasses work?

Learning aims:

- Understanding that light can be polarized
- Understanding that the intensity through two polarizers may be described by Malus's Law

Materials:

Two polarizers, two neutral density filters

Suggestions for use:

The students should be asked to discuss how sunglasses work. Typical responses will involve 'coloured glass/plastic' that 'only allows some of the light through' which could be used as a starting point for a discussion on absorption, filters, and energy.
Next, the students are invited to examine the properties of 'neutral density' filters of the kind found on most sunglasses and asked to consider the following questions:
If each filter only allows 50% of the light through it, what percentage is transmitted through both filters when placed on top of one another?
This question establishes that the total transmission is found by multiplying (50% of 50% is 25% or 0.50 x 0.50 = 0.25). The students are then posed the question as to whether the order or orientation of the filters makes a difference.
The students are then given Polaroid filters and asked to examine their properties:
Does the relative orientation of the filters change the light intensity transmitted? If zero degrees is defined as the relative orientation providing maximum throughput, what relationship in terms of angle gives minimum throughput?
Does the order of the filters make a difference?
The Worksheet includes an optional experiment utilising a data logger to examine Malus's Law.

Possible questions:

- How can you use a polarizer to remove reflections from a surface?
- How do 3D movies work and why do you have to wear glasses?

Activity 2.7: Why are sunsets red?
Learning aims:
• Understanding that light can be scattered by small particles • Understanding that scattering is wavelength dependent
Materials:
Large transparent plastic or glass container of water, Projector or Overhead projector, White screen, Dropper containing Dettol
Suggestions for use:
The container of water should be placed in front of the projector and a beam of white light passed through it. Alternatively, a circular hole can be cut in a sheet of card and placed on an overhead projector. The container should then be placed over the card to allow the circular beam to pass through the water. The students should be asked to consider how the on-screen spot of light will change as Dettol is added to the water. The teacher then gradually adds a few drops of Dettol, causing the transmitted light to change colour from yellow, through orange, to red. The students should be asked to explain what they think is happening and should be invited to examine the colour of light escaping from the sides of the water container (blue light).
Possible questions:
• What is the difference, in terms of the wave model, between blue and red light? • What property of the Dettol determines which wavelength is scattered? • Why is the sky blue during the day and red at sunrise and sunset? • Why are clouds white?

SOUND

The development of this unit has been led by the ESTABLISH partners:

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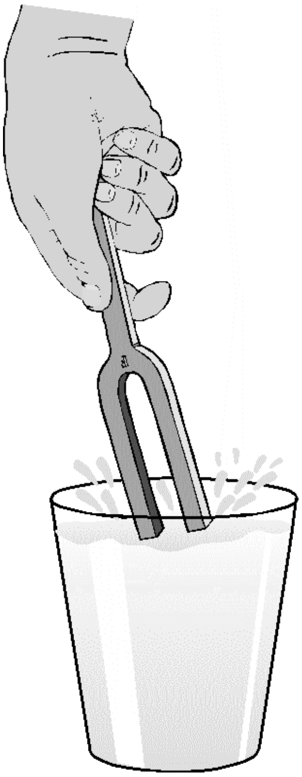


UNITS CONTENTS

I. Unit Description

The unit Sound is divided into 3 subunits, which can be used independently or sequentially. Each subunit can take different directions and emphasis depending on the curriculum and particular learning aims of the teacher.
The subunits 1 and 2 can also be used in a spiral type curriculum with subunit 1 focussed at an introductory level and subunit 2 at the higher stages of secondary school level.
The subunit 3 offers an extension for higher secondary school level and introduces students to the fascinating area of human speech.

The Sound unit is enriched with many ICT activities in which a sound sensor, an interface and software are used to record sound and to analyse the resulting sound waveforms.

Subunit 1: Exploring sound

In this subunit students study the basics of physics of sound. They learn that sound is caused by vibrations, and they explore how sound travels. They learn about the relationship of loudness and pitch to the amplitude and frequency of vibrations. They investigate the sounds of the human vocal cords. They also learn about the anatomy and functioning of the human ear and sound protection.

- **Student level:** Lower secondary school level, students of age 11-15
- **Discipline involved:** Physics
- **Estimated duration:** 5-6 class periods

Subunit 2: String instruments and wind instruments

This subunit starts with an experiment of resonance in a model of a swing. Students can feel that a minor influence can give a great effect. Further on, students perform experiments with strings, including double bass, guitar and the Melde's experiment on standing waves. After experiments involving sound in air columns follow. At the end of this subunit, some open inquiries are described that students can choose from. The knowledge build in activities 1 to 7 is a good basis to start to work on each of the activities 9 – 11.

- **Student level:** Higher secondary school level, students of age 15-17
- Discipline involved: Physics
- **Estimated duration:** 5-7 class periods and 2 class periods of independent working time

Subunit 3: Human speech

In this subunit students study the principles of human speech, speech analysis and synthesis. They learn fundamentals of human speech production, they record different sound signals and learn how to read and interpret a time signal and a spectrogram. They study how the human speech can be artificially produced.

- **Student level:** Higher secondary school level, students of age 16-19
- **Discipline involved:** Biophysics (Physics, Biology)
- Estimated duration: 3 class periods

II. IBSE character

Subunit 1: Exploring sound

To introduce a new subject like sound, the teacher should address the student's curiosity with questions involving both known, or seemingly known, concepts and unexpected holes in their understanding. This approach is therefore a form of the inquiry-based method of 'teaching by questioning'. The main problem here for most teachers is the delicate balance between not saying too much and not answering too soon while at the same time keeping track of time and not letting the students go astray into unrealistic and unprofitable directions. Having said that, it should be emphasized that not every scientifically unacceptable scenario or solution is necessarily unprofitable. A proposed explanation may at the one hand be incorrect but may at the other hand contain nice elements of scientific thinking and motivation to solve the problem.

Being introductory at an elementary level, the main IBSE approaches employed here are reflective discourse, interactive demonstration, guided discovery and guided inquiry. Through the activities in this subunit students develop basic abilities to do and understand scientific inquiry.

- Asking and answering questions.
- Planning and conducting simple investigations.
- Employing tools to gather data.
- Using data to construct reasonable explanations.
- Communicating investigations and explanations.
- Understanding that scientists use different kinds of investigations and tools to develop explanations using evidence and knowledge.

Some activities are ICT activities in which a computer with sound sensor is used to record sound waveforms.

Subunit 2: String instruments and wind instruments

The context of a guitar or other string instrument will trigger the student to do their own investigations. What knowledge is required to build a guitar? Which physical laws are there to keep in mind when building a guitar? To get to know this, students analyse the playing of a double bass and the frets on a guitar. The knowledge gathered in these activities is applied to the new context of air columns in wind instruments.
The main IBSE approach in this subunit are guided discovery and open inquiry.
Inquiry based skills developed in this unit are amongst others:

- Performing experiments.
- Analyzing results obtained with experiments (or presented by the teacher).
- Communicating results with the use of graphs.
- Using results from one experiment (double bass) to analyze the results of another experiment (frets of a guitar).
- Using knowledge from one field of acoustics (strings) in another field of acoustics (air columns).

In some activities the computer is used to record sound and to analyse the data.

Subunit 3: Human speech

The speech analysis and speech synthesis activities in this subunit are open inquiry assignments. In these activities students have to formulate their own research questions. This type of assignment is generally considered to be the highest level of inquiry-based learning. In these activities student develop many fundamental skills of inquiry-based science education like diagnosing problems, critiquing experiments, planning investigations, searching for information, constructing models, debating with peers, forming coherent arguments.

Afterwards, students should express their understanding in a discussion with their peer students and the teacher, and or share their reports with another group for peer reviewing. In this way, they confront and share their preliminary (group) conclusions with others and come to final conclusions and explanations they construed themselves.

It is expected that students gain a deeper understanding of the phenomena in this approach and will probably remember the “new” knowledge longer through the process of internalization.

III. Science Content Knowledge

Subunit 1: Exploring sound

In this subunit, students are not supposed to have any (formal) prior knowledge of the subject but some understanding of the concepts from their everyday life.
The activities in this subunit introduce students to the following concepts and ideas:

- Sounds are produced by vibrating objects and vibrating columns of air.
- Pitch and loudness are two characteristics of sound.
- Changing the way an object vibrates can change the pitch or volume of the sound produced
- Pitch is determined by the frequency and loudness by the amplitude of vibrations.
- Sound is produced by human vocal folds as air moves through the tightened folds.
- Sound requires a medium (for example, air, glass, metal, wood) to travel through.
- Speed of sound is less than the speed of light.
- The human ear has a membrane that vibrates when sound reaches it; the ear and the brain translate these vibrations into sensation of sound. Exposure to very loud sounds can cause damage to hearing.

Subunit 2: String instruments and wind instruments

As pre-requisite knowledge, students are supposed to be familiar with the concepts: wavelength, amplitude, frequency, period, sine function. Of course these concepts should be repeated in this subunit but a basic understanding is required to build new knowledge.

The activities in this subunit introduce the students to the following concepts and ideas:

- Resonance
- Fundamental frequency
- Harmonics
- Standing waves
- Relation between the frequency and length of string/air column
- Timbre.

As a source for the teacher, the available physics courses should be appropriate. There are also numerous books that describe the relation between physics and music.

A recommended source, focusing on the physics of musical instruments is the book "Measured tones, the interplay of physics and music" by Ian Johnston (ISBN-10: 0750307625 ISBN-13: 978-0750307628).

Subunit 3: Human speech

The activities in this subunit introduce students to the human speech production mechanism, human speech analysis and synthesis. The content is both about biology and physics. For biology students learn about the human vocal system and how the human speech is produced. In physics they create a model to describe how the human speech is produced, they analyse the human sounds and learn how human sounds can be created artificially.

As pre-requisite knowledge, students are supposed to know the concepts frequency, amplitude, standing waves, resonance, fundamental frequency and harmonics, and should be able to handle those both qualitatively and quantitatively.

Since this unit goes beyond a traditional school curriculum a model of human speech production is given as reading text for students in the Worksheet: Model of human speech production. The text is based on an article of Johan Sundberg "The acoustics of the singing voice", Sci. Am. 236, 82 (March 1977).
Some useful resources:

- Johan Sundberg "The acoustics of the singing voice", Sci. Am. 236, 82 (March 1977) (see http://www.zainea.com/voices.htm)
- Timothy Moran, "Application of sound spectrum analysis", Phys. Teach. 45, 94 (2007)
- Klaus Fellbaum, Jorg Richer, 'Human speech production based on a linear predictive vocoder", ESCA/Socrate workshop on Method and Tool Innovations for Speech Science Education (1999), see http://www2.spsc.tugraz.at/add_material/courses/scl/vocoder/.
- The Java simulation 'Model of the Human Speech Production' allowing sound analysis and synthesis is available at: http://www2.spsc.tugraz.at/add_material/courses/scl/vocoder/simulation.html

IV. Pedagogical Content Knowledge

General common students' difficulties identified by Science Education Research around "Sound" are:

- Sounds can be produced without using any material objects.
- Hitting an object harder changes the pitch of the sound produced.
- Loudness and pitch of sounds are the same things.
- The pitch of a tuning fork will change as it "slows down", (i.e. "runs" out of energy)
- Frequency is connected to loudness for all amplitudes.
- Human voice sounds are produced by a large number of vocal cords that all produce different sounds.
- Sounds can travel through empty space (a vacuum).
- Sounds cannot travel through liquids and solids.
- Sound moves faster in air than in solids (air is "thinner" and forms less of a barrier).
- Sound moves between particles of matter (in empty space) rather than matter.
- You can see and hear a distinct event at the same moment.
- Music is strictly an art form; it has nothing to do with science.
- In wind instruments, the instrument itself vibrates (not the internal air column).
- Sound waves are transverse waves (like water and light waves).
- Waves transport matter.
- Waves do not have energy.
- All waves travel the same way.
- Big waves travel faster than small waves in the same medium.
- When waves interact with a solid surface, the waves are destroyed.
- Ultrasounds are extremely loud sounds.
- Noise pollution is annoying, but it is essentially harmless.
- Sounds made by vehicles (like the whistle of a train) change as the vehicles move past the listener because something (like the train engineer) purposely changes the pitch of the sound.
- In actual telephones, sounds (rather than electrical impulses) are carried through the wires.

Students have to apply their knowledge in new situations and this might reveal misconceptions. The teacher should be aware of this, with asking questions to the student the teacher can make the student reflect on their pre-knowledge.

By giving answers or presenting data the students can work with, the character of the activity can become more closed. For example, without the graph or the demo on YouTube, the activity about harmonics in the subunit 2 is bounded inquiry. The question asked is ‘in what ways might a string vibrate?’ and the students have to find their own way to answer this question. If students have enough prior knowledge and endurance, they are able to come up with the preferred answers. If not, the teacher has to decide how much he wants to help them (by doing a demo, presenting the graph or showing the YouTube movie).

An unpredictable variety of alternative or even misconceptions in the understanding of the content of the Human speech subunit is to be anticipated, as speech is such an everyday phenomenon that probably everyone has created his own model or mental picture of it. Special attention has to be devoted to common frequently felt obscurities like:

- How can it be that the same vowel pronounced by different persons may sound completely different, yet one is able to recognise the vowel as such immediately?
- What are formants and in what way do they differ by age and gender?
- Is the recorded spectral sound-pattern reproducible and recognizable?

It is here that the IBSE approach comes into play to provide a more tangible picture of the phenomenon of speech to the students. One may expect that the understanding achieved by own discoveries is less superficial and more concrete, as it is more linked to reality.

V. Industrial Content Knowledge

Subunit 1: Exploring sound

To start illustrating the relevance of sound to industry at this introductory stage, finding and mentioning professions (rather than the industries themselves) may be more effective. With sound the industrial applications are clear almost immediately e.g. through professions like musician, sound technician (TV broadcast), sound mixer (concert), audiometrist (selling hearing aids), audiologist (making audiograms), acoustic engineer, speech-trainer.

For example an audiologist can be invited to visit the class during activities about sound hearing and sound protection to answer questions prepared by students.

To engage students in technological design they could design and build their own simple models of the human eardrum or vocal cords.

Subunit 2: String instruments and wind instruments

There is a lot of physics involved in designing and producing musical instruments. For an existing instrument, one can make adjustments to change the sound of it. There are differences between guitars and students can do research on which instrument sounds better. How is better defined, can you do scientific measurements to find out which instrument is better? How well tuned is a guitar, what are the right positions for the frets on the fret board? What is meant with the timbre of an instrument? The basic knowledge to start answering these questions is implemented in the activities. In an open inquiry students will be able to answer (some of) the above questions.

Examples of industry links for activities in this subunit are:
2.1. Resonance – constructions of buildings or bridges;
2.2. Fundamental frequency; double bass – designing musical instruments;
2.3. Fundamental frequency; guitar – designing musical instruments;
2.4. Melde's experiment – constructions of buildings or bridges;.
2.7. Standing waves in air, soprano saxophone – differences and similarities of wind instruments: clarinet, saxophone and oboe.

Subunit 3: Human speech

The first speech recognizer appeared in 1952 and consisted of a device for the recognition of single spoken digits. There are many domains for the commercial application of speech recognition for example:

- Health care – for converting voice-recorded reports as dictated by physicians and/or other healthcare professionals, into text format; medical analysis of voice problems.
- Military - speech recognizers have been operated successfully in fighter aircraft, with applications including: setting radio frequencies, commanding an autopilot system, setting steer-point coordinates and weapons release parameters, and controlling flight displays.
- Telephony - speech recognition is used mostly as a part of the user interface, for creating pre-defined or custom speech commands.

Scientists have attempted to simulate human speech since the late 1700s, when Wolfgang von Kempelen built a "speaking machine". By the 1970s digital computing enabled the first generation of modern teach-to-speech systems with fairly wide use. Speech synthesis is now an assistive technology tool which use is significant and widespread. The use of it includes delivery of up-to-the-minute news, reading machines for handicapped, automotive voice controls and retrieving email over the phone – or any systems where the vocabulary is large, the content changes frequently or unpredictable, and a visual display isn’t practical. Speech synthesis techniques are also used in entertainment productions such as games and animations.

VI. Learning paths

The topic of sound as outlined in this unit is made up of a series of subunits with a series of activities. Each subunit can take different directions and emphasis depending on the curriculum and particular learning aims of the teacher. The activities could be formulated in various different combinations to achieve the overall learning outcomes envisioned for the subunit. However in this section we outline one possibility of the order and flow of the activities.

Subunit 1: Exploring sound

This subunit consists of 9 activities. The exemplary sequence of activities, in which all activities are used, is given in the table below sequence.

Activity	Inquiry Type	E-emphasis
1.1 Introduction to sound	Interactive discussion	Engagement
1.2 How sounds are made?	Guided inquiry	Engagement, Exploration, Explanation, Elaborate
1.3 Make sound visible	Guided inquiry	Exploration, Explanation, Elaborate
1.4 Analysis of voice sounds	Guided discovery	Engagement, Exploration, Explanation
1.5 How sound travels?	Interactive demonstration/ Bounded inquiry	Engagement, Exploration, Explanation, Elaborate
1.6 How fast sound travel?	Guided discovery	Engagement, Exploration, Explanation, Elaborate
1.7 Hearing sound	Guided inquiry	Explanation, Evaluate
1.8 How loud is too loud?	Guided inquiry	Explanation, Evaluate
1.9 What have you learned about sound?	Interactive discussion	Elaborate, Evaluate

Subunit 2: String instruments and wind instruments

In the table below, the activities are stated in the advised order. The activities 1-7 are mandatory and required to build the knowledge on sound. The activities 8, 9 and 10 are meant to test and evaluate the knowledge built in this subunit. These activities can be done independent from each another. Students can choose one or two activities and for instance present these to the rest of the class.

Activity		Inquiry Type	E-emphasis
2.1	Resonance	Guided discovery	Engagement
2.2	Fundamental frequency, double bass	Guided discovery	Exploration
2.3	Fundamental frequency, guitar	Guided inquiry	Explanation
2.4	Melde's experiment	Interactive demonstration	Extend, Exploration
2.5	Harmonics of the guitar	Bounded inquiry	Exploration, Evaluate
2.6	Standing waves in air; air column	Bounded inquiry	Evaluate
2.7	Standing waves in air; soprano saxophone	Guided inquiry -> Open inquiry	Elaborate
2.8	Timbre	Open inquiry	Elaborate, Evaluate
2.9	Beats	Open inquiry	Elaborate, Evaluate
2.10	Tuning the guitar	Bounded inquiry	Elaborate, Evaluate

Subunit 3: Human speech

This subunit consists of 5 activities. The following sequence of activities is recommended. Activities 4 and 5 are similar open-inquiry assignments. Half of the class could perform Activity 4 and half Activity 5.

Activity		Inquiry Type	E-emphasis
3.1	Sound graphs	Guided inquiry	Engagement
3.2	Model of human speech production	Interactive discussion	Exploration, Explanation
3.3	Sound signal analysis	Guided inquiry	Exploration, Explanation
3.4	Human speech analysis	Open inquiry	Extend, Elaborate
3.5	Human speech synthesis	Open inquiry	Extend, Elaborate

VII. Assessment

Subunit 1: Exploring sound

Preferably, the students' assessment includes both a theoretical test (understanding basic concepts, understanding of sound waveforms) as well as a practical assignment.

Subunit 2: String instruments and wind instruments

The assessment might include both a theoretical test and a presentation about an experiment or literature research. These presentations can differ for the (groups of) students.

Subunit 3: Human speech

Preferably, the student's assessment includes both a theoretical test and a practical assignment. The theory of speech analysis may be tested as part of a school exam on waves and oscillations.

Students can write a report on the findings of their practical assignment (open inquiry activity) and present their results to the rest of the class. In addition, they share the data acquisition/analysis part in digital form.

VIII. Student learning activities

Activity 1.1. Introduction to sound

Learning aims:

- Developing a concept map to realize the richness of sound as well in terms of physics as well in terms of everyday life
- Triggering student's' interest and curiosity about sound

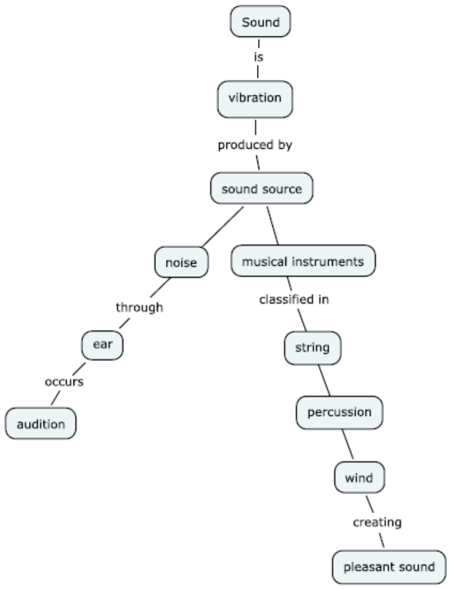
Materials:

- Laptop/data projector, or Overhead projector/acetate, or Whiteboard/marker

Suggestions for use:

Let students shut their eyes and be still and silent for 3 minutes. Tell them to concentrate on what they hear. Have students open their eyes and list the sounds they heard.

Then, together with the students, develop a concept map to ascertain student's prior knowledge and to gain information regarding preconceptions students may have in relation to the topic of sound.



While doing this allow students to collectively give their opinions on what they know about sound, each time writing up the ideas onto the concept map. Try to group similar terms or ideas together so that by the end of the class discussion you have a concept map with a structure, which will relate to the series of lessons that you will teach on this topic. Allow students, as a group, to tell you all they know about sound. There may be some idea's missing from your concept map that you intend to cover in the lessons, or ideas that you feel students may have just forgotten about. Ask probing and guiding questions to get students to think about and come up with the ideas that relate to content but are missing in the concept map.

Possible questions:

- What do you know about sound?
- What makes a sound loud/soft?
- What was the loudest sound ever heard?
- What makes a sound pleasant/unpleasant?

- What makes a sound high/low?
- How do you think sound travels?
- How do we hear sounds?
- How do blind people use sounds “to see”?
- How do music and noise differ?
- How do musical instruments make their sounds?

Activity 1.2. How sounds are made?

Learning aims:

- Understanding that sounds are produced by vibrations of objects or columns of air
- Understanding that sound is a form of energy

Materials:

- An elastic ruler (metal, wooden), a rubber band, tuning fork, a drum, a pipe, other musical instruments e.g. guitar, violin, flute etc.

Suggestions for use:

Divide the class into small groups and hand out tuning forks, drums, rulers, and musical instruments. Ask students to produce sounds with given objects.
Then hand out **Worksheet: How sounds are made? (Part I)** and let students do investigations. They have to answer a set of questions for each, investigated object. While the students are carrying out the investigations walk around the room asking each group questions to probe students’ understanding. Once they have completed their investigations discuss with them: - how sounds are produced (providing energy), - what is the object doing as it produces the sound (vibrating), - how long does the sound last (as long as the object vibrates), - how the sound can be stopped (by “damping” vibrations), - how to change the properties of the sound (e.g. by changing the characteristics of the vibrating object).
Hand out Worksheet: **How sounds are made? (Part II).** Let students identify what vibrates to make the sound of instruments showed on the pictures. Ask them to come up with other examples of creating sounds.

Possible questions:

- How does the object produce sound?
- How energy was provided to the object to produce the sound?

- What is the object doing as it produces the sound?
- How long does the sound last?
- How can you stop the sound?
- How can you make the sound higher or lower and softer or louder?
- Do you see the ends of the tuning fork vibrating? Why or why not?
- How sound is produced by an organ pipe or flute? What vibrates there?
- How sound is produced by a guitar or violin? What vibrates there?

Activity 1.3. Make sound visible

Learning aims:

- Learning how to record sound with a sound sensor
- Interpreting the recorded sound waveform graphs
- Understanding that the sound signal is changing periodically
- Introducing concepts of frequency, pitch and loudness
- Exploring how the sound waveform is changing by changing loudness and pitch

Materials:

- A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6)

Suggestions for use:

Start the activity by asking students: 'What do you think a sound would look like if we could see it?' Have student volunteers come up to the board to illustrate.

Divide the class into groups, hand out **Worksheet: Make sound visible (Part I**) and let students do their own investigations with a sound sensor and tuning forks. If needed, help students to set up the experiment and perform measurements with the computer.

Hand out **Worksheet: Make sound visible (Part II),** discuss the recorded sound waveform and let students calculate the frequency of the recorded sound signal. Then let them perform Investigation 1 and 2 and summarize their findings by defining the properties of sound: loudness (defined by sound amplitude), pitch (defined by sound frequency).

Possible questions:

- How sounds can be made visible?
- What is the frequency of vibrations?
- Determine the frequencies of the tuning forks used in your experiments? How did you figure this out?
- Can you notice any relationship between the tuning forks appearance and the sound they produce?
- What determines pitch?
- What determines loudness?

Activity 1.4. Analysis of voice sounds

Learning aims:

- Understanding that the vibration of vocal cords creates our voice
- Interpreting sound waveforms of a variety of voice sounds
- Understanding differences between sound waveforms of different voice sounds

Materials:

- A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6)

Suggestions for use:

Divide the class into small groups, hand out Worksheet: Analysis of voice sounds (Part 1) and let students do activities described under Observation and Investigation. Then discuss with them how voice sounds are made.
Then divide students to work with computers, hand out **Worksheet: Analysis of voice sounds (Part II)**. Let them do their own investigations with a sound sensor. If needed help students to set up the experiment and perform measurements with the computer.
Once students have completed their investigations summarize the results of their investigation by discussing the results of their experiments.

Possible questions:

- How voice sounds are made?
- How the vocal cords work?

- What is the difference in waveforms of tuning fork and voice sounds?
- What is the difference in waveforms of different vowels?

Activity 1.5. How sound travels?

Learning aims:

- Recognising that the sound needs a medium to travel
- Understanding that sound travels through different mediums, including solids, liquids, and gases

Materials:

- Sound source, bell jar, vacuum, a string telephone, balloon with water, water, different medium for example wood, metal, glass, plastic, ceramic etc.

Suggestions for use:

Hand out **Worksheet: How sounds travel (Part I)**, let students read and answer questions.

Then show them the following demonstrations:

Place five coins, in a line next to each other, flat on the table. Flick a sixth coin so that it hits the first coin in the line. Last coin in the line will move.

Place an alarm clock or an electric bell in a large bottle. Let the bell ring in air. Then pomp the air out of the bottle and let the bell ring in a vacuum.

Place a candle in front of a speaker. Turn on the speaker (frequency 5 – 10 Hz). The flame flickers indicating air movement. (Instead of the demonstration the included video can be displayed).

1. Use a coiled spring (slinky); send pushes and pulls along the spring.

Discuss with students their observations and help them to construct the following ideas:

1. Energy can be transmitted through the particle of a substance.
2. Sound needs a medium to travel through; it cannot be transmitted in the absence of particles.
3. Sounds waves are alternate compressions and expansions caused by the back-forth motion of the particles of a medium.

Divide the class into groups and hand out **Worksheet: How sounds travel (Part II)**. Give each group a sound source and materials to investigate. These can be two cans (or paper cups) connected with a string, a balloon with water, book, and different medium like wood, metal, glass, plastic, ceramic, etc. In this activity

students are asked to design their own investigation to find out if sound can travel through different materials and through which material(s) sound travels the best. Walk around and give students some tips if necessary. Ask them about the designs of their (fair) investigations. Finally let each group present their conclusions, allow students to debate their reasoning.
Possible questions:
• How sound energy is transmitted? • Why can you not hear the bell ringing in the jar? • Can you hear the sound from a sound source when it is held in the air? • What medium was the sound travelling through in this case? • Does sound travel through string? • Can you hear your partner better when the string is wet or dry? • Does sound travel through glass? Wood? Etc? • Do sounds get weaker with distance?

Activity 1.6. How fast sound travels?

Learning aims:

- Understanding the speed of sound is lower then the speed of light
- Determining the speed of sound in air by using the echo method
- Understanding that the speed of sound depends on the medium

Materials:

- A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6), 1-m long cardboard or plastic tube

Suggestions for use:

Hand out **Worksheet: How sounds travel (Part I)**, let students read and answer Show a video clip of lightening in the sky. Hand out Worksheet: How fast sound travels? (Part I) and ask students to answer question 1. Discuss with students why we see the light before we hear the sound.
Then divide students into groups to work with computers. Hand out Worksheet: How fast sound travels? (Part II) and let students perform computer measurements to determine the speed of sound in air. If needed help students to set up the experiment and perform measurements with the computer.
Once students have completed their investigations compare the sound speed values determined by students with the theoretical value. Here you can also discuss more examples of the use of echoes (ships navigation, animals using "echolocation" etc.)
Let students find out the speed of sound in other materials. Discuss whether sound travels better in liquids, gases, or solids?

Possible questions:

- Why do you see lightning before you hear thunder?
- What is the measurement method used to calculate the speed of sound in air?
- How do you calculate the speed?
- What do you think can influence the speed of sound?
- In which materials the speed of sound is the highest?
- In which materials the speed of sound is the lowest?

Activity 1.7. Hearing sound
Learning aims:
• Understanding that the ear detects sound vibrations • Understanding how the human ear works • Understanding that human hearing range lays between 20 and 20000 vibrations per second
Materials:
• A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6), a model of the human ear
Suggestions for use:
Hand out **Worksheet: Hearing sound** and let students read and answer questions 1 to 3. Then discuss how the human ear works. To visualize it you can use an animation, for example: http://www.sciencekids.co.nz/videos/humanbody/ear.html. There is a possibility for cross-curricular links here. It would be a good opportunity to link to the biology topic of the ear. Here students also could be engaged in technological design as they could design and build their own simple models of the human eardrum. As the last activity let students read question 4. Start a discussion about what they can hear and what they cannot hear – and lead onto hearing ranges of humans and animals
Possible questions:
When a compression in a sound wave in the air hits the eardrum, in which direction does the eardrum move? In which direction does the eardrum moves when an expansion of a sound wave arises? If you hear a bird sing with a frequency of 2000 vibrations per second, how many times per second does the eardrum vibrates? How does the ear response to a loud sound differ from its response to a soft sound? How does the ear response to a high sound differ from its response to a low sound? Why sounds aren't as loud when you cover your ear? How does the ear strengthen the sound waves so that they will be strong enough to affect the liquid of the inner ear? Why you do not hear a dog whistle while your dog does?

Activity 1.8. How loud is too loud?

Learning aims:

- Understanding that sound intensity (loudness) is measured in decibels
- Understanding that exposure to very loud sounds can cause damage to hearing

Materials:

- A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6), a sound source, a shoe box, different isolation materials like cotton wool, fabrics, egg boxes, foam, newspaper, etc.

Suggestions for use:

Divide the class into small groups to work with computers, hand out **Worksheet: Sound protection (Part I)**. Let students perform computer investigations to determine the sound intensity of different sound sources and to determine the best sound insulator. Once students completed their investigations discuss their results.
Then hand out **Worksheet: Sound protection (Part II)**. Have students research the effects of sound on their health (Research assignment: How loud is too loud?). In their investigation they can use a nice interactive animation – 'Interactive sound ruler' available via http://www.nidcd.nih.gov/health/education/decibel/decibel.asp.
Then use protective earmuffs to show students and have a class discussion on why different professions might need to use these, and what would be the effects for these people if the ear protection is not worn. Discuss the possible damages loud sounds can have on human hearing.
This lesson would be an excellent time to invite an audiologist to visit the class. Have students write questions for the speaker on slips beforehand. In this students should be encouraged to relate their question with the research assignment.

Possible questions:

- Why do you think construction workers wear earmuffs?
- Can you think of any other profession who need to wear ear protection?
- What might happen if these people don't wear ear protection?
- Which material is the best at stopping sound?
- Which material is useless at stopping sound?
- Does the twice the thickness of the material stop the sounds any better? enough to affect the liquid of the inner ear?

- Why you do not hear a dog whistle while your dog does?

Activity 1.9. What have you learned about sound?
Learning aims:
• Elaborating concepts learned throughout the subunit
Materials:
• Whiteboard/marker, or Laptop/data projector, or Overhead projector/acetate
Suggestions for use:
Use the concept map generated in the first activity to have an interactive group discussion on what students have learned about sound. Students need to revisit their original ideas. The final concept map should show a schematic summary what was learned.

Activity 2.1. Resonance

Learning aims:

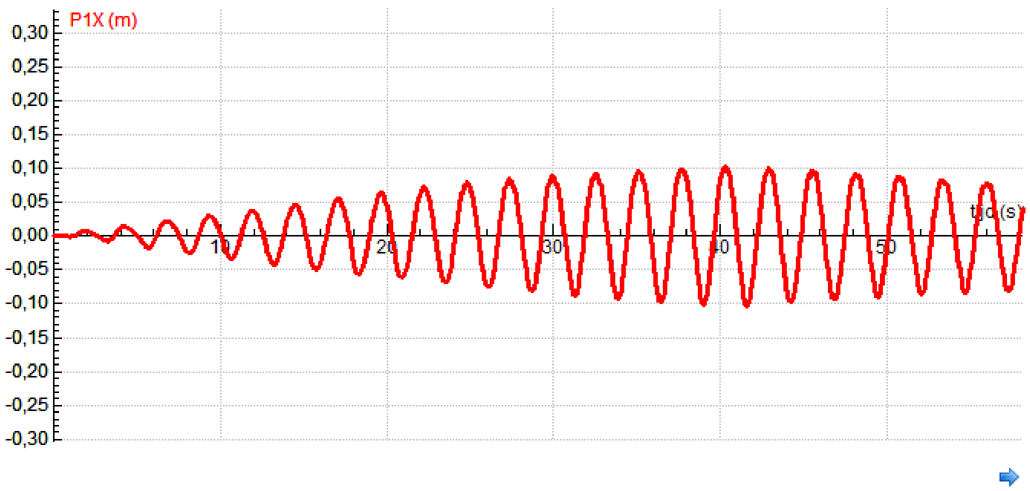
- Recapture prior knowledge about oscillations
- Trigger curiosity about resonance
- Realize that small forces can cause a huge effect
- Introduce the concepts of resonance and natural frequency

Materials:

- Heavy object (approx. 5 kg – 10 kg) and double rope (to stabilize the motion)

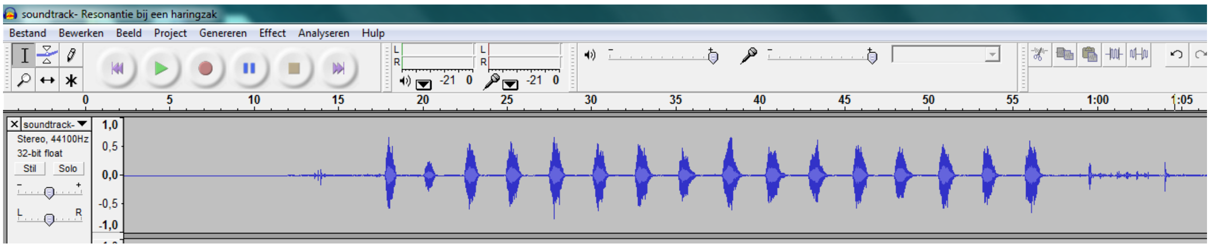
Suggestions for use:

In this activity students try to get a heavy object to oscillate by blowing and answer the question: how can it be that such a small force results in such strong effect?
See for a demonstration of this experiment: http://youtu.be/zqhF7NEOStY
It should be enough to do this experiment two or three times, with different teams of two- three students. Try to see how the students work together and check if the team that has a student on each side of the swinging object gets larger amplitude.
This experiment is also available as Coach data video activity. Students that are not able to do the experiment might want to work with this activity.
The figure below shows the graph of a heavy bag oscillating (5 kg). A graph like this might be used as a basis for assessment questions. If students are familiar with the theory (and the relation between length of the rope and the frequency), they might want to calculate the length of the ropes used.



Position of the heavy object oscillating.The measurement lasts 60 s, one can see that the blowing stops around t = 40 s.

Another way to determine the frequency of the movement is by analysing the sound file of the YouTube movie. Every blow is easy to recognize and since the blows are in the right frequency, the frequency of the vibration can be derived from this sound file.



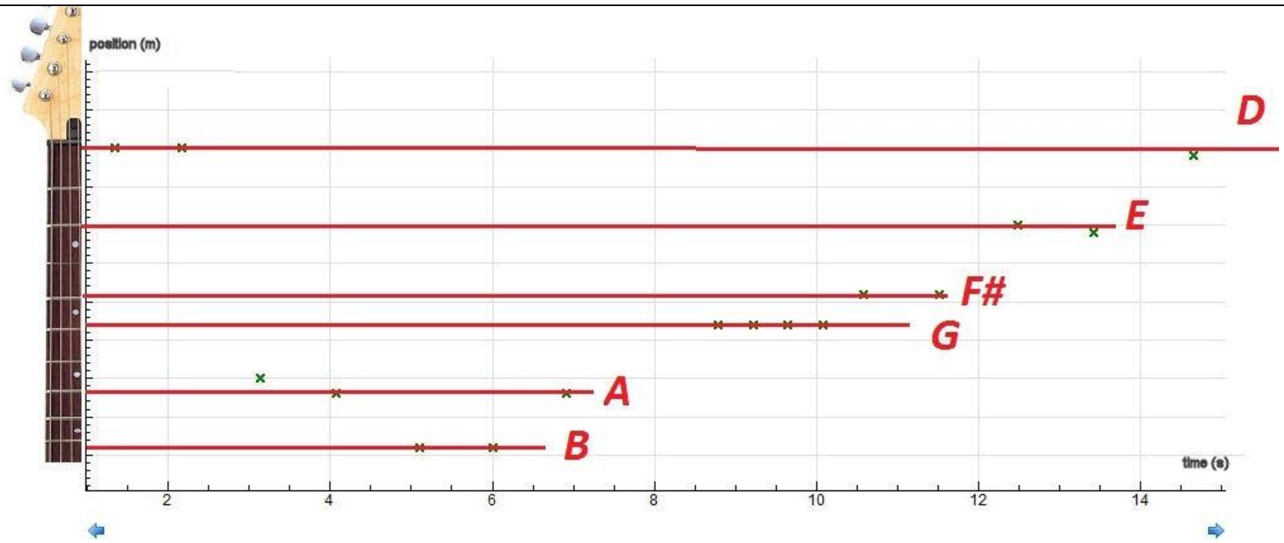
The sound file of the movie of this experiment. Each blow is easy to recognize on the sound track. Between t = 18 s and t = 56 s, there are 16 blows. This means a frequency of 16 / 38 = 0.42 Hz (or T = 2.38 s).

Another example of resonance might be the Chladni experiment: http://www.youtube.com/watch?v=Zkox6niJ1Wc. See for more information: http://hyperphysics.phy-astr.gsu.edu/hbase/sound/reson.html#resdef or http://en.wikipedia.org/wiki/Resonance

Possible questions:

- How can it be that such a small force causes such a strong effect?
- Define the influence of the mass, rope length and amplitude on the frequency of oscillations (recapturing prior knowledge).
- Based on the graph of the position of the object one can ask how many blows were given.
- Determine amplitude and frequency of the oscillation based on the graph at a certain moment.
- Check if the amplitude has any influence on the frequency.
- One can calculate the energy of the object (mass is 5 kg) and thus calculate how much energy is transported with each blow.
- As an application of the theory, one can calculate the length of the ropes based on the frequency of the oscillation.

Activity 2.2. Fundamental frequency, double bass
Learning aims:
• Determine qualitatively relation between string length and its fundamental frequency • Discover that only certain lengths of the string are used when playing music
Materials:
• Pen and paper • Coach 6 file with original data
Suggestions for use:
In this activity students analyse positions where a bass player places his fingers during playing different notes. The students use the graph to answer the given questions. During the activity they get a better understanding of what is showed in the graph. The questions 1 to 4 are easy to answer for most students. Question 5 goes a little deeper and requires some calculations. It is up to the teacher to decide how much help is needed here. Depending on the spirit in the class and the skills in music, the teacher can decide how much time is spend on question 6 (let the students guess which tune is played). Even make a contest out of it (be sure to remove the link to the answer in the worksheet) or let the students draw a graph for another simple tune. Answers to the questions in the worksheet: There are six different notes played (question 1) and the first time the A is played, the finger is a bit too high (question 2). When the finger is too high, the string is too long and the tone is too low (question 3). The semitone (question 4) between F# and G is also clear from this picture. In the picture below the graph of position of the finger of the bass player against time is combined with a picture of a guitar. The positions match the positions of frets of the guitar. The names of the tones played are also indicated.



Question 5:

Going from the first notes (D) to the third note played (an A at t= 2 s) the frequency is multiplied by 1.5. This means that the remaining length of the string is 66.7 % of the original length. Thus, a difference of 33.3 % of string length is 32 cm (90-58). This means that the string has a length of 96 cm.

In reality this length is slightly more, the results are affected by the movement of the bass during the video recording. However, the differences between theory and measurement are not that big (less than 10%).

Possible questions:

- Which are the lengths used on double bass? Is this comparable to other stringed instruments like guitar?
- Explain if a graph like this would be different for a guitar or violin.
- Make a similar for another simple tune (a suitable question for students with a bit of experience in music).
- Compare the graph in the worksheet with a tablature for guitar or bass (see for example http://www.bassmasta.net/charts.php?chan=popular-bass-tabs or

  http://www.ultimate-guitar.com/top/top100.htm)

Activity 2.3. Fundamental frequency, guitar

Learning aims:

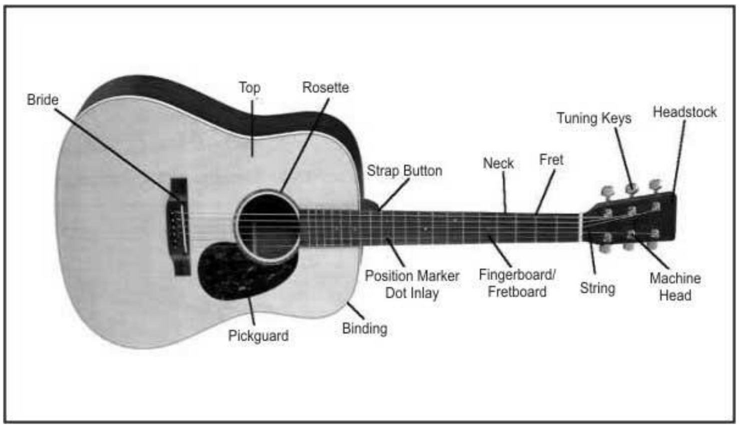
- Determine relation between fundamental frequency f if the string and its string length L.

Materials:

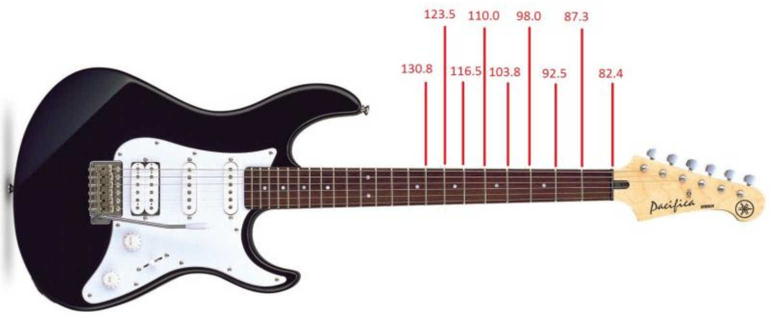
- Guitar
- Measuring ruler
- A computer with a sound sensor and Sound analysis program.

Suggestions for use:

In this activity students measure the length of the string shorted by using guitar frets and the corresponding natural frequency of the shorted string. Based on the measurements they determine the relation between the natural frequency of the string and its length ($f \approx 1/L$).
It is highly recommended to do measurements with a real guitar and to have one guitar for 3 or 4 students. Try to get some guitars from the music teacher or let the students bring their own guitar. A bass guitar or any other fretted instrument (ukulele, banjo, mandolin) will do as well.
It also might be useful to know some parts of the guitar by name, see the picture below.

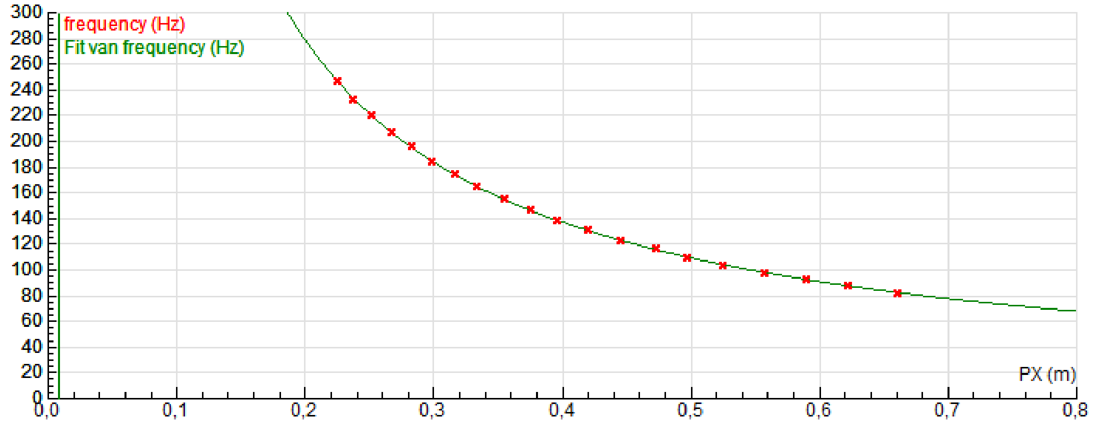


If there is no guitar available, the following data can be used:



or other data can be found on the internet: http://entertainment.howstuffworks.com/guitar3.htm or http://www.physics247.com/physics-tutorial/guitar-string-harmonics.shtml

Hand out the Worksheet: Fundamental frequency, guitar.
Let the students do their measurements and check these data during the measurements. There might be small differences between the different types of guitar but in general the values measured will be similar. The diagrams should all have the same shape, similar to the one showed below.



The relation between f and L is f = v / 2L. Here, f is frequency in Hertz, v is the wave speed in a certain string, L is the length of the string that is able to vibrate.

Besides this measurement, students might want to check the ratio between two string lengths with just one fret between them. If we define the length from the string, measured from the bridge to the *n*-th fret as L*n*, then the ratio L*n* / L*n+1* is a constant.
This is supposed to be L*n* / L*n+1* = 1.06 (start to number n at the machine head).
There is a lot of material about the physics of a guitar available on the internet. You might want to check these sources:
http://www.physics247.com/physics-tutorial/guitar-string-harmonics.shtml
http://www.cs.helsinki.fi/u/wikla/mus/Calcs/wwwscalc.html
Teachers who have access to Physics Teacher Online might want to read

'Experimenting with Guitar Strings' by Michael C. LoPresto:
http://tpt.aapt.org/resource/1/phteah/v44/i8/p509_s1?isAuthorized=no

Possible questions:

- Does the relation f = v/2L corresponds with the information given in the previous activity about the bass string (if frequency is multiplied by 1.5 than the string length is divided by 1.5)?
- What do you think how your resulting graph would look like if the tension of the string would be higher?
- What do you think how your resulting graph would look like if the string would be thicker?
- What do you think what the effect will be for the frequency if the temperature is higher or lower?
- Why has a guitar six strings?

Activity 2.4. Melde's experiment

Learning aims:

- Study the relation between the frequencies and standing waves in a vibrating string
- Understanding concept of fundamental frequency and harmonics

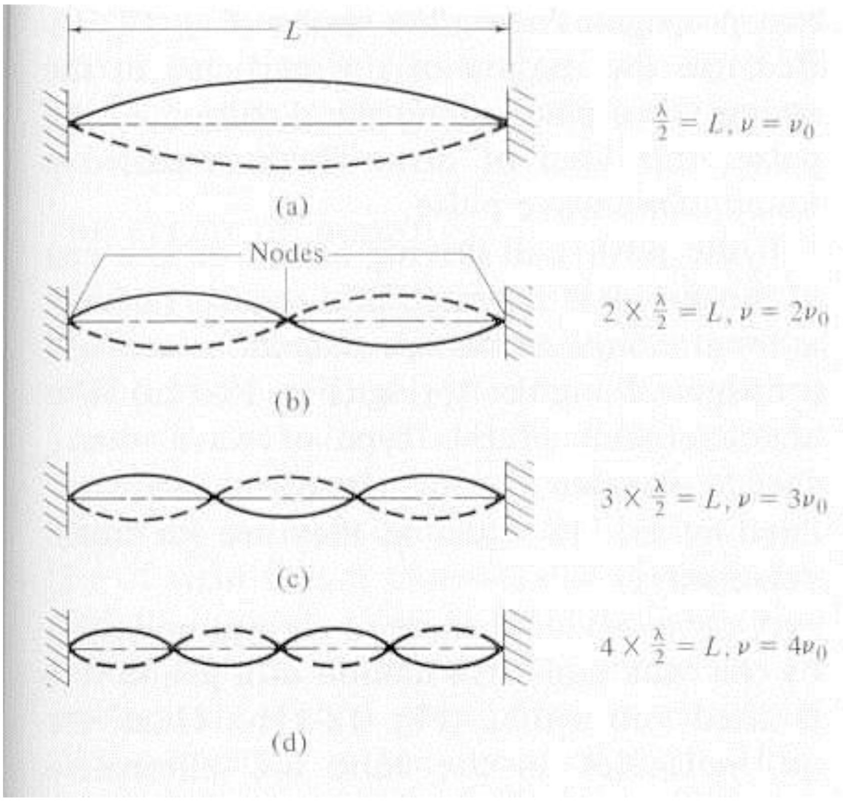
Materials:

- Function generator and mechanical vibrator
- String
- Pulley and weights to adjust the tension in the string

Suggestions for use:

In this activity students perform 'Melde's experiment' in which one end of a stretched string is attached to a vibrating support and the other end passes over a pulley to a hanging weight, which produces tension in a string. The stretched string is set in motion by the vibrating support, but if the frequency of vibration is not one of the natural frequencies (fundamental or harmonics) of the string the vibrational amplitude of the string is very small. However when the frequency of the vibrating support is the same as one of the natural frequencies the amplitude will be large and will clearly show patters (nodes and antinodes) of standing waves.

During the experiment the vibration frequency is changed and different patterns of resonant standing waves in a string are observed. The experiment is repeated for a different string tension.

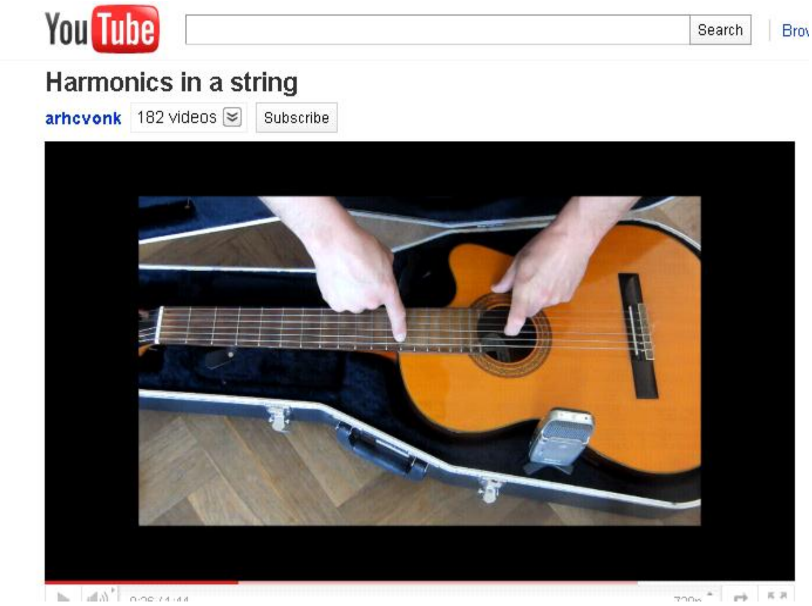


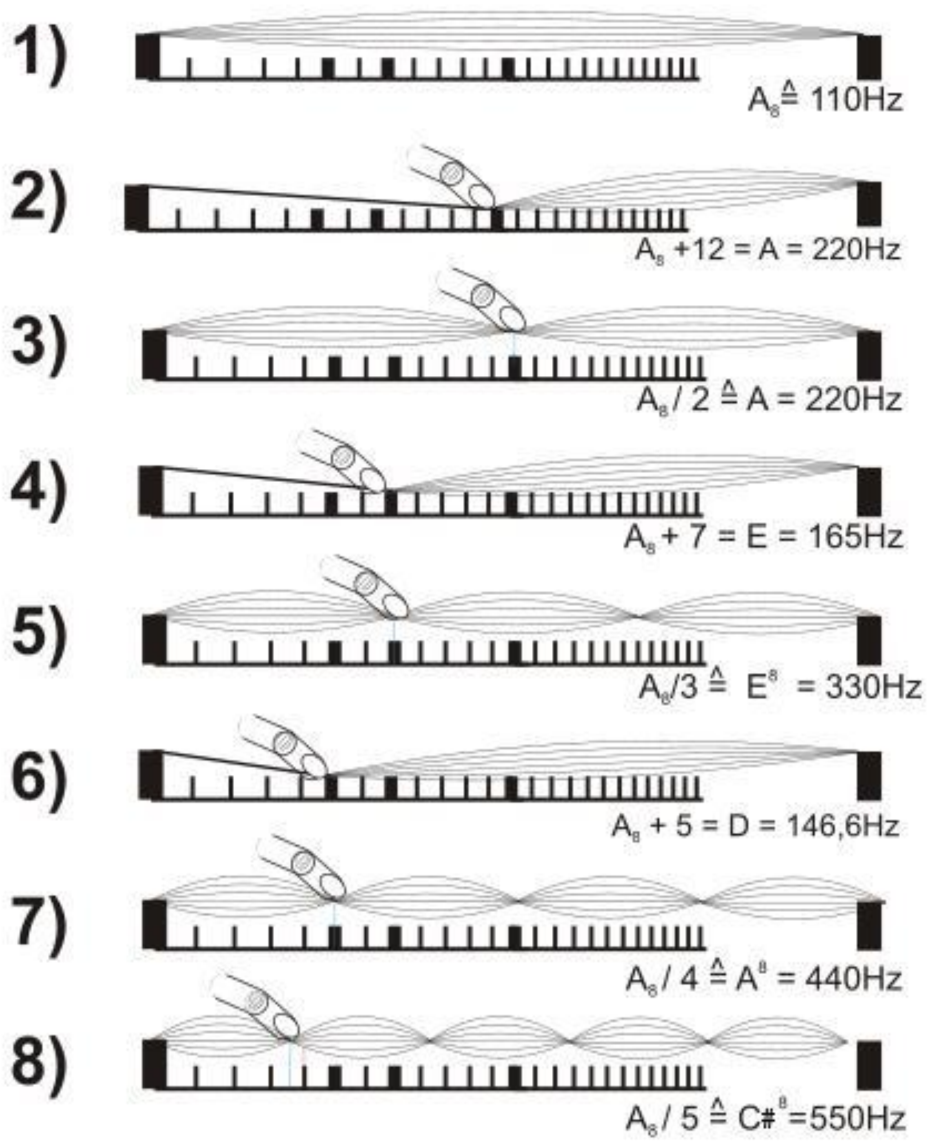
Standing waves in a vibrating string, fundamental frequency and for 1st. 2nd and 3rd harmonics.
Here, λ is a wavelength of standing wave, L is the length of the string, and υ is frequency of vibrations.

The harmonics are multiples of the fundamental frequency. So, a string of length L can vibrate with the fundamental frequency: $f_0 = v/2L$ and also with frequencies: $f_1 = 2f_0$; $f_2 = 3\ f_0$; $f_3 = 4f_0$; $f_4 = 5f_0$; *etc*.
This experiment can be done as a demo for a class or in groups. Each group might use a different string tension. The students discover the similar standing wave patterns but for different frequencies. If there is time one might do this experiment with strings of different thickness.

If it is not possible to do this experiment in a classroom the different internet demos can be used, for example: http://youtu.be/_S7-PDF6Vzc or http://youtu.be/MT7EpS4OX3k .

Possible questions:
• Draw different modes of vibrations for other sources (a string has both ends fixed but there are also musical instruments with one fixed end). • Are these different modes of vibrations also possible in a guitar?

Activity 2.5. Harmonics of a guitar string
Learning aims:
• Understanding how to manipulate a string in order to get the required mode of vibration
Materials:
• Guitar or other string instrument to check
Suggestions for use:
In this activity, students apply the knowledge about fundamental frequency and its harmonics to a guitar string. Harmonics are used to tune the string instrument. The understanding of harmonics is necessary to understand the concept of timbre. Students watch YouTube video (http://youtu.be/4NFljc5mi-s?hd=1) to understand how to produce harmonics on a guitar string. In similar way they have to produce harmonics on the real guitar. 



In the figure above, some harmonics are represented.

Possible questions:

- Define other possible positions to touch the string slightly to get the same harmonics as presented here.
- For the situation in the graphic, at which positions could a frequency of 660 Hz be produced?
- Can you hear these different modes of vibrations?
- Which mode of vibration is used in guitar?
- Is this true for any type of musical instruments?

Activity 2.6. Standing waves in air, closed-end air column

Learning aims:

- Understanding standing waves in closed-end air column
- Investigate the resonance frequencies of standing waves

Materials:

- Sound generator
- Tube
- Stand material

Suggestions for use:

In activity students examine the resonance frequencies of a closed-end column.
By changing the frequency of the signal generator the frequency at which air inside of the tube is also changing. When the frequency of signal generator is closed the natural frequency of the air column then resonance occurs and a loud sound results.

It is up to the teacher to what extent the students are supported in this experiment.

Possible questions:

- How can you, for a certain length of the tube, be sure to have the lowest frequency required for resonance?
- Draw the standing wave patterns for the fundamental frequency and the first three harmonics.
- What would happen with length of the air column or frequency if the speed of sound is changed?
- Predict what the effect will be for the frequency if the temperature is changed.

Activity 2.7. Standing waves in air: soprano saxophone

Learning aims:

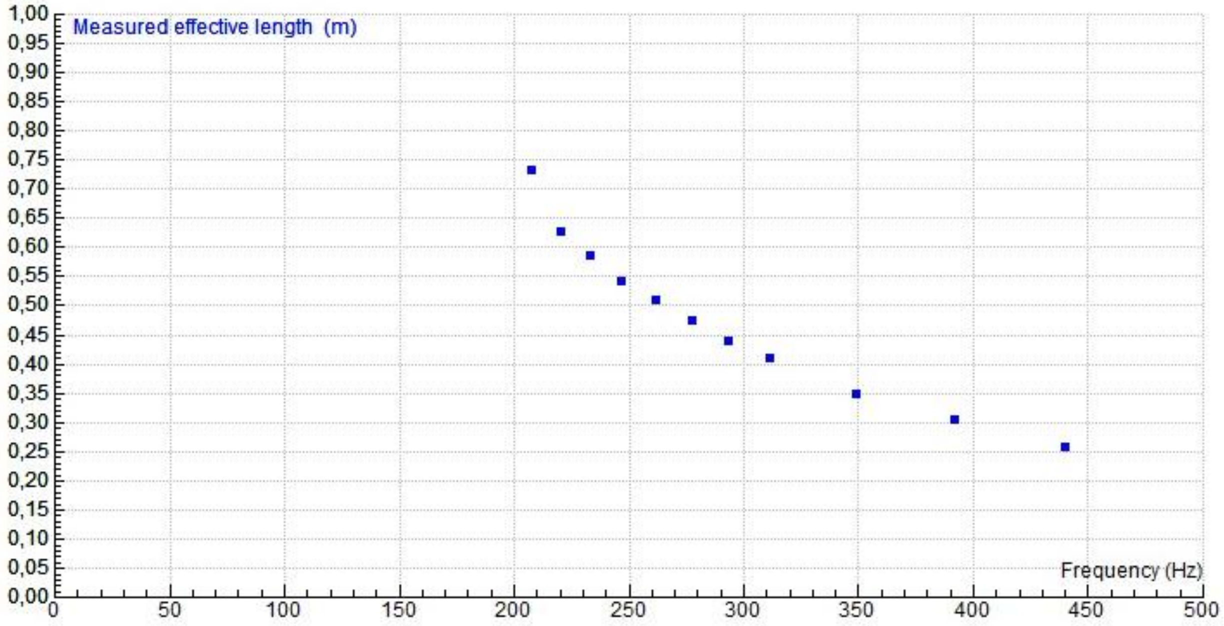
- Determine relation between the air column L and frequency f for conical tube

Materials:

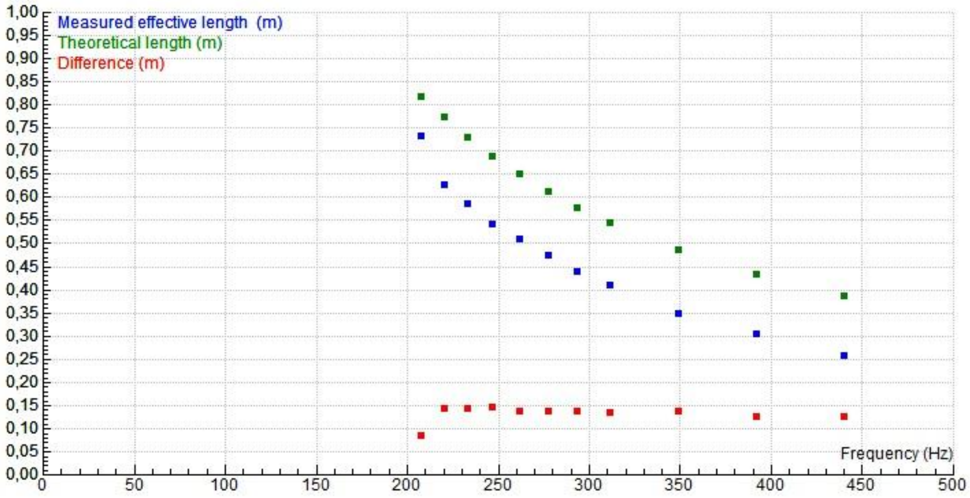
- Pen and paper (and a worksheet)
- Coach file with original data

Suggestions for use:

This activity is similar to the one with the guitar and will result in a similar graph. However, the relation between frequency and length is not that simple for a conical tube. Students will find out (and can check this with theory) that the length of the conical tube has to be raised a constant to get a simple relation.

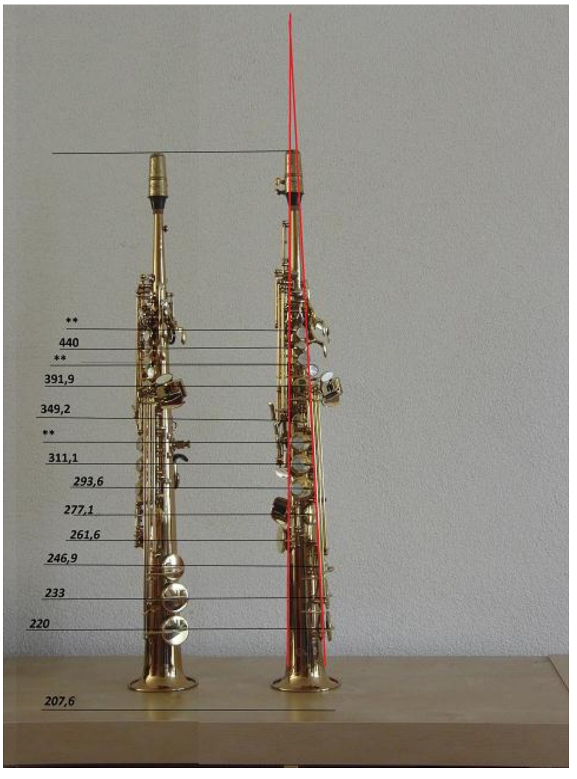


The results based on the original data.



The theoretical value for a cylindrical tube, the measured value and the difference in one diagram.

It appears that this difference is indeed a constant.



Determining the constant based on the photograph.

Possible questions:

- Predict what the effect will be for the frequency if the temperature is changed.

Activity 2.8. Timbre

Learning aims:

- Understanding why different instruments have a different sound

Materials:

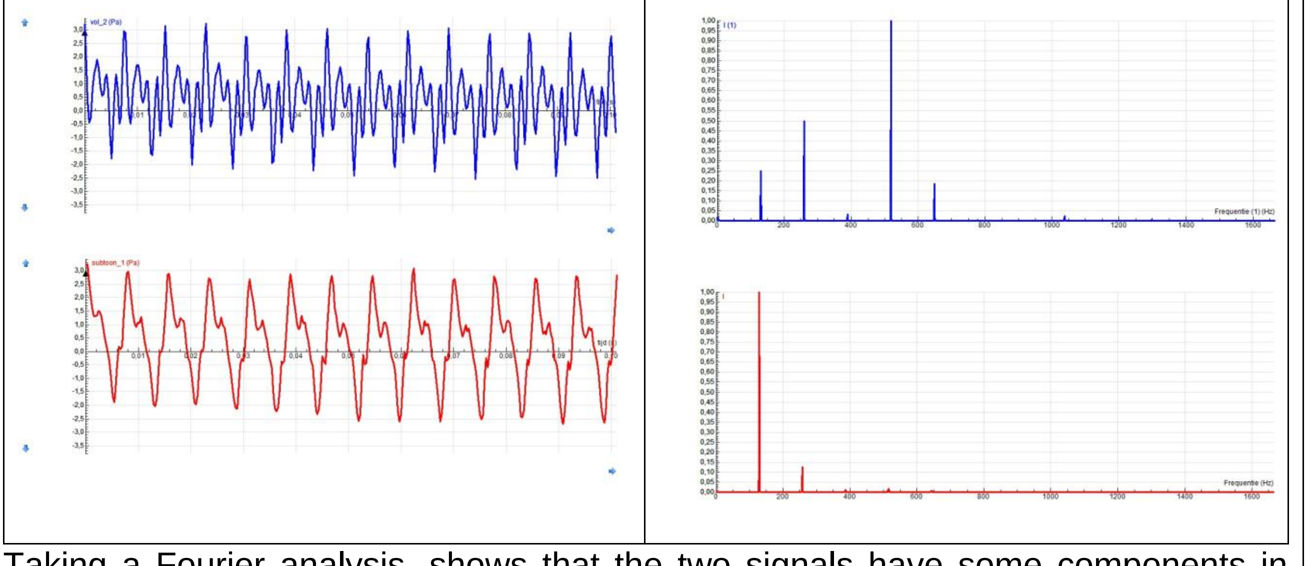
- Sound sensor, measuring and analysing software (e.g. Coach 6)

Suggestions for use:

Students should be familiar with sound sensor measurements (for instance Coach 6) and analysing possibilities. When students have the required knowledge on the subject, it is possible to do this as an open inquiry.

It is possible to divide the class in different groups and let all groups do another instrument. One can think of all the available musical instruments but also bottles or plastic pipes or even the human voice (other possibilities are toys)

See for an example of analysing the timbre of a saxophone: http://youtu.be/0nff7Lbe9xM. In this movie, you see and hear the same tone played twice in a different way. In the diagrams below we see these two tones: the frequency is the same but the shape differs.



Taking a Fourier analysis, shows that the two signals have some components in common but that the first one (with the blue graphs) has a much richer timbre.

Possible questions:

- Predict which harmonics are expected, based on the properties of the instrument.
- Check similarities and differences between the sound of instruments and relate this to the type of instrument (why does a trombone and trumpet have

sounds that are closely related and why does a violin sounds very different)

- Try to make ‘families’ of instruments and define the characteristics of sound for each family

Activity 2.9. Beats
Learning aims:
• Understanding beats
Materials:
• Pen, paper, internet, tuning forks or musical instruments
Suggestions for use:
Though the concept of beats is on itself not very hard to understand, it requires some pre- knowledge and in many situations it is no part of the standard curriculum. However, when students have the basic knowledge on sound they should be able to understand the concept of beats. Students can find their own ways and sources to gather information.
Possible questions:
• Find examples of beats occurring in daily life. • Are there musical instruments that use beats? • Develop an experiment where you demonstrate beats (may be related to music but that is not obliged).

Activity 2.10. Tuning the guitar
Learning aims:
• Apply gathered knowledge in a new situation • Evaluate knowledge
Materials:
• Guitar, tuning fork
Suggestions for use
Let the students tune a guitar in different ways. Let them find information on internet about the different tuning methods. Perhaps the students know other ways as well. The ways to tune the guitar are: • Using of beats One way is to play the same tone on different strings (by shortening one of the strings). Play these tones together, when the two strings are slightly out of tune, beats will occur. When the strings are well tuned, there will be no beat. See (and hear) for an example of beats on the double bass: http://youtu.be/a0VWWbr6O1I. In this movie you see the double bass (starting out of tune) and you can hear the sound of it. This sound is recorded with Coach and you see the beats occurring in the pattern (Around t=32 s in the movie) When the tuning of the strings is changed, you see less beats in the same time (t = 56 s): the strings are more in tune then before. At the end of the movie there are almost no beats (t = 1 m 30 s). Take notice that the graphs showed in this movie are all given for a measure time of three seconds. • Using harmonics By playing harmonics on different strings, the same tone should occur. Let the students find out which frets are used for this. • Using resonance When a string that produces a low tone, is shortened, there is a position where this string produces the same tone as the string next to this. Find this position and play the shortened string. When both strings are well tuned, the not-shortened string will resonate. See for an example of resonance with strings the next movie of a double bass: http://youtu.be/d8uH7SeAtZA.
Possible questions:
• Ask fellow students who play the guitar, which method they prefer to tune

their guitar

- Which way of tuning the guitar would you prefer?

Activity 3.1. Sound graphs

Learning aims:

- Introducing of sound graphs (sound amplitude versus time)
- Understand that sound graphs can be used for speech recognition

Materials:

- A computer to play MP3 file and files: mama_papa.mp3.

  Or

- A computer with microphone, sound card and Sound analysis program. For example Audacity is a free, open source, sound recorder and editor program.

  Free to download at http://audacity.sourceforge.net/download/.

Suggestions for use:

In this activity students are introduced to speech analysis. They analyse simple sound graphs and try to recognise the sound waveforms of certain syllables and words. The students' tasks are given in Worksheet: Sound graphs. Let students perform these tasks. If possible let them work in groups. The given mp3 files can be played on the computer, if possible in the Audacity program.
Once students have completed their tasks discuss with them what speech analysis is, how it can be used, what possibilities and difficulties of speech analysis are, etc.
This activity should encourage students' interest in speech analysis.

Possible questions:

- Do you know what speech analysis is?
- Do you see any examples or applications of it?
- What do you think of the present and future level of technology in this field?
- Can you think of societal use and abuse of this technology?
- Would you as a judge admit evidence based on speech analysis in court?
- Could voice recognition be abused?
- Can you come up with commercial applications in the field of advertisement and security?

Activity 3.2. Model of human speech production

Learning aims:

- Understanding the model of the human speech production
- Understanding of physics concepts (sound spectrum resonance, formants)

Materials:

- Text about model of human speech production is given in the worksheet
- Other internet resources concerning modelling human speech

Suggestions for use:

In this activity students focus on a model of the human vocal system and physics concepts related to this model.

Hand out **Worksheet: Model of human speech production** and let students read the text. Then discuss with them the given bio-physics model and mechanism of speech production.

Show them the animation of vocal folds at:

http://www.humnet.ucla.edu/humnet/linguistics/faciliti/demos/vocalfolds/vocalfolds.htm

Show them X-ray sample movies of human speech:

http://psyc.queensu.ca/~munhallk/05_database.htm

Extend the discussion by asking the questions given below.

Possible questions:

- Does temperature influence the pitch of your voice or the pitch of your musical instrument, respectively? In what way? Can you explain the underlying mechanism of this phenomenon?
- Donald Duck is known for his high-pitched speech. Breathing helium will give you temporarily a similar voice. Could you explain this? What property of the intermediating gas is responsible?
- What are the voice differences between man/female, loud/soft, sung/spoken?
- How could we recognize a vowel from its formants?

Activity 3.3. Sound signal analysis

Learning aims:

- Interpreting the recorded speech waveforms
- Determining formants of the recorded speech waveforms by using sound signal analysis tools (e.g. Fast Fourier Transform or Liner Prediction)
- Understanding a spectrogram

Materials:

- A sound sensor, interface and software that displays sound waveforms and allows to perform sound analysis (e.g. CMA Coach 6 or Raven Lite program which also produce Sound spectrogram)

Suggestions for use:

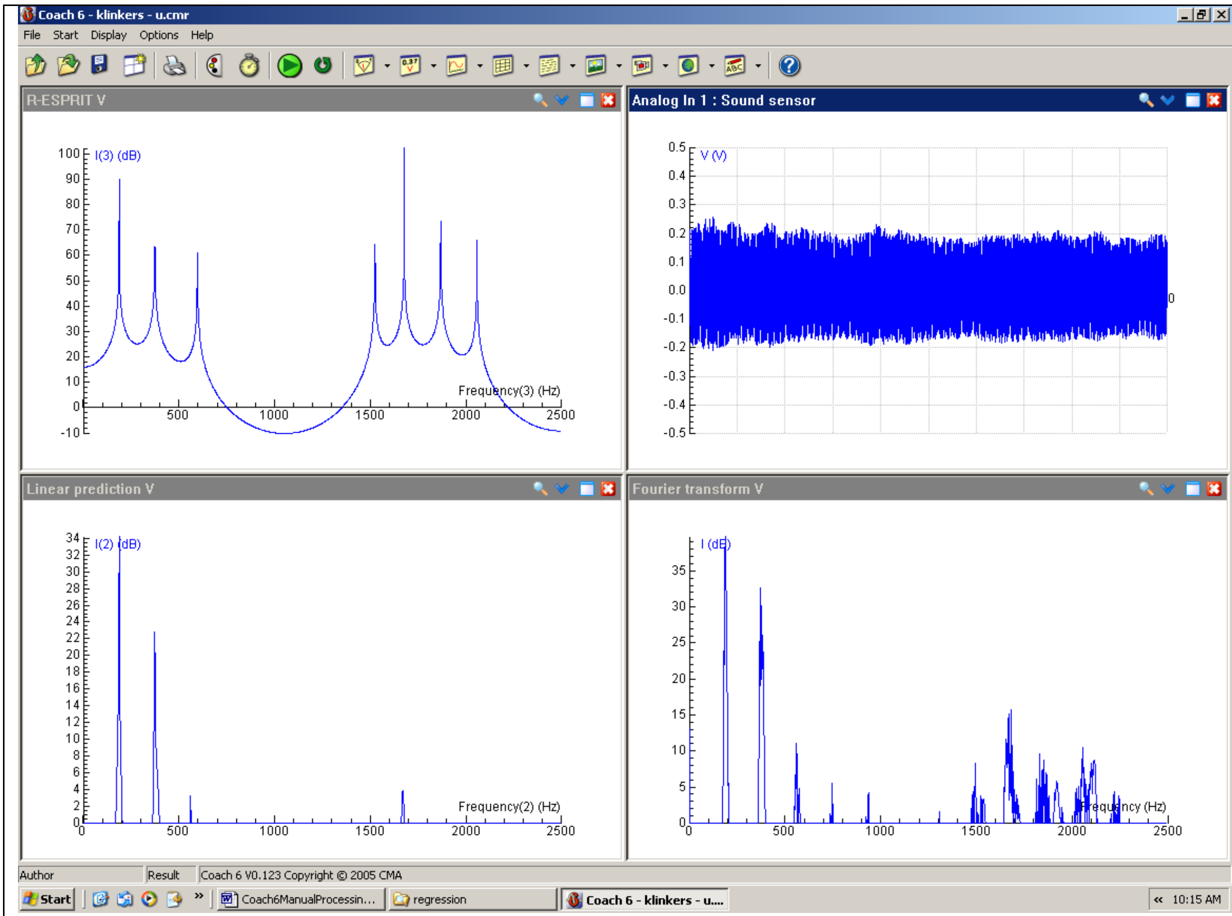
In this activity students use a sound sensor to record the human voice sounds. Software for recording and analyzing sound is required. It can be for example:

- Coach 6 software together with a sound sensor and interface, or
- Raven Lite program, an application originally developed for use by ornithologists studying bird sounds, can be downloaded at: http://store.birds.cornell.edu/Raven_Lite_p/ravenlite.htm and used for free, or
- Java simulation: Model of the Human Speech Production, which includes as well sound analysis as sound synthesis, available at: http://www2.spsc.tugraz.at/add_material/courses/scl/vocoder/simulation.html

By using Signal analysis tools like Fourier Transform or Linear Prediction students can display the frequency spectrum of the recorded sounds and find the frequency components.

Analyzing a simple sine wave signal produced by a tuning fork is especially illuminating, since frequencies can be calculated in different ways and compared.

Further students investigate sounds of different vowels and determine the formants of these vowels.



Speech analysis of the vowel ‘u’ in Coach 6.

In the upper-right diagram the recorded signal is shown (2 seconds of the sound signal has been recorded with a sample interval of 0.2 milliseconds, which gives 1000 data points).

The lower-right graph shows the spectrum resulting from Fourier method, the lower-left graph shows results of the Linear Prediction method and the upper-left corner shows the result of the R-ESPRIT method.

Possible questions:

- How could we recognize a vowel from its formants?
- Which frequencies determine the voice differences between a male and a female ‘aa’-vowel?
- Which frequencies determine the voice differences between a ‘aa’-vowel and ‘oo’-vowel said in the same pitch.

Activity 3.4. Human speech analysis

Learning aims:

- Investigating the formants of various vowels
- Finding and formulating a research question concerning the human speech analysis

Materials:

- A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6, Ravel Lite or Java simulation Model of the Human Speech Production http://www2.spsc.tugraz.at/add_material/courses/scl/vocoder/simulation.html

Suggestions for use:

In this activity students investigate the human speech analysis. This is an open inquiry in which students learn to find and formulate their own research question without strict guidance of their teacher. They learn to setup and successfully finish (possibly adjust along the way) their own practical experiment. With their conclusions, they practice critical thinking. Finally, they get a good picture of the content and (societal, industrial) applications of speech analysis. The research questions given below give an idea of the scope of possibilities in this subject, they are not meant to share with the students beforehand, as finding their own research question is an important element of this assignment.

Possible research questions

Below, a number of the research questions are listed:

- What, if any, is the difference in amplitude and frequency between vowels ‘a’ , ‘e’, ‘o’, and ‘u’? Which property can be used best to distinguish them?
- How to approach orally the sound of a tuning fork?
- Analysis and recognition of the sound pattern of the word Earth.
- How do we recognize gender in the same vowels ‘a’, ‘e’ and ‘u’? Man versus woman!
- Is there a difference (if so, which?) between the various ways of pronouncing the vowel ‘a’: with a pinched nose, behind a cloth, singing, whispering etc.
- Comparison of the spectrum of a flute and a singing voice, producing the same note.
- Which (of the lowest five) formant is typical for the sound or the voice, and

which for the pitch (height of the tone)?

- What feature is the most characteristic for a given vowel produced by different people: the relations between the formant frequencies and/or their amplitudes or the absolute differences between them?

Activity 3.5. Human speech synthesis
Learning aims:
• Investigating which parameters and how influence the quality of artificial created human speech • Finding and formulating a research question concerning the human speech synthesis
Materials:
• Software that is able to synthesis recorder sound waveforms (e.g. Java simulation Model of the Human Speech Production http://www2.spsc.tugraz.at/add_material/courses/scl/vocoder/simulation.html)
Suggestions for use:
In this activity students investigate the human speech synthesis. This is an open inquiry in which students learn to find and formulate their own research question without strict guidance of their teacher. They learn to setup and successfully finish (possibly adjust along the way) their own practical experiment. With their conclusions, they practice critical thinking. Finally, they get a good picture of the content and (societal, industrial) applications of speech analysis. The research questions given below give an idea of the scope of possibilities in this subject, they are not meant to share with the students beforehand, as finding their own research question is an important element of this assignment.
Possible research questions:
Below, a number of the research questions are listed: • How to make a computer or a robots talk? • What parameters influence the quality of synthetic speech system? • What are applications of the human speech synthesis technology?

HEATING AND COOLING: DESIGNING A LOW ENERGY HOME

The development of this unit has been led by the ESTABLISH partners:

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Universita Degli Studi di Palermo (University of Palermo), Sicily, Italy.

UNIT CONTENTS

I. Unit Description

This unit is aimed at engaging students in designing and building an energy-efficient scale model house through the understanding of relevant concepts of energy flow in thermal systems. It is developed into 4 subunits that analyse the different processes of thermal energy transfer (conduction, convection and radiation). The project intends also to introduce pupils to infrared thermography, thermal imaging and thermograms, i.e. infrared imaging science.

The content area of the unit is energy and power in thermal systems. The subunits are suitable for 14-16 year old students while the data analysis and more theoretical parts of the unit are suitable for 16-18 year old students.

The estimated duration of the whole unit is 30 hours. However, it can be used partially.

The unit uses hands-on activities, scientific simulations and probe-ware measurements as tools to develop an Inquiry Based Approach.

II. IBSE Character

This unit can be used to develop students' ability to plan investigations, develop hypothesis, distinguish alternatives, searching for information, constructing models and debating with peers. It covers different types of inquiry activities, from interactive demonstration to open inquiry. The main problem dealt with the unit is divided in sub-problems faced in the different subunits that develop by increasing student participation and independence.

The unit can be implemented in different ways, and for each subunit, emphasis can be placed on different elements of inquiry. However, in each subunit a progression in assigning autonomy to student is foreseen by making the suggested questions more general.

In each subunit, the teacher may start with either a series of questions or with an interactive demonstration, like in subunit 2, where the initial demonstration poses the problem to be investigated and inquiry can be developed in different steps (some of them are suggested by the activities that lead to questions for further investigations). All the activities may be guided, bounded or lead into open inquiry settings. However, the initial activities given in each subunit will form the background for further open inquiry activities to be performed by students.

In order to focus on the different skills connected with the inquiry process, the starting point of each activity is a well-defined problem whose solution requires students' engagement, raising questions and developing hypotheses. The teacher control of students' activities is mainly connected with students' expertise in autonomous work and during the succession of the proposed activities the degree of teacher's guidance decreases.

Details about the inquiry types and E-emphasis will be supplied for each sub-unit.

III. Science Content Knowledge

Core physics concepts of this study are: thermal energy, heat and temperature. Such concepts involve many difficulties that often are connected with different definitions in textbooks. For this reason we, here, clarify the main definitions of the involved concepts.

In the unit, we discuss Thermal Energy arising from the fact that particles of matter are in constant motion and that this motion relates directly to the state of matter of the object (solids, liquids, or gases). Temperature affects how fast these particles move. The higher the temperature the faster the particles move. Moving particles possess kinetic energy.

Temperature is defined as a measure of the average kinetic energy of the particles of an object.

Thermal Energy is the total sum of all the energies of the object particles.

As a consequence, thermal energy and temperature are related though different: temperature is proportional to the average kinetic energy of the particles; thermal energy is the total amount of the kinetic energy of the object particles.

Transfer of thermal energy between systems can happen through three different processes:

- Conduction – direct contact
- Convection – through a fluid
- Radiation – by electromagnetic waves

The term heat involves the quantity of energy transferred from one place in a body or thermodynamic system to another place, or beyond the boundary of one system to another one due to thermal contact when the systems are at different temperatures. In this description, it is an energy transfer to the body in any other way than the mechanical work performed on the body

Transfer by conduction is the transfer of thermal energy between regions of matter due to a temperature gradient. Heat spontaneously flows from a region of higher temperature to a region of lower temperature, temperature differences approaching thermal equilibrium.

On a microscopic scale, conduction occurs as rapidly moving or vibrating atoms and molecules interact with neighbouring particles, transferring some of their kinetic energy. Heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Conduction is the most significant mean of heat transfer within a solid or between solid objects in thermal contact. Conduction is greater in solids because the network of relatively fixed spatial bounds between atoms helps to transfer energy between them by vibration.

Transfer by convection is the transfer of thermal energy through a substance by mean of currents of fluids (liquids and gases).

Transfer by radiation is transfer by electromagnetic waves. These waves may pass through all matter states and also through the vacuum space by transferring energy called radiant energy.
Transfer by conduction and convection involves a direct contact between bodies at different temperatures. In this case we say that heat is exchanged between the two bodies. Transfer by radiation involves interaction between one body and the electromagnetic radiation emitted by the other body.
Concerning the specific content objectives, these involve the ability to:

- Differentiate between heat and temperature;
- Understand the concept of thermal equilibrium and thermal process;
- Differentiate among conduction, convection, and radiation;
- Give examples of how conduction, convection, and radiation are considered in choosing materials for buildings and designing a house model;
- Explain how environmental factors such as wind, solar radiation, and temperature affect the design of a house and the choice of the materials.

IV. Pedagogical Content Knowledge

PCK involved in the Unit is related to the analysed physics topics, as well as to its IB approach. With reference to the domain of physics topics, relevant elements are the following:

- To make teachers aware of expected difficulties, misconceptions and/or alternative conceptions in the understanding of the content (as for example "Heat as energy contained in a body", "Temperature as a measure of heat in a body", "Different bodies placed in the same environment have different temperatures")
- To gain ability in using Scientific Instructional Representations (models, mathematical representations, etc.) by connecting them and making evident their rationale to fit students' reasoning
- To be aware of students' learning difficulties in sketching microscopic behaviours
- To connect physics concepts with everyday phenomena
- To relate observation of phenomena with students' representations and models

With regard to the features of IBSE approach, teachers especially need to gain pedagogical content knowledge enabling them to "engage students in asking and answering scientific questions, designing and conducting investigations, collecting and analysing data, developing explanations based on evidence, and communicating and justifying findings". This mainly involves teachers:

- Providing questions to frame unit and questions for discussion
- Suggesting approaches for using technologies as laboratory and cognitive tools.

- Suggesting approaches for collecting and analysing data.
- Supporting students in designing their own investigations.
- Suggesting approaches to help students construct explanations Based on Evidence
- Providing approaches for promoting science communication Baseline feature.

V. Industrial Content Knowledge

Thermal insulation has a lot of industrial applications, as it reduces of the effects of the various processes of heat transfer between objects in thermal contact or in range of radiative influence. Examples go from building construction and mechanical insulation for pipes, aircrafts and refrigerators to clothing.

V.1: Related Industrial Topics

- Building materials: concrete, insulators, films, rigid structural foam, pipes and conduits, barrier layers (water, air, radon)
- Solar thermal technologies, control systems, storage of heat, heat recovery
- Photovoltaic panels, storage systems (batteries), thermo-cameras, inverters, links to electricity grid
- Measurement of heat conductivity, heat loss; thermal imaging
- External cladding

V.2: Industry Link: Building Materials – Insulation Properties, Thermocameras

Focal Organisations: Cement Roadstone Holdings, Istituto Giordano S.p.A., R&D innovAction, FLIR Systems, inc.

Cement Roadstone Holdings (CRH) is a leading international building materials manufacturer and distributor. The company was founded in Ireland in 1970 by the merger of Irish Cement Ltd. and Roadstone Ltd**.** and now operates in 35 countries globally with annual sales of over €20 billion. CRH shares are listed on the Irish, London and New York stock exchanges. The product range is vast and includes cement, lime, aggregates, asphalt, ready-mixed concrete, pre-cast concrete products, clay products, glass and insulation materials. Energy efficiency is a major focus of the European Construction Industry and some of the most efficient buildings in the world are being constructed using products manufactured by **CRH** companies.

Instituto Giordano S.p.A. (IG) is a Contract Research Organisation, classified as a "Centre of Excellence" in the assistance of Industrial SMEs in R&D, Innovation and Technology Transfer activities.
Established in 1959, IG today employs 120 employees (50% graduates) + 130 inspectors. IG 2010 turnover was more than11 Million Euros. More than 285 thousands certificates and test reports issued up to July 2011. IG's fields of activity comprise: Testing. R&D and TT on Building/Construction Materials & Components, Heat Technology, Fire Safety, Thermo-mechanical and Plants, Transportation, Electric, Chemistry, Naval.

R&D innovAction (**R&DI**) aims at identifying innovative solutions to improve the competitive advantages of its customers in terms of compliance with technical and economic sustainability. Based in Milan (Italy), it carries out research, development, industrialization and commercialization of innovative products and services at high technological content, mainly in the field of Materials, Process, Energy Efficiency, Renewables and Environment. R&D innovAction cooperates with leading companies in Italy and abroad to develop new Services for energy efficiency by monitoring consumption and providing Energy Management support to identify inefficiencies.

FLIR Systems, Inc. is a leading manufacturer of innovative imaging systems that include infrared cameras, aerial broadcast cameras and machine vision systems. Pioneers in the commercial infrared camera industry, the company has been supplying thermography and night vision equipment to science, industry, law enforcement and the military for over 50 years. From predictive maintenance, condition monitoring, non-destructive testing, R&D, medical science, temperature measurement and thermal testing to law enforcement, surveillance, security and manufacturing process control, FLIR offers the widest selection of infrared cameras for beginners to pros.

Examples of ICK application on Thermal insulation

1. Heating and Insulation in the home

An effective way to save energy in the home is to reduce heating costs. In terms of construction, this can be achieved by:

- building a structure that is free of draughts.
- improving insulation levels
- avoiding large temperature fluctuations by utilising the *thermal mass*.of materials.

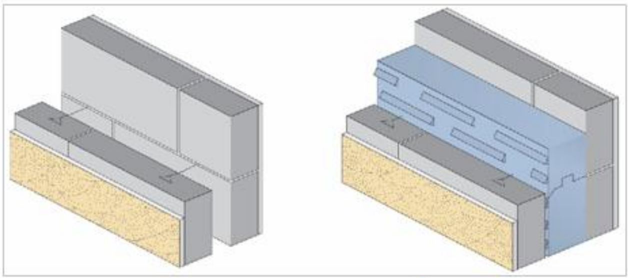
Building materials providers supply products to assist with all of these measures.

2. Heat Loss from a House

Much heat is lost from a house by conduction through the material of the floor, walls, windows, doors and roof. The *conductive efficiency* of materials is usually expressed in terms of their *U-values, expressed as* watts per square metre kelvin (W/m^2K). A material with high *thermal resistance* has a low U-value. The inverse of the U-value is called the R-value.

3. Avoiding Temperature Fluctuations

A standard way of constructing external walls of houses is to use two layers of concrete block with a cavity between them. The cavity may contain a suitable insulating material. The temperature of the outer layer of the wall varies with the external temperature. The insulated inner layer acts as a heat store. It absorbs heat when the inside temperature rises during the day and releases it when the temperature drops at night. By using the *thermal mass* of concrete in this way, the inside air temperature is maintained at a relatively stable level, resulting in a more comfortable living environment and a more efficient use of energy. Another form of construction is the *externally insulated* single leaf concrete block wall.



Uninsulated cavity wall, U-value 1.76 W m^{-2} K; and i**nsulated** with 140 mm modern insulation: U-value 0.20 W m^{-2} K

4. Insulation in refrigerators

The best way to make efficient refrigerators is to use different types of thermal insulators in their construction. Depending on the type of refrigeration device, the insulator may be a vacuum, styrofoam or a type of fiberglass. The main aim of a refrigerator insulator is to keep outside thermal energy from getting in the refrigerator, which is, therefore, kept cold with less electric power consumption. The insulation is generally in a place we can't see it, i.e. inside the refrigerator walls. Thermal energy outside the refrigerator has a very hard time permeating the wall of the refrigerator, extending the duration of food inside the refrigerator in case of electric blackout.

Low-cost home refrigerators are mainly equipped with rigid foam board insulation, as it provides affordable, adequate protection against thermal energy loss from the appliance. Rigid foam board insulation is typically made from polystyrene or polyurethane. These insulating boards are resistant to moisture and have a high thermal resistance (R) value. R is a rating for the insulation's efficiency: the higher it is, the more effective the product will be in reducing thermal energy loss.

Another widely method used for reducing thermal energy loss in domestic refrigerator/freezers and improve their energy efficiency is to use Gas-Filled Panel thermal insulation technology. Gas-Filled panels contain a low-conductivity, inert gas at atmospheric pressure and employ a reflective baffle to suppress radiation and convection within the gas. (see B. T. Griffith, D. Arasteh, and D. Türler paper (link below) for more details).

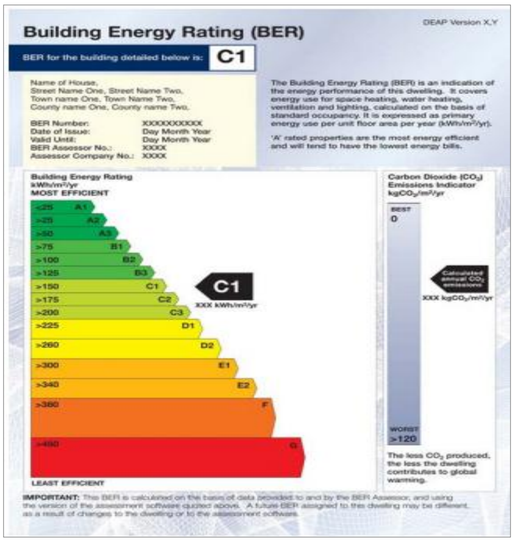
4. Infrared Thermography

Infrared thermography, i.e. the measurement of surface temperature by means of specially designed, infrared-sensitive thermo-cameras, can provide remarkable, nondestructive information about construction details and building performance. These include validation of structural details, verification of energy performance (thermal conduction, air leakage, i.e. convection, and radiation from windows), location of moisture intrusion, thermal bridges.

Surface temperature has started to play a major role in both audits and energy surveys, as it can be used to evaluate the condition of the building itself as well as the electrical, mechanical, and plumbing systems.

Energy Performance Certificates

EU Directive 2002/91/EC calls on .Member States *to 'ensure that, when buildings are constructed, sold or rented out, an energy performance certificate is made available to the owner or by the owner to the prospective buyer or tenant...'*



A Building Energy Rating Certificate as issued in the Republic of Ireland

V.3: References and Links

- The CRH website - www.crh.ie
- The IG website - www.giordano.it
- The R&DI website - www.rd-innovaction.com/en
- Then FLIR website – www.flir.com

- http://vimeo.com/40214470 - a video titled BER for homeowners explained from
- the Sustainable Energy Authority of Ireland (www.seai.ie)
- Directive 2002/91/EC of the European Parliment on the energy performance of buildings contains a range of provisions aimed at improving energy performance of residential and non-residential buildings, both new-build and existing
- From 2013, the EPBD will be superseded by the Recast EPBD. Recast Energy Performance of Buildings Directive
- Implementation of the Energy Performance of Buildings Directive in other Member States 2010
- B. T. Griffith, D. Arasteh, and D. Türler, Energy Efficiency Improvements for Refrigerator/Freezers Using Prototype Doors Containing Gas-Filled Panel Insulating Systems, Proceedings of the 46th International Appliance Technical Conference held May 15-17, 1995 at the University of Illinois at Urbana-Champaign – LINK: http://gfp.lbl.gov/papers/lbl-36658.pdf

The following relevant items are all available in Science and Technology in Action (www.sta.ie).

- The Energy Efficient Building - CRH
- Technologies Protecting the Environment - EPA
- Enzymes and Biofuels - EI Biotech
- Climate Change - EPA

In each part of the Designing a Low Energy Home Unit, examples will be supplied about how conduction, convection, and radiation are considered in choosing materials for buildings and designing a heating system and in explaining how environmental factors such as wind, solar angle, and temperature affect design of houses.

VI. Learning Path(s)

The learning path is developed through 4 sub-units that face the different aspects of constructing an energy-efficient scale model house.

Subunit 1

This unit guides students in the construction of a model house and makes explicit the different factors that contribute in heat dispersion and energy consumption to keep the house warm. Each factor is analysed in the other sub-units and are developed around a particular problem that guides the inquiry.

This sub unit introduces basic concepts such as heating/cooling rates, energy conservation, conduction, convection, and radiation, and engineering elements such as insulation, glazing, thermal storage, and passive heating and cooling. It also aims at recalling previous learned concepts of heat, temperature and thermal equilibrium by taking into account the well-known misconceptions held by students at this school level.

At the end of this subunit, students should have a basic understanding of some physical processes, such as how heat transfer occurs between the house and the environment under different weather conditions.

Students will be involved in constructing a scale model house using a hands-on kit supplied by the teacher. They will learn to use sensors to measure the heat gain or loss and evaluate insulation. They will explore different heating and cooling factors using the tools provided and other low-cost materials on hand. For instance, a light bulb (covered by an aluminium foil) models the heather, the effects of wind can be simulated using an electric fan, and sun shining heating by using a lamp .

The subunit involves 3 student learning activities:

Activity 1.1 aimed at the construction of different kinds of house models and at evaluating the main difficulties in maintain them warm;

Activity 1.2 aimed at analysing the distribution of temperature inside the house model;

Activity 1.3 aimed at analysing the heating effects of light on the house models.

The following table characterises the three activities from the point of view of the required type of inquiry and considering the 5E model of the Learning Cycle (Engage, Explore, Explain, Extend, Evaluate).

Activity	Student Task	Inquiry Type	E-emphasis
1.1	Discussing and experimenting how to maintain heat in a house model	Interactive demonstration Guided discovery	Engage Explore
1.2	Experimenting distribution of temperature inside the house model	Guided inquiry Bounded Inquiry	Engage Explore Explain
1.3	Hypothesizing and experimenting the sunshine effects on the house model temperature	Guided inquiry Bounded Inquiry Open Inquiry is also possible	Engage Explore Extend

Subunit 2

This unit analyses the role of different materials in heat dispersion by developing the relevant concepts connected with energy transfer through conduction.
This subunit analyses the transfer of thermal energy between regions of matter due to a temperature gradient. Conduction characterizes the heat flows through the region of matter itself, as opposed to requiring bulk motion of the matter as in convection. Conduction takes place in all forms of matter, viz. solids, liquids, and gases but does not require any bulk motion of matter. However it mainly characterizes heat transfer in solids, since in liquids and gases convection is the main process of heat transfer.

OBJECTIVES OF THE SUBUNIT:

- To be aware that the nature of material influence transfer of thermal energy between two thermal systems
- Students will rank the materials used, according to their thermal conductivity.
- Students will use experimental evidence to decide on an everyday problem.
- Students will work in groups in order to design and carry out an experimental investigation.
- Students will reflect on the purpose and nature of experimental activities they carried out in the unit

The subunit is developed in 2 activities.
The following table characterises the two activities from the point of view of the required type of inquiry and considering the 5E model of the Learning Cycle.

Activity	Student Task	Inquiry Type	E-emphasis
2.1	Observing ice liquefying in plates of different materials	Interactive demonstration Guided discovery	Engage Explore
2.2	Measuring isolation properties of different materials	Guided inquiry Bounded Inquiry Open Inquiry is also possible	Engage Explore Extend

Subunit 3

This unit analyses energy transfer in fluid material and the main concepts connected with the convection process.
This subunit analyses the transfer of thermal energy due to a bulk, macroscopic movement of matter (fluids or gases) from a hot region to a cool region.
The starting point is the analysis of Activity 1.2 of subunit 1 that will be supported by further observations performed in Activity 3.1 whose objective is to make evident the currents of hot fluids moving from hot to cold regions.
This activity will end by supplying an explicative model, i.e. a qualitative mechanism of functioning explaining natural convection on the base of density differences among fluid volumes at different temperature. Such a model will be used in order to explain the "stack effect" or the "chimney effect", where rising hot air pushes outward at the top of a building and cold air is drawn inward at the bottom.
A second activity (Activity 3.2) will analyse the effect of moving air on surface temperatures by confronting results of two experiments measuring natural cooling and forced cooling. Data can be analysed at different levels by characterising phenomena qualitatively or quantitatively in dependence of the classroom mathematical knowledge.
The following table characterises the two activities from the point of view of the required type of inquiry and considering the 5E model of the Learning Cycle.

Activity	Student Task	Inquiry Type	E-emphasis
3.1	Observing convection currents	Interactive demonstration Bounded Inquiry	Engage Explore
3.2	Experimenting different kinds of convection	Guided inquiry	Engage Explore Elaborate Extend

Subunit 4

This unit introduces the concept of energy transfer by radiation, analysing the different effects of solar radiation spectrum.

This subunit analyses the transfer of energy due to radiation and explores thermal radiation. In dependence of classroom curriculum, the development of activities here described needs a recall or introduction of the main concepts connected with electromagnetic radiation. The deepening level of such introduction is dependent from the knowledge level of the classroom as well as from previous students' curriculum.

Usually pupils are more familiar with heat transfer by conduction because of their experiences of everyday-life phenomena. The physical concept of energy propagation by radiation is introduced to the class usually by reporting the example of the light radiation travelling from the Sun to the Earth across the empty space, without any support from conduction and convection, which both need a medium. This example, even if quite convincing, is not strong enough to persist into the student imagery of energy propagation, probably because of the absence of any practical activity which can help the class to directly experience the transfer of energy by radiation. The following experimental activities are proposed as an inquiry based learning path aimed at the practical exploration of energy transmission by thermal radiation.

The main concepts to recall can be synthesised as follows.

Radiation is the common name for electromagnetic energy travelling through space. It can travel very fast (the light speed $c = 2.998 \times 10^8$ m/s), also through the vacuum. It doesn't need material to travel in. It has many forms, including visible light, infrared (IR), ultraviolet (UV), X-rays, microwaves, and radio waves. These are all the same form of energy, just with different frequencies and amounts of energy.

Different frequencies of radiation interact with matter differently and this fact makes them seem more different to us than they really are. In many everyday situations we observe bodies heated by radiation gaining thermal energy, which is mostly transferred by infrared (IR) and visible radiation.

During the development of the subunits, new instruments will be analysed: the infrared thermometers and cameras.

The starting point is the analysis of Activity 1.3 of subunit 1 that pointed out that light can warm the walls of our house models and this warming effect is increased if the wall colour is dark or black.

The first problem to face is that to better measure the heating effects of radiation by constructing a simple "radiometer" (see Activity 4.1).

Activity 4.2 will measure the heating effect of sun radiation on bodies of different colours.

Activities 4.3 will show that our radiometers are able to make evident a radiation different than the visible one and introduce the IR radiation.

One of the last two activities can be chosen by the teacher according to the level of the classroom.

Activity 4.4 will propose an open inquiry approach to the analysis of IR apparatuses (video, images, thermometers, etc.)

Activity 4.5 proposes a video were the same experiment is performed in presence and absence of atmospheric air in order to deepen the knowledge of IR radiation.

The following table characterises the activities from the point of view of the required type of inquiry and considering the 5E model of the Learning Cycle.

Activity	Student Task	Inquiry Type	E-emphasis
4.1	Build and use home-made radiometers	Interactive demonstration	Engage Explore
4.2	Illuminating objects of different colours.	Interactive demonstration Guided inquiry Bounded Inquiry	Engage Explore Elaborate
4.3	Radiation from hot and cool bodies	Guided inquiry Bounded Inquiry Open Inquiry is also possible	Engage Explore Extend
4.4	An open Inquiry about Infrared thermography	Open Inquiry	Engage Explore Elaborate Extend
4.5	Analysis of the cooling processes of a hot body in different conditions. Cooling in air and in a vacuum environment.	Bounded Inquiry Open Inquiry is also possible	Engage Explore Elaborate Extend

I. Assessment

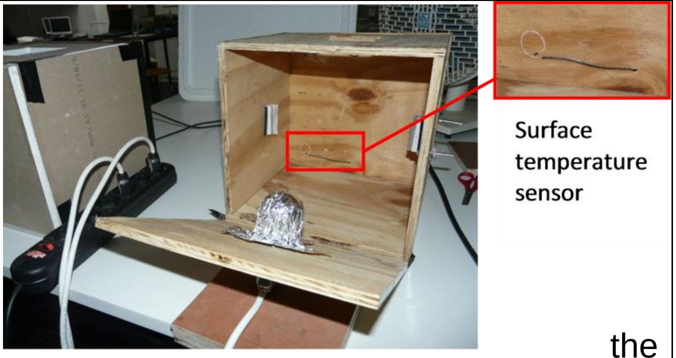
In all Subunits the students' assessment should include both a theoretical test (understanding basic concepts) as a practical assignment. Assessments of students' understanding of operative procedures such as observation, hypothesizing, explaining, etc. is also to be taken into account.

Examples of prototypical question are given in each subunit. A practical assignment could be based on any of the activities in the subunits, or experiments on the curriculum that are not specifically covered but related to these activities.

An example of a theoretical test is given at the end of this document. It can be modified for either the younger or older student groupings, and could involve either qualitatively or quantitatively determining the behaviour of light after interaction with a number of optical components. In the case of the older groups, values could be added, for example the wavelength of light or refractive index of the materials.

VII. Student Learning Activities

Activity 1.1: How to maintain heat in your house model
Learning aims:
• Design an experiment to measure the heating and cooling of different house models by using the same heating procedure; • Identify the different factors that can influence the heat dispersion and control them in the design; • Measure how much energy is necessary to warm each house model 5°C warmer than the environment.
Materials:
• Boxes of different materials (Styrofoam, wood, glass, aluminium, plasterboard) and equal dimensions, models of different kinds of houses. • Temperature sensors to put in the wall opposite to the heater. • Heaters (light bulbs covered by aluminium sheets)
Suggestions for use:



Different groups of students can be supplied with different house models having the same dimensions and constructed using different materials. The heater and the sensor are placed as reported in Fig 1.1.
Students are asked to :

- Turn on the heater and register the temperature until it reaches approximately the value of T_{env} +5°C.
- Then, turn off the heater so that the temperature lowers until T_{env}.
- Record the times in which the heater is turned on and off.
- Calculate the time amount the heater has to be on to keep the house warm (T_{env} +5°C).

Each group will report to the whole classroom its results in order to point out what model is better for saving energy.
NOTE
In this activity the teacher can introduce students to the different types of thermometers. Starting from the familiar mercury-in-glass one, the teacher can present and discuss the use of modern digital thermometers, based on

semiconductor probes, and infrared ones, that allow measurement of the temperature of distant objects, without having to have a "physical" contact with it.
Then, microcomputer based temperature sensors can be presented and, in particular, the surface type one, that will be extensively used in this and in the following activities.
As a last step, photos of thermograms can be shown, in order to introduce students to thermal/colour analysis, a subject that will be deepened in the fourth subunit.

Possible questions:

- How do you think you could reduce the power necessary to maintain heat in the house?
- What would you change about your house to minimize the necessary power to keep the house warm and why?

Activity 1.2: How is the temperature distributed inside your house model?

Learning aims:

- Understanding that variations of temperature are present inside the house in places at different distances from the heater and at different heights from the floor.

Materials:

- As in Activity 1.1
- Two temperature sensors per student

Suggestions for use:

Students are requested to analyse temperature distribution inside the house. A preliminary discussion will guide students to identify the factors that affect the temperature in a given position. Distance from the heater and height from the floor can be identified as relevant factors.
Students are requested to design appropriate experiments that take into account the control of the relevant variables.

- Two sensors at the same distance from the heater and at different height from the floor
- Two sensors at the same distance from the heater and at the same height from the floor

Possible questions:

- What can you say about the efficiency of a heater mounted high on the wall of a room

- Can you infer a mechanism explaining why cool air goes upward?

Activity 1.3: What is the effect of sunlight on the temperature inside your house model?

Learning aims:

- To point out the effect of wall colours on the radiation absorption;
- To make evident that the house model temperature is affected by absorption and conduction of wall materials;
- To be able to make prediction on the basis of everyday experience;
- To be able to justify evidence on the basis of everyday experience.

Materials:

- Boxes of different materials (styrofoam, wood, glass, aluminium, plasterboard) and equal dimensions, models of different kinds of houses (see Activity 1.1)
- Temperature sensors to put in the wall opposite to the heater
- A light bulb simulating the sun.

Suggestions for use:

In order to analyse the effect of an outdoor heating source we add a very bright light bulb (200 W) outside as the "sun".
Students are requested to test the effect using a temperature sensor posed on the wall opposite to the lit wall.
A different experiment can be performed by using both the heaters (internal and external), e.g. by turning the internal heater on and off, but leave the sun on all the time.
Students can measure the difference in the temperature of a wall painted black and a wall painted white.

Activity 2.1: Observing ice melting in plates of different materials

Learning aims:

- To be aware that the nature of material influences transfer of thermal energy between bodies at different temperatures.
- To be able to classify materials according to their capability to conduct heat.

- To identify variables that influence the heat conduction.

Materials:

- Squares of different dimensions (surfaces and thickness) and different materials.
- A set of ice cubes of almost the same dimension and at the same temperature (taken from the same refrigerator).

Suggestions for use:

The teacher can show the apparatus (see fig. 2.1a) and stimulate students to make predictions about the melting times

NOTE. It could be useful, at this stage, to discuss about the feeling of warmness and coldness coming from touching different bodies, and also ask students about their bodies' temperature.

At this stage, it is also interesting to discuss about the concept of thermal equilibrium.

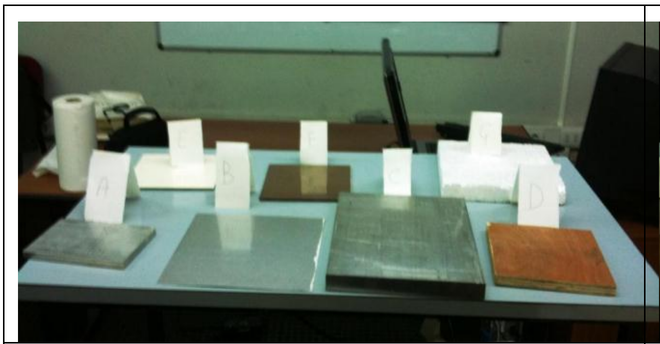


Figure 2.1a

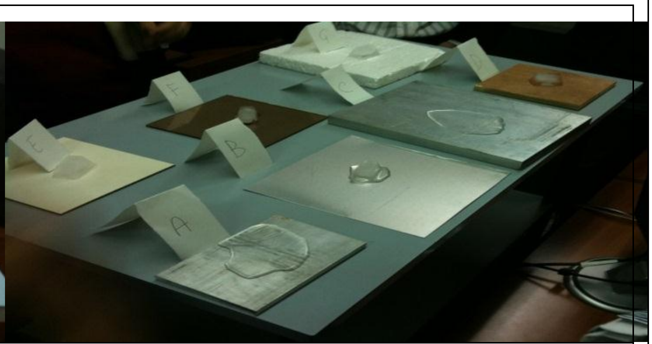


Figure 2.1b

After the observation the whole class will discuss the results, by confronting them with their own predictions and making hypotheses about the influence of different parameters on melting times

Teachers will introduce the concept of thermal conduction by discussing with pupils how to analyse the different parameters influencing the results (see fig. 2.1b).

Possible questions:

Questions referring to materials commonly used in everyday life and allowing a discussion about thermal insulation and thermal exchanges between environments at different temperature.

Activity 2.2: Measuring insulation properties of different materials

Learning aims:

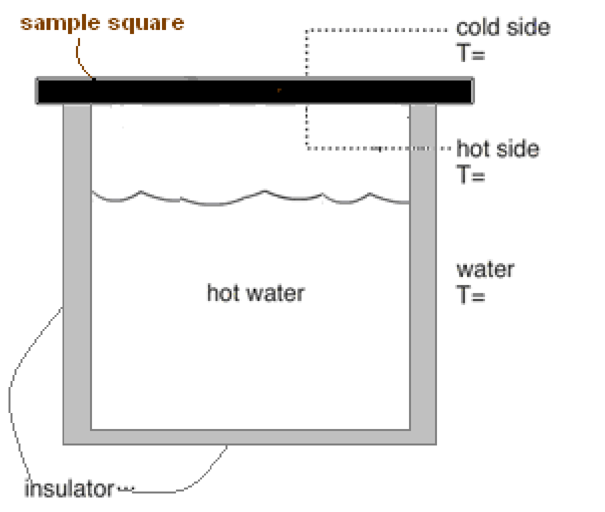
- To be aware that the nature of material influences transfer of thermal energy between bodies at different temperatures.
- To be able to classify materials according to their capacity to conduct heat.
- To identify variables that influence the heat conduction.

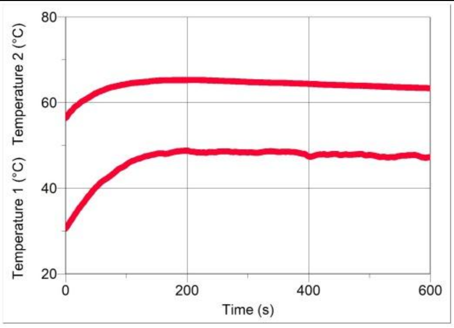
Materials:

- Couples of squares of the same material and surface and different thickness.
- Cups of Styrofoam
- Temperature sensors to be put on the inner and outer surfaces (see Fig 2.2a).

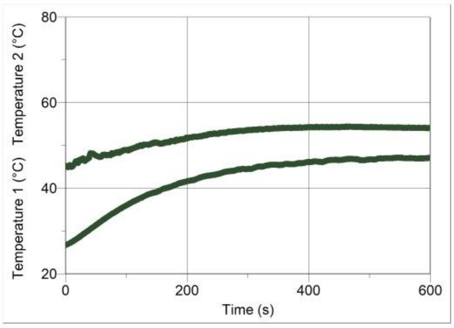
Suggestions for use:

Students place in the cup, along with a thermometer, a given quantity of hot water. They can register temperature at fixed time instant. To use temperature sensors can speed up the procedures and it results more effective in the visualization of temperature data.
Students can analyse:
The difference between the inside and outside temperatures of all the materials (see fig. 2.2a) and verify that their temperature are almost constant (for a time of the order of some minutes). See figure 2.2b.





Plastic



	Aluminium
Figure 2.2a	**Figure 2.2b**

The whole class can analyse the data of groups that used squares of the same thickness and order the materials from the greatest to the lowest temperature difference and define (on the basis of measurements) which material they think is the best conductor and the best insulator.

Teachers will discuss with pupils how to analyse the different parameters influencing the results

NOTE

Students compare the results of their experiments to their predictions and proceed in identifying and justifying any differences.

Possible questions:

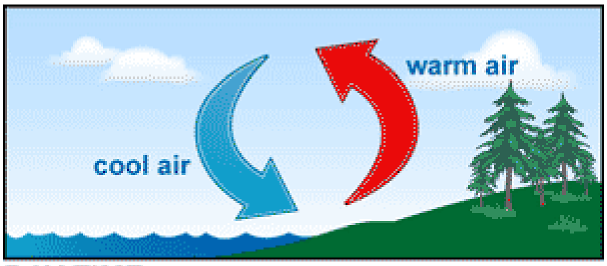
- Outline differences of materials used in the construction of different kinds of buildings with respect to thermal insulation.

Activity 3.1: Observing convection currents
Learning aims:
• To be aware that temperature gradients in fluids produce convective currents. • To identify mechanisms of functioning" on the base of density differences among fluid volumes at different temperatures and buoyancy properties.
Materials:
• Two bowls filled of hot water and ice, respectively. • A small fish tank filled with water at room temperature. • Small amount of red and blue dyes.
Suggestions for use:
The fish tank filled with water is placed over the two bowls and two drops of red and blue dyes are gently posed on the tank surfaces. You can see the video of the experiment at http://www.youtube.com/watch?v=7xWWowXtuvA&feature=related. The teacher can perform the demonstration and put questions recalling everyday phenomena stimulating students to identify variations of density in equal volumes of the same fluid at different temperatures and the consequent upward movement of hot fluid. The students should then be asked how they would need to alter the setup if they changed the angle of one of the straws, or the angle of the mirror.
Possible questions:
• What happens if we put a drop of oil at the bottom of a basin containing water? Why? • Analyse the heating of a pot of water on a stove and describe what happens. **NOTE**: A well-known example of heat transfer by convection is provided by the heating of a pot of water on a stove. Turning on the stove thermal energy is transferred first by conduction from the stove to the bottom of the pot and from this latter to the water. After a given time some bubbles of hot water on the bottom of the pot appear. These bubbles, that actually are local regions of hot water less dense than the cold one, rise to the surface and by the mechanism of convection transfer heat from the hot water, at the bottom, to the cold water, at the top. At the same time, the cold water at the top, denser then the hot one, falls to the bottom and is heated to this latter. • Why does the balloon move upward?

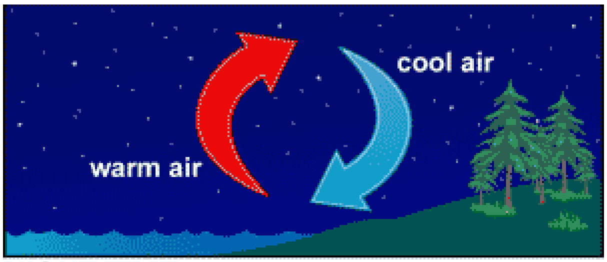
NOTE: By analysing students' answers to posed questions, the following kind of mechanism can be hypothesized.

Suppose we consider heating up a local region of air. As this air heats, the molecules spread out, causing this region to become less dense than the surrounding, unheated air. As a consequence, being less dense than the surrounding cooler air, the hot air will rise due to buoyant forces and this movement of hot air into a cooler region will transfer energy by heating the cooler regions.

Further questions can be posed through the analysis of the following phenomenon:



DAY TIME



NIGHT TIME

Phenomena of breezes over land masses near to large basins of water supply a relevant example of convection currents. Water has a larger heat capacity than land. As a consequence it holds heat better than land and takes longer to change its temperature, either upward or downward. Thus, in the morning, due to the sun heating, the air above the water is cooler than that over the land. This creates a low pressure area over the land, with respect to the high pressure area over the water. Due to this pressure difference air is pushed from the water to the land as a blowing breeze. On the other hand, during the night water cools off more slowly than the land, and the air above the water is slightly warmer than over the land. This produces a low pressure area over the water with respect to the high pressure area over the land, and this time air is pushed from the land to the water.

Activity 3.2: Natural and forced cooling

Learning aims:

- Make students aware of different aspects of convection in air.
- Make students aware of how experimental evidence can help them to decide on an everyday problem.
- Gain abilities in collaborative work aimed at design and carry out an experimental investigation.
- Gain abilities in reflecting on the purpose and nature of experimental activities they carried out in the unit.

Materials:

- Two squares of aluminium (side ≅15 cm, depth ≅ 3mm),
- Two temperature surface sensors
- A bowl with hot water (about 90°C)
- Two plastic bags
- Two isolating supports (Styrofoam)

Suggestions for use:

Two squares of aluminium (side ≅ 15 cm, depth ≅ 3mm), previously heated at a temperature of about 90°C (for details see Classroom activities) are set on Styrofoam isolating blocs. One is left cooling by air, while the second is cooled using a fan. The temperature is measured by two surface sensors previously posed in contact with one square surface using two pieces of scotch.

Figure 3.2a shows typical cooling curves for natural and forced convection. Date for forced convection refer to different values of the fan power (P1 < P2).

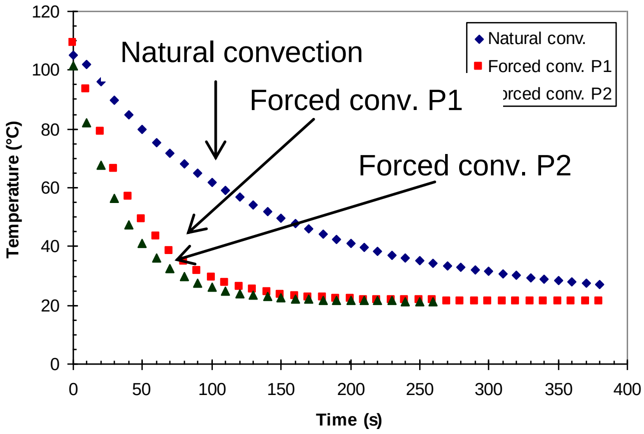


Figure 3.2a

Possible questions:

- Compare the three curves shown in figure 3.2a and say what are the main differences?
- What are the main differences between the two curves representing forced convection?

NOTE

An analytical expression for the cooling curves can be obtain through fitting procedures (Figure 3.2b) or by representing data in a different format. Figure 3.2c) give an example of data fitting obtained by plotting the opposite of the temperature to time difference ratios (– $\Delta T/\Delta t$) as a function of the temperature increase with respect to the environmental ($T-T_e$) (see Classroom materials).

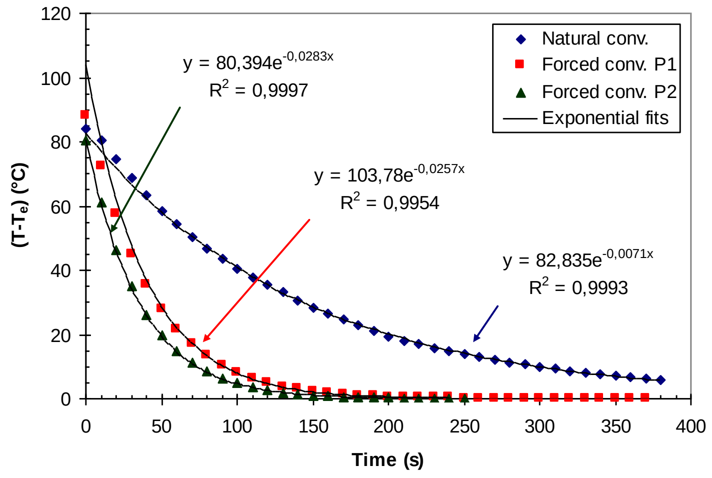


Figure 3.2b

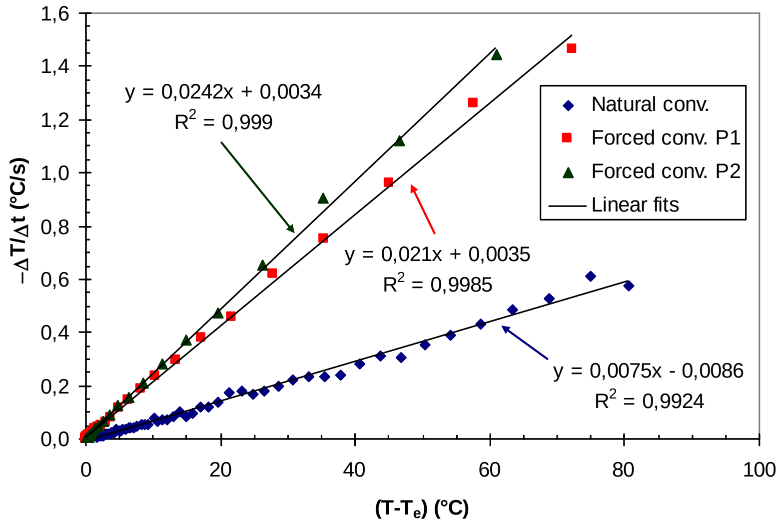


Figure 3.2c

Activity 4.1: Build and use home-made radiometers

Learning aims:

The aim of this activity is to show the evidence of the energy transmission by thermal radiation, with respect to heat conduction and convection, between a source of radiation and a home-made radiometer.

Materials:

We assemble three home-made radiometers and carry out our experimental activities by using the following materials:

- N. 3 thin aluminium plates (for example, obtained by cutting some “Pepsi” cans);
- N. 3 surface temperature sensors, interfaced to PC;

- N. 1 halogen lamp (400 W)
- N. 1 visible light filter. It is possible to build a visible light filter in a simple and economical way by using two layers of color film impressed to sunlight and developed. The layers can then be fixed to a transparent plastic support (crilex) for a more practical use.

Suggestions for use:

Building procedure:

We cut the cans in order to obtain three aluminium plates of equal surface 4x7 cm2. We paint one of these plates with a black gloss paint and another one of a white paint; the last one is left unpainted. We connect the back of each plate with the tip of the surface temperature sensor by a small piece of scotch tape. After that, we mount the three plates on polystyrene supports. The reason of painting the plate surface of our home-made radiometers is based on the everyday experience of dark object exposed to solar radiation that show higher surface temperatures with respect to lighter ones.

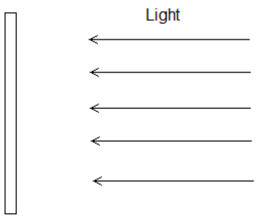
Home-made radiometer

Commercial visible light

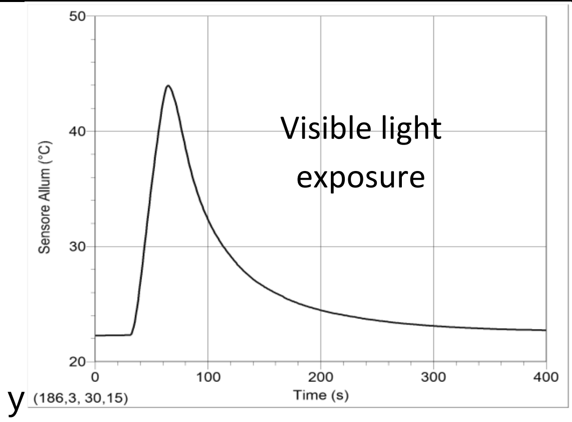
Halogen lamp

“Home-made” visible light filter

First experimental activity (performed by the teacher)

The unpainted aluminium radiometer faces the halogen lamp at a distances of 25 cm from the light source.  The lamp is switched on and the radiometer is illuminated for 30 seconds,	

after that the lamp is switched off and removed. The temperature of the radiometer plate is recorded as a function of time: it rises until a maximum value is reached and subsequently starts a decreasing cooling trend.



Possible questions:

- Why does the surface temperature of the radiometer increase?
- Which is the main mechanism of energy transfer during this experiment?
- We know that the energy could reach the surface of the radiometer by heat conduction, convection and radiation, but which of these mechanism is dominant here? How can we discriminate among the various mechanisms?

In order to answer these questions the teacher can repeat the experiment by using also a classical thermometer (not illuminated) which is used to measure the temperature of the surrounding air. After 30 seconds of light illuminating the radiometer in the same condition as before, we measure the temperature of the air between the halogen lamp and the radiometer plate and find that there is not any significant change on the air temperature with respect to the room temperature measured few seconds before the light transmission.

NOTE:

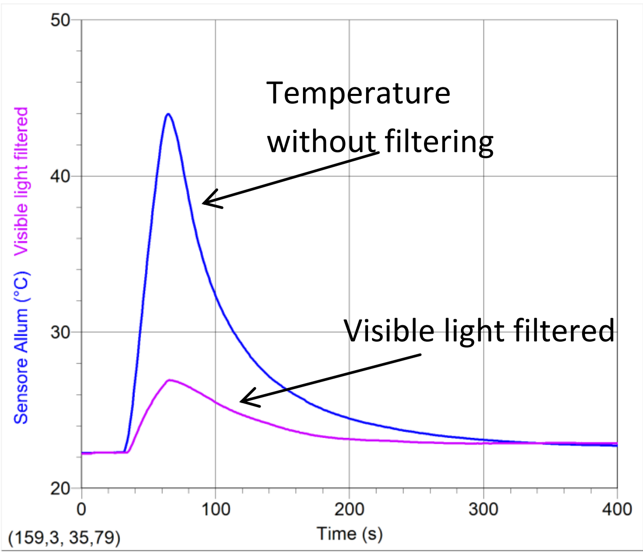
If a change of air temperature in the space between the lamp and the radiometer is not observed, this means that the transfer of energy from the lamp to the radiometer plate is not due to heat conduction or convection in the air. Therefore, the dominant mechanism of energy transmission is different and can be ascribed to lamp radiation.

It is also possible to answer the third question by repeating the experiment so that the surface of the radiometer is not frontally exposed to light of the lamp, but the lighting is made at a certain angle of inclination (see figure). For example, first the plate of the radiometer is placed at 45 ° with respect to the incident light and then at 90 ° with it, without significantly affecting the total distance between the light source and the radiometer.

The experiment will show that the greater the angle between the surface of the radiometer and the incident light, the lower the temperature change detected by the radiometer. If the heating was to be ascribed to conduction through the air, there should be no significant difference between the various cases of inclination of the radiometer, while in case of irradiation the angle formed between the radiometer and the incident light should critically influence the variation of temperature detected by the radiometer, as it happens.

- The temperature increase of object exposed to solar light is a well known phenomenon. We already know that the solar light propagates through empty space and heats up the atmosphere and the objects on the Earth surface. What happens if we eliminate the visible component of the radiation emitted by the lamp?

In order to further explore the transmission of energy by thermal radiation the teacher can repeat the same experiment as before, but now filtering the visible light incoming on the radiometer plate. An increase of the radiometer surface temperature, even in the case of total absence of visible light, is evident.
The temperature increase and the following cooling trend is recorded as a function of time and compared with that observed in the presence of light. The maximum value of the temperature reached in this latter case is lower than the one measured without filter (see figure).



In order to further explore the transmission of energy by thermal radiation the teacher can repeat the same experiment as before, but now filtering the visible light incoming on the radiometer plate. An increase of the radiometer surface temperature, even in the case of total absence of visible light, is evident.
The temperature increase and the following cooling trend is recorded as a function of time and compared with that observed in the presence of light. The maximum value of the temperature reached in this latter case is lower than the one measured without filter (see figure).

Questions:
In this case the light is absent, what is now transmitting the energy?”
The teacher can invite some students to experience this “invisible radiation” by

putting their hands in front of the filtered source.
"When the lamp is switched on, you don't see any light but you can feel a warming sensation on your hand. When the filtered lamp is switched off, the heating sensation on your hand immediately disappears."

Activity 4.2: Illuminating objects of different colours

Learning aims:

- To analyse different aspects of the radiation absorption from bodies of different colours.
- To use experimental evidence to decide on everyday problems.
- To design and carry out an experimental investigation by controlling variables.

Materials:

As in activity 4.1.

Suggestions for use:

The three home-made radiometers face the halogen lamp at equal distances (25 cm) from the light source (see Fig 4.2a). The lamp is switched on and the radiometers are simultaneously illuminated for 30 seconds, after that the lamp is switched off and removed.
Results show the black sensor reaching the higher temperature, the white sensor the lower temperature and the unpainted aluminium sensor an intermediate temperature (see Fig. 4.2b). Students assert that the black painted radiometer is the most sensitive to changes on surface temperature induced by the energy transmission of light because it is able to absorb more energy with respect to the white-painted and aluminium sensors, which are both interested by a reflection phenomenon of the incident radiation.

Figure 4.2a

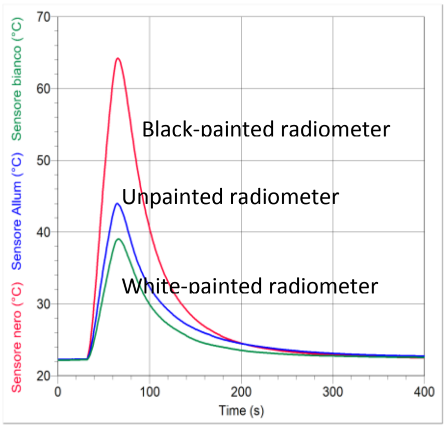


Figure 4.2b

Possible questions:

- What happens if we obscure the radiation, using the previous filter? ,
- What is the role of the “invisible light”?

Note:
Results of both previous activities can be discussed by introducing also analogies with the case of warm sensation in proximity of hot objects.
Infrared radiation (IR), i.e. the thermal radiation (not visible) emitted by hot objects can be introduced as well as the different times characterizing the transfer of energy by thermal radiation with respect to that with heat exchange by conduction and convection (which both appear to be slower processes).

Activity 4.3: Radiation from hot and cool bodies

Learning aims:

- The aim of this activity is to show the relevance of the energy transmission by thermal radiation, with respect to heat conduction and convection.

Materials:

- N. 2 plastic bottles (one filled with hot water and the other with cold water)
- N. 1 home-made radiometer (see Activity 4.1).

Suggestions for use:

First experimental activity (it can be performed by the teacher or a couple of students guided by the teacher)
The black radiometer faces the hot bottle at a distance of approximately 20 cm (see Fig 4.3a).
The temperature of the radiometer is registered and shown to the classroom (see Fig 4.3b). After almost 500 seconds the radiometer is rotated by 90° with its plate facing upward (see inset of Fig 4.3b). The temperature starts to decrease even in presence of the hot bottle. At a time of about t≈1300s the bottle is removed and a further decrease of the radiometer temperature is observed.

Figure 4.3a

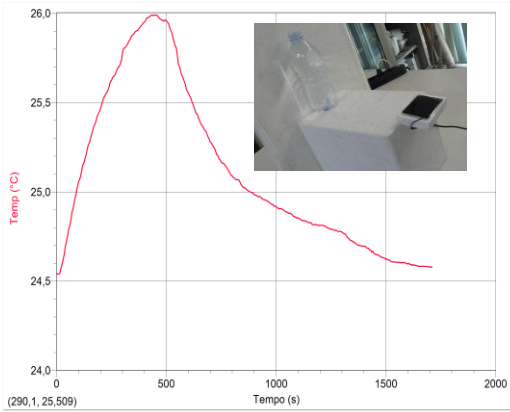


Figure 4.3b

Second experimental activity (it can be performed by the teacher or a couple of students guided by the teacher)

The black radiometer faces the cold bottle at a distance of approximately 20 cm (see Fig 4.3c).

The temperature of the radiometer is registered and shown to the classroom. After almost 800 seconds the cold bottle is removed and the temperature of the radiometer starts to approach the ambient temperature. At the time of about t≈1400 s the hot bottle is placed in front of the radiometer, as in the previous activity, and a further increase of the radiometer temperature is measured. Finally the radiometer surface is rotated again by 90° with its plate facing upward. All the measured changes of the radiometer surface temperature with the time are shown to students (Fig 4.3d).

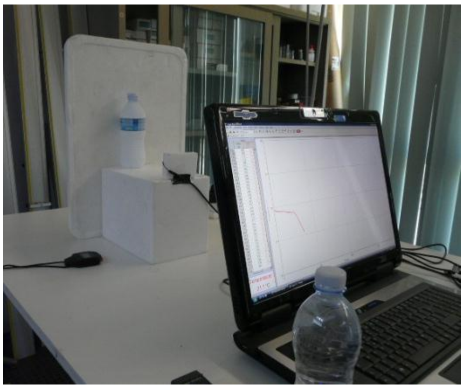


Figure 4.3c

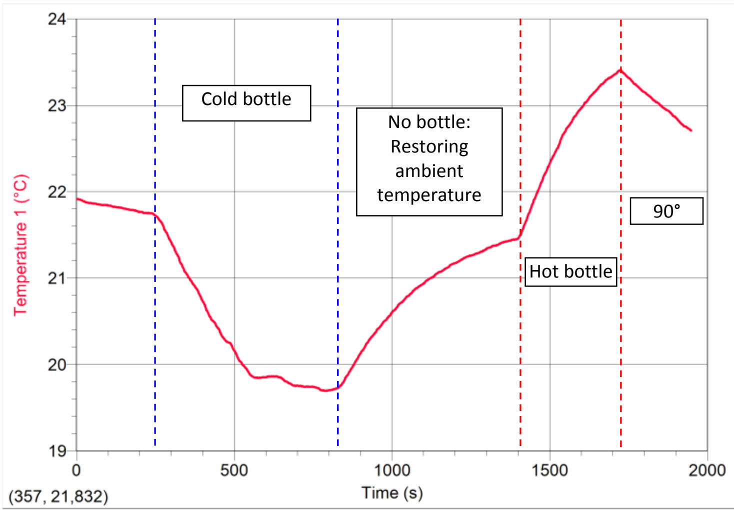


Figure 4.3d

Possible questions:

- Why does the surface temperature of the radiometer increase in the case of Fig. 4.3b?
- Which is the main mechanism responsible of the heating? Explain your

answer.

- What do you think about the cooling process shown in Figure 4.3d?

Activity 4.4: An open Inquiry about Infrared Thermography

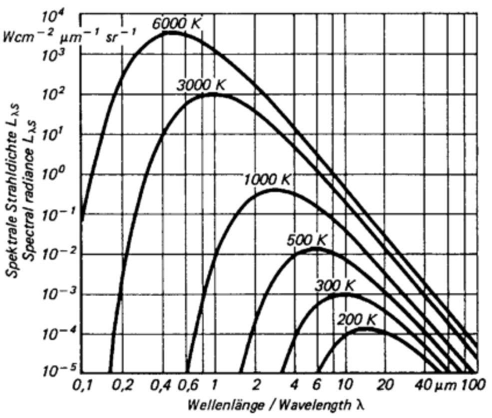
Learning aims:

- To compare different types of thermometers
- To investigate applications of infrared thermography

Suggestions for use:

Temperature plays an important role as an indicator of the condition of a product or piece of machinery, both in manufacturing and in quality control. Accurate temperature monitoring improves product quality and increases productivity.

Infrared technology has been utilized successfully in industrial and research settings for decades but now new innovations have resulted in non-contact infrared sensors offering faster and better measurements. In particular measurements can be taken of hazardous or physically inaccessible objects (high-voltage parts, great measurement distance); measurements of high temperatures (greater than 1300°C) present no problems (in similar cases, contact thermometers cannot be used). Furthermore there is no risk of contamination and no mechanical effect on the surface of the object.

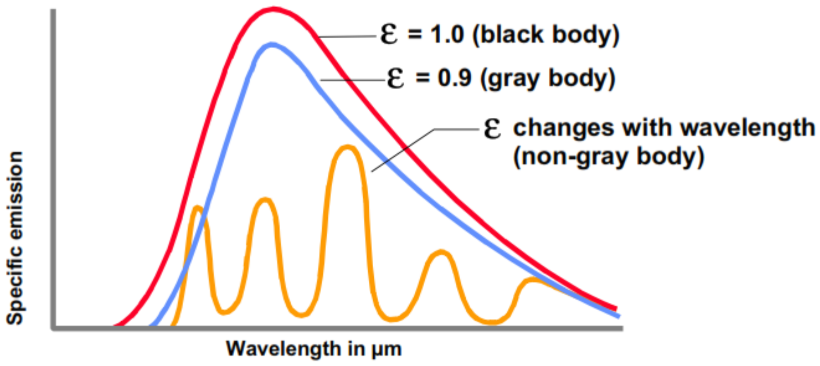


Every form of matter with a temperature above absolute zero emits infrared radiation according to its temperature. This is called characteristic radiation. The cause of this is the internal mechanical movement of molecules. The intensity of this movement depends on the temperature of the object. Since the molecule movement represents charge displacement, electromagnetic radiation is emitted. The spectrum of this radiation ranges from 0.7 to 1000 µm wavelength. For this reason, this radiation cannot normally be seen with the naked eye. Typical radiation of a body at different temperatures is shown in figure.

The radiation maximum move toward ever-shorter wavelengths as the target temperature rises, and that the curves of a body do not overlap at different temperatures. The radiant energy in the entire wavelength range (area beneath each curve) increases to the power of 4 of the temperature. These relationships were recognized by Stefan and Boltzmann in 1879.

The goal should be to set up the IR thermometer for the widest range possible in order to gain the most energy (corresponding to the area below a curve) or signal from the target. The greater the radiance difference per temperature difference, the more accurately the IR thermometer works.

Previous figure shows the ideal case, the so-called "blackbody" radiation. Many bodies, however, emit less radiation at the same temperature. The relation between the real emissive power and that of a blackbody is known as emissivity and can be a maximum of 1 (ideal blackbody) and a minimum of 0. Bodies with emissivity less than 1 are called gray bodies. Bodies where emissivity is also dependent on temperature and wavelength are called non-gray bodies. A further reason for having devices for different wavelength ranges is the emissivity pattern of some non-gray bodies (glass, metals, and plastic films).



Determining Emissivity

There are various methods for determining the emissivity of an object. You can find the emissivity of many frequently used materials in a table. Emissivity tables also help you find the right wavelength range for a given material, and, so, the right measuring device. Particularly in the case of metals, the values in such tables should only be used for orientation purposes since the condition of the surface (e.g. polished, oxidized or scaled) can influence emissivity more than the various materials themselves.

It is possible to determine the emissivity of a particular material yourself using different methods:

First method: Heat up a sample of the material to a known temperature that you can determine very accurately using a contact thermometer (e.g. thermocouple). Then measure the target temperature with the IR thermometer. Change the emissivity until the temperature corresponds to that of the contact thermometer. Now keep this emissivity for all future measurements of targets on this material.

Second method: At a relatively low temperature (up to 260°C), attach a special plastic sticker with known emissivity to the target. Use the infrared measuring device to determine the temperature of the sticker and the corresponding emissivity. Then measure the surface temperature of the target without the sticker and re-set the emissivity until the correct temperature value is shown. Now, use the emissivity determined by this method for all measurements on targets of this material.

Measuring the temperature of metals:

The emissivity of a metal depends on wavelength and temperature. Since metals often reflect, they tend to have a low emissivity which can produce differing and unreliable results. In such a case it is important to select an instrument which measures the infrared radiation at a particular wavelength and within a particular temperature range at which the metals have the highest possible emissivity.

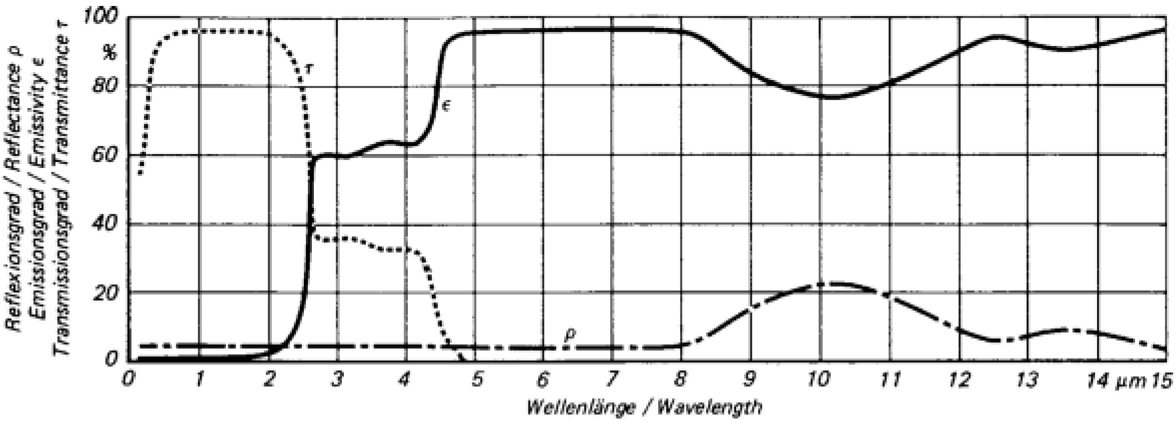
Measuring the temperature of plastics:

The transmittance of a plastic varies with the wavelength and is proportional to its thickness. Thin materials are more transmissive than thick plastics. In order to achieve optimal temperature measurement it is important to select a wavelength at which transmittance is nearly zero. Some plastics (polyethylene, polypropylene, nylon, and polystyrol) are not transmissive at 3.43 µm; others (polyester, polyurethane, Teflon FEP, and polyamide) at 7.9 µm.

Measuring the temperature of glass:

When measuring the temperature of glass with an infrared thermometer, both reflectance and transmittance must be considered. By carefully selecting the wavelength, it is possible to measure temperature of both the surface and at a depth. When taking measurements below the surface, a sensor for 1.0, 2.2, or 3.9 µm wavelength should be used. We recommend you use a sensor for 5 µm for surface temperatures. At low temperatures, 8-14 µm should be used with the emissivity set to 0.85, to compensate for reflectance. Since glass is a poor conductor of heat, and can change surface temperature rapidly, a measuring device with a short response time is recommended.

Spectral transmittance of glass:



Activity 1: Comparisons among different kinds of thermometers including infrared thermometers.

Activity 2: Investigation on Infrared thermography applications for building inspection to improve energy efficiency, non-destructive testing of parts, materials or systems through the imaging of the thermal patterns at the object's surface, safety driving systems based on night vision assistant with pedestrian detection and

warning, searching the darkness for missing people. Analysis of Infrared images and inferences about their thermal conditions.
(See the slideshow at www.uop-perg.unipa.it/establish/videoIR1_eng2.wmv)

Activity 4.5: Analysis of the cooling processes of an hot body in different conditions. Cooling in air and in a vacuum environment

Learning aims:

- The aim of this activity is to study the way a body cools in different environmental situations.

Materials:

- A 150 W, 10W ceramic resistor.
- A K type Thermocouple;
- Transducer voltage - temperature module for thermocouple (for example Fluke 80TK already prepared for type K thermocouple);
- Multimeter with a resolution of at least 0.1 mV in d.c.;
- Electrical cables;
- DC 40 V power supply
- Bell vacuum glass;
- Vacuum grease;
- Rubber hose vacuum;
- Rotary vacuum pump;
- Pressure gauge;
- PC software for data acquisition (for example, LabView, Coach, LoggerPro, DataMate)

Suggestions for use:

The analysis of heating and cooling in different environment conditions is performed by using a ceramic heating element (see figure 4.5a).

Figure 4.5a

As a first step, the resistance is secured to a rigid support set on a Teflon base, where all the electrical connections (rigid wires) that are necessary both to the heating of the resistance and the reading of the temperature values are also anchored (see Fig. 4.5b and Fig. 4.5c).

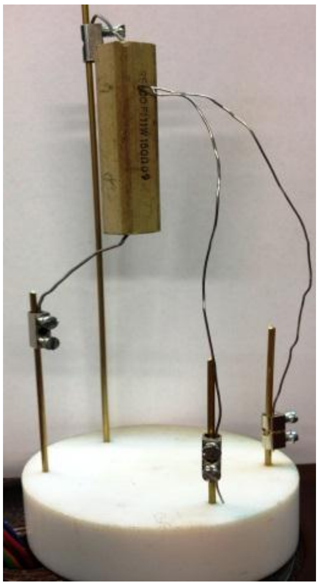


Figure 4.5b

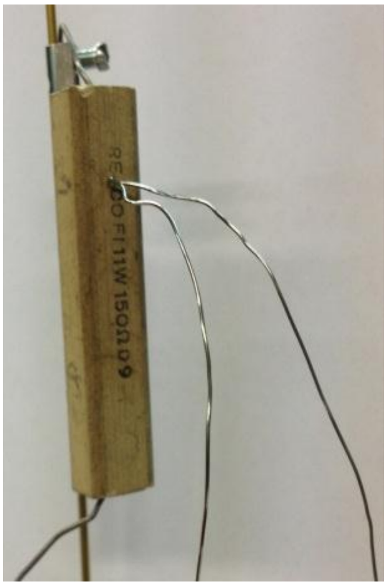


Figure 4.5c

As a second step, the edge of a vacuum bell is greased using vacuum grease, so that it can adhere well to the base (generally a glass disk), eliminating all the inevitable roughness that would not allow a good seal of the vacuum.

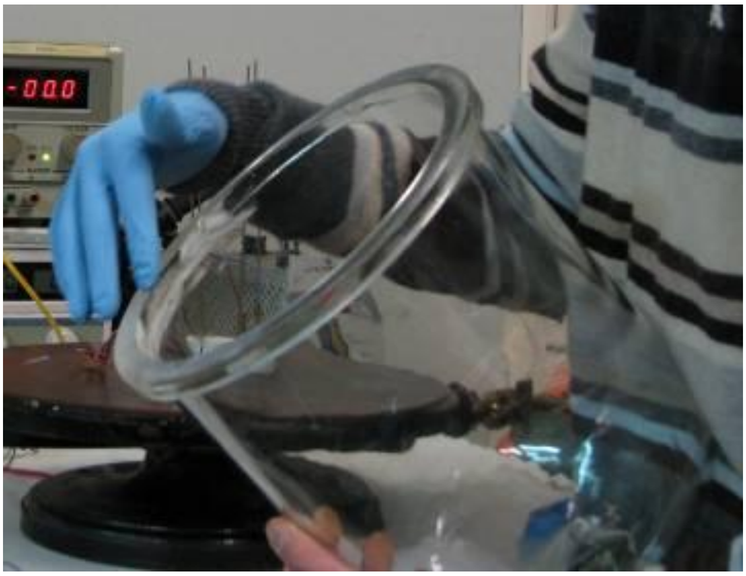


Figure 4.5d

The resistance is then enclosed into the bell which is resting on a base which in turn is resting on a metal platform in order to provide high rigidity.

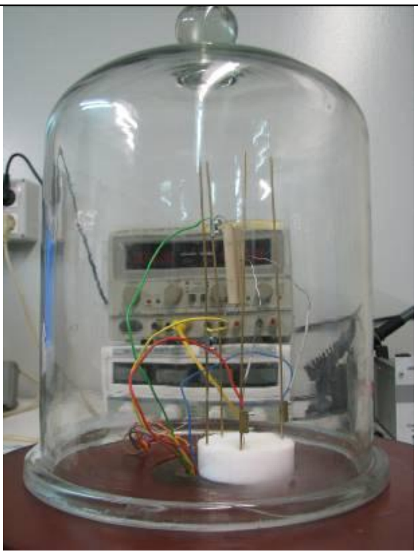


Figure 4.5e

Then, we are ready to turn on the pump starting the vacuum procedure.

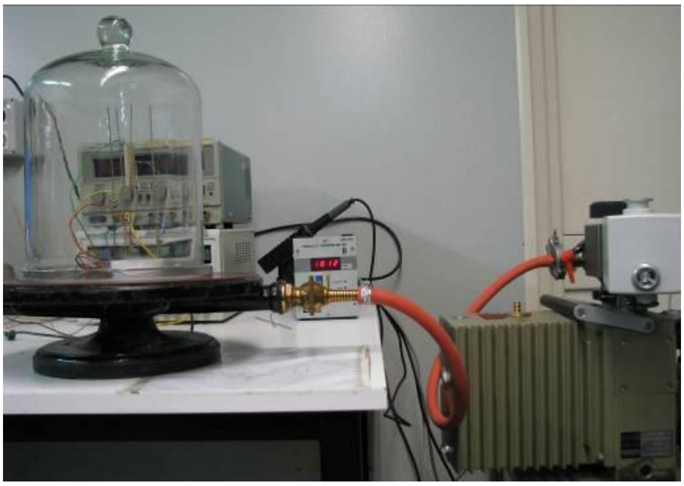


Figure 4.5f

This phase needs some time (usually 30/40 min) in order to obtain a vacuum of about 0.1 mbar. The bell is then isolated from the pump with a special valve and the pump can be turned off.

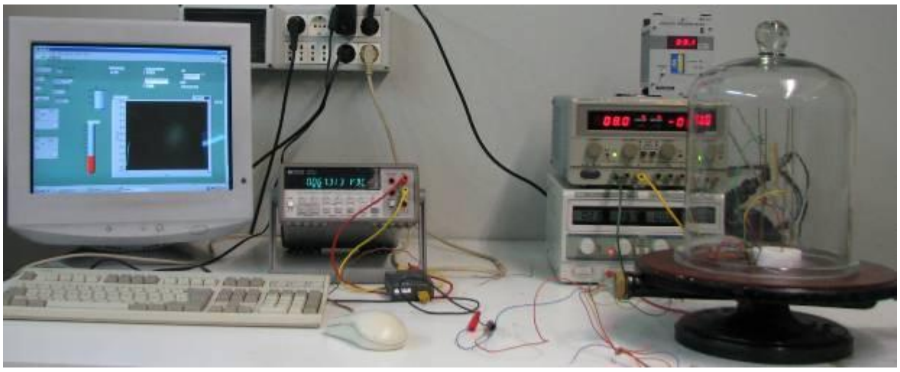


Figure 4.5g

The heating of the resistance is obtained by simply turning on the current (Joule effect) and the values of temperature are directly obtained from the output signal of the thermocouple placed in contact with the resistance. Such a signal is suitably amplified and calibrated by the Fluke module which provides values of voltages in mV directly interpreted as Celsius degrees (1mV/1°C).

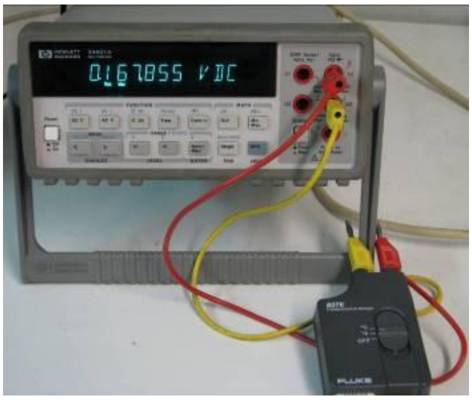


Figure 4.5h

The measures to be carried out for the three different conditions (radiation, free convection and forced convection) are performed on the base of the following protocol. For each condition, the resistance is heated by using the same electrical power (for example 8 W), so we are able to compare the maximum temperatures reached (the plateaux of curves in Figure 4.5k). Then, the current is turned off and the cooling process is analyzed.

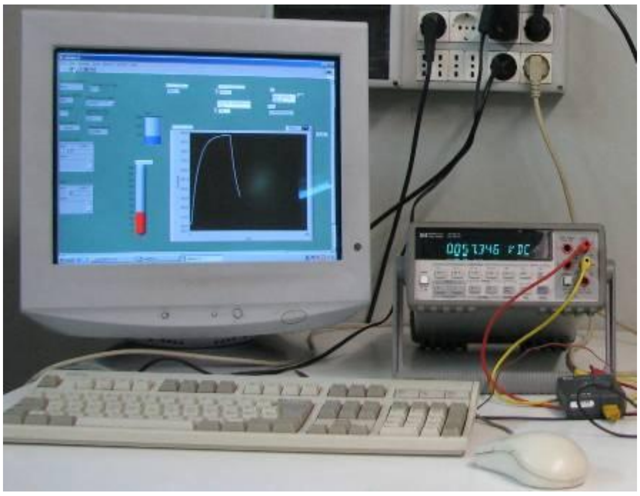


Figure 4.5i

The same procedure can be performed allowing air to enter up to atmospheric pressure and then doing the measurement in free convection and in forced convection without the bell and with a fan placed in the direction of the resistor just during the cooling phase.

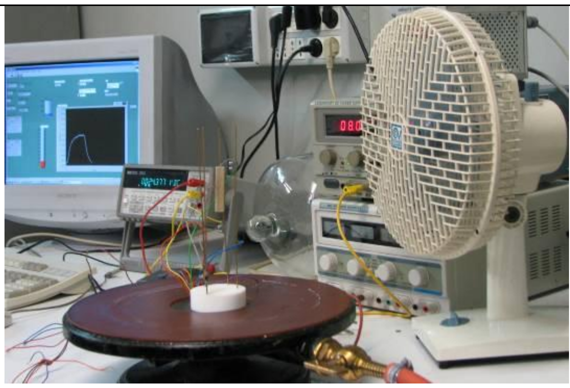


Figure 4.5j

The following graph shows the results at constant power in the three experimental situations:

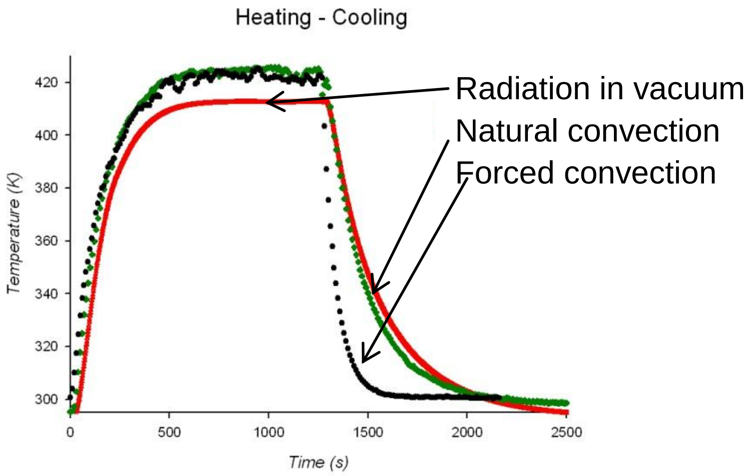


Figure 4.5k

It can be observed that the equilibrium temperatures of equilibrium are very close for heating in a vacuum and in open air and differ significantly with respect to the forced convection.

The following figure represents only the cooling processes and allows us to easily compare the different cooling rate in the three different situations.

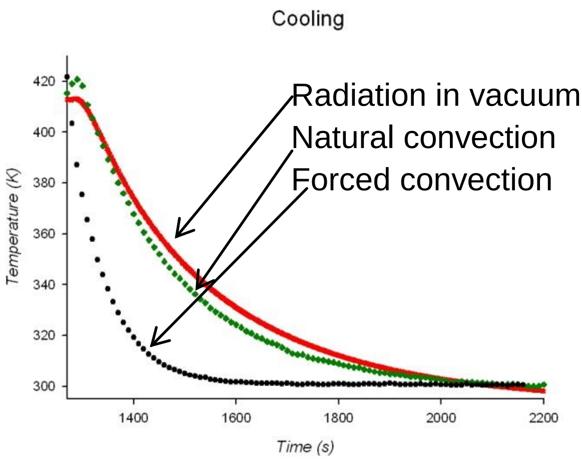


Figure 4.5l

Figure 4.5l shows that the cooling rate for the natural convention and irradiation are almost the same, whereas the cooling rate in the case of the forced convection is much greater.

Deepening the analysis:

An additional analysis of the results may be performed by using the numerical derivatives of the temperature with respect to time.

In fact, for finite variation, the rate of temperature variation is described by the following differential equation:

$$C\frac{\Delta T}{\Delta t} = -e\sigma S\left(T^4 - T_b^4\right)$$

where C is the body heat capacity, e is the emissivity, □ is the Stefan's constant and T_b is the room temperature, and by the following differential equation

$$C\frac{\Delta T}{\Delta t} = -hS\left(T - T_b^4\right)$$

where h is the coefficient of convection and S is the surface of the hot body, respectively for radiation in vacuum and for natural or forced convection cooling.

The graph of the ratio of finite differences - □T/□t as a function of temperature allows us to obtain very important information.

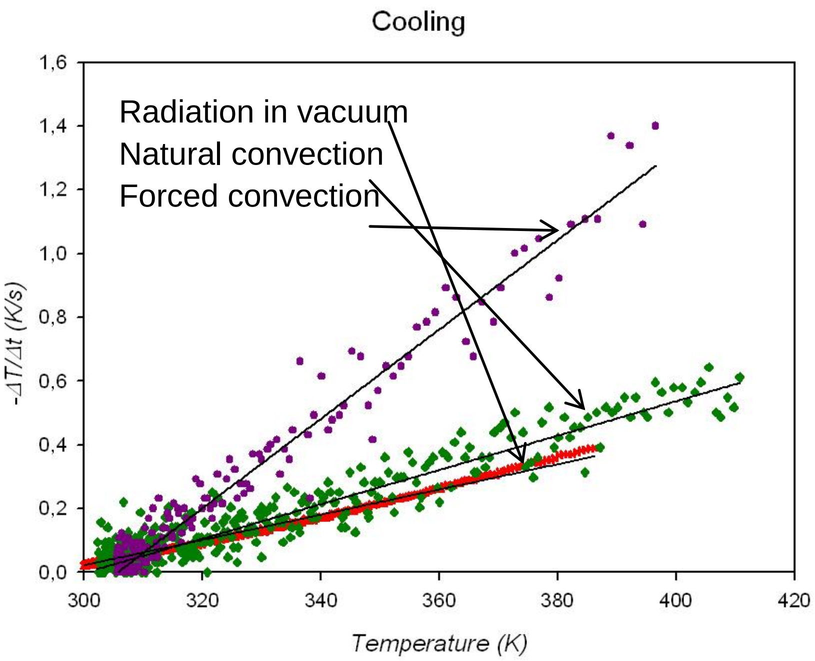


Figure 4.5m

In fact, in this graph, the slope of the straight lines represents the speed with which the cooling takes place for the three cases.

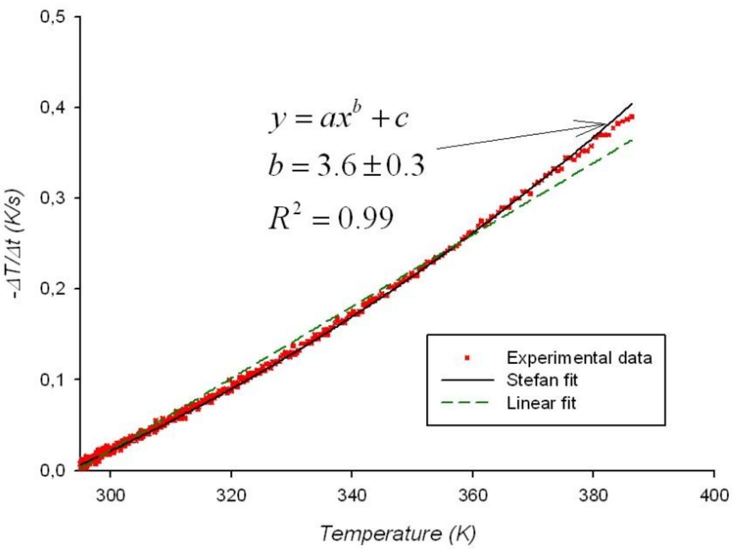


Figure 4.5n

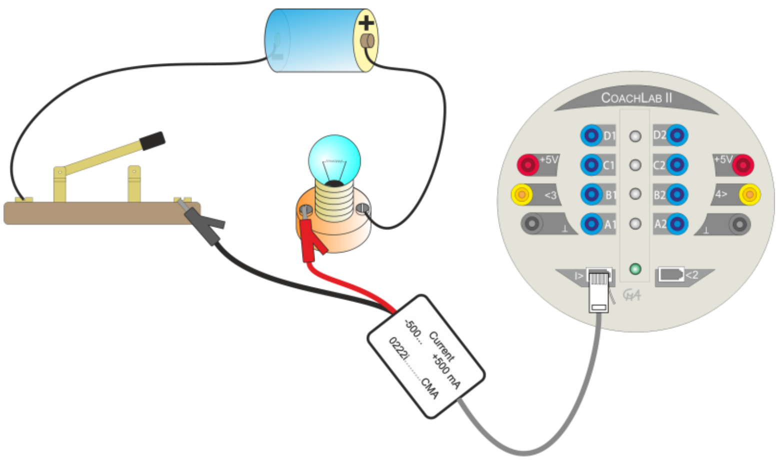
It is also worth to note that, as shown in figure 13, in the case of irradiation the best fit are not the linear function but is represented by a polynomial of degree b = 3.6 ± 0.3 in good agreement with the Stefan's law.

DIRECT CURRENT ELECTRICITY

The development of this unit has been led by the ESTABLISH partners:

Zuzana Jeskova, Marian Kires and Ludmila Onderova,

Univerzita Pavla Jozefa Safarika v Kosiciach (University of Kosice), Slovakia.



UNIT CONTENTS

I. Unit Description

In this unit, students study electric current and the basics of direct current circuits. They learn about the simple electric circuit, conductivity of different materials and how to measure current and voltage. They learn that a potential difference across a conductor causes a current through that conductor. They investigate the behaviour of different electric elements in circuits. They are introduced the concept of electric resistance and investigate its temperature dependence. They learn about the model of electric conductivity and are introduced the serial and parallel connection of resistors. They learn about the effect of electric current on human body. They get known about the electric energy and power delivered to the circuit. They also explore simple electrochemical sources followed by the investigation of the behaviour of real EMF devices and its parameters. They learn about the properties of the batteries.

The goal of this unit is not to cover all the topics but to provide inquiry-based activities to support teaching and learning the topic of Direct current electricity in an inquiry way.

The unit is enriched with many ICT activities using a voltage and a current sensor and a temperature sensor together to measure the physical quantities and to analyse the results.

- **Student level:** students aged 12-19
- **Discipline(s) involved:** Physics
- **Estimated duration:** Approx. 13 class periods

II. IBSE Character

The activities designed within the unit were all selected to emphasise the IBSE approach. The activities are aimed at learning the basics of simple electrical circuits and their properties. They are designed for upper secondary level of students (15-19). But several of them can be used for lower secondary level as well (aged 12-15).

III. Science Content Knowledge

Before starting the activities of this unit, students should have prior knowledge of:

- Some electrostatics: the matter consists of two kinds of electric charge and that some negative charge can be moved from one object to another leaving the first positively charged and the second negatively charged. Once the charges stopped moving we explore the electrostatic forces between them (Coulomb´s law) and the concept of potential difference (voltage).

- Phenomenon of electric current, the physical quantity of electric current.
- The schematic symbols for basic circuit elements. A circuit sketch.

The set of designed activities do not cover all the topics concerning direct current electricity. The activities presented here were selected and designed with regard to their potential towards IBSE. Nevertheless, there are some concepts that are needed within the activities (like power, energy delivered to the circuit, electromotive force) and hence they should be introduced before the activity starts.

In the unit students are introduced to the following scientific concepts and ideas:

- In order to have stable electric current we need a closed electric circuit with certain elements.
- There are materials that conduct electric current. They can differ according to their ability to conduct electric current.
- The amount of electric current can be measured by ammeter. Voltage can be measured by a voltmeter. Students learn how to connect an ammeter and a voltmeter into the circuit. ICT tools such as current and voltage sensors may be used for measurement. The electric current is the same at all places of the simple circuit.
- The concept of resistance and Ohm´s law. There are many elements that can be a part of the circuit. They can behave differently when connected in a electric circuit.
- The resistance depends on temperature. This relationship can be increasing (metal conductors) and decreasing (semiconductors). This relationship can be used for designing a thermometer.
- Theoretical model of electric circuit based on the concept of surface charges. Resistors in series and parallel.
- Electricity and human body. Ohm´s Law for a human body.
- The concept of power and energy delivered to the circuit. The basic introduction of these concepts is not a part of the activities. Their introduction must be done within a lesson before activity 9 (Intriguing behaviour of bulbs). Electric current delivers energy (power) to the circuit (e.g. to the bulb). The energy delivered determines the bulb brightness.
- The concept of electrochemical cell (primary and secondary) and a battery made of a connection of several cells.
- The concept of terminal voltage (compared to the electromotive force) and its dependence on the current flowing through the circuit. The concept of internal resistance.
- Power transferred from the battery to the load. Power transfer efficiency. Theoretical model of the battery behaviour.

- Batteries connected in series and parallel. EMF and internal resistance of these batteries.
- The properties of battery. Battery capacity. Energy supplied by the battery. Other important parameters.
- Everyday use of batteries. Environmental aspects of battery disposal.
- Alternative electric sources (fuel cell, photovoltaic cell)

The detailed explanation of the model of electric circuit can be found in the articles:

- Haertl, H.: The electric Circuit as a System: A New Approach, Eur.J.Sci.Educ., 1982, vol.4, No.1, 45-55
- Sherwood, B., A., Chabay, R., W. A unified treatment of electrostatics and circuits, available at: http://matterandinteractions.org/Content/Articles/circuit.pdf>

IV. Pedagogical Content Knowledge

Electricity is one of the basic areas of physics that is important at all levels of physics teaching. At the primary level, young children gain experience with simple electric circuits. At the secondary level, electricity is taught more systematically. In this sense, the activities can be used at different levels. For lower secondary level students (aged 12-15), it is recommended to carry out activities 1, 2, 3, 4, 5.1, 5.2, 8, and 10.

Electricity is one of the most difficult concepts for students to grasp. It is around us but at the same time it is invisible. Current and voltage are difficult to understand because they cannot be observed directly. As a result, there are many misconceptions concerning electricity identified by physics education research.

The most common misconceptions concerning electric circuits involve:

- Current is used up in a bulb. It is consumed while running through the resistor so that less current is flowing back to the battery.
- There is no potential difference across an open switch because V=IR and there is no I.
- Ohm´s Law applies to all circuit elements (not just resistors).
- Electrons move quickly (near the speed of light) through a circuit. That’s why when we connect the bulb to the battery, it lights up immediately.
- Charges slow down as they go through the resistor.
- A conductor has no resistance.
- The resistance of a parallel combination is larger than the largest resistance.
- Battery is a source of electric current. Battery either outputs zero current (if nothing is attached to it) or outputs a standard amount of current,

independent of what is attached to the battery. EMF and potential difference are synonymous.

- There is no current between the terminals of a battery.
- Charges that flow in circuit are from battery.
- Current and voltage are the same.

The activities are designed to confront these common misconceptions. To reveal misconceptions, the teacher should ask questions so that the student can confront his/her pre-knowledge with the results gained in the experiment. The activity **Model of the electric circuit (why is it more or less resistive)** presents an approach to teaching electric circuit concepts described by Herman Haertl that successfully addresses some of the standard student misconceptions.

The activities are designed for particular levels of inquiry. But it is up to the teacher and the level of his students to change the activity to more open investigation or vice versa.

V. Industrial Content Knowledge

This topic can involve a lot of industrial and everyday applications. We use electric devices in everyday life. It should be stressed that to make the electric devices work, a closed electric circuit is needed.

Electric circuit elements are parts of electric devices. Changing the electric resistance of resistors can change the current in the circuit and hence we can change the brightness of a lamp, the speed of a race car, etc. Electric resistance is used in archaeology for electrical resistance survey of the potential excavation sites.

Light-dependent resistors are used to switch the light on at night.

Diodes gave basis for the wide development of electronics. Light-emitting diodes are widely used instead of bulbs.
Teaching about different elements in electric circuit gives opportunity to visit a place where electronic devices are dismantled into electronic components and separated. The excursion can lead to discussion about possible environmental problems connected with electronic waste.

The temperature dependence of metal or semiconductor (thermistor) resistance leads to the application of this in thermometer design.

To engage students in technological design, they can design and build their own thermometer.

The applications of Ohm´s Law can involve also the effect of electric current on human body and the ways how to increase safety to prevent from being electrically shocked.

The concept of power and energy delivered to the load can be illustrated by the examples of electric devices and their corresponding power input and comparing different electric devices comparing their energy consumption. The power consumption of incandescent bulbs compared to other types of electric lights can be a good example of energy-efficient devices.

Wide industrial application is connected with the concept of battery. Students can build their own simple battery. The analysis of different batteries from the point of view of their EMF, internal resistance, and energy supplied to the circuit and other important properties can give students a picture about the battery properties and their reasonable use in everyday life.

The application in animal world (electric eel) can be a good example to illustrate the purpose of batteries in parallel and series. The environmental aspects of batteries disposal can be discussed and students can find where the nearest battery recycling place is and how and where we can get rid of the used batteries. This is also a good opportunity to find out information about the electric vehicle.

Connected to the batteries as sources of energy, students could look for other electrochemical sources, such like fuel cells or photovoltaic cells (used in solar panels).

VI. Learning Path(s)

This unit involves 16 activities altogether, some of which consist of several parts. They offer a wide range of IBSE activities on different inquiry level. The teacher can choose the activity that is appropriate for his own curriculum. Here is the possible arrangement of the activities with respect to the e-learning cycle.

Activity		Inquiry Type	E-emphasis
1	Electric current, battery and bulb		
1.1	How does a torch work?	Guided discovery/guided inquiry	Engage/explore
1.2	Construct a simple electric device	Bounded inquiry	Engage/explore
2	What material conducts electric current?	Guided inquiry	Explore/Explain
3	Determine the connections inside a black box	Guided discovery/inquiry	Explore/Explain
4	Measuring current and voltage	Guided inquiry	Exploration
5	Electric element in a dc circuit		
5.1	Resistor	Guided discovery	Explore/Explain
5.2	Bulb		
5.3	Other elements in a dc circuit (diode)		
5.4	What element is hidden in the black box?	Bounded inquiry	Extend/elaborate
6	Resistance and temperature (build your own thermometer)		
6.1	Metal conductor	Guided inquiry	Explore/Explain
6.2	Thermistor	Guided inquiry	Explore/Explain
7	Model of the electric circuit (why is it more or less resistive?)	Interactive discussion/demonstration	Explain

8	Does the human body obey Ohm's Law?	Bounded inquiry	Extend (elaborate)
9	Intriguing behaviour of bulbs		
9.1	Two identical bulbs in series	Guided inquiry	Extend (elaborate)
9.2	Two different bulbs in series	Guided/bounded inquiry	Extend (elaborate)
9.3	Switch on the circuit	Bounded inquiry	Extend (elaborate)
9.4	Two identically labelled bulbs	Bounded inquiry	Extend (elaborate)
10	Build your own battery		
10.1	Coins in solution	Guided inquiry	Engage/explore
10.2	Fruit cell	Guided inquiry	Engage/explore
10.3	Lead storage battery	Interactive demonstration	Engage/explore
11	Battery and its basic parameters		
11.1	Terminal voltage	Guided discovery	Explore/explain
11.2	Power transfer to the load	Guided inquiry	Explore/explain
11.3	Power transfer efficiency	Guided inquiry	Explore/explain
11.4	Build up a model of battery behaviour	Bounded inquiry	Extend (elaborate)
12	Batteries in series and in parallel	Bounded inquiry	Extend (elaborate)
13	How does an electric eel kill its prey	Bounded inquiry	Extend (elaborate)
14	How much energy is stored in a battery?	Guided inquiry	Explore/explain
15	Batteries and their reasonable use	Open inquiry	Elaborate/evaluate
16	Other alternative electrical sources		
16.1	Fuel cell	Bounded inquiry	Extend (elaborate)
16.2	Photovoltaic cell	Bounded inquiry	Extend (elaborate)

VII. Assessment

The activities 1, 2,3,4,5 are aimed at basic knowledge about simple electric circuit. The assessment can include practical assignments on constructing a simple circuit and measuring voltage and current.

The activities 5,6,7,8 involve V-A characteristics (Ohm´s Law), the temperature dependence of resistance and resistors in series and parallel. The assessment of the conceptual understanding of these concepts can include theoretical test as well as a presentation based on searching information on the effect of electricity on human body.

Activity 9 is aimed at the conceptual understanding of the concept of power delivered to the circuit. A theoretical test can be appropriate to check the understanding.

The activities 10-16 aimed at the understanding the concept of battery and its parameters can be assessed by a theoretical test. A presentation or a written report on the results of open inquiry based on searching information about batteries (activity 15) can be assessed when presenting results in front of the class.

In all the activities where students use guided/ bounded inquiry to carry out an investigation on a specific topic and they collect and analyze data to draw conclusions consequently, the written report on the labwork can be a part of the assessment, as well.

VIII. Student Learning Activities

Activity 1: Electric current, battery and bulb

Learning aims:

- To understand how a potential difference can cause an electric current through a conductor
- To learn to design and construct simple electric circuits using batteries, bulbs, wires and switches
- To learn to draw circuit diagrams using symbols

Materials:

- A few cheap torches that can be taken apart,
- Three bulbs (e.g. 4.5V/0.3A), Zinc-carbon battery (4.5V), leads, one-way switch, two-way switch

Suggestions for use:

Divide the class into small groups of 2-4 students and hand out the worksheet: **Electric current, battery and bulb**. The students working in groups go step-by-step from simple observation to guided discovery up to bounded inquiry.
Let students play in groups with a torch and dismantle and examine its components. Students should identify three basic components: a switch, a bulb and a battery that are connected in series. They learn that a closed circuit is needed for current to flow. The torch case can be a part of the circuit. After this first simple investigation, they learn to build their own simple electric circuit from a battery, a bulb, leads and a switch.
Once the students know to light up a single bulb, they can design and build some simple electric devices using extra switches, wires and bulbs. They are asked to invent and construct more complicated circuits with series or parallel connection of bulbs using switches. Even if the students do not know what goes on in electric circuit in details, this task can motivate them to think and investigate in order to find out the appropriate solution. Once they have completed the investigation, they summarize the results and present them to the other groups. In cases of limited materials or time, each group can construct one of the suggested electric circuits.

Possible questions:

- What are the basic components of the torch?
- What makes the bulb light up?
- What components can a simple electric circuit be made of?

- What influences the bulb brightness?
- How is the current direction set?
- How do different switches work?

Activity 2: What materials conduct electric current?

Learning aims:

- To learn to design and construct simple electric circuits using batteries, bulbs, wires and switches
- To understand that there are different types of materials conducing or not conducting electric current

Materials:

• Zinc-carbon battery (4.5V), leads, wires of similar size and different materials, pencil lead, match, piece of plastic, distilled water, tap (salty, sweet) water, glass, porcelain, china plate with metal strip, etc.

Suggestions for use:

Divide the class into small groups of 2-3 and hand out Classroom Material: **What material conducts electric current?**

Once the students can construct simple electric circuits, they can be asked to plan and design their own experiment to examine different materials and their conductivity. They should use a bulb as an indicator of current. Once they have completed the investigation, they summarize the results and present them to the other groups. I In cases of limited materials or time, each group can investigate several of them. Finally we can do a contest on the longest electric circuit that makes the bulb light up.

Possible questions:

- What physical quantity does the bulb brightness indicate?
- How do different materials connected into the circuit influence the brightness of the bulb?
- Compare the current flowing through the circuit in each case.
- Which materials are good conductors and which are not?
- Why is it important to know if the material conducts electricity?

Activity 3: Determine the connections inside a black box

Learning aims:

- To deepen and widen students' knowledge about the simple electric circuit.

Materials:

- Black boxes with four connectors (that are mutually interconnected in different ways inside each box using wires or resistors), bulbs, batteries (or some other convenient source of DC voltage), leads.

Suggestions for use:

We divide the class into groups of three. Each group has the necessary equipment ready on their table. We hand them out the **Black box's secret worksheet** and let the students perform their own experiments in a guided discovery/inquiry way. At the beginning, they should answer introductory questions that should update their knowledge necessary for independent investigation. In accordance with the principles of inquiry based learning, students first draw possible ways of interconnection, then they propose a procedure for investigation and finally, they perform an experiment to reveal the internal structure of the boxes. They use a power source, wires and a bulb to indicate the current (present or not, strong or less strong) through a selected path. During the independent investigation, the teacher observes and moderates the individual work of the students by asking questions. (In case of a less advanced class, the questions are answered one by one and the correctness of the answers of different groups is checked in the form of a class-wide discussion). After the experiments are finished, the contents of the black boxes are revealed – the students check the correctness of their investigations and they try to analyse the cause of any mistakes they have made.

Possible questions:

- What internal connection corresponds to the situation when the bulb lights up?
- What internal connection corresponds to the situation when the bulb lights up but it shines dimmer than in the previous case?
- When is the brightness of a bulb connected in an electric circuit lower and when higher?
- What internal connection corresponds to the situation when the bulb does not shine at all?
- What is understood by the term "black box"?

- Where can we find black boxes in everyday life?

Activity 4: Measuring current and voltage

Learning aims:

- To understand the measurement of two basic physical quantities that describes the operation of electric circuits: current and voltage using current and voltage sensor (alternatively an ammeter and a voltmeter)
- To understand that current is the same at all points in simple circuits
- To understand how voltage is distributed across different parts of a simple electric circuit.

Materials:

Battery (e.g. zinc-carbon or fresh alkaline, 4.5V), two bulbs (e.g. 4.5V/0.3A), leads, computer, interface and software (e.g. COACH 6), current sensor, voltage sensor (ammeter and voltmeter eventually)

Suggestions for use:

Divide the class into small groups of 2-3 and hand out **Classroom Material: Measuring current and voltage**. This is a simple activity aimed at developing basic skills concerning measurement of current and voltage in a simple electric circuit with the help of sensors and understanding about current and voltage in the simple circuit. It is important that students work in small groups so each student has a chance to manipulate with the circuit components. Students learn that to measure the voltage across an element in a circuit, the voltage sensor has to be connected in parallel, and to measure the current flowing through it the current sensor has to be connected in series with it. They learn that the current is the same at different points of a simple electric circuit and that it is not used up by the circuit element. They learn how the voltage is distributed across different parts of the electric circuits. Students follow the instructions in the worksheet, answering the questions and predicting the behaviour of the circuit.

Possible questions:

- Is the current the same at different points of a simple electric circuit? Explain.
- Is the voltage the same across the battery and the bulb in a simple electric circuit? Explain.
- Is there a circuit element with zero voltage across it?
- What is the voltage expected to be at the two ends of the same wire?

- How is the voltage across a battery influenced by the number of bulbs connected in series?
- How is the current through a circuit influenced by the number of bulbs connected in series?
- Is the battery a source of a constant current or a constant voltage?

Activity 5: Electric elements in a DC circuit

Learning aims:

- Understanding that the potential difference across the conductor causes a current through it
- Exploring the relationship between the current flowing through a conductor and a potential difference across it.
- Interpreting the current – voltage diagram of a conductor
- Understanding the concept of resistance
- Investigating the behaviour of different electric elements in a direct electric circuit
- Interpreting the current – voltage diagram of different electric elements

Materials:

Variable power source (up to 10V), leads, resistors of different values of resistance (e.g. 20Ω or higher), bulb (e.g. 6V/0.05A), other electric elements (e.g. semiconducting diode) limiting resistor to be used in a circuit with diode, computer, interface and software (e.g. CMA Coach6), current sensor, voltage sensor (if computer with interface is not available, ammeter and voltmeter can be used)

Suggestions for use:

Divide the class into small groups of 2-3 and hand out **Classroom Material: Electric element in a DC circuit**. In this activity, students carry out an experiment in order to investigate the relationship between the current flowing through a resistor and the voltage across it and to understand the concept of resistance. We expect students to be confident enough in measuring current and voltage with the help of sensors.

Firstly, they are introduced the concepts of resistor and resistance – as a physical quantity defined as $R = \frac{V}{I}$. During the investigation students discover that this relationship is linear and they learn to understand the current-voltage diagram and the concept of resistance.

The important point of this investigation is to connect the experiment with its graphical representation and to develop the ability to grasp the required information from the graph. Students learn to understand the physical meaning of diagram features (linear, non-linear, slope of the line) and to interpret the diagram correctly.

In the next step, they investigate the behaviour of other electric components in the direct electric circuit, such as bulbs and diodes and compare it with the behaviour of a resistor.

In order to enhance conceptual understanding of Ohm's law, the activity can be followed up by the additional activity carried out in the inverse sequence. The components are hidden in a "black box" and on the basis of their current- voltage relationship measurement students reveal the black box content. This activity is carried out as a bounded inquiry with students having the problem to solve and materials available to design the experiment in order to find the problem solution. The black boxes can contain a resistor, a bulb, a diode and a thermistor so that the students decide about the component that behaves differently than the other ones.

Let students plan the measuring procedure without significant help.

In this activity, there are wide opportunities to connect this knowledge with Industry.

This can involve the application of resistors and other electric elements and electronic components, here are several examples:

- Standard applications of resistors in electric circuits in various devices. The brightness of the lamp can be changed using a variable resistor to change the current. In some electric model race car sets, squeezing the trigger controls a variable resistor and hence the current through the car motor can increase so the car speeds up.
- The use of electric resistance in a wider context, e.g. in archaeology for electrical resistance survey, when metal probes are inserted into the ground to obtain a reading of the local electric resistance. Soil resistivity testing is used to find potential excavation sites. Scientists use meters to find and map out man-made areas beneath the surface. Roads and building foundations tend to be dry and compacted, producing high soil resistivity. Covered ditches and trenches have high moisture content and readily conduct electricity.
- Light-dependent resistors decrease in resistance with more light. They are widely used in light-night to switch the light on at night. Thermistors decrease in resistance when their temperature rises.
- Diodes gave basis for the wide development of electronics. Light-emitting diodes (LED) give out light when a current passes through. LEDs hardly ever

fail, and are used instead of bulbs.

Teaching this topic provides a good opportunity to visit a place where electronic devices (such like TV sets, radios, computers, mobile phones, etc.) are dismantled into electronic components and separated according to their possible reuse. When dealing with electronic waste a question of their influence on the environment should be taken into account and may be discussed.

Possible questions:

- What does the voltage applied across a circuit element cause to happen?
- Do different elements (resistor, bulb, diode) behave the same way in a DC circuit?
- How is the current flowing through an element influenced by the voltage applied across it? Does the current increase, decrease or stay constant when applying increasing voltage? What is the mathematical relationship between current and voltage (I-V relationship) for a circuit element?
- How could you distinguish between several elements knowing their I-V diagram?

Activity 6: Resistance and temperature (build your own thermometer)

Learning aims:

- Understanding that the resistance of the electric element can depend on its temperature
- Understanding that different elements react on increasing temperature differently
- Exploring the relationship between the resistance of a metal conductor and its temperature
- Exploring the relationship between the resistance of other elements like thermistor and its temperature
- Interpreting the resistance – temperature diagram of a metal conductor and that of a thermistor
- Understanding the use of resistance thermometer for measuring temperature

Materials:

Variable power source (up to 10V), leads, computer, interface and software (e.g. CMA Coach6), current sensor, voltage sensor, temperature sensor (if computer with interface is not available, ammeter and voltmeter and thermometer can be used), metal conductor (e.g. a long thin copper wire), thermistor

Suggestions for use:

Divide the class into small groups of 2-3 and hand out **Classroom Material: Resistance and temperature**. In this activity students carry out an experiment in order to investigate the relationship between the resistance of a resistor (thermistor) and its temperature. The resistance is measured via measuring current flowing through the element and voltage across it calculating the corresponding resistance. At this stage students should be confident enough in measuring current and voltage as well as the temperature with the help of sensors.

The main idea is to find out the main difference between the metals and semiconductors in terms of the temperature dependence of their resistance and understand that based on this dependence the element can be used as a device for measuring temperature.

Since the temperature coefficient of resistance for metals is rather small (α is typically from 3.10-3K^{-1} to 6.10-3K^{-1}) we need a long thin wire to have the initial resistance big enough to see the difference when heated. In case we do not have an appropriate wire available, students can use the results measured already in COACH 6 that they can analyse. (the file Resistance and temperature_metal.cmr.)

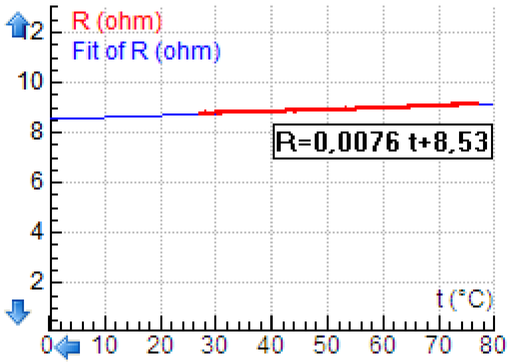


Fig. Experimental results for metal

The resistance temperature dependence for a thermistor is much more significant with negative temperature coefficient of resistance. The result can be seen in the file temperature_metal.cmr.

In both cases students carry out measurement and the following analysis in a guided inquiry mode. The ready-made result can be used in case of lack of time but real measurement is preferable. In both cases the analysis should lead to the data fit that is linear for the metal but much more complicated for thermistor. We introduce the idea of the temperature calibration. Thermistor calibration can be done if students are already familiar with the exponential function. They can compare their thermometer with data from the temperature sensor.

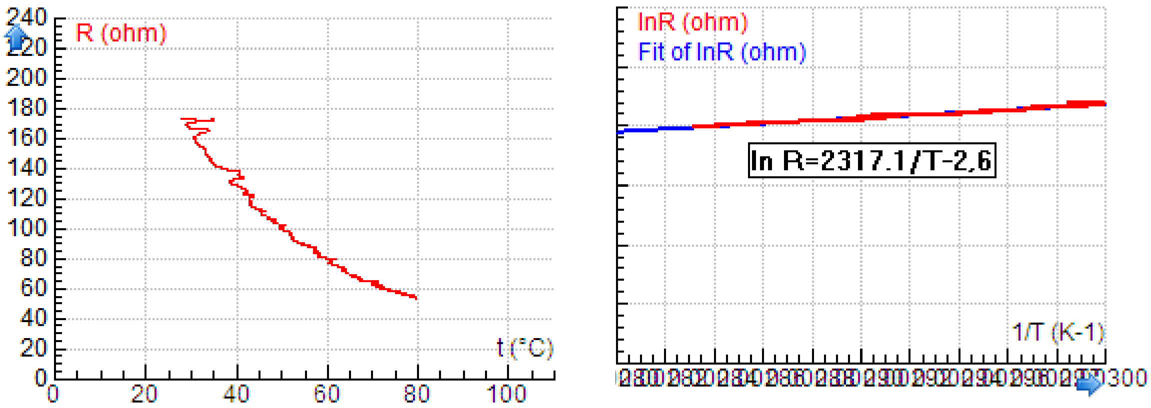


Fig. Example of thermistor calibration result

The important point is to understand the principle of resistance thermometer and its calibration. The connection with industry can involve information about resistance thermometers and thermistors and their applications (thermistors in automotive industry for monitoring the coolant and oil temperature in the engine, temperature of the incubator, etc.).

Possible questions:

- How does the resistance of a metal conductor change with temperature?
- How does the resistance of a thermistor change with temperature?
- How can the resistance-temperature dependence be used for measuring temperature?
- How can we calibrate a metal or a thermistor for measuring temperature?

Activity 7: Model of the electric circuit (why is it more or less resistive)

Learning aims:

- Understanding the conduction mechanism in metals in terms of the electrons´ motion
- Understanding the concept of surface charges on conductors
- Understanding the role of resistor in a current carrying circuit
- Understanding that the current is divided at the junction
- Understanding what is the final resistance of two resistors connected in series (parallel)

Materials:

- Animations available at

  http://www.astrophysik.uni-kiel.de/~hhaertel/CLOC_doc/CLOC_doc_uk/index.htm

Suggestions for use:

This activity is aimed at conceptual understanding of electric circuit through the concept of surface charges. The explanation can be found in

- Haertl, H.: The electric Circuit as a System: A New Approach, Eur.J.Sci.Educ., 1982, vol.4, No.1, 45-55
- Haertl, H.:Conceptual learning of Circuit, available at
- http://www.astrophysik.uni-kiel.de/~hhaertel/CLOC_doc/CLOC_doc_uk/index.htm
- Sherwood, B., A., Chabay, R., W. A unified treatment of electrostatics and circuits, available at http://matterandinteractions.org/Content/Articles/circuit.pdf

The activity should be guided by the teacher who carries out an interactive discussion to explain the basic mechanism of electric current in a circuit and the related concepts. Within the interactive discussion, teacher ask questions and students try to formulate answers. The important point is not to give the answer but try to make students think to come to the answer by themselves. Therefore the questions are formulated to revise the already known facts towards new situations and coherence.

Here is a possible scenario how to carry out the activity with the questions and corresponding answers. The first set of questions is aimed at the revision of the already known facts.

1. When is the object electric?

Describe your idea about the internal structure of a matter.

Every material object shows a grainy structure, where the basic elements of this structure - the atoms or molecules - consist of charge carriers of opposite polarity - the protons inside of the core and the electrons at the outer shells.

What is the reason of interaction between electrons and protons?

The existence of charge with opposite polarity has to be accepted as given by nature. The same holds for the fact that charge of equal polarity repel while charge of opposite polarity attract each other. Protons and electrons carry the same elementary charge with opposite polarity. For historical reasons, the charge of electrons is called negative while the charge of the protons are positive.

How does a group of equal number of positive and negative charges behave?

Every macroscopic amount of charge is always an integer multiple of the elementary charge.

The unit of charge has been defined (again for historical reasons) as consisting of $6.2x10^{18}$ elementary charges. The unit is called 1 Coulomb, in honour of the French physicist Charles Augustin de Coulomb (1736-1806).

An equal amount of protons and electrons are seen from outside as neutral.

What happens when we add a single electron (or proton) to the group of charges that are in equilibrium?

Charge cannot be created or annihilated. Within an electric device electrons can only be displaced.

If electrons pile up at some place it is certain that positive charge carriers will pile at some other place which has been neutral before. Repelling forces will show up between charge carriers with equal polarity and attracting forces between charge carriers of opposite polarity - the so-called Coulomb forces. These Coulomb forces are counteracting the original separation and prevent any further displacement of electrons.

The area with extra negative (positive) charge is called electrically negative (positive).

2. What is an electric power source?

How could you describe the operation of electric power source?

An electric power source consists in principle of a conductive device which is connected to the outside by two metallic contacts. A power source can apply a force on the internal electrons to move them from one external contact towards the other. The kind of force is different for different kinds of power sources. Within a battery chemical forces are active, within a generator electromagnetic forces can be applied.

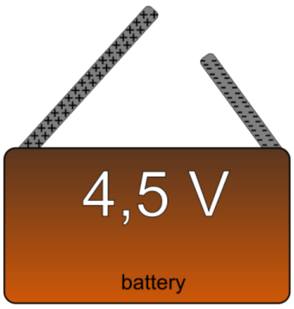


Fig. 1. Power source with surface charges at the metallic contacts

The action of these forces is always the same: At one of the external contacts an excess of electrons will occur. These electrons are missing at the other contact and will show up there as a positive charge (Fig. 1).

How is the excess charge (electrons) distributed on the metal electrode of the power source?

A basic law comes into play here: Additional electrons can never exist inside of a metallic conductor but only at its surface. It is sufficient to accept as an experimentally proven fact that additional electrons can exist at the surface of a metallic conductor and only at its surface.

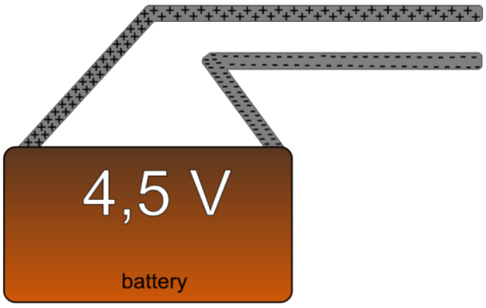


Fig. 2. Power source with connected conductors and surface charges

The larger the density of the additional negative charges at the surface of the metallic contacts, the more these charge carries repel each other. A certain limit will be reached, which is characteristic for the actual power source, where these repelling Coulomb forces will prevent any further accumulation of electrons.

A state of equilibrium will be established between the internal force of the power source and the back driving Coulomb forces from electrons in metallic contact surface.

What happens with the electrons when we attach leads to the power source electrodes? The leads are not mutually connected, the circuit is open.

Connecting the contacts of a power source with metallic conductors is in principle nothing different than increasing the surface of these contacts.

Caused by their mutual repulsion, these charge carriers will redistribute on this enlarged surface and therefore reduce their density. For a short moment this implies non-equilibrium between the internal force of the power source and the Coulomb forces. Some additional electrons will be pushed on to these enlarged surfaces until the original density and equilibrium between the involved forces is re-established.

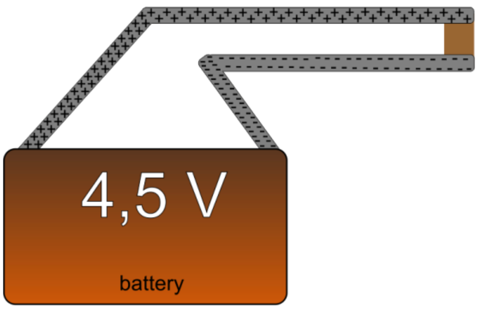


Fig. 3: A closed circuit and surface charges

3. How does electric current flow through a conductor?

Now the leads that come from the power source electrodes are connected by a piece of metal. We created a closed electric circuit. What will the electrons do in a circuit?

All conductors possess a certain internal resistivity. If the power source is strong enough to replace the electrons drifting through the resistor, a circular current will result, where all electrons inside of the conductors will take part.

As long as the driving force of the power source remains constant the charges on the surfaces of the conductors will remain, however, will start drifting along together with the bulk of internal charges. To maintain an electric current through such a conductor it therefore needs an internal driving force to overcome the opposing effect of this resistivity.

For the simplest case of a rectilinear homogeneous conductor, carrying a constant current, it can be calculated that it needs a linear change in the distribution of surface charges to produce an internal constant force oriented parallel to the conductor.

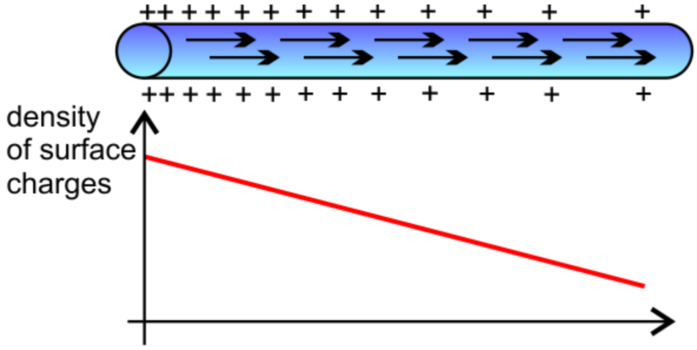


Fig. 4: Linear density distribution of surface charges on a rectilinear conductor

Within the copper wire, the electrons experience a very small resistive force; and it is possible to think of a mechanism of conduction where the single electrons are accelerated under the influence of the interaction with the surface charges and collide with some atoms within the lattice. The number of collisions per second is high (about 10^{14}/s), and the mean free path between two collisions is about 10 diameters of a copper atom.

4. How does electric current flow through a resistor?

Now the leads that come from the power source electrodes are connected by a resistor. We created a closed electric circuit. What will the electrons do in a circuit?

If a conductor is electrically connected with a resistor a layer is formed separating the area with high conductivity from the resistive part with low conductivity. Depending on the type of resistor these layers have a different thickness. These layers at both ends of a resistor do not remain neutral when electrons are pushed through.

Within the layer in front of the resistor a few electrons will pile up because ahead of them lies an area of low conductivity. This layer will carry a charge with negative polarity.

From the layer behind the resistor some electrons will escape because an area with high conductive lies ahead of them. Some charged atom ions with positive polarity are left behind. This layer will carry a charge with positive polarity.

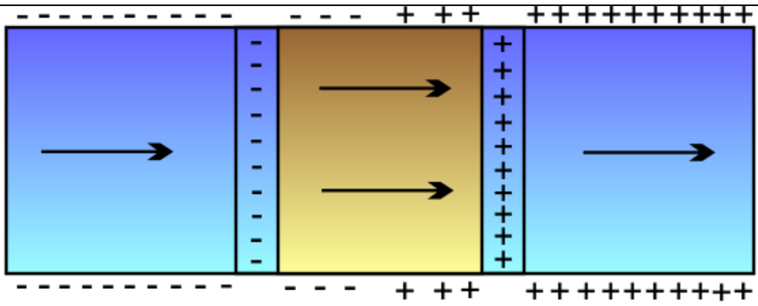


Fig. 5: Charged layers between conductors and resistors

Differently distributed charges on the surfaces as well as the charged layers at both ends of the resistor will produce attracting and repelling forces to drive the electrons through the resistor.

If the force of the battery is increased, the gradient of the charge density and the charge within the separating layers will be increased. As a result the force on the mobile electrons will be increased, resulting in a larger current, i.e. a larger number of electrons passing a cross section per time period.

5. Why is the voltage on the current–carrying resistor?

When we connect a voltmeter across the resistor we can measure the voltage. How does the resistor create a different value of charge in order to create potential difference (voltage)?

A voltage or potential difference between two points within an electric circuit is present whenever charges are separated, either in form of surfaces with a certain density of charges with opposite polarity or with a difference in surface charge density.

Such a separation of charges call some Coulomb forces into existence which try to re-install neutrality and these forces are the actual cause for voltage or potential difference.

The work is done by surface charge forces or in other words the energy transformation which results from a certain current driven by a certain voltage.

This offers the possibility to relate voltage or potential difference between two points A and B to the amount of energy which is transformed when a certain amount of charge is moved from A to B. Numerically voltage is equal to the amount of energy which is transformed if a unit of 1 Coulomb is moved from A to B.

6. Model of the electric circuit

To illustrate the process within an electric circuit it is helpful to compare such a circuit with a stiff ring driven by a motor at one place and restricted in its motion by a brake at another place. The stiff ring is used as a device to transmit a force. It can be concluded that ring consists of two parts. The part before the brake is under the push and the part behind the brake is under the pull. The pushed part will become slightly compressed, the pulled part will become slightly stretched. This difference in deformation will be sustained by the motor and will produce the necessary force at the brake to keep the ring moving.

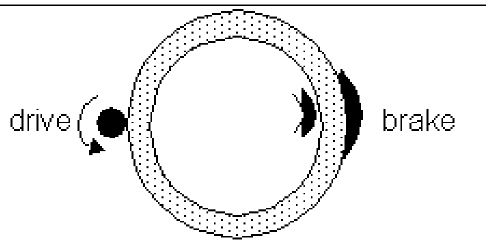


Fig. 6 The stiff ring model of the electric circuit

The similarities between the electric circuit and a stiff ring with a drive and brake can be summarized as follows:

Stiff ring	Electric circuit
The stiff ring serves to transmit a force	The electric circuit transmit a force
Matter moves in a circle	Electrons move in a circle
Matter is not consumed	Electrons are not consumed
The stiff ring is pushed by the motor on one side and pulled on the other side	Electron gas is pushed at one side and pulled on the other side by the power source
The stiff ring is compressed or stretched by the motor.	The density of the charges at the surface is changed.

Restricted models for the electric current

In comparison with the stiff ring, the bicycle chain, the drive belt, blood circuit or circular systems like hot water system can be used as model for the electric circuit in a much more restricted manner. These systems do not transmit a force but mainly energy-rich matter. The transmission of energy is therefore couple to the motion of the transmitting medium. Within an electric circuit the electrons are drifting with a rather low velocity while the energy is spread out with nearly the speed of light.

As problematic model for the electric circuit could be also models, where the single components can be driven individually (e.g. trucks on the highway). In contrast to such a system electron do not have an own drive but are driven by an external power source.

7. Simulation of current and voltage in a circuit

Students can construct simple electric circuits with the help of interactive applet in order to understand the surface charges distribution.

The current is visualised graphically at selected locations in the form of triangles.

The voltage along the components is related to the density of surface charges (display perpendicular to the circuit).

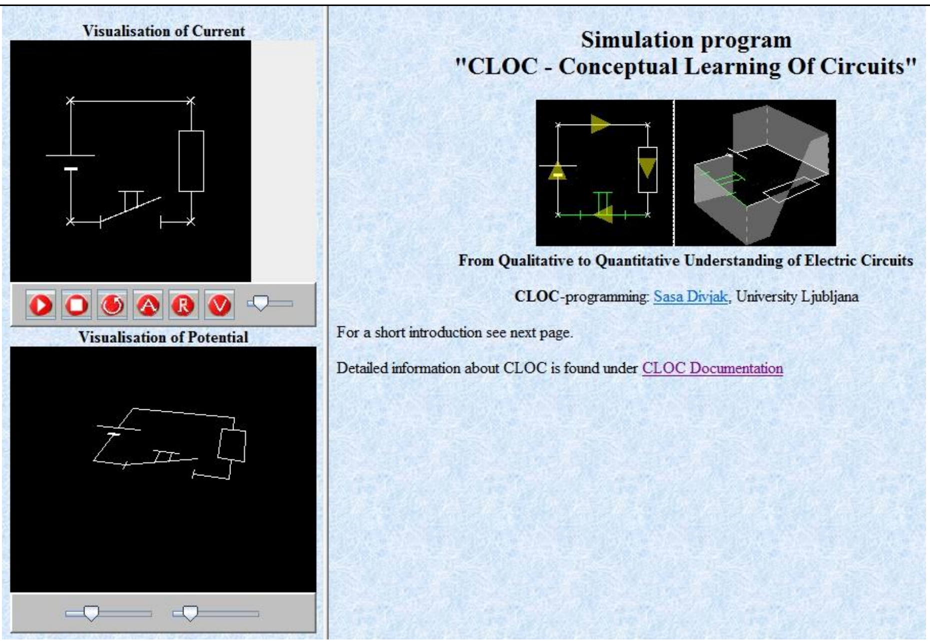


Fig. 7 Simulation of current and voltage as interactive applet

8. When do electrons pull together (resistors in series)

The resistance of the circuit element describes its ability to act against the current flowing through it. If we connect the resistors in series then the current must act against the resistance of all the connected resistors. What is the final resistance of all the resistors connected in series?

In each of the resistors there is a surface charge at the area between the resistor and the lead. The total difference between the surface charges before and after the resistor equals the sum of the charges at each of the resistors.

Hence the total resistance of resistors connected in series is a sum of the resistance of each of the connected resistors.

Students use interactive simulation for visualization of the current and voltage in the series circuits.

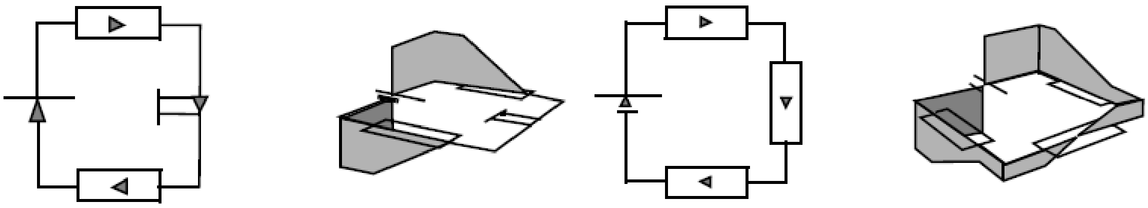


Fig. 8 Series circuit with resistors

9. How is the current divided in a junction?

In an electric circuit with a branching point, the current is split up at the branching point according to the resistors within the different parallel branches.

How can you explain the mechanism to divide the current in a junction?

Shortly after closing the circuit with parallel branches the same current flows through each of the branches. At the points where the resistors are connected in a junction the surface charges start to pile up. Their density is influenced by the value of resistance in the branch. The larger the resistor in such a branch, the smaller the current through this branch.

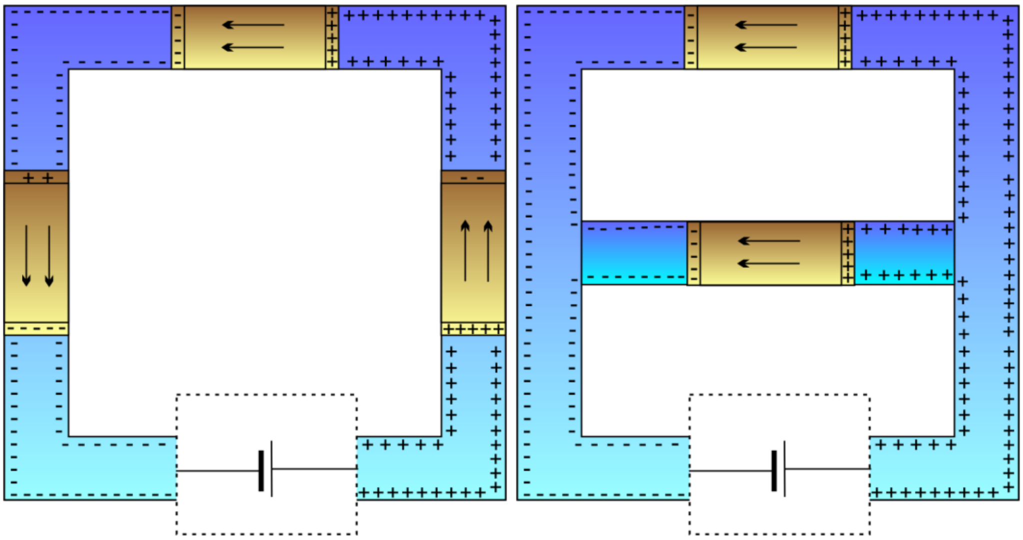


Fig. 9 Left: Surface charge distribution in a series circuit and Right: Parallel circuit

Students use interactive simulation for visualization of the current and voltage in the parallel circuits.

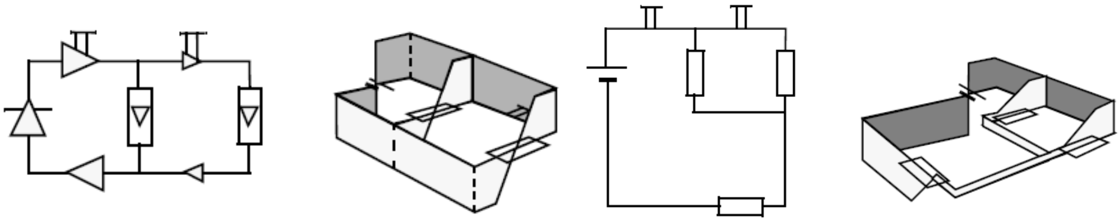


Fig. 10 Parallel circuit with resistors

Possible questions:

- When is the object electric?
- What is an electric power source?
- How does electric current flow through a conductor?
- How does electric current flow through a resistor?
- Why is the voltage on the current-carrying resistor?
- When do electrons pull together (resistors in series)?
- How is the current divided in a junction?
- What is the resistance of two resistors connected in series (parallel)?

Activity 8: Does human body obeys Ohm's Law?

Learning aims:

- Understanding that the human body acts like a resistor obeying Ohm´s law
- Understanding what determines the danger of electricity
- Understanding the effects of electricity on human body
- Introducing the applications of electric current through a human body (e.g. in medicine)

Materials:

- Text about the effects of electricity on human body
- Internet resources on the effects of electricity on human body and about other applications of electricity in human body

Suggestions for use:

In this activity students study the text about the effect of electricity on human body or they can use internet or other resources to study the topic. They can then prepare a short presentation on the effects of electric current on human body. A group of students can do this activity on their own, looking up information in different sources, then preparing a presentation on the topic and sharing it with their peers. The interdisciplinary physics-biology approach can be enhanced by searching information about the physiological effects of electricity (burning, muscle contraction, heart fibrillation).
There are also good examples of the deliberate uses of the application of Ohm's law for a human body, e.g. medical uses or bioelectrical impedance analysis for estimating body composition. Another group of students can study these applications and prepare a presentation to be discussed in the class.

Possible questions:

- Is the human body a good conductor of electricity?
- What will happen if electricity travels through you?
- Is it a voltage or a current that causes electric shock?
- Why are people good conductors of electricity?
- Why should you never touch anything electrical while you have wet hands or while standing in water?
- How can you increase your safety to prevent yourself from being electrically

shocked?

- What are the medical uses of electric current in your body?

Activity 9: Intriguing behaviour of bulbs

Learning aims:

- Conceptual understanding the concept of electric energy and power delivered to a resistor by investigating the behaviour of bulbs in dc circuit

Materials:

Two identical bulbs (e.g. 6V/0.3A, 6V/0.1A), two identical bulbs (e.g. 6V/0.05A), power source (6V), leads, computer, interface and software (e.g. CMA Coach6), current sensor, voltage sensor differential (if computer with interface is not available, ammeter and voltmeter can be used)

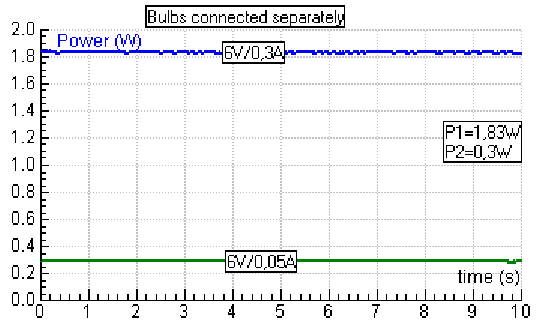
Suggestions for use:

Before starting this activity, students are already introduced to the connection of resistors in series and the concept of energy and power dissipated in the resistor. In this activity, students have two problems to investigate based on the behaviour of bulbs in a DC circuit. Both of them can be solved as guided (or bounded) inquiry activities depending on the students´ level. In both cases, students work in groups of 2-3. Supposing we have two different bulbs and a power source with voltage standard to light each separate bulb, we can light the bulbs separately as well as connecting them in series. From understanding these simple experiments new problems can emerge.

Problem 1, activity 1.2:

If we put two identical bulbs in the holders they shine equally brightly. If we put two identical bulbs (different from the first ones) they also shine equally brightly. When we put two different ones in the holders, then one lights up but the other does not (or very faintly).

In a guided inquiry, students carry out experiments according to the instructions in their worksheets. They investigate what physical quantity is responsible for the bulb brightness in order to find out that energy (or power) dissipated is crucial. They make measurements using sensors on the current through the bulb and voltage across it to determine the power dissipated in each of the bulb. If two bulbs are connected in series, the power dissipated in each of them drops. In steady state, the one that draws power closer to its normal condition will shine; the other one will barely glow at all.



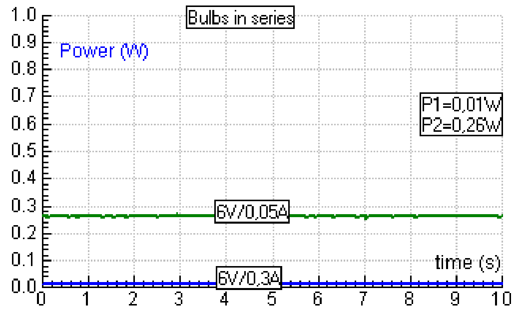


Fig. Example of measurement results for two bulbs connected to 6V power source

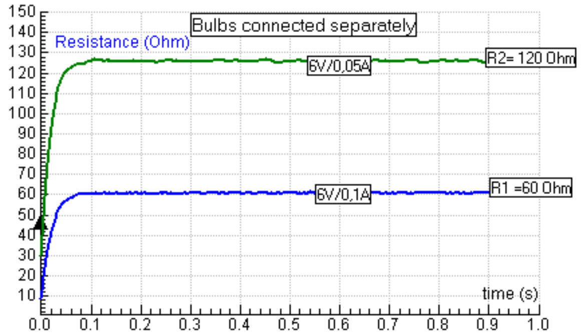
In a bounded inquiry, students design their own experiment to investigate the intriguing behaviour of bulbs.

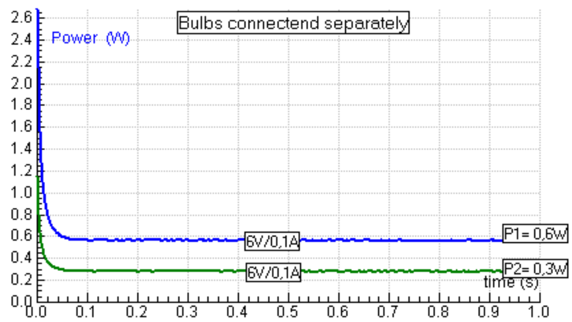
Problem 2, activity 3. 4:

If we put two different bulbs in the holders, one of them will light up later then the other. There is a noticeable delay between the two bulbs.

If they did the previous investigation, they could do this activity as a bounded inquiry to design their own experiment and decide about measurement and analysis of the relevant quantities.

Analysing the current, voltage, resistance and power diagrams students can draw conclusions. When connected in series, bulbs are heated gradually, so their resistances change after some time and hence the voltage and power is redistributed. As a result, one bulb gradually lights up (power rises) while the other bulb fades a little (power decreases).





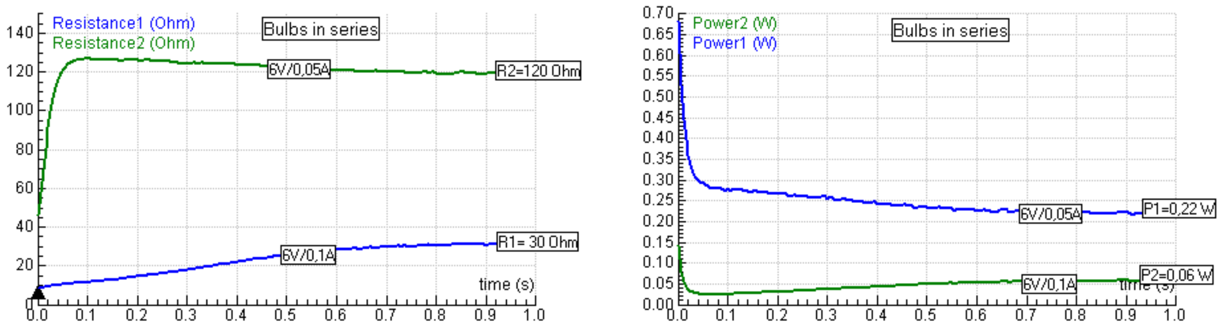


Fig. Example of measurement results for two bulbs in series connected to 6V power source

The investigation can be extended to exploration of identically labelled bulbs from different sources or even from the same producer but different batches. It can be pointed out that even if the label presents identical parameters, the reality can be different in some cases.

The industrial content can be illustrated by examples of bulbs with different energy consumption. Incandescent bulbs are gradually being replaced by other types of electric lights which have a higher energy-efficiency. Students can look up some other electric devices and compare the same kind of device made by different producers in terms of the power input.

Possible questions:

- What determines the bulb brightness?
- How is the bulb brightness influenced if we connect two identical bulbs in series compared to if they are connected individually to the same power source? Describe and explain in terms of current, voltage, power and resistance.
- How is the bulb brightness influenced if we connect two different bulbs in series compared to if they are connected individually to the same power source? Describe and explain in terms of current, voltage, power and resistance.
- What happens just after the switch is closed if we connect two different bulbs in series? Describe and explain in terms of current, voltage, power and resistance.
- How do identically labelled bulbs from different sources or even from the same producer but different batches behave in a dc circuit?
- Compare different bulbs you find in a shop considering their power input.
- Compare some other electric devices in terms of their power input.

Activity 10: Build your own battery

Learning aims:

- Understanding the basic principles of the electrochemical cell as a voltage source
- Discovering which combination of materials produce a voltage
- Distinguishing between the chargeable and non-chargeable batteries and main differences between these two types of batteries.

Materials:

Coins of different metal, salt solution (acid, alkaline solution eventually), paper tissue, lemon, alligator clips, scalpel, graphite pencil (C), iron nail (Fe), magnesium strip (Mg), zinc strip (Zn), led strips, beaker for electrolysis, sulphuric acid solution (10%), power supply (6V), two-way switch, interface and software (e.g. CMA Coach6), voltage sensor (if computer with interface is not available, voltmeter can be used)

Suggestions for use:

Divide the class into small groups of 2-3 and hand out Classroom Material: **Build your own battery**.
The first two activities are aimed at construction of primary cells made from simple materials and can be carried out in groups as guided inquiry activities. If we lack time or materials, each group could study different combination of materials and then all the findings are put together and conclusions are drawn within a class discussion.
The third activity on building the secondary cell can be carried out as an interactive experiment presented by the teacher who carries out voltage measurement during charging/discharging with the help of voltage sensor connected to the computer (or voltmeter). Nevertheless, students can use their worksheets to record the findings. While doing the experiment, teacher interacts with students to discuss and answer the questions in the worksheet.
These activities are good examples to highlight industrial applications. Batteries are devices that students often use so this is a good starting point to attract their attention and continue investigation and inquiry. The environmental aspects can be also mentioned about the batteries disposal and their recycling.

Possible questions:

- How is the electrical energy produced in an electrochemical cell?

- What is the difference between the primary and the secondary cell?
- What is the basic physical principle of the primary cell?
- What is the basic physical principle of the secondary cell?
- What are the applications of batteries in everyday life?
- What are the environmental aspects of the use of batteries

Activity 11: Battery and its basic parameters

Learning aims:

- Understanding the differences between ideal EMF device and real EMF device
- Understanding the concept of internal resistance of EMF device and its influence on the current-carrying capability
- Understanding the relationship between the voltage across the battery and the current flowing through the circuit and interpreting the diagram
- Understanding the power transfer to the load and the power transfer efficiency in relation to the load resistance.

Materials:

Battery (e.g. 4.5V zinc-carbon, older one with high internal resistance recommended), leads, resistor with adjustable resistance (e.g. 100 Ω)), computer, interface and software (e.g. CMA Coach6), current sensor, voltage sensor (if computer with interface is not available, ammeter and voltmeter can be used)

Suggestions for use:

In this activity students learn about the battery and its properties that influence its use. Before starting this activity students are already introduced Ohm's Law, the concept of energy and power dissipated in the resistor. They understand the concept of electromotive force (in terms of work or energy) and internal resistance of the EMF device. Firstly they are introduced that the energy produced by the EMF device is transferred via resistive dissipation in the external part (load with the total resistance R) and internal part of the circuit (with internal resistance R_i):

$$V_e Q = VQ + V_i Q$$

$$V_e I^2 t = RI^2 t + R_i I^2 t$$

Hence the voltage across the external part of the circuit (i.e. the terminal voltage) can be expressed as $V = V_e - R_i I$.

The theoretical background introduction is followed up by four small activities. To carry them out, divide the class into small groups of 2-3 and hand out Classroom Material: **Battery and its properties**. Each group of students can investigate the behaviour of different battery and finally the results can be compared and discussed within a class discussion.

In order to gain expected results, the battery used in the experiment should have quite a large internal resistance (significantly larger than that of the current probe and the connections) so the minimum external resistance can be set to lower value than the battery internal resistance itself. The zinc-carbon 4.5V battery works well since its internal resistance increases significantly as a result of aging.

In the first activity, students explore the behaviour of real battery in a DC circuit measuring the voltage between its terminals in relation to the current through the circuit. Using a current and a voltage sensor, they record the voltage-current relationship and they interpret the diagram. Students learn that the terminal voltage of real EMF device is always less than the EMF because there is an internal resistance, R_i. An ideal EMF device has zero internal resistance. They understand that the internal resistance of the power source influences its current-carrying capability. The activity is carried out in a guided discovery mode.

In the following two activities, they investigate the power transfer from the battery to the load and its efficiency in relation to the load resistance. They carry out guided inquiry in order to discover the condition for the maximum power transfer and maximum efficiency.

The connection with industry can be stressed by giving examples in which maximum power transfer or maximum power transfer efficiency is used. The efficiency of power transfer from the source to the load increases as the load resistance increases. However, the maximum power transfer is achieved when the load resistance matches the internal resistance of the source, while the efficiency of power transfer is only 50%. The problem of a desire for both high efficiency and maximum power transfer is resolved by a compromise between maximum power transfer and high efficiency. Where the amounts of power involved are large and the efficiency is important, the load resistance is made large relative to the source resistance so that the losses are kept small and high efficiency is achieved in this case (batteries, power supplies, power plants). Where the problem of matching a source to a load is important, as in communications circuits (amplifiers, radio receivers or transmitters), a strong signal may by more important than a high percentage of efficiency. The efficiency in this case is only 50%; however, the power transfer would be the maximum which the source is capable to supply.

In the last activity, students can create simple models on the phenomena investigated experimentally in the previous activities. Based on theoretical knowledge about the processes, the students build the models of terminal voltage related to current flowing through the circuit, power transfer and power transfer efficiency related to the load resistance. Hence they compare the model with the experimental data looking for the data that best fit the experimental results.

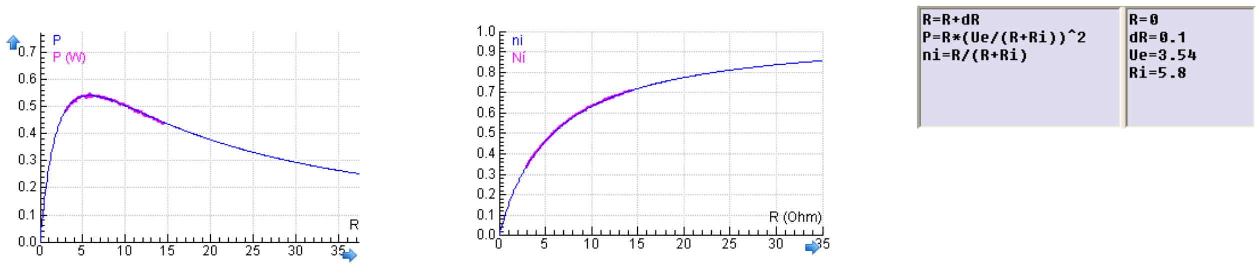


Fig. Model vs. experimental data for a battery (V_e=3.54V, R_i=5.8W)

Possible questions:

- Is the voltage across the power source terminals constant? Does it change with different load (current)?
- How is the voltage across the power source terminals influenced by the current flowing through the circuit?
- What is the main reason the voltage across the power source terminals is not constant?
- Is there any difference between e.g. zinc-carbon battery and an alkaline battery of the same EMF?
- What is the power transfer to the load influenced by?
- Under what condition is the maximum power transfer to the load?
- What is the power transfer efficiency under the condition of maximum power transfer?

- Under what condition is the maximum power transfer efficiency reached?
- What is the main goal: to achieve the maximum power transfer or maximum power transfer efficiency?

Activity 12: Batteries in series and in parallel

Learning aims:

- Understanding what is the purpose of batteries in series and how the series connection of batteries influences its characteristics
- Understanding what is the purpose of batteries in parallel and how the parallel connection of batteries influences its characteristics

Materials:

Two (or more) batteries (e.g. 4.5V zinc-carbon battery), leads, resistor with adjustable resistance (e.g. 100 Ω), computer, interface and software (e.g. CMA Coach6), current sensor, voltage sensor (if computer with interface is not available, ammeter and voltmeter can be used)

Suggestions for use:

In this activity, students investigate the behaviour of batteries connected in series and in parallel in order to find out the purpose of these connections. They should be already familiar with the battery characteristics in terms of EMF and internal resistance as well as with the series and parallel connection of resistors.
Divide the class into small groups of 2-3 and hand out Classroom Material: **Battery in series and in parallel**. The activity can be carried out in a bounded inquiry mode. They can investigate the connection of identical or different batteries. Students plan the experimental procedure on their own and draw conclusions about the EMF and internal resistance of a battery that is equivalent to series or parallel connections. They can investigate the power supplied to the load.
Linear fits to terminal voltage vs. current allow students to extract values for EMF and internal resistance and compare the calculated maximum power and the load resistance at which it occurs with the experimental data.

Possible questions:

- How does the EMF and internal resistance change if batteries are connected in series (parallel)?
- Discuss the connection of two identical and two different batteries.
- How to connect two batteries for maximum power transfer to the load?

Activity 13: How electric eel kills its prey
Learning aims:
• Applying knowledge about the properties of batteries connected in series/parallel in a real life situation • Understanding the effects of electricity on a living organism
Materials:
• Text about the electric eel • Internet resources on how the electric eel creates electricity
Suggestions for use:
In this activity, students apply previously gained knowledge in a real life situation of the animal world. Students study the text or use other internet resources about the electric eel. On the basis of it they can prepare a short presentation analysing and explaining the fact that the electric eel can manage to produce a current in order to kill its prey without shocking itself. The interdisciplinary physics-biology approach can be enhanced by looking up information about the anatomy and physiology of electric eel (electric ray, electric catfish, etc.) and its organs producing electricity. The activity can be carried out in a bounded inquiry mode, e.g. as a home assignment. Students in groups or individually search information in order to present and discuss it in front of the class.
Possible questions:
• How can the electric eel manage to produce a current that large without shocking itself? • What are the EMF devices of the electric eel? How are they connected? Draw a sketch of its EMF devices. • What is the typical voltage produced by the electric eel? • Explain why the eel kills its prey and does not hurt itself. • What other animals hunt prey in the same way?

Activity 14: How much energy supplies a battery?

Learning aims:

- Understanding that battery stores energy that is consumed by load
- Understanding how much charge and energy is supplied by a battery measuring current and voltage in a circuit.
- Understanding the properties of good battery in terms of life and economy
- Understanding what parameters producers take into account in order to build a battery appropriate for its application.

Materials:

Batteries of the same size (e.g., AAA, AA, C, D) and different producers, connecting leads, computer, interface and software (e.g. CMA Coach6), voltage sensor (not necessarily), current sensor (if current sensor is not available, the resistor of known value R_A is recommended, e.g. $R_A=1\,\Omega$ in order to measure current)

Suggestions for use:

The activity is aimed at understanding the battery properties in terms of energy it can supply to the circuit and what battery is considered to be good. During one lesson, students set several measuring spots depending on how many batteries are going to be measured. They can use the same EMF value batteries from different producers (non-chargeable and chargeable, eventually). They measure current and voltage across the external load during battery discharging. Since the measurement can last up to 24 hours, it is recommended to start the measurement during one lesson and the next day to save the results. Then, students working in groups of 2-3 analyse the results. Each group analyses one of the measured batteries. Firstly, they determine battery capacity from the area under current-time graph. Then they analyse the power delivered to the external part of the circuit and hence they count the energy amount delivered to the circuit by determining the area under power vs. time graph. Finally, the groups compare their results for batteries of different producers in term of energy delivered to the load and they draw conclusions.

Measurements can be made in a guided inquiry manner according to the instructions in the worksheet. Teacher can also use the activity in a bounded inquiry mode depending on the students' level of understanding

This activity offers a lot of industrial applications. They include the knowledge about other properties of the battery that are important for the consumer (chargeable, non-chargeable, voltage, current, energy supply, life, economy, price, weight, self-discharging of batteries, memory effects of chargeable batteries).

The activity can be followed by an open inquiry assignment aimed at formulating some other research questions considering the properties of batteries, e.g. the self-discharge, the effect of temperature on the battery performance, the memory effect, battery performance when the operation is interrupted several times (the effect on the terminal voltage and current), etc. Students design an experiment in order to answer the research question.

Possible questions:

- What energy is stored in a battery?
- How much charge is stored in a battery?
- What is the energy delivered into the circuit during the battery discharging?
- What parameters should be taken into account when you buy a battery for a certain purpose?
- Research questions can include:
- What do we mean by self-discharge, memory effect?
- What is the influence of temperature on the battery performance?
- How does the battery work when its operation is interrupted several times?

Activity 15: Batteries and their reasonable use

Learning aims:

- Understanding the industrial and environmental aspects of batteries.
- Understanding the basic principles and properties of batteries to learn about the applications of batteries in everyday life regarding their purpose of use.
- Understanding the environmental aspects of batteries (disposal and recycling).

Materials:

- Internet resources, available printed resources

Suggestions for use:

Once they understand the principles and properties of batteries, students can work on the industrial applications and environmental and ecological aspects of batteries. This activity is aimed at small home assignments meant as project work to search for information on a selected problem and prepare a short presentation for the class. The activity can be carried out as an open inquiry assignment. Student

working in groups can formulate their own problem to solve. They use internet resource and other available printed resources to search relevant information.
Possible questions:
Possible assignments to carry out an open inquiry on industrial and environmental aspects of batteries can include: • Look for information about non-rechargeable batteries that are available in stores. Find out what materials they consist of, what are the voltages produced and energy supplied and what they are mainly used for. • Look for information about chargeable batteries, e.g. a car battery. Describe its properties and name the possible problems the user can come across with. • Look for information about chargeable batteries that are available in stores. Find out what materials they consist of, what are the voltages produced and energy supplied and what they are mainly used for. • Compare batteries of the same size and EMF from different producers. • Battery electric vehicle and its future perspective. • What rules should people follow in regard to batteries disposal and recycling (where is a battery recycling place close to your school?). • What are the environmental hazards of batteries?

Activity 16: Other alternative electrical sources
Learning aims:
• Introduce other electrochemical sources, such like a fuel cell • Introduce a photovoltaic cell
Materials:
Internet sources, other sources about the fuel cell and a photovoltaic cell
Suggestions for use:
This activity can be carried out as a bounded inquiry. Students are given a task to prepare a presentation on the alternative electrical sources, like fuel cell and photovoltaic cell. They are expected to prepare a presentation for their peers. Some of the resources can include: http://en.wikipedia.org/wiki/Photovoltaics#Solar_cells http://en.wikipedia.org/wiki/Fuel_cell
Possible questions:
• How does photovoltaic cell work? • What is the photovoltaic cell used for? • How does the fuel cell work? • What are the applications of the cells?

VOLUME 1 | PHYSICS

ESTABLISH IBSE - Teaching & Learning Units

Establish

European Science and Technology in Action
Building Links with Industry, Schools and Home

These teaching and learning materials have been produced within the scope of the European ESTABLISH project. They serve as exemplary materials for science teachers and educators to experience the benefits of Inquiry-Based Science Education (IBSE) and are offered openly to inspire, guide and stimulate the further development of IBSE resources and practices.

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CASTeL
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