4.1 The Lambert-Beer law with grey filters

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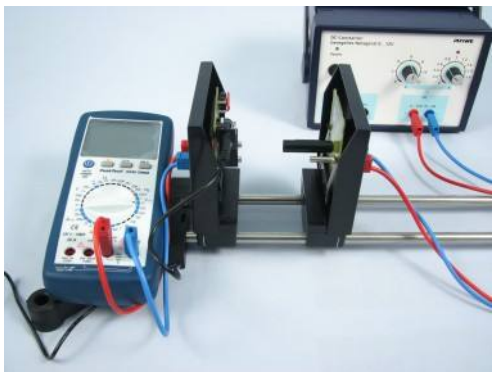
interTESS (Version 13.06 B200, Export 2000)

Task

Task

How id light attenuated when passing through substances?

When light passes trough a substance or liquid the intensity is attenuated. This attenuation can be demonstrated by means of a light sensor.
In this experiment the number of absorbing layers (grey filters) is modified and the light intensity is measured. Eventually you will develop a formula in this experiment for the reduction in intensity as a function of the thickness of the layer that the light passes through.
Note: The variation in the number of grey filters can be interpreted as a variation in the thickness of a single body.



Use the space below for your own notes.

Logged in as a teacher you will find a button below for additional information.

Additional Information

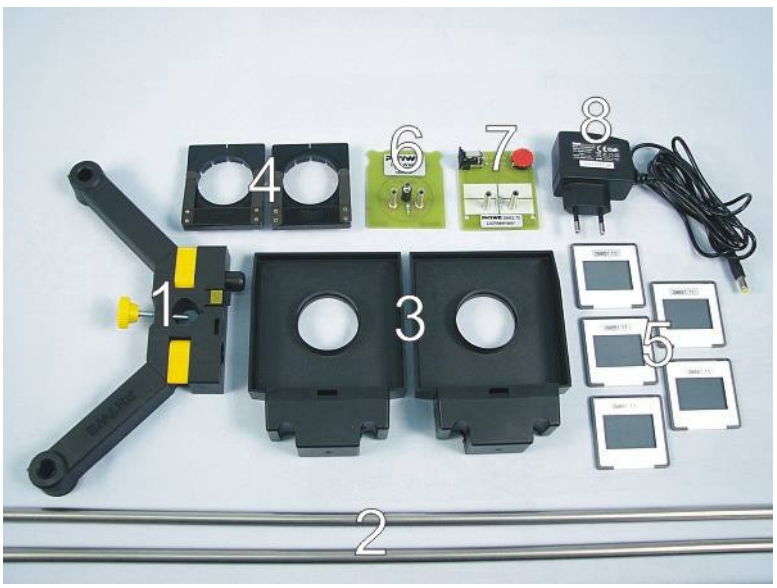
In order to be able to set up in such a way that all the slides fit between the light sensor and the LED without having to shift the mounts, the 5 slides are first held between the light sensor and the tube on the LED and the mounts are pushed together accordingly.

Material

Material from "TESS-Optics and Atomic Physics" (Order No. 13286.88)

Position No.	Material	Order No.	Quantity
1	Support base	02001-00	1
2	Support rod	02037-00	2
3	Slide mount without angle scale	09851-02	2
4	Aperture holder	22604-09	2
5	Grey filters 50%	09851-11	5
6	LED-white	09852-60	1
7	Light sensor	09852-70	1
8	Power supply, 5 V DC	09852-99	1
9	Stray light tube	09852-71	1
10	Stray light tube for LED	09852-01	1
Additional Material			
11	Power Supply, controlled 0...12 V	13505-93	1
12	Digital multimeter	07122-00	1
	Connecting lead, red	07362-01	2
	Connecting lead, blue	07362-04	2

Material required for the experiment




DC-Constanter
Geregeltes Netzgerät 0...12V
PHYWE
Power
AC
max. 5A
0
6V~
12V~
DC
0...12V~/0...2A
11
12
9
10

Setup

- Note: For carrying out this experiment it is necessary for the room to be darkened.
- Setup as shown in figure 1.
- Fit the LED with an object holder into a mount and connect it to the power supply. Observe the correct polarity!
- Fit the stray light tube over the LED.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

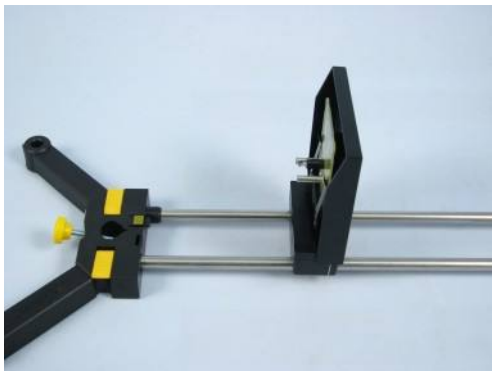


Fig. 5

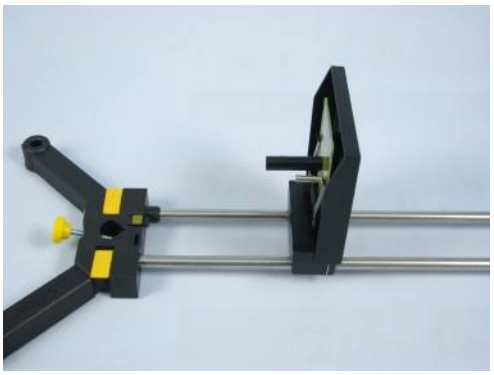


Fig. 6

- Also fit the light sensor with the stray light tube and with an object holder in a mount and connect it to the 5 V DC power supply.

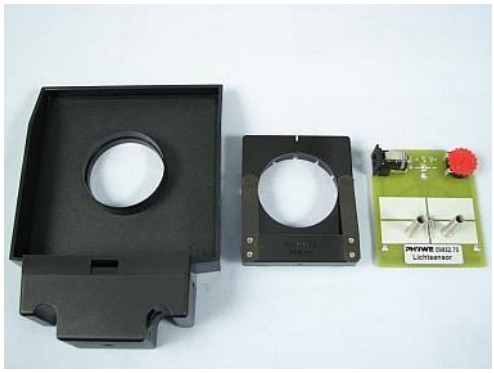


Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

- Connect the multimeter as a voltage meter (measuring range: 4 V) to the light sensor.

Fig. 10

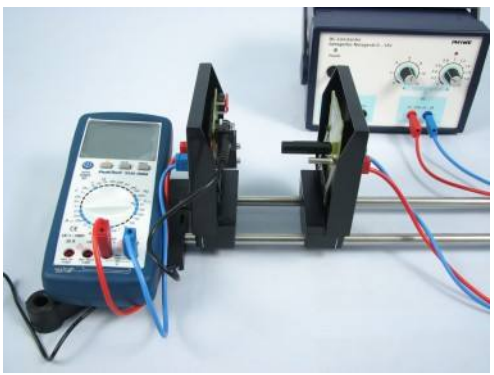


Fig. 11

Action

- Turn the amplifier for the light sensor clockwise up to stop (max. amplification)

Fig. 12

- Adjust the LED voltage so that the light sensor operates in the sensitive range and is not overamplified. (The maximum measuring value is approx. 3.9 V – the brightness of the LED should be adjusted to such a value that the measured value is just below 3.9 V and the light sensor can react both upwards and downwards.
- Record in table 1 the value measured at the light sensor with and without grey filters.
- Hold the first grey filter in the path of the light and record the measured voltage at the light sensor.
- Repeat the process until all 5 grey filters are in the path of the light.

Fig. 13

Note

- While the experiment is being carried out the distance between the LED and the light sensor must not be changed. The slides must be handled cautiously when they are held in the path of the light.
- The light sensor is very sensitive to any change in the distance and this would falsify the measured values!

Additional Information

Reading the multimeter can be somewhat difficult when the room is darkened. In order to be able to read the display without falsifying the measured value, it is recommenden to make use of the HOLD function of the multimeter. For this the slides are placed in the path of the light and then the HOLD button is pressed. Then the light can be brightened a little so that the value can be read.
Alternatively, the meter can be placed behind the light sensor where a weak light source can be used for illuminating the display.
This experiment can also be carried out in the physics classroom with the light dimmed.

Results

Table 1: Measured results

Number of slides	Voltage at the photodiode in V
0	
1	
2	
3	
4	
5	

Measured results

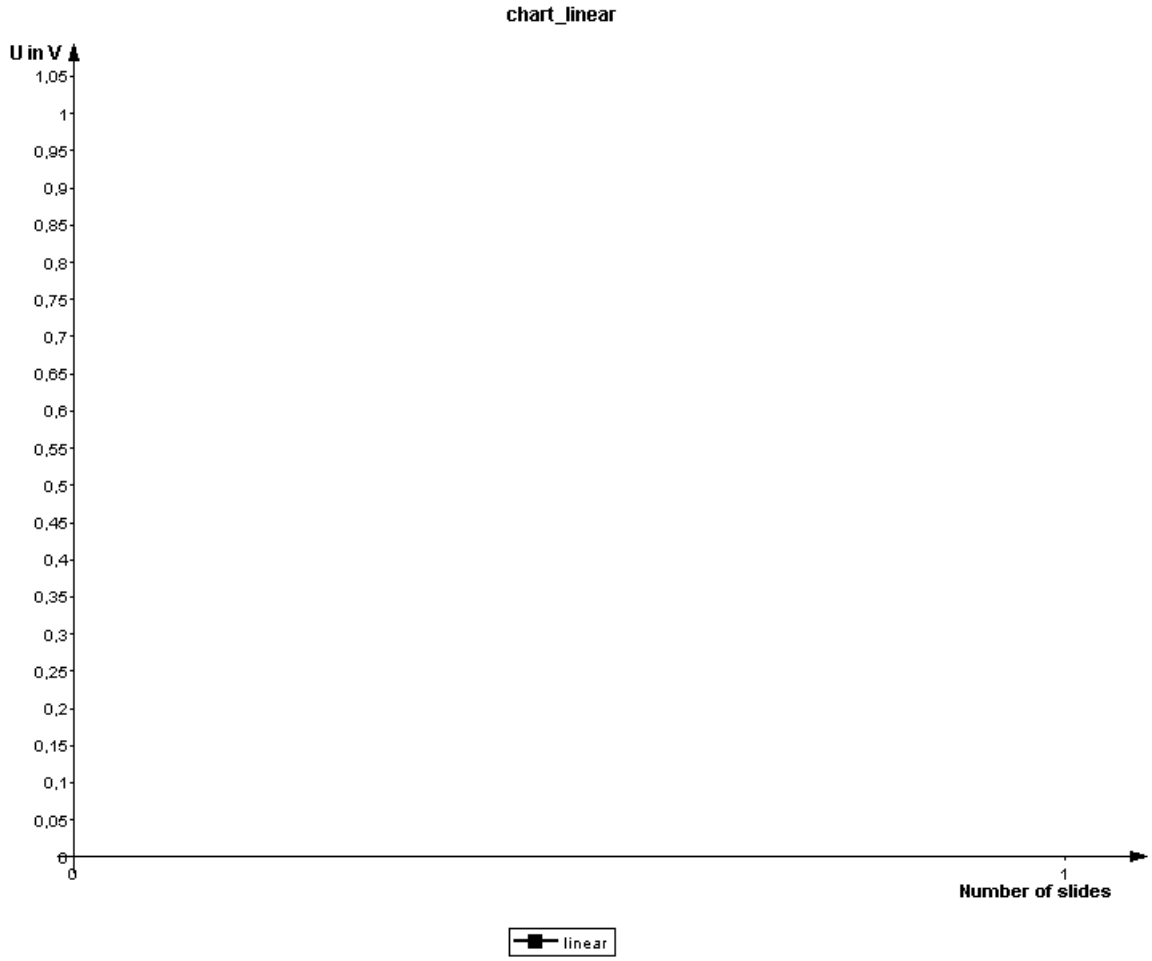
Table S1: Measured results

Number of slides	Voltage at the light sensor in V
0	3.398
1	1.604
2	0.806
3	0.437
4	0.245
5	0.158

Evaluation

Question 1

The measured voltage at the light sensor are plotted in a coordinate system as a function of the number of grey filters.

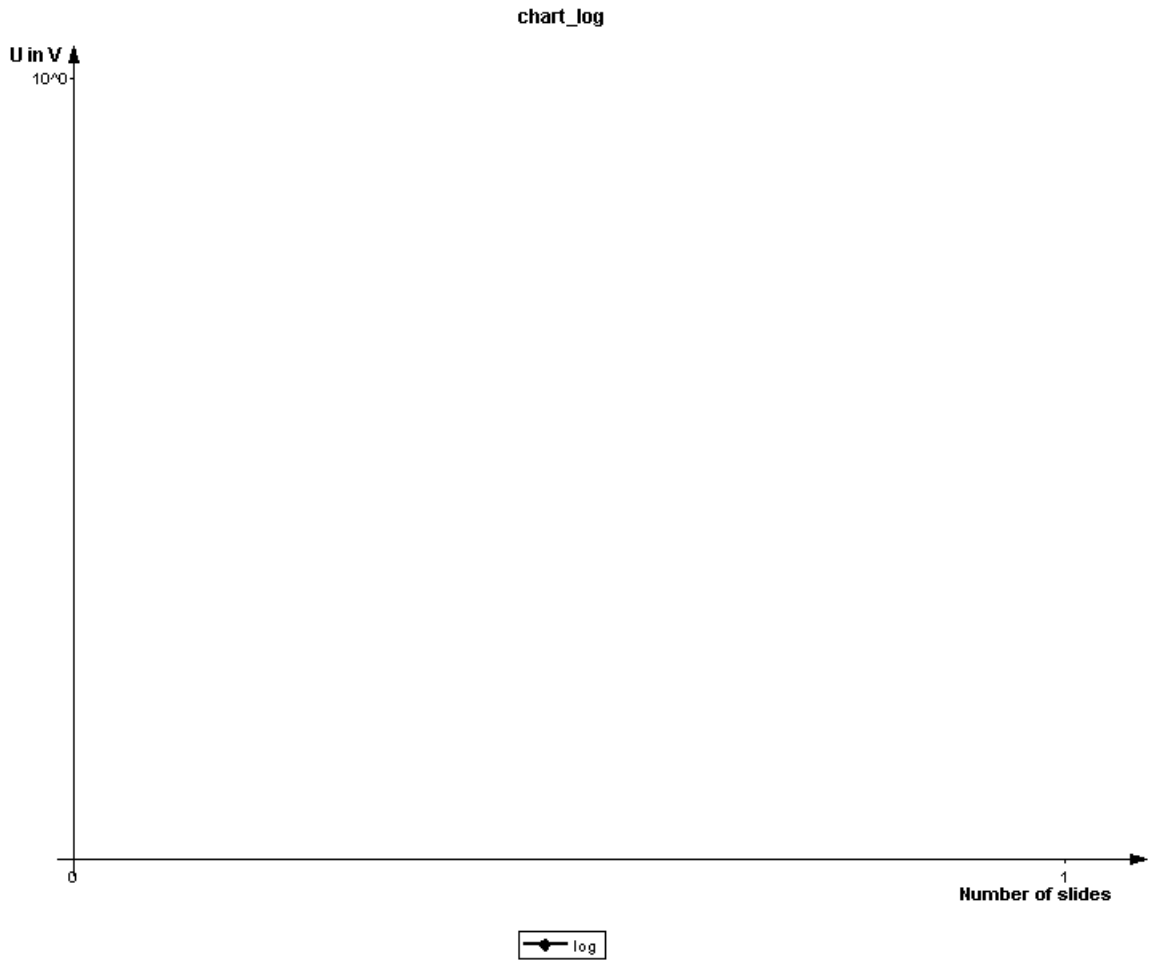


Question 2

Make a sketch of the measured values on paper and fit a curve. What is your assumption about the relationship between the number of slides and the measured photo-electric voltage?

Question 3

The measured values are plotted in a log-linear coordinate system. Make a sketch again and also fit a curve.



Question 4

Make a statement about the relationship between the number of grey filters and the light intensity at the photodiode.

Evaluation

After plotting the measured results in the Cartesian coordinate system, the function below is obtained:

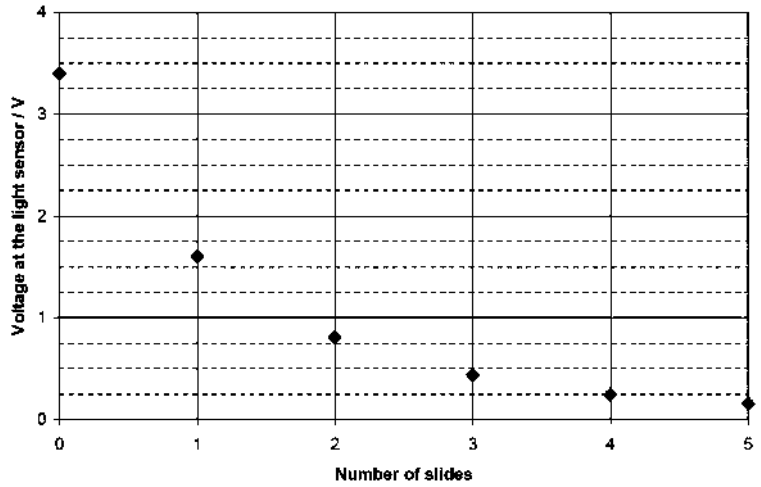


Figure S1: Measured values shown in the Cartesian coordinate system

When plotting the fitted function, the suspicion arises that the it might be exponential. This assumption is confirmed by plotting the measured values in a semi-logarithmic coordinate system:

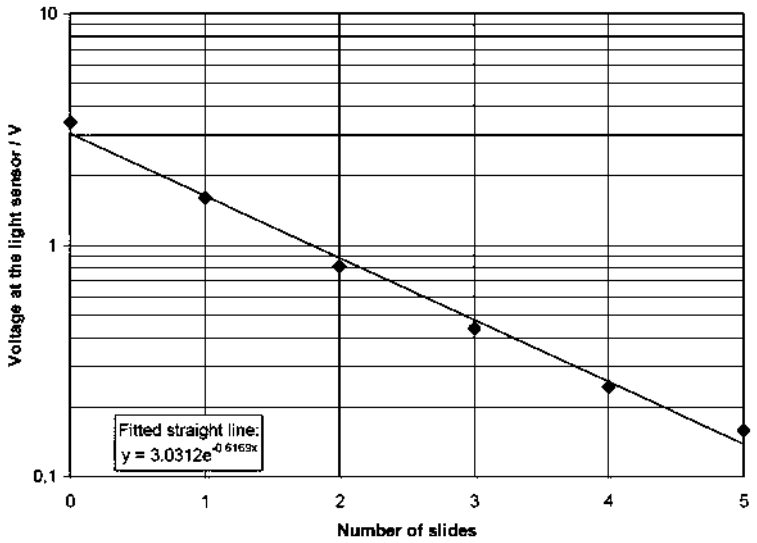


Figure S2: Measured values shown in the log-linear coordinate system

The measured values lie approximately on a straight line which means that an exponetial relationship between the number of absorbing layers (and therefor the thickness of the resulting absorbing layer) and the reduction in intensity found. The gradient of the straight line gives the attenuation coefficient of the slides.

Background

The reduction in intensity is described by the Lambert-Beer law: $I = I_0 \times e^{-\alpha c l}$ with l being the distance passed through the liquid and αc the substance-specific reduction coefficient, which depends on the wavelength of the incident light and the liquid. For the calculation the equation is rearranged:

$\alpha c = -\ln(I/I_0)/l$. The percentage reduction for each unit of length is calculated using $p = (1-e^{-\alpha c}) \times 100\%$.

In this case the intensity is reduced by approximately 45.68% for each slide, which proves an attenuation of 50% for each slide with deviation of less than 10%.

An important condition for the method chosen here is the linearity of the voltage at the light sensor with respect to the intensity of the incident light, which is apparent from figure S3.

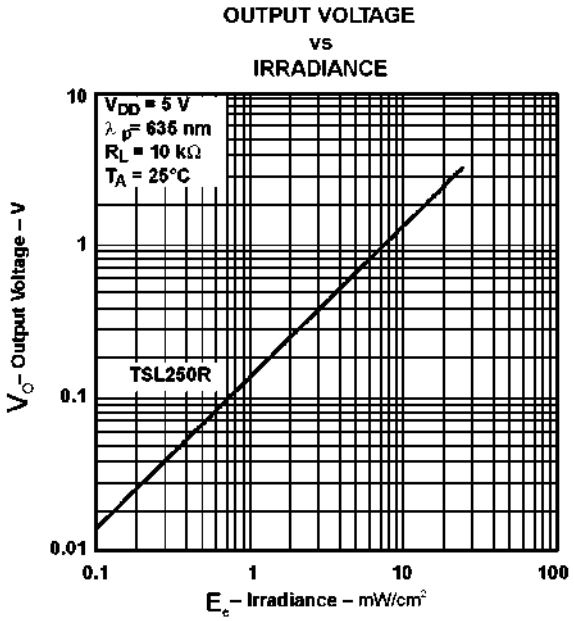


Figure S3: Linearity of the light sensor used — the dependency between the irradiating light intensity and the measured voltage is sufficiently linear.