Establish

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

VOLUME 4 | INTEGRATED

ESTABLISH IBSE
Teaching & Learning Units:

Forensic Science
Medical Imaging
Renewable Energy
Photochemistry
Photosynthesis

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SEVENTH FRAMEWORK PROGRAMME | SCIENCE IN SOCEITY
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Contact Information:

Project website:
www.establish-fp7.eu
www.castel.ie/establish
Email: castel@dcu.ie

ESTABLISH Project Coordination & Editorial Team:

Dr. Eilish McLoughlin,
Dr. Odilla Finlayson,
Dr. Deirdre McCabe,
Dr. Sarah Brady

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 interdisciplinary-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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FORENSIC SCIENCE

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

Ron Vonk, Vincent Dorenbos and Ton Ellermeijer

Stichting Centrum voor Micro-Computer Applicaties (CMA), Netherlands.

UNIT CONTENTS

I. Unit Description

In this module, we are going to look at forensic science from different points of view. There are two subunits, the first one focused on students aged 12 to 14/15 years old; the second focused on students aged 15 – 18.

Subunit 1

In the first unit the students do research on fingerprints and on properties of human beings like length, mass and step distance. There are links with the classical school disciplines like biology and physics. Where possible, we introduce computer based measurement or educational games (for instance in identifying fingerprints).

- **Student level:** Lower secondary school, age 13 – 15 years
- **Discipline(s) involved:** Biology, physics, mathematics (statistics)
- **Estimated duration:** Five lessons of one hour approximately

Subunit 2

In the subunit meant for older students, three different case studies are treated. The first is based on a real case in the Netherlands where a woman was found dead with a ballpoint in her head. Students do research to find out how likely it is that the woman had fallen and dropped on the pen or if it was possible that the pen was fired at her with the use of a crossbow. In the second case study the students try to do face recognition, they do several tests and try to solve a crime they have themselves witnessed. The third case is to study DNA as a way to identify criminals.

- **Student level:** Higher secondary school, age 15 – 18 years
- **Discipline(s) involved:** Biology, physics, chemistry, mathematics (statistics and geometry)
- **Estimated duration:** Seven lessons of one hour approximately

II. IBSE Character

Forensic science is developed outside the classroom as a tool to investigate crime scenes. It contains subjects related to chemistry, physics, biology and technology. The approach in forensic science is an inquiry based approach. Forensic scientists have to work with different types of investigation and gather and record data from different sources found on the crime scene (and on the victim). In many cases there is not directly a 100% solution available. With the use of different techniques and different types of evidence, the researcher can state how likely it is that a certain crime was committed by the suspect. The forensic researcher has to be open minded and be aware not to use a tunnel vision. All these aspects make forensic science very suitable to be used as an IBSE approach in education.

Subunit 1

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 (fingerprints, properties of human beings).
- Using data to construct reasonable explanations.
- Communicating investigations and explanations.

Subunit 2

The activities in this subunit address the same abilities as the former one, but at a higher level. The students also see that there are more possible solutions for one problem and that there are different ways to find this solution.
Besides that, students have more opportunity to do open inquiry (compared to the first unit). The abilities addressed in this unit are:

- 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.

III. Science Content Knowledge

For both the subunits, basic knowledge on biology, physics, chemistry and mathematics is required at the level the module is written for. The activities in this subunit introduce students to the following concepts and ideas:

Subunit 1

- Properties of fingerprints and the fact that fingerprints are unique
- Techniques to identify fingerprints
- Techniques to take fingerprints (both from a suspect and from a crime scene)
- Properties of the human body and ways to use this in identifying a criminal
- Relation between step distance and length of a person
- Basic rules about statistics

Subunit 2

- Mechanics in collisions (impetus, kinetic energy, inertia).
- Working with models to simulate reality (it is not possible to do experiments on living people in the ballpoint case).
- Memory and the reliability of witnesses.
- Face recognition.
- Properties of DNA and the fact that DNA is unique.
- Techniques to isolate, multiply and analyse DNA
- Doing real and accurate measurements on pictures.
  - Gathering evidence from pictures of a crime scene
  - Inferring suspect features from the pictures

IV. Pedagogical Content Knowledge

This unit gives insight in many different concepts of forensic science. One of the common beliefs is that people in ordinary life expect a forensic scientist to solve any crime whatsoever. This unit puts the high expectations on forensics in proper perspective. On the one hand this will moderate the expectations on forensics, on the other hand it will show that a good mix of small clues will lead to a solution of a crime.

As far as moderating the expectations is concerned, students should be aware of the statistics involved. A lot of clues will lead to average values from which minor derogations are possible. For instance, based on footprints the suspect is identified as being around 1.88 m tall and having a mass of 90 kg. In this case it is still possible that the criminal has a mass of 85 kg and is 1.95 m tall. Students will have to learn to work with this. Students have to be flexible and versatile in using theories, keeping a good eye on the procedures.
Because forensics is built up from different sciences, some aspects of this module will be familiar to the students while other parts are completely new. It is important to the check these familiar subjects on misconceptions. Problems and misconceptions the teacher should be aware of might be:

- Fingerprints are the same for identical twins.
- Fingerprints change during time.
- Difficulties with statistic calculations.
- Problems with impetus, impulse, kinetic energy, gravity, inertia.
- DNA is different for identical twins.
- Difficulty with three-dimensional thinking

V. Industrial Content Knowledge

Forensic science can be seen as industrial content by itself. It is what's being done by professionals in their daily routine. With the use of scientific concepts, crime scenes are researched and hopefully crimes are solved. The forensic science has aspects of chemistry, biology, mathematics and physics. All these disciplines are combined.

VI. Learning Path(s)

Subunit 1

The activities in this subunit can at best be taught in the given sequence. However, it is possible to change a bit in this sequence. It is up to the teacher to decide which sequence will be used. In the table below the activities are given in the advised sequence. The type of inquiry and the E-emphasis is described (see 'Guide for developing ESTABLISH Teaching and Learning Units').

Activity		Inquiry Type	E-emphasis
1.1	How can fingerprints be categorized?	Guided discovery	Engagement
1.2	Fingerprints as a way to identify persons.	Guided Inquiry	Engagement Exploration
1.3	Take your own fingerprint.	Guided discovery	Exploration Elaborate
1.4	Take fingerprints from an object	Guided Inquiry	
1.5	Identify the criminal	Guided Inquiry	Explanation
1.6	Solve another crime.	Interactive discussion/ Guided discovery	Exploration
1.7	Crime solving game.	Guided discovery	Elaboration
1.8	Properties of human beings	Interactive discussion/ Guided discovery	Exploration
1.9	Whodunit	Guided discovery	Explanation Evaluate
1.10	Traces in the snow	Guided inquiry	Exploration Elaboration Evaluate
1.11	Can you use footprints to determine if a person was running or walking?	Open inquiry	Elaboration
1.12	Other indirect clues	Open inquiry	Elaboration

Subunit 2

The sequence of the activities in this unit is less important. The teacher can decide to change the sequence or even skip some of the items. The three main activities (ballpoint case, face recognition and DNA) are all independent of the other activities. However, to do the activity on face recognition in an appropriate way, it is necessary to use the introductory video to the ballpoint case. Parts of this introductory video (playing time 2:45 min) are used in the module on face recognition. Without knowing it in advance, the students witness a crime (ballpoint theft) in this clip.
In the table below the activities are given in the advised sequence (as said before, the sequence can easily be changed).The type of inquiry and the E-emphasis is described (see Guide for developing ESTABLISH Teaching and Learning Units).

Activity		Inquiry Type	E-emphasis
2.1	Introduction movie	Interactive demonstration*	Engage
2.2	Historical Trials	Guided inquiry	Explore
2.3	Modelling the ballpoint case	Bounded inquiry	Explore
2.4	Calculations on the ballpoint case	Guided discovery/ Interactive discussion	Evaluate
2.5	Other effects of collisions	Bounded inquiry	Extend
2.6	Telescoping effect	Guided discovery/ Interactive discussion	Extend
2.7	The trial	Open inquiry	Evaluate
2.8	Face recognition	Interactive demonstration	Engage
2.9	Ballpoint theft, cloths and glasses	Guided discovery	Evaluate
2.10	Awareness test and change blindness.	Open inquiry	Explore-> Extend
2.11	What is DNA?	Interactive discussion	Engage-> Explore
2.12	PCR technique	Guided discovery	Explore
2.13	Analyzing the DNA	Interactive discussion	Explain ->

		Evaluate
2.14 Identifying with the use of DNA	Open inquiry	Evaluate
2.15 Measuring on crime-scene pictures	Guided discovery	Engage, Explore, Explain

VII. Assessment

In the table below some ideas are given for assessment
For both subunits it is possible to take a questionnaire / knowledge test for the whole subunit.

Subunit 1

Activity	Assessment
1.1. How can fingerprints be categorized?	Poster presentation, log file or essay
1.2. Fingerprints as a way to identify persons.	
1.3 Take your own fingerprint.	
1.4 Take fingerprints from an object	Presentation, log file
1.5 Identify the criminal	Presentation (poster or powerpoint) All the activities on fingerprints can be assessed with a knowledge test.
1.6 Solve another crime.	Log file
1.7 Crime solving game.	Summary with screenshots from PC game.
1.8 Properties of human beings	Log file
1.9 Whodunit	Log file
1.10 Traces in the snow	Essay, presentation.
1.11 Can you use footprints to determine if a person was running or walking?	Essay, presentation.
1.12 Other indirect clues	Essay, presentation.

Subunit 2

Activity	Assessment
2.1 Introduction movie	None
2.2 Historical Trials	Essay, knowledge test.
2.3 Modelling the ballpoint case	Essay, presentation (powerpoint, poster, video)
2.4 Calculations on the ballpoint case	Knowledge test with similar calculations.
2.5 Other effects of collisions	Presentation (powerpoint, poster, video)
2.6 Telescoping effect	Essay
2.7 The trial	Essay, log file.
2.8 Face recognition	Essay with screenshot from PC game.
2.9 Ballpoint theft, cloths and glasses	Log file.
2.10 Awareness test and change blindness.	Presentation (powerpoint, poster, video); log file of the process and planning.
2.11 What is DNA?	Essay, presentation.
2.12 PCR technique	Log file, essay.
2.13 Analyzing the DNA	Knowledge test with similar calculations.
2.14 Identifying with the use of DNA	Screenshot from PC game, essay or presentation.
2.15 Measuring on crime-scene pictures	Coach result file or short student report

VIII. Student Learning Activities

Activity 1.1: How can fingerprints be categorized?	
Learning aims:	
• Introduction to fingerprints. • Develop a system to categorize fingerprints. • Learn more about the different properties of fingerprints. • Learn that an incomplete fingerprint is still very worthwhile evidence.	
Materials:	
• PC with internet connection: http://www.trutv.com/shows/forensic_files/games/fingerprint/index.html Screenshot from the fingerprint identification game.	
Suggestions for use:	
This introductory activity can be done without any pre-knowledge. In a playful and attractive way the students get introduced to the subject. However, it is more than just an appetizer, students have to reflect on the way they recognize the fingerprints. It might be that they discover some of the rules of the system to categorize fingerprints. • Introduce the problem with the use of the fingerprint game. • In the game, let students motivate why they choose the specific fingerprint. • Let the students write down which properties of the fingerprint they use during the game. • After playing the game, students do further research on how to categorize (and recognize) fingerprints.	
Possible questions:	
• Write down three properties that you might use to recognize (categorize) a fingerprint • http://www.fun-science-project-ideas.com/The-science-of-fingerprints.html for a suggestion	

- After doing the research, play the game once more. Is it more easy now?

Activity 1.2: Finger prints as a way to identify persons

Learning aims:

- Building knowledge on finger prints
- Find out how unique fingerprints are
- The role of fingerprints in identifying a criminal

Materials:

- PC with internet connection, see these sources for example
  - o http://www.cyberbee.com/whodunnit/fp.html
  - o http://www.biometrics.gov/documents/fingerprintrec.pdf
  - o http://www.exploreforensics.co.uk/Fingerprints.html
  - o http://en.wikipedia.org/wiki/Fingerprint
  - o http://onin.com/fp/fphistory.html
- Information in text files (print outs from some of the sources mentioned above)

Suggestions for use:

In this activity, students discover the theoretical framework behind fingerprints. They discover how powerful fingerprints are in identifying criminals. The method chosen here is an essay, where a student writes a comment on a letter in a magazine or newspaper. The activity starts with a letter from a lawyer who argues that his client is wrongly accused on the basis of fingerprints. The students have to write an answer to this letter, defending the use of fingerprints.

- Students do a literature review to gather knowledge on fingerprints.
- Let the students exchange the information they find to increase their knowledge on fingerprints.
- When internet is not available, the teacher can spread hard copies of the information.
- Based on the information they find, the students write an answer to the letter in the newspaper/magazine.
- The teacher can decide in which year the essay was written. It might be at the very beginning of the use of fingerprints, or in this time where one can imagine that technology is so sophisticated that fingerprints can be falsified.

- Be sure to focus on the scientific basis of the arguments.

Possible questions:

- How valuable (unique) are fingerprints in identify a criminal?
- Are fingerprints unique? Or do relatives have the same finger prints?
- When were finger prints used for the first time in solving a crime?
- How long and how can fingerprints be saved?
- Is it allowed to file a person's finger prints?

Activity 1.3: Take your own fingerprints

Learning aims:

- Ability to take own fingerprints (or in general fingerprints from a person).
- Learning about different methods to take fingerprints.
- Learning about which materials easily show fingerprints and which do not.

Materials:

- Pencil, paper, stamp pad.

Suggestions for use:

- Experiment in groups.
- See http://youtu.be/to6NYRgM184 or http://makefingerprintjewelry.com/tutorials/taking-fingerprints-easily-found-materials/

- As it is presented here, these experiments are rather straightforward. That is mainly to save time and to give the students a good example of how fingerprints work. Besides that, the fingerprints taken will be used to identify persons in a later part of the subunit.
- The next part (1.4) will give more freedom to the students.

Possible questions:

- Discuss (and write down) which method to take fingerprints from a person you prefer. Explain why you prefer your method.
- Describe a way to file the fingerprints from the students in your classroom.

Activity 1.4: Take fingerprints from an object

Learning aims:

- Compare different methods to take fingerprints from an object

Materials:

- Ability to decide which method serves the best for which circumstances

Suggestions for use:

- Students work in groups to decide which method is the best to collect fingerprints from objects.
- The objects examined might be: glasses, letters, door handle, knife.
- Students have to write a tutorial (manual) to take fingerprints from the suggested objects.
- They present their results in a poster presentation.

Setting to take fingerprints with the use of cocoa and a brush. On the right a print taken with this method

Possible questions:
• Which method serves the best for which object? • Make a list of tools that are needed to take fingerprints from an object.

Activity 1.5: Identify the criminal
Learning aims:
• Ability to identify a criminal based on fingerprints found on objects.
Materials:
• Magnifying glass, pencil, transparent tape.
Suggestions for use:
• Experiment in groups. • See background material named in the student material. • Depending on the students, the teacher can make a contest out of this: which team is the quickest to identify the criminal.
Possible questions:
• What might criminals do to avoid that they can be identified by fingerprints?

Activity 1.6: Other clues to solve a crime
Learning aims:
• Reflection on which other types of evidence there might be, besides fingerprints. • Comparing pros and cons of different types of evidence.
Materials:
• Pen and paper
Suggestions for use:
• At first, students think for themselves which clues there might be. • In a classroom discussion students exchange their clues and discuss

which are the most valuable.

- How valuable a clue is, depends on the circumstances (if a crime takes place outside in muddy garden, it can be very useful to look for footprints).
- The teacher can emphasize that it is not possible that in a crime scene all the things are investigated, depending on the severity of the crime. It is a bit out of balance if the police will take fingerprints, footprints, DNA-profiles, etc. in case of a bicycle theft.
- Answers of the students (in the classroom discussion) might look like:

Clue	**Easy to collect and use?**	**Unique way to iden criminals?**
Fingerprints	+ -	++
Footprints (shoe size)	+ -	-
Footprints (profile)	-	+
DNA from blood	-	++

- Let the students give valid arguments to decide which five clues are the most powerful.

Possible questions:

- Students can make a flow chart or table, where the evidence to collect depends on the circumstances. Part of this table might look like this:

	Yes	**No**
Is it raining outside or is it muddy?	Look for footprints.	Do not look for footprints.
Was there a struggle on the crime scene?	Look for blood traces.	Do not look for blood traces.

Activity 1.7: Solving another crime

Learning aims:

- Matching the different types of evidence.
- Work systematically, write down results systematically.

Materials:

- PC with internet connection.
- Pen and paper.

Suggestions for use:

- Be sure that the students do not look at the results from one another; it is always the same person who kidnaps the bird.
- This can be done as homework as well.
- The different types of evidence each eliminate another suspect. When in doubt if the students were working serious on their activity, the teacher can check the table. See below for the different clues of the criminal as they match the different suspects.

	Karen	Aileen	David	Sam
Blood	*match*	*match*	*no match*	*no match*
Fibre	*match*	*match*	*match*	*match*
Footstep	*match*	*match*	*no match*	*match*
Fingerprint	*match*	*no match*	*match*	*match*

Possible questions:

Be sure to ask these questions before finishing the game (the part where the police visits the house of the suspect).

- How sure are you about your answer?
- If it is a set-up, how could one of the other suspects falsify the clues?

Activity 1.8: Properties of human beings, properties of a suspect.

Learning aims:

- Develop a list with ten properties that can be used to identify a person.
- Compare the different properties; decide which properties are the most useful.
- Write down for each property how easy it is, as a criminal, to cheat on this property.

Materials:

- Pen and paper.

Suggestions for use:

- Start this as a classroom discussion.
- The first list with properties might look like this:

Property	Easy to cheat on
Mass	No, however one can go in disguise to pretend to be a lot fatter than in reality.
Length	No, also difficult to pretend to be shorter or taller than in real life.
Age	No, however by going in disguise one can seem to be of a different age.
Gender	No, however by going in disguise a woman may look like a man and vice versa.

- The second list, filled in for the students, might look like this.

Name	Age (year)	Gender (M/F)	Length (m)	Mass (kg)	Eye color
John	16	M	178	75	Brown
Susan	17	F	164	58	Blue
Omar	16	M	168	79	Green
Britt	15	F	169	67	Green
Holger	17	M	183	79	Blue

Possible questions:

- Which properties are the most distinctive in this class?
- How precise do you need to know certain properties?

For this specific case, all the suspects are part of the class and thus have similar age and background.

- Would the same list be useful for the police in general, when the group of suspects is more divers?
- Which properties (that are not important inside the group of students) might be important for general purposes, when the group of suspects is more divers?

Activity 1.9: Whodunit?

Learning aims:

- Decide on the basis of evidence who committed a crime.

Materials:

- List as it was filled in in the previous activity.

Suggestions for use:

- Make a contest to find the suspect with as few questions as possible. Make teams to compete with each other.
- Give penalty points if someone is falsely accused.

Possible questions:

- How sure are you when this list is used?
- How many students would be found guilty if one of the clues appears to be false (in other words: how many students match with all but one of the given clues).
- What properties might be investigated to be sure that the suspect is indeed the criminal?

Activity 1.10: Traces in the snow (or in the mud)
Learning aims:
• Using a related clue to identify a criminal. • Performing an experiment, work precisely. • Register, analyze and present the results from your experiments.
Materials:
• Tape-measure, video or photo camera (optional).
Suggestions for use:
• Information on stride length is available for example at: http://walking.about.com/cs/pedometers/a/pedometerset.htm or http://moon.ouhsc.edu/dthompso/gait/knmatics/stride.htm • With the use of video it is very easy to collect data for different persons.
Possible questions:
• What else can be deduced from a footprint? • How useful (valuable) can this be in a legal process? • Suppose you are a lawyer who defends a suspect. What arguments would you use to prohibit the use of footprints in a legal case?

Activity 1.11: Can you use footprints to determine if a person was running or walking?
Learning aims:
• Develop a scientific experiment. • Use prior knowledge in a new setting.
Materials:
• To be decided by the students
Suggestions for use:
• This is an open inquiry, the students have to take the initiative to develop their own experiment. • Depending on the time available, the teacher can skip one of the activities 1.11 and 1.12. However, it is highly recommended to do at

least one of these.
- In supporting the students, also give attention to the process (how to plan the experiment etc.).
- Check the experiment plans from the students before they can do their experiment.

Activity 1.12: Other indirect clues
Learning aims:
• Develop a scientific experiment. • Use prior knowledge in a new setting.
Materials:
• To be decided by the students.
Suggestions for use:
• This is an open inquiry, the students have to take the initiative to develop their own experiment. • Depending on the time available, the teacher can skip one of the activities 1. 11 and 1.12. However, it is highly recommended to do at least one of these. • In supporting the students, also give attention to the process (how to plan the experiment etc.). • Check the experiment plans from the students before they can do their experiment.

Activity 2.1: Introduction movie
Learning aims:
• To give an overview of this activity • To prepare the students for activity 1.9
Materials:
• PC with internet, projector
Suggestions for use:
Students watch the film, available at http://youtu.be/VOgyHjMBSOA
Possible questions:
• Ask the students after seeing this video if they did see something strange on the video. • If so, what did they see?

Activity 2.2: Write an article in the series 'Historical trials'
Learning aims:
• Gather information on the ballpoint case. • Judge which information is most important. • Write the information in own words.
Materials:
• PC with internet connection • Different articles in hardcopy (made available by the teacher)
Suggestions for use:
• Though it is more time consuming, students might make a documentary on this subject, using the video camera en editing tools. • Students can write down some questions they have about this case (questions that cannot be answered with the information they have found so far).

Possible questions:
• Design your own cover of a magazine with information on the ballpoint case

Activity 2.3: Modelling the Ballpoint case
Learning aims:
• Using experiments to see if both mentioned scenarios are possible: scenario 1: accident: the victim falls in the pen; scenario 2: murder: a pen is shot into the victim. • Use creativity to model this case. • Find out that here are limits to a model.
Materials:
• Ballpoint, materials to simulate a head (fruit, clay, cotton cushion, etc.) • Stand material • Optional video camera (preferably with high-speed possibilities) • Program Coach (optional)
Suggestions for use:
• Students have to simulate both scenarios (accident and murder) by means of an experiment and have to discuss which of these scenarios is possible. In two experiments it can be made clear what the impact of the pen is: in the accident scenario the students let the object fall on the pen, in the murder scenario they let the pen fall on the object. They investigate the differences. • Be aware of the differences and the similarities between experiment and the ballpoint case.
Possible questions:
• Students take the role of the CSI-investigator. Their job is to argue which of the scenarios is most likely. • Discuss which materials are suitable to model the head of the victim. Make sure to address both the practical use and the ethical aspects and physical properties of the head.

Activity 2.4: Calculations on the modelling of the ballpoint case
Learning aims:
• Students use calculations to be able to decide better which of the scenarios are possible.
Materials:
• Pen, paper, calculator • Program Coach (optional)
Suggestions for use:
• Introduce the physics concepts necessary for this calculation in a classroom discussion. • In order to prepare the students for the next activity, focus on inertia. • The first part of this activity is a rather 'closed' activity to make sure that all the students are at the same level. • In the second part the students have to discuss the probability of both the scenarios. They have to compare the results from different experiments with each other. • Let the students discuss how valuable, objective and discerning their results are.
Example of a calculation:

Pen dropping on a mandarin
• The height from which the pen starts is 100 cm, the mass of the pen is 11 g, the pen penetrates the mandarin for 0.5 cm. Calculate the force between pen and mandarin during the collision.
    ○ First put all the data in SI-units: h = 1.00 m ; m = 0.011 kg ; d = 0.005 m
    ○ The speed that the pen has when making first contact with the mandarin (we neglect friction) can be derived from: E = mgh = ½ m v^2
    ○ v2 = 2 * g * h = 2 * 9.8 * 1 = 19.6 (m/s)2
    ○ v = 4.4 m / s
    ○ The starting velocity is v = 4.4 m / s, the stopping distance is 0.005 m. We use W = F * s for the work done, this work is equal to the kinetic energy of the ballpoint at the beginning of the collision.
    ○ Ek = ½ m * v2 = 0.5 * 0.011 * 19.6 = 0.108 J

- $F = W / s = 0.108 / 0.005 = 21.6$ N

Mandarin dropping on a pen

- We now take a mandarin (100 g) and assume that the force between mandarin and pen is a constant 21.6 N. We then calculate how far the pen would penetrate the mandarin when the mandarin would drop from a height of 1.00 m.
  - The starting velocity is v = 4.4 m / s (as follows from the previous calculation), the force is 21.6 N. We use W = F * s to calculate the stopping distance.
  - The kinetic energy of the mandarin is $Ek = ½ m * v^2 = 0.5 * 0.100 * 19.6 = 0.98$ J
  - The stopping distance s is $s = W / F = 0.98 / 21.6 = 0.045$ m

Possible questions:

- Calculations with other data (height, weight).
- Derive a general formula for two objects (with masses m1 and m2) falling from the same height, to calculate the penetration distance s.
-
  - Using the same steps as in the former calculation, we find

  $m_1 * g * h_1 = F * s_1$ and for the other case $m_2 * g * h_2 = F * s_2$
  We can write $F = (m_1 * g * h_1) / s_1$
  and thus find: $m_2 * g * h_2 = \{(m_1 * g * h_1) / s_1 \}* s_2$
  In this specific question $h_1 = h_2$ and g is also the same in both cases. This means:
  $m_2 = \{ m_1 / s_1 \}* s_2$ and this can be written as: $m_2 / s_2 = m_1 / s_1$ or $m_1* s_2 = m_2 * s_1$

- Derive a general formula for two objects (with equal masses) colliding with different velocities, to calculate the penetration distance s.
  - This time we calculate the kinetic energy, this is equal to the work done while stopping the object. $½ m v^2 = F * s$

  $½ m_1 v_1^2 = F * s_1$ and $½ m_2 v_2^2 = F * s_2$
  Since F is equal for both cases, we find: $½ m_1 v_1^2 / s_1 = ½ m_2 v_2^2 / s_2$
  For equal objects ($m_1 = m_2$) we then find:
  $v_1^2 / s_1 = v_2^2 / s_2$

Activity 2.5: Other effects of collisions
Learning aims:
• Further experiments to find out which of both scenarios is most likely • Reflecting on the students' knowledge of physics to apply to this case.
Materials:
• To be decided by the students.
Suggestions for use:
• Classroom discussion as introduction to the subject. • Emphasize that further research is needed when the research thus far is not sufficient to draw a definitive conclusion. • Address the fact that there are still doubts in this case, sometimes this is inevitable. • Which other effects might occur in this case? How can this be demonstrated? • If it is difficult for the students to plan the experiments, activity 2.6 might be done first, followed by activity 2.5. In that case it is a more guided inquiry: find an experiment that demonstrates the telescoping effect.
Possible questions:
• Are there other facts that might be investigated further?

Activity 2.6: Telescoping effect
Learning aims:
• Further literature research on the case to find out which of both scenarios is most likely
Materials:
Article: Cause celebre – Ballpoint Murder, See: http://library-resources.cqu.edu.au/JFS/PDF/vol_45/iss_5/JFS4551144.pdf
Suggestions for use:
• Give the students (part of) the article **Cause celebre – Ballpoint**

Murder and pay special attention to the telescoping (page 2, paragraph 'results').

- Depending on the results of activity 1.5 students might come up with the telescoping effect themselves. In that case the teacher can start a classroom discussion and the students can discuss what will have to be investigated by the forensic scientist.

Possible questions:

Can you make a better decision now if the suspect is guilty? Discuss why or why not.

Activity 2.7: The trial

Learning aims:

- Come to a verdict: is the suspect guilty or not guilty?

Materials:

- Presentation tools (this activity is a classroom discussion based on the facts and the information available).

Suggestions for use:

- Make three groups (not necessary the same size):
    - Judge and jury (independent)
    - This group will organize the trial, and will give the verdict about the suspect
    - Group that argues that the suspect is guilty
    - This group will look in literature and forensic research for evidence to accuse the suspect. They prepare their part of the trial and give a plea where they will plead guilty for the suspect.
    - Group that argues that the suspect is not guilty
    - This group will look in literature and forensic research for evidence to clear the suspect. They prepare their part of the trial and give a plea where they will plead not guilty for the suspect.
- Leave the rest as open as possible, let the students from group one decide how the trial is organized.
- Make sure that the physics used in the arguments of the students is correct.

Possible questions:
• Decide with the group if the suspect is guilty or not. • How sure are you about your verdict?

Activity 2.8: Face recognition
Learning aims:
• Knowledge on face recognition. • Reflection on reliability of witnesses.
Materials:
• PC with internet connection, website http://www.bbc.co.uk/science/humanbody/sleep/tmt/instructions_1.shtml • Pen and paper.
Suggestions for use:
In this game there are twelve pictures shown to the user. In a second round another twelve pictures are shown. After these two rounds, users see another series of pictures. They have to declare for each picture in this series if they have seen the picture before, and if so in which round. It seems that the game has an archive of about fifty pictures to choose from, each round there are randomly chosen some pictures from this archive. • Make a contest of this. • Make sure that the students take their rest between each round of the game. • Let each student make a screen capture of the results.
Possible questions:
• Is it possible to find differences depending on gender? For instance, do male students recognize other males better than females (or the other way around)? • How sure are you about your answers? • Make for each picture that is used in the game a data sheet: how often was this picture used, how often was it recognized?

Activity 2.9: Ballpoint theft - With clothes and glasses
Learning aims:
• Reflection on reliability of witnesses. • Reflection on your own reliability.
Materials:
• PC with internet connection, projector.
Suggestions for use:
• Individual students can be mixed in groups to try to match and discuss their answers. • Teacher can choose some students and instruct them to give (on purpose) false information in a very convincing way. This will influence the other students. • In a classroom discussion the value of eye witnesses as part of the evidence might be discussed.
Possible questions:
• Further research on the way witnesses can be influenced during a trial. See for example: https://www.ncjrs.gov/nij/eyewitness/procedures_intrv.html • Further research on how witnesses (and suspects) may be questioned when they give a statement.

Activity 2.10: Awareness test, change blindness
Learning aims:
• Applying the new knowledge in a case study.
Materials:
• Video camera, photo camera. • Further to be decided by students.
Suggestions for use:
• Open inquiry
Possible questions:
• What would you change if you could do this experiment again? • What other experiments could you do to treat change blindness?

Activity 2.11: DNA
Learning aims:
• Gathering basic information on DNA • Be able to find out which information is the most valuable • Write down the information in your own words.
Materials:
• PC with internet connection. • See for information http://www.ipn.uni-kiel.de/eibe/ENGLISH/U2.HTM (also available in German and Danish) • Teacher can take care of hardcopies of the information by EIBE (see previous bullet).

Activity 2.12: PCR technique
Learning aims:
• Gather information on PCR technique. • Compare and evaluate information from different sources. • Discuss information with other students.
Materials:
• PC with internet connection • Text files (see sources)
Suggestions for use:

• In this activity a specific method is being used to divide the work between different groups of students. The steps of this method are described here:
  ○ At the first step, students work on different sources individually.
  ○ In the second step, students exchange information and discuss this with fellow students who have studied the same source. Each student then will become an expert in this particular source. Students write down their own questions about the PCR-technique, these might be questions that can be found in their source but also questions they have themselves.
  ○ In the last step, the student mix again and now exchange information with the experts from the other sources. In the group, the questions of the individual students have to be answered.
 	
This method is highly recommended but of course the teacher can decide to use another method.
 	
• The teacher divides the students in several groups and gives each student the proper sources. Each group (A, B and C) has to study two sources: a text file and an animation on youtube. The sources are as stated below:
 	
  ○ Group A
  http://www.ipn.uni-kiel.de/eibe/UNIT02EN.PDF (page 16 and 17)
  http://youtu.be/2KoLnIwoZKU
  ○ Group B
  http://en.wikipedia.org/wiki/Polymerase_chain_reaction
  http://youtu.be/JRAA4C2OPwg

- Group C
  http://www.dnalc.org/resources/animations/pcr.html
  http://youtu.be/vmlLj1aLZ7s

Activity 2.13: Awareness test, change blindness

Learning aims:

- Applying information on DNA to find out if a suspect is guilty or not guilty.

Materials:

- Pen and paper.

Suggestions for use:

- Students have to answer some questions on DNA profiles.
- Evaluate this in a classroom discussion. Use this to check if the information so far is clear to the students.
- Give extra information for those students who do not master the topic so far.

Example of an answer:

- The frequency of feature 19 on locus D18S51 is 0.039. This means that from 100 persons, 3.9 will have this specific property.
- The sum of all the possibilities has to be 1.0 (or 100%).
- For the individual properties, the probability is

p = 0.067 (VWA 14)
p = 0.141 (D18S51 17) and
p = 0.011 (D21S11 32)
This means the probability of this mix is 0.067 * 0.141 * 0.011 = 0.000104 (that is 0.0104 %)

Possible questions:

- Students can make similar questions (with answers) based on the profiles given to them.

Activity 2.14: Identifying with use of DNA
Learning aims:
• Apply knowledge on DNA in solving a case (game and real life). • Develop an own DNA-profiling experiment.
Materials:
• PC with internet connection. • Online game: http://www.biotechnologyonline.gov.au/popups/int_dnaprofiling.html • Up to the students to decide.
Suggestions for use:
The game is a good method to check if the students have enough knowledge on DNA and if they are able to apply this. A weak point in this game is that they can click what they want without knowing anything. The teacher has to be aware that students can clarify why they click on certain choices. The DNA experiment in real life is a difficult part. It would be very interesting for students to do their own DNA-experiment. However, proper DNA-kits are very expensive. These DNA-kits cost € 20,000 or more. There are some affordable (but still not cheap) alternatives but these are not reliable. In many countries however, there are institutions that promote DNA research and it is often possible to hire or rent a DNA kit here. Another possibility is to contact these partners for an excursion. It is up to the teacher to do research in the own region to contact these institutions. When the materials are available, the students can do their own experiments. • Open inquiry. • Depending on the available materials, students can perform their own experiment. • Find connections to industry, this topic is very suitable for an excursion.
Possible questions:
• Do research on the historical use of DNA profiling.

Activity 2.15: Measuring on crime-scene pictures
Learning aims:
• Understand why crime scene photography is so important in forensic science. • Do accurate distance measurements on a picture, even when taken from a point of view • Learn about perspective deformation • Use different methods to correct for perspective distortion
Materials:
• PC with the program Coach or pen and paper for the first part if Coach is not available.
Suggestions for use:
In this part, the students work individually or in pairs first on the introduction, then on two or three Coach activities for measurements of distances between objects on a few pictures of crime scenes. They learn why it is so important that there are pictures available of crime-scenes, and how perspective distortion in the pictures can be overcome such that accurate distance measurements between objects on the picture is possible. The first activity offers instructions how to do perspective correction and come to correct scaling in the software. In the second and third activities the students have to perform the measurement (and perspective correction) on their own. These activities have some assignments. In the third activity students are asked to find some features of the suspect. From the stride length, an estimate can be made of the suspect's height, using the same website as activity 1.10 of Subunit 1. Moreover the footsteps on the picture are rotated to the inside, which may be an indication that the suspect suffers from knock-knees (which happens more in adult women than in men). Reasons for photography of a crime scene are amongst others: • The crime scene cannot stay as it is e.g. when it is in a public place. Then pictures are the only way to retain images of it. • By walking in the scene evidence may be destroyed • The pictures can be used for future reference • The pictures give an unprejudiced image of the scene • A picture may be used to do measurements of distances between objects. Students may come up with the fact that nowadays digital pictures are easy to

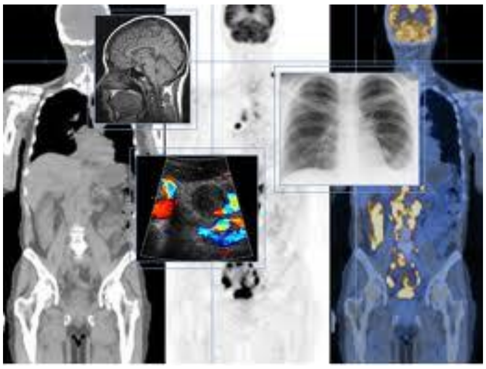
manipulate. So it is important that they are not manipulated. If this comes up, you can let students look for clues of digital manipulation of the three pictures used in this part. Are the pictures original to their opinion?
Possible questions:
• Questions are in the student material and in the Coach activities. • How can the police or forensic scientist make sure that the pictures are not manipulated?

MEDICAL IMAGING

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

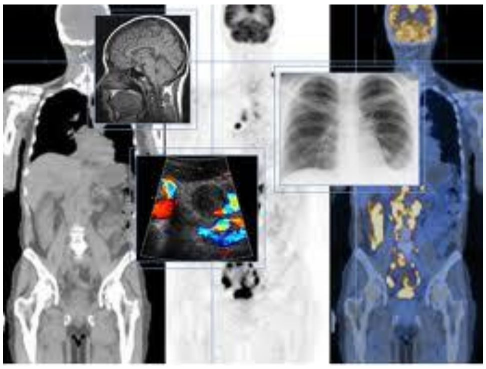
Ewa Kedzierska, Vincent Dorenbos and Ton Ellermeijer

Stichting Centrum voor Micro-Computer Applicaties (CMA), Netherlands.



UNIT CONTENTS

I. Unit Description



Medical imaging is the technique used to create images of internal parts of the human body for clinical purposes. Many of us have had some experience with the techniques and practices of medical imaging.

It began with the discovery of X-ray photos. During the 20th century other medical imaging techniques were developed: X-rays images, CT, MRI and ultrasound scan. Each of these techniques has advantages and disadvantages that make them useful for different conditions and different parts of the body.

The goal of this unit is to introduce students into fascinating areas of imaging techniques used in modern medicine and to make them familiar with scientific principles underlying these techniques.

The unit is divided into 3 subunits. Subunit 1 focuses on ultrasound imaging and is designed for lower secondary level. Subunits 2 and 3 focus on X-rays and nuclear imaging and are designed for higher secondary level.

The Medical Imaging unit is enriched with ICT activities. The following ICT tools are used here data logging, modelling, on-line simulations, on-line movies.

Subunit 1: Ultrasound imaging

Origin:http://www.vanguardmedicalimaging.com/svc_ultrasound.php

Despite todays sophisticated, high-tech systems, ultrasound imaging remains a science built upon the simple sound wave. By beaming high-frequency sound waves into the body, physicians can translate the "echoes" that bounce off body tissues and organs into "sound you can see" - visual images that provide valuable medical information.

In this subunit students get familiar with basic physics concept needed to understand ultrasound imaging.

Student level: Lower secondary school level, students of age 12-15

Discipline involved: Physics

Estimated duration: 5-6 class periods

Subunit 2: X-rays imaging

X-ray imaging is the oldest and probably the most used imaging technique in medicine. X-ray imaging is a transmission-based technique in which X-rays from a source pass through the patient and are detected either by film or an ionization chamber on the opposite side of the body. Contrast in the image between different tissues arises from differential attenuation of X-rays in the body.

Origin: http://en.wikipedia.org/wiki/X-ray

Planar X-ray radiography of overlapping layers of soft tissue or complex bone structures can often be difficult to interpret, even for a skilled radiologist. In these cases, X-ray computed tomography (CT) is used. This technique allows producing images, which show sections through a human body.

Student level: Higher secondary school level, students of age 15-18
Discipline involved: Physics
Estimated duration: 5-8 class periods

Subunit 3: Nuclear imaging

Nuclear medicine addresses the body's physiological processes rather than the anatomical structure. In nuclear imaging, short-lived radioactive materials that emit gamma rays (radiopharmaceuticals) are injected into a patient's bloodstream and are attracted to the particular organ being analysed. A gamma camera then takes a time-exposure image of the pharmaceutical as it concentrates in the tissues or organs or enters the bloodstream.
Nuclear medicine is used also in medical treatment; the radiopharmaceuticals go directly to the organ being treated. This subunit focuses only on medical imaging.

Origin: http://www.sydneyxraybondi.com.au/content_common/ns-spectctfacet.seo

Student level: Higher secondary school level, students of age 15-18.
Discipline involved: Physics
Estimated duration: 5-8 class periods

II. IBSE Character

Subunit 1

The main IBSE approaches employed in this subunit are interactive demonstration, guided discovery and guided inquiry. Inquiry based skills developed in this unit are amongst others:

- Asking and answering questions.
- Planning and conducting simple investigations.
- Performing experiments.
- Employing tools to gather data.
- Analysing results obtained with experiments.
- Communicating results with the use of graphs.
- 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.

Activity 5 involves open inquiry; students have to prepare questions to ask during a visit to a hospital to be able to make a leaflet for patients having an ultrasound examination.

Some activities in this subunit make use of ICT tools:

- Data logging - measurements with a sound sensor
- On-line simulations
- Computer as source of information.

Subunit 2 & 3

This subunit is designed for higher levels of secondary education. The main IBSE approaches employed in this subunit are interactive demonstration, guided discovery and guided inquiry. Inquiry based skills developed in these subunits are amongst others:

- Designing experiment
- Planning scientific investigations
- Using tools and techniques to gather data
- Analysing and describing data
- Explaining results and drawing conclusions.
- Constructing models
- Comparing models with experimental results
- Debating with peers
- Forming coherent arguments

- Communication scientific procedure and explanations.

Activity 5 in the subunit X-ray imaging is an open inquiry type of activity. Students have to collect the evidence, construct their logical proofs and defend their point of view in a class debate.
Activity 3 in the subunit Nuclear imaging can be enriched with an open type of inquiry – an excursion to a hospital, which has a nuclear imaging department or inviting to school a person working at such department. Students should prepare their interview questions and after the excursion reports their findings.

III. Science Content Knowledge

In this unit, students learn scientific principles underlying the major medical imaging techniques. Since a lot of activities in this unit go beyond school textbooks a lot of extra science background information has been included in the student worksheets

Subunit 1

This subunit goes beyond a school curriculum. It links to basic sound concepts, which are part of the standard curriculum and shows application of ultrasound in medicine.
For this subunit students should have prior knowledge about sound, for example a good background gives ESTABLISH Unit 1 'Sound', 'Subunit 1. Sound exploration'.
Students should be familiar with concepts like wave nature of sound (propagation, reflection), sound echo, sound speed, they should know that the speed of sound depends on the medium. Students should be able to calculate the distance covered by a sound wave based on a given time interval and speed of sound.
The activities in this subunit introduce students to the following physic concepts and ideas:

- ultrasonic sound
- echolocation
- sound reflection
- the speed of sound varies in different media
- ultrasound can be used to make images of inside
- ultrasound A-scan and B-scan
- advantages and disadvantages of ultrasound imaging.

Subunit 2

As pre-requisite knowledge, students are supposed to be familiar with the concepts:
radiation, electromagnetic wave, wavelength, wave frequency, structure of the atom (Bohr model, energy levels), electron, photon, energy of photon etc.
To recall the knowledge about the atom a Phet simulation can be used: http://phet.colorado.edu/en/simulation/build-an-atom
At the end of this subunit the student is able to:

- describe properties of X-rays (electromagnetic wave, ionisation, penetration)
- explain how the X-rays are produced and detected
- explain the absorption law and half-value layer concept
- explain how X-ray images are created
- explain how CT scans are created
- specify the value of X-rays and CT scans in medicine

Unfortunately there are not many suitable lab experiments, which can be performed in school.

Subunit 3

As pre-requisite knowledge, students are supposed to be familiar with the concepts from subunit 2 and with the structure of nucleus, radioactive isotopes, nuclear force.
The activities in this subunit introduce students into nuclear medicine. At the end of this subunit the student is able to:

- describe the nature and properties of the alpha, beta and gamma radiation
- explain the radioactive decay law
- explain the concepts of decay constant and half-life
- explain how radioactive materials are used in nuclear medicine
- explain why Technetium 99m is suitable as the radioactive tracer
- explain how gamma camera works
- measure background radiation
- explain the health hazards in use ionising radiations
- specify ways of protection from ionising radiation.

This unit does not explain the principles of a detector of ionising radiation. This subject should be treated separately.

Experiments with radioactive sources may be difficult to perform in schools. In such cases virtual labs can be used, below a few Internet examples are listed:

1. Virtual Physics lab http://www.polyhedronlearning.com/cengage/
   Lab 45: Geiger Counter Measurement of the Half-Life of 137Ba"
   Lab 47: Absorption of Beta and Gamma Rays
2. Radioactive decay simulation: http://www.7stones.com/Homepage/Publisher/halfLife.html
3. Applets:
   http://lectureonline.cl.msu.edu/~mmp/applist/decay/decay.htm
   http://www.walter-fendt.de/ph14e/lawdecay.htm
   http://www.7stones.com/Homepage/Publisher/halfLife.html

IV. Pedagogical Content Knowledge

Medical imaging is a topic in which students might have some preconceived ideas and models because of their own or somebody from their family's medical experience. They will almost certainly have heard something about it.
General common students' ideas identified by Science Education Research around Sound are:

- 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).
- Ultrasounds are extremely loud sounds.

It is quite difficult to find research on students' understanding of ultrasound, X-rays and CT scans. This is probably because these topics are not covered in regular physics curricula.
Almost all of the students either have undergone some ultrasound of X-ray procedure in their lives or know of someone who has.
The studies by Kalita and Zollman [1] showed in their research that
"… *students transfer pieces of knowledge from very different sources such as their own X-ray experience, previous physics and other science courses and mass media. This transfer results in mental models that are not necessary stable, consistent or coherent."*
These models should be taken into account.
Some general common students' ideas around Radioactivity [2], [3] are:

- Atoms cannot be changed from one element to another.
- Radiation causes cancer, thus it cannot be used to cure cancer.

- Once material is radioactive it is radioactive forever.

1. S.Kalita, D.Zollman, Investigating Students' Ideas About X-rays While Developing Teaching Materials for a Medical Course, Proceedings of the Physics Education Research Conference, 2006

V. Industrial Content Knowledge

The traditional physics curriculum rarely relates physics to other fields of science or shows its relevance to industry and professions. This unit tries to do this. Another goal of this unit is to link basic physics knowledge to applications of physics in contemporary medicine.
Providing a link between physics and different professions such as medical imaging is very effective. For example: nuclear medicine is practised only by licensed physicians who are assisted by certified technologists and supported by specially trained physicists, pharmacists and radio-chemists. (See also http://www.theonlinelearningcenter.com)
It is very valuable for students to bring them into hospital departments of medical imaging: ultrasound, radiology and nuclear medicine.
In this unit students analyse the main products of medical imaging such X-ray machines, CT-scan machines, gamma cameras.

VI. Learning Path(s)

Each subunit may be studied independently, but it is advised to cover subunit 2 before introducing subunit 1Each unit is made up of a series of activities. The order and flow of activities are presented below. The activities are created in this way that they offer a complete learning cycle.

Subunit 1

Activity		Inquiry Type	E-emphasis
1.1	Can we use sound to "see"?	Guided discovery Guided inquiry	Engagement Exploration Explanation Elaboration/Evaluation
1.2	Do muscle, fat and bone sound the same?	Guided discovery Guided inquiry Bounded inquiry	Engagement Explanation Elaboration

		Evaluation
1.3 Make an A-scan.	Guided discovery	Engagement/Exploration Explanation Elaboration/Evaluation
1.4 Make a B-scan.	Guided inquiry	Engagement/Exploration Explanation Elaboration/Evaluation
1.5 Ultrasound imaging	Guided inquiry Open inquiry	Engagement/Exploration Explanation Elaboration/Evaluation

Subunit 2

Activity	Inquiry Type	E-emphasis
2.1 X the unknown	Guided discovery	Engagement Exploration Explanation Elaboration/Evaluation
2.2 Interaction with matter	Bounded inquiry Guided inquiry	Engagement Exploration Explanation Elaboration/Evaluation
2.3 X-ray medical machine	Guided discovery	Engagement/Exploration Explanation Elaboration/Evaluation
2.4 CT scans	Guided inquiry	Engagement Exploration Explanation Elaboration Evaluation
2.5 Are X-rays bad for you?	Open inquiry	Elaboration/Evaluation

Subunit 3

Activity	Inquiry Type	E-emphasis
3.1 α, β, and γ	Guided discovery Bounded inquiry	Engagement Exploration Explanation Elaboration/Evaluation
3.2 Radioactive decay	Guided inquiry Bounded inquiry	Engagement Exploration Explanation Elaboration/Evaluation
3.3 Tracing substances in the human body	Guided discovery	Engagement Exploration Explanation Elaboration Evaluation
3.4 Radiation exposure	Guided inquiry	Engagement Exploration Explanation Elaboration Evaluation
3.5 Radiation protection	Bounded inquiry Open inquiry (5)	Engagement Exploration/ Explanation Elaboration Evaluation

VII. Assessment

Preferably, the students' assessment includes both a theoretical test (basic concepts and laws) as a practical assignment (skills).
Teachers can assess practical skills also during the lessons, from students' reports and from presentations.

VIII. Student Learning Activities

Activity 1.1: Can we use sound to "see"?
Learning aims:
• To explain the concept of echolocation • To explain how sound can be used to measure distance • To determine an unknown length of a tube by using the echo method
Materials:
• A computer, a sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6), a cartoon or plastic hollow tube
Suggestions for use:
Start by giving the students the **Activity 1 worksheet**. Let them first discuss the questions with their classmates and then write their answers. Let them read the explanation given in the **Activity 2 worksheet** and discuss with the whole class what echolocation is, how bats use it to navigate and find their food. Discuss other applications of echolocation. At the end of the discussion ask the question '*Can blind people use echolocation to "see"?*' Let them formulate their hypothesis. To check their hypothesis show the discovery channel movie 'Real-life Bat Man" http://dsc.discovery.com/videos/is-it-possible-real-life-bat-man.html. Discuss the movie with students, rise questions and act as a facilitator. Activity 1.3 is an Explanation activity. Students should realise how to calculate the distance covered by sound waves, based on the measured interval time of echo and speed of sound (notice that echo time covers double distance). Activity 1.4 students apply learned concepts. Based on the echo time method they have to determine an unknown length of a tube. In this experiment a sound sensor, data-logger and computer are used. Students record sound signal of the initial sound and echoes. They read the echo time from a graph. Based on the echo time and speed of sound in air they calculate the length of the tube. The final conclusion at the end of this lesson should be that (ultra)sound can be used to measure distances. Another nice application of this idea is a motion detector. If you have such device you can show it and let student measure different distances in class. Again discuss how computer knows what the measured distance is. 

Possible questions:
• Do you know other animals than bats, which make use of echolocation? • Do you know other applications of echolocation? • What is ultrasound? • What is the speed of sound in air? In water? • Does the speed of sound depend on the medium (air, water, etc..)?

Activity 1.2: Do muscle, fat and bone sound the same?
Learning aims:
• To explain when an echo occurs • To define the concept of reflection interface • To be able to interpret the recorded sound graphs • To identify on what the strength of reflection depends • To apply the concept of reflection interface for ultrasound and human body tissues
Materials:
• A computer, a sound sensor, data-logger and software that displays sound waveforms (e.g. CMA Coach 6), a cartoon hollow tube or plastic tube.
Suggestions for use:
Hand out the **Activity 1 worksheet**. Let students work in small groups of 2 or 3. They have to first describe when an echo occurs. Summarize their answers in a class discussion. In Activity 1.2 students are introduced to the concept of reflection interface and are asked to answer the research question: 'Does the strength of the reflection, in other words strength of echo, depend on the material which reflects sound?' Let the students formulate their hypotheses. To test their hypotheses let them perform the experiment in which two different reflection media are compared: hard (e.g. plastic) and soft (e.g. foam) material. They should find out that hard material reflects sound better than soft material. The evidence for this is that the first echo pulse is stronger for hard material than for soft material (in each trial the initial sound should be the same and have similar intensity). In Activity 1.3 students have to answer the next research question: 'Does sound travel with the same speed in different media?'

To answer this question the students perform investigation in which they compare the speed of mechanical waves in water and in vegetable oil. Each student group is provided with the following materials: two plastic droppers, a metric ruler, a stopwatch that measures tenths of seconds, water and vegetable oil in plastic bottles, two ripple tanks (e.g. aluminium foil lasagne pans with mirrors at the bottom). The students have to design their experiment. Check their plans before they begin their experiments. The ripple tanks should be filled one with water, one with vegetable oil, to the same depth of 1-2 cm. In the most likely setup a student will release a drop of medium into one end of a ripple tank and start a stopwatch at the same time. In each trial, the drop should be released from the same height and distance from the edge of the tank. When the first wave produced by the drop reaches the opposite side of the tank, the second student will call out to stop the watch. The students should record this time in their data table. They should also measure and record the distance from the point where the drop hit the liquid to the opposite side of the ripple tank. The speed of wave can be calculated by dividing the distance by the time measured on the stopwatch. Students will find that, under similar conditions, waves travel faster in water than in oil. In Activities 1.4 and 1.5 students apply the concepts and realise how ultrasound pulses reflect from human body tissues.
Possible questions:
• Why do echoes occur? • In what kind of place would you expect to hear echoes? • Does the strength of the sound reflection depend on the material which reflects sound? • Give examples of good sound reflectors • Does sound travel with the same speed in different media? Give examples. • How do ultrasound waves reflect from human body tissues?

Activity 1.3: Make an A-scan
Learning aims:
• To explain how ultrasound pulses are used to measure a distance • To describe how an ultrasound A-scan is created • To interpret a simple ultrasound A-scan
Suggestions for use:
In this activity students learn what an ultrasound A-scan is and how it is created. They start with activity 1.1 (exploration) in which they once more analyse the experiment with the sound reflection in the cartoon tube. This time they get a recorded sound graph and they have to predict how the graph will look when a tube is 50% longer and when there is another barrier inside the tube. There is a small step from the graph of the sound signal versus time to a graph of the sound signal versus position - an A-scan. The explanation of the A-scan concept is given in activity 1.2. In Activity 1.3, an A-scan of the human eye is presented. Let the students analyse the given A-scan. Discuss the scan with them, let students identify which eye parts generate respective ultrasound peaks. Based on the given photo discuss how the A-scan is taken by a doctor.
Possible questions:
• What would you assume the speed of sound in the human? • Which parts of the eye generate the ultrasound spikes?

Activity 1.4: Make a B-scan

Learning aims:

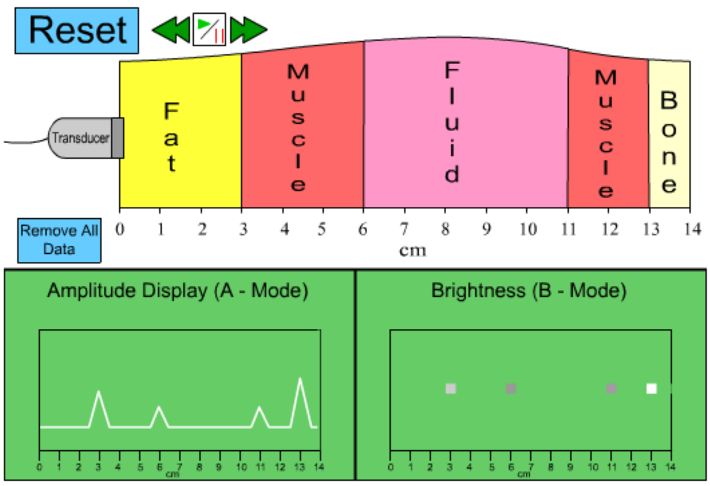
- To describe how an ultrasound B-scan is created
- To interpret a simple ultrasound B-scan

Materials:

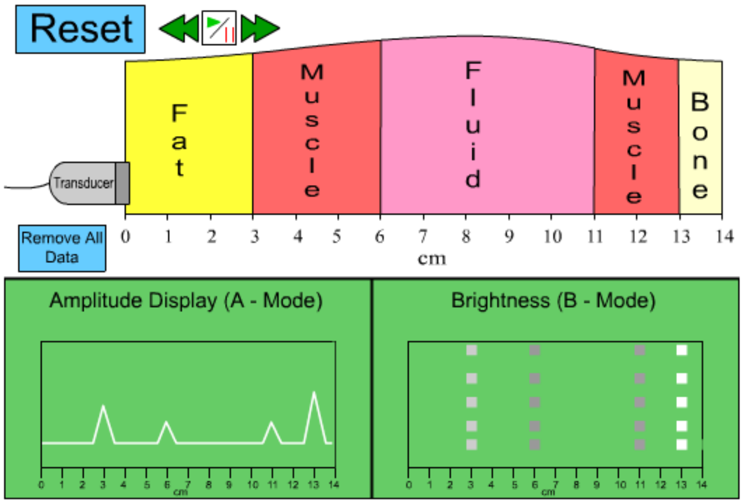
- A computer with internet connection

Suggestions for use:

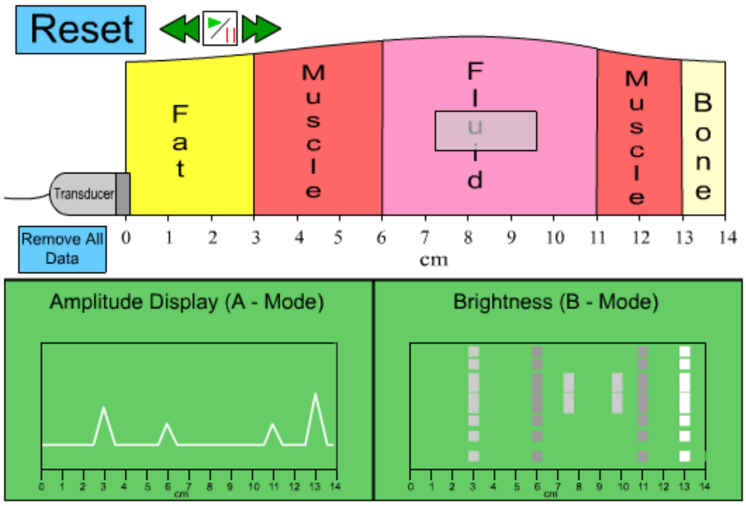
In this activity students learn how an ultrasound B-scan is created.
In exploration Activity 1.1 students use the simulation Ultrasound Imaging without Object.
(http://physics.doane.edu/hpp/Resources/Media/Flash/UltraSoundImagingwithoutObject2.html).
In this simulation a transducer generates an ultrasound pulse, which is transmitted into a patient body built from layers pf fat, muscle, fluid, muscle and bone. The transmitter also records reflected from the "human layers" pulses. Students should first analyse and explain how the ultrasound pulses travel through the body.
The two graphs show created scans, the A-scan (left) and B-scan (right). Students should be able to discover that small squares in the B-scan respond to the strength of the reflected ultrasound. The strongest (white square) for the muscle-bone transition, The less strong (light grey) for the fat-muscle transition, the weakest (dark grey) for the muscle-fluid and fluid-muscle transitions.



In activity 2 the explanation of a B-scan is given. Students continue to work with the simulation but now they move the transducer to get a complete scan.



Then by using the simulation *Ultrasound Imaging with Object* http://physics.doane.edu/hpp/Resources/Media/Flash/UltraSoundImagingwithObject2.html students create a new scan. This time there is an extra object inside the body.



Students should explain how they can see on the B-scan that there is an extra object inside the body.

In activity 1.3, an example of the ultrasound B-scan is given. The scan shows a human fetus. Students should be able to distinguish and indicate on the scan the baby head, neck, torso.

Both simulations origin from The Humanized Physics Project http://physics.doane.edu/hpp.

Possible questions:

- What are differences between an ultrasound A-scan and B-scan?
- How is an ultrasound B-scan created?

Activity 1.5: Ultrasound imaging

Learning aims:

- To identify advantages and disadvantages of ultrasound imaging for humans
- To explain how an ultrasound machine works
- To explain how an ultrasound examination is done
- To establish an informational folder for patients having an ultrasound examination

Materials:

- Computer with internet connection for finding information

Suggestions for use:

This activity is an excursion to a hospital department where ultrasounds are taken and an interview with a sonographer.
Students should prepare their visit by first exploring ultrasound safety and ultrasound advantages and disadvantages of ultrasound (activity 1) and by preparing interview questions (activity 2). During the visit they should understand what the sonographer profession is. If an excursion to a hospital is not possible then at least a sonographer should be invited for an interview at school.
Based on information collected during the excursion students have to prepare a folder for patients who will have to undergo an ultrasound examination.
Advantages of ultrasound:
1. Ultrasound examinations are non-invasive i.e. they do not require the body to be opened up, or anything to be inserted into the body. This is a major advantage compared to fibre-optic endoscopy, for example, which may involve much more patient discomfort as the probe is inserted.
2. Ultrasound methods are relatively inexpensive, quick and convenient, compared to techniques such as X-rays or MRI scans. The equipment can be made portable, and the images can be stored electronically.
3. No harmful effects have been detected, at the intensity levels used for examinations and imaging. This contrasts with methods based on X-rays or on radioactive isotopes, which have known risks associated with them, and ultrasound methods are preferred whenever possible. This is particularly relevant to examination of expectant mothers.
4. Ultrasound is particularly suited to imaging soft tissues such as the eye, heart and other internal organs, and examining blood vessels.

Disadvantages of ultrasound:

1. The major disadvantage is that the resolution of the images is often limited. This is being overcome as time passes, but there are still many situations where X-rays produce a much higher resolution.
2. Ultrasound is reflected very strong on passing from tissue to gas, or vice versa. This means that ultrasound cannot be used for examinations of areas of the body containing gas, such as the lung and the digestive system.
3. Ultrasound also does not pass well through bone, so that the method is of limited use in diagnosing fractures.

Possible questions:

- Is ultrasound safe?
- Does ultrasound hurt?
- How does an ultrasound machine work?
- What are the main parts of an ultrasound machine?
- How is an ultrasound examination performed?

Activity 2.1: X the unknown

Learning aims:

- To be able to describe how X-rays were discovered
- To be able to explain what X-rays are and how they are produced

Materials:

- A computer with internet connection

Suggestions for use:

Let student watch the Science Channel's movie (2.5 min): Discovery of X-rays (Play http://videos.howstuffworks.com/science-channel/29105-100-greatest-discoveries-discovery-of-x-rays-video.htm). This short movie gives background information about the discovery of X-rays. Let students answer the questions given in Activity 1.

Activity 2.2 is an Exploration activity. Based on the given picture discuss with the students what X-rays are. Listen carefully to students, act as facilitator, ask questions if needed.

In activity 2.3, an Explanation activity, students learn how X-rays are produced. To be able to understand the theory students need to have some

pre-knowledge about Bohr's model of the atom, photons, energy levels of electrons, etc. Activity 2.4, an Extension activity, goes deeper into the theory. By watching the YouTube movie 'How does an X-ray Tube Work' (http://www.youtube.com/watch?v=Bc0eOjWkxpU) students learn more about atom interactions which cause the X-ray radiation. Encourage the students to explain their findings in own words.
Possible questions:
• In which experiment X-rays were discovered? • What are X-rays? • What is the energy of X-rays? • What is the wavelength of X-rays? • How X-rays are produced?

Activity 2.2: Interaction with matter
Learning aims:
• To introduce the students into the field of X-ray imaging • To interpret an X-ray image • To design experiments to determine how the degree of absorption of radiation depends on the material used and on the thickness of the absorbing material • To define the law of attenuation and the concept Half Value Layer (HVL) and apply these to human tissues
Materials:
• A computer with internet connection • gamma source e.g. Cobalt-60. This isotope emits photons with energies 1332 keV and 1173 keV. In comparison to an X-ray generator, cobalt-60 produces energies comparable to a 1250 keV X-ray system. • a device to detect the radiation e.g. a Geiger-Mueller tube or a radiation sensor with computer and data collection software (e.g. Coach 6) • a set of absorption plates of the same thickness made from different materials e.g. Plexiglas, aluminium, steel, lead. • a set of absorption plates of the same thickness made from lead.
Suggestions for use:

Activity 2.1 engages students into the field of X-ray images and their interpretations. Let the students answer the given questions and discuss their answers with the whole class. Act as facilitator of the discussion.

In Activity 2.2 students explore the process of attenuation. They have to design experiments to answer two research questions:

a) How does the degree of absorption depend on the material?

b) How does the degree of absorption depend on the thickness of absorber?

Experiment A.

In order to demonstrate how the degree of absorption depends on the material, 2 mm plates of Plexiglas, aluminium, steel and lead can be used.

Exemplary data: Co-60 gamma radiation, measurement time: t = 10 s

The measurements show that substances having a higher atomic number (“heavy elements”) are better able to attenuate gamma radiation than substances with a lower number. It can be seen that lead shields gamma radiation the best but it is able to penetrate even a 2 mm layer of lead but only a small part of the radiation is attenuated.

Absorber	**Counts per 10s**
Without absorber	172
2 mm Plexiglas	163
2 mm aluminium	161
2 mm steel	154
2 mm lead	140

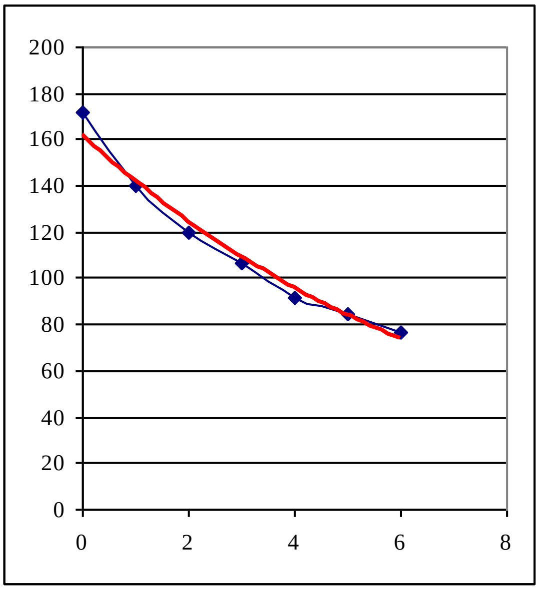
Experiment B.

The thicker the material, the more the gamma radiation is attenuated. This effect may be demonstrated by using lead plates, since the thickness of lead needed for a half-value layer can be easily achieved in an experiment.

Exemplary data: Co-60 gamma radiation; t = 10 s

The resulting graph (blue: measurement, red: function-fit) shows the exponential decrease.

The half-value layer for lead when used to shield Co-60 gamma radiation can be found. During a nuclear decay, Co-60 emits two consecutive photons having energies of 1332 keV and 1173 keV respectively. This makes it impossible to determine an exact curve describing the absorption behaviour of lead or to accurately determine the half-value layer.



The HVL for lead is approximately 12 mm.

Activity 3 explains the law of attenuation and gives definition of the concept Half Value Layer.

Activity 4 encourages students to apply the learned concepts to human tissues.

Calculated HVLs for soft tissue and bone at 30 and 60 keV are:

Material	30 keV	60 keV
Soft Tissue HLV (cm)	1.82	3.3
Bone HLV (cm)	0.43	1.54

Possible questions:

- Which material is the best absorber of gamma radiation?
- What is the function, which describes the relationship between the intensity of the radiation and the thickness of the absorber for lead?
- What is the thickness of lead for which radiation is reduced to 50% of the original radiation?
- What would you expect if you would use X-rays instead of gamma rays?

Activity 2.3: X-ray medical machine
Learning aims:
• To explain how an X-ray machine works • To examine the different medical applications of X-rays
Materials:
• A computer with internet connection
Suggestions for use:
In this activity students learn how X-machine used in medicine works. In Activity 2.1, students explore the X-ray source device. In Activity 2.2, further explanations of the parts of the X-ray machine are given. In Activity 2.3, students extend their knowledge about X-ray machines by looking into different applications of X-ray images in medicine. Discuss in what types of medical examinations X-rays are used and how an X-ray machine may differ depending on the aim of photo. Act as a facilitator of this discussion. Medical x-rays are used in many types of examinations like: • radiography - to find orthopaedic damage, tumours, pneumonias, foreign objects, • dental photos – to image the internal structures of teeth, • mammography - to image the internal structures of breasts.
Possible questions:
• How are X-rays produced in an X-ray source? • What are the basic parts of an X-ray machine? • What are applications of X-rays in medicine?

Activity 2.4: CT scans

Learning aims:

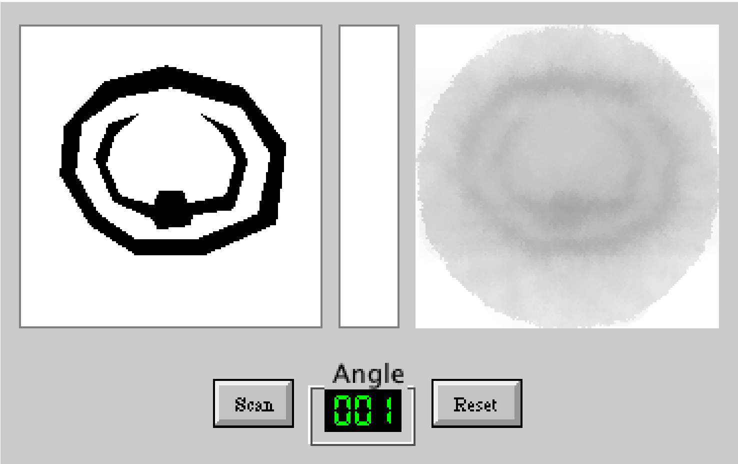
- To explain how a CT scan is created
- To explain how a modern CT scan machine works

Materials:

- A computer with internet connection

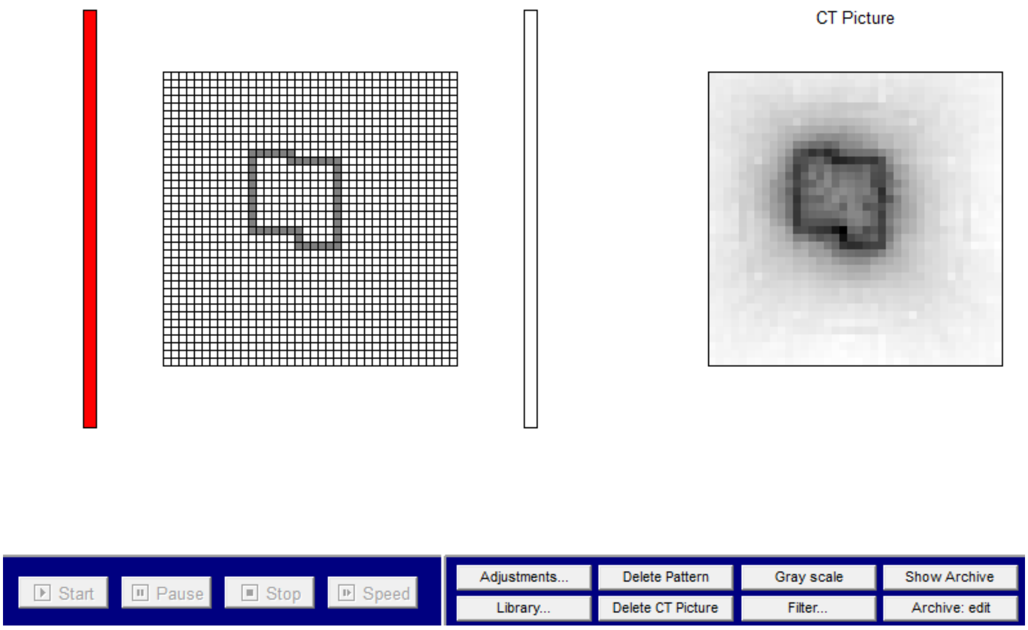
Suggestions for use:

In Activity 2.1, students are faced with a problem that conventional X-ray shadow images are only two-dimensional flat images and they do not provide complete information. In Activity 2.2, they explore how several shadow images can be combined to create a more complete picture.
In Activity 2.3 they use simulation available at
http://www.colorado.edu/physics/2000/tomography/final_rib_cage.html and learn how the CT scan is created.
In the simulation a simple model of a rib cage is shown. The model can be scanned with an X-ray beam. By turning the model around and scanning it for each selected position (angle) a CT scan of the model is created.



After playing with the simulation encourage the students to explain in their own words the principles of this technique. Raise extra questions, for example about the attenuation of the X-rays, the grey scale of the image, ideas of improving the quality of the scan.
Another nice simulation of creating a CT scan is included in the program called CTSim available at Kansas State University Physics Education Research Group
http://web.phys.ksu.edu/mmmm/software/CTSim/

Here the user can create an own model to scan and after pressing the Start button the computer produces its CT scan.



This program also provides an extended and more advanced explanation of the CT scan technique.

In activity 2.4 students learn how this principle is applied in CT scan machines and get a basic explanation on how a CT scan machine works.

The ‘Analog slices’ movie shows analogue representations of tomography, using everything from horned melons to violins and hairdryers. http://videos.howstuffworks.com/discovery/45162-the-ge-show-presents-analog-slices-video.htm

Additionally students can watch the YouTube movie ‘CT Scans How it works’. http://www.youtube.com/watch?v=rN4E8Y5loAs&feature=related.

Possible questions:

- Why conventional X-ray machines cannot provide a complete image of the inside body?
- How is the image of a slice of the body created?
- What is the basic principle of a CT scan machine?
- What are the basic parts of a CT scan machine?

Activity 2.5: Are X-rays bad for you?

Learning aims:

- To understand the health risks of X-rays and CT scans
- To establish inquiry based skills like: identifying problems to investigate, analysing and evaluating scientific arguments, constructing logical proofs, communicating and defending scientific arguments,

Materials:

- A computer with internet connection

Suggestions for use:

In this activity, students investigate the health risks of X-rays. They research the problem to be able to defend a statement in which they believe.
The statement is:
Many people are concerned about the risks to their health from getting medical X-rays and CT scans. In my opinion X-rays and CT scans may be important in medicine but they are also very harming, I think they are not good for me.
They should realise:

- advantages and disadvantages of X-rays and CT-scans
- health risks connected to both techniques
- how much benefit is needed to accept certain health risks.

This is an open inquiry type of activity. Students have to collect the evidence, construct logical proof and defend their point of view in a class debate.
The best approach is to divide students in smaller groups and let them divide the tasks in the group themselves.
A nice addition would be to organize a visit to a radiology department in a hospital or to invite a radiologist into the class.

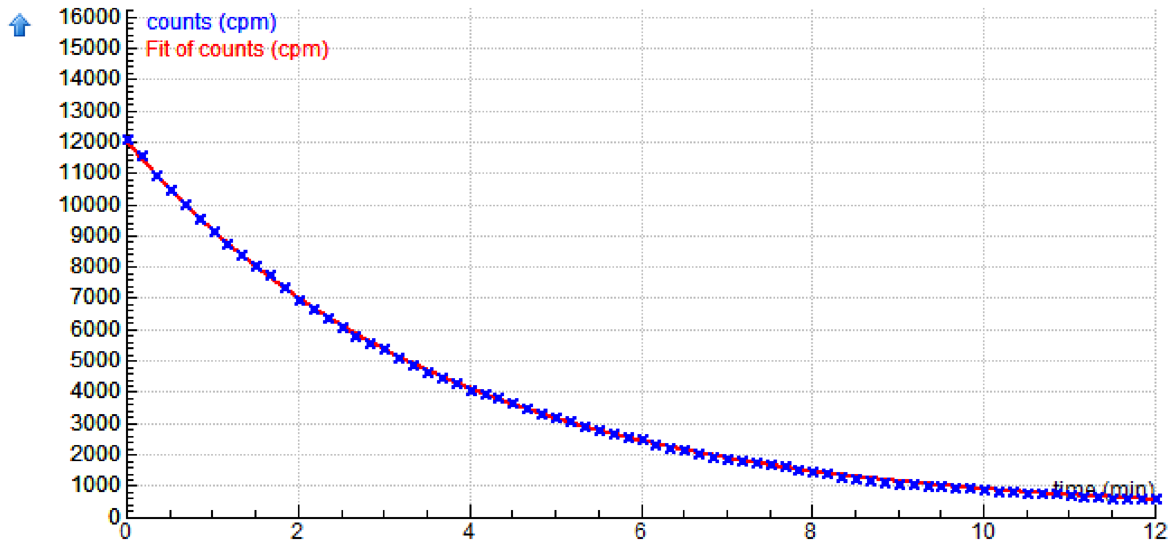
Possible questions:

- What are advantages and disadvantages of X-rays and CT scans?
- What are biological effects of X-rays?
- How much radiation is exposed in X-ray image? CT scan?
- Is there a minimal radiation dose, which is not harmful? What are results of too large dose?
- Can modern medicine miss X-ray and CT medical imaging?

Activity 3.1: Studying real and apparent depths
Learning aims:
• To identify three kinds of radiation and their properties • To measure the absorption properties by matter for alpha, beta, and gamma radiation
Materials:
• A computer with internet connection • Radiation sources: Alpha source (e.g. Po-210), Beta source (e.g. Sr-90) and Gamma source (e.g. Co-60) • A detection device: a Geiger-Müller counter or radiation sensor with a data-logger and software (Coach 6) • A set of absorbers e.g. paper, aluminium and lead of varying thicknesses 
Suggestions for use:
Here students get familiar with different types of natural radiation. In Activity 3.1 they recall their knowledge about gamma radiation. In Activity 3.2 they explore alpha, beta, and gamma radiation properties, their behaviour in an electric and magnetic field and penetration properties. Instead of analysing images included in the worksheet students can use animation available at: http://www.passmyexams.co.uk/GCSE/physics/properties-of-radiation-electric-magnetic-field.html. **Alpha particles** are attracted to the negatively charged plate and are deflected by a magnetic field. This confirms that they must be positively charged. Alpha particles are helium nuclei; they contain 2 protons, which gives them their positive charge. **Beta particles** are attracted to the positively charged plate and are deflected by a magnetic field in the opposite direction of alpha particles. This confirms that they are negatively charged. Beta particles are fast moving electrons. They are deflected much more than the heavier alpha particles. **Gamma** rays are unaffected by an electric field and are also unaffected by a magnetic field. Gamma rays are highly energetic waves with no charge associated with them. In the investigation of penetrating properties students use sources of different radiation. They measure the effect of absorbers placed between the source

and the detecting device. Alpha particles should be stopped by anything except the very thinnest piece of paper or foil. If you do not have a pure alpha source, you need to be careful about trying to show the properties of alpha using a Geiger-Müller tube. The radiation from a mixed source like ^{241}Am can penetrate aluminium and has a long range. This is because it gives out gamma as well as alpha radiation. Beta radiation can be stopped by a sheet of Perspex, an exercise book, or thin aluminium. Gamma radiation is very penetrating and needs thick layer of lead to reduce it to a low level. It can be easily demonstrated that alpha radiation has a very short range (between 3-10 cm), beta has a range of about 10 cm, and gamma gets weaker with distance but doesn't come to a stop at any particular distance. If there is no equipment for student investigations then a teacher demonstration should be performed in which students should be actively involved. Also students can perform these experiments in a virtual lab, for example in a virtual radiation lab at http://visualsimulations.co.uk/software.php?program=radiationlab In activity 4 students evaluate why radioactive materials emitting alpha and beta radiation are not suitable for nuclear medicine.
Possible questions:
• What is alpha, beta and gamma radiation? • What are properties of alpha, beta and gamma radiation? • Which material stops alpha radiation? Beta radiation? Gamma radiation? • Which radiation, alpha, beta or gamma has the longest range? How do you know? • Why alpha and beta radioactive materials are not suitable for nuclear medicine?

Activity 3.2: Radioactive decay
Learning aims:
• To measure radioactive decay • To determine the decay constant • To calculate the half-life time
Materials:
• A computer with internet connection • A radioactive isotope generator • A detection device: a Geiger-Müller counter or data-logger with a radiation sensor and software (Coach 6)
Suggestions for use:
Here students focus on the process of radioactive decay. In Activity 3.1, students simulate the process of radioactive decay and learn that it is a random process. In Activity 3.2, they explore a given radioactive decay model and determine the function, which describes the radioactive decay. In Activity 3.3, the radioactive decay law, the decay constant and the half-life time are introduced. In Activity 3.4, students measure the activity of a radioactive isotope. Based on the measured results they determine the decay constant and calculate the half-life value. The short-lived radioisotope Ba-137m is very suitable for measuring and by using a Cs-137/Ba-137m Isotope Generator easy to make. The isotope generator Barium 137m contains Cesium-137 as the long parent nuclide, which has a half-life of 30.25 years. Cs137 decays, by emission of beta radiation, into stable isotope Ba137. This transition is partly affected (approx. 5%) by direct conversion into stable isotope Ba137 and partly (95%) via the metastable energy state of Ba137m. In the experiment Ba is “milked” out of the Isotope Generator by pressing eluting solution through the generator. The half-life of Barium-137m is approximately 153 seconds (2.55 minutes).



Exemplary data of the Barium-137m radioactive decay:
measurement with MoLab data-logger and ML26m Radiation sensor, the coefficient of exponential function is $\lambda = 0.272$, the half-time $t_{1/2} = \ln 2/\lambda = 0.6931/0.272 = 2.548$ min.

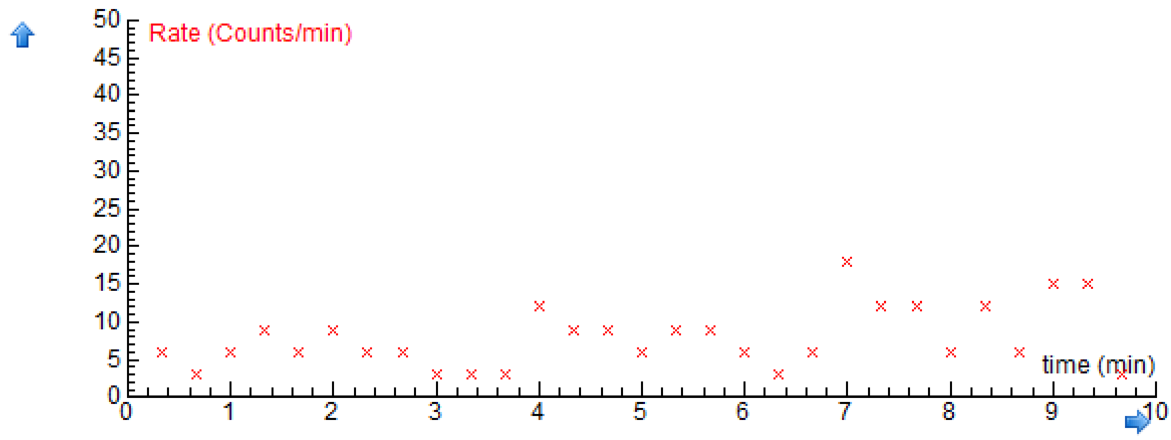
In activity 5, students modify the model of activity 2 to create a model of radioactive decay of the isotope used in their experiment and compare the model data with the experimental results.

Possible questions:

- Which function describes the radioactive decay?
- What is the decay constant?
- What is the half-life?
- What does it mean that radioactive decay is a random process?
- How do you measure radioactive decay?
- How do you model radioactive decay?

Activity 3.3: Tracing substances in the human body
Learning aims:
• To explain which type of radioactive materials can be used in nuclear imaging • To explain why Technetium 99m is suitable for nuclear imaging • To specify the main elements of a gamma camera
Materials:
• A computer with internet connection
Suggestions for use:
Here students learn how radioactive materials are used in nuclear imaging and how they are detected. In activity 3.1, students identify properties of radioactive materials suitable for nuclear tracing. In activity 3.2 they explore Technetium 99m, a radioactive material often used in nuclear tracing. In activity 3.3 they learn more about Technetium 99m, about its decay, the way of producing and preparing for use in medicine. In activity 3.4 they learn the basic ideas of gamma cameras and PET scans. This activity is quite full of facts and inquiry based approach is here quite limited. On the other side this activity gives a good opportunity to link to the medical industry. A good addition here, activity 3.5, would be an excursion to a hospital, which has a nuclear imaging department or inviting to school a person working at such department (there are few professions involved). In both cases students should prepare interview questions and after the excursion/visit write a report. (A worksheet for this activity is not provided).
Possible questions:
• What kind of radioactive materials can be suitable for nuclear imaging? • What are radiopharmaceuticals? • What is Technetium 99m? • How is Technetium 99m produced? • How is Technetium 99m stored? • How are radiopharmaceuticals injected into a body detected? • What is a PET scan?

Activity 3.4: Radiation exposure
Learning aims:
• To understand that radiation origins from natural and from artificial (man-made) sources • To give examples of radiation from natural and man-made source • To measure the radiation background and the radiation from naturally occurring radioactive substances. • To observe the random nature of the radiation process • To explain the way the effective exposure dose is calculated • To calculate a personal annual radiation dose • To explain effects of radiation
Materials:
• A computer with internet connection • Sources of natural radiation • A detection device: a Geiger-Müller counter or data-logger with a radiation sensor and software (Coach 6)
Suggestions for use:
Here students learn to which radiations people are exposed, how an annual radiation dose is calculated and what are effects of radiation on humans. In activity 3.1, students analyse the sources of ionising radiation on Earth. Ionising radiation in our direct environment arises from natural processes (e.g. cosmic radiation, radioactivity in the body, inhalation of radon gas, radionuclides in food and drink) and from artificial process (such as medical X-rays, fallout from nuclear weapons tests, and discharges of radioactive waste). In activity 3.2, students investigate the radiation of their environment, they measure background radiation in different places and measure the radiation of some natural materials. In this activity they observe the random nature of the radiation process. Exemplary data: Background radiation, Number of measurements: 30, Max: 18.00, Min: 3.00, Average: 8.00, Standard deviation: 3.97



In activity 3.3 they learn how absorbed radiation doses by the human body are calculated and in which units they are measured.

In activity 3.4 students realise that the personal annual radiation dose exposure depends on many factors (the amount of natural radioactivity depends on the location on earth, the amount of artificial radiation depends on the dose of medical radiation, etc.). They calculate the annual personal radiation dose. For this they use the provided chart (origin American Nuclear Society).
Such an annual personal dose can also be calculated via computer for example at:
http://firstyear.chem.usyd.edu.au/calculators/radiation_dose.shtml, or
http://www.epa.gov/rpdweb00/understand/calculate.html
In activity 3.5 the students find out and discuss the effects of radiation on the human body and cells.

Possible questions:

- What are natural sources of radiation?
- What are man-made sources of radiation?
- What is the most significant natural source of radiation?
- What is the background radiation in your environment?
- How do you measure the background radiation?
- What does it mean that background radiation has a random nature?
- What is the absorbed radiation dose and in which units is it measured?
- What is the equivalent radiation dose and in which units is it measured?
- What is the effective radiation dose and in which units is it measured?
- What is your personal annual radiation dose and how is it calculated?
- What are the biological effects of radiation?

Activity 3.5: Radiation protection
Learning aims:
• To measure how radiation changes with the distance to the radiation source • To measure how beta radiation is absorbed • To describe methods of protection against ionising radiation • To compare the health risks of an ionising radiation dose to other risks
Materials:
• A computer with internet connection • Radiation sources of alpha, beta and gamma radiation • A detection device: a Geiger-Müller counter or a radiation sensor with data-logger and software (Coach 6)
Suggestions for use:
This activity is about radiation protection. In activity 4.1, students analyse the health risks associated with ionising radiation. In activity 4.2, they investigate: 1. how the radiation changes with the distance from the source, and 2. how beta radiation is absorbed by cardboard or aluminium foils. In activity 4.3, they learn three factors of minimising the radiation: minimising exposure time, maximising distance, and the use of shielding. In activity 4.4, students find out how film badges are used for monitoring the radiation exposure.
Possible questions:
• What is a health risk of an X-ray dental image? • How to minimise the radiation dose? • What is the ALARA principle? • How is the radiation exposure of health care staff involved in radiology or nuclear medicine monitored?

RENEWABLE ENERGY

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

Stephan Domschke, Martin Lindner and Louise Bindel

Martin-Luther-Universitaet Halle-Wittenberg (MLU), Germany.

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UNIT CONTENTS

I. Unit Description

This unit encourages pupils to conduct their own studies about the character and application of renewable energies, with a focus on experimental approaches and an evaluation of the technologies.
The unit is guided by the question “Which energy source is the best?” and is supposed to give students a positive yet critical point of view on renewable energies, and to enable them to participate in discussions about different technologies and different points of view. Furthermore, they will learn to think and work scientifically, acquire a positive attitude toward sciences and train their abilities with tools and electric circuits.

- **Student level:** Higher secondary level, ages 14+
- **Discipline(s) involved:** Biology, chemistry, physics and science
- **Estimated duration:** At least 10 hours

II. IBSE Character

The main idea of this unit is that of “open inquiry”, which means the pupils autonomously research on the guideline question “which energy source is the best?” Directing them in this process is done with the help of “bounded inquiry”, i.e. through given questions and criteria, which also adjusts focus on the experimental material at hand. Because the pupils develop their own criteria to assess renewable energies and use them to guide their research and studies, this unit satisfies every aspect of IBSE in the definition used by ESTABLISH. The teaching and learning aids present possible ideas that could be researched.

III. Science Content Knowledge

The much-debated study The Limits to Growth, which was published as early as 1972 by Dennis L. Meadows *et al* on behalf of the “Club of Rome”, already predicted shortages of natural resources and especially fossil fuels (coal, oil and gas) alongside irreparable damage to the environment if nothing was done about the world population growth, industrialization, pollution, food industry and exploitation of resources of that time. Oil crises and price increases of the past have shown how nearly every state is dependent on oil. Even the seemingly eco-friendly nuclear power uses limited resources and poses severe and still unsolved problems concerning the permanent disposal of its waste.

With all these insights, the focus is on other eco-friendly and safe approaches to power generation independent of limited resources, yet sufficient in quantity. One concept is the use of renewable energies in connection with storage of excess energy. Before fossil fuels were discovered, mankind relied solely on renewable energy and fossil fuels really only gained their importance during the course of the industrialization.

Renewable energies include:

- Wind power
  - wind turbines
- Hydropower
  - hydroelectric dam with turbine
  - run-of the-river hydroelectricity
  - Pumped-storage hydroelectricity
  - Tide power
- Solar energy
  - Photovoltaics
  - Solar thermal energy
- Biomass
  - Thermal conversion
  - Chemical conversion
  - Biochemical conversion
- Biofuel
  - Bioethanol
  - Biodiesel
  - Biogas
- Geothermal energy
  - Geothermal heating
  - Geothermal heat pump

One way of storing excess energy is by using electricity to generate hydrogen through electrolysis of water, which can then later be oxidized to generate electric energy from the chemical energy stored in the hydrogen.

RELEVANT SCIENTIFIC CONCEPTS:

Energy	Definition	The ability of a physical system to do work or transmit light or heat.
	Formula	E
	Units	one joule (1J), one watt-second (1Ws), 1J = 1Ws
	Measuring instrument	---
Force	Definition	Any influence that causes an object to undergo a certain change.
	Formula	$F = ma$ (mechanic) or $F=qE$ (electric)
	Units	one Newton (1N)
	Measuring instrument	spring scale
Work	Definition	A physical system does work, when there is movement under the action of a force.
	Formula	$W = Fs$ (mechanic) or $W = qU$ (electric) or $W = \Delta E$
	Units	one newton-meter (1Nm), one joule (1J), 1Nm = 1J
	Measuring instrument	---
Power	Definition	The rate at which energy is transferred, used or transformed.
	Formula	$P = \Delta E/t = W/t$ (mechanic) or $P = UI$ (electric)
	Units	one watt (1W), one joule-second (1Js), 1W = 1Js
	Measuring instrument	---
Electric Current	Definition	A flow of electric charge through a conductive medium.
	Formula	$I = q/t$ or use Ohms law
	Units	one ampere (1A)
	Measuring instrument	ammeter
Voltage	Definition	The „force or push“ that moves electric current through a circuit.
	Formula	$U = W/q$ or use Ohms law
	Units	one volt (1V)
	Measuring instrument	voltmeter, potentiometer
Electrical Resistance	Definition	The opposition to the passage of an electric current through an electric element.
	Formula	$R = U/I$ or $R = \rho\ell/A$

	Units	one ohm (1Ω)
	Measuring instrument	ohmmeter
Temperature	Definition	A measurement of how hot or cold a body is.
	Formula	T or ϑ
	Units	one kelvin (1K) or one degree celsius (1°C)
	Measuring instrument	thermometer
Heat	Definition	The amount of energy that is transferred from one system to another by thermal interaction.
	Formula	$Q = \Delta E$ or $Q = cm\Delta T$
	Units	one joule (1J)
	Measuring instrument	---
Irradiance (Light intensity)	Definition	The power of light per unit area incident on a surface.
	Formula	$I = P/A$
	Units	one watt per square meter (1W/m^2)
	Measuring instrument	light sensor

Relevant scientific concepts and phenomena

- Energy conversion
- Heat transfer
- Electric generator
- Direct and alternating current
- Electric circuit
- Ohms law
- Kirchhoffs laws
- Inner photoelectric effect
- Electrolysis
- Fuel cell
- Fermantation
- Ecosystem
- interaction between animate and inanimate nature
- Water cycle (hydrological cycle)

IV. Pedagogical Content Knowledge

Based on the theory of self-determination by Decy & Ryan, the main idea is that pupils develop their own questions and solve them autonomously. This includes devising own criteria to answer the guiding question, coming up with own experiments as well as estimating the time needed. The pupils should follow the criteria during their studies and also evaluate them accordingly. Another important aspect is that there are no wrong questions or answers, as long as they are on topic.

The answers to the guiding question will vary from pupil to pupil, depending on their criteria. Therefore, the aim of the final discussion should be to find a reasonable compromise between every group, which could be an agreement on a mix of energy sources.

The unit is supposed to be done in the form of project work with small group sizes of 3-4 pupils. If the method of guided inquiry is used, particular stations with relevant activities can be prepared beforehand.

Possible criteria:

- Quantity of energy produced
- Efficiency of energy conversion
- Cost-benefit approach
- Environmental sustainability

Possible misconceptions:

- The difference between current and voltage
- The difference between heat and thermal energy
- Polarity in electric circuits
- How photovoltaic modules generate electricity (e.g. thermal)

V. Industrial Content Knowledge

This unit provides a link to renewable energy industries, including renewable energy products (solar collectors, wind turbines), power plant operators and energy companies as well as research groups. Energy consumers such as simple households, communities or the industry are important to the discussion about the best power source as well.

Some of the activities include design tasks which may require a look at existing systems for inspiration. Talking to industry experts can also be helpful. In any case, industry visits are recommended for every activity.

VI. Learning Path(s)

The following table characterises the twelve activities from the point of view of the required type of inquiry and the estimated duration of the activities.

	Activity	Inquiry Type	Estimated Duration
1	Designing a wind power plant	Bounded Inquiry	8h
2	The power of a wind power plant	Guided Inquiry	2h
3	Designing a hydroelectric power plant	Bounded Inquiry	8h
4	Cooking with the heat of the sun	Guided Inquiry	2h
5	Designing a solar collector	Bounded Inquiry	8h
6	Building a dye-sensitized solar cell	Guided Inquiry	5h (distributed over 2 days)
7	The power of a photovoltaic module	Guided Inquiry	2h
8	The power of a solar cell garden pump	Bounded Inquiry	4h
9	My iPod works with energy from bull shit!	Guided Inquiry	several days
10	The efficiency of a hybrid power plant	Guided Inquiry	2h
11	Designing a hydrogen car	Bounded Inquiry	2h
12	Designing an island system	Bounded Inquiry	2 days

VII. Assessment

The unit focuses on devising guideline criteria, following them during the course of the studies and also applying them to evaluate the results. Assessment can be done various ways.
The teacher could monitor the process of the studies with the help of lab notes and other documentation by the pupils.
Predictions and assumptions as well as descriptions of the experiments and a summary of results should either be written down on worksheets or collected in personal interviews.

The teacher should observe the activities of every member of a group and also of the group discussion on the whole, but not interfere too early. He should rather let pupils also move in a not so promising direction, at least for a while.

The presentation of the results in the penal discussion and the ensuing discussion shows how extensively the pupils have worked on their topics and questions.

Furthermore, pupils could also asses themselves and each other within their respective groups.

VIII. Student Learning Activities

Activity 1: Which energy source is the best?
Learning aims:
• Learn about fossil fuels and renewable energy • Understand advantages and disadvantages of various types of energy
Materials:
• Laptops, internet, crafting material, writing material, a choice of experiments and related equipment, tools, ICT… • Recommended experimental kits and manuals: ○ **Horizon Kits** (e.g. renewable energies, etc) http://www.horizonfuelcell.com/store_euro.htm# http://www.conrad.com/Experimental-cases-alternative-energy.htm?websale7=conrad-int&ci=SHOP_AREA_17618_2420141 ○ **Fischertechnik Kits** (Oeco Tech, Hydro cell Kit, E-Tec), http://www.fischertechnik.de/en/desktopdefault.aspx/tabid-20/38_read-2/usetemplate-2_column_pano/ http://www.conrad.com/Fischertechnik-Experiment-Kits.htm?websale7=conrad-int&ci=SHOP_AREA_17618_2420170 ○ **KOSMOS Kits** (fuel cell, wind energy, solar energy, solar master, solar generation, solar cooker), http://www.kosmos.de/content-824-824/alternative_energy/ http://www.conrad.de/ce/de/overview/2420160/?page=0&filter_selection_1=ATT_TOPIC%3B~Erneuerbare+Energien~&filter_selection_2=&filter_selection_ATT_GLOBAL_Brandname=&filter_selection_ATT_TOPIC=ATT_TOPIC%3B~Erneuerbare+Energien~&filter_selection_ATT_PRODSPEC_0071=&pricerange=&bvRating=&feature=&orderBy=&orderSequence=&indivPriceRangeA=&indivPriceRangeB= http://www.kosmos.de/produktdetail-838-838/solar_kocher-318/ ○ **Mansolar solar cells kit** (dye-sensitized solar cell) http://www.mansolar.nl/products.html http://www.solaronix.com/documents/dye_solar_cells_for_real.pdf http://www.camse.org/scienceonthemove/documents/DSSC_manual.pdf see also ESTABLISH unit “Photochemistry” chapter IV experiment IV-3a ○ **Software HOMER**

https://homerenergy.com/download.html; ○ **Solar fountain system** http://www.conrad.com/Solar-fountain-system-Palermo.htm?websale7=conrad-int&pi=551132&Ctx={ver%2F7%2Fver}{st%2F3ec%2Fst}{cmd%2F0%2Fcmd}{m%2Fwebsale%2Fm}{s%2Fconrad-int%2Fs}{l%2Fint%2Fl}{sf%2F%3Cs1%3Epalermo+pump%3C%2Fs1%3E%2Fsf}{p1%2Fd332d0672e5b87438ed004a8593081ff%2Fp1}{md5%2F3448a6f48751c6ef3267c1153f8b7bdc%2Fmd5} ○ **Biogas (My iPod works with energy from bull shit)** http://www.parsel.uni-kiel.de/cms/fileadmin/parsel/Material/Berlin/neu2/08FUB4b-Teachers_Bull_Shit.pdf http://www.parsel.uni-kiel.de/cms/fileadmin/parsel/Material/Berlin/neu2/Overall_Bull_Shit.zip
Suggestions for use:

• To carry out the topic and raise students awareness could use:
  ○ Newspaper articles or headlines(e.g. http://www.teenink.com/hot_topics/environment/article/491395/Fossil-Fuels-Are-a-Dead-End/)
  ○ Science journal articles
  ○ Book chapters (e.g. Jorgen Randers (2012). 2052 – A Global Forecast for the Next Forty Years; Donella H. Meadows (1972). The Limits to Growth)
  ○ Movie chapters (e.g. An Inconvenient Truth, by Al Gore)
  ○ TV report
  ○ …
• The recommended activities show possible experiments that could be suggested by the students or used as mandatory activities
• Link to industry (see ICK description)
• Teaching method: inquiry learning (see IBSE description)

Possible questions:
• How efficient is the energy source? • How much does it cost to generate electricity using this source of energy? • What impact does this energy source have on the environment?

Activity 2: Designing a wind turbine
Learning aims:
• To build a functional model of a wind turbine to power an electric device, e.g. a lamp • Understanding of energy conversion in a wind turbine • Understanding of the functional principles and properties of wind turbines
Suggestions for use:
Students should build a functional model of a wind turbine to power an electric device, e.g. a lamp. They may take cues from existing turbines and work with their form and features. They should discuss their own designs and determine the needed materials. Trial and error methods may be required to get the electric device running. Pupils should then determine the power output of the model.
Possible questions:
• How does a wind turbine work? • Which types of wind turbines exist, which are planned? • How much useful energy could be generated by your wind turbine? • Which parameters influence the power of a wind turbine? • Why are wind turbines so expensive? • What do you need for building a wind turbine? Which materials are useful? • Is your wind turbine efficient enough to …? • What do experts know about building a wind turbine?

Activity 3: The power of a wind turbine
Learning aims:
• Understanding factors that affect the efficiency of a wind turbine
Materials:
• e.g. renewable energies kit from Horizon (see unit description)
Suggestions for use:
The pupils design an experiment to evaluate the capacity of a wind turbine depending on a number of different influences. The model provides methods to change the number, form and angle of attack of the rotor blades. They can also determine favorable wind velocities with the help of suitable devices. • The pupils come up with possible influences on the power of a wind turbine, test them and present them easy to understand • An industry visit at a wind turbine factory or expert interview is recommended.
Possible questions:
• How does a wind turbine work? • Which types of wind turbines exist, which are planned? • How much useful energy could be generated by a wind turbine? • What factors influence the power of a wind turbine? • How can you measure the power of a running wind turbine? • How much power is generated by a local wind turbine?

Activity 4: Designing a hydroelectric power plant
Learning aims:
• energy conversion in a hydroelectric power plant • functional principles and properties of hydroelectric power plants;
Suggestions for use:
• Pupils should determine possible influences on the power of a hydroelectric power plant and test these out, then present their findings easy to understand. • An industry visit at a hydroelectric power plant or expert interview is recommended.
Possible questions:
• How does a hydroelectric power plant work? • Which types of hydroelectric power plants exist, which are planned? • How much energy can be generated by your hydroelectric power plant? • Which values influence the power of a hydroelectric power plant? • Why are hydroelectric power plants so expensive? • What do you need to build a hydroelectric power plant? Which materials are useful? • Is your hydroelectric power plant efficient enough to …? • What do experts know about building a hydroelectric power plant?

Activity 5: Cooking with the heat of the sun
Learning aims:
• energy conversion; • law of reflection; • properties of mirrors
Materials:
• e.g. solar cooker from KOSMOS (see unit description)
Suggestions for use:
• The pupils should consider possible influences on the efficiency of their solar oven, test them and present the results easy to understand. • An industry visit at a solar thermic power plant or expert interview is recommended.
Possible questions:
• Which materials are needed for building a solar oven? • Which values influence the temperature of the oven? • Which food could be cooked by your solar oven? • Can you cook a whole menu?

Activity 6: Designing a solar collector
Learning aims:
• energy conversion in a solar collector; • functional principles and properties of solar collectors
Suggestions for use:
• The pupils should think of possible influences on the efficiency of their solar collector, test them and present their results easy to understand. • An industry visit at a solar collector factory or expert interview is recommended.
Possible questions:
• How does a solar collector work? • Which types of solar collectors exist, which are planned?

- How much energy can be collected by your model?
- Which values influence the power of a solar collector?
- Are solar collectors more expensive than other methods of power generation?
- What do you need for building a solar collector? Which materials are useful?
- Is your solar collector efficient enough to …?
- What do experts know about building a solar collector?

Activity 7: Building a dye-sensitized solar cell

Learning aims:

- Build a dye-sensitized solar cell (DSC) with the help of material found in the kit from Mansolar
- energy conversion in a DSC
- functional principles and properties of DSC; production of solar cells

Materials:

- e.g. solar cell kit from Mansolar (see unit description)

Suggestions for use:

- The pupils should think of further dye suitable for use in DSC, test their ideas and present the results easy to understand.
- An industry visit at a solar cell factory or expert interview is recommended.

Possible questions:

- How do dye-sensitized solar cells work?
- Which chemicals are used to produce solar cells?
- How are solar cells produced?
- What is the electric power of a DSC?

Activity 8: Measuring the power of a photovoltaic module
Learning aims:
• to evaluate the power output of a photovoltaic module with regard to various factors. • energy conversion in a solar cell • functional principles and properties
Materials:
• Photovoltaic module, two multimeters, light source, variable resistor, load
Suggestions for use:
• The pupils should determine possible influences on the power output of a single solar cell and test their ideas. They should also work out how to connect multiple cells to a photovoltaic module of a predefined electric power, and present their findings easy to understand. • An industry visit at a solar cell factory or expert interview is recommended.
Possible questions:
• What is the definition of electric power? • Which parameters influence the power of a solar cell? • How good are your results?

Activity 9: The power of a solar powered garden pump
Learning aims:
• To determine the power of a solar powered water pump • Energy conversion; mechanical work and power
Materials:
• Solar cell and garden pump (e.g. solar fountain system; see unit description), bucket, water, ruler, clock, beaker or measuring cylinder
Suggestions for use:
Introduction: "Imagine you want to know the power of the solar cell but you only have a garden pump!" The pupils should come up with ideas to measure the power output and create convenient tests for them. They may approach the problem deductively by deriving a formula or inductively by testing. They should compare the results with the product specifications and present them easy to understand. A connection to industry could be an online research for similar products with different parameters.
Possible questions:
• How can power and work be described / defined? • Which parameters influence the power of a solar cell? • How good are your results?

Activity 10: My iPod runs on bullshit energy
Learning aims:
• using biogas as energy source
Suggestions for use:
See description in http://www.parsel.uni-kiel.de/cms/fileadmin/parsel/Material/Berlin/neu2/08FUB4b-Teachers_Bull_Shit.pdf http://www.parsel.uni-kiel.de/cms/fileadmin/parsel/Material/Berlin/neu2/Overall_Bull_Shit.zip
Possible questions:
• How is biogas produced? • What are the main difficulties in biogas production? • Which material do you need for building a biogas plant? • How efficient is your biogas plant? • Is your biogas plant efficient enough to …?

Activity 11: The efficiency of a hybrid hydrogen power plant
Learning aims:
• determine the efficiency of a hybrid hydrogen power plant with regard to various primary energy sources • functional principles and properties of fuel cells • energy storage
Materials:
• e.g. renewable energies kit from Horizon (see unit description)
Suggestions for use:
• The pupils should think of possible ways to determine the efficiency of a hybrid hydrogen power plant, use them on different combinations of power plants and present their results easy to understand. • An industry visit at a hydrogen factory or expert interview is recommended.

Possible questions:
• How does a fuel cell work? • How does a hybrid hydrogen power plant work? • Which types of hybrid power plants are possible? • How efficient is your hybrid power plant? • Which parameters influence the efficiency of a hybrid hydrogen power plant?

Activity 12: Designing a hydrogen vehicle
Learning aims:
• to build a working model of a hydrogen vehicle • functional principles of fuel cell and electric motor; • properties of fuel cells and electric motors
Materials:
• e.g. Hydrocar or H2 Racer from Horizon (see unit description) • electric motor(s), fuel cell, electrolytic cell, electric supply, cables, hydrogen storage
Suggestions for use:
• The pupils should determine what factors influence the efficiency of a hydrogen vehicle, test them and present their results easy to understand. • An industry visit at a hydrogen vehicle factory or expert interview is recommended
Possible questions:
• How does a fuel cell work? • Which materials do you need for building a hydrogen vehicle? • Which values influence the efficiency of your hydrogen car? • Whose hydrogen car is the best?

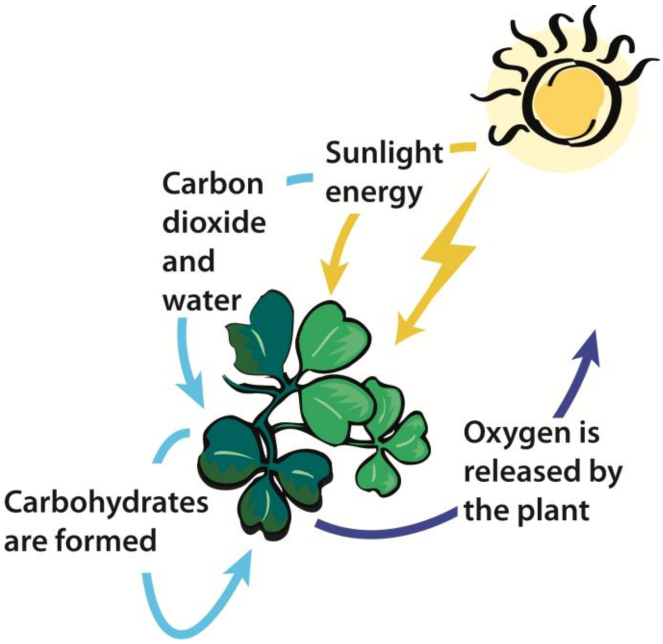
Activity 13: Design an island system!
Learning aims:
• to build a working model of an island system that may be based on existing instances and copy their elements and features • functional principles of energy converters and storage; • properties of energy converters and storage facilities
Suggestions for use:
• The pupils should investigate the local situation regarding energy production, find suitable solutions for energy transformation and eventually a continuous energy supply, and present their findings easy to understand. • An industry visit at an existing island facility or expert interview is recommended.
Possible questions:
• What are possible ways of energy transformation? • Which way is most effective? • How is energy stored? • How is the facility managed? • Which materials are needed? • What is the power output of our facility?

PHOTOCHEMISTRY

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

Paweł Bernard.

Uniwersytet Jagiellonski (JU), Poland



UNIT CONTENTS

I. *Unit Description*

Photochemistry is an interdisciplinary unit which covers chemistry, biology and physics topic. The whole unit is based on the properties of light and electromagnetic waves. It consists of 4 subunits:

Subunit	Level	Number of hours
1. The magic of colours	Lower secondary school	2
2. In the rainbow-hued land	Lower/upper secondary school	5
3. How to measure the colour?	Upper secondary school	12
4. In the world of energy	Upper secondary school	8

Each of the subunits contains engaging questions and research activities for students.
As well as providing opportunities for students to engage with hands-on activities, this unit also offers opportunities for students to construct research equipment, specifically in:

- Subunit 2 – construct a simple spectroscope,
- Subunit 3 – construct a colorimeter,
- Subunit 4 – construct light source chambers and a solar cell.

Where time is constrained, such devices can be replaced with their commercial equivalents.

Subunit 1: The magic of colours

Laboratory exercises for students	Type of inquiry	Topics
Where does the colour of an object come from?	Guided discovery	• The concept of colour • Mono- and polychromatic light • UV-VIS spectroscopy
Mixing colours	Guided discovery	

Subunit 2: In the rainbow-hued land

Laboratory exercises for students	Type of inquiry	Topics
Are the colours of a rainbow always the same?	Guided discovery	• Structure of the atom • Excited state of electrons • Diffraction and scattering of light • Continuous and band spectrum of light • Types of radiation • Absorption and emission of light • Mechanism of colour vision • Structure of the eye • UV-VIS spectroscopy
What is the spectrum of white light after passing through coloured objects?	Guided discovery	
Visible light and what's next?	Guided discovery	
What is the difference between light from a fluorescent lamp and light from an incandescent bulb?	Guided discovery	

Subunit 3: How to measure colour?

Laboratory exercises for students	Type of inquiry	Topics
Construction of a colorimeter	Guided discovery	• Colorimetry • Lambert Beer's law • Methods of measurement of the concentration of coloured solutions • Properties of d-block elements • Structure and properties of complex compounds
Determination of the Lambert Beer's law	Guided inquiry	
Determination of $CuSO_4$ concentration in unknown samples.	Guided inquiry	
Estimation of the iron(III) ions amount in water.	Bounded inquiry	
The equilibrium between cobalt complexes	Guided inquiry	
Cyanotype.	Guided inquiry	

Subunit 4: In the world of energy

Laboratory exercises for students	Type of inquiry	Topics
Photos from starch. How do plants get their energy?	Guided inquiry	• Nutrition of plants – photosynthesis process • Anatomy and physiology of plants • Reserve substances of plants • The flow of energy in nature • Extraction of dyes • Performance of solar cells • Determination of device capacity
Photosynthesis performance	Bounded inquiry	
How can we use solar energy?	Bounded inquiry/ Open inquiry	

II. *IBSE Character*

Each of the activities presented in the unit are based on engaging questions. A teacher should guide a discussion in such a way that students will define the research problem by themselves. Activities 3.3, 4.2, 4.3b are open inquiry. Exemplary approaches for solving these problems as well as exemplary results are included. Due to the fact that students should design the procedure for the activity by themselves, the outcome may strongly depend on the method chosen.

III. *Science Content Knowledge*

Light is a form of energy whose properties can be explained either on the basis of wave or particle theory. The wave nature of light is indicated in the Planck relationship, $E = hv$, which relates the energy of the particle to one of the wave properties by one of the wave properties – frequency. In the following work, we will focus on light as an electromagnetic wave. Electromagnetic waves are characterized by two main parameters: the amplitude (A), and the frequency (v) that determines the colour of the light. Frequency and wavelength are related to each by a constant, the speed of light. Directly adjacent to the VIS spectrum is the IR (infrared) (lower energy) spectrum and UV (ultraviolet) (higher energy) spectrum.

The human eye perceives colour due to the presence of three types of cones. Each type of cone is sensitive to 1 colour (blue, red or green). Other colours are perceived due to the analysis of the differences in the intensity of those three colours. Colour blindness (daltonism) is a result of the impairment of one or more of the three types of cones.

The colour parameters of light-emitting elements can be encoded with the RGB colour scale (R – red, G – green, B – blue). The scale gives the intensity of the primary colours in the range of 0-255, for example: white (255,255,255), black (0, 0, 0).

Camcorders and digital cameras record electromagnetic waves through silicon detectors. These detectors are sensitive to light with wavelengths shorter than 1.1 μm energy of over 1.1 eV). LED diodes, commonly used in remote controls for operating various devices, emit light of wavelength of 0.9 μm (having an energy greater than 1.4 eV). Silicon detectors can thus be used for recording light not visible to the human eye. It is interesting, that bees have the ability to see the ultraviolet light.

Matter may:

- produce the light (emission),
- consume (absorption),
- change the direction of propagation (scattering).
- transmit the light

The mechanism of colour creation is a combination of above-mentioned processes.

A continuous spectrum of light is characteristic of objects that are luminous because of their high temperature, such as light bulbs and the sun. Coloured substances absorb certain wavelengths, and reflect the remaining. Absorption is connected for example with the excitation of electrons, which are moved from their ground states to the excited states. Below, in the Figure 1a the absorption spectrum of hydrogen is presented. In the spectrum of white light, colours that correspond to the energy absorbed by the excited electrons in hydrogen atoms are missing. In Figure 1b the emission spectrum of hydrogen is shown. This spectrum arises, when the excited electrons in hydrogen atoms go back to the state of a lower energy and emit the excess energy.

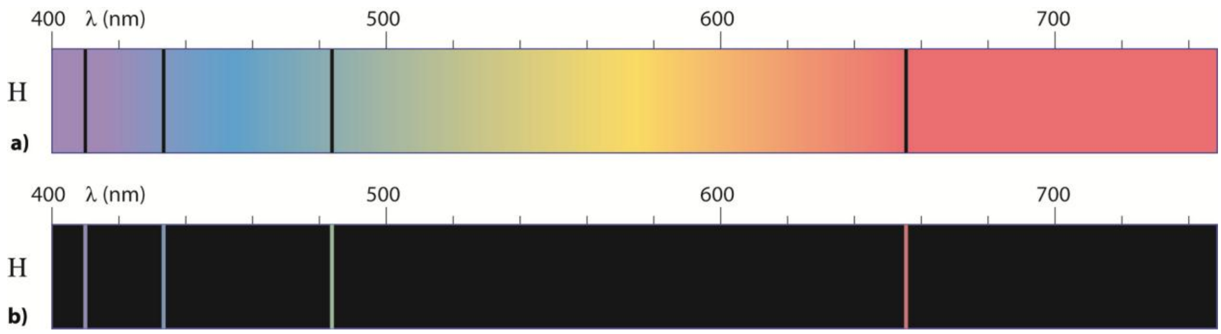


Figure 1. Hydrogen spectrum a) absorption spectrum, b) emission spectrum. *(Derived from: Physics for Scientists and Engineers (6th ed.) by Serway and Jewett,Thomson Brooks/Cole, 2004).*

Only some of the electron transitions in the hydrogen atom are associated with the visible light. Emission spectrum of hydrogen and the possible electronic transitions are presented in Figure 2.

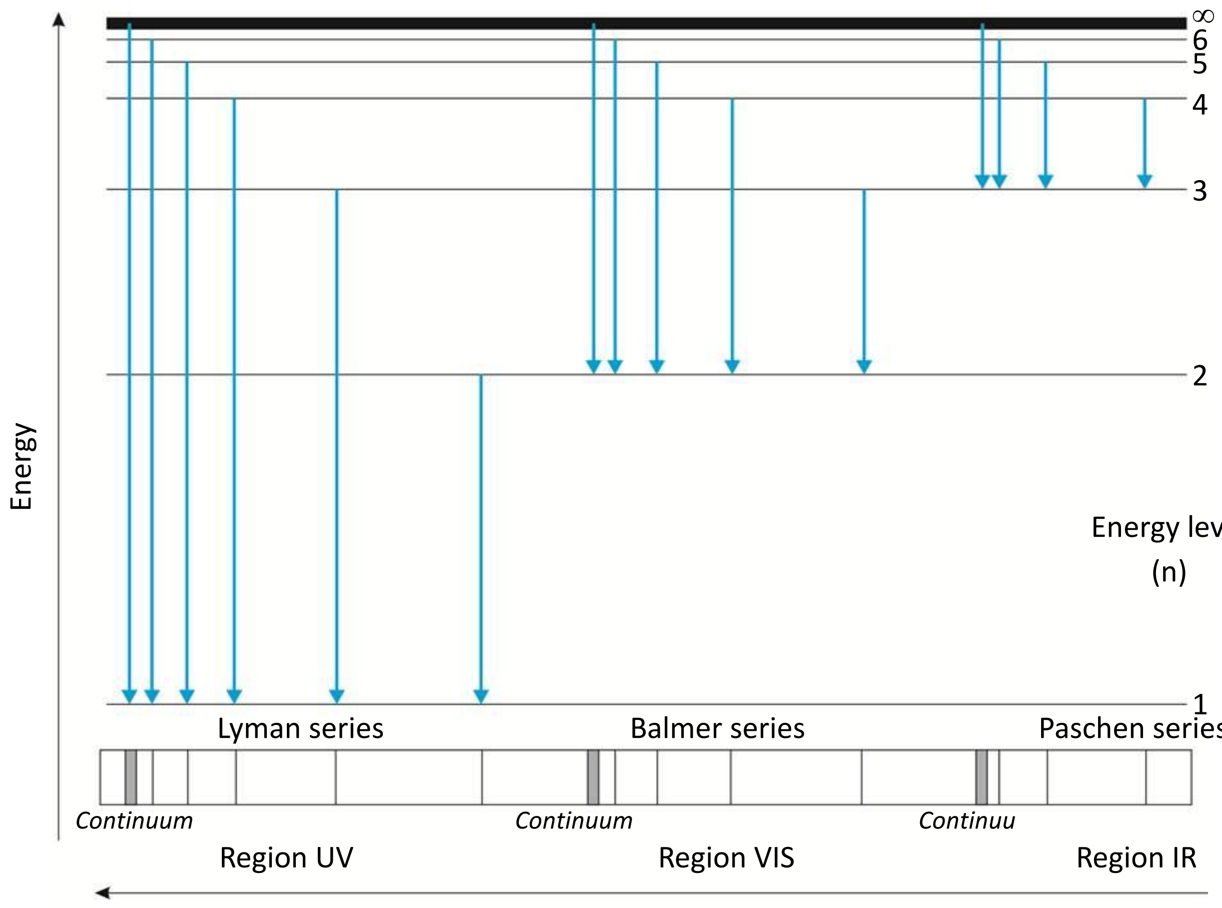


Figure 2. Possible electron transitions and series of the hydrogen emission spectrum. (Derived from: John Green, Sadru Damji, Chemistry (3rd ed.), IBID Press, 2007)

Hydrogen and other elements are able to emit electromagnetic waves not only in case of heating them to high temperature. After excitation, the light creates a band spectrum, characteristic for each element. Fluorescent lamps are examples of a “cold” light source.

The ability to absorb (and therefore emit) light from the visible spectrum is a characteristic of the coordination compounds of transition metals. The d-type atomic orbitals of the isolated atoms of a given element are of the same energy. In the surroundings of ligands, the energy levels are split into sublevels. For the compounds that have an octahedral structure (coordination number 6), the characteristic splitting is that, when three energetic sublevels are of the lower energy, and two – of the higher energy (Figure 3).
Differences in energy of the levels correspond to the energy of the visible light and depends on the geometry of the coordination compound, coordination number and the type of ligands. However, it should be remembered, that according to the quantum chemistry theories, the d-d transitions in octahedral complexes with a centre of symmetry are forbidden.

This is the main problem that occurs during the interpretation of the spectra of complex compounds. The Laporte selection rule states: the only transitions allowed are those, which are accompanied by the parity change. Nevertheless, as a result of asymmetric vibrations, the complex centrosymmetry is disturbed. Therefore, due to the lack of the centre of symmetry, d-d transitions are no longer forbidden and gain slight intensity. In such cases, when due to asymmetric vibrations in the molecule, the transition gains in intensity, it is called the vibronic transition.

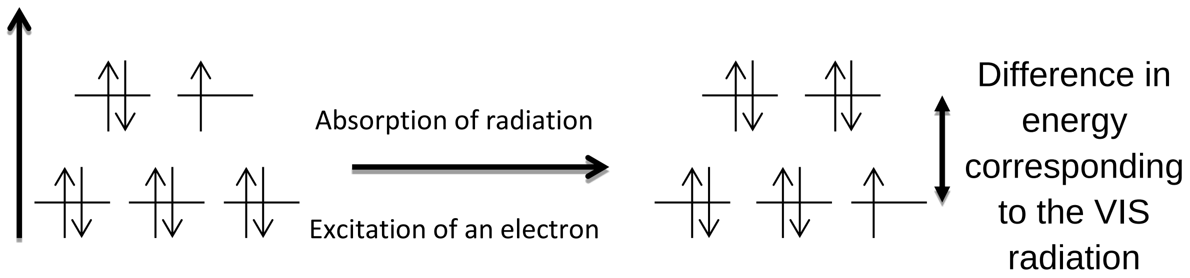


Figure 3. Diagram of d-type orbitals splitting and the electronic excitation for the octahedral coordination compounds.

Spectroscopy is a set of techniques involved in studying the interactions of electromagnetic radiation with matter; it is also a broad area of various techniques of chemical analysis. Depending on the energy of the analysed waves, different types of spectroscopy are distinguished e.g., infrared, visible, UV.

Another method based on the interaction of radiation with matter is colorimetry. It allows the determination of the solution concentration on the basis of its colour intensity. In the measurements, a device called a colorimeter is used, and it was invented by a Polish researcher Jan Szczepanik. The colorimeter measures the amount of light that passes through the sample. The dependence of light intensity on the concentration is described by the second absorption law, called the law of Lambert-Beer. It is expressed by the equation $A = log\frac{I_0}{I} = \varepsilon bc$; where: A represents absorbance, I_0 – the radiation intensity before passing through the sample, I – the intensity of radiation that passed through the sample, c – the concentration of the solution, b – the cuvette thickness, ε – the molar absorption coefficient. As follows from the above-presented equation, the absorbance (A) – which describes the ability of the absorption of radiation - is directly proportional to the concentration of substance in the solution and that proportionality is used in colorimetric measurements.

The absorbed energy of electromagnetic waves may be emitted, as in the case of simple chemical compounds. However, plants possess the ability of storing and processing solar energy – in the process called photosynthesis. Photosynthesis can be defined as an anabolic biochemical process, as a result of which, with the use of solar radiation and with the participation of assimilatory pigments and enzymes, monosaccharides (in the form of hexoses) are produced from the carbon dioxide. Before the solar energy will take part in this complicated biochemical process, it has to be "captured" – in order to do this, plants need chlorophyll. Thanks to this dye, plants are capable of absorbing light and using it in photosynthesis. Chlorophyll is green, because it absorbs blue and red light, whereas green light is passed through it without being absorbed. The energy of light is absorbed by chlorophyll for wavelengths corresponding to the red and blue colour of light and then it is used for the conversion of carbon dioxide into the glucose. If the amount of the glucose produced in this process in greater than a demand for it, the sugar is converted into starch by linking many glucose molecules together to form a long chain (polymer). At night, it is the starch that is transformed back to the grape sugar (glucose) to provide energy for plants until the sun rises again and the chlorophyll is able to absorb the appropriate amount of light to renew the starch reserve.

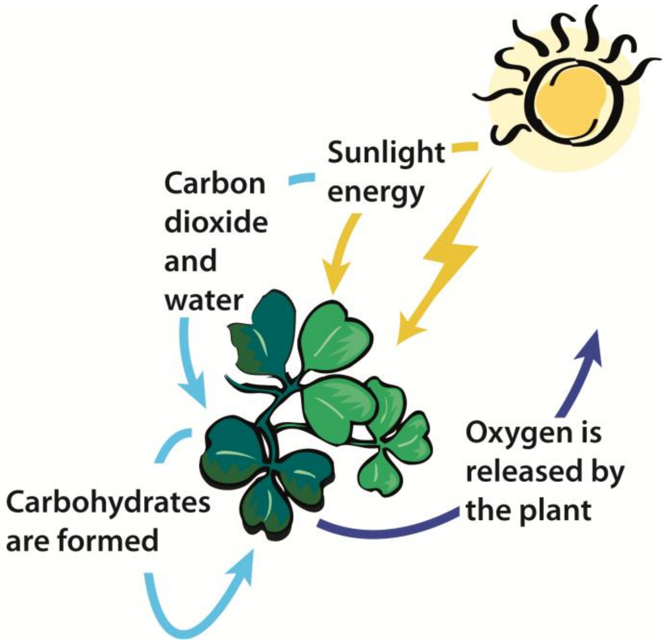


Figure 4. A graphic scheme of photosynthesis

The possibility of using solar energy and transforming it into electricity is extremely important for the future of humanity. Solar cells are semiconductor devices, in which the conversion of solar energy into electricity occurs as a result of the photovoltaic phenomena. Solar cells are used e.g. in artificial satellites, space probes, calculators and watches. However, their disadvantage is that they absorb mainly ultraviolet light, whereas the highest amount of solar energy that reaches the Earth is visible light. Hence, the idea of sensitization of semiconductor by organic dyes, which efficiently absorbs visible light, was developed. Such a cell was first built in the Swiss Federal Institute of Technology in Lausanne, Switzerland in 1991 and now attracts considerable attention of researchers - although it is not yet used commercially.

Further reading:

- Physics for Scientists and Engineers (6th ed.) by Serway and Jewett,Thomson Brooks/Cole, 2004
- Krzysztof Korona, Materiały do wykładu Fizyka w doświadczeniach, Uniwersytet Warszawski 2010
- John Green, Sadru Damji, Chemistry (3rd ed.), IBID Press, 2007
- Peter Atkins, Physical Chemistry, sixth edition Oxford University Press, Oxford Melbourne Tokyo 1998.
- Stefan Paszyc, Podstawy fotochemii, PWN, Warszawa 1981.
- Łukasz Boda, Materiały dydaktyczne: ‘Nanokrystaliczne ogniwo słoneczne’ Uniwersytet Jagielloński

IV. *Pedagogical Content Knowledge*

In this unit, the student:

- explores how colours are formed,
- becomes familiar with the RGB scale,
- learns how the human eye works,
- learns the concept of the primary and complementary colours and can explain their meaning,
- understands the phenomenon of splitting the light and is able to give an example in everyday life,
- discovers continuous and linear spectrum,
- discovers the existence of UV and IR radiation,
- learns to associate light with the wave of a certain energy,
- learns about methods of invisible light detection,
- becomes familiar with the structure and operation of a colorimeter,
- becomes familiar with elements of environmental analytics in the example of contamination of water with iron compounds,
- becomes familiar with elements of instrumental analysis and its application in measuring the concentration of substances in solution,
- learns about the chemistry of the photographic process and its chemical origin,
- becomes familiar with the properties of complexes - a discussion of their properties is given in the example of the cobalt compounds,
- becomes familiar with alternative energy sources in the example of the solar cell
- consolidates knowledge from the field of structure and nutrition of autotrophic organisms,
- learns about redox systems and their application in getting energy.

This unit can also be used to develop students' skills, such as:

- developing a research hypotheses,
- verification of hypotheses and making conclusions,
- evaluation of the investigation,
- independent design and construction of research equipment.

V. *Industrial Content Knowledge*

The topics discussed in this unit lie on the borderline of chemistry, physics and biology and have obvious links to industrial applications. For example, the RGB scale is used e.g. in the case of monitors, computer and television. The composition of colours is applied in painting (colour mixing). Interactive websites that show demonstrate the mixing the colours are worth visiting:

- http://meyerweb.com/eric/tools/colour-blend/,
- http://www.colourschemer.com/online.html,
- http://www.colourblender.com/

Optical phenomena are widely used in technology: the reflection of light – in pier glasses, mirrors, reflectors; the refraction of light – in lenses and devices containing lenses; the total internal reflection – in optical fibres; polarization in displays. Prisms are used in sights and rangefinders.

UV lamps are applied for instance in:

- polygraphy – drying and curing of paints and varnishes (digital printing, pad printing and offset printing, and also the furniture industry), exposures of templates for screen printing, production of packaging for foods (the UV flexo),
- curing of adhesives and nail tips,
- dealing with harmful microorganisms and disinfection of:
    - transporters and conveyor belts (the food, chemical and cosmetic industry)
    - air (laboratories, the so-called “cleanrooms” e.g. in the pharmaceuticals industry, offices, hospitals)
    - water – in the water supply systems, swimming pools and aquariums

The infrared lamp (Sollux) in used for the treatment of such disorders as ear, nose and throat diseases, it is also used for the treatment of bruises, as well as in the treatment of rheumatic diseases. It is widely applied in dermatology and cosmetology e.g. in the treatment of acne. Infrared lamps irradiation helps in the treatment of muscle diseases, rheumatism, arthritis and back pain. Moreover, such irradiation can strengthen the immune system and may suppress the development of the disease when the first symptoms of colds occur. Infrared rays have also relaxing and calming effects. Such lamps are being increasingly used for hair drying in hairdressing salons and beauty salons, as well as for heating churches and cafes in the autumn-winter season.

Knowledge about light and its effects on the skin is used in the production of sunscreen means (creams / foams / sunbathing oils).
Photosensitive materials are used in photography, production of films, and some fax machines.

Mid-infrared spectroscopy is used for: identification of substances of known structure, determination of molecular structure on the basis of group frequency table, determination of the compounds purity, control of the course of the reaction, quantitative analysis, the study of intermolecular interactions.
The near-infrared spectroscopy is used in the study of the moisture content in flour, starch, milk powder, instant coffee, crisps, and also in the analysis of the spectrum of light reflected or emitted by the planets.

Colorimetry is an analytical technique for determining of the concentration of colour solutions through visual comparison of the colour intensity of the test solution with the intensity of the colour of the reference solution. The method is regarded as simple, fast and accurate. Miniature handheld colorimetric kits with colour tables are used in medicine, food testing (beer, alcoholic drinks of a whisky type, and the caramel dye, oils and fats present in them):

- http://www.donserv.pl/index.php?option=com_content&view=article&id=137&Itemid=131,

Colorimetry is used to measure water parameters in the power industry and the production of industrial water, drinking water and in the wastewater treatment plants:

- http://www.metrohm.pl/Applikon/Alert_Colorimeter.html,
- http://www.mera-sp.com.pl/przyrzpom.php?go=kolorymetry,

Other uses include agricultural measurements and the environmental contamination studies:

- http://www.envag.com.pl/aparatura-terenowa-rzeki-jeziora-cieki-wodne/kolorymetry/564-kolorymetr-dr800-firmy-hach.

Colorimetry is widely used for quick estimation of solution pH by means of the calibrated indicator papers. It is one of the methods widely used in the water studies in the laboratories of the National Sanitary Inspection.

VI. *Assessment*

Assessment is very much dependent on how the activity is taught and the elaborated content. This will differ in each school, each class and each country. Assessment tasks have to be constructed together with the teacher in charge.

VII. *Student Learning Activities*

Activity 1.1: Where does colour of an object come from?
Learning aims:
• To understand the relationship between reflected/absorbed light and the colour of an object
Materials:
Jelly bears of different colours. Instead of the bears, cuvettes filled with the coloured solutions can be used, these could be solutions of food dyes (recommended for younger children) or for example: • green solution: $FeCl_2$ at the concentration of 1 mol/L • red solution: HCl at the concentration of 1 mol/L + methyl orange, • violet solution: $KMnO_4$, 1 mol/L (or blue solution: $CuSO_4$, 1 mol/L) Equipment: flashlights, laser pointers of various colours.
Suggestions for use:
Students: 1. Highlight jelly bears (cuvettes) with a flashlight. 2. Highlight a finger with a torch. 3. Highlight jelly bears (cuvette) with lasers. 4. Highlight a finger with a green and then a red laser pointer.
Possible questions:
• Why does the finger highlighted with the flashlight appear red? • What is the difference in the colour of the object when illuminated with a laser and a flashlight?

Activity 1.2: Mixing colours
Learning aims:
• Understanding that white light is made up of different colours • Understanding that filters only allow some colours through • Understanding that white light can be produced by mixing red, green and blue light
Materials:
Flashlights, filters: green, blue, red (they can be made of tinted film)
Suggestions for use:
Students put filters on the torches, and then watch the colour of light on a white sheet of paper. Then, they illuminate the same spot using two torches. They investigate: • What colour of light will be formed as a result of superposition of light from all 3 torches? • What colour of light will be formed as a result of putting 2 different filters on a torch?
Possible questions:
• How are colours on the TV set created? • What are the base colours? • How are complementary colours formed? • What is the mechanism of the human eye action? • What colours can the human eye perceive? • What is the RGB scale?

Activity 2.1: Are the rainbow colours always the same?

Learning aims:

- Understanding diffraction of light
- Understanding how a rainbow is created
- Learning how to construct a spectrometer

Materials:

- a cardboard or PCV tube of the length of about 50 cm,
- carton – for aperture preparation,
- plasticine – as a sealant,
- a lamp with bulb or a flashlight,
- splitting element e.g. diffraction grating, prism or CD/DVD (from the recorded disc, the layer of an aluminium foil should be removed, e.g. by sticking and unsticking the adhesive tape),
- recorder – digital photo camera (the mobile phone camera may be used).

Suggestions for use:

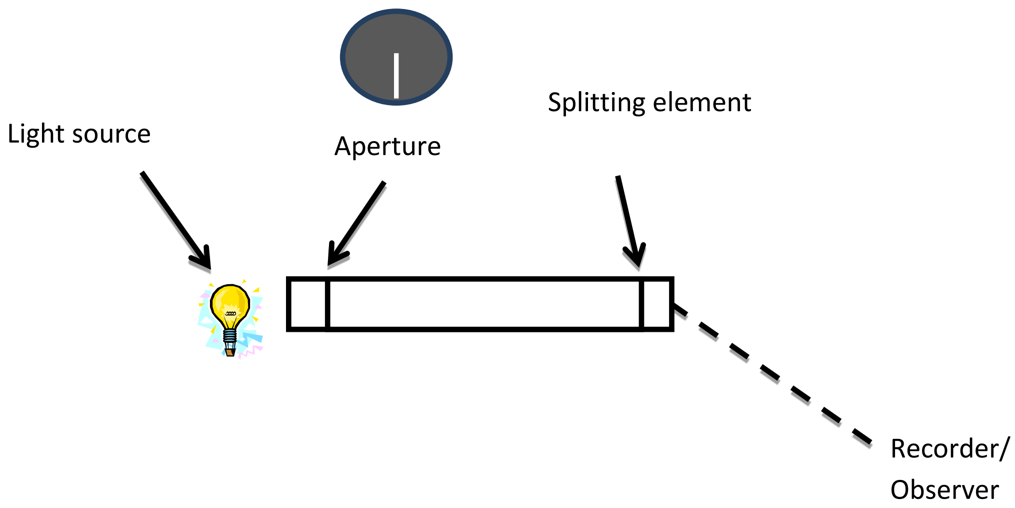


Figure 5: Diagram of a spectroscope

One side of the tube should be shut off by the aperture (a cardboard disk with a slit as narrow as possible). The disk can be embedded and sealed with the use of plasticine. On the other side of the tube (about 3-4 cm from the end), a transverse incision should be made and the splitting element placed there. The light source should be placed on the side with the slit. On the other side, at an angle of about 30 degrees, a light detector should be placed. In order to prevent light entering the detector from the side, it can be covered with a cloth.

The spectrum of the bulb and of the sun are recorded.
Possible questions:
• Are the observed light colours similar to the rainbow? • Are the colours of the rainbow arranged in the specific order? • Are the observed light colours similar to the colours of the sky? • Why is the light being split? • What parameter influences the level of colour separation?

Activity 2.2: What is the spectrum of white light after passing through the coloured objects?
Learning aims:
• Understanding that white light is composed of many different colours • Understanding that filters only allow some colours through
Materials:
• green solution: $FeCl_2$ 1 mol/L • red solution: HCl + methyl orange, • violet solution: $KMnO_4$ (or blue solution: $CuSO_4$ 1 mol/L) • Spectroscope from the activity 2.1, lamp with a bulb, cuvettes.
Suggestions for use:
Students fill the cuvette with the coloured solution. Cuvettes are placed in the spectroscope on the light path, in front of the shutter. Students collect the spectra.
Possible questions:
• What colour will objects in the room (illuminated by daylight!) appear to be if we cover the window with red foil? • How does the spectrum of the light bulb change after passing through the red filter? • What will the spectrum of the red light bulbs look like?

Activity 2.3: The visible light, and what's next?

Learning aims:

- Understanding how invisible light may be detected

Materials:

TV remote control (VCR or DVD player), cell phone with a camera (or digital camera, camcorder).
Box (e.g. shoe box), prism, light-sensitive blueprint paper, (a description of the paper preparation can be found in activity 3.5), Pencil.

Suggestions for use:

IR radiation
Students try to see the light from the remote control with the naked eye and then through a camera. They may take photos or make a video.
Students discuss:

- Why can we not see the light emitted by the TV remote control?
- Why does not every remote control works with each TV set?
- Are we able to switch the TV channel turning the remote control in the opposite direction from our TV set?

UV radiation
Students make an incision in a box and they place a prism at this point (see http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/ritter_experiment2.html for diagram and further details). The box is then placed in the sun. The sunlight should be split into different colours of light when it passes through the prism – on the bottom of the box, the white light spectrum should be seen. In the place where the spectrum is visible, students place the blueprint paper and copy the spectra contour plot (marking the red and blue colour) as soon as possible. The activity is left for the light exposure for about 20 minutes.
NOTE: The activity should be performed during a sunny day. In case of poor insolation, the effect may be difficult to observe or may occur after a long time.
Experiment developed by:
http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/ritter_experiment2.html

Students discuss:
Discussion:

- Why is the paper exposed in a larger area than the copied contour?

• From which side of the spectrum is the exposure outside the contour bigger?
Possible questions:
• When a TV channel is changed, certain information is sent from the remote control to the television set. How does the remote control communicate with the TV set? • How does the human eye work? • Does every person perceive colours in the same way? • Daltonism is a disorder of colours vision and recognition. With what may it be related? Compared to the camera, are we all daltonists? • How does a thermal imaging camera work? • Why do cats see well at night? • Why does the ozone hole carry an increased risk of sunburns and its consequences? • Should we cover our eyes with special eye protection if the light of lamps does not dazzle us through the closed eyelids? • What should the parameters of sunglasses be to effectively protect our eyes?

Activity 2.4: What is the difference between the light from the fluorescent lamp and the light of bulb?
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:
• spectroscope from Activity 2.1, • fluorescent lamp.
Suggestions for use:
Students record the white light spectrum with the use of a lamp with a typical bulb, and then they exchange it for the fluorescent lamp and compare both images.

Discussion:

- Why can only some lines be observed in the spectrum of fluorescent lamp?
- What do the location of particular bands of light mean?
- In Figure 6, the emission spectrum of hydrogen atoms is presented. Compare this spectrum with the recorded one. What is the reason for similarities and differences?

Figure 6. Emission spectrum of hydrogen atoms. Derived from Physics for Scientists and Engineers (6th ed.) by Serway and Jewett (Thomson Brooks/Cole, 2004).

- How can the hydrogen spectrum be related to the structure of its atom?
- With what process is the light emission by hydrogen connected?
- The spectrum you recorded is the emission spectrum. Consider what the absorption spectrum of hydrogen and of the fluorescent lamp would look like.
- The emission spectrum of hydrogen presented in Figure 6 is the atomic spectrum. If we fill the fluorescent lamp with hydrogen, it would be in the molecular form (H_2). Will the emission spectrum of the hydrogen fluorescent lamp be the same as the presented atomic one?

Possible questions:

- What gases are in the fluorescent lamp?
- Why are there no fluorescent lamps filled with the atomic hydrogen?
- What is the working mechanism of the light bulb and the fluorescent lamp?
- Why does the fluorescent lamp not heat up during working?

Activity 3.1: Construction of a colorimeter

Materials:

- Contact plate (electronic breadboard)
- RGB LED 5 mm
- Photodiode 5 mm
- Resistor 220 Ω - 3 pieces
- Resistor 1MΩ

• 3-channel (or more) programmer
• Voltage regulator - 7805 IC
• 9 V battery
• 9 V battery connector with cables
• Cables
• Superglue (quick-drying glue)
• Plasticine
• Cable cutters
• Tweezers
• Cuvette
• Multimeter
• Cuvette holder – see description below
  ○ Aluminium tubes
  ○ Self-adhesive felt or rubber veneer.

Suggestions for use:
The aim of the activity is to build a measuring tool – a colorimeter. The constructed device will be used in activities 3.2 and 3.3. See the **Classroom materials** for further instructions. Alternatively, a commercial colorimeter can be used (for example: http://www.vernier.com/products/sensors/col-bta/

Activity 3.2: Determination of the Lambert Beer's law

Learning aims:

- Understanding the relationship between absorption of light by coloured solutions and the concentration of that solution

Materials:

- $CuSO_4$ – solution 0.5 mol/L
- colorimeter
- cuvettes x 5
- pipettes 10 ml x 2
- beakers 25 ml x 7

Suggestions for use:

1. Prepare a series of aqueous $CuSO_4$ solutions in range 0.1 - 0.4 mol/L by diluting the standard solution. A dilution scheme is presented below:

Solution [mol/dm^3]	Preparation
1. 0.5	standard
2. 0.4	8 cm^3 of solution 1 + 2 cm^3 of water
3. 0.3	6 cm^3 of solution 1 + 4 cm^3 of water
4. 0.2	4 cm^3 of solution 1 + 6 cm^3 of water
5. 0.1	2 cm^3 of solution 1 + 8 cm^3 of water
6. 0	water

2. Perform colorimetric measurements for all the samples for different colours.
3. Plot the voltage dependence on concentration and develop a calibration standard by fitting the data to a linear line.
4. Prepare two samples as below:
   - sample 1 – concentration from range 0.1 - 0.5 mol/dm3
   - sample 2 – concentration > 0.5 mol/dm3
5. Students perform measurements using samples of unknown concentration and determine the concentration based on the previously obtained calibration using the graphical method.

Possible questions:
• What happens to the light when it passes through the solution of the coloured substance? • How do tinted windows in cars work? • What does the floor under the stained-glass window look like? • Does the light intensity change after passing through a substance? • Does the colour of the light influence the change in its intensity when passing through the sample? • How would you choose the colour of light to maximise the change in light intensity for a particular solution colour? • What colour of light should be chosen for the measurements? • What is the nature of the dependence on concentration? • How could you get similar result, without changing the concentration of the solution? • You already know the voltage dependence on the sample concentration. Could you use this data to determine the $CuSO_4$ concentration in an unknown sample? • Why do we perform measurements on pure water? • Does the test sample concentration have to be in the range 0.1 - 0.5 mol/L?

Activity 3.3: Estimation of the iron(III) ions concentration in water
Learning aims:
• Understanding what types of impurities may be in tap water • Understanding what types of testing (any the reasons for these tests) is done in water treatment facilities
Materials:
Computer Chemicals: • 0.1% HCl solution • 20% KSCN solution (CAS: 333-20-0) • Fe^{3+} standard solution of 1 mg/mL concentration
Suggestions for use:
Students should research the following questions: • What substances are present in tap water? • Which of those substances are desirable and why? • What are the differences in composition of mineral water and tap water? • Can mineral water be used in the water supply? • Which substances in water may have a negative impact on the human body? • Who/what institution controls the composition of the tap water? • Is rainwater safe for drinking? Possible sources for information: http://www.filtsep.com/view/18744/ground-water-dealing-with-iron-contamination/ http://www.epa.gov/nrmrl/wswrd/cr/corr_res_iron.html http://www.ianrpubs.unl.edu/epublic/live/g1714/build/g1714.pdf The amount of iron(III) in water may be estimated with the use of the thiocyanate method. Fe^{3+} ions form a complex ion of an intense red colour with thiocyanate ions. $Fe^{3+} + SCN^{-} = Fe(SCN)^{2+}$ Ions of iron(III) can form with thiocyanate several different coordination compounds of similar colour: $Fe(SCN)^{2+}$, $Fe(SCN)_2^{+}$ to $Fe(SCN)_6^{3-}$. In the solutions where the Fe^{3+} cation concentrations are on microgram level, the $Fe(SCN)_2^{+}$ dominates. In addition, this coordination ion may undergo

hydrolysis in solutions with a pH>3. The thiocyanate complex is unstable, and degrades with time. Imagine that in the laboratory where you work, a water sample with unknown amount of Fe^{3+} ions was delivered. Plan an activity in which you determine the molar concentration of Fe^{3+} by the colorimetric method. Answer the question whether the water is safe for drinking. Compare the result obtained for the sample with the results for the tap water. You have: • 0.1% HCl solution • 20% KSCN solution (CAS: 333-20-0) • Fe^{3+} standard solution of 1 mg/mL concentration *Information for the teacher: a maximum acceptable iron concentration in water is 0.2 mg/L (0.3 mg/L in some countries), recommended iron concentration in the sample: 0.05 – 0.5 mg/L.*
Possible questions:
• Is the water safe for drinking as regards the iron(III) ions concentration? • What is the effect of excessive amounts of iron in water on the human body? • What ways of water treatment/purification do you know? • How can the activity be modified to account for the concentration of the iron(II) ions?

Activity 3.4: The equilibrium between cobalt complexes.

Learning aims:

- becomes familiar with the properties of complexes

Materials:

5 test-tubes, technical scales (giving results in two decimal places), a spatula, measuring cylinder.

Suggestions for use:

Students weigh out 0.1 g $CoCl_2 \cdot 6H_2O$ for each of the test-tubes and for each of them they add 10 drops of concentrated hydrochloric acid. Then, they dilute the obtained solutions with a solvent of a composition presented in the Table 1.

Table 1. The composition of a solvent

Number of the test-tube	Solvent [% vol.]
1	100 % of deionised water
2	50% of water - 50% of ethanol
3	20% of water - 80% of ethanol
4	5% of water - 95% of ethanol
5	100% ethanol

Discussion:

- What are the differences in the solution colours in the test-tubes?
- Is there any regularity in the change of colour?
- What ions are present in the test-tube 1 and 5?
- What is the structure of the formed coordination compounds?
- In Figure 7 the spectra of solutions number 1 and 5 are presented:

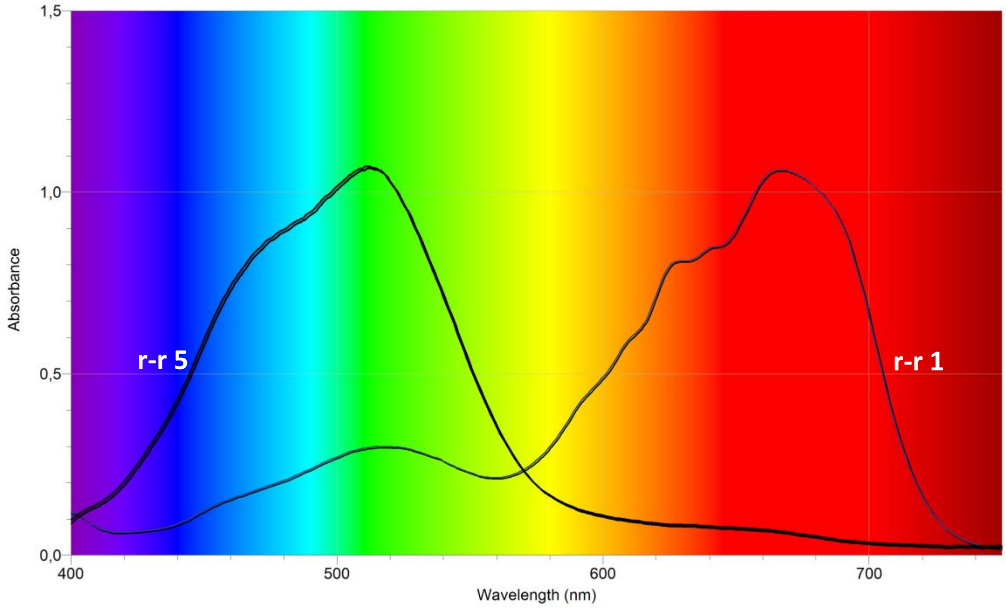


Figure 7. UV-Vis spectrum for the samples 1 and 5.

- What determines the position of the peak in the spectrum?
- What determines the height of the peak in the spectrum?
- What will the spectra for the test-tubes number 2-4 look like?
- Are Sc and Zn transition metals?
- Why is +II is the typical degree of oxidation for many d-block elements?

Possible questions:

- Why are the solutions of iron(III), iron(II), copper(II), cobalt(II) coloured, and the solutions of e.g. sodium and potassium ions not?
- What determines the colour of the coordination compounds?

Activity 3.5: Cyanotype

Learning aims:

- Develop an image using photochemistry
- Understanding how photographs are developed using an analogue camera

Materials:

Reagents:

- $K_3[Fe(C_2O_4)_3]$ CAS:[5936-11-8] (version 1), or
- ammonium iron(III) citrate (preferred – green), CAS: [1185-57-5] (version 2)
- $K_3[Fe(CN)_6]$, CAS: 13746-66-2
- glycerine,
- citric acid.

Note! $K_3[Fe(CN)_6]$ is non-toxic compound, but in contact with strong acids it forms toxic, highly poisonous gases. Citric acid is an irritant compound. Use a laboratory coat, gloves and protective glasses during this activity.

Suggestions for use:

Note: The activity can be carried out in one of two ways, depending on the reagents availability.

a) Making the photosensitive paper and blueprint photo version 1:

1. Dissolve 1g of $K_3[Fe(C_2O_4)_3]$ in 25 cm^3 of water.
2. Take 10 cm^3 of this solution and pour into the Petri dish and immerse a little blotting-paper disc in it.
3. Remove the disc with tweezers and leave it for a while in an upright position to drain of the solution.
4. Place paper between paper towel sheets and dry (protect paper from the light).
5. Dry paper is ready for exposure. The 'blueprint' photo can be made e.g. by displaying on the paper the image from the multimedia projector. The illumination time is 20 - 30 minutes, depended on the power of lamp and the type of an image.
6. After illumination, put the disc in the Petri dish with 25 cm^3 of 0.03 M $K_3[Fe(CN)_6]$.
7. Immerse the blotting paper in the Petri dish with distilled water and dry it again.

b) Making the photosensitive paper and blueprint photo version 2:

1. Weigh out a 90 g of the ammonium iron(III) citrate, transfer it to the flask of 250 cm^3 and filling the flask with distilled water up to the mark.
2. In the second flask of 250 cm^3 put 10 g of potassium ferricyanide and fill with the distilled water up to the mark.
3. Combine the solutions together in a flask or beaker of 1000 cm^3 and add about 1 cm^3 of glycerol. Protect the solution from the strong illumination.
4. Immerse the blotting paper in the prepared solution.
5. Place paper between paper towel sheets and dry (protect paper from the light).
6. Dry paper is ready for exposure. The 'blueprint' photo can be made e.g. by displaying on the paper the image from the multimedia projector. The illumination time is 20 - 30 minutes, depended on the power of lamp and the type of an image.
7. After illumination, immerse the blotting paper in 1% solution of citric acid and dry it again.

Discussion:

- Which areas of the image are brighter and which are darker?
- The blue colour observed on the image is connected with the formation of prussian blue with the formula $KFe[Fe(CN)_6]$. What is the degree of oxidation of Fe in this compound?
- What processes need to occur on the blotting paper under light illumination to form this compound?
- Design an activity in which a photo in the form of a positive image could be made.

Possible questions:

- How does an analogue camera work?
- How are analogue photos created?
- What does it mean to develop and fix photos?
- What coloured coordination compounds of iron II and III do you know?

Activity 4.1: Photos from starch. How do plants get their energy?
Learning aims:
• Understanding that plants need light to make starch
Materials:
• plant – Geranium (stored in a darkness for 48-72 hours before the activity), • solution of baking soda or $NaHCO_3$ (10g/200 ml), CAS: 144-55-8 • ethanol 95%, (CAS number: 64-17-5) , • I_2 solution in KI (1 g I_2/25 KI/500 ml of water – prepare the day before, store in a dark bottle) CAS: 7553-56-2 the solution is not classified as dangerous, but it can cause stains that can be difficult to remove. • paper towels, • tweezers/forceps, • 3 crystallisers.
Suggestions for use:
1. Place 2 layers of paper towels on top of the acrylic glass plate. 2. Drip the towel with the baking soda solution. 3. Place 1 Geranium leaf on the paper towel with the green side (top side) up. The leaf should be “starved”. To get this, store the plant in darkness for at least 48 hours before carrying out the activity. The leaf should be removed from the plant just before the activity. 4. Place the small object made of the material impermeable to light (e.g. a coin) on top of the leaf. 5. Place the clear plexiglass sheet on top. This way, a sandwich with the Geranium leaf inside would be formed. 6. Hold the sandwich together with rubber or paper clips.. 7. Place the sandwich in direct sunlight, or in the light of the projector. 8. Let the leaf to be exposed for 45 minutes. 9. After 30 minutes of exposure, heat about 100 ml of ethanol in the water bath or heating mantle. 10. After exposure, take the sandwich apart. Using the forceps (tweezers) pick up the leaf by the stem (petiole) and place it in the beaker of hot ethanol. 11. After about 5 minutes, the leaf should be nearly white. 12. Fill two crystallising dishes halfway with water. Place the leaf in the first crystallising dish and swirl it underwater to remove the ethanol. 13. Put the I_2/KI solution to the second crystallising dish.

14. Immerse the leaf in the I_2/KI solution. Watch the changes.
15. Transfer the leaf into the second crystallising dish with water to wash off excess iodine.
16. Dry the leaf on the paper towel.
17. Look at the leaf and record your observations.

Experiment developed by:

http://sites.bio.indiana.edu/~nsflegume/download/Photosynthesis%20Activity.doc

Possible questions:

- Explain the observed change in colour.
- Where does the light pass through the leaf and where it was blocked?
- Where is the coloured stain greatest?
- Which areas contain the highest concentration of starch?
- Why is starch accumulation not uniform?
- How do plants synthesise starch?
- When do plants consume starch?
- What is the role of starch in the human diet?
- How much starch do we consume every day?

Activity 4.2: Photosynthesis performance
Learning aims:
• Understanding the influence of the colour of light on photosynthesis
Materials:
• 5 boxes (may be shoe boxes), • 25 test-tubes,, • 3 pieces of LED strip (1. Illuminating red colour, 2. Illuminating blue colour, 3. Illuminating green colour,). LED strips can be bought in most building materials supermarkets. They are sold by the meter. For this activity, about 0.5 m of the strip of each colour should be used. (http://www.amazon.co.uk/WHITE-FLEXIBLE-STRIP-LIGHT-ADAPTER/dp/B003M7YQXK/ref=sr_1_3?ie=UTF8&qid=1323769498&sr=8-3) • Canadian waterweed (Elodea canadensis Michx.) – 25 pieces of about 5 cm.
Suggestions for use:
The purpose of the activity is to examine the influence of the colour of light on photosynthesis. Students design the activity by themselves. For technical reasons, it is advisable to use water plants. Houseplants may be used if oxygen or carbon dioxide sensors and data logging devices are available. Install the LED strip of different colours (red, green, blue, white) in the four cardboard boxes. For powering the strip, one power supply of 12 V should be enough. Prepare five sets of test-tubes with the Canadian waterweed. The length of the plant should be similar (preferably the same) in all test-tubes. Pour the same amount of water into the test-tubes and mark its level with a pen. Plug the test-tubes with stoppers or cover with parafilm. Put the set of test-tubes in the prepared boxes. Put the final set into the box with no lighting. Leave the boxes for few days. The photosynthesis performance may be indicated by the number of oxygen bubbles on the walls of the test-tubes. Alternatively, a lamp with a bulb or daylight may be used with filters placed in front of the bulb/entrance of box illuminated by daylight.
Possible questions:
• What is the mechanism for plant nutrition? • What is necessary for plants to live? • Why are leaves of most plants green?

- Why do most plants turn yellow when there is no access of light?
- Why are some algae that live deep under water brown rather than green?
- In what way can we prove the occurrence of the photosynthesis process? Consider the problem theoretically for water plants – what is a reactant and what is a product of this process, how could the pH of the environment and the water level be changed?
- Which water is the best for this activity: distilled water, still mineral water or sparkling mineral water?
- What types of measurements can be used to determine the photosynthesis performance besides counting the gas bubbles formed?
- In what light does the photosynthesis occur and why? In what light is it the most effective?
- Which colour of light is best to encourage growth of green plants?
- Some algae have red leaves. Consider whether the results of this activity would be the same if these plants were used? Give reasons for your answer.
- What is the difference between the activity with the use of the LED lighting and the activity with the use of filters of different colours? Should the results be the same? Justify your answer.

Activity 4.3a: How can we use the solar energy?

Learning aims:

- Understanding principals of operation of a solar cell

Materials:

- TiO_2
- HNO_3 10^{-4} mol/L
- methanol
- I_2 solution in KI in ethylene glycol (description of the preparation below)
- plates for the conductive glass (http://www.sigmaaldrich.com)
- fruit (blueberries, cherries, strawberries, etc.),
- candle,
- multimeter (voltmeter),
- halogen lamp,
- burner with a tripod,

- adhesive tape,
- a piece of cardboard.
- Solar cell
- Decade resistors: R=10 kΩ, R=1000 Ω , R=100 Ω, (multimeters with variable resistance may be used),
- multimeter (ammeter),
- cables for connection.

Suggestions for use:

Students discuss the following questions:

- What renewable energy sources do you know?
- How do solar panels work?
- Where are the solar cells used?
- What will happen when the calculator powered by the solar cell will be closed in the dark place?
- Why do blueberries ripen despite growing in the dark forest?

Description of the Activity :

a) Preparation of the I_2 solution in KI: 0,127 g of I_2 dissolve in 10 cm^3 of ethylene glycol, mix, add 0,83 g of KI mixing again. Note! The reagent absorbs moisture. It should be kept in a closed dark bottle, protected by the parafilm.

b) The cell preparation:

The first step is to prepare an emulsion of TiO_2:

1. In a small beaker mix 1 cm^3 of nitric(V) acid solution of a concentration of about 10^{-4} mol/L, pH 3-4 with 3.25 cm^3 of ethanol.
2. Add 0.75 g of titanium(IV) oxide to the prepared solution, stirring all the time.
3. Continue stirring until the suspension appears uniform.
4. Having TiO_2 suspension ready, a layer of titanium(IV) oxide may be put on the electrode cell.
5. Wash the two conductive glass plates (pre-coated with the layer of SnO_2) with methanol and dry.
6. Put the plates next to each other on the cardboard underlay and attach them to it with the use of an adhesive tape (in such way, that only edges of the plate are in contact with the tape). The top plate should be turned to the top from the conductive side, and the bottom one – from the non-conductive. The bottom plate will not be covered; it just helps to cover the top plate.

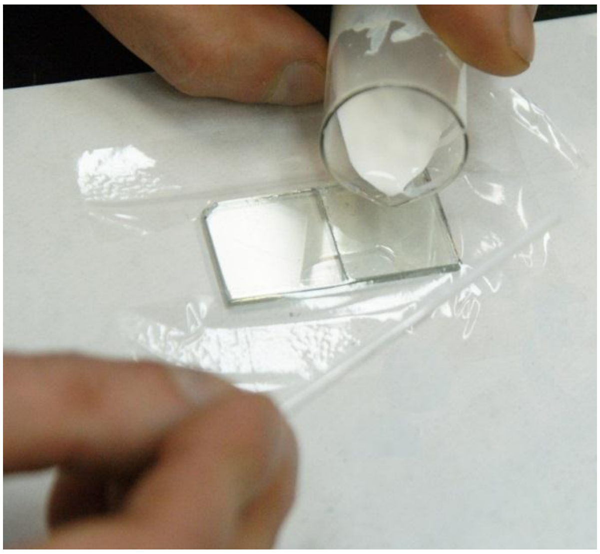


Figure 8. Preparation of the plates for the emulsion distribution.

7. Using a dropper, put several drops of TiO_2 emulsion in the straight line along the top edge of the plate.
8. Using a glass rod, spread the suspension of TiO_2 over the top plate. In order to do this, it is recommended to make a few quick moves of the rod up and down.
9. Remove carefully the tape attaching the plates to the cardboard and wash the bottom plate (the one that was not covered) and cover its surface with soot by heating it over the candle.

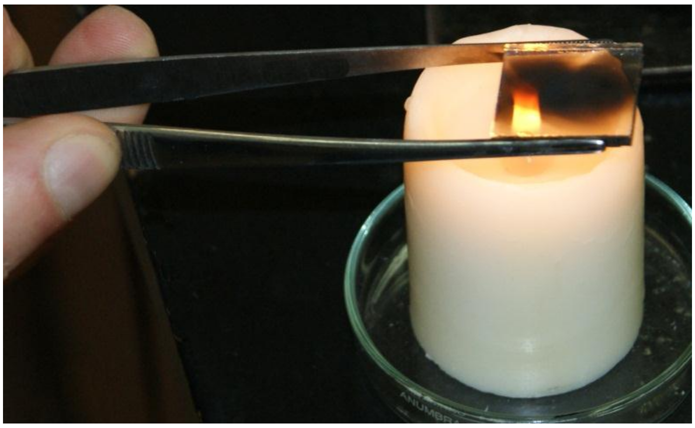


Figure 9. Covering the plate with the soot layer.

10. A few minutes after the covering with TiO_2, put the plate on a wire gauze with ceramic centre and heat it over the burner flame for about 20 minutes. After that time, wait until the plate cools to room temperature.
11. In a mortar, smash a few strawberries, (or blackberries, cherries, chokeberry) and add about 2 cm^3 of water.
12. Put the plate covered with TiO_2 in the so-obtained solution (with the TiO_2 layer to the bottom) and leave for about 20 minutes.

13. Rinse the plate with water, and then with methanol and leave for drying. The plate should be strongly coloured as a result of the dye adsorption at the surface of the titanium oxide. Such prepared plate is one of the electrodes.

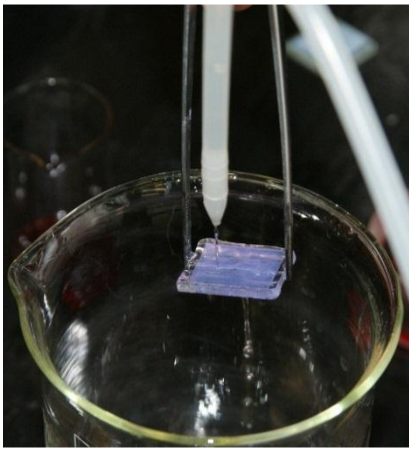


Figure 10. Rinsing the plate with methanol.

14. Put the electrode with the adsorbed dye on the flat surface and place from the top, the counter electrode covered with graphite or soot in such way, to enable the contact of plates by the graphite and titanium oxide covered side, with a 4 mm shift between them. The part of the electrode that is has not the titanium(IV) oxide layer, should remain uncovered.

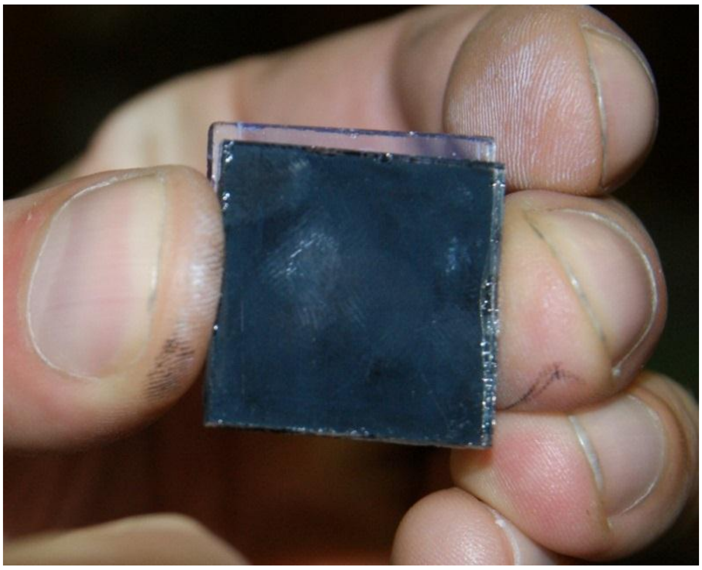


Figure 11. Combination of the plates prepared.

15. The plates may be combined with the use of paper clips.
16. Drop an electrolyte between the plates – solution of iodine and potassium iodide in ethylene glycol.

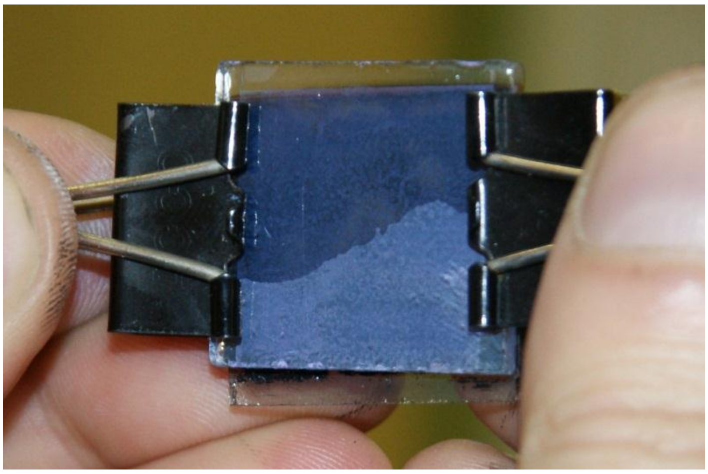


Figure 12. The plates combines with the paper clips after dropping an electrolyte.

17. The system prepared in such way, is ready to work.

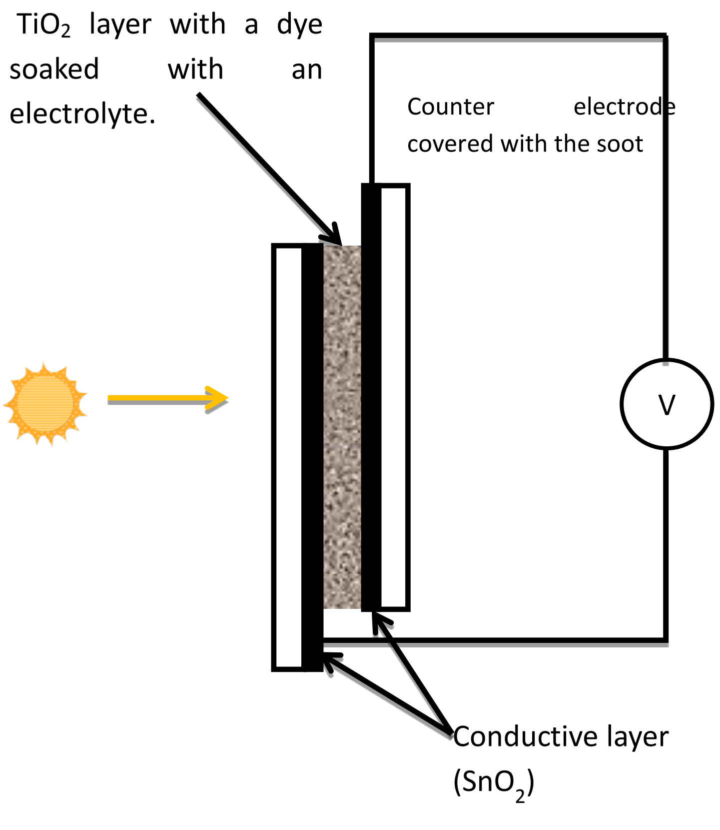


Figure 13. A diagram of the solar cell.

18. Connect the multimeter

19. Illuminate the cell with the halogen lamp and the other types of light

(sunlight, torch, laser pointers). Note: You must be careful not to increase the temperature of the cell with the heat emitted by the light sources.

Experiment developed by:
Łukasz Boda, Materiały dydaktyczne: 'Nanokrystaliczne ogniwo słoneczne' Uniwersytet Jagielloński

Discussion:

- How does the voltage generated by the cell depend on the type of the light source? Explain, the effect observed.
- How does the voltage generated by the cell depend on the intensity of light?

Activity 4.3b: How can we use the solar energy?
Determination of the maximum power of the constructed device.
The power **P,** of the cell is equal the product of voltage U and current I from the external circuit:

$$P = U \cdot I$$

Knowledge of this characteristic enables determination of the maximum power that can be taken from the cell. On the other hand, the ratio of this power to the intensity of light falling on the cell gives the efficiency of solar energy conversion into electricity.
Engaging questions:

- How can the current intensity be influenced?
- What parameters should be fixed in subsequent measurements?

Students can design the system for measuring the dependence of the voltage on the current intensity by themselves. The exemplary system is presented in Figure 14. Resistance may be changed in the range of 100 Ω -10000 Ω

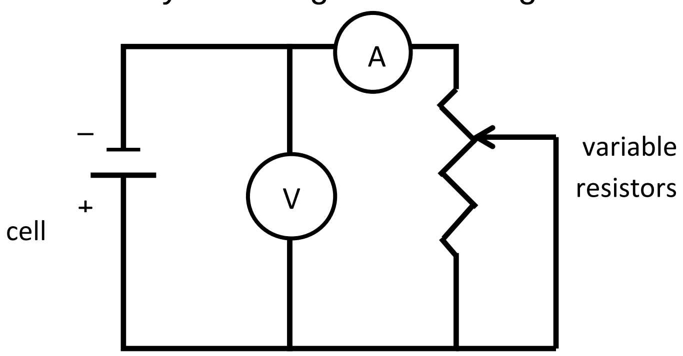


Figure 14 A diagram of a circuit for the measurement of the voltage-current characteristic.

Table 4.1. Exemplary results:

U [mV]	*I* [mA]	*R* [W]	*P* [mW]
355	0.038	11100	13.490
331	0.040	9100	13.240
303	0.048	7100	14.544
269	0.056	5100	15.064
214	0.075	3100	16.050
116	0.110	1100	12.760
101	0.115	900	11.615
84	0.123	700	10.332
64	0.130	500	8.320
30	0.145	300	4.350
4	0.155	10	0.620

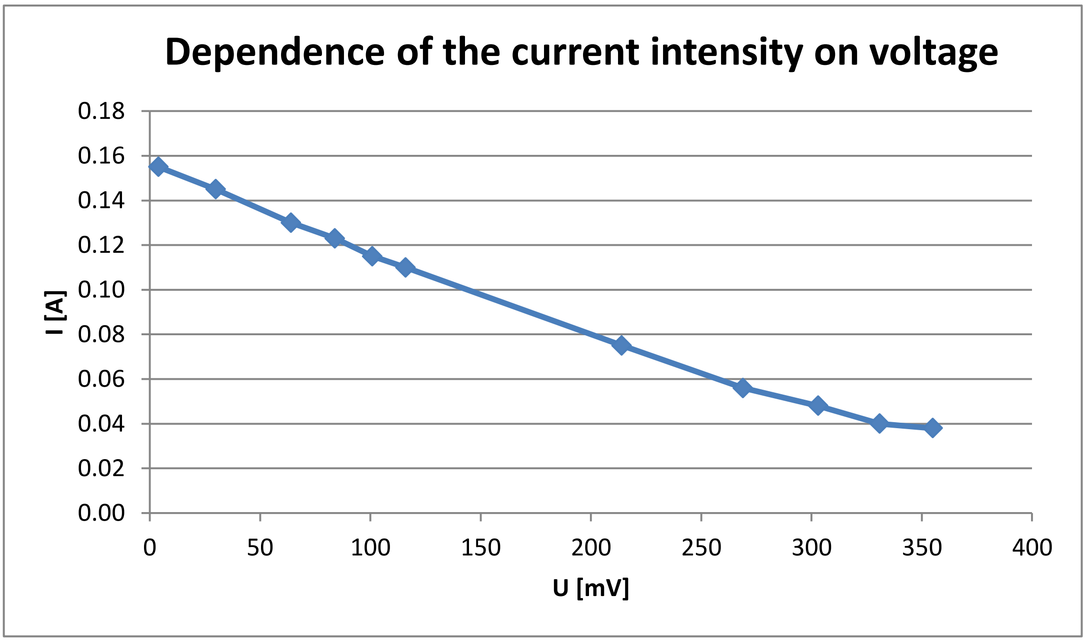


Figure 15. An example of the dependence of the current intensity on voltage for the working blueberry cell.

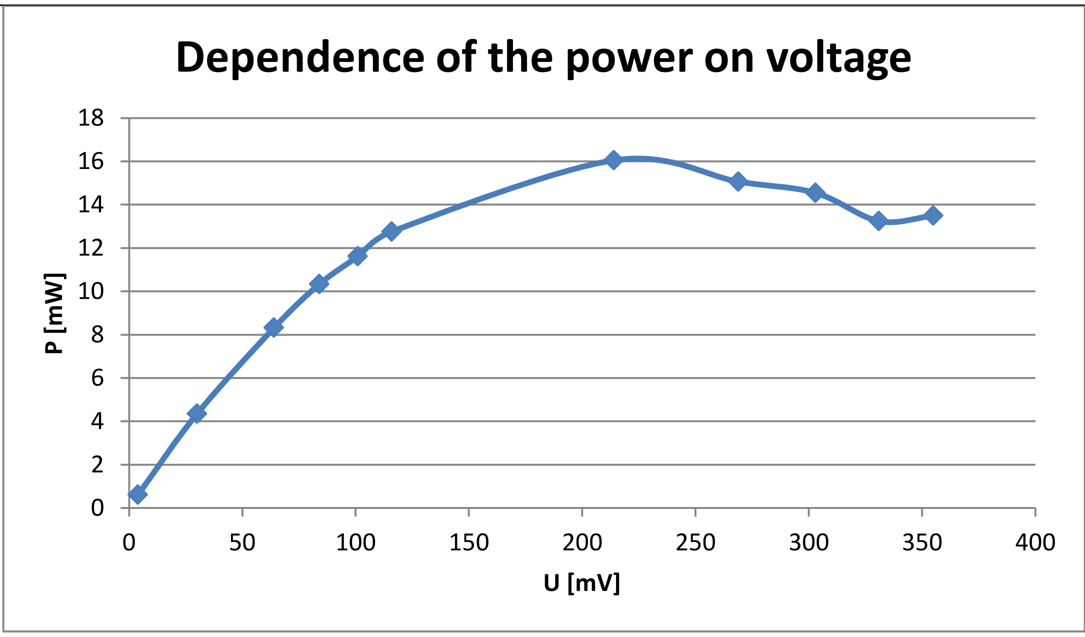


Figure 16. An exemplary dependence of the power on voltage for the working blueberry cell.

Possible questions:

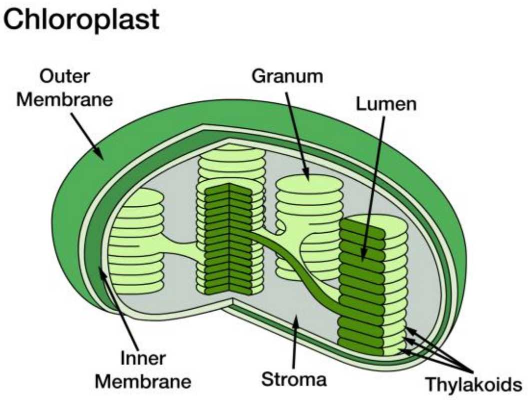
- Will the use of different fruit change the power of the device? (the possibility of an Activity al verification)
- How do the changes in resistance affect the cell power?
- Where can this type of the cell be applied?

PHOTOSYNTHESIS

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

Katrin Vaino, Miia Rannikmäe and Jack Holbrook..

University of Tartu (UTARTU), Estonia



UNIT CONTENTS

I. Unit Description

Greenhouses on Mars?!

In this unit, students learn about photosynthesis by introducing students to a problem involving how to design a Martian greenhouse capable of growing plants to produce food and oxygen. Students investigate questions relating to how basic conditions for long term living can be created in an artificial environment. The results of these investigations is expected to lead to the idea that plants and other organisms are able to carry out photosynthesis thereby providing the station with oxygen and at the same time absorbing carbon dioxide. During the unit they are also expected to answer to the question “How do we know what we know about photosynthesis?” through researching the development of related scientific discoveries. Through student inquiry, the factors that influence photosynthesis are explored providing students with ideas needed for designing their own space greenhouse.

- **Student level:** Students aged 16-19
- **Discipline(s) involved:** Biology, physics, chemistry
- **Estimated duration:** 7- 10 lessons

II. IBSE Character

In this unit students are given an opportunity to develop a number of scientific process skills including aspects related to higher order learning:

- planning an investigation, discussing procedures, searching for information, developing argumentation skills and/or making justified decisions in addition to conceptual science acquisition;
- using empirical evidence to assist learning and decision-making;
- using creative and critical thinking skills.

The unit of photosynthesis also has learning objectives/outcomes which include nature of science aspects such as the conceptions that scientific ideas are subject to change, science demands evidence and science is a complex social activity.

III. Science Content Knowledge

Photosynthesis is a process whereby light energy is converted to chemical energy and that chemical energy is stored in the bonds of carbohydrates. While this process mainly takes place in plants, it also occurs in some bacteria and algae. Because photosynthetic organisms can produce their own food, they are called *autotrophs.* In the process of photosynthesis in plants, algae and cyanobacteria, carbon dioxide and water are used to produce carbohydrates and release oxygen as a by-product of the process. Photosynthesis is necessary for the existence of all aerobic life on Earth. Namely, photosynthesis helps maintain normal levels of oxygen in the atmosphere and is the source of energy for nearly all life on earth. The role of photosynthesis in energy production is both direct, through primary production, and indirect, as the ultimate source of the energy in food.

Photosynthesis is performed in the **chloroplasts**, specifically using **chlorophylls**, the green pigments involved in photosynthesis.

Photosynthesis takes place in green parts of plants. A typical leaf is made up of the **upper and lower epidermis**, the **mesophyll**, the **vascular bundle(s)** (veins), and the **stomata** (See Figure 1). Because the upper and lower epidermal cells do not contain chloroplasts, photosynthesis does not occur there. Instead, the primary function of these cells is the protection of the rest of the leaf. The stomata are pores that can primarily be found in the lower epidermis. Their function is to facilitate gas exchange, letting in CO_2 and out O_2. The vascular bundles or veins in a leaf form part of the plant's transportation system. They move water and nutrients to different parts of the plant as needed. The mesophyll cells of a plant have chloroplasts and therefore, this is where photosynthesis takes place.

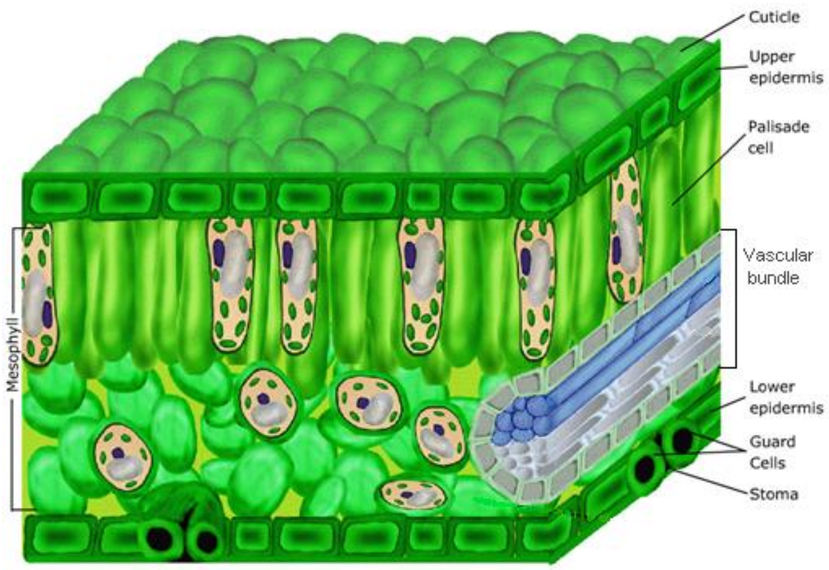


Figure 1. Cells in a cross section of a leaf

(Source: http://www.emc.maricopa.edu/faculty/farabee/biobk/biobookps.html)

A chloroplast (Figure 2) is made up of the following parts: the outer and inner membranes, inter-membrane space, **stroma**, and **thylakoids** stacked in **grana** (singular granum). The chlorophyll molecules are located within the thycaloid membranes of chloroplasts.

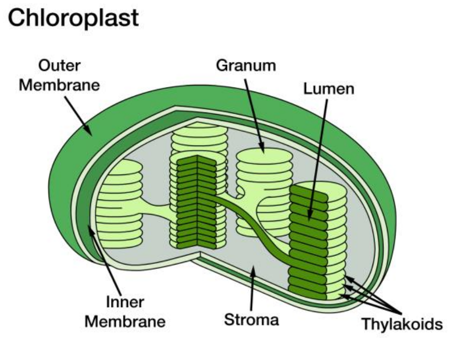


Figure 2. The structure of cloroplast

(Source: http://passscience.blogspot.com/2010/09/structure-of-cell-part-3.html)

The sunlight that reaches the Earth is made up of many different wavelengths of light. A wavelength of light corresponds to its colour and therefore, the mixture of wavelengths found in sunlight also includes those that we perceive as colours. The process of photosynthesis requires visible radiation. While various colours of light can be used for photosynthesis, not all the colours of visible light are equally efficient at helping the photosynthesis take place.

The green colour of chlorophyll comes from the fact that the chlorophyll absorbs red and blue light and reflects green light. It is the energy of the red and blue light that is captured and used in the process of photosynthesis. The green light that makes the plant appear green is not absorbed by the plant, rather it is reflected by the plant. Therefore, it cannot be used in photosynthesis

The overall chemical reaction of photosynthesis is:

$$6CO_2 + 6H_2O \text{ (+ light energy)} = C_6H_{12}O_6 + 6O_2$$

Photosynthesis, therefore, is the source of the O_2 that we breathe. The latter fact is an important consideration in a debate on deforestation[1].

[1] Only new plantations make a contribution to atmospheric oxygen. Old forests that have reached a steady state absorb as much oxygen as they produce.

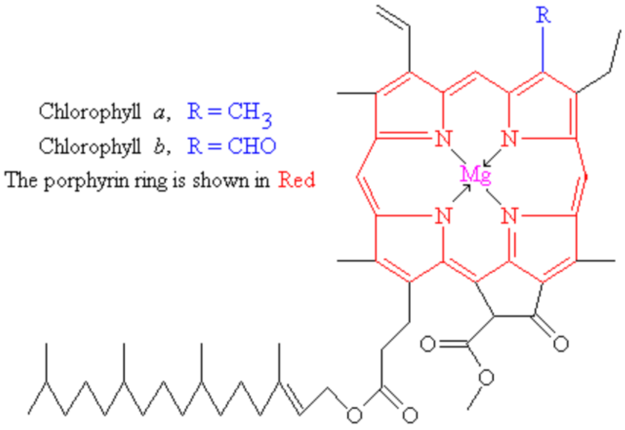
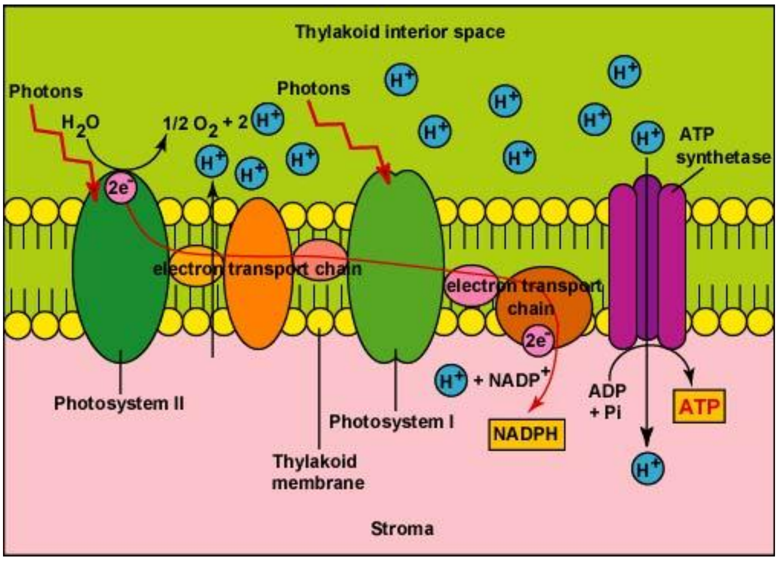


Figure 3. The structure of chlorophylls

Photosynthesis takes place in two parts. Namely, there are light reactions and light-independent reactions or dark reactions. Importantly, the light reactions capture and use light energy to produce high energy chemicals. These chemicals in turn are used to power light-independent reactions whereby carbohydrates are made.

The light reaction

The **light reaction** (Figure 4) takes place in the thylakoid membrane. Because the light reaction converts light energy to chemical energy, it must, therefore, take place in the light. The light reaction involves chlorophylls and a number of other pigments, such as **beta-carotene.** They are organised in clusters and situated in the thylakoid membrane. While clorophylls can exist in different forms, the most important ones are chlorophyll a and b shown in Figure 3.
As differently-coloured pigments are involved in the light reaction, each of these pigments can capture a slightly different colour of light. This light energy is then passed on to the central chlorophyll molecule to power photosynthesis. The main part of a chlorophyll molecule is a **porphyrin ring.** This consists of several rings of carbon and nitrogen atoms joined together with a magnesium ion in the centre of this main part.



As photons are absorbed by pigment molecules in the antenna complexes of **Photosystem II**, excited electrons from the reaction centre are picked up by the primary electron acceptor of the Photosystem II electron transport chain.

Figure 4. Light-dependent reactions of photosynthesis at the thylakoid membrane
(Source: http://lilykid.wix.com/photosynthesis#! inside-the-chloroplast)

During this process, Photosystem II splits molecules of H_2O into 1/2 O_2, $2H^{+,}$ and 2 electrons. These electrons continuously replace the electrons being lost by the chlorophyll A molecules in the reaction centres of the Photosystem II complexes.

$$H_2O \rightarrow 1/2\ O_2 + 2H^+$$

2. During this process, adenosine triphosphate (ATP) is generated by the Photosystem II electron transport chain and chemiosmosis. According to the chemiosmosis theory, as the electrons are transported down the electron transport chain, some of the energy released is used to pump protons across the thylakoid membrane from the stroma of the chloroplast to the thylakoid interior space producing a proton gradient or proton motive force. As the accumulating protons in the thylakoid interior space pass back across the thylakoid membrane to the stroma through ATP synthetase complexes, this proton motive force is used to generate ATP from ADP and Pi.

3. Meanwhile, photons are also being absorbed by pigment molecules in the antenna complex of **Photosystem I** and excited electrons from the reaction centre are picked up by the primary electron acceptor of the Photosystem I electron transport chain. The electrons being lost by the chlorophyll a molecules in the reaction centres of Photosystem I are replaced by the electrons traveling down the Photosystem II electron transport chain. The electrons transported down the Photosystem I electron transport chain combine with 2H+ from the surrounding medium and NADP+ to produce NADPH + H+.

The light-independent (dark) reaction

The **light-independent (dark) reaction** (Figure 5) occurs in the stroma of the chloroplast. During the dark reaction CO_2 is converted to carbohydrates. While light is not directly necessary for this reaction, it is the products of the light reaction (ATP and another chemical called NADPH) that are needed. In the light-independent reaction CO_2 and energy from ATP are used to form glycose. This process is called the **Calvin cycle.** In fact, the first product of photosynthesis is a three-carbon compound called **glyceraldehyde 3-phosphate**. Almost immediately, two such compounds join to form a **glucose** molecule. The glucose molcule can then be transported to other cells, or packaged for storage as insoluble polysaccharides (e.g. starch).

$$3\ CO_2 + 6\ H^+ \rightarrow C_3H_6O_3\text{-phosphate} + 3\ H_2O$$

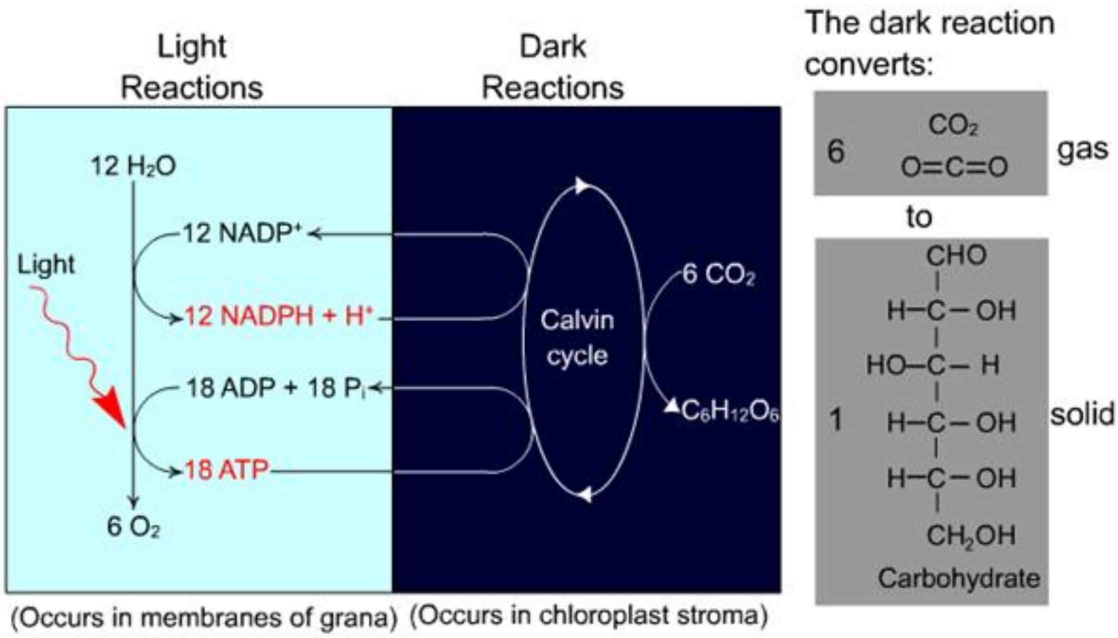


Figure 5. Relationship between light dependent and light independent reactions

Factors that affect photosynthesis

There are four main factors that affect the rate of photosynthesis. In addition to these four factors, several other factors also impact the process. The main factors, however, are: (1) **light intensity and (2) wavelength, (3) carbon dioxide concentration, and (4) temperature.**

When the temperature is constant, the rate of photosynthesis varies with light intensity. Initially, as light intensity increases, the rate of photosynthesis also increases. However, at a higher level of light intensity this correlative relationship ceases and the rate of photosynthesis reaches a plateau (Figure 6).

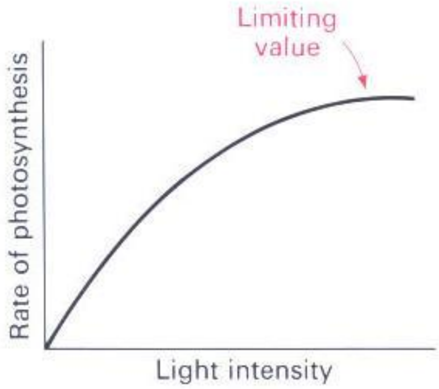


Figure 6. The dependency of rate of photosynthesis on light intensity
(Source: http://fhs-bio-wiki.pbworks.com/w/page/12145771/Factors%20effecting%20the%20rate%20of%20photosynthesis)

Variations in the colour of light have impact the rate of photosynthesis. While the entire spectrum of light reaches the plant at the same time, there are certain colours that bring about higher amounts of photosynthesis than others. Because of chlorophyll each plant has its own individual colouring. Chlorophyll can have four kinds of pigments: Chlorophyll A, Chlorophyll B, Xanthophyll, and Carotene. Some leaves contain more of certain colour pigments than of others, and as a consequence some leaves can appear yellow-green while others appear bright green, blue-green or even orange or red. With regard to photosynthesis, however, such pigmentation does not matter
The colours that influence photosynthesis most are blue and red, while yellow light is the least helpful in the process of photosynthesis. It is important to bear in mind that, when testing the rate of photosynthesis in the case of various colours, the leaf used in such an experiment should not be exposed to natural light. It is important to use an absolutely dark room and any light that is not a part of the experiment itself should be carefully screened from the experimentation area. White light, also a part of the spectrum of light, should be used as a control element in the experiment.

Temperature
The rate of photosynthesis increases as the temperature is increased over a limited range. However, this relationship holds true only at high irradiance. At low intensity, increasing the temperature has little influence on the rate of photosynthesis.

Carbon dioxide concentration

The level of carbon dioxide in the atmosphere is relatively constant. Therefore, CO_2 concentration does not limit the rate of photosynthesis. Nevertheless, higher concentrations of CO_2 increase the rate of photosynthesis (the rate at which sugars are made by the light-independent reactions). Thus, in industrial greenhouses, this factor is used to encourage photosynthesis.

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IV. Pedagogical Content Knowledge

After completing this unit, students will understand:

- The importance of photosynthesis for plants, other organisms and the biosphere.
- The mechanisms of light-dependent and light-independent reactions; and the factors influencing photosynthesis.
- Current and future applications of photosynthesis.

The students are expected to:

- analyse the tasks, results and importance of photosynthesis;
- analyse the light dependent and light independent (dark) reactions of photosynthesis
- relate physical plant characteristics (chloroplasts, pigments, stomata, etc.) to their functions
- understand the transfer of energy from light to usable chemical energy
- plan and perform an inquiry, use experimental data to make conclusions about the factors influencing photosynthesis
- communicate and present their ideas and results
- apply their knowledge to the topics related to the current and future applications of photosynthesis

- design a model of a space station
- seek relevant information from different sources
- conduct an experiment on planar chromatography of plant pigments,
- explain the results using scientific knowledge
- work successfully as a team
- develop their understanding of the nature of science aspects related to the knowledge of photosynthesis
- take a responsible attitude towards living organisms

Before starting this unit, students should be aware of the energy needs of organisms and the methods of energy production used by autotrophic and heteroprophic organisms; general flow of substances and energy in organisms; ATP as the universal intermediary for energy storage and transfers; respiration as a mechanism providing organisms with energy.
Some basic knowledge in organic chemistry and chemical bonding (hydrogen bond) would be useful.
Students should be familiar with independent inquiry, planning and carrying out experiments using safe and sustainable working methods.

Common misconception:
Students often misunderstand the basic process of photosynthesis. Rather than believing that plants make their own food internally using carbon dioxide, water, and sunlight, they think that plants take in their food from the outside environment using sources such as water and soil. They are missing the main principle of a process they have been taught in detail.

V. Industrial Content Knowledge

When designing their greenhouses for Mars, students must be introduced to the Martian conditions: the concept of gravity, the consistence of Mars' atmosphere and surface, length of the year and the day, temperature, etc. and what, therefore, the main problems are, that scientists are confronted with in designing a suitable green house.
The following information is adapted from the article:
"Greenhouse design for the Mars environment: Development of a prototype, deployable dome" by R.A. Bucklin, P.A. Fowler, V.Y. Rygalov, R.M. Wheeler, Y. Mu, I. Hublitz, E.G. Wilkerson

1. Atmospheric pressure and gravity
Atmospheric pressure measured on Mars varies widely with location and season from 0.69 kPa to 0.9 kPa. Atmospheric pressure is always extremely low compared with that on Earth and from a structural analysis viewpoint effectively zero. Martian gravity is 0.38 of the Earth's gravity (3.73 m/s^2) so one's weight will be less than on Earth. The Martian atmosphere has a density of about 0.01 of that of the Earth.

2. Wind and dust
Because of low atmospheric density, the wind load will be low. However, the dust carried by wind is important, as dust suspended in the air changes the overall quantity of light and the distribution of direct and diffuse radiation. It is suggested that it would be necessary to develop a method of dust removal from the exterior of the greenhouse.

3. Temperature
The average surface temperature on Mars is approximately –63°C with an average diurnal range of around –103°C to –5°C (Hiscox, 2000 as cited in Bucklin et al.,2004). The daily temperature range observed was –89° C to –32°C. Daytime temperatures in the summer at the equator may be suitable for plant growth, but night-time temperatures are far below the temperature range where plants can survive.

4. Light Levels
Estimates of light levels vary and it is difficult to determine whether values are for the Martian surface or for the Martian orbit. The distribution of direct and diffuse light is needed. Ambient light levels on Mars are high enough to sustain plant growth. However, because of extremely low temperatures and

pressures, any plant production must be conducted inside an enclosure. Even the best transparent wall materials reduce light levels. An ideal wall material would allow transmittance of the wavelengths above 400 nm at angles of incidence from zero to 90° and zero transmittance out of the structure for all thermal wavelengths beyond 3000 nm (Aldrich and Bartok, 1994; as cited in Bucklin, et al., 2004).

The wall materials with the highest light transmissivity are thin films that have low thermal resistance and low mechanical strength. Thin films can be reinforced by straps or frames, but these reinforcing elements reduce the amount of light. It may be necessary to supplement ambient light with artificial lighting to achieve satisfactory plant growth. The power requirements of artificial lighting are very high; however, in contrast to most situations on Earth, the waste heat from artificial lights would be very useful on Mars.

5. Structural needs

The main structural load on any configuration of Martian greenhouse will be imposed by internal pressure. Gravity loads and wind loads will be much smaller. The stresses in a curved shell are directly related to the internal pressure and the shell radius and are inversely related to the wall thickness. Stresses in flat sheets increase with pressure and sheet width. Bending stresses in flat sheets also increase as sheet thickness decreases. Walls must be as transparent as possible, which means walls should be as thin as possible. Most greenhouse films are less than 1 mm thick, so stresses can rapidly approach the film's failure strength. Reinforcing material can be added to films and sheets, but reinforcing material blocks or reduces light levels. A spherical shape gives the best strength to weight ratio for carrying pressure loads and curved shapes such as hemispherical domes or half cylinders have better strength to weight ratios than shapes with flat sides. Curved shapes also have lower surface area to volume ratios, which is an advantage when considering heat loss through the wall surfaces. However, the lower surface area to volume ratio can be a disadvantage when light collection is considered. Many film materials exhibit large thermal expansion and contraction. Large stresses are produced if the film is restrained from changing length as the temperature decreases and wrinkles can appear when the temperature increases. Cycles of expansion and contraction can also produce stresses at joints. Many clear materials are sensitive to ultraviolet radiation.

6. Environmental control

The dominant environmental parameter in a Mars deployable greenhouse will be temperature. A heating system will be a necessity at night. Solar collectors can be used to increase the amount of energy, but collectors will not be effective during times when light is diffuse because of dusty conditions or clouds. Even on the best days, supplemental heating will be required. If a transparent film is used for wall material, the heating system will consume major quantities of energy, so utilising as much solar energy as possible will be critical. Significant quantities of solar energy are available on the Martian surface, but as on Earth, solar energy on Mars is not always available when required and is never available at night. If supplemental lighting is used, cooling may be necessary because electrical lights produce very large quantities of waste heat. Because of the cold surroundings, cooling should consume much less energy than heating. The quantity of solar energy available to heat a greenhouse can be increased by the use of solar collectors and concentrators when direct sunlight is available. Thermal storage is necessary when using solar systems in order to provide a steady supply of energy throughout the day and night. Glass is transparent to visible wavelengths of light and opaque to infrared wavelength and is an ideal wall material for the greenhouse effect. Unfortunately, many plastic films are relatively transparent to infrared radiation. The radiation characteristics of wall materials must be carefully selected to optimise transmission of photo synthetically Active Radiation (PAR) and block as much radiation in the infrared range as possible. Gas leakage will occur from the greenhouse. All practical closed systems holding gas under pressure leak because of the pressure differential across wall surfaces and the difficulties of maintaining tight seals of flexible materials. Heating of replacement gases will add to the energy load of the greenhouse. Carbon dioxide can be replaced from the Martian atmosphere, but water vapour and oxygen will be difficult to make up. The greenhouse will require a ventilation system. Plants will require some minimum air velocity over leaves for gas exchange. Plants transpire and release oxygen as a by-product of photosynthesis. Even if the overall system is closed, the plant growth volume must be maintained within a certain range of relative humidity and at some point, surplus oxygen must to be removed from the system and carbon dioxide will need to be added.

Temperature and relative humidity must be constantly controlled to maintain a satisfactory environment for plant growth. An overall environmental control system will be required to manage the interactions between lighting, temperature, relative humidity, oxygen level, carbon dioxide level, pressure, the hydroponics system and plant growth.

7. Plant considerations

The plant consideration that has the largest impact on structural design is the internal pressure of the greenhouse. The absolute minimum internal pressure is the sum of the partial pressures of carbon dioxide, water vapour and oxygen inside the greenhouse. The partial pressure of carbon dioxide in Earth's atmosphere is 0.035 kPa. The partial pressure of carbon dioxide in the Martian atmosphere is about 0.57 kPa. The partial pressure of water vapour in Earth's atmosphere, referred to as the vapour pressure, varies with temperature and relative humidity. At comfortable room conditions of 25°C and 50% relative humidity, the vapour pressure for Earth's atmosphere is 1.6 kPa. The variation of humidity can be neglected in open systems operating at Earth atmospheric pressure, but the variation is important in closed systems operating at reduced pressures. Tests in the vacuum test chamber at Kennedy Space Center (KSC) (Fowler et al, 2000 as cited in Bucklin, et al., 2004) indicate that plants tolerate pressures down to 20 kPa without problem, but begin to wilt below this value. In other tests at KSC, plants survived below 10 kPa for short periods of time.

Plants have a region of temperatures in which they function best and also upper and lower limits beyond which they display heat or cold damage. Temperature also has a major influence on transpiration rate and on dissolved oxygen levels in root moisture.

The internal gas mix must contain minimum levels of carbon dioxide, water vapour and oxygen. The maximum desirable levels of these components will not total 10 kPa so some inert gas will be required to supply the remainder of the desired pressure. The pressure and the gas mix in the greenhouse will require monitoring and control. In a closed system, the carbon dioxide partial pressure will drop as carbon dioxide is consumed by photosynthesis. At the same time, oxygen is released by the plants and the oxygen partial pressure will increase. Water vapour partial pressure will increase as the plants transpire and add water to the gas mix. Excess water vapour will have to be removed from the gas mix and recycled into the soil media or the hydroponics system's water. Water vapour pressure will fluctuate by several kilopascals as relative humidity varies. Carbon dioxide will have to be replaced as it is consumed by photosynthesis and oxygen will have to be harvested and stored or discharged before it reaches undesirable levels. Just as with temperature, plants require a certain range of relative humidity to function. Relative humidity is the ratio of the ambient water vapour pressure to the water vapours pressure at saturation for the same temperature. For a given temperature, relative humidity is a function of ambient water vapours pressure. Vapour pressure increases as moisture is added to the air through transpiration or evaporation from leaks in the hydroponics system. Under Earth atmospheric pressure in an open system, the change in vapour pressure is not important, but in a totally closed system at low pressure, fluctuations in vapour pressure will significantly influence total pressure. Hydroponics systems will need to be as tight as possible to reduce the quantity of water that evaporates from leaks. At high relative humidity, condensation on interior wall surfaces will occur. Condensation by itself will reduce light levels and over time will promote dirt and mineral collection on wall surfaces that will further reduce light levels.

A minimum internal air velocity is needed for the gas exchanges required for photosynthesis to occur. Velocities in excess of this minimum should be produced by the ventilation system operating to remove moisture from the system, so maintaining the minimum required velocity is not expected to be a problem. The plant will also require some minimum volume for its canopy. The biggest challenge for the design of a deployable Martian greenhouse is to achieve maximum light transmittance while keeping heat loss to acceptable levels. Radiation heat transfer will dominate for Martian conditions. The low density atmosphere will reduce conductive and convective heat transfer through the atmosphere outside the greenhouse. Operating greenhouses at internal pressures as low as 0.1 Earth atmosphere has been discussed, but it appears that plants may not be productive at pressures below 0.2 or 0.3 Earth atmospheric. Conduction and natural convection inside the structure will be greatly reduced at 0.1 Earth atmosphere and hence a higher pressure may be required to maintain a good thermal and mass transfer balance. During the day, the greenhouse will receive direct radiation from the sun and some diffuse radiation. The greenhouse will lose radiant energy to all of the very cold surrounding objects and depending on sky conditions; it will lose radiant energy to cold portions of the sky away from the sun. At night, the surrounding objects will be even colder and the greenhouse will lose radiant heat to the cold sky. The presence of plants complicates the heat transfer analysis by adding latent heat transfer (evaporation and condensation) to sensible heat transfer (conduction, convection and radiation). The changing mix of carbon dioxide, oxygen and water vapour in the greenhouse must be accounted for in heat transfer analysis. Other factors of importance include leakage from the hydroponics plumbing and condensation on the inside of the greenhouse wall.

Laboratory tests

Several research groups are developing facilities to study the behaviour of plants at low pressure (Brown and Lacey, 2002; Chamberlian et al, 2003; Ferl et al, 2002; Goto et al, 2002; all cited in Bucklin et al., 2004). The tests described here are from preliminary studies with a 1 meter diameter dome shaped low pressure growth chamber developed as a prototype of a Mars

Greenhouse by the Advanced Life Support group at KSC and the University of Florida. Tests conducted to clarify air and moisture relationships at low pressure have been conducted in a large vacuum chamber used to test space suits and several small chambers (Fowler et al, 2000; Fowler et al, 2002; Rygalov et al, 2002 as cited in Bucklin et al., 2004). An automated closed environmental growth chamber (see Figure 8) was developed at KSC that operates at pressures down to 25 kPa.


Figure 8. Mars Dome Greenhouse

The base of the dome is stainless steel and the dome is made of clear Lexan. Internally, a monitoring and control system regulates the atmosphere to predetermined set points. The system is controlled electronically by a microcontroller which interacts with sensors and appropriate relays and solenoids to enact systems for each parameter. Algorithms were developed to control each parameter. The main component of the system is a central tower, the Automated Tower Management System (ATMS). (Source: http://science.ksc.nasa.gov/biomed/marsdome/pictures.html)

The ATMS consists of a tube with a fan and heater at the top to create airflow in the system. Directly below the fan a cooling coil is used both for air temperature and humidity control. Underneath the cooling coil is a water collection pot that receives condensation from the cooling coil. This pot of water is then pumped back through a selective manifold that distributes the water back to the plants, thus completing the water cycle of the system. An outside PC is used to log data from the experiment. A regulated vacuum pump is used to maintain the desired pressure. The ability of the system to grow a crop was tested by growing nine plants of Waldmann's Green Lettuce at 25 kPa pressure, 0.2 kPa carbon dioxide and 5 kPa oxygen. Plants were grown in arcillite medium with Osmocote time release fertiliser. An automated watering system was used. The watering system was based on scales continuously weighing each plant. Water and CO2 were the only two outside inputs to the system. The experiment lasted 45 days with the first week (germination) done at regular pressure and then the plants were trans-planted and put into a 25 kPa environment. At the end of the experiment, the plants were harvested and analysed. One plant died and was removed from statistics. Six plants displayed tip burn, four plants had rusty spots on older leaves and there was mould on the soil surface under dead leaves of one plant. The system successfully grew a crop of lettuce past the typical harvest date.

VI. Learning Path(s)

This unit consists of 6 activities. The exemplary sequence of activities, in which all activities are used, is given in the table below.

Activity		Inquiry Type	E-emphasis
1	Capturing students' interests	Interactive discussion	Engagement
2	Exploring history of the development photosynthesis knowledge	Guided inquiry	Exploration
3	Exploring plant pigment	Guided inquiry	Exploration/Explanation /Elaborate
4	The processes of light-dependent and light-independent reactions	Interactive demonstration/ Guided inquiry	Exploration /Explanation
5	Inquiry on factors that influence the intensity of photosynthesis	Open inquiry	Engagement/Exploration /Explanation
6	Designing the model of a space station	Guided inquiry	Engagement/Exploration/ Elaborate

VII. Assessment

Students will be assessed in many different ways throughout the course, including science process skills, general competences, and topic-related content knowledge. The types of assessments will include formative assessments including observation, participation and quizzes and summative assessments such as a final project. For computer simulated inquiry (see activity 5a) the following assessment criteria are suggested:

	Poor	Satisfactory	Good
Introduction	Explanation of light dependent reaction lacking and/or hypothesis missing.	Offers explanation of the reaction, some parts vague or incorrect. Hypothesis unclear or does not answer the experimental question completely.	Offers good explanation of the light dependent reaction, includes how light is used to produce ATP and NADPH. Proposes a hypothesis to answer the experimental question.
Data	Variables not separated, data disorganised, trends not apparent.	Organised, though trends are not obvious from the layout. Hard to read, taking some time to figure out.	Well organised into tables, variables separated, data clearly shows trends
	Not enough data was collected to test variables	A fair amount of data was collected, enough to show trends	Enough data was collected to clearly show trends
	Graphs poorly labelled, difficult to read.	Graphs missing some labels or incorrectly set up	Graphs all labelled correctly, easy to read
Conclusion	Does not answer the experimental question. Erroneous conclusion.	Answers the experimental question, data used to support argument unclear, or partially incorrect analysis	Answers the experimental question, follows data, conclusions are not erred.
	Explanation attempted, but fails to explain data trends	Explanation is reasonable, but does not take into account important aspects of photosynthesis	Explanation for results is reasonable and takes into account principles of photosynthesis
Format	Not typed, not neat	Typed, neat	Total:

VIII. Student Learning Activities

Activity 1: Capturing students' interests
Learning aims:
Students are expected to • express their previous knowledge, and • generate and share ideas for further exploration about photosynthesis after discussing the idea of living in a space station on Mars with their group members.
Materials:
Overhead Projector
Suggestions for use:
After presenting the introduction, a group discussion is carried out on how to create conditions for living in such a space station and on problems related to the management of a space station. The purpose of this activity is, among others, to assess the prior knowledge that the students have about photosynthesis and existing conditions on Mars compared to the Earth. The topic itself may be related to a complex combination of problems related to food, living in an artificial environment, how to create psychological and physical comfort, etc. However, it is the teacher's task to address the themes more related to photosynthesis and conditions needed for that. All the other students' ideas may be developed further and be included in their final project (Activity 6).
Possible questions:
• What are the conditions required for living in a space station? What are the main problems?

Activity 2: Exploring history of the development of knowledge on photosynthesis

Learning aims:

It is expected that students:

- seek relevant information from internet or library
- develop further an understanding of the nature of science, including how knowledge of photosynthesis has been developed.
- are able to give some examples representing the three aspects of the nature of science (that scientific ideas are subject to change; science demands evidence; and science is a complex social activity).

Materials:

- Information from World of Biology (McGrath, 1999, p.600) http://www.geocities.com/barefeetchild/history.html?200611
- Jeffery Kahn: Calvin Photosynthesis Group Subject of History Project http://www.lbl.gov/Science-Articles/Archive/Calvin-history-project.html
- Discovery of Photosynthesis http://www.biocrawler.com/encyclopedia/Photosynthesis

Suggestions for use:

During the first lesson, students put forward a range of ideas on what could be done in order to create proper conditions for living in space including growing plants or other organisms there for producing oxygen and absorbing carbon dioxide. The purpose of the following lesson is to encourage students to think about how do we know what we actually know about photosynthesis.
In other words, when students claim something related to photosynthesis, it is the right moment to ask "how do you (or we) know that?". This emphasis will nicely link activity 1 to activity 2 where discoveries as a result of human endeavour are revealed by introducing historical figures and experiments that contributed to the body of knowledge scientists have on the processes of photosynthesis.

Activity 2. 1 Writing activity
Groups (3-5 persons) are asked to use the Internet or library resources to research the experiments conducted by one of these scientists related to photosynthesis:
Jan van Helmont (1643)
After careful measurements of a plant's water intake and mass increase, van

Helmont concludes that trees gain most of their mass from water.

Joseph Priestly (1771)

Using a bell jar, a candle, and a plant, Priestly finds that the plant releases a substance that keeps the candle burning – a substance that we know is oxygen.

Jan Ingenhousz (1779)

Ingenhousz finds that aquatic plants produce oxygen bubbles in the light but not in the dark. He concludes that plants need sunlight to produce oxygen.

Julius Robert Mayer (1845)

Mayer proposes that plants convert light energy into chemical energy

Samuel Ruben and Martin Kamen (1941)

Ruben and Kamen use isotopes to determine that the oxygen liberated in photosynthesis comes from water.

Melvin Calvin (1948)

Calvin traces the chemical path that carbon follows to form glycose. These light-independent reactions are known as the Calvin cycle.

Rudolph Marcus (1992)

Marcus wins the Nobel prize in chemistry for describing the process by which electrons are transferred from one molecule to another in the electron transport chain.

Based on their investigation, students write a summary (e.g. in the form of a poster) describing how the scientist contributed to the modern understanding of photosynthesis.

An alternative version of this stage may be that groups produce a PowerPoint presentation or even a video clip about the explored scientist and his discovery. In the last case the activity takes much more time (2-3 lessons + home work) as it involves both the process of setting and videotaping of a role-play.

Activity 2. 2 Compiling a flowchart

In this phase, students put together the results of their group work, e.g. students present their posters on the classroom wall. Depending on the time sequence, groups introduce the ideas (~5 min.) that contributed to the development of photosynthesis-related knowledge.

Possible questions:

- What are the main stages in the development of knowledge about the photosynthesis?
- Which of those discoveries has contributed most to the current understanding of photosynthesis? Justify your choice!

Activity 3: Exploring plant pigment

Learning aims:

- Student are expected to
- Identify where photosynthesis takes place
- Experiment to discover the sources of pigmentation in plant leaves
- Interpret, analyse, and describe the structure and function of chloroplasts
- Give some examples of photosynthetic pigments
- Understand the process of chromatography

Materials:

- 50 mL graduated cylinder
- chromatography (filter) paper
- (spinach) leaves
- coin
- cork stopper
- goggles
- pencil
- scissors
- solvent (1 part acetone with 1 part ethanol)
- Ruler
- http://www.phschool.com/science/biology_place/labbench/lab4/intro.html

Suggestions for use:

Activity 3.1 Independent reading exercise

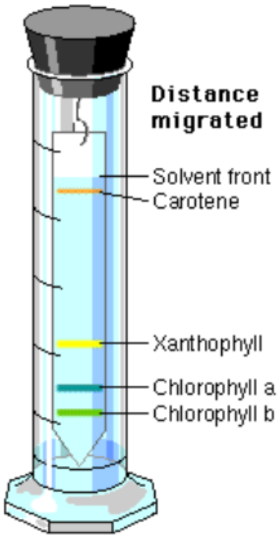
In this part, students develop their understanding of the structure and functions of chloroplasts (students are provided with the relevant text), after what they answer the questions (individually). Questions are discussed afterwards in the class.

Activity 3.2 Experiment: Plant pigment chromatography[2]

In this stage students conduct the experiment using paper	Expected results:

[2]This practical work is adapted from http://www.phschool.com/science/biology_place/labbench/lab4/design1.html

chromatography technique in order to separate plant pigment substances in a mixture based on the movement of the different substances up a piece of paper by capillary action. Beta carotene is carried the furthest because it is highly soluble in the solvent and because it forms no hydrogen bonds with the chromatography paper fibers. Xanthophyll contains oxygen and does not travel quite as far with the solvent because it is less soluble than beta carotene and forms some hydrogen bonds with the paper. Chlorophylls are bound more tightly to the paper than the other two, so they travel the shortest distance. Spinach leaves are given only as an example. As a solvent, the mixture of acetone and ethanol (1:1) or petroleum ether and acetone (92:8) is used.



$$Rf = \frac{\text{distance pigment travels}}{\text{distance the solvent front travels}}$$

Attention: Students must be warned to keep the bottle tightly closed except when one is using it because the solvent is very volatile and produces fumes.

Possible questions:

- Interpret, analyse, and describe the structure and function of chloroplasts
- Give some examples of photosynthetic pigments
- Understand the process of chromatography

Activity 4: The processes of light-dependent and light-independent reactions
Learning aims:
Students are expected to • Identify the products of the light-dependent and light-independent photosynthesis • Explain the roles of light, pigment, water, and the electron transport system in the light-dependent phase • Understand the transfer of energy from light to usable chemical energy • Explain the processes of light-independent phase
Materials:
Supporting computer simulations: http://filebox.vt.edu/users/dwilhelm/portfolio/biounitplan.pdf http://www.pbs.org/wgbh/nova/nature/photosynthesis.html http://www.wiley.com/legacy/college/boyer/0470003790/animations/photosynthesis/photosynthesis.htm http://www.mhhe.com/biosci/genbio/biolink/j_explorations/ch09expl.htm
Suggestions for use:
In this part, it is suggested that the teacher uses direct teaching as it is considered the most difficult part within the unit for students to understand. After that students are asked to individually fill in the concept map, and then share it in pairs (or groups). In addition, students' work sheets are provided with short questions for student self-assessment.
Possible questions:
• What are the products of the light-dependent and independent phases of photosynthesis? • What are the roles of light, pigment, water, and the electron transport system in the light-dependent phase? • What happens with a plant which is: (a) always exposed to the light? (b) kept in dark for days?

Activity 5: Inquiry on factors that influence the intensity of photosynthesis

Learning aims:

Students are expected to
- develop a testable hypothesis
- design an experiment (whether virtually or a real) that will answer a question about photosynthesis
- present collected data in the form of tables and graphs
- explain results using scientific knowledge
- use data and observations to form a conclusion.

Materials:

digital data logger	ice cubes
CO_2 gas sensor	1 L beaker
O_2 gas sensor	thermometer
250 mL respiration chamber	lamp with adjustable light intensity
plant material	coloured films

Suggestions for use:

This part of learning is provided with alternative strategies and suggestions that the teacher can choose depending on available resources. Alternatives are given as activity 3a, 3b, 3c.

Students will be given the materials and asked to design an experiment to answer the question. When they have finished planning their experiment the students will be required to set up their experiment and record their hypothesis and rationale of what will happen in their experiment. Students will make observations and collect data from their experiment. They will record their results in a data table. The students will form conclusions based on their data and explain any anomalies. The results of students' inquiry will hopefully feed the ideas of students' space project.

http://www.biologycorner.com/worksheets/photosynthesis_sim.html

Activity 5a Using computer models to explore the factors controlling photosynthesis (effects of light intensity and wavelength on the rate of photosynthesis)

In this simulation, students will stimulate two variables: light intensity and light wavelength. The amount of ATP produced will change depending upon the set parameters. The simulation "Johnson Explorations: Photosynthesis" is located at http://www.mhhe.com/biosci/genbio/biolink/j_explorations/ch09expl.htm

The students' task is to use the simulation to determine how wavelength and intensity of light can affect the rate of photosynthesis (and the production of ATP).

In addition, valuable animations of the processes can be found at the website: http://science.nhmccd.edu/biol/bio1int.htm#photo

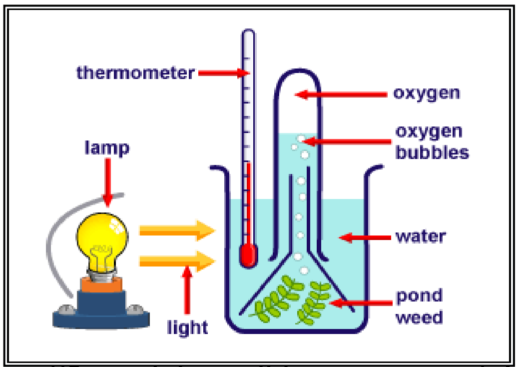
Technology in the classroom, when available, provides an ideal situation in which multiple representations of information can be disseminated to the students.

Activity 5b. Using digital sensors and data logger to explore the factors controlling photosynthesis (effects of light intensity and wavelength, temperature and on the rate of photosynthesis)

In this experiment, students will

- Plan and carry out an experiment on factors controlling photosynthesis
- Study the effect of at least one condition (light intensity, wavelength, plant, or temperature) on the rate of photosynthesis
- Use an O_2 Gas Sensor to measure concentrations of oxygen gas.
- Use a CO_2 Gas Sensor to measure concentrations of carbon dioxide gas

Activity 5c. Using pond weed to explore the factors controlling photosynthesis



(Source: http://9arevision.wikispaces.com/plants)

This alternative is given in case the other possibilities are unavailable. It takes more time to get visible results (oxygen displacing water but all the aforementioned variables are testable.

Possible questions:

- How do different factors influence the intensity of photosynthesis?

Activity 6: Designing the model of a greenhouse for space station
Learning aims:
Students are expected to: • analyse critically the conditions people will encounter on Mars when designing a greenhouse, • propose solutions to the possible problems and develop a model of a greenhouse.
Materials:
Computers and internet http://science.nasa.gov/science-news/science-at-nasa/2004/25feb_greenhouses/ http://en.wikipedia.org/wiki/Life_on_Mars_%28planet%29 http://hortist.blogspot.com/2009/09/greenhouse-on-mars.html Sheet of paper (A3 or A2), coloured or felt-tip pencils.
Suggestions for use:
In this activity, it is expected that students will research the relevant information themselves regarding the conditions on Mars (gravity, air pressure, atmospheric conditions, temperature, mineral consistency of the soil, is it possible to use the existing soil for growing plants, level of radiation, length of the day and year) and fill in the table using 1) critical thinking to understand what the main problems related to greenhouse design are, and 2) creative thinking to offer possible design solutions. When drawing the scheme, students may just use a pencil and paper (at least A3), but all other solutions (e.g. digital) are welcome as long as the picture is supplemented with relevant details and comments. In the last lesson, all groups will present their models to the other groups where students can test their ideas with the help of the comments and questions of class mates.
Possible questions:
• Which wavelengths of radiation, temperatures, etc. are needed to make the photosynthesis effective in artificial conditions? • Is the existing soil on Mars suitable for growing plants? • What are the most critical problems when growing plants on Mars?

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Electronic versions of these units and associated classroom materials are available for download from the project website at:
www.establish-fp7.eu
and
www.castel.ie/establish

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

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