Absorption spectra of pigments on a screen

Aims of the experiment

- To observe and understand absorption spectra.
- To recognise the connection between absorption, reflection and transmission.
- To appreciate colour as light of characteristic wavelengths.
- To learn about the splitting of light through a prism.
- To understand the difference between perceived colour and absorbed colour.

Principles

In order to interpret an absorption spectrum, we first need an explanation of what light is. Light is usually understood as that part of electromagnetic radiation that is visible to the eye. This radiation is found in the wavelength range of about 380 nm to 780 nm and consists of light particles, so-called photons. Violet light with a wavelength of 400 nm is the most energetic radiation in the visible spectrum and red light with a wavelength of 700 nm the least energetic.

Light possess the property of propagating in a straight line, unless it hits another subject. There are three possible ways it can be influenced by the body: Reflection, refraction and scattering. In this example experiment, the light enters a prism and is refracted in dependence upon the wavelength.

The prism is usually in the form of an equilateral triangle and made of glass or plastic. When a light beam meets the prism at an angle on one of its basic sides, it is refracted at the surface. As each colour of the light has a characteristic wavelength, each colour is refracted to a different degree. For this reason, long-wave red light is not refracted as strongly as short-wave blue light, for example. The light entering the prism continues to travel in a straight line until it meets the second outer surface. The light is refracted again at this surface, thus intensifying the splitting effect. If the beam then strikes a screen, a continuous colour spectrum can be seen.

If a dye solution is placed between the prism and the screen, then the light will interact with the liquid medium. There are again three possibilities for interaction: Reflection, absorption and transmission. In the case of reflection, the light is reflected at the surface of the medium with the angle of incidence being equal to the angle of reflection. In the case of absorption, the light will be partially or completely absorbed through interaction with the medium and less light will be transmitted. Transmission is the passage of the light through the solution without interaction with the medium.

For interpretation of the absorption spectra, it is important primarily to consider the absorption. If a medium absorbs a colour with a characteristic wavelength, the medium will appear in the complementary colour (see Table 1). Another possibility is that all wavelengths apart from the wavelength of the transmitted colour are absorbed. In this case, the transmitted colour is the colour of the medium.

Risk assessment

Some of the chemicals used are hazardous to health.

Iron(III) chloride hexahydrate is corrosive and should only be handled with suitable protective gloves.

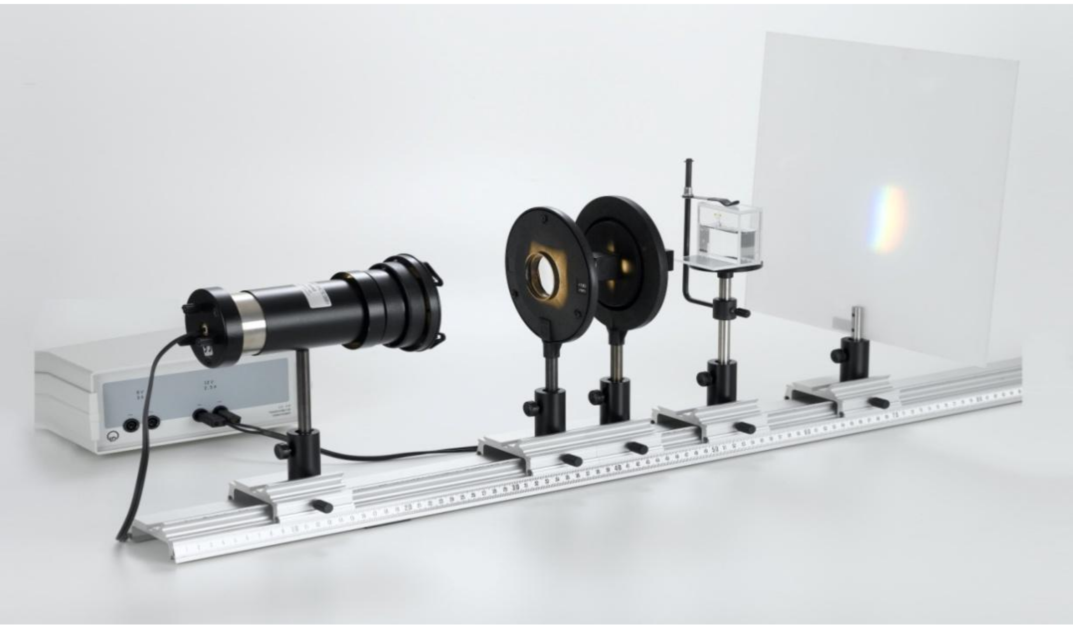

Fig. 1: Experimental apparatus for displaying the absorption spectra of dyes on a screen.

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Iron(III) chloride hexahydrate	
  **Signal word: Hazard**	**Hazard statements** H302 Harmful if swallowed. H315: Causes skin irritation H318 Causes serious eye damage. **Safety statements** P280 Wear protective gloves/eye protection/face protection. P302+P352 IF ON SKIN: Wash with soap and water. P305+P351+P338 IF IN EYES: Rinse continuously with water for several minutes. Remove contact lenses if present and easy to do. Continue rinsing. P313 Get medical advice/attention.
Methylene blue	
 **Signal word: Caution**	**Hazard statements** H302 Harmful if swallowed.
Universal indicator	
 **Signal word: Hazard**	**Hazard statements** H225 Highly flammable liquid and vapour. **Safety statements** P210 Keep away from heat/sparks/open flames/hot surfaces. No smoking.

Set-up and preparation of the experiment

Preparing the solutions

Preparing a red dye solution: For a red solution, weigh 0.2 g of dye (red, non-toxic) into a beaker and add 35 mL of water using the measuring cylinder. Then stir the solution until the substance has completely dissolved. *Preparing a yellow dye solution:* For a yellow solution, weigh 1 g of Iron(III) chloride hexahydrate into a beaker and add 35 mL of water using the measuring cylinder. Then stir the solution until the substance has completely dissolved. *Preparing a blue dye solution:* For a blue solution, weigh 4 mg (a few grains) of methylene blue into a beaker and add 35 mL of water using the measuring cylinder. Then stir the solution until the substance has completely dissolved.

Preparing a violet dye solution: Place 35 mL of water into a beaker. Add about 2 mL (a full dropping pipette) of universal indicator followed by about 1 mL of 2 M sodium hydroxide solution. In this way, the solution should turn violet (pH value of about 10).

Set-up of the apparatus

On the optical bench, set up the apparatus consisting of a transformer, a lamp, a lens, a direct vision prism, a prism table, a glass cuvette and a screen for displaying the absorption spectra of dyes on a screen (see Fig. 1).

Note: When setting up the apparatus, ensure that the lens and the prism are placed as close together as possible. For better observation, the screen can also be turned around so that the experimental set-up and the absorption spectra on the screen can be viewed at the same time.

Equipment and chemicals

1 Lens in frame, f = +100 mm.................. 460 03
1 Direct vision prism............................ 466 05
1 Holder for direct vision prism................. 466 04
1 Optical glass cell (cuvette), 10 mm......... 477 20
1 Prism table on a rod........................... 460 25
1 Screen, translucent............................ 441 53
1 Lamp housing with cable...................... 450 60
1 Bulb 12 V/30 W, E14, set of 2................ 450 521
1 Condenser with diaphragm holder.......... 460 20
1 Transformer 6/12 V, 30 W..................... 521 210
1 Optical bench, S1 Profile, 1 m............... 460 310
5 Optical carriage with clamp................... 460 311
1 Compact balance 200 g : 0.01 g............ 667 7977
5 Beaker, Boro 3.3, 50 mL, squat............. 602 021
1 Measuring cylinder 50 mL, plastic base... 665 753
4 Glass stirring rod 200 mm x 8 mm, set..... 665 212ET10
2 Dropping pipette, 150 x 7 mm, from set... 665 953
2 Rubber bulbs, (pipette bulbs), from set.... 665 954
1 Wash bottle, PE, 500 mL...................... 661 243
1 Water, pure, 1L................................. 675 3400
1 Iron(III) chloride hexahydrate, 50 g.......... 671 8700
1 Methylene blue, 1 g............................ 673 2900
1 Universal indicator, liquid, 50 mL........... 675 2550
1 Sodium hydroxide, dil., c. 2 M, 500 mL.... 673 8400
1 Dye, red, 10 g................................... 309 42

Performing the experiment

1. First place 35 mL of water into the glass cuvette and place the cuvette onto the prism table.

2. Insert the lamp connection leads into the transformer (12V) and switch the transformer on. The entire absorption spectrum can now be observed and, if necessary, can be brought into focus by moving the lamp, the lens, the screen, the sample and/or the prism.

3. Then empty the cuvette, fill it with red dye solution and place it on the prism table. The change in the absorption spectrum can now be observed.

4. A change in the absorption spectrum can thus be observed for each dye solution by exchanging the solutions.

Observation

The first cuvette is filled with pure water. It can be observed that no colour is absorbed and therefore all colours of the visible spectrum are transmitted (see Fig. 2).

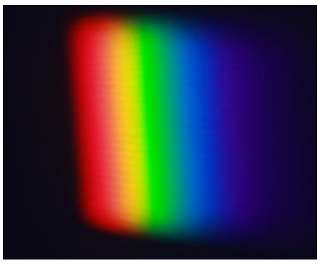

Fig. 2: Absorption spectrum of water.

However, if the cuvette is filled with a red solution, all wavelengths of the light are absorbed apart from that of red light. The red light is transmitted and the solution appears red (see Fig. 3).

If the cuvette is filled with a violet dye solution, all colours of the light are transmitted apart from yellow-green, and only yellow-green is absorbed. As yellow-green is the complementary colour of violet, the solution appears violet (see Fig. 4).

Fig. 3: Absorption spectrum of a red dye solution.

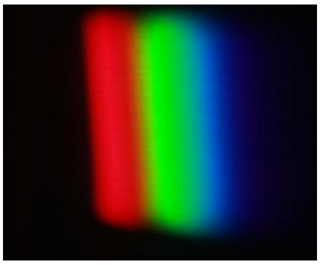

Fig. 4: Absorption spectrum of a violet dye solution.

In the case of the blue dye solution, only red-orange light is absorbed and all other colours are transmitted. The solution therefore appears blue, as the complementary colour orange is absorbed (see Fig. 5).

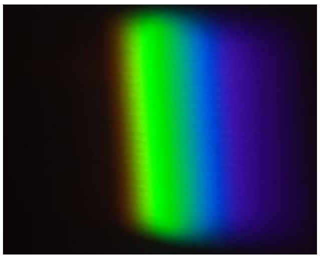

Fig. 5: Absorption spectrum of a blue dye solution.

In the case of the yellow dye solution, the violet-blue light is absorbed and all other colours are transmitted. As violet-blue is the complementary colour of yellow, the solution appears yellow (see Fig. 6).

Fig. 6: Absorption spectrum of a yellow dye solution.

Evaluation

As shown in the various examples, there are two possibilities for absorption which determine the perceived colour of a solution. The first case occurs with the red absorption spectrum, as an example. Here, all wavelengths of the visible colours are absorbed except that of the colour of the solution, which is transmitted. The solution appears red because only the wavelength of red light is transmitted.

The second case is that only the complementary colour is absorbed and all other colours are transmitted. This is the case with, for example, the violet solution. The wavelengths of the complementary colour yellow-green are absorbed and all other colours are transmitted. The colour therefore appears violet, the complementary colour of the absorbed colour yellow-green.

The correlation of perceived colour perception to transmitted light through absorption of the complementary colour can also be looked up in the following table.

Tab. 1: Correlation of absorbed light to transmitted light.

Absorbed light		Transmitted light
Wavelength	**Colour**	**Observed colour**
730 nm	deep red	green
640 nm	red	blue-green
590 nm	orange	blue
550 nm	yellow	blue-violet
530 nm	yellow-green	violet
510 nm	green	deep red
490 nm	blue-green	red
450 nm	blue	orange
425 nm	blue-violet	yellow
400 nm	violet	yellow-green

Results

It can be shown through the absorption spectra of various liquids that every coloured liquid absorbs wavelengths of a characteristic colour. These absorbed wavelengths of a colour can be colour correlated to perception by determination of the complementary colour (see Table 1). Furthermore, this experiment can explain how light is split by a prism into a continuous colour spectrum.

Cleaning and disposal

The methylene blue and the universal indicator solution should be disposed of in the container for organic halogen-free substances, the iron(III) chloride solution in the canister for heavy metals. The red dye can be disposed of in the laboratory drain as it is non-toxic.