Notes for teachers

on module 06:

Making light

The generation of a photon is not just a physical effect. Ever since the first beacon fires were lit in caves, the making of light has been important for our quality of life. Especially today, when the saving of energy is more than just of economical interest, it is important to understand how light can be generated and used in a smart way.

This module will discuss the blackbody radiation and introduce the concept of photons as discreet energy packages. However, the main focus is on practical aspects the lighting and the understanding of the physics of different light sources.

Summary: In a class project, students analyse the lighting concept of their school and compare different light sources for illumination. The second part discusses lighting efficiencies, incandescence, blackbody radiation and the concept of photons.

The module is structured in 2 chapters:

- Analysing the lighting concept of the school
- The relationship between heat and making light

Designed for: upper secondary level (age ca. 16 to 18)

Duration: The first chapter requires one and a half lessons (20 + 40 min), the second chapter one lesson of ca. 40 min.

What students should already know:

- the atomic model

What students will learn:

Facts

- the physics of different light sources
- incandescence and blackbody radiation
- the concept of photons

Skills

- organizing a research project
- teamwork
- presenting research finding with convincing arguments

This module includes:

- 2 worksheets
- 1 fact sheets

Chapter 1 | Lighting concept of your school

Suggested lesson outline

In a class project, you students will analyse the lighting concept of your school, and make suggestions on how to improve it. Thus, they will become familiar with the types of light sources that are typically available, compare their advantages and disadvantages based on where they are used, and present their research results with convincing arguments.

Timing in minutes	**Activity**	**Material**
	First lesson (part)	
0 – 20	Overview of project and division of research work	WS06.1
homework	Students research the information needed for the project	WS06.1
	Second lesson	
0 – 10	Review research results (homework)	WS06.1
10 – 25	Catalogue of criteria for 'good' light	WS06.1
25 – 40	Developing suggestions to improve your school's lighting concept	WS06.1

Description of suggested lesson

Overview of project and division of work

In the second half of a lesson, explain to your students that you plan to work with them on a project on lighting in their school. This project will require them to work together as a team. Please hand out a copy of the worksheet WS06.1 to each student and give them time to read it. Then discuss with them what research work needs to be done in order to prepare the next lesson. It is recommended to prepare point 1) of the worksheet as homework. If needed, please help your students to organise the division of the research work. Note down who will be responsible for which task.

The goal of this project is to give your students a motivation to research the different lighting options and to compare them in view of a real-world problem. The students will find out that they need physical measures like *lumen* to make a meaningful comparison, and that they need to understand the basic functioning of a light source to know which light source fits what application (e.g. a low-pressure sodium-vapour lamp might be very energy efficient but it is not suitable to illuminate a blackboard).

Review research results

At the beginning of the next lesson, go through the questions in point 1) of the worksheet along with your students. Summarizing their research, let them work out a short answer for each question while naming their sources for the respective information.

Catalogue of criteria for 'good' light

Please give your students the opportunity to work out the catalogue themselves, providing guidance only where needed. The research questions in point 1) and the text in point 2) give some hints in regards to possible criteria. You might need to intervene if the selected criteria tend to be too general.

Developing suggestions to improve your school's lighting concept

The table in point 3) of the worksheet is meant as a tool to structure the discussion. In the context of the project, lighting situations might be both areas (rooms, spaces) as well as specific applications, like the illumination of a blackboard or the school building at night.

After your class has identified the most relevant lighting situations, let them summarize the currently used light sources and light management, before they start to collect ideas for an improved concept. Wherever possible, encourage your students to work with quantitative arguments, using real numbers.

Similarly, the letter to the principal in point 4) of the worksheet should include quantitative arguments, wherever applicable. Even if your students come to the conclusion that the lighting concept of their school could primarily be improved in aesthetic aspects, encourage them to estimate the cost of their proposed changes and to propose them to the principal of the school.

Chapter 2 | Warm light

Suggested lesson outline

In this lesson your students discuss the relationship between making light and heat. Starting with the topic of energy efficiency of light sources, the discussion is guided to incandescence, the topic of blackbody radiation and the concept of photons.

Timing in minutes	**Activity**	**Material**
0 – 5	Reflection on project work	
5 – 30	Group work on the WS “Warm light”, including a demonstration of incandescence on glowing metal	WS06.2 diffraction gratings LED modules *Not included in the kit:* either electric heated iron/steel wire or Bunsen burner, piece of metal, something to hold the hot metal
30 – 40	Discussion of fact sheet	FS06.1

Description of suggested lesson

Preparation

A central part of this lesson is the observation of glowing metal. Please prepare an experiment that allows all of your students to observe how the colour of the glowing metal changes with its temperature. For the spectral analysis of the emitted light, an electric heated iron or steel wire against a black background might be preferable. Alternatively, the experiments can also be conducted with a piece of metal that is heated above a Bunsen burner.

Reflection on project work

If you used chapter 1 of this module with your class, please take 5 minutes to reflect with your students on the project work they did. Did your students like this way of working? Are they content with the way they organised the project work? What went well, and what would they do differently next time?

Worksheet “Warm light”

The Worksheet “Warm light” (WS06.2) is designed to make the transition from the project work in chapter 1 to blackbody radiation and the introduction of the photon. This worksheet alternates between tasks that students can do individually or in groups and parts that are discussed together as a class. The provided information on the worksheet is limited to what is needed to complete the tasks of the worksheet – you may add as much additional information and depth as is required according to your curriculum.

At point 1) of the worksheet, your students compare the energy efficiency of different light sources

	Temperature In ° Celsius	efficiency
Candle (Tealight)	600-1400	0,3 lm/W (see 'Background information')
Light emitting diode latest technology white LED in 2010 White light emitting diodes with super-high luminous efficacy; Yukio Narukawa *et al.*, **2010** *J. Phys. D: Appl. Phys.* 43 354002	High energy LEDs can become hot, while regular LEDs produce hardly any heat.	135 lm/W at 1A drive current up to 250 lm/W at 20mA
Incandescent light bulb (100 W tungsten filament)	filament: 2500	17.5 lm/W
Halogen light bulbs (tungsten filament in quartz envelop)	filament: ca. 3000	24 lm/W
Compact fluorescent light bulbs	60 — 80	60 lm/W
Fluorescent light bulbs (electronic ballast)	60 — 80 (at tube ends)	100 lm/W
Fireflies	Practically no heat is produced	
Plasma TV screen (data from Panasonic NeoPDP series, year 2010)	33 — 45	2,3 lm/W
Sun (source: NASA Sun Fact Sheet, 2010)	Photosphere: 5505	80 lm/W assuming a perfect black-body radiator

Table 1: Comparing the lighting efficiency of different sources

Interestingly, fluorescent light tubes, most so-called energy saving light bulbs (compact fluorescent light bulbs) and plasma TV screens are based on the same physical effect to produce light: a gas-discharge with a bit of mercury in the gas and phosphors on the tube or cell walls to convert the radiation into visible light (see fact sheet FS06.1). However, the lighting efficiency is very different for the different technical application.

Incandescence

Point 2) of the worksheet makes the transition to the topic of blackbody radiation. Starting with the commonly used terminology of 'warm' and 'cold' light, which contradicts physical reality, students are guided to the understanding that incandescence at increasing temperatures leads to the radiation of shorter wavelengths (towards the blue end of the optical spectrum).

Please repeat the demonstration of the glowing wire or piece of metal several times and give your students time to discuss their observations in their groups before discussing the answers in class.

The information in point 3) of the worksheet is not meant to replace text books, but is limited to what is needed to complete the following tasks. Please take time to discuss the blackbody radiation and the concept of photons as discrete energy packages with your students.

In point 4), your students analyse the change in the optical spectrum of glowing metal while it cools down. This simple experiment should help them to understand that photons with shorter wavelengths have a higher energy.

A comparison with other light sources like LEDs shows that incandescence is only one possible way of generating light.

In order to close the circle with point 1) of the worksheet, the students then compare incandescence with the generating of light in LEDs. This should lead them to the conclusion that incandescence is not the most efficient way of generating light and raise their interest in the question of how light is generated in LEDs and other light sources.

Discussing the factsheet

The journey from efficient lighting solutions to the photon and back has hopefully sparked the curiosity of your students and raised many questions. Please reserve about 10 minutes to discuss with your students the information summarized on the factsheet (FS06.1) and to answer their questions.

(The consecutive module “Laser” will include a video in which the generation of light in an incandescent light bulb, in a fluorescent light tube and in a Laser are visualized. If you plan to use this module in the next lesson, you may choose to keep some of the questions open to be answered in the next lesson.)

Background information

A tealight in numbers

A typical tealight consists of about 13g paraffin wax (heat of combustion: 12,5 kWh/kg). Since it burns typically about 4 hours, the energy of a tealight can be approximated with (13g * 12,5 kWh/kg) / 4h ≈ 40W.

The luminous intensity of a tealight is a bit less than 1 candela (the SI unit for luminous intensity). Assuming that the candle emits light in the solid angle of 4π steradians (in all directions) the power of the candle light as perceived by the human eye is about 12 lumen.

The efficiency of a candle can therefore be estimated as 12lm/40W = 0,3 lm/W.

Fireflies

Fire flies and other insects produce light with a chemical reaction. Their bodies produce luciferin and an enzyme called luciferase. In special organs, the luciferin is oxidised with the help of the luciferase which results in a molecule in an unstable transition state. When this molecule reacts further (via a decarboxylation) to more stable products, it often emits a photon at a wavelength of around 500 nm (green). The insects can control the light emission by the amount of oxygen they let into their light producing organ.

Although only roughly every third luciferin molecule emits a photon in this reaction, it is a very energy efficient way of producing light.

Students might ask

remains to be seen at field tests