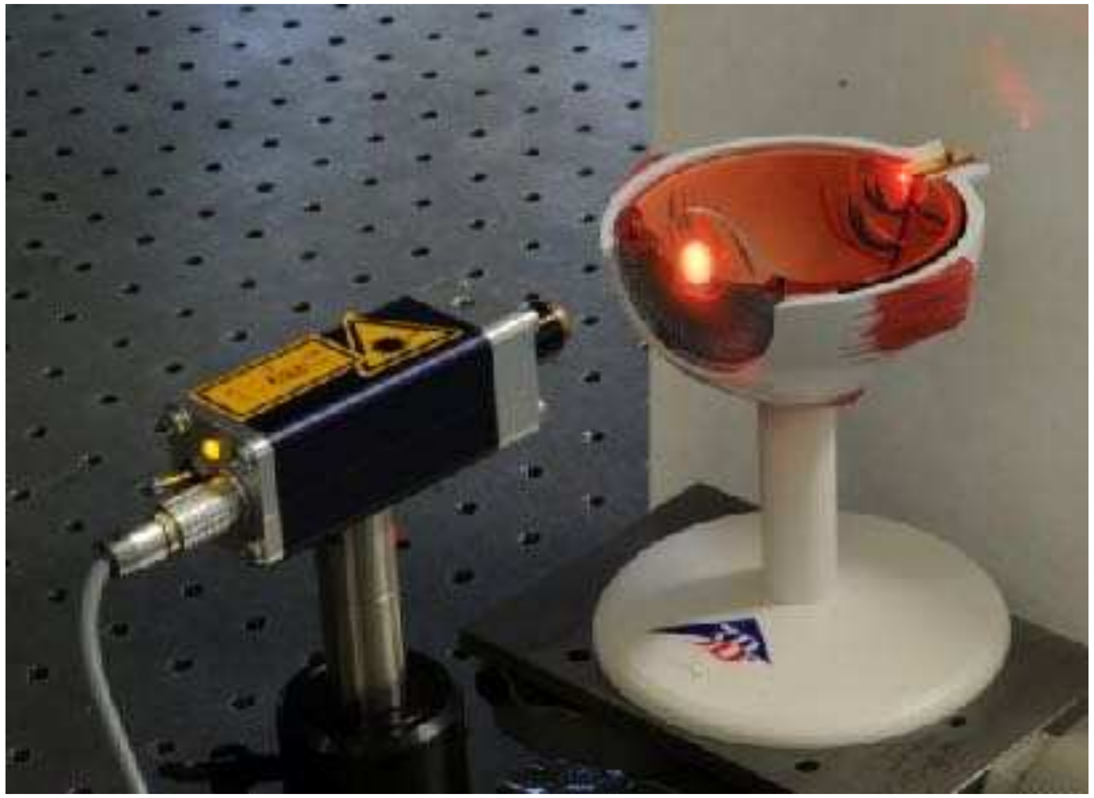
PhotonLab

Guide

Laser safety



Why is laser light dangerous?

Lasers emit an almost parallel beam of light, which is why laser light is collected in a point (focal point or focus) by a converging lens (as in the eye). In the eye, this point lies on the retina, i.e. the entire power of the laser hits a small point and can destroy the retina. In the best case scenario, the eye is so damaged that a black spot remains in the field of vision that cannot be regenerated. In the worst case scenario, if the laser hits the wrong spot, you can even go blind. This is why lasers are only safe for the eye below a power of 0.4 mW.

Nevertheless, you should never look directly into the beam!

Image: Thorsten Naeser, MPQ

Quiz

Why does the red balloon explode, but the green one does not, when green laser light of 85 mW is focused (bundled) on it?

Which answer is correct?

a) Because it was more inflated.

b) Because it absorbs green light.

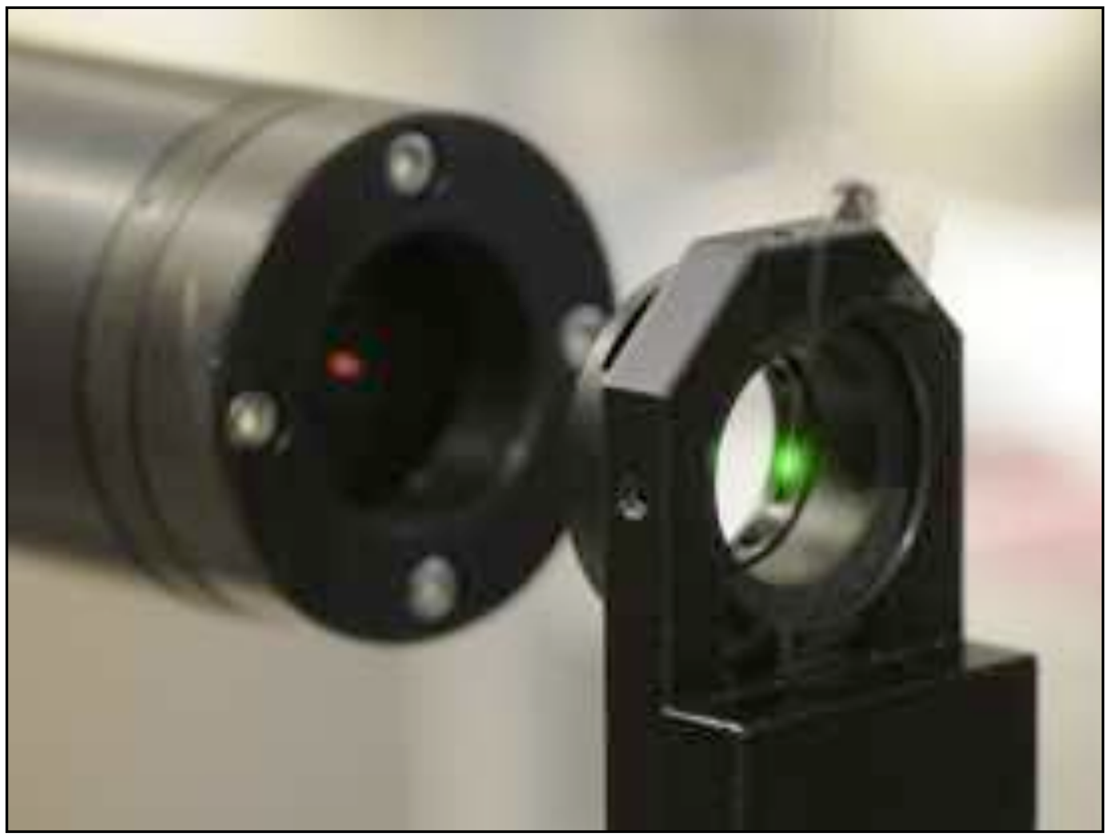
c) Because it reflects green light.

d) Because of stimulated emission.

Answer b) is correct.

EXPERIMENT 2: HAIR THICKNESS

Measuring hair thickness

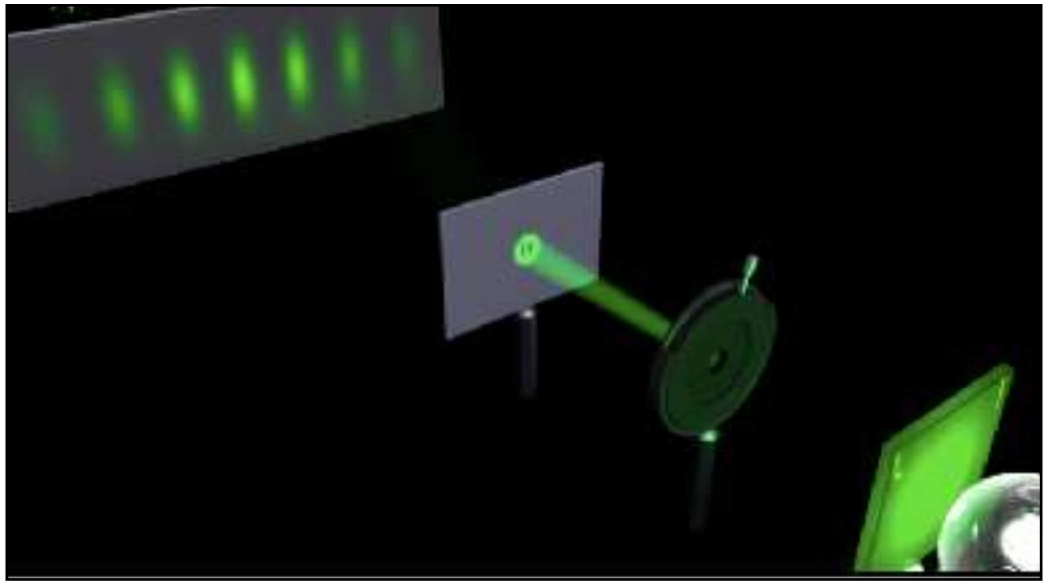


How thin is your hair?

Lasers are often used for measuring. The wave properties of laser light can be used to measure small distances. The interference of waves is used for this purpose.

Image: Thorsten Naeser, MPQ

Basics



Waves can interfere with each other, i.e. amplify or cancel each other out. This creates interference patterns. Such a pattern can also be seen in the middle picture on a beach.

Because light behaves like a **wave**, such patterns can also be created with lasers. In the picture below, light waves have passed through a double slit (two small slits) and an interference pattern can be seen on the screen.

Can you recognize the similarities between the interference patterns in the three pictures?

You can also use the interference patterns to examine the arrangement through which the light has passed.

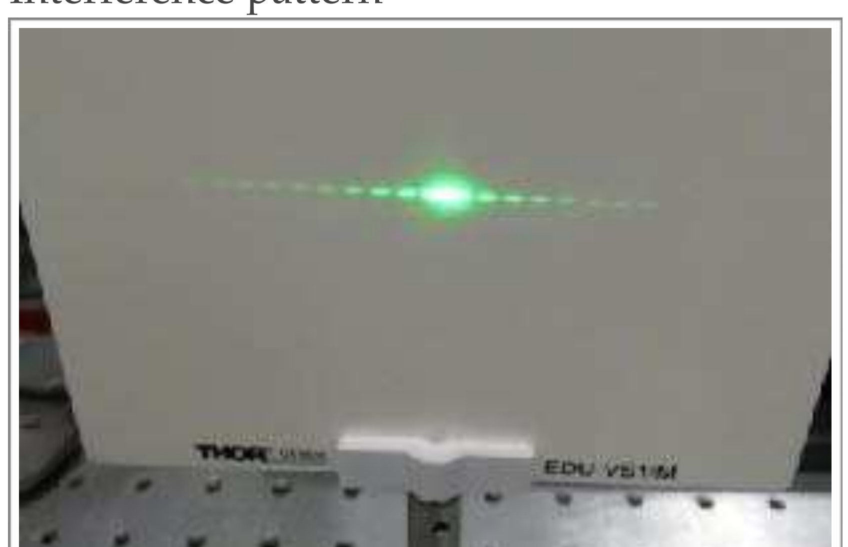
https://boule-braunschweig.jimdofree.com/boulelexikon/mannschaft-kommunikation/interferenz-resonanz-d%C3%A4mpfung/
https://www.leifiphysik.de/mechanik/mechanische-wellen/ausblick/wellenmuster-der-natur
Image below: Screenshot by photonworld.de

Before beginning...

...it is important that you understand what the **single slit** has to do with the experiment. To do this, set up the variable single slit directly behind the laser so that the interference pattern can be seen on the screen. Now change the **slit width** by **turning** the scale. How does the interference image change? Note down your observations!

By the way: In the far field, as here, the interference pattern of a slit and an obstacle with the same dimensions also looks the same (= **Babinet's theorem**).

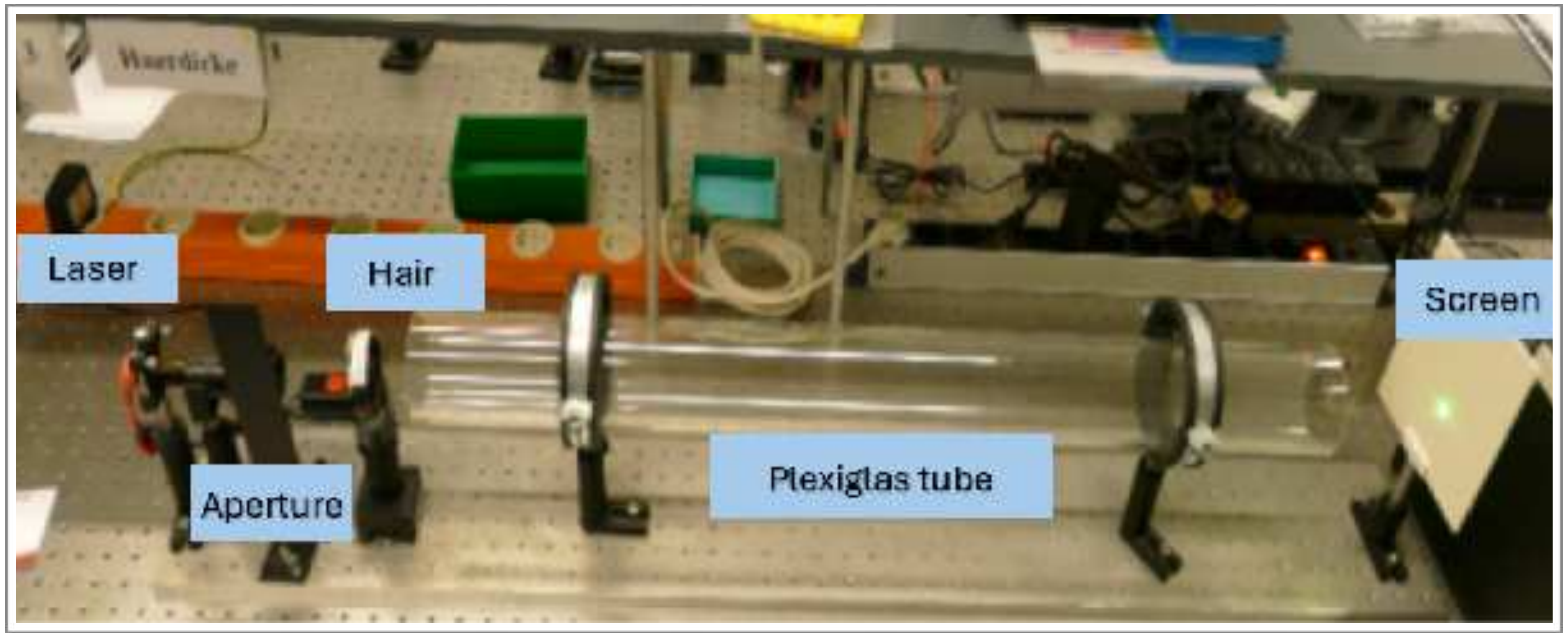
Interference pattern



Variable single slit

Experimental setup

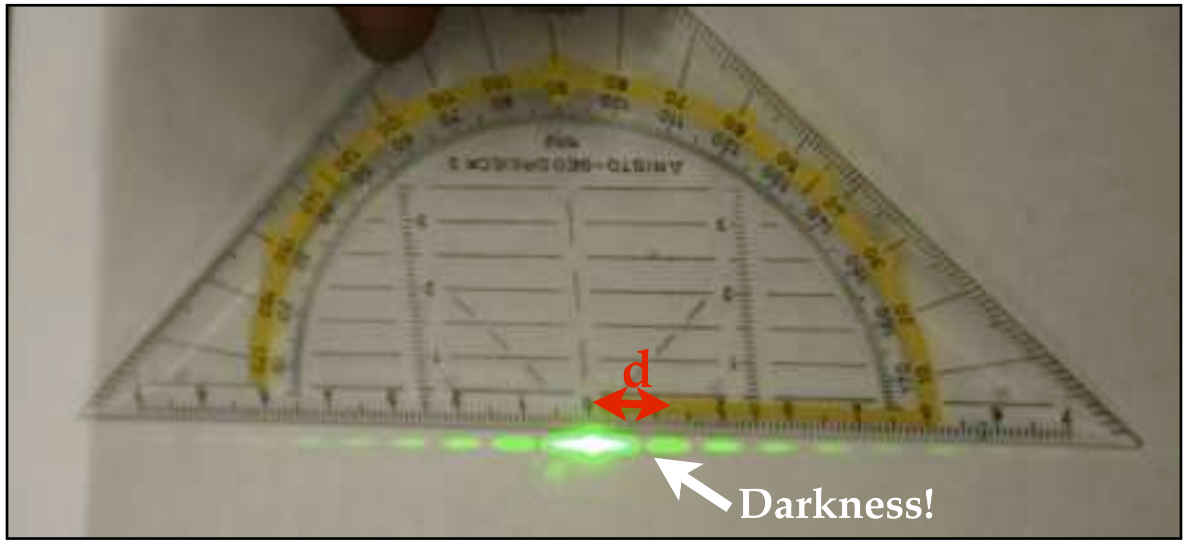
Stick the hair **vertically** behind the circular holder with tape as shown in the picture (only stick the hair at the top and bottom), i.e. the laser should only illuminate the hair, not the tape!



Hair in holder

Put on the laser safety glasses and release the laser beam!

Procedure



This pattern should appear on the screen.

Measure the distance **d** in cm between the center of the brightest stripe/dot (maximum 0th order) to the center of the second brightest stripe to the right or left of it (maximum 1st order).

Determine the distance **D** in cm between your hair and the screen. Use the measuring tape for this!

For a **hair of thickness h**, which is illuminated with a laser of **wavelength λ** (red: λ =633 nm = 0.633 micrometers, green: λ = 532 nm = 0.532 micrometers), the following formula results :

$$\mathbf{h} = \frac{\mathbf{3}}{\mathbf{2}}\lambda\frac{\mathbf{D}}{\mathbf{d}}$$

Now use your measurement results and this formula to calculate your hair thickness in micrometers.

Tip: Enter the wavelength in micrometers in the formula!

For anyone interested:

Click here for the derivation of the formula for the double slit and here for the formula for the single slit.

Quiz

How thick is your hair?

Which answer is correct?

a) 50 - 200 nanometers

b) 50 - 100 micrometers

c) 500 - 1000 micrometers

d) 1 meter or more

For advanced students:

Would you like to determine the distance between the grooves on a CD or DVD? Then click here!

Answer b) is correct.

3D Vision

How does the 3D glasses turn two images into one and why do we see it in 3D?

In a 3D movie theater, you only see a strangely blurred image without glasses. However, it is actually two images that are **overlapped**.

With the right glasses, however, you get the special 3D effect. How does it work that the glasses separate the overlapping images and transmit them into the **correct** eye?

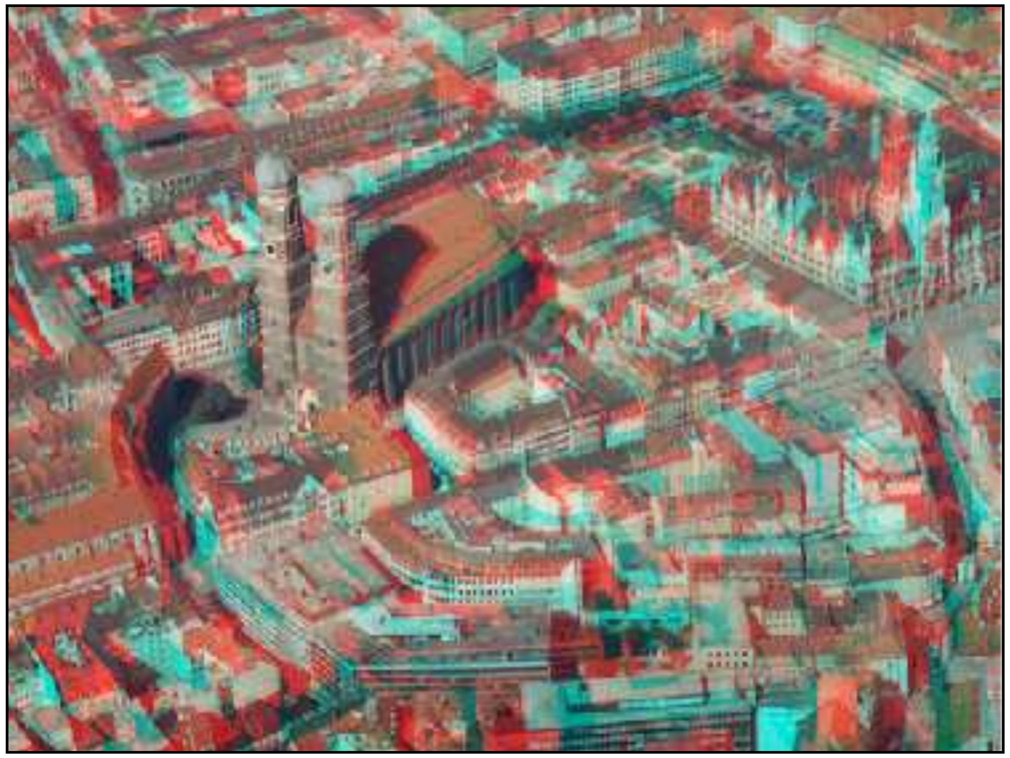
https://www.simplyscience.ch/system/html/3D_Kino_shutterstock_75005647-b3eaf11c.jpg

https://www.dinosaurier-interesse.de/web/Bilder/Saurierarten/tyrannosaurus.html

Basics

The key point:

Stretch your arm in front of you with your thumb pointing upwards, now close one eye in turn.



What do you notice? And what does this have to do with 3D?

In everyday life, we 'automatically' see everything in 3D, as our brain combines the two different images from our eyes into one single image.

If you want to imitate this effect with pictures or videos, you have to take **two pictures from different positions**. The distance between the positions is as large as the average eye distance (between 50-70 mm for adults).

It must then be ensured that only **one of the images is perceived by the corresponding eye**. This can be achieved by using various techniques. Nowadays, **(colour) anaglyph technology**, polarization, shutter glasses or layer displays are mainly used. In our experiment, we take a closer look at the first two of these techniques.

https://www.flexicad.com/bild.php?id=6260

Anaglyph technique: Setup

1. Place the blue and red slides with writing facing the screen very close to the lamp. (You can also use a colored slide with a different motif and the color filters).

2. **Attention:** There should no longer be any rainbow colors or edge rays visible on the canvas!

3. Position the lenses until the images overlap and are in focus. **Do not move or turn the lamps!** (They should be slightly tilted towards each other).

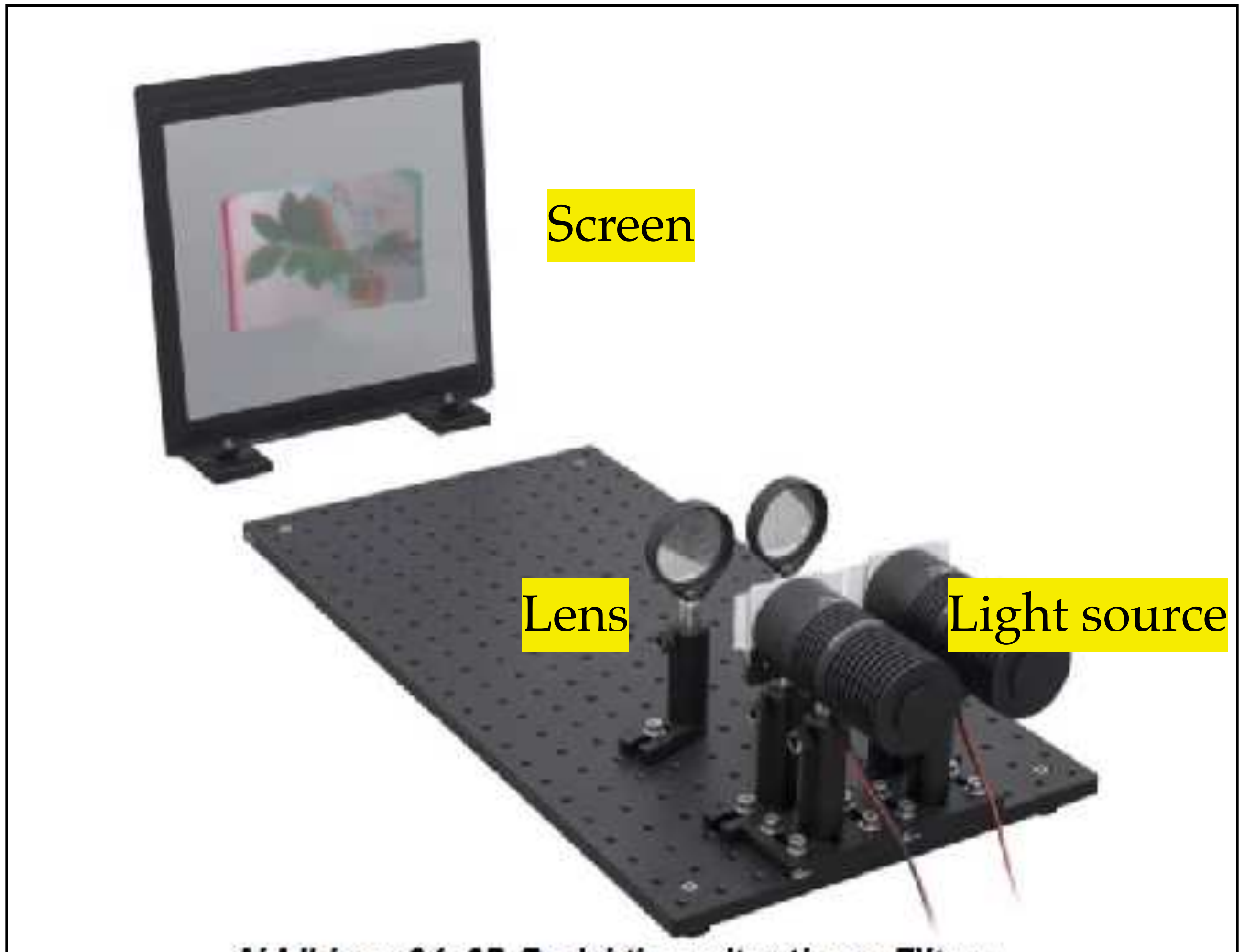


Abbildung 34: 3D-Projektion mit rot/cyan Filtern.

Image: Instructions THORLABS

Anaglyph technique: Procedure

4. Now put on the anaglyph glasses (blue/red lenses) **UNDER** your laser safety glasses.

5. If necessary, make fine adjustments by looking over the lamps at the screen. **Caution: the lamps can become hot during prolonged operation.**

Are you satisfied with the result?

*For experts (and anyone who wants to become one):

Why do you see natural colors in the picture, even though one slide is red and the other is blue?

Click here for the solution!

Practical experiment: Polarization

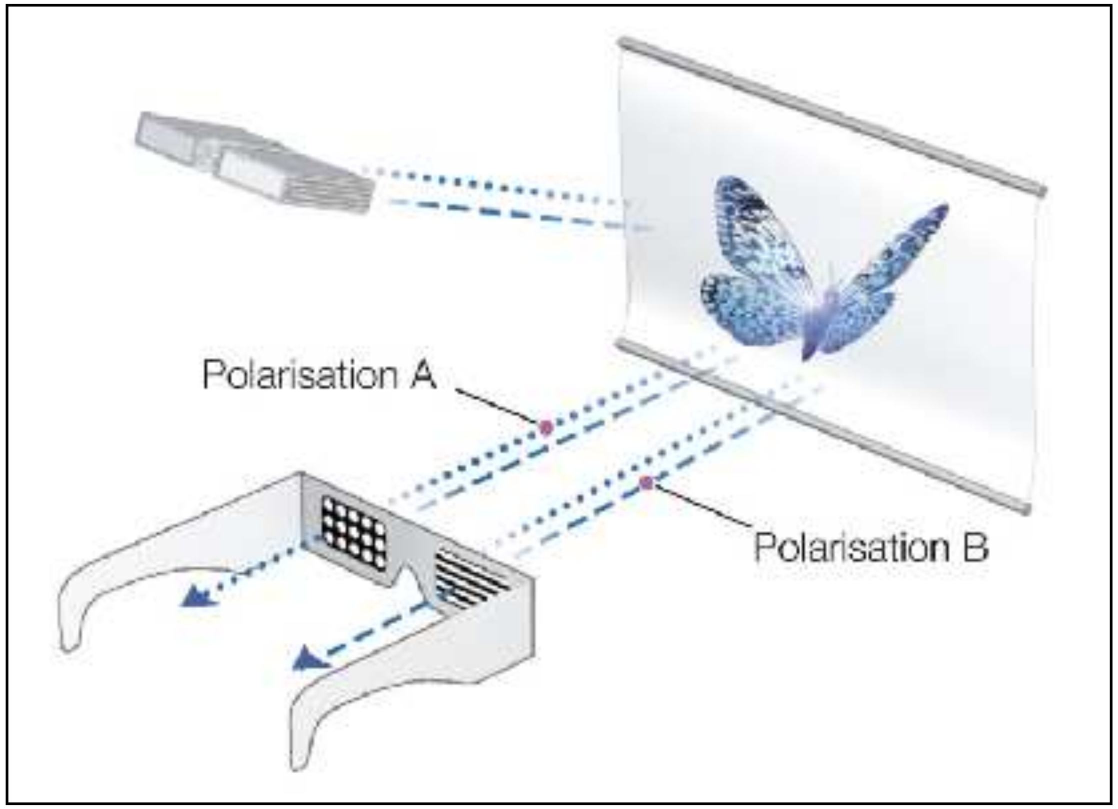
Polarization filters do the same thing to slides as colour filters; they ensure that each eye receives the correct information.

Practical experiment:

Put on the (linear) glasses **UNDER** your laser safety glasses.

Now look at the LCD television. This already emits polarized light.

Take an additional polarization filter, close one eye and turn it until it goes dark.



How can we transfer what we have observed to our experiment? Do you have any ideas?

If you are even more interested in the phenomenon of polarization, then go to the "Polarization" station (chapter 15)!

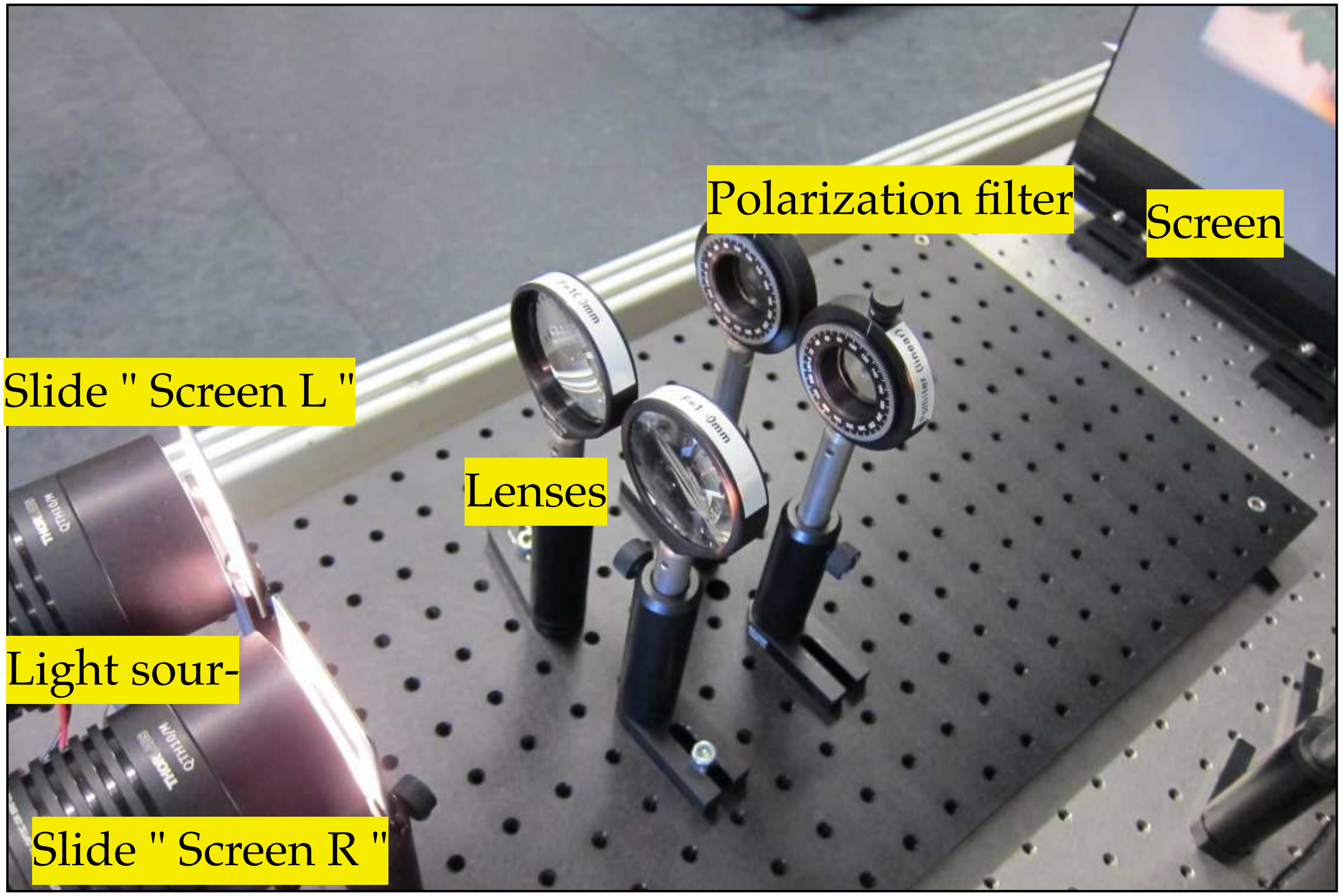
http://www.chip.de/artikel/3D-TVs-im-Technik-Duell-Polarisation-versus-Shutter-2_51183986.html

Polarization (linear): Experimental setup

1. Place the slides with the writing facing the screen very close to the lamp. **Important**: You should no longer be able to see any rainbow colors or edge rays on the screen!

2. Position the lenses to ensure that the images overlap and are in focus. **Do not move or turn the lamps!** (They should be slightly tilted towards each other).

3. Place the polarizing filter behind the lenses.



Polarization (linear): Procedure

4. Put on the (linear) polarization glasses **UNDER** your laser safety glasses.

5. Cover the left lamp first by placing a black metal between the slide and the lens. Now close your left eye. Now you should only see the right image with your right eye.

6. Now turn the right polarizing filter until the image on the screen is as dark as possible.

7. Do the same with the left filter. (To do this, cover the right-hand slide and only look through your left eye).

8. Uncover both images and look at the image across the lamps

For each person, the 3D effect is perfect in a different place; if your partner has made the settings, you may need to adjust them!

In the movie theater, this technique is still slightly modified, if you want to know more about it, you can read it here!

For experts: Circular polarization (RealD)

Experiment:

Take one of the 3D glasses (circular) and hold them 'the right way up' (the way you would put them on) in front of the TV.

A LCD display always emits polarized light.

Now turn the glasses.

What do you notice?

Now take the glasses 'upside down' and turn them again. What can you observe?

Solution!

http://www.cineplex.de/media/0beb9fa2c9ca6f2/650

Polarization (circular): Setup

1. Use the linear polarization setup. This can easily be supplemented.

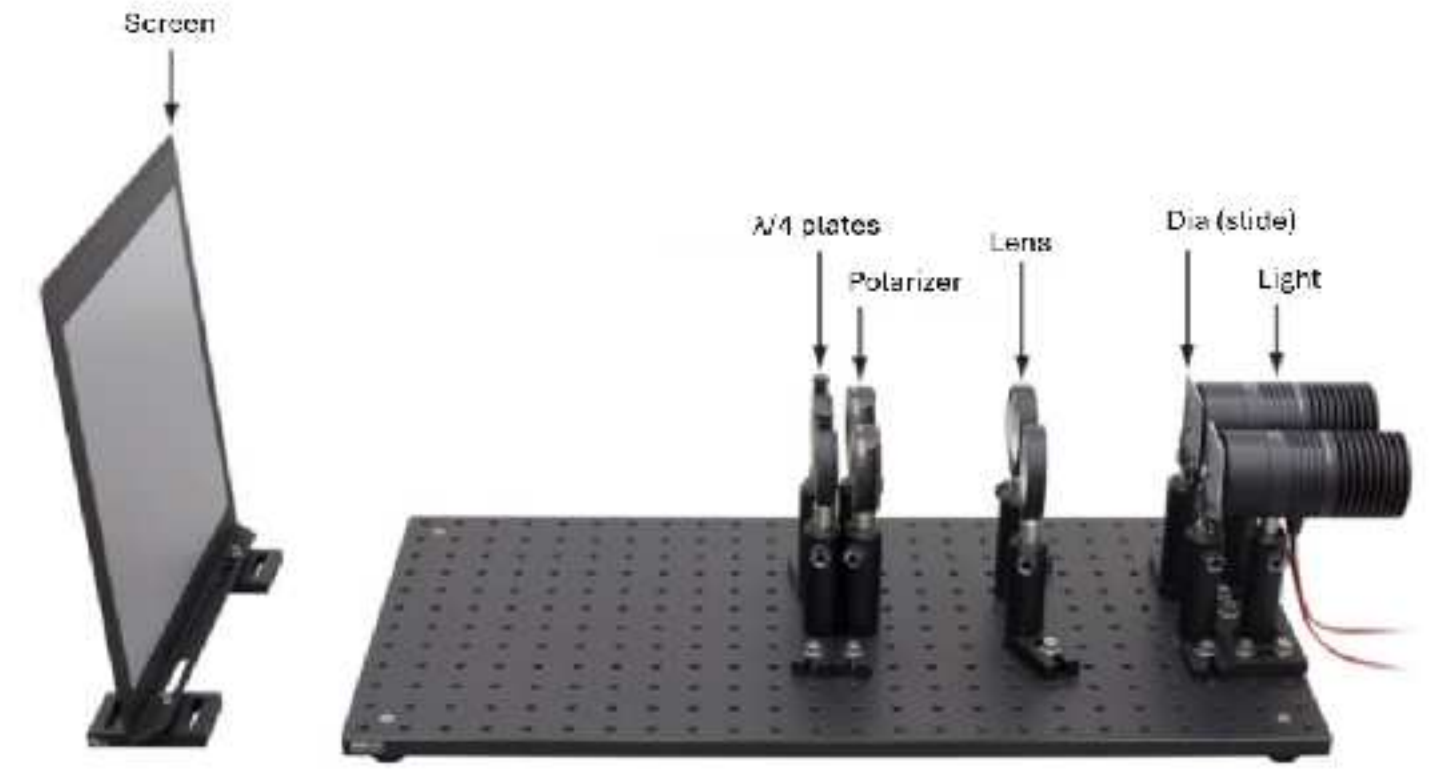
2. Set the polarizers as followed:

   Right polarizer: 255°

   Left polarizer: 182°

The values were measured in advance in a special procedure to match the $\lambda/4$ plates!

3. Place the $\lambda/4$ plates into the beam path, preferably directly behind the polarizers.



Picture 23: Polarizers and λ/4 plates in the beam path

Image: Instructions THORLABS

Polarization (circular): Procedure

4. Put on the circular/realD polarization glasses UNDER your laser safety glasses.

5. Adjust the $\lambda/4$ plates: First cover the left lamp and close your left eye. Look at the screen with your right eye. Carefully open the screw on the $\lambda/4$ plate and turn it (do not touch directly on the plate!) until the image on the screen appears as dark as possible. (The easiest way to do this is to work together in pairs). Finally, carefully close the screw again.

6. Repeat the process for the other eye/image.

7. Now look over the lamps onto the screen again.

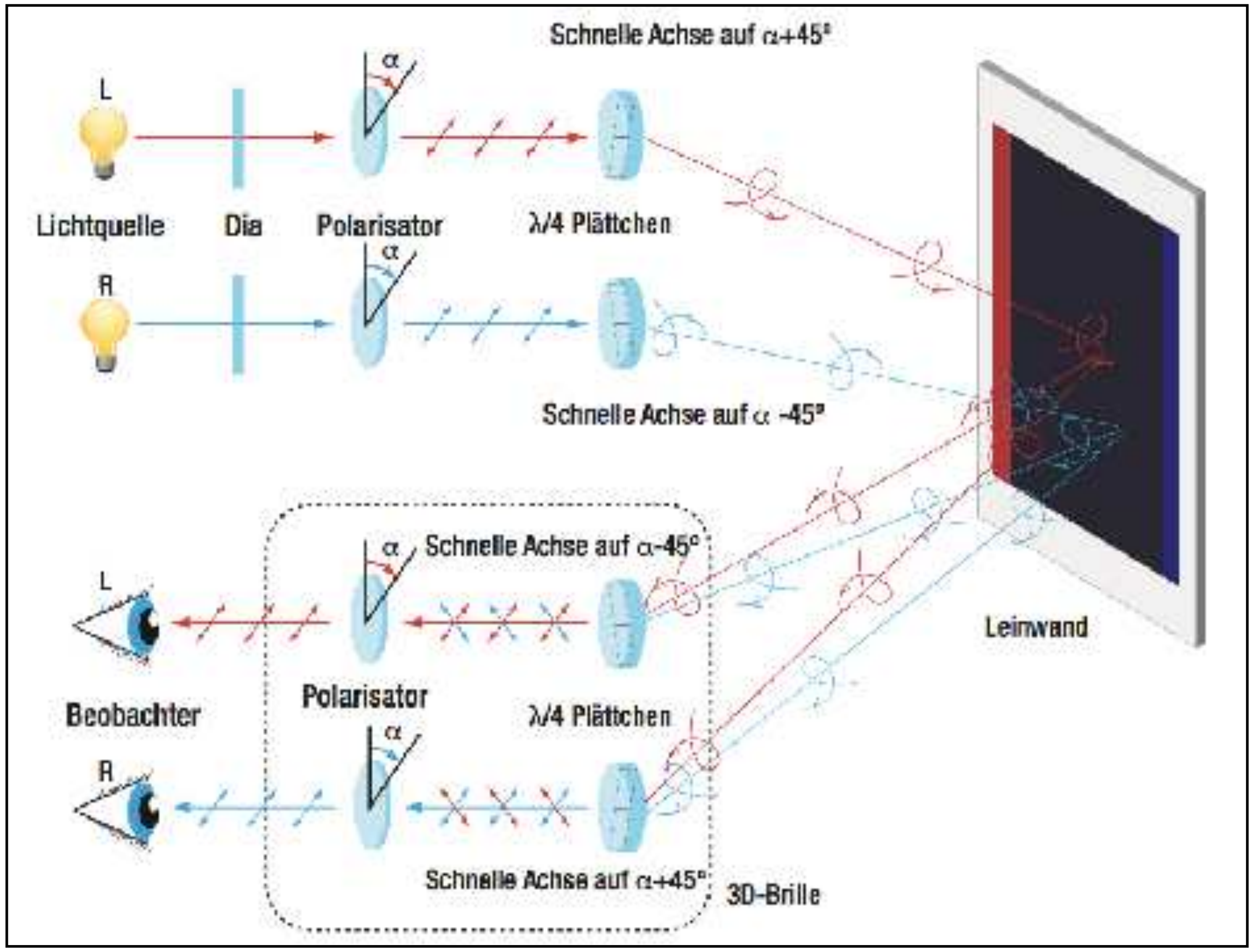
Turn your head slightly in both directions, what do you notice? Is the effect disappearing?

Polarization (circular): Explanation

In circular polarization, the light beam passes through various stations.

The first is a polarizer, which polarizes the light linearly in the same direction for each eye.

The second is the λ/4 plate or retardation plate. It turns linearly polarized light of a certain wavelength into circularly polarized light (and vice versa). Depending on the orientation of the platelet, the transmitted beam is left- or right-circulated.



When the beam hits the coated screen, it is reflected and experiences a phase shift of 90°. This means that the previously right-circulated beam is now left-circulated and vice-versa.

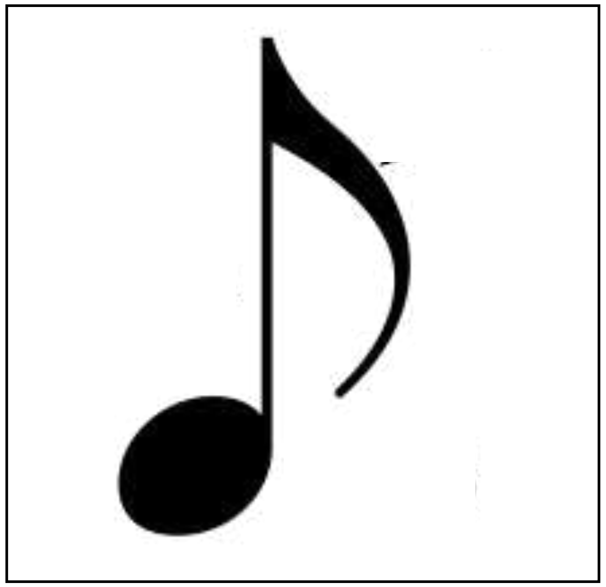
When it hits the glasses, steps one and two are performed in reverse order.

This ensures that we only ever receive one of the images in the eye intended for it. This technology also allows us to move our head in the cinema, as it does not matter from which angle the light hits the glasses.

Image: Instructions THORLABS

EXPERIMENT 4: MUSIC TRANSMISSION

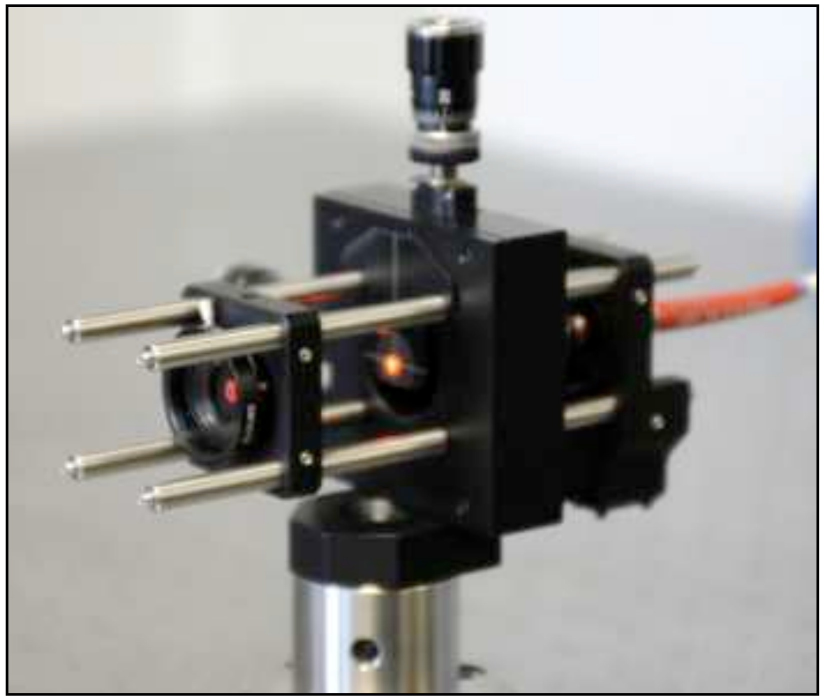
Music transmission



How can a laser transmit music?

Like a cable, a laser can be turned on and off. In the case of a cable, this corresponds to current flowing through the cable or not - in other words, there can be voltage in the cable. This is why you can also use a laser to **send data**. The electrical signals are converted into light signals.

In this experiment, you can transmit music from a YouTube video or your cell phone to the loudspeaker using a laser.



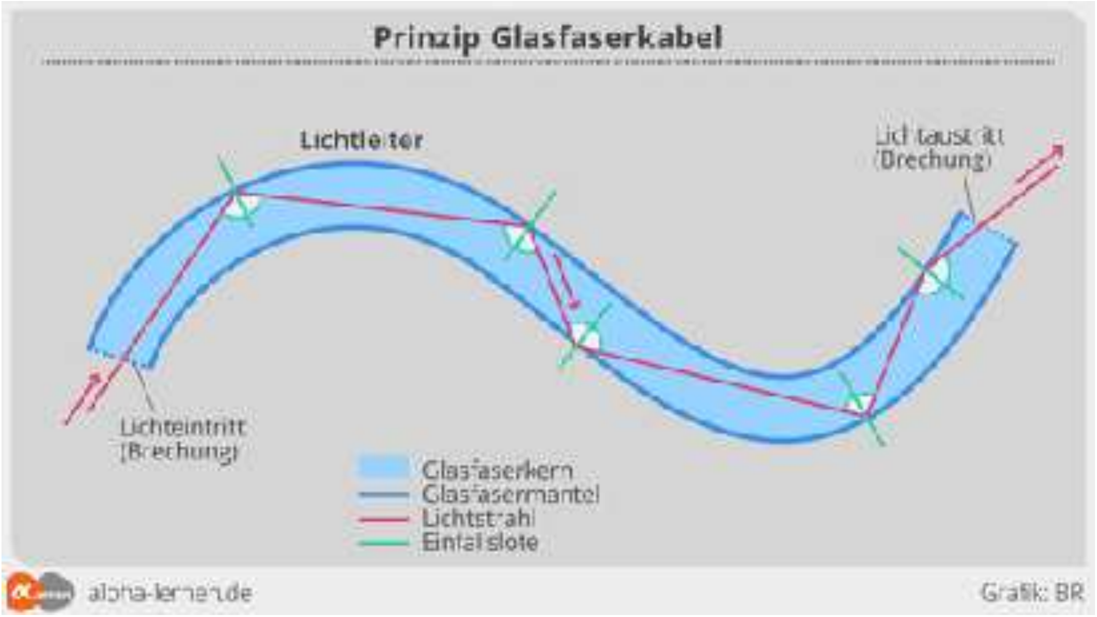
Adjustment aid

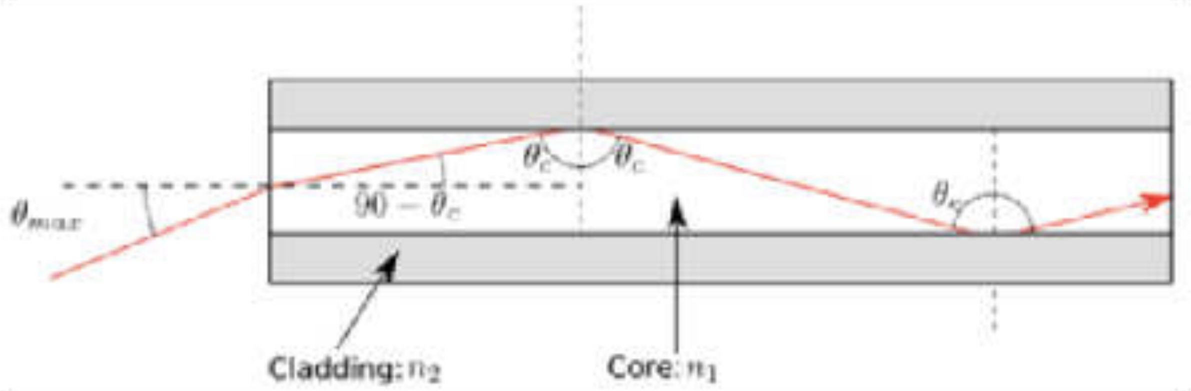
http://de.wikipedia.org/wiki/Note_(Musik)#mediaviewer/Datei:Parts_of_a_musical_note.svg

Image: Thorsten Naeser, MPQ

Basics

When light hits a boundary layer of different media with different refractive indices, refraction occurs. Optical fibers consist of a core material that has a significantly higher refractive index than the mantle material. As a result, when a light beam hits the boundary layer at a flat angle, total internal reflection occurs and the light beam moves along the fiber. The same effect also occurs when light is reflected at the interface between water and air. This is why a jet of water can also act as a light guide. However, because total internal reflection only occurs when the light strikes at a sufficiently flat angle, only light that falls within an acceptance angle into the light conducting path is transmitted.

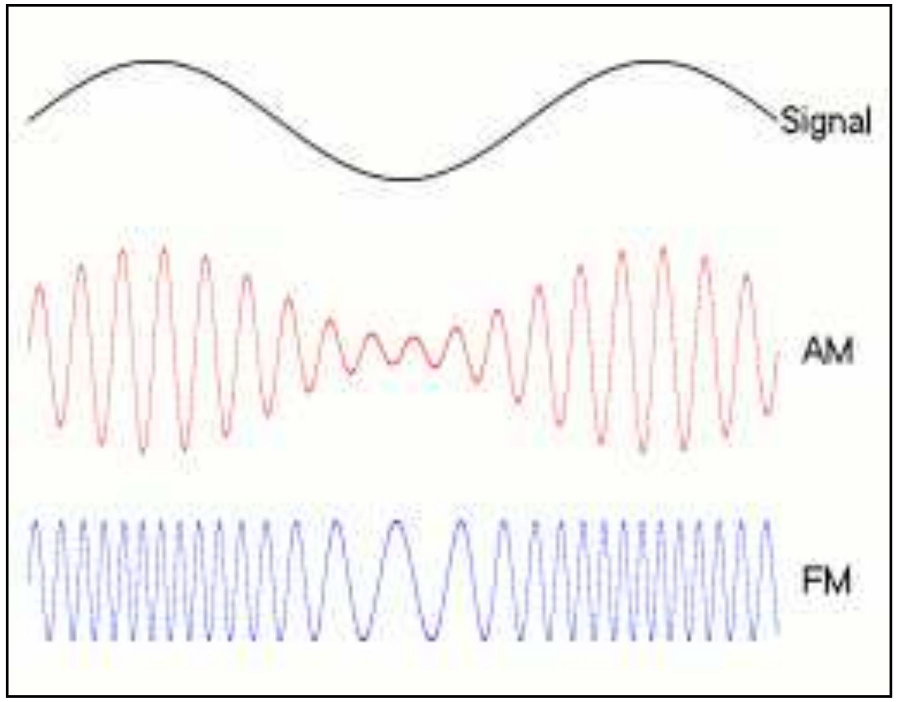




Totalreflexion, Hecht, Optik

Theory

In this experiment, electrical signals are converted into laser signals. This is called modulation. The stronger the electrical signal, the stronger the laser emits light. This is done with the assistance of a laser modulator.

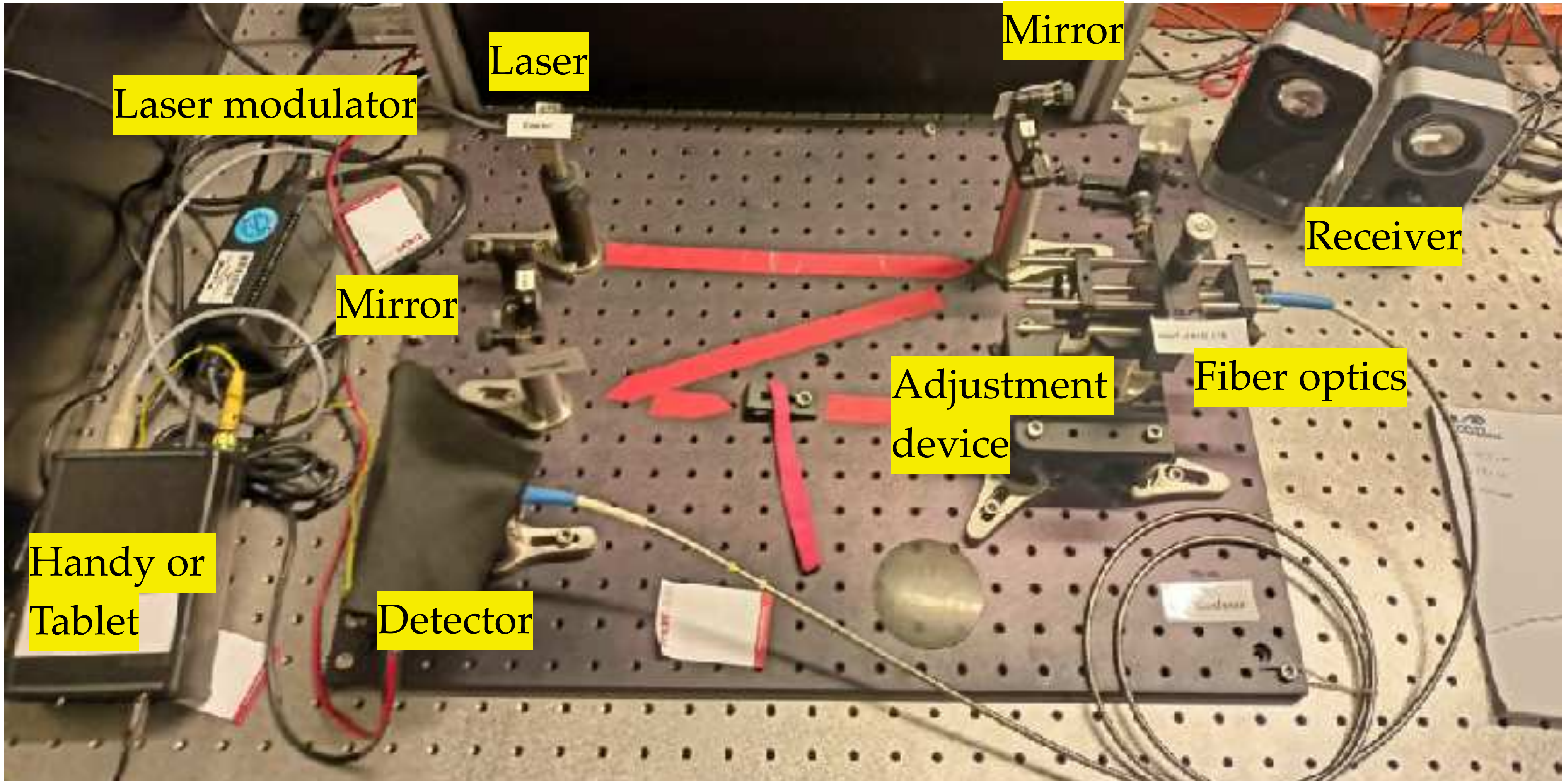


With modulation, a signal (e.g. music, speech, data) can be transmitted due to a carrier. This carrier is modulated, i.e. changed so that the envelope of its intensity change corresponds to the signal to be transmitted (**amplitude modulation**). Alternatively, the frequency can be changed accordingly (**frequency modulation**).

Here you can find the circuit layout of this device.

http://de.wikipedia.org/wiki/Datei:Amfm3-en-de.gif

Procedure



The experiment should be set up as shown in the picture above. If this is not the case, you can find further information on the setup here.

The goal is now to **focus** the laser beam into the light fiber in such a way that a red spot of light can be seen on the receiver. Only the adjusting screws on the two mirrors should be used for this.

Caution:

Put on laser safety glasses and switch on the laser pointer!

Do not bend the fiber optic cable too much!!!!

Do not touch the fiber optic cable, the mirrors or the receiver!!!!

Adjustment : The screws on the mirror mounts change the tilt of the mirrors. The aim is for the laser light to fall onto the center of the **closed** iris diaphragm (then there is still a small hole in the center) and then through the center of the target. Then open the diaphragm and remove the target, the light should then fall into the fiber optic cable and be visible at the other end. Otherwise repeat the procedure.

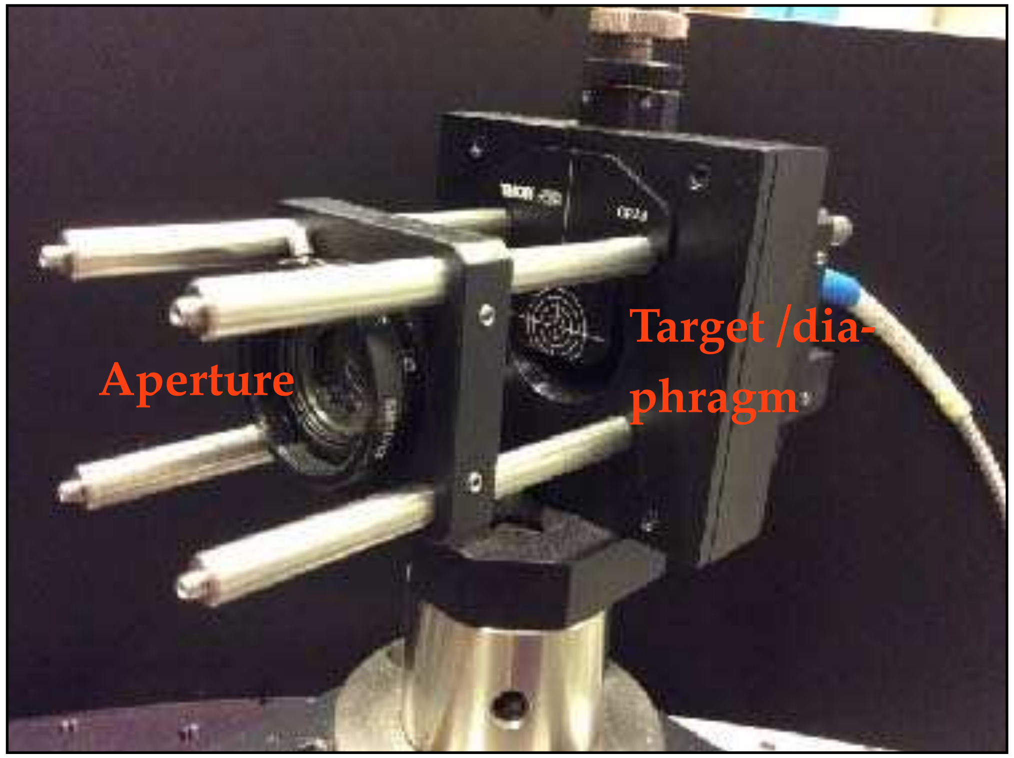
The light should now also hit the receiver! To turn on the **music**, connect your iPad to the WLAN "MPQ-Guests" and use the user name "PhotonLab" and password "PhotonLab". Now select a **YouTube video** and set the sound and speakers to maximum. Connect the iPad to the device using the AUX cable.

Hold your **hand** or a polarization filter in the beam path! What happens?

Also try out the **laser guitar**: Take a rubber band, stretch it and pluck it. Hold this vibrating "string" in the beam path.

Adjustment tool

The light beam should hit through the **center of the closed aperture** **and** **through the center of the target** (a small hole in the center is open on both). Once this has been achieved (only by adjusting the two mirrors), the diaphragm can be opened and the target removed. At least some light should then leave the fiber optic cable. Check this with a piece of paper. To do this, hold the piece of paper between the detector (under the black cloth) and the output of the fiber optic cable. Then readjust the mirrors until the light is as bright as possible.



Quiz

What do you observe if you place a polarization filter vertically in the beam path and then rotate it (it remains vertical)?

A. The sound gets louder

B. The sound gets quieter

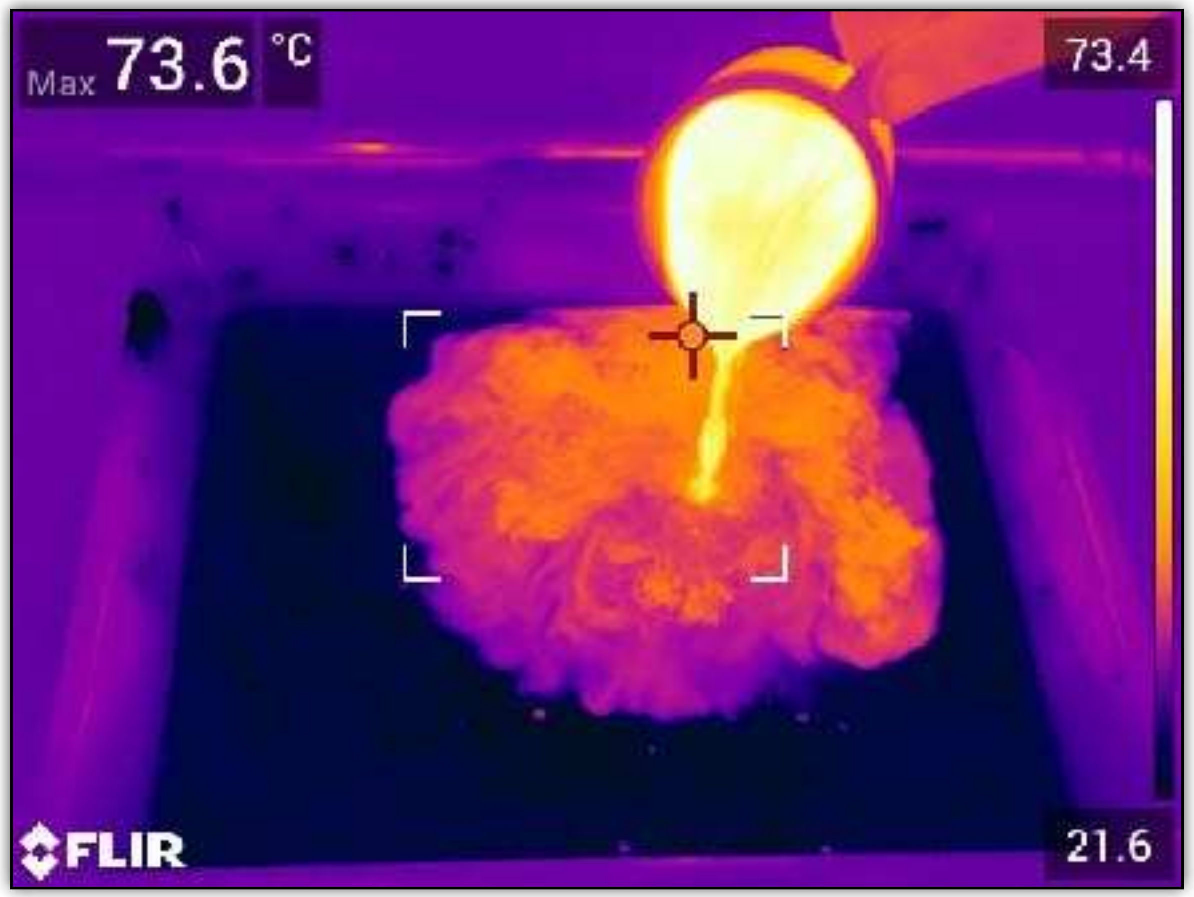
C. There is no sound

D. The sound gets louder and quieter again

Correct answer: D

Infrared light

On the Trail of Climate Change with Infrared Cameras



In this picture, hot water is added to cold water.

Infrared radiation falls within the wavelength range of **780 nm** and **1 mm**. Although it is not visible to the naked eye, we can sense it as heat. For instance, the warmth of the sun is perceived by the nerves in our skin as infrared radiation. This is due to the fact that all objects with a temperature **above absolute zero (0 K ≈ -273.15 °C) emit infrared light**.

As objects with higher temperatures emit a different wavelength than those with lower temperatures, temperature differences can be visualized. This is the fundamental principle of **thermography**.

Part 1: Thermal imaging camera

Making heat visible

All bodies emit thermal radiation, regardless of their temperature.

A thermal imaging camera translates this radiation into visible light, which is then displayed.

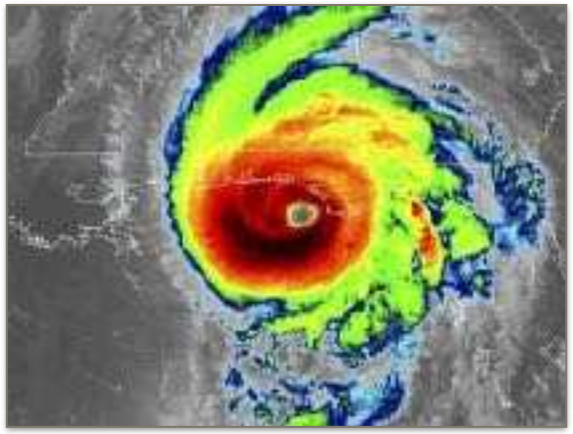
Applications

From space research to medicine.

On a major assignment with the fire department

Mid-infrared image of a galaxy

Thermographic image of a person



Infrared image of a tropical storm

1. Thermal imaging cameras are utilized by the **fire department** to locate individuals in low-light conditions, as infrared light can penetrate obstacles such as treetops more effectively than visible light. Additionally, it is easier to locate individuals in smoke.
2. In **space research**, infrared light is employed to visualize through galactic nebulae and determine the distance to galaxies.
3. In **medicine**, thermography is used to measure the body temperature of patients.
4. In **meteorology**, infrared light is utilized to measure the amount of water in the atmosphere and its temperature.

Click here to learn more about the different types of infrared light.

(NASA, JWST https://www.flickr.com/photos/nasawebbtelescope/53150967876/in/album-72177720305127361/
(https://www.researchgate.net/figure/Infrared-satellite-image-captured-at-approximately-1140-am-EDT-as-Hurricane-Michael_fig2_328881020)
https://www.rosenbauer.com/wp-content/uploads/2015/05/argus_057.jpg

How to: Thermal imaging camera

Camera start and function

1. **Plug in battery**
   Remove from the charger and insert it into the thermal imaging camera.
2. **Activate**
   Press and hold the button at the bottom right briefly
3. **Manuel focusing**
   Turn the wheel behind the lens
4. **Automatic focusing**
   To activate automatic focusing, press the small trigger located at the top.
5. **Photography**
   To take a photo, press the large trigger (below). Please delete the pictures again.
6. **Rangefinder**
   To measure a distance with the laser, press and hold the laser button and aim at the target.

Do you want to learn about the functionality and operation of the thermal imaging camera?

Click here for detailed instructions.

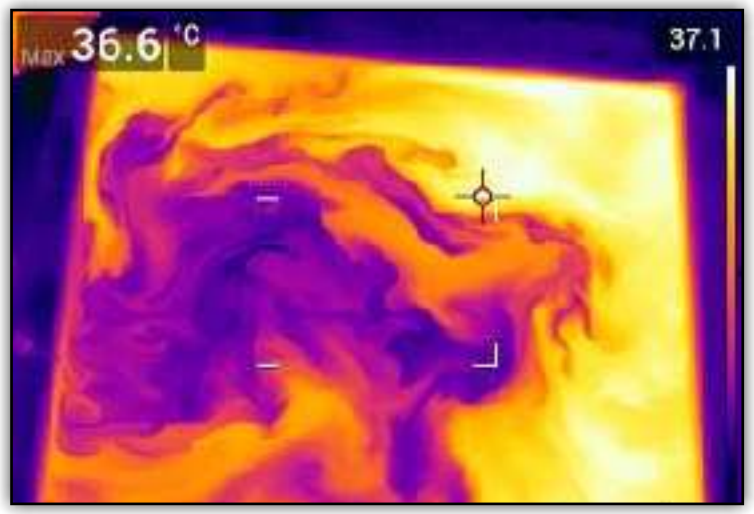
Experiments

1) Camouflage coat

1. One of you hides behind the rescue blanket.
2. Then point the thermal imaging camera at the blanket and the person behind it.
3. What can you see and what can't you see?

2) Air balloon

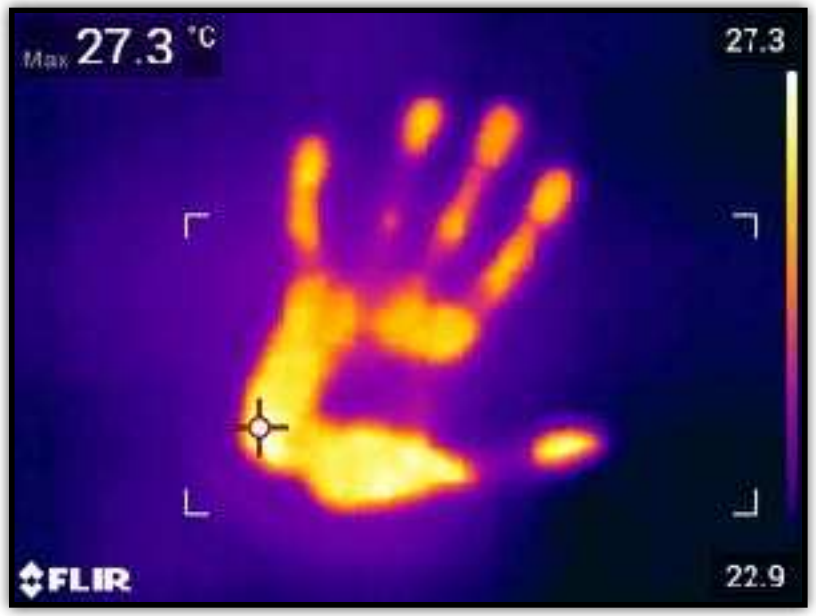
1. Position the inflated balloon in front of your face.
2. Your team partner points the thermal imaging camera at the balloon.
3. Observe the supposed temperature difference on the objects behind the balloon.



3) Water (optional)

1. Fill one plastic cup with hot water and one with cold water in the sink. The cups must always be **in** the sink.
2. What difference can you see with the thermal imaging camera?
3. Carefully empty the cups in the sink and observe how the hot water mixes with the cold water.

Experiments



4) Handprint

1. Place one hand on the (non-metallic) wall.
2. Look at the spot on the wall through the thermal imaging camera.

5) Reflection

1. Place one hand over a metallic surface (e.g. the lab bench).
2. Point the thermal imaging camera at the hand and the metal and observe the reflection.

6) Rubber band

1. Hold a rubber band approx. 10 cm in front of the camera lens and stretch it.
2. When stretched, let it cool down to room temperature.
3. Let it collapse again and observe the temperature difference.

7) Footprint

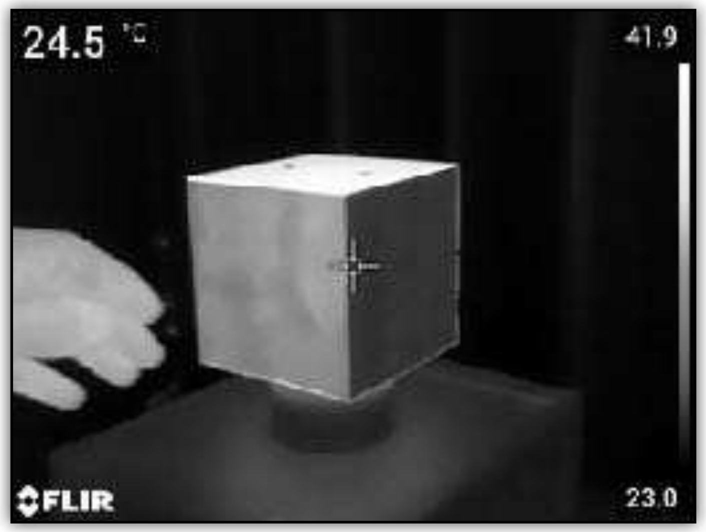
1. Rub the floor with your feet.
2. Look at the spot on the floor with the thermal imaging camera.

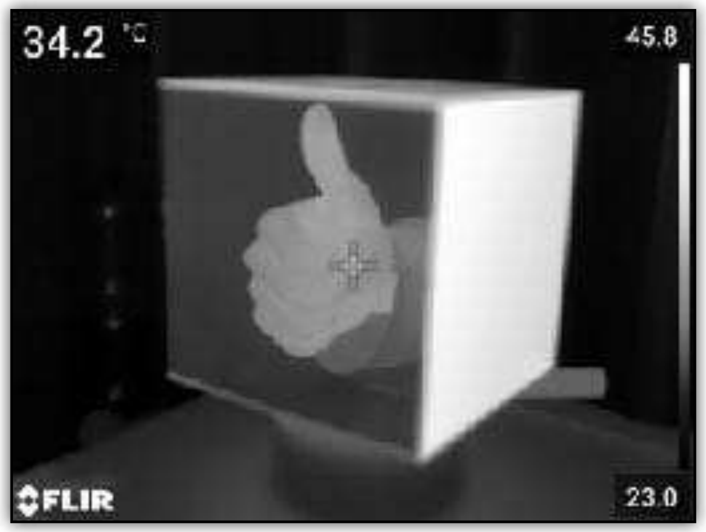
It's all about the surface

8) Laslie cube

1. Switch on the Laslie cube at the back (plug in the power cable if necessary).
2. After a few seconds, point the thermal imaging camera at the sides of the cube.
3. Now measure the surface temperature of the respective sides.

Laslie cube in the lab





The Laslie cube exemplifies how surface properties affect infrared imaging. Despite having uniform temperature across all sides, the thermal camera detects varying temperatures due to differences in reflection properties and emission factors.

The surface with the highest emission factor and lowest reflection, namely the matte black surface, reflects the actual temperature most accurately. In contrast, all other surfaces emit weaker infrared radiation, which does not necessarily indicate a lower temperature.

Source: https://www.3bscientific.com/leslie-cube-with-heater-115-v-5060hz-1017729-u8498299-115-3b-scientific,p_887_26818.html

Part 2: IR in the atmosphere

Making climate change visible

Electromagnetic waves carry energy from the sun to the earth. A fraction of this, visible light, passes through the atmosphere almost unhindered. It reaches the ground, which partially absorbs the light. The ground then radiates this absorbed solar energy back into space as long-wave infrared heat radiation.

Without the atmosphere, all of this heat would be lost to space, and the temperature on Earth would be about -18°C!

The picture gives you a glimpse of the experiment that will follow.

Experiment 1 is an introduction for everyone and experiment 2 is for experts and interested parties

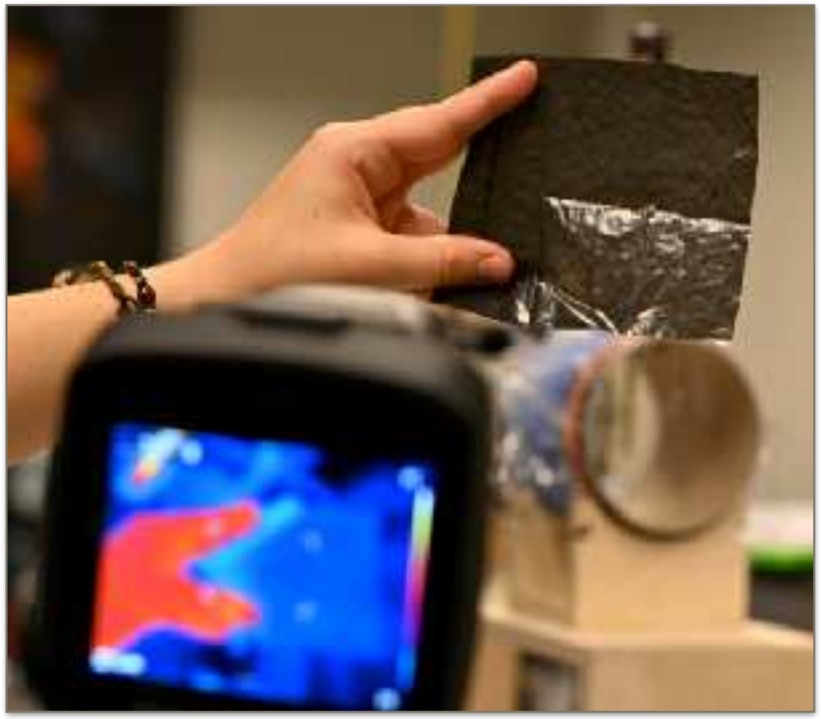
Experiment 1b: Light/IR transmission

Which materials are permeable to light and which to IR radiation?

Visible light and infrared radiation have different properties. Some materials are permeable to infrared radiation (IR radiation), others to visible light - or both, or neither. Complete the table to find out which material is permeable to which radiation!

To do this, point the camera at the objects in the folder as shown in the picture on the right.

Material	Permeable to IR radiation	Permeable to visible light
Glass		
Black bag		
Ballon		
Plastic wrap		



The greenhouse gases in the atmosphere allows visible light to pass almost unhindered, but absorbs infrared radiation. Which of the studied materials also have these properties?

Solution: Plastic wrap and glass

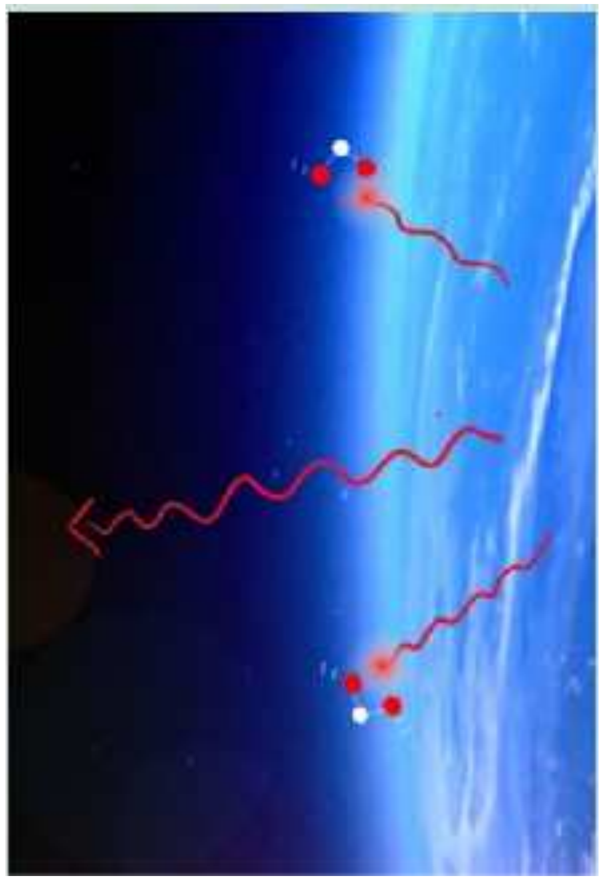
Experiment 2: The effect of greenhouse gases

The Earth's atmosphere is primarily composed of nitrogen (78%) and oxygen (21%). Greenhouse gases such as carbon dioxide (0.04%) and methane (0.0002%) are present in trace amounts, but still have a major impact!

The molecules of greenhouse gases absorb the invisible infrared radiation emitted by the Earth's surface, causing them to vibrate. Some of this vibrational energy is then transferred to particles in the environment in the form of kinetic energy - the atmosphere heats up.

So what happens to the temperature of the atmosphere when humans release large amounts of CO_2 into the atmosphere by burning fossil fuels?

To find out, we must first understand what the greenhouse effect is.



Absorption of IR radiation by the atmosphere

Image: Klimakoffer Handbuch

The natural greenhouse effect

Without the atmosphere, the temperature on Earth would be as cold as -18°C, which is simply too cold for humans.

The **natural** greenhouse effect is therefore vital for our survival. You can now learn exactly how it works.

The earth is in a state of radiative equilibrium with its surroundings. We can take advantage of this: 340 watts per square meter are radiated onto the surface of the earth, of which the it reflects 30% directly back into space. This reflectivity α is called "albedo". The earth therefore absorbs 1-α=70% of the sun's energy. If we multiply this by the intensity that hits the earth, we get the energy absorbed by the earth per square meter:

$$I_{Erdoberfläche} = (1-\alpha) \cdot 340 \frac{W}{m^2} = 238 \frac{W}{m^2}$$

Without an atmosphere, all of the absorbed radiation is re-emitted. Using the Stefan-Boltzmann law, we can now calculate the average temperature on Earth T that would prevail without an atmosphere:

$$I_{Erdoberfläche} = \sigma \cdot T^4 \rightarrow T = \sqrt[4]{\frac{238 \frac{W}{m^2}}{5{,}67 \cdot 10^{-8} \frac{W}{m^2 K^4}}} = -18° C$$

In this context, σ represents the Stefan-Boltzmann constant. ($\sigma = 5{,}67 \cdot 10^{-8} \frac{W}{m^2K^4}$).

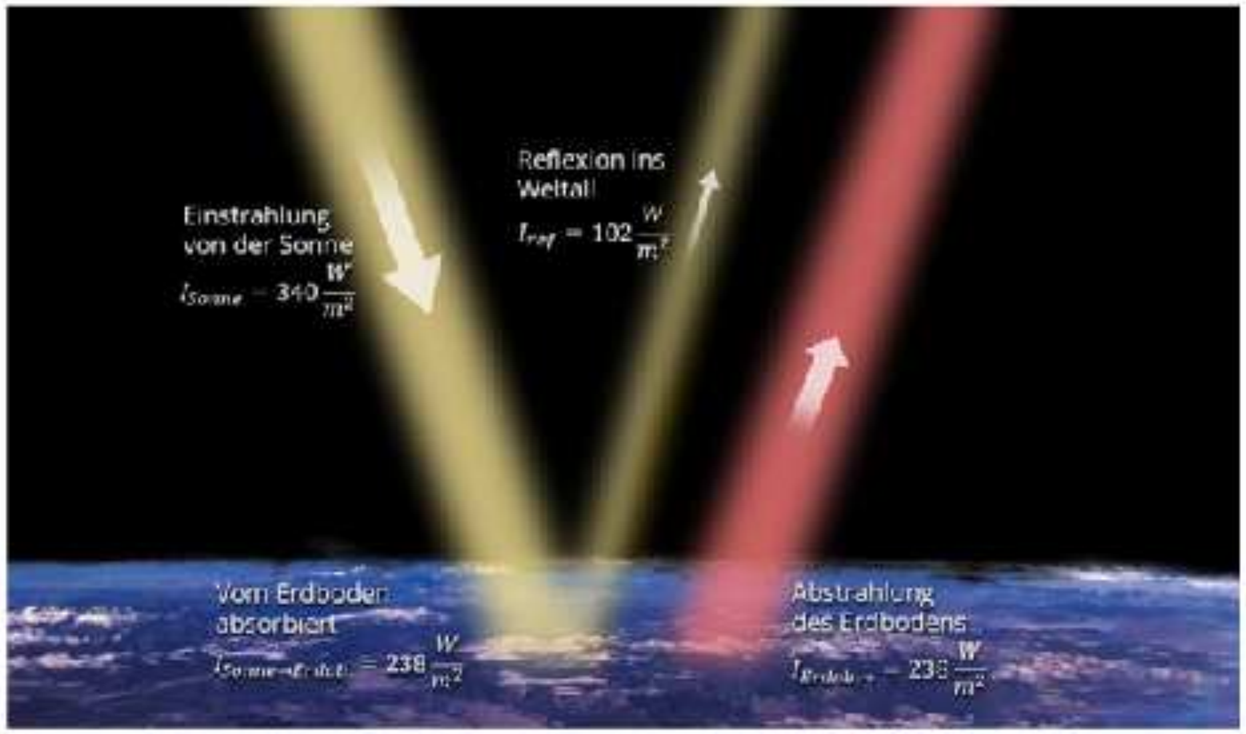


Abbildung 14 - Strahlungsbilanz einer Felsenerde ohne Atmosphäre (Credits: Strähle, Hohmann)

The natural greenhouse effect

With an atmosphere, some of the radiation emitted by the earth is radiated back to earth. The same conditions apply as without an atmosphere, except that greenhouse gases now come into the equation: Greenhouse gases such as CO2, methane and water vapor now have the capacity to absorb some of this thermal radiation emitted from the Earth's surface.

This is taken into account in the pre-factor $\frac{1}{1-0{,}4}$, because greenhouse gases increase the intensity emitted from the Earth's surface, as they absorb around 80% of the radiation emitted by the Earth.

$$I_{Erdoberfläche} = \sigma * T^4 \rightarrow T = \sqrt[4]{\frac{\frac{1}{1-0{,}4} * 238\frac{W}{m^2}}{5{,}67 * 10^{-8}\frac{W}{m^2K^4}}} = 16°\,C$$

Thus, due to greenhouse gases, the average temperature on earth is 16° C, and life is possible!

If you are interested, you can learn exactly how this pre-factor is calculated, just click here.

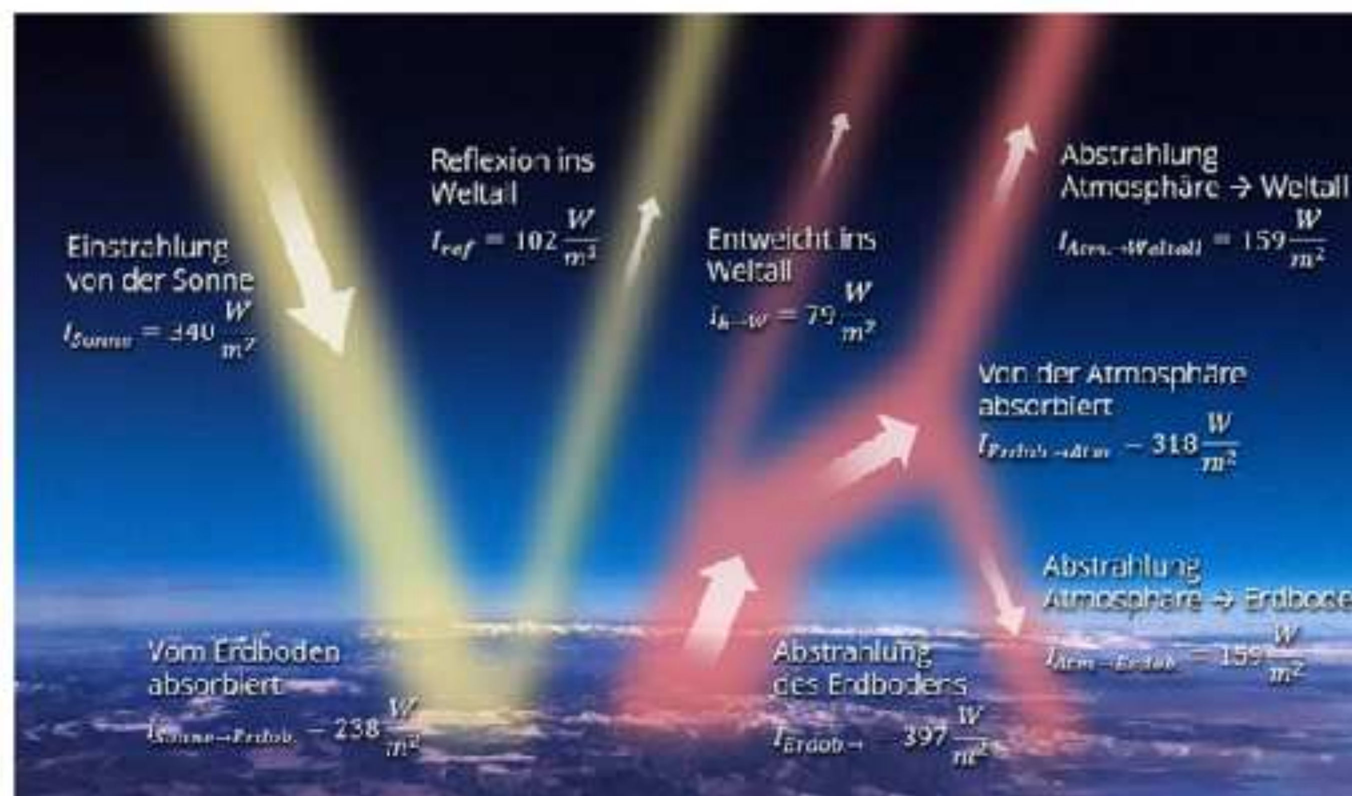


Abbildung 17 – Strahlungsmodell mit Atmosphäre (Credits: Strähle und Hohmann)

What's the catch?

And now humans come into play: the temperature on Earth depends on the ability of the atmosphere to absorb (and thus also reflect back to Earth) thermal radiation from the Earth's surface in the infrared range. So what happens if humans increase this absorption capacity?

Let's assume that humans increase the concentration of greenhouse gases in the atmosphere so that 85% instead of 80% of the radiation emitted by the earth is now absorbed by the greenhouse gases.

The pre-factor now increases to $\frac{1}{1-0{,}425}$.

If we add this changed factor to our calculation, we can then calculate that the average temperature of the earth has increased by 3° C!

$$I_{Erdoberfläche} = \sigma * T^4 \rightarrow T = \sqrt[4]{\frac{\frac{1}{1-0{,}425} * 238 \frac{W}{m^2}}{5{,}67 * 10^{-8} \frac{W}{m^2 K^4}}} = 19° C$$

This global warming has dramatic consequences for the planet because we are disturbing the natural carbon cycle and causing the planet to heat up. You are certainly aware of the consequences of anthropogenic climate change, such as rising sea levels, higher probabilities of more severe natural disasters, the extinction of many animal species and the increase in heat deaths.

In the following experiment, you can see for yourself what happens to the temperature of the atmosphere when humans release large amounts of CO_2 into the atmosphere by burning fossil fuels.

https://www.swr.de/wissen/1000-antworten/1658307444646,waldbrand-klima-100~_v-16x9@2dM_-ad6791ade5eb8b5c935dd377130b903c4b5781d8.jpg

Preparation (usually already done)

We need the following equipment for our experiments:

✓ Ceramic infrared heater in protective basket
✓ Cardboard tube on wooden holder
✓ Plugs, cling film and rubber bands
✓ Digital thermometer
✓ Erlenmeyer flask with stopper and tube
✓ Natron, citric acid and water

Experiment: Absorption von Wärmestrahlung I

➞ Place the ceramic infrared heater with the wooden holder on the folded-up feet of the wooden frame and push the wooden holder for the cardboard tube into the two holes as far as it will go (see picture).

➞ Close the large openings of the cardboard tube with cling film and household rubbers and then secure the cardboard tube to the wooden holder with rubbers so that the distance between the infrared radiator and the can is 8 cm.

➞ Insert the thermometer into the small hole in the middle (so that the tip is in the middle of the tube) and seal the other two holes (CO2 inlet and air outlet) with a plug each.

➞ Switch on the infrared heater. Wait until the temperature in the can no longer changes within 30 seconds and you can assume that the equilibrium temperature has been reached (approx. 27 °C). This can take up to 25 minutes if the heater has not yet heated up.

Caution! Very hot emitter: risk of burns! Chemicals: Wear safety glasses!

Image: Klimakoffer Handbuch

Experiment 2.1: Procedure

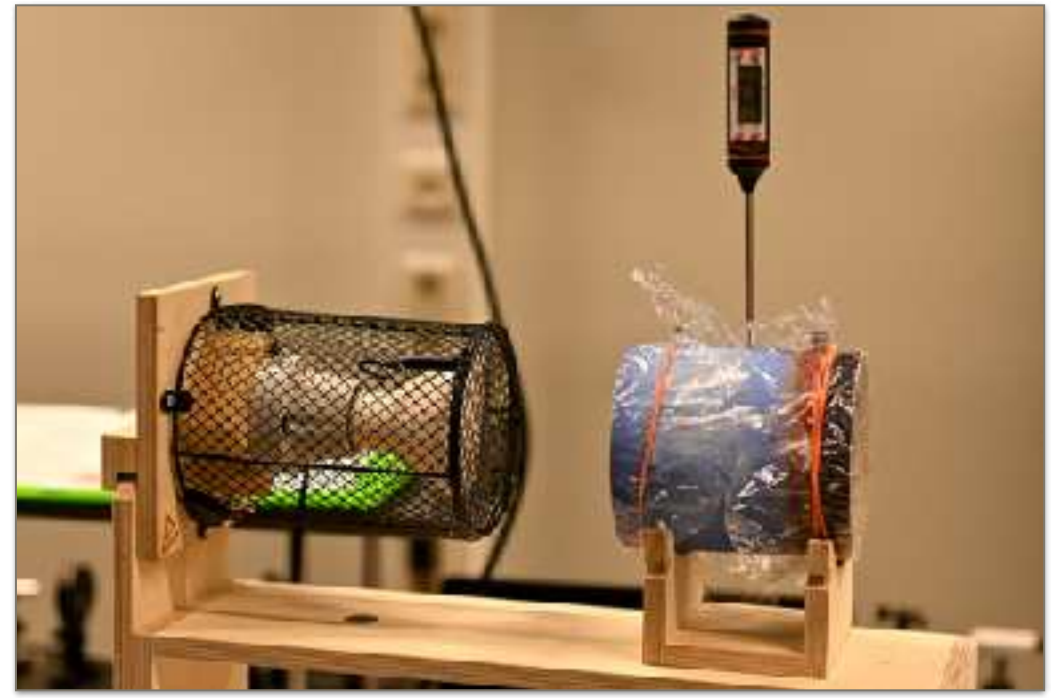
CO_2 absorbs radiation energy

1. start the experiment when the temperature is constant and write it down.

2. **generate CO_2 and feed it into the can**: Mix two teaspoons each of natron and citric acid in the Erlenmeyer flask (still without water) and remove the two small stoppers from the can. Then push the tube through one of the holes, add approx. 30 ml of water to the acid and natron mixture and quickly replace the stopper with the tube!

3. gently swirl the Erlenmeyer flask and remove the tube from the can again after approx. one and a half minutes. Now quickly close the holes again with the small plugs. (1)

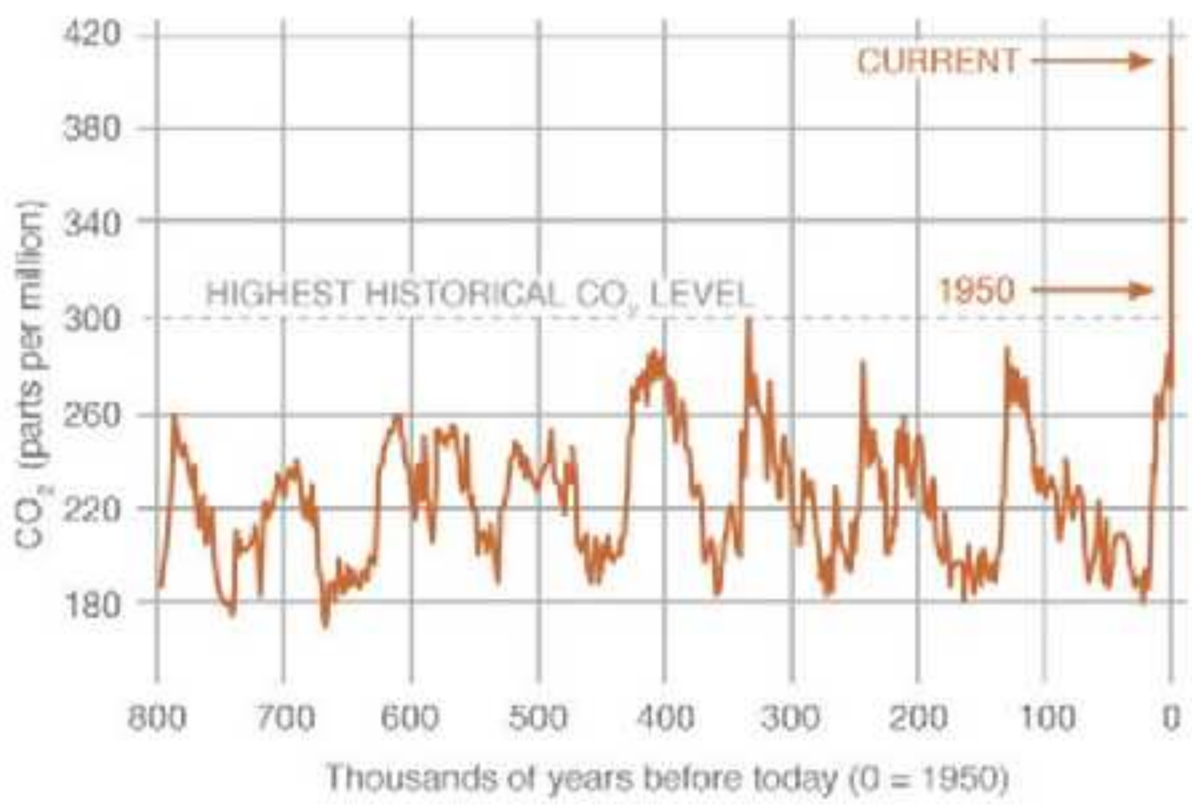
4. observe the measured temperature over the next few minutes and wait until an equilibrium temperature is reached again. Note its value and compare it with the previous temperature.



(1) The CO_2 concentration in the can is now significantly higher - much higher than it is on Earth. This is necessary because the cardboard tube is only a few centimeters long, but the atmosphere is several kilometers thick!

Task

The CO_2 concentration in the atmosphere is measured in parts per million (ppm). This means how many molecules of CO_2 are contained in one million molecules of dry air. Today, the concentration of CO_2 in the atmosphere is much higher than before industrialization (1750).



Quelle: NASA

? Look at the diagram. What has led to the observed increase in greenhouse gas concentration since about the 19th century?

? How does the experiment relate to this data?

! The burning of fossil fuels (e.g. coal, natural gas, crude oil) releases Co_2. Deforestation is also contributing to the increase in greenhouse gas concentrations. As it gets warmer and warmer, the polar ice caps and permafrost soils, under which methane and CO_2 deposits lie frozen, are melting faster. If the ice melts, these greenhouse gases are also released.

! In the experiment: The second temperature value determined is higher than the initial value. The higher CO_2 concentration therefore leads to an increase in temperature in the system (see: Effect of greenhouse gases). In the diagram: The increased CO_2 concentration leads to an increase in the average global surface temperature.

Experiment 2.2: Procedure

Interception of infrared radiation

In addition to measuring the temperature in the can, the radiation that passes through the can (transmission) can also be measured.

Preparation: Position the thermal imaging camera so that the heat radiation through the cardboard tube hits the center of the measuring opening of the thermal imaging camera.

1. wait until the temperature remains constant (as above) and then observe the temperature display.
2. observe the visible image of the thermal imaging camera when filling CO_2 into the cardboard tube.

Quiz

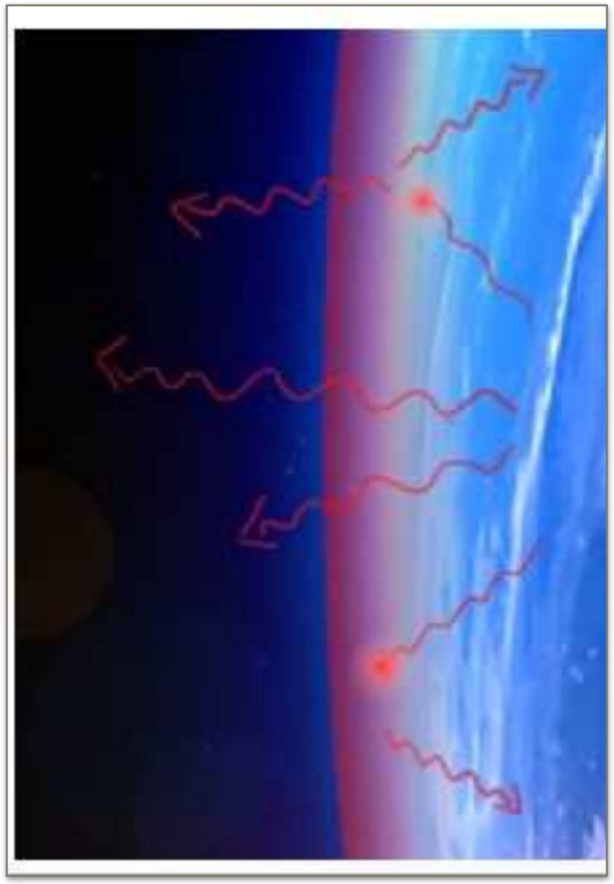
Greenhouse gases in the atmosphere absorb some of the heat radiation emitted by the earth. By absorbing this radiant energy, the atmosphere heats up. Due to this second source of radiation (i.e. sun + atmosphere), the earth's surface warms up - and the more energy the atmosphere absorbs through greenhouse gases, the more it increases. In turn, the atmosphere now emits the absorbed energy equally in all directions, i.e. also towards the earth.

What is the Researcher Question for this experiment?

a. Why does the absorption of infrared radiation in the atmosphere lead to a rise in temperature on the Earth's surface?

b. Why does a warming of the earth's surface lead to an increased CO2 concentration?

c. Why does an emission of IR radiation from the heat source lead to a reflection of visible light in the atmosphere?



Re-radiation of IR radiation through the atmosphere

Image: Klimakoffer Handbuch

Holography

What exactly is a hologram?

Anyone familiar with films such as Star Wars will certainly have heard of the term "hologram". Holograms come from the ancient Greek and mean something like "complete image". In comparison to a classic photo, which only provides a two-dimensional image, a hologram therefore claims to capture an image completely, i.e. to be three-dimensional. But what exactly is a hologram? Let's start with Pepper's ghost:

https://www.filmstarts.de/nachrichten/18518175.html

Peppers Ghost

In the 19th century, John Henry Pepper developed a technique for special effects to amaze theater guests. In the middle of the performance, the ghost of a person appeared between the actors, whom they could not touch.

This technique can be recreated using an iPad and a Plexiglas holopyramid.

1. For this experiment, you need to dim the lights a little.

2. Start a Holo video that you like under "Videos" on the iPad.

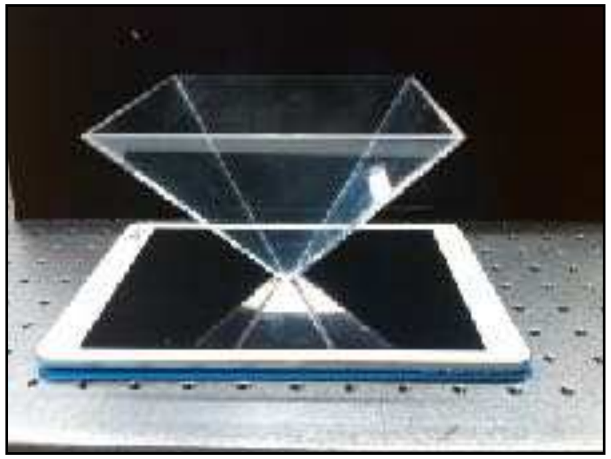
3. Place the iPad on the stand with the screen facing the top of the pyramid. If the image is upside down, place the "holopyramid" with the tip in the middle of the screen. The faces should point towards the pictures.

4. if you now look at the pyramid from the side, you will see a floating image.

Discuss the questions in your group:

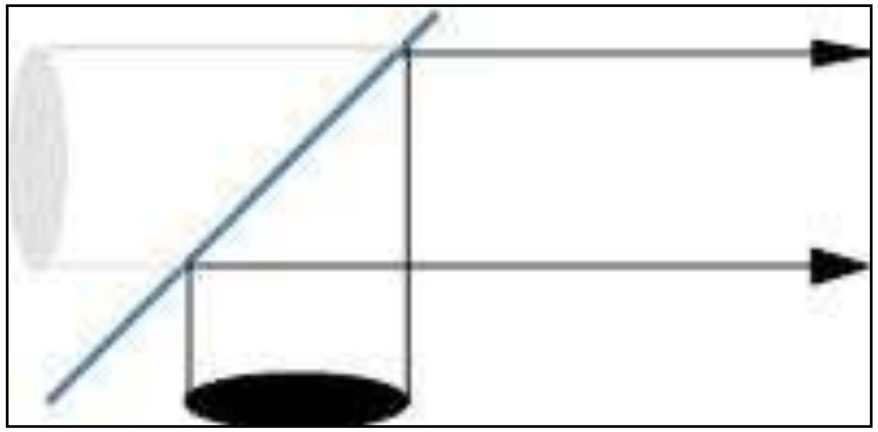
Is this a **hologram**?

And what are the **characteristics** of a hologram?



As beautiful as the floating image looks, it is not a hologram!

It just uses an effect that everyone is familiar with. If you are sitting on a train, for example, you can see other people through the reflection in the windows. They appear to be sitting outside the train, like ghosts in the landscape. The pyramid is therefore simply a reflection of the screen in the glass of the pyramid.



If you move your head while looking at the pyramid, you can see that the perspective on the image does not change. It therefore remains two-dimensional, as on the iPad, even if it floats freely in space. Both properties should be fulfilled in a real hologram.

And if the "holo-pyramid" is already knocking your socks off, then you should take a look at a real hologram.

Image-Source: Zulassungsarbeit von Philipp Müller "Holographie"

Procedure

1. Place the car with the tires on the markings.

2. Switch on the laser. (Put your glasses on your nose!)

3. Look at the car through the window.

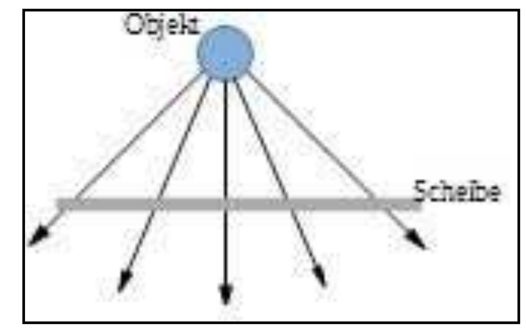
4. Remove the car from the experiment and continue looking at the window.

Is that a hologram?

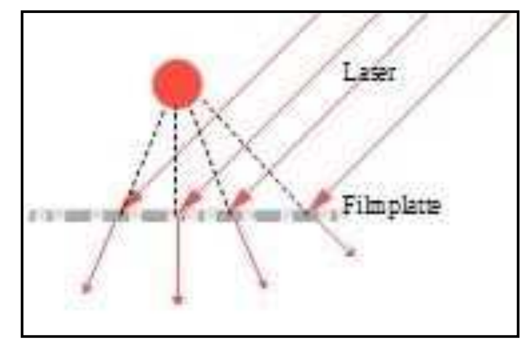
Understanding holography

To understand holography, consider the following **thought experiment**:

1. an object is illuminated with a laser and viewed through a transparent film plate. The light path from the object to the observer is shown here by the black arrows. Logically, the object is seen in three dimensions and from different angles.



2 Now the disk is additionally illuminated by a laser, which is represented by the parallel red beams. A pattern is now burned onto the film plate by the interference of both light sources.



3. if the object is now removed from the experiment and the described film plate is only irradiated with the laser, the laser is **diffracted** at the interference pattern. The diffracted beams now correspond to the former object beams. For the viewer of the film plate, it makes no difference whether the object is **really** behind the film plate or not. The same rays arrive in the eye. The only difference is that the object only shines in the color of the laser.

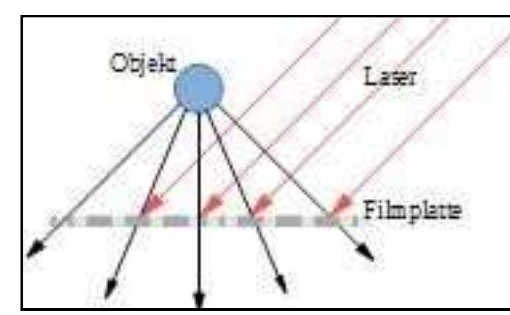


Image-Source: Zulassungsarbeit von Philipp Müller "Holographie"

The physics of holography

For interested readers

If a **wave front** radiates into space from a point of position, we can speak of a **spherical wave**, as the locations of all maxima form concentric spherical shells around the point. The further you move away from the center, the smaller the curvature of these spherical shells becomes. At some distance, it can almost no longer be perceived. A spherical wave in the **far field** can therefore be understood as a plane wave.

This effect is used in the holography process. The simplest setup for recording a hologram consists of a laser and a lens. The lens expands the laser beam, turning it into a spherical wave. If you now place the object and the film plate in the expanded beam as shown in the following picture, the waves reflected from the object (object beam) and the wave coming directly from the lens (reference beam) can interfere on the film plate.

Since the film plate is now in the far field (plane wave) of the reference beam and in the near field (spherical wave) of the object beam, these two wave geometries can interfere.

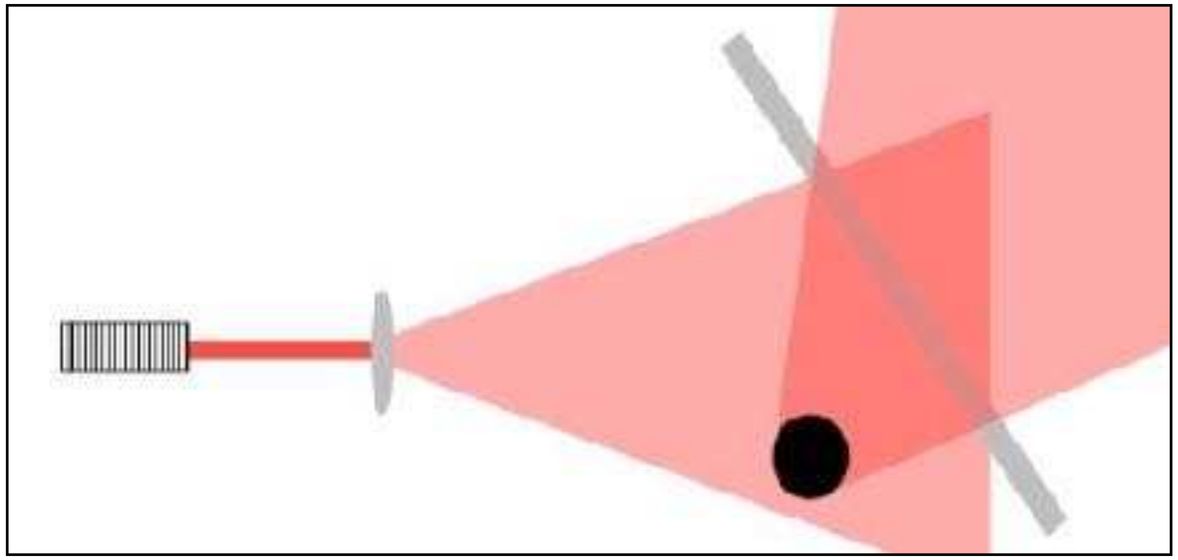
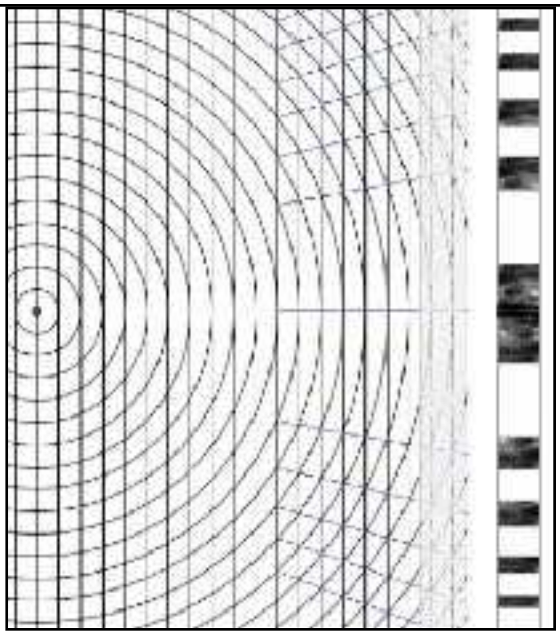
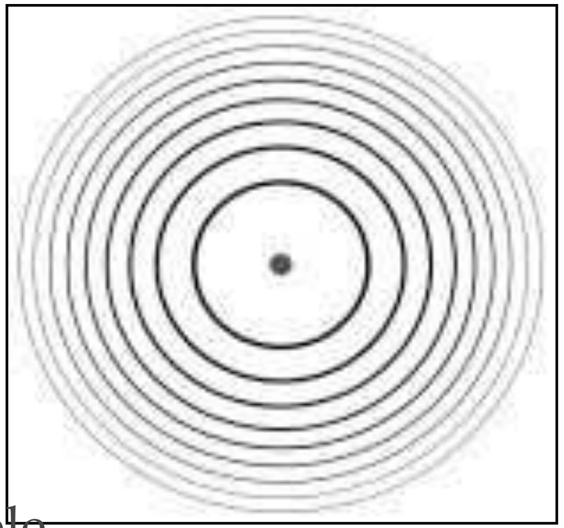


Image Source: Zulassungsarbeit von Philipp Müller "Holographie"



For the purpose of simplicity, let us assume that we are producing a holograph of a single object point. A perfect spherical wave is emitted from it, which interferes with a perfect plane reference wave. The result is not an arbitrary pattern as described above, but a geometry called a Fresnel zone plate. The following picture shows such a superposition. The black lines are the wave fronts and indicate the maxima of the waves. If the film plate is penetrated by them, constructive interference occurs at the points marked by the blue areas. Destructive interference occurs in the areas in between. If a film plate is developed, the areas of constructive interference turn black and unexposed areas remain transparent.

Concentric circles can now be seen on the film plate, whose thickness and distance from each other decreases towards the outside.



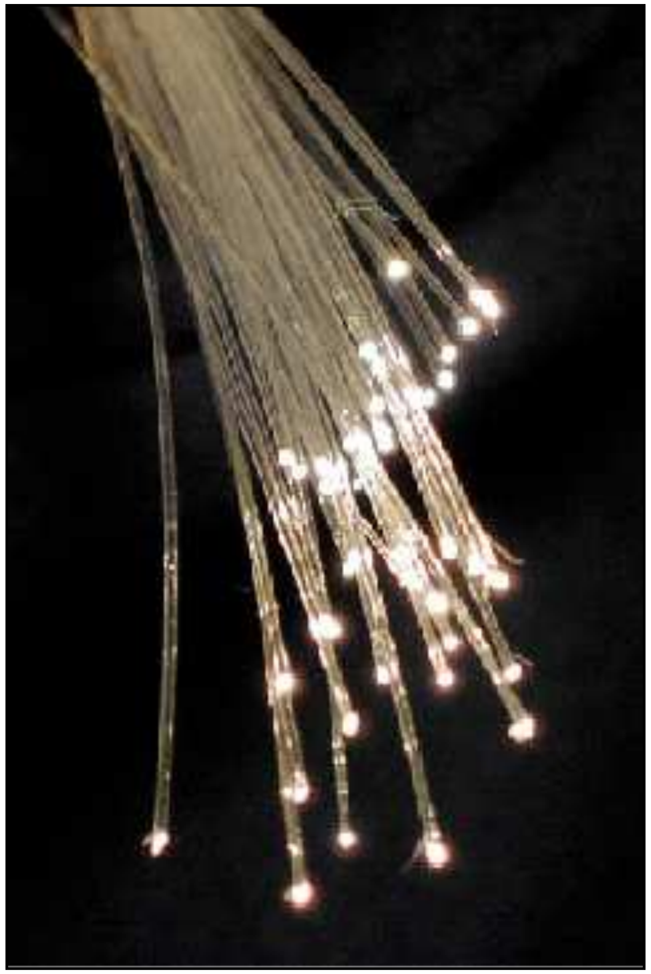
If you observe a developed film plate, you can see these individual Fresnel zone plates.

This pattern of Fresnel zone plates is now able to diffract wavefronts. As already explained in the section "Understanding holography", the film plate is a kind of buffer. The complex object wave is reconstructed through it and is therefore indistinguishable from the real object wave for the viewer.

If you would like to find out more about interference, try the Michelson interferometer experiment!

Image Source Zulassungsarbeit von Philipp Müller "Holographie"

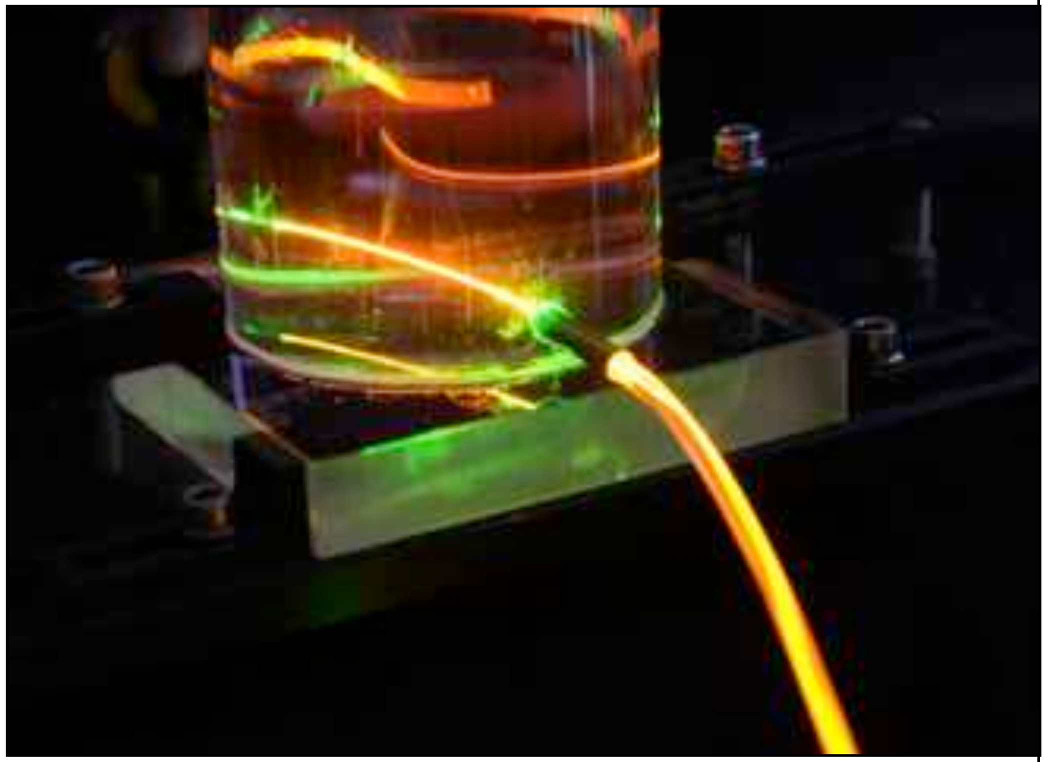
Water as an optical fiber



Can you guide light around curves?

Over 2.5 trillion bytes of data are produced worldwide every day. The emissions for this are considerable: if the Internet were a country, it would rank 6th worldwide in terms of CO_2 emissions. To generate this enormous data rate, you need light guides (like fiber optic cables).

This requires optical fibers. In Germany, 650,000 km of them have already been laid. That is twice the distance from earth to the moon!

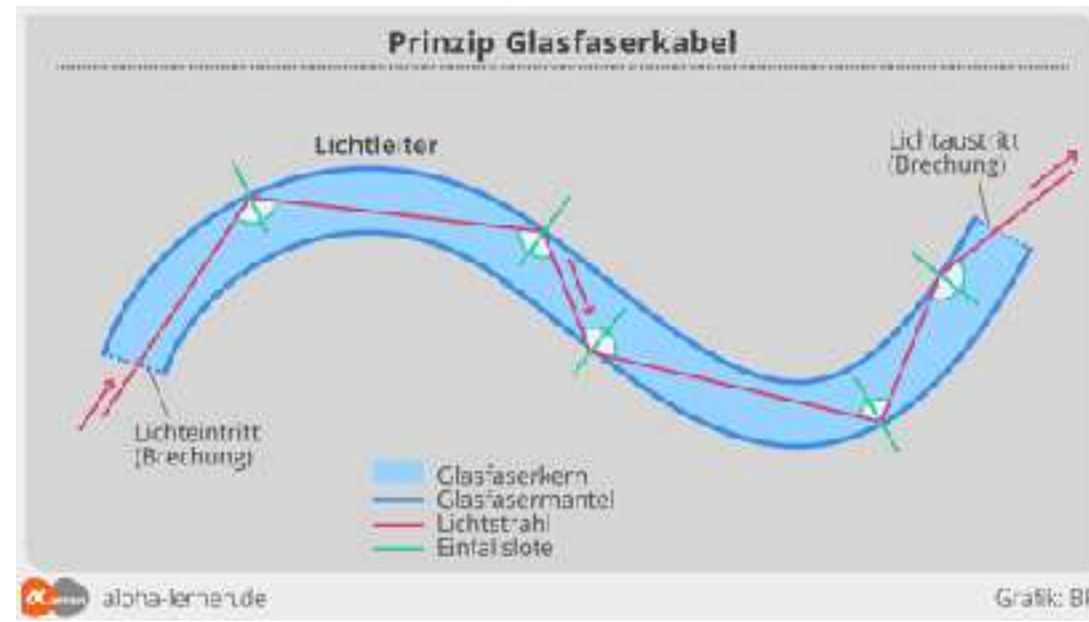


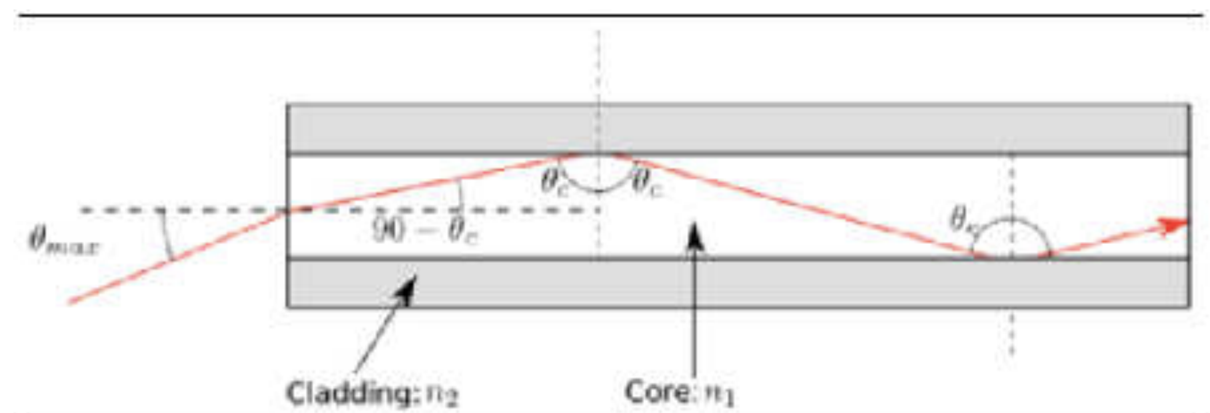
In this experiment, you can see how fiber optics work with your own eyes.

http://de.wikipedia.org/wiki/Glasfaserkabel#mediaviewer/Datei:Fibreoptic.jpg

Basics

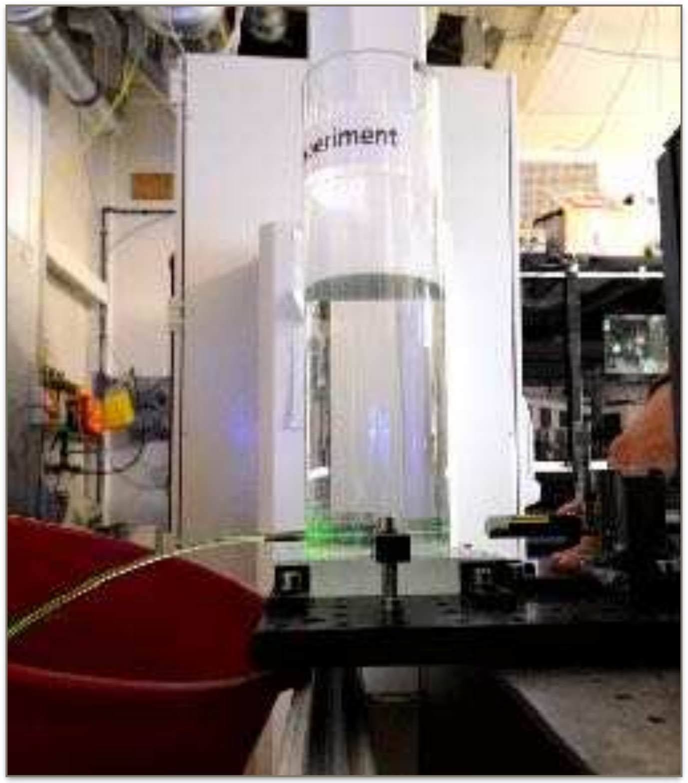
When light hits a boundary layer of different media with different refractive indices, refraction occurs. Light guides consist of a core material that has a significantly higher refractive index than the cladding material. As a result, when a light beam hits the boundary layer flat, total internal reflection occurs and the light beam moves along the line. The same effect also occurs when light is reflected at the interface between water and air. This is why a jet of water can also act as a light guide. However, because total internal reflection only occurs when the light strikes at a sufficiently flat angle, only light that falls within an acceptance angle into the light guide is transmitted.





Totalreflexion, Hecht, Optik

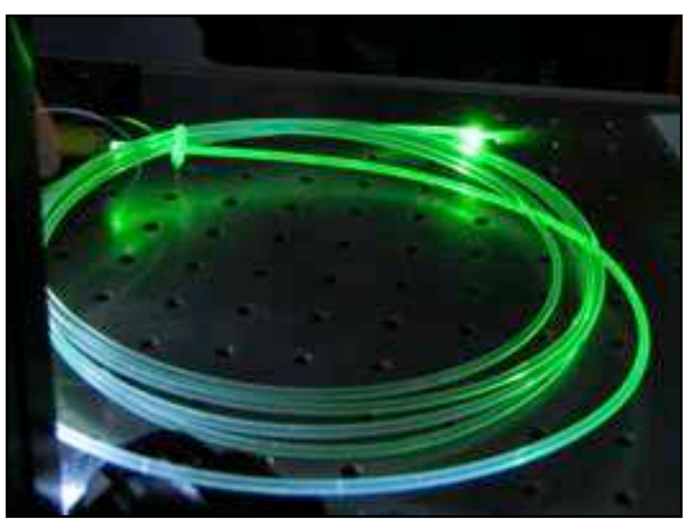
Procedure



Pour water from the bucket into the Plexiglas cup.

Attention! The stopper must be in place and when you pull it out, hold the bucket all the way up!!!!

Now press on the laser pointer from above (and below) and shine a light into the flowing water jet from behind. What do you observe?



EXPERIMENT 8: DELICIOUS IN LIGHT

Delicious in light

Unripe tomatoes: Color manipulation in the supermarket?

Whether it's a crunchy green bell pepper, fresh, shiny farmhouse bread or the red, juicy meat from the counter: everything looks delicious in the supermarket. But how do they do it? And can our senses even be tricked?

Image: Carolin Mantsch

In this course, we take a closer look at this. It's not enough just to look at light physically. We have to include physiology! What do our eyes and brain do with the light we perceive?

The idea for this experiment came from Carolin Mantsch, who wrote a seminar paper entitled "Delicious in the light - How does lighting influence the appearance of our supermarket goods?".

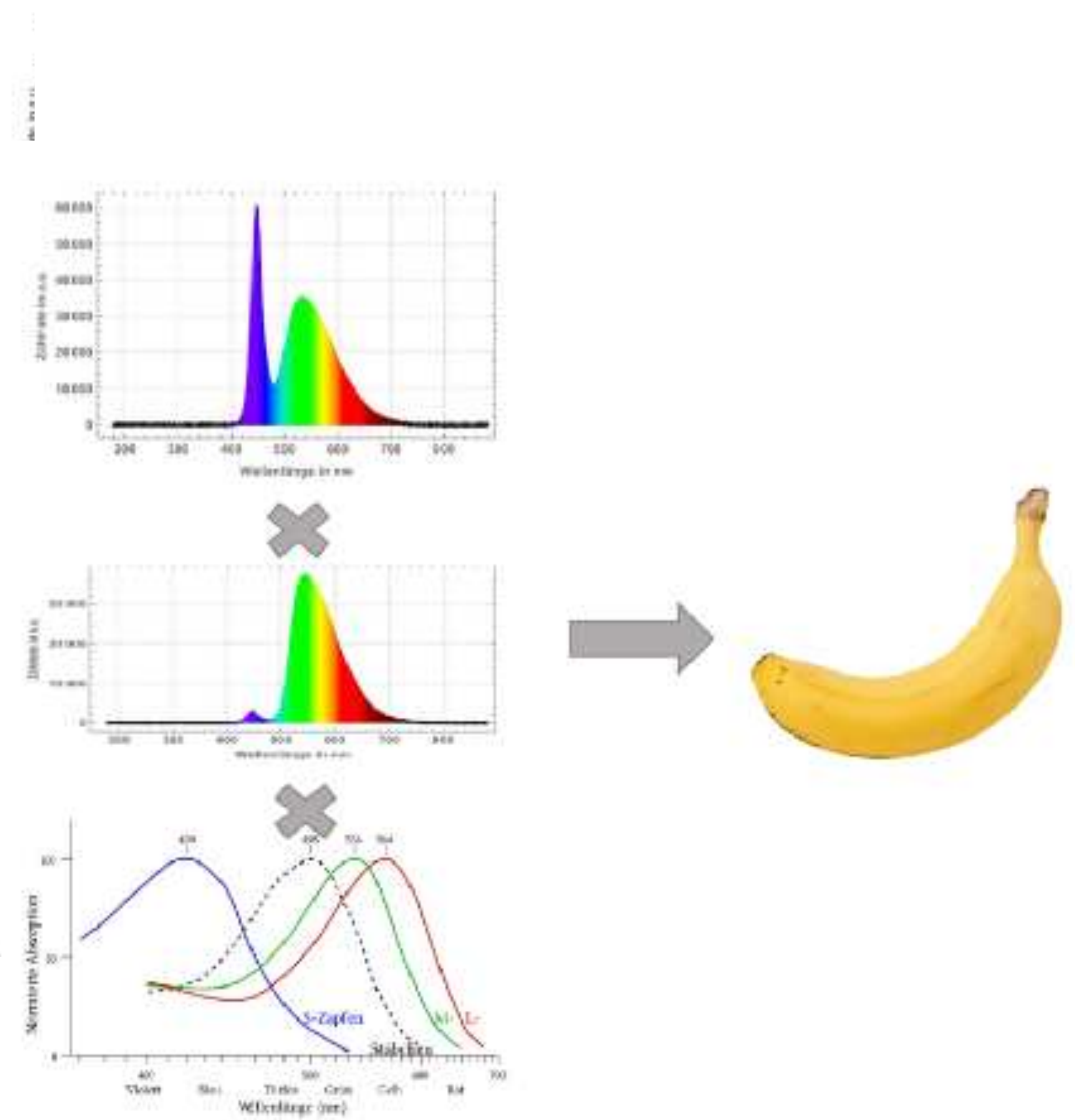
What does our color perception depend on?

As you can see in the diagram, our **perception of the color** of a banana, for example, depends on **three components**:

1. the spectrum of the incident light source (top)

2. the reflectivity of the object in the incident light (center)

3. the **biology** of our eye. The receptors in the eye with which we perceive light have different **intensity curves** for different colors, which are slightly different for each person (bottom)



All these **components** combined describe our **sensory impression** of the banana. In this **course**, you will learn step by step how exactly you can imagine this.

Source: Wikipedia (Graph und Banane)

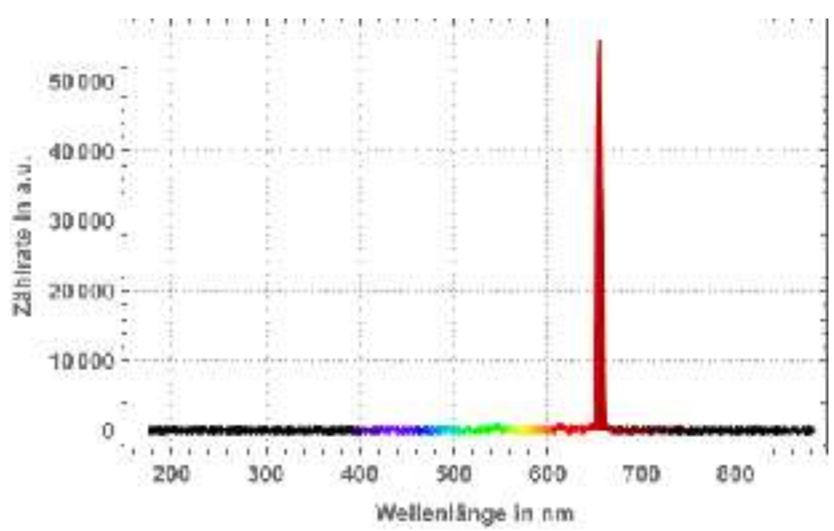
Basics: Physics I

1. spectrum of the incident light source:

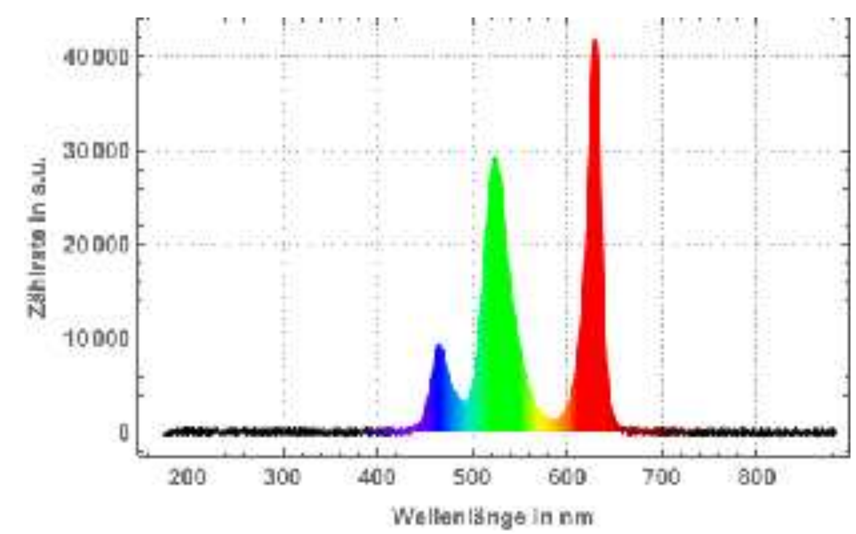
Here you can see the **visible spectrum of electromagnetic waves**.
This part of the spectrum only ranges from **wavelengths** of approx. 380 nm to 780 nm.

Das sichtbare Spektrum [Wikipedia]

Different **light sources** have different **spectra**. For example, a single-color light source, such as a red laser, emits a different spectrum than an LED light. You can see this here:



Spectrum of a red laser



Spectrum of a white LED

Basics: Physics II

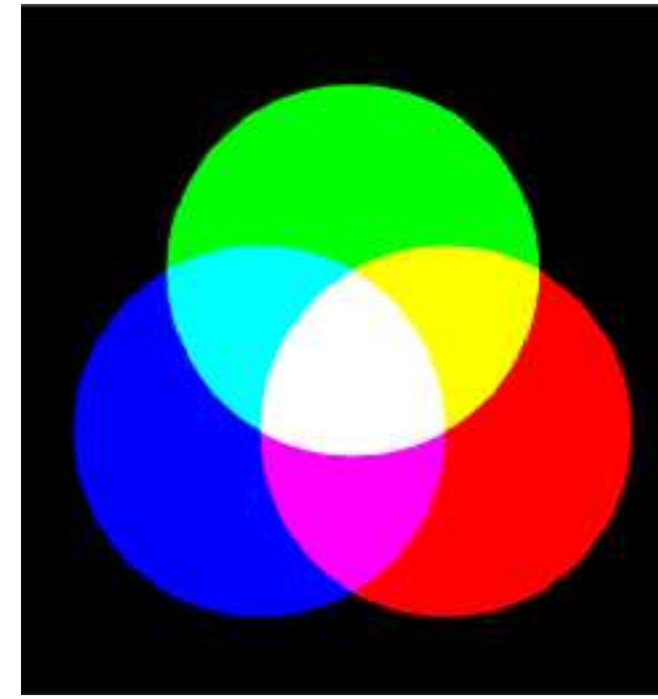
2. Reflectivity of the object

Depending on which **colors** are reflected, the **sensory impression** of the object changes in our eyes.

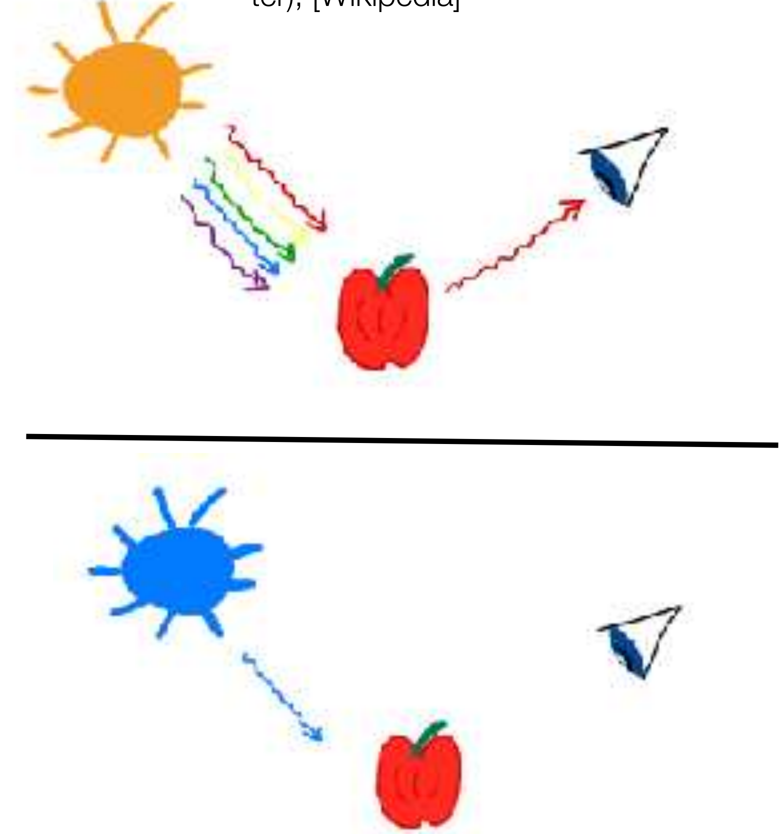
When we look at an object, e.g. in **daylight**, we perceive a **color**. This color is determined by the proportion of **wavelengths** of the **visible spectrum** that fall into our eyes after reflection.

White light is the superposition of the three primary colors **green, blue** and **red**. If, for example, green, blue and red light from a flashlight is **superimposed** on a (white) screen, we obtain **white** (right-hand image). The visible spectrum of the **sun** contains **all** colors and therefore we perceive it as white.

If we now illuminate a **bell pepper** with white **light** (= superimposition of all colors), only the red part of the light is reflected and falls into our eyes. The rest is **absorbed** and so the **bell pepper appears red**.
However, if we now illuminate the bell pepper with **blue light**, it **absorbs** this light and the **bell pepper appears dark** because the red part is not reflected.



The color wheel with white overlapping (center), [Wikipedia]

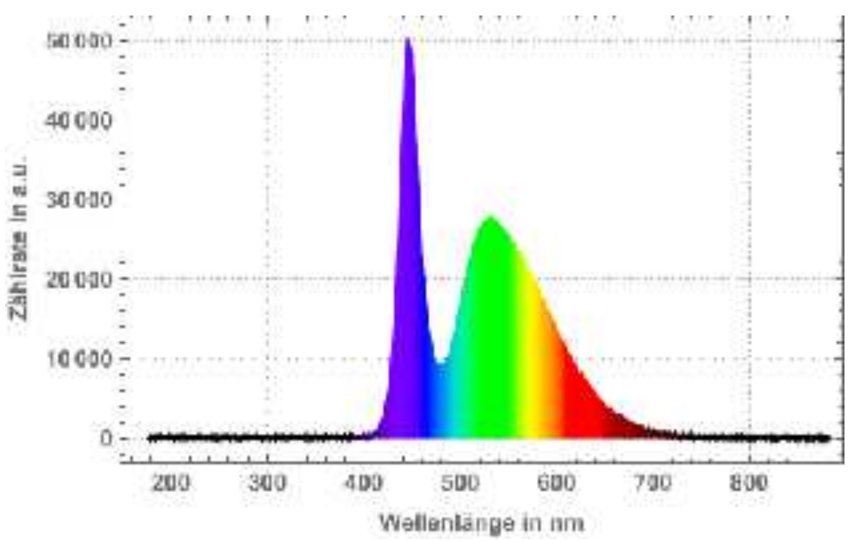


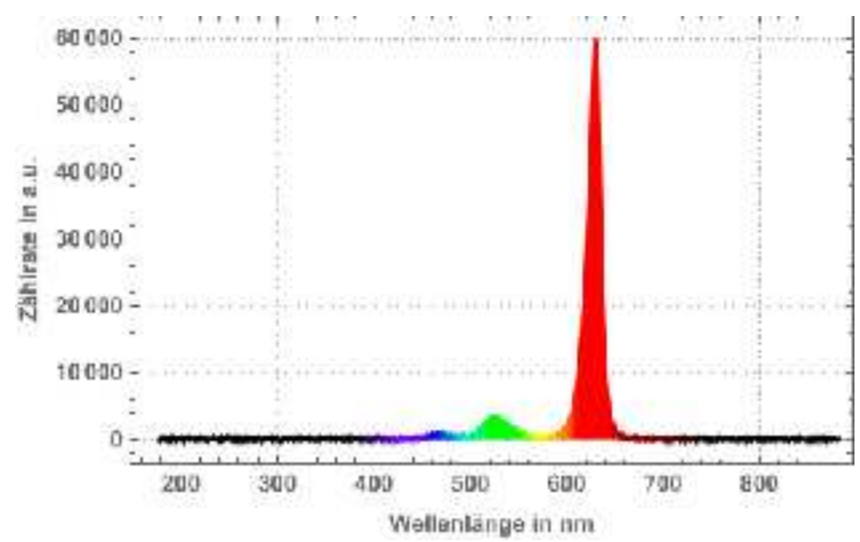
Sketch of reflectivity

Measurement of reflectivity

We can also illustrate the **reflectivity** of a bell pepper using a **spectral analysis**. In the left-hand image you can see the spectrum of the incident light source, here it is an **LED**. Almost only the **red component** is reflected, and that by almost 100%. This is why we perceive the bell pepper as red!

Caution: The **reflectivity** depends on the **incident spectrum** and the **reflecting** object!



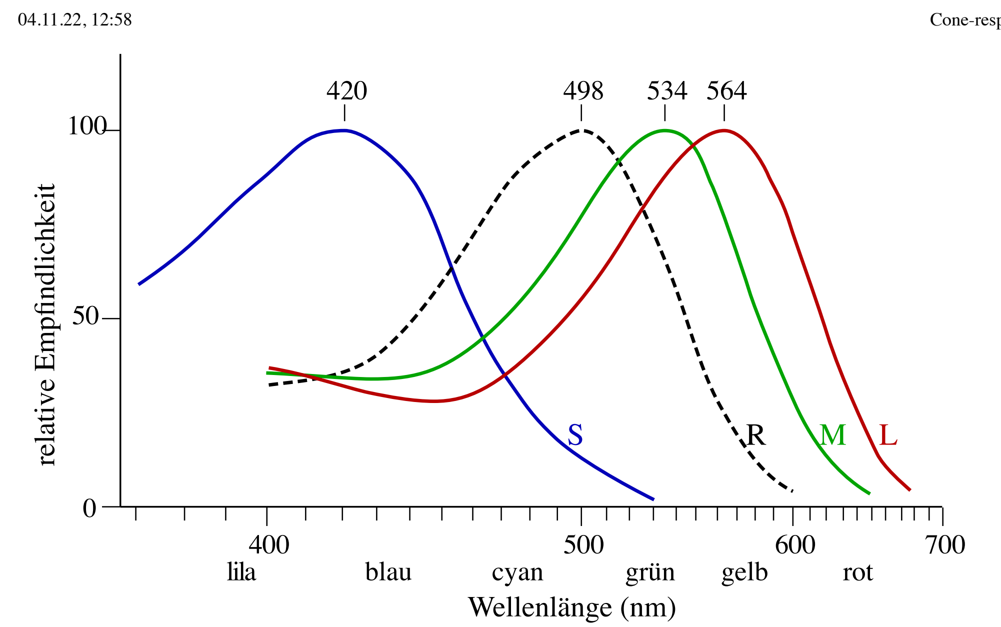


Of course, this also works in **reality**. *Carolin Mantsch* has illuminated a **tomato** with green and red light, and we can see that it glows beautifully and looks **delicious**.
If we only illuminate the tomato with **green light**, it is dark and does not look tasty.
So we always have to illuminate an object with light of **its color** to make it look tasty.

Abb. 5: Beleuchtung einer Tomate mit rotem und grünem Licht

Abb. 6: Beleuchtung einer Tomate mit grünem Licht

Basics: Biology



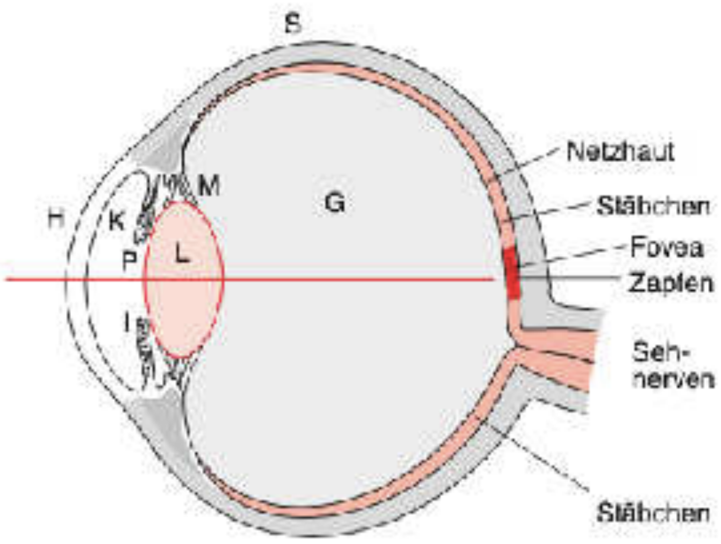
Empfindlichkeit des Auges [Wikipedia]

3. the biology of our eye

<u>Cones and rods:</u>

Cones (figure on the right, solid, day) can perceive **red, green** and **blue** through three different receptors. You can see the **brightness sensitivity** curves at the top right. When seeing colors, the receptors are activated to **different degrees**, which the brain processes into a sensory impression.
The type of cone determines which basic colors we have: If cones perceive the colors red, green and blue, these are our primary colors. The superposition of all primary colors is always white.

Rods (dashed, night) are responsible for the perception of **light** and **dark** and are activated in the dark. You can see the **sensitivity curve** at **night** in black dashed lines at the top right.



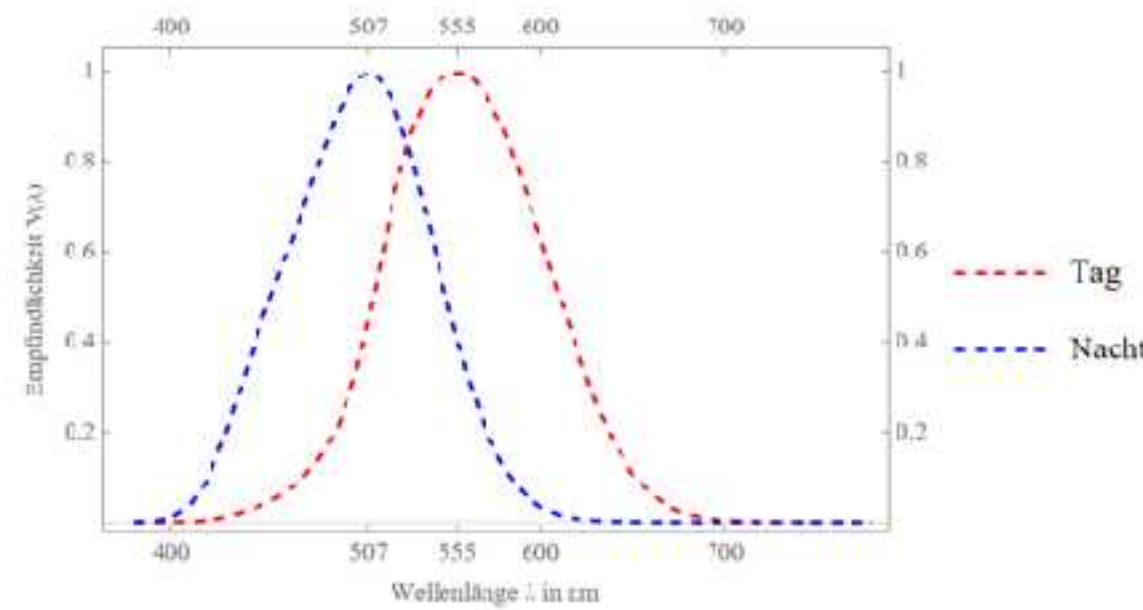
Querschnitt des Auges [Demtröder 2, Lehrbuch der Experimentalphysik]

Influence of the eye

At dusk, we see with both **rods** and **cones**.
In the graph on the right you can see the **sensitivity curves** (V-lambda curve) for **cones** and **rods**.

The graph means that we perceive green (at about **555** nm) best during the day and **507** nm best at night.

The **V (lambda) curve** is important for us because it shows us how our **human biology** distorts the **true color impression**. Not all people have the same **sensitivity curve**: some have a **red/green weakness**, i.e. they lack a receptor. Animals see very differently to us. **Dogs**, for example, only have **two receptors**: one for **green** and one for **yellow**. The picture on the right shows how a dog perceives the world.

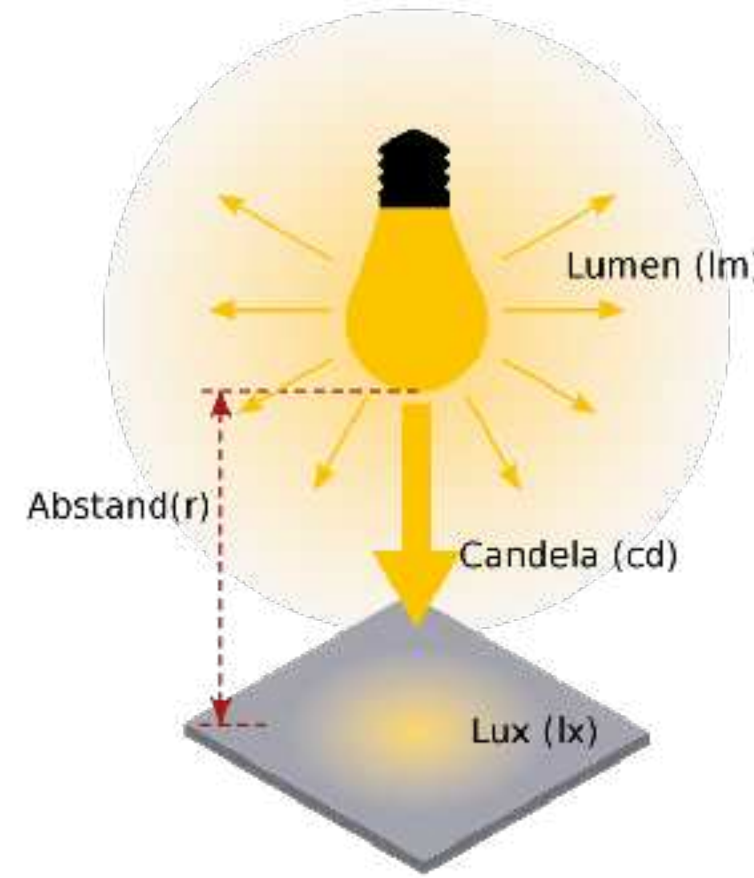


Sensitivity curve by day (red) and night (blue)

Visual perception of a dog [What does the earthworm actually see? by Guillaume Duprat]

Units and definitions

Are you interested in the different units we use to measure illuminance? Here is an overview!



Overview of photometric units

[Wikipedia]

CANDELA

1 cd is the SI unit for **light intensity**. 1 cd corresponds to the luminous intensity of a **candle**.

LUMEN

Lumen is the SI unit of luminous flux. It indicates how much light a light source emits in total per period of time. The symbol sr denotes the **steradian**, which corresponds to the **solid angle**.

$$1lm = 1cd \cdot sr$$

LUX

Lux is the unit of **illuminance** that indicates how much light is emitted per time span and per surface area ("brightness" at the illuminated location).

$$1lx = 1\frac{lm}{m^2}$$

Experiment

We need the following devices for our experiments:

Black box
We put our fruit and vegetables in here and illuminate them to reduce background radiation such as from the ceiling light.

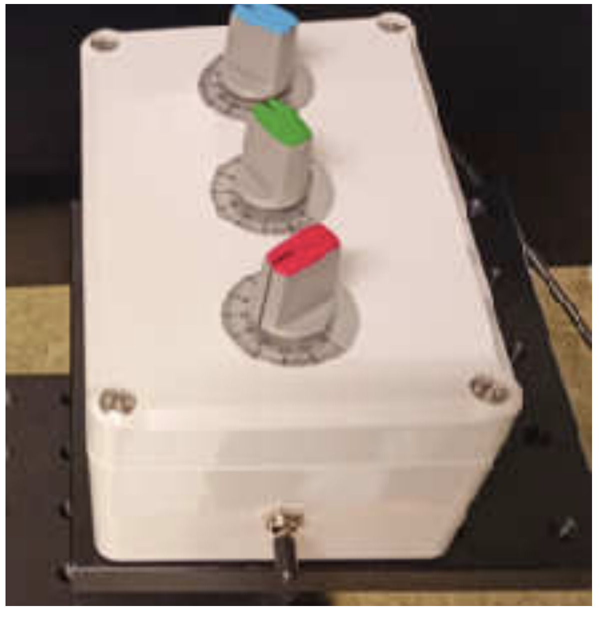
Handheld spectrometer

You can use this to determine the **spectrum** of a light source. Look through the **opening** of the **spectrometer**, hold it up to a bright **light source** and close one eye. The spectrum you see is **not intensity-resolved**, but you can recognize dark **lines** in an **absorption/emission spectrum** or a **continuous spectrum**.

Hand spectrometer

LED light mixer

With the **LED light mixer**, you can mix the primary colors **red**, **green** and **blue** at levels **0-10**. Flip the switch on the side upwards to switch on the **light mixer**.



LED light mixer

Experiment

<u>LED with remote control</u>
You can use the **remote control** to set different **colors**, which are mixed proportionally from the basic colors **green**, **blue** and **red**.

Now we need **instruments** to **measure** the **incidence of light**.

<u>Luxmeter</u>
You can use the **luxmeter** to measure the **illuminance** (unit: [lux]) of an **area**, i.e. how much **light** hits it **per unit of time** and **area**. It already takes into account the **sensitivity curve (V-lambda curve)** of our eyes. You can therefore regard the **luxmeter** as an artificial eye.

<u>Power meter, here: Photometer</u>
This **powermeter** can be used to measure the **power** (unit: [Watt]) of light sources. It has different **sensitivities** depending on the **color**, so you have to press Lambda after switching it on and set the color (**wavelength**). Then press lambda again and you can now measure the power of the color that is being emitted. The unit that the meter outputs is **microwatts**.

LED mit Fernbedienung

Luxmeter

Photometer

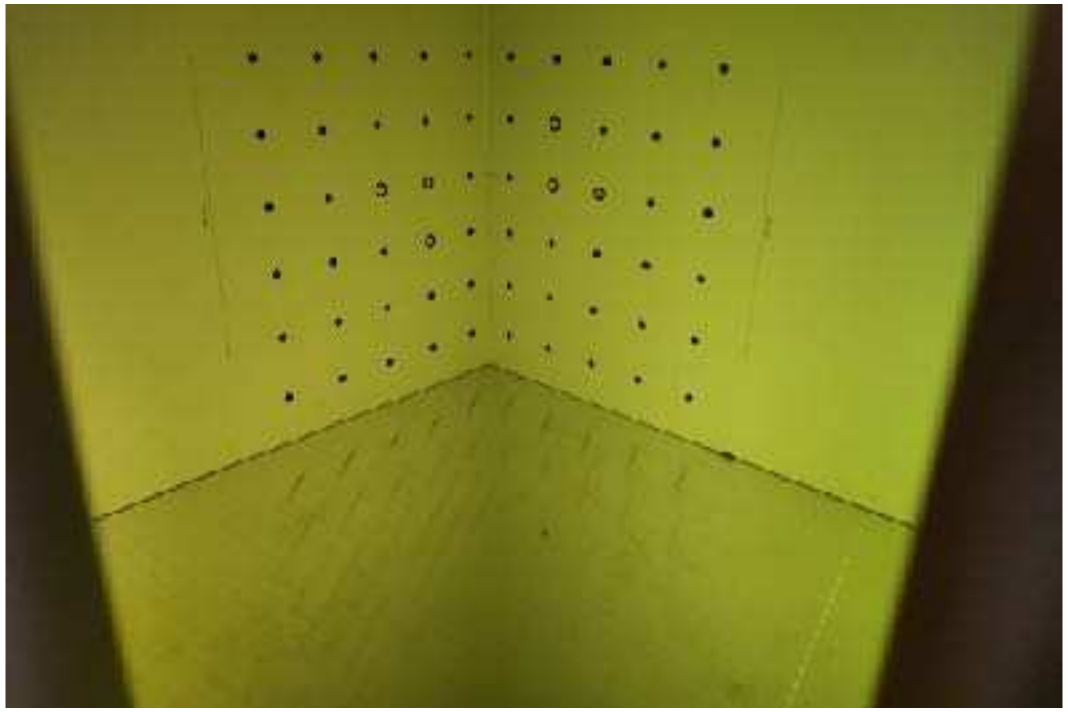
Pre-experiment

Darken the room!

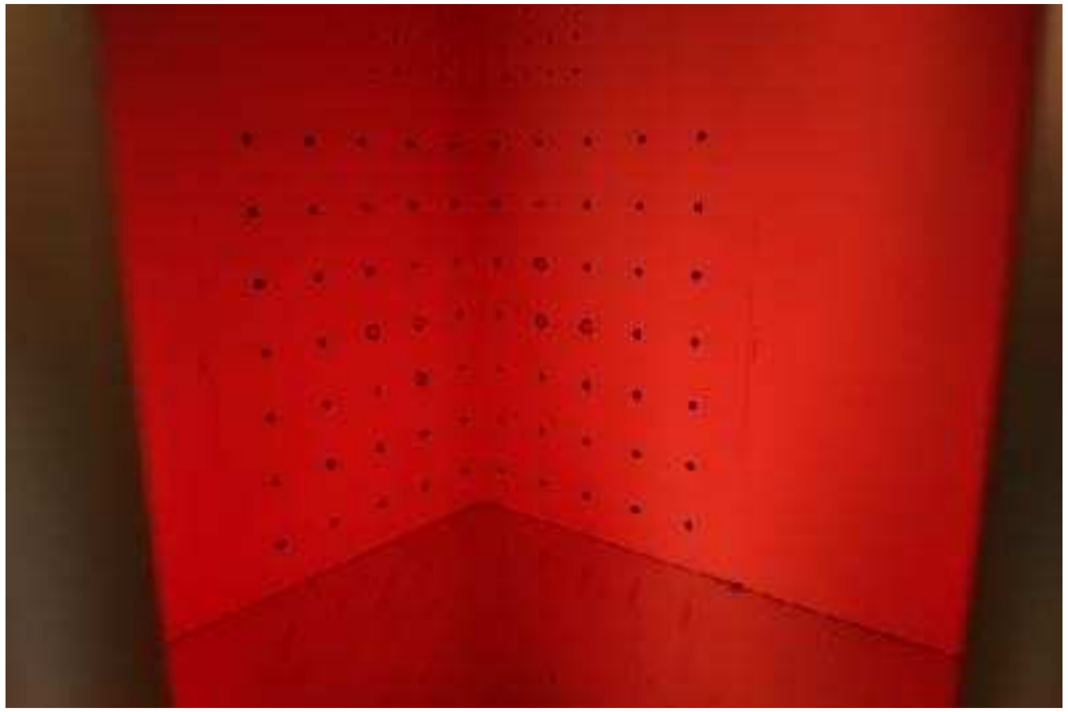
Place the round LED in the outlet and switch it on with the remote control. Use the **LED projector** to **illuminate** the inside of the **black box** and hold a **spectrometer** in front of the **opening**.
Take a close look at the **spectrum** you see through the **spectrometer**!

Now set a **different color**. Can you see a **difference**?

If you are even more interested in analyzing **spectra**, you can carry out the spectroscopy experiment afterwards.



Box in green light



Box in red light

Experiment I - LED light mixer and fruit (beginners)

1) Now place a **single-colored** fruit of your choice in the **black box** and illuminate it with any color. Now try the following colors: **White**, the three **basic colors** of human vision and the color to which you assign the fruit in white light. Which lighting would you **recommend** to the **supermarket**?

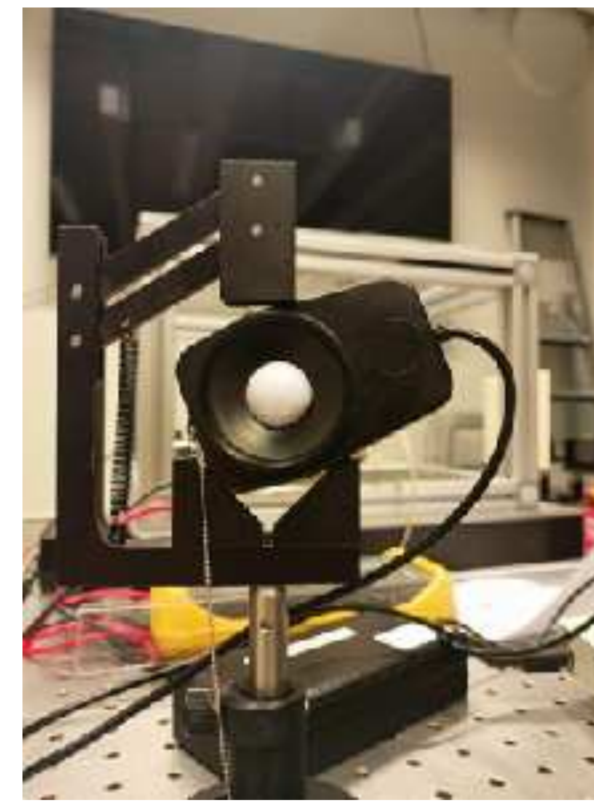
2) **Repeat** the experiment with **multicolored fruit**. Here you cannot simply **illuminate** the light in the color to which you assign the fruit. Try it with the mixed color of your fruit! (e.g. beet is **purple** and **green**: **purple** and **green** becomes **turquoise**, so use **turquoise** light)

3) Now measure the **reflectivity** of your fruit with an **intensity-resolving** spectrometer. To your right is the spectrometer station: Open the Ocean View app on your laptop and hold the **sensor** of the **spectrometer** close to the illuminated fruit in the black box and look at the spectrum on the screen.

A banana in yellow light.

A banana in red light.

Experiment II.1 - LED light mixer and complementary colors (for advanced readers)



1. Now clamp the **luxmeter** into the holder, remove the protective cap and place the luxmeter at a **distance** of **1 cm** in front of the light mixer (measure with a ruler!).

2. Now measure the **illuminance** in **lux** for **red** with the **luxmeter**. To do this, press the POWER button for **2 seconds** and then the REC button (until it beeps) and use the **arrow buttons** to change the setting to **L2**. Press ENTER. Now turn the control for **red** to **level 10** and make a note of the value.

3. Now do the same for **green** and **blue**. Set level **L4** for **green** and level **L5** for **blue** and make a note of the **illuminance** for **level 10** in each case.

4. identify the color with the **lowest illuminance** (e.g. **blue** with **40 lux** at **level 10**) and set the **different colors** to the same value. To do this, **change** the **settings** again using the REC button and note the level at which the colors have the same **illuminance**.

5. now turn up all colors simultaneously to the level at which you have identified the same **illuminance**. What does the **color** look like if you hold a **white sheet of paper** in front of the LED between the **luxmeter** and the **LED**?

6. now switch off the luxmeter (hold down POWER for 2 seconds until it beeps) and put the protective cap back on.

Experiment II.2 - LED light mixer and complementary colors (1)

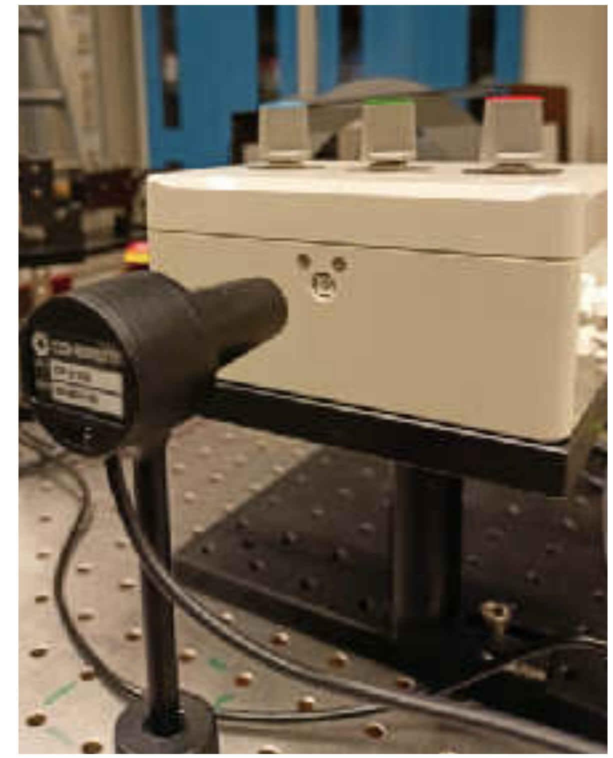
Now we do the **same** for the **power meter** (photometer).

1. Place the **power meter** in front of the light mixer at a distance of 1 cm. Switch it on.

2. Now click on the *lambda* symbol on the **power meter** and first measure the **power** for the color **red**. To do this, press the **arrows** on the **power meter** until **0.630** micrometers is displayed. Now click on the lambda symbol **again**.

3. Now turn up **red** to level **10** and **note** the power.

4. **Repeat** this process for **green** (set the wavelength to **0.530** micrometers) and blue (wavelength **0.470** micrometers) and make a **note** of the values for level **10**.



Experimental setup (with power meter)

Button for selecting the wavelength

Experiment II.2 - LED light mixer and complementary colors (2)

5. identify the **smallest value** and repeat the process as with the luxmeter. Find out what the correspon-ding power levels are for the other two colors and then set a **superposition** of all these levels. Don't forget to always change the wavelength!

6. what color results from the **superpostion**? It should be white. Why? To understand this, take a look at the color wheel. If you superimpose two opposite colors, the result is always white. So if you overlay the three primary colors, the result will also be white.

7. then **switch off** the power meter.

[webmaster-crashkurs.de]

Experiment II.2 - Comparison

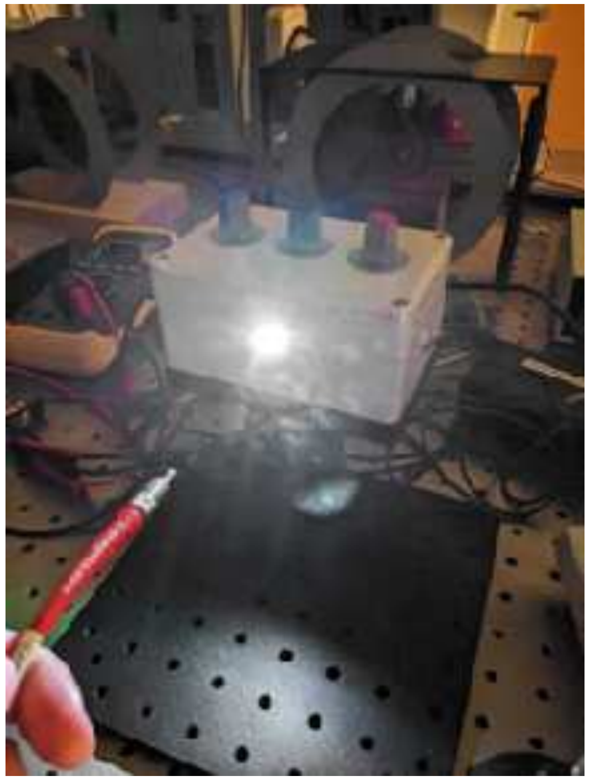
Weiß per Powermeter

Weiß per Luxmeter

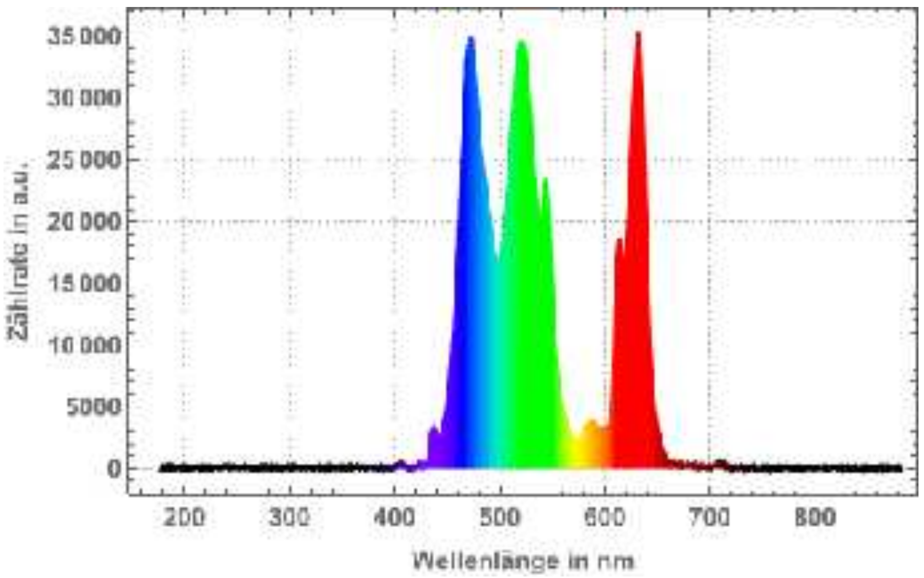
- Both colors are white, but still different, as you can quickly see, because:
- the **luxmeter** measures the **luminous** intensity in **lux**, which indicates **how much light** falls on a **surface**.
- the **power meter** measures the **power** of the light in (micro)**watts**, which indicates **how much energy** is emitted per **unit of time**.
- for example, the **luxmeter white** appears slightly different because the measured **luminosity** contains more **green** components than the **power meter white**.
- This is because the **power meter** measures all colors of the **visible spectrum** equally due to its measuring method, while the luxmeter is more **sensitive** to **green** light.
- But now the light looks whiter with the power meter! The reason for this is evolutionary and can be explained by the fact that we are looking at the inverse of the V-lambda curve. That's why you see purple with the luxmeter setting.

Experiment II.2 - Alternative: Spectrometer

1. Mix the individual colors so that you see the best possible white.
2. Alternatively, white can also be mixed with the **spectrometer** in the experiment next to it.
3. To do this, **open** the OceanView **software** on the laptop and select QuickView. Switch on the **light mixer** again.
4. Now **point** the fiber optic cable of the (intensity-resolved) spectrometer at the light of the **light mixer**, as shown in the **figure** above right.
5. You should now be able to see the **spectrum** analogous to the figure on the bottom right of the screen. **Change** the **intensities** of the individual colors to become familiar with the **program** and the **changes** in the resulting **spectrum**.
6. Next, try mixing **white** by adjusting the intensities equally by eye. Tip: Squint your eyes and look directly into the LED (you can only do this here because the LED is weak enough not to harm you). Then try to distribute the **intensities equally** through the **spectrometer**.
7. **Vary the intensities** until the **white** appears optimal for you and **compare** it again with the **white** tones from the **previous experiments**.



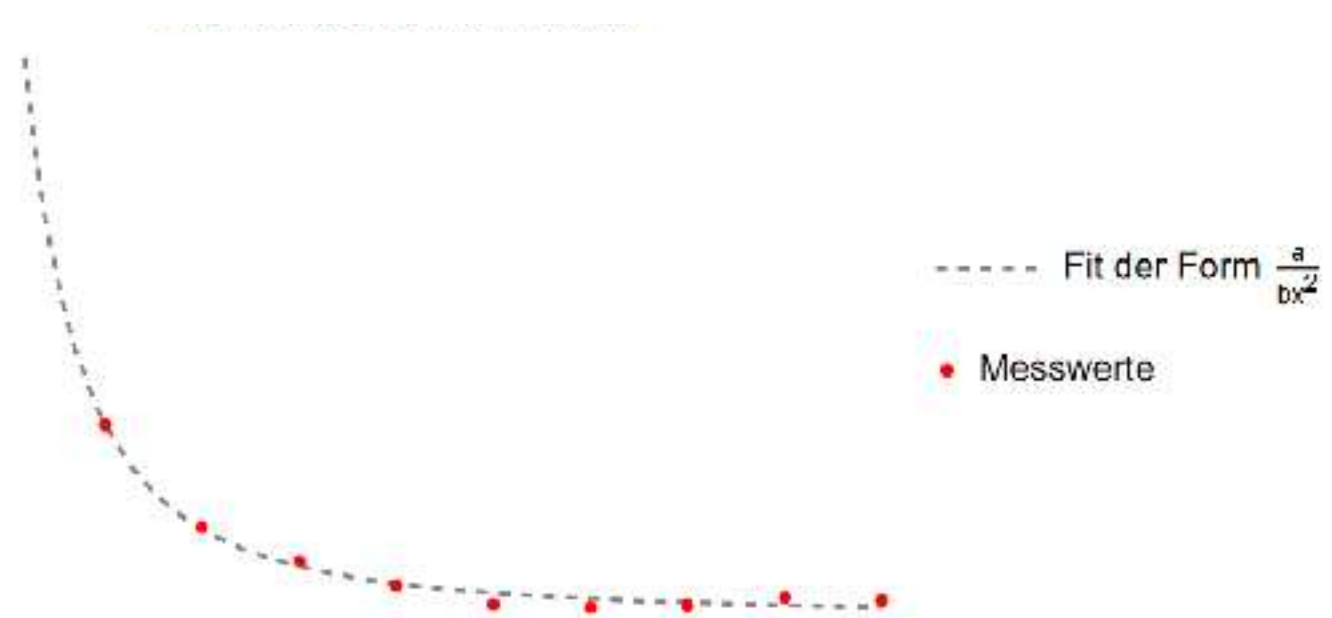
White per spectrometer



From the QuickView of Oceanview

Experiment III - Determination of the sensitivity curve (expert experiment)

1. This is an **expert** experiment(!), so it will probably take a lot of time and is not important for understanding the experiment.
2. First we want to **check** or show that the **intensity of light** decreases **quadratically** with **distance**.
3. To do this, use a **luxmeter**, for example. Measure the **light intensity** at as many different **distances** as possible. Create a table of values for this. If you **plot** this, you should be able to establish an inverse square relationship, can you recognize the shape of the curve? You can see an example below:



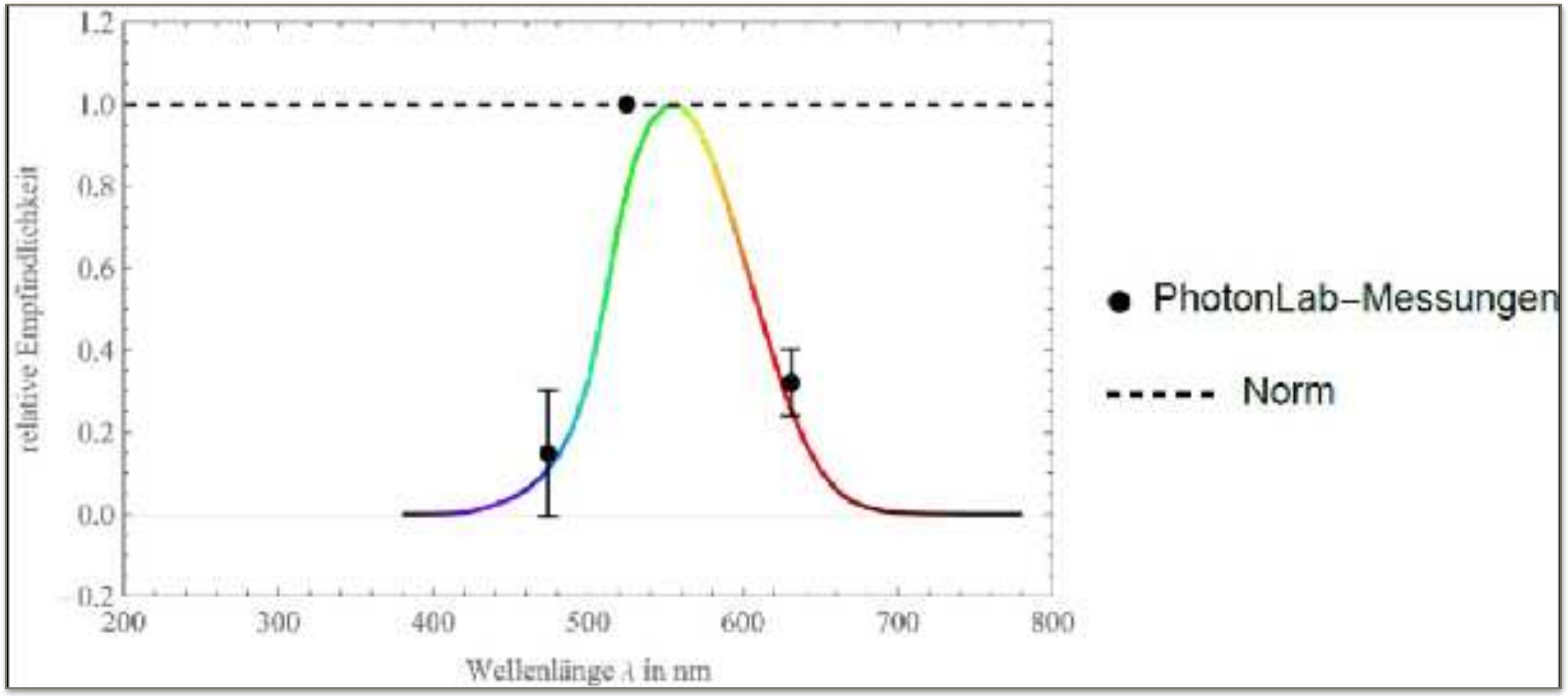
Întensität (y) gegen Abstand (x)

Experiment III - Determination of the sensitivity curve (expert experiment)

1. Now we want to determine the **V-lambda curve** quantitatively, i.e. **confirm it with measured values**
2. To do this, measure (**individually**!) the **luminosity B** in lux of the **three colors** (red, green and blue) with the luxmeter at a distance of about 1 cm. **If you have already done experiment 2, you can use the values for this and the next step**. Turn the intensity to level 10 and, as in the previous experiment, remember to set the **correction factors** (red: L2, green L4 and blue L5).
3. **Now** also **measure** the power of the light P in microwatts (at the same distance, also at setting 10).
4. It is important to note the **units**. The **sensitivity curve** is defined by **lumen/watt**, so **multiply** the luminous intensity B (in lux) by a factor of **10^-4** and the power P (microwatt) by **10^-6** to obtain lumen or watt.
5. To obtain the **V-curve**, we divide the measured **individual values**, i.e. **B by P** and **normalize** with the values obtained for **green** (this is quite complicated, the **equation** below hopefully explains the procedure).

$$V(\lambda) := N \cdot \gamma(\lambda) \overset{\lambda - 631nm}{\approx} \underbrace{\frac{P_{525nm} \cdot 10^{-6}}{B_{525nm} \cdot 10^{-4}}}_{\text{SI-Einheiten (Normierung)}} \frac{W}{lm} \underbrace{\frac{B_{631nm} \cdot 10^{-4}}{P_{631nm} \cdot 10^{-6}}}_{\text{Messwerte in SI-Einheiten}} \frac{lm}{W} \approx 29\%$$

Experiment III - Determination of the sensitivity curve (solution)



Here you can see our **measurements**:

The **measurement** point at **green** corresponds to our **normalization**, we use this as a guide.

The measurements at **blue** (left) and **red** (right) should be **close to the curve**.

As in every **experiment**, the **values** do not match the **theory/literature** perfectly, as the **error bars** above show

Fata Morgana

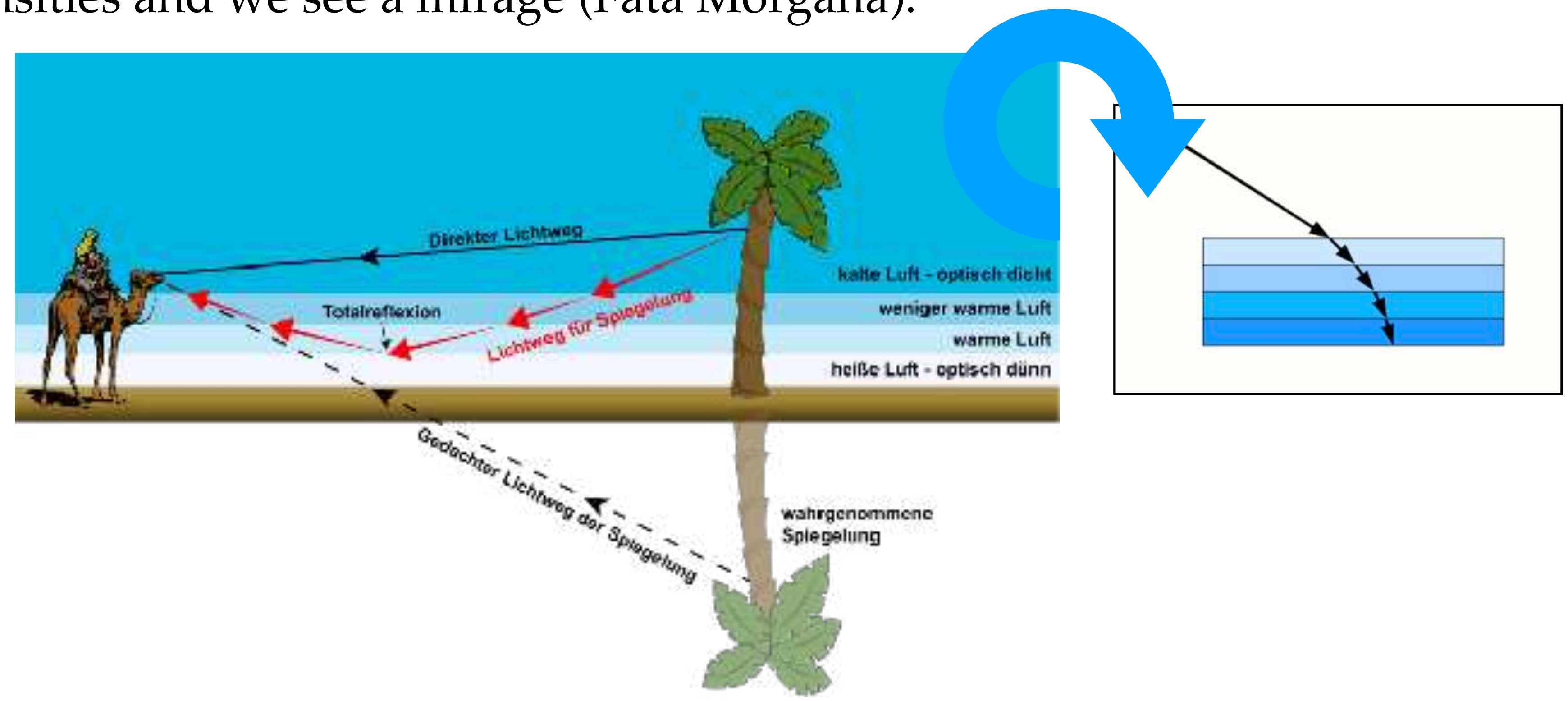
http://de.wikipedia.org/wiki/Fata_Morgana#mediaviewer/Datei:Spiegel100531.jpg
https://www.watson.ch/wissen/international/436174308-fata-morgana-fliegendes-schiff-vor-englands-kueste-gesichtet

How can ships fly and black roads reflect like mirrors?

The explanation is known from the desert under the name **Fata Morgana**. Because hot air has a different refractive index than cold air, light rays can be deflected at the transition between layers of air. This is why light rays from objects hit our eyes from a different direction than the one in which the objects actually are. So it either appears as if a ship is flying, or as if a black road is reflecting.

Basics

Because hot air has a different refractive index than cold air, light is also refracted or even reflected at the transition between layers of air. As a result, light rays from a different direction hit our eyes and we think that the object in question is in a different place, or we see its reflection. In the picture, the light path is also refracted by different air densities and we see a mirage (Fata Morgana).



Sugar solutions of different concentrations also have different refractive indices. In this experiment, you will use a sugar solution that has a lower concentration at the top than at the bottom. As the light passes through the transition between the different concentration layers, it is repeatedly deflected. It looks as if the light is "flying around the bend".

https://www.leifiphysik.de/optik/lichtbrechung/ausblick/fata-morgana

Procedure

The liquid in the cuvette is tonic water.
The tonic water is poured onto a layer of sugar; this creates a sugar gradient in the solution: the sugar concentration therefore increases from top to bottom.

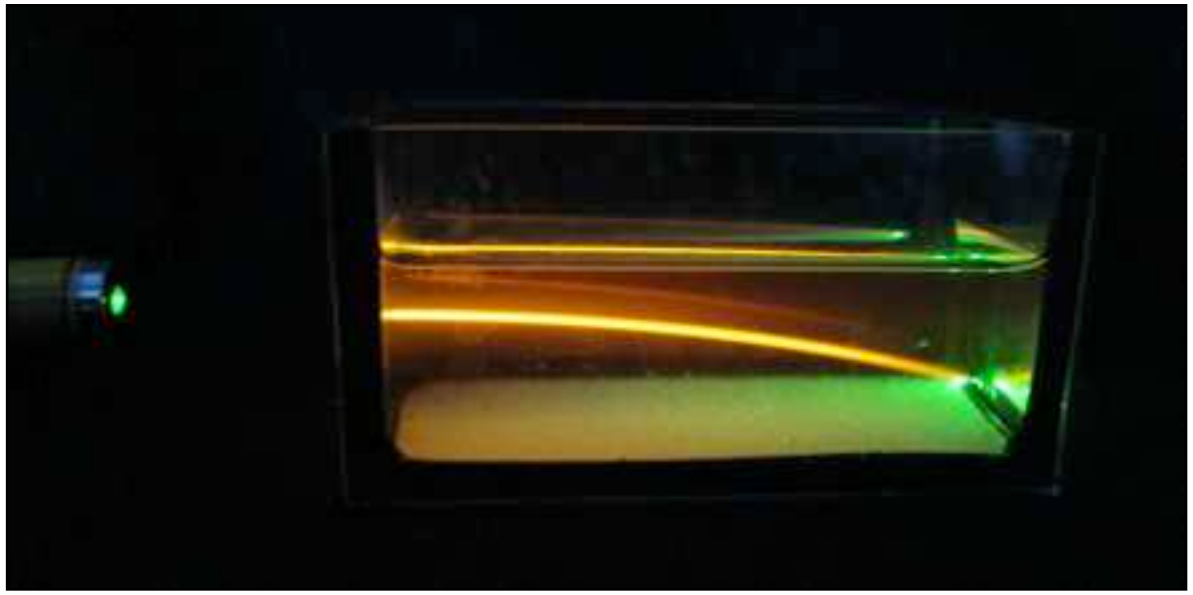
Now switch on the laser. Dim the ceiling light if necessary.

1: Shine the light into the cuvette below the surface of the water, as shown in the picture.

What do you observe?

2: Hold the laser pointer so that the beam strikes the boundary between water and air at a shallow angle.

What do you observe?



Solution: If the angle is large ("flat") enough, total internal reflection can occur. The light is then refracted at the air/water boundary layer and the light is reflected back again.

Sugar concentration in cola

How much sugar is in cola and how can I find out with lasers?

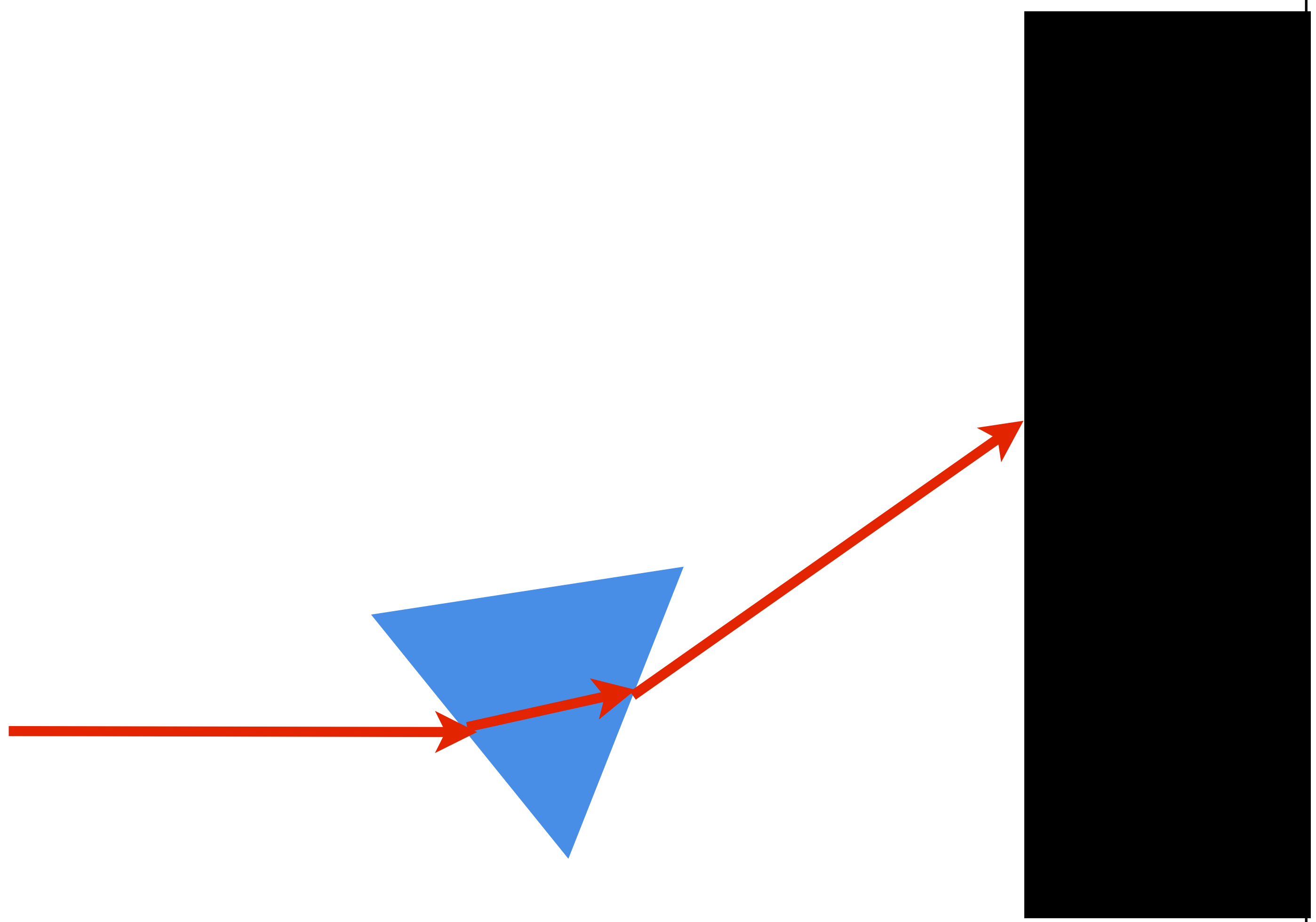
When a ray of light hits the boundary between air and a liquid, it is refracted (i.e. deflected). Sugar solutions of different concentrations refract light to different degrees. This makes it possible to determine the concentration of sugar in liquids.

http://de.wikipedia.org/wiki/Würfelzucker#mediaviewer/Datei:Sugar_cubes.jpg

http://de.wikipedia.org/wiki/Cola#mediaviewer/Datei:Glass_cola.jpg

Basics

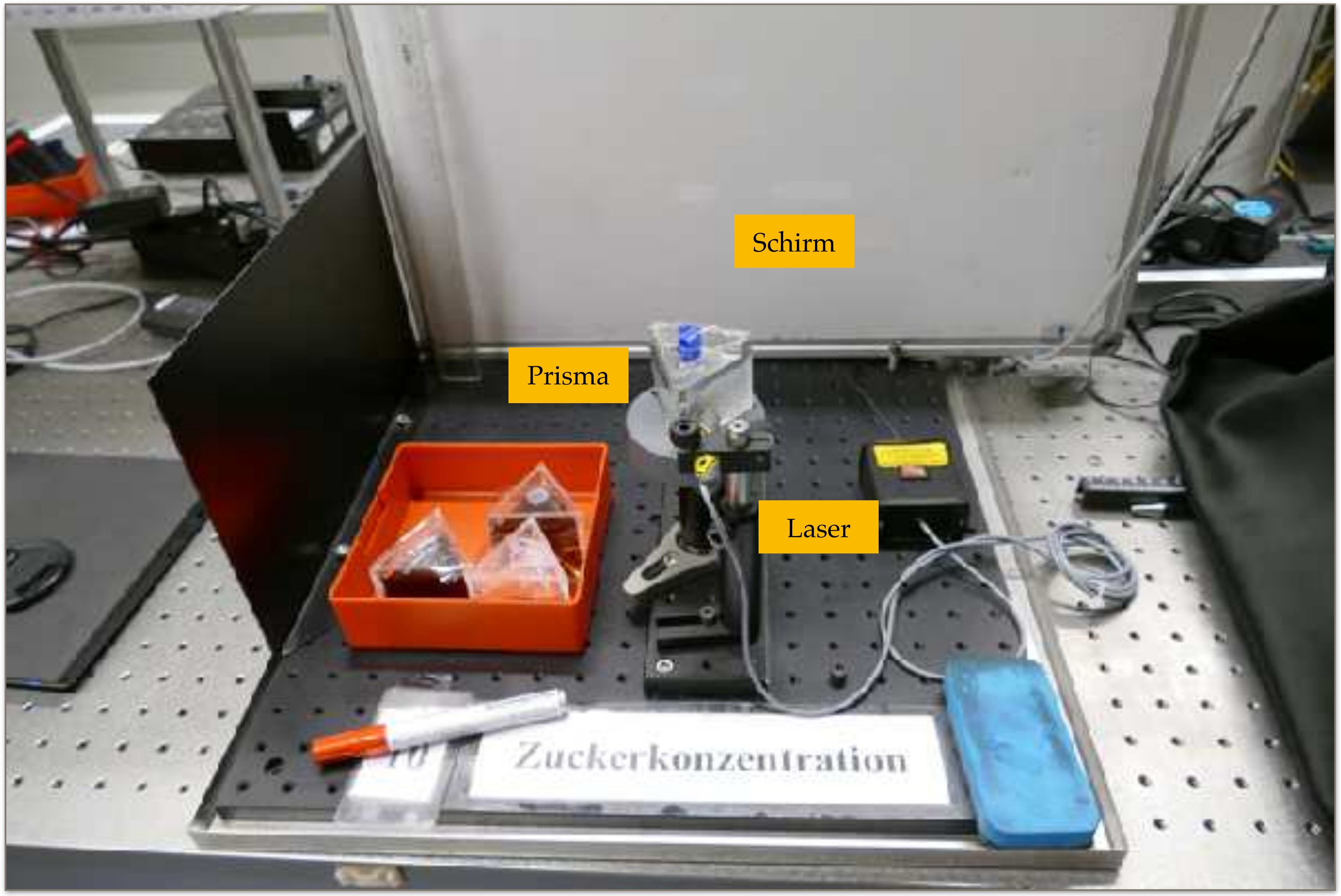
Light is refracted at the transition between media with different optical densities, i.e. it then moves in a different direction. If it then exits the medium again, it is refracted again. The two deflections add up. Sugar solutions of different concentrations refract light to different degrees, so that the concentration of the sugar can be determined based on the angle of refraction.



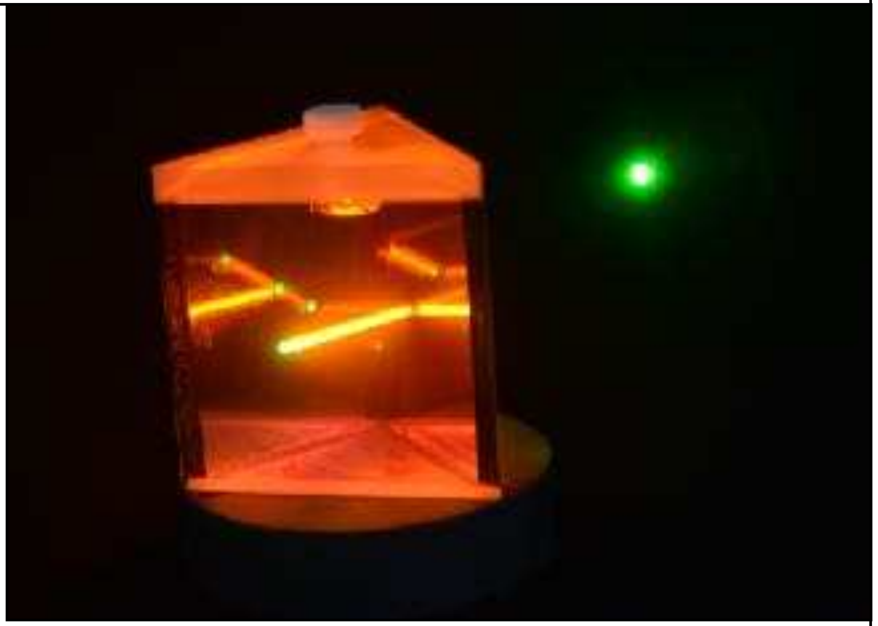
Construction

To set up, place the first prism in the holder. Position it so that the laser shines through the prism and onto the whiteboard.

Important: The laser beam must hit the side surface of the prism and not the edges!



Procedure



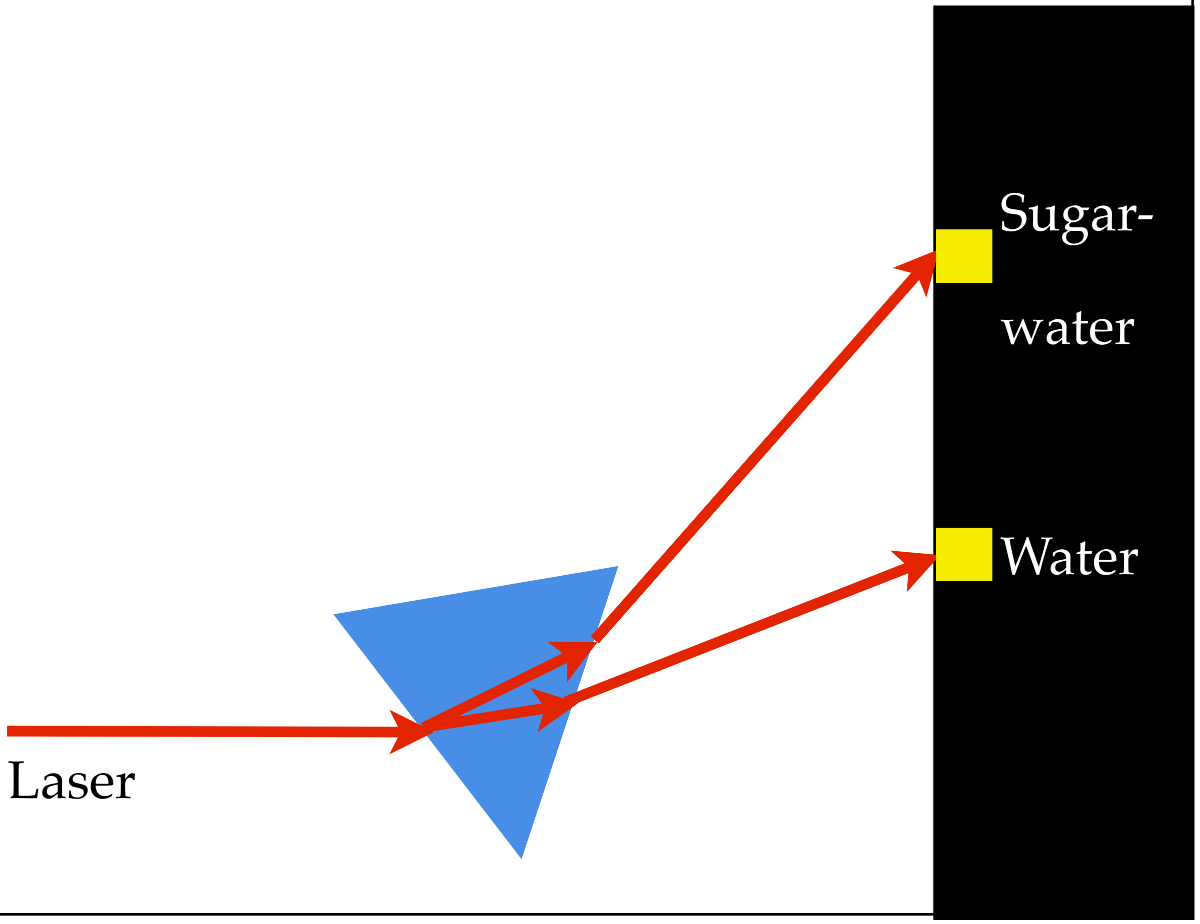
1. Adjusting the arrangement

Laserschutzbrille aufsetzen und Laserpointer einschalten!!!

Put on laser safety goggles and switch on the laser!

Adjust the prism filled with water so that the deflection of the laser beam is as low as possible. You can find this point by turning the prism with the holder in the same direction until the direction of movement of the laser dot on the wall changes. When you have found exactly this point, tighten the screws.

Then place the prisms with water or sugar water (sugar solution with 17 sugar cubes) in the holder, scan them with the laser and mark the laser points on the white-board with the whiteboard markers!

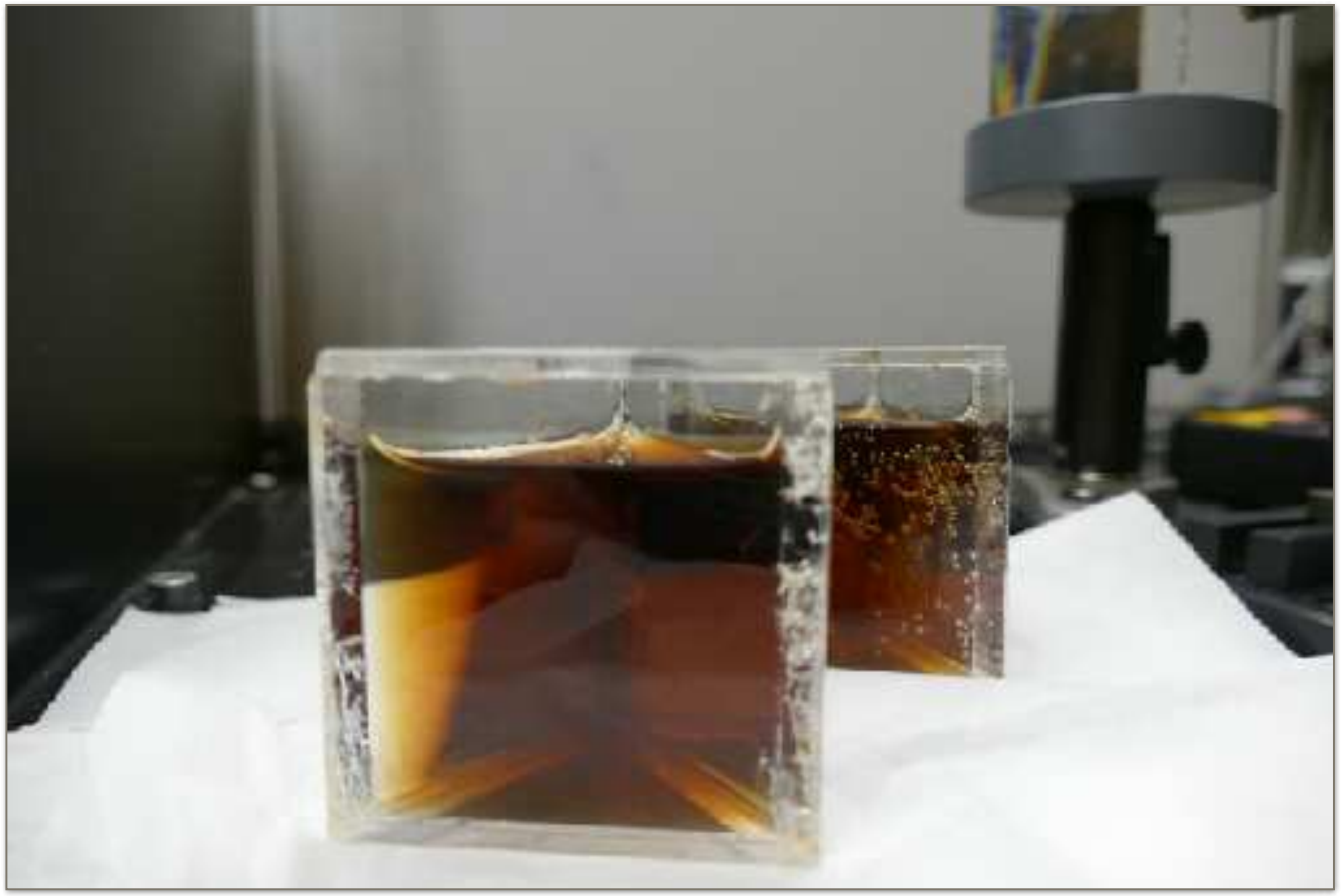


2. Cola or Cola light?

This time, place the two prisms filled with cola in the holder, shine a light through them again and compare the points of the two colas with those of water and sugar water.

In which prism is the normal cola?

(The light cola is no longer needed).



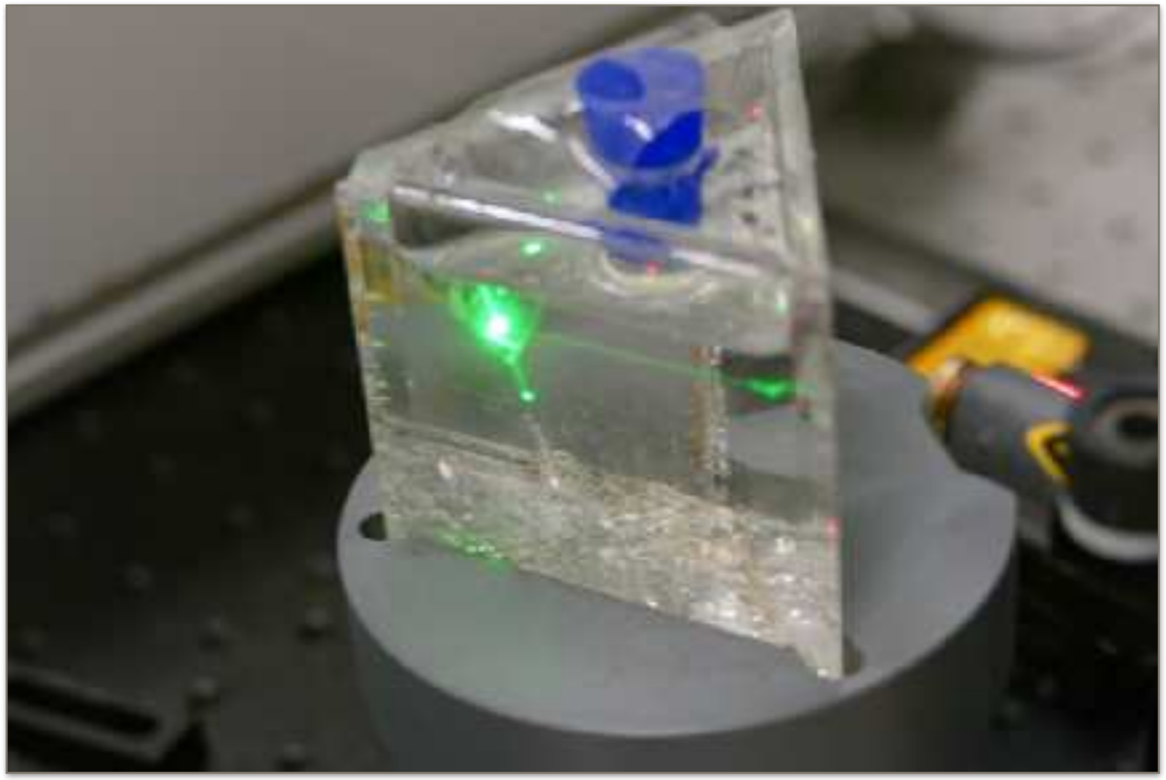
3. Determination of the sugar content in cola

Mark the point of the normal cola on the whiteboard. By measuring the distances between the dots on the whiteboard, you can now calculate how many sugar cubes are in one liter of cola.

To do this, measure the distance between the dot of the known sugar solution, the pure water and that of the normal cola. The deflection is directly proportional to the concentration.

Decide how you can determine the volume of the liquid in the prism. The correct method will give you approx. 56 ml.

Calculate this using the rule of three.



How many sugar cubes are in a liter of cola?

a) 24 - 33

b) 34 - 43

c) 44 - 53

d) 54 - 63

Answer b) is correct.

EXPERIMENT 11: SECRET SCREEN

Secret screen

Crack the cipher on the LCD screen!

LCD screens are not only found in monitors, but also in pocket calculators, digital watches and clinical thermometers. However, if you remove the top film of an LCD (liquid crystal display) monitor, you will only see a white image. But if you hold a polarization filter in front of it at the right angle, you get the actual image.

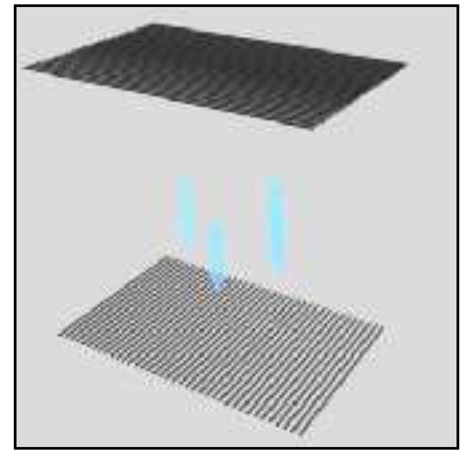
LCD function

There are a number of lamps, such as LEDs, in the lower part of the display for good backlighting.

Now the light is distributed evenly over the entire surface of the screen by several layers of glass on top of each other.

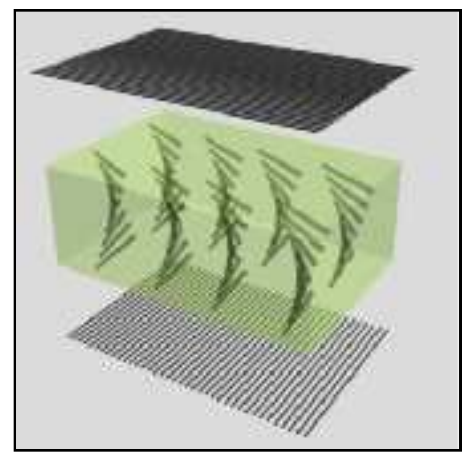
However, the secret of the LCD display lies

lies in the glass plate above it.

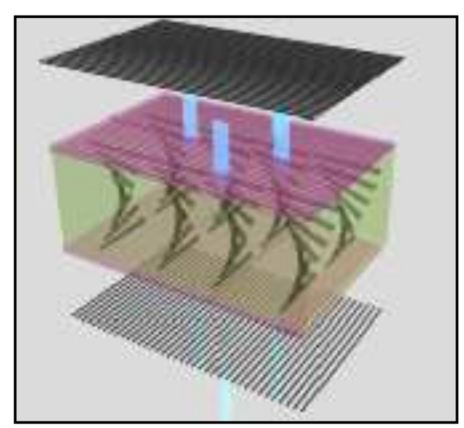


This contains two **polarization filters** that are offset exactly vertically. If the light passes through the first filter, only one direction of polarization passes through. The second, however, absorbs exactly this

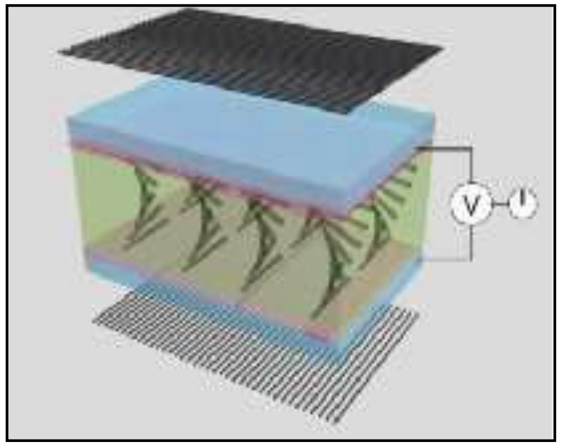
polarization direction, which means that in the end no light gets through at all.



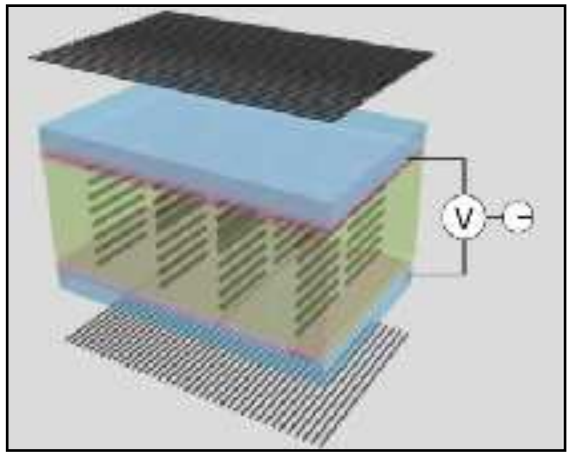
However, the liquid crystal is now inserted between the two polarization filters. Due to its optical activity, the crystal rotates the polarized light by approximately 90°, which means that the light that makes it through the first polarization filter can now also pass through the second.



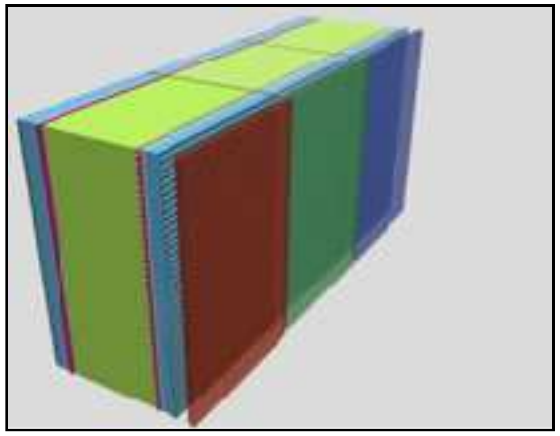
A thin layer of polymide is applied between the polarization filters and the liquid crystal, which ensures that the rod molecules of the crystal are perfectly aligned.



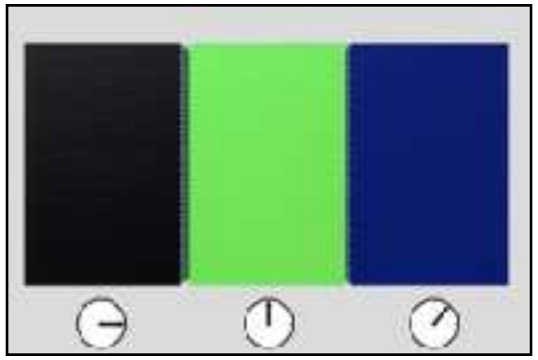
Now the final layer is added: A small glass plate to which an electrode is attached, through which a voltage can be applied to the liquid crystal.



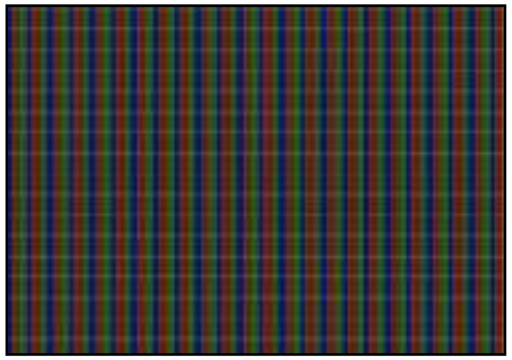
The higher the voltage applied, the less the rod molecules twist, which means that the polarization of the light is less strongly rotated and therefore only a small proportion can pass through the polarizer (second filter).



A color filter, which is green, blue or red, is then attached to each of these elements, also known as pixels.



Depending on the voltage applied, different amounts of light flow through. This allows you to mix any color. For example, if you want to create purple, you can apply voltage to the green pixels while not applying any voltage to the red and blue pixels.



There are several thousand of these elements on a screen, which together form an image, as the individual, tiny elements and their colors merge in the eye.

Voilà! This is the result!

Procedure

The polarizing film has already been removed from one half of the screen.

1. Connect the screen (if not already done) to the computer.
2. Turn on the screen (at the bottom behind the screen).
3. Take the polarizing filters (from the ones in the introduction) and look through them
4. Rotate the polarizing film until the colors match

Quiz

Wieso verändern sich die Farben, wenn man den Polarisationsfilter dreht?

a) Deine Augen spielen dir etwas vor, eigentlich verändern sich die Farben nicht.

b) Durch das Drehen der Folie verändert man den Lichteinfall und somit die Farben.

c) Keine der Antworten ist richtig.

d) Durch das Drehen der Folie kann man mehrere Polarisationsrichtungen sehen.

Correct answer Chapter 22 Explanation

Antwort d) ist richtig.

Mirascope magic mirror

How can the spider float in the air? And why can I reach through it?

Arachnophobia is not a problem here because you can't touch the spider. It floats in the air!

History of discovery:

Incidentally, the mirascope was discovered quite by accident. Around 1969, a worker had the task of tidying up a cupboard in the physics department. In this cupboard, parabolic mirrors were carefully stacked on top of each other like shells. They had a hole in the middle so that an arc lamp could be stuck through. The worker discovered dust here that could not be wiped away. He told this to a young physicist who was able to explain the phenomenon and obtained a patent together with the worker.

Procedure

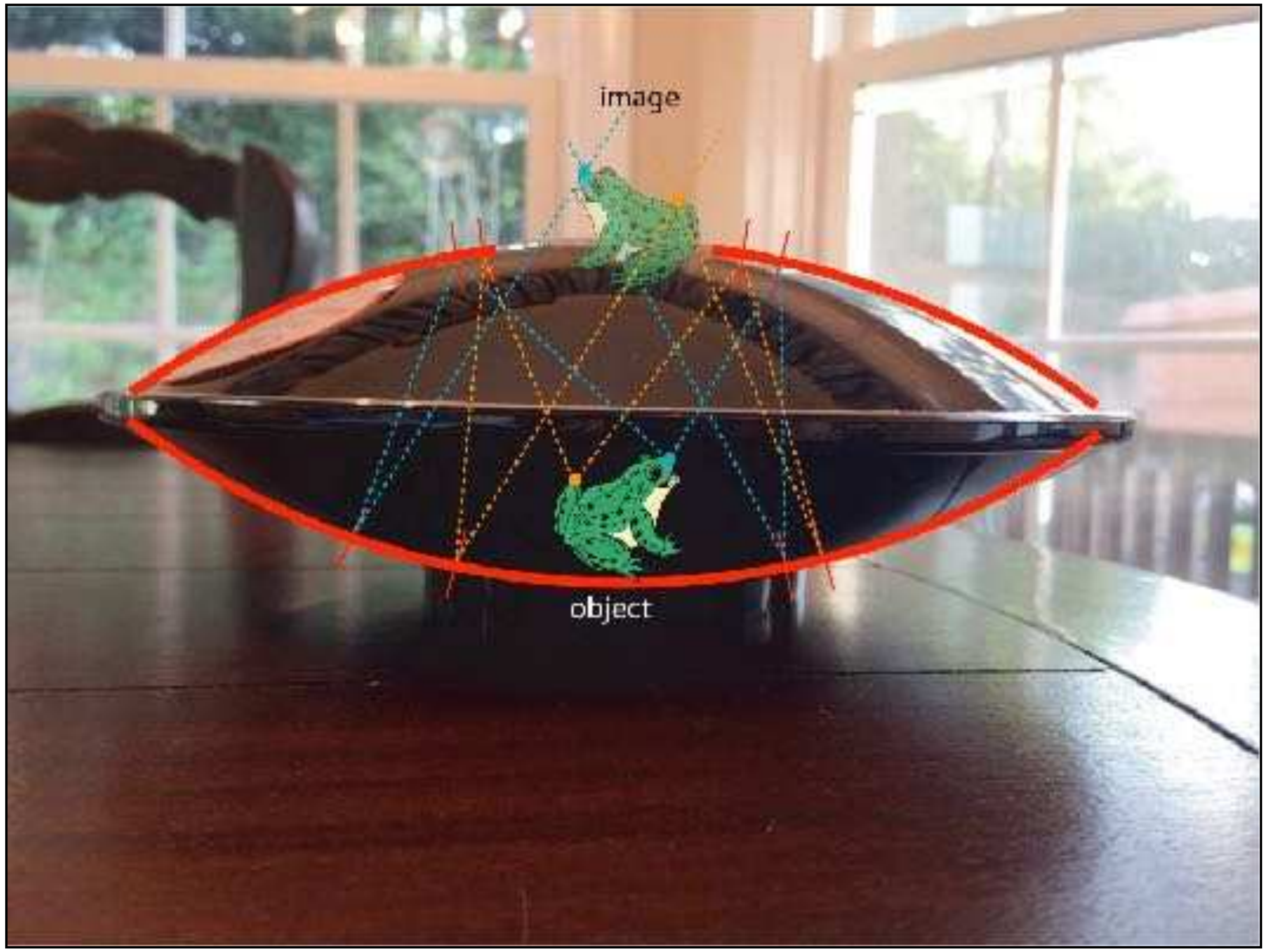
Place the Mirascope in front of you and look at the large opening. The spider is hovering in the middle of the opening! When you try to reach for the spider, you reach through it.

Can you explain this phenomenon?

Attention!!! Please do not reach in!!!!

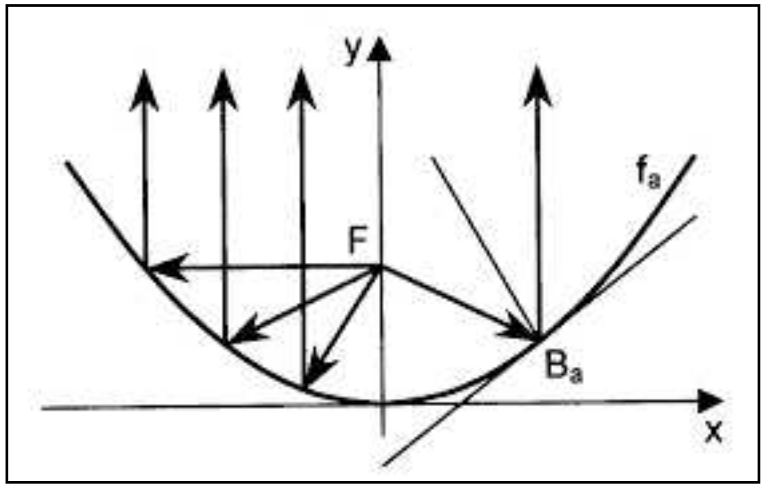
Explanation (inaccurate): The amazing optical illusion is created by placing two concave mirrors on top of each other. The light from the spider below is reflected by the upper mirror, thrown back down and then lands in the (physically non-existent) focal point of the upper concave mirror. This creates an image of the spider that looks deceptively real.

By the way: this phenomenon is not a hologram!

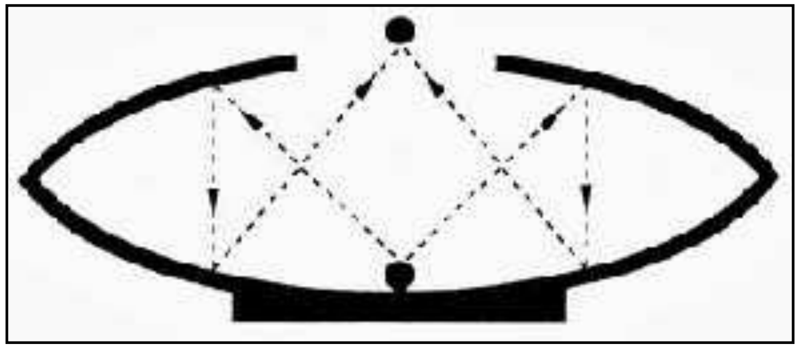


https://skullsinthestars.files.wordpress.com/2016/05/mirascopegeometric2.jpg

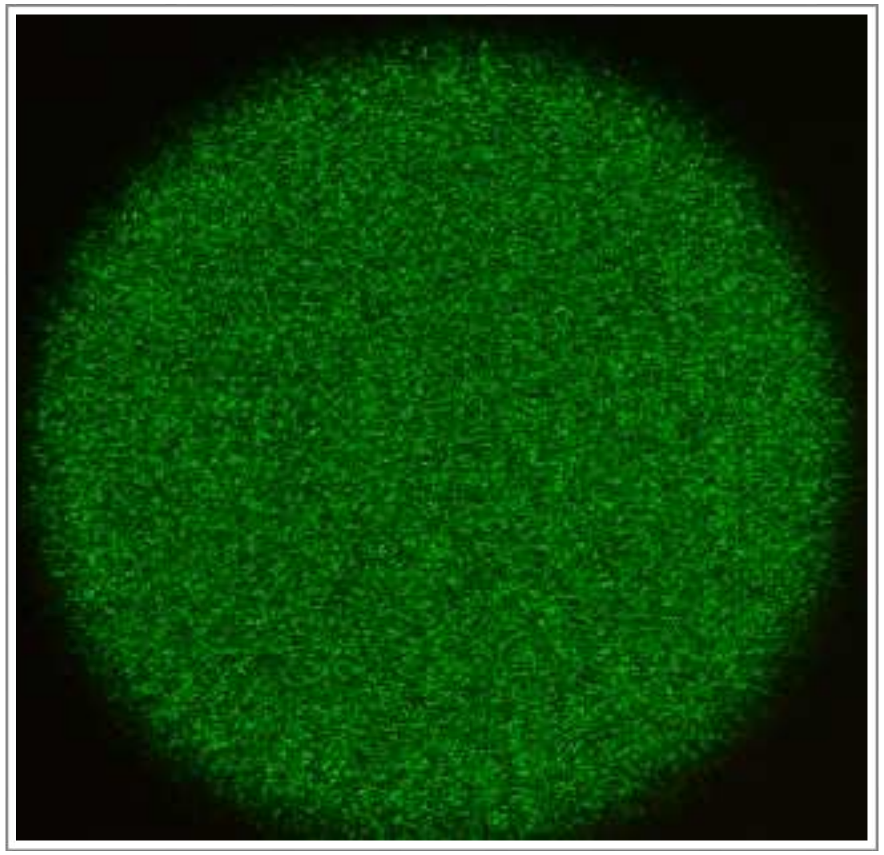
Explanation (exact): The ray diagram shows that parallel rays of light incident on a parabolic mirror meet at the focus (= focal point). This also works the other way round, i.e. if the light source is positioned at the focal point, e.g. in a lighthouse.



If two parabolic mirrors are placed on top of each other as in a mirascope, the object being viewed is at the **lower focus**. The light emanating from here is reflected by the upper mirror into parallel rays of light to the lower mirror. This now collects the parallel incident rays in its focus, which is located in the hole of the upper mirror, which then creates the image.



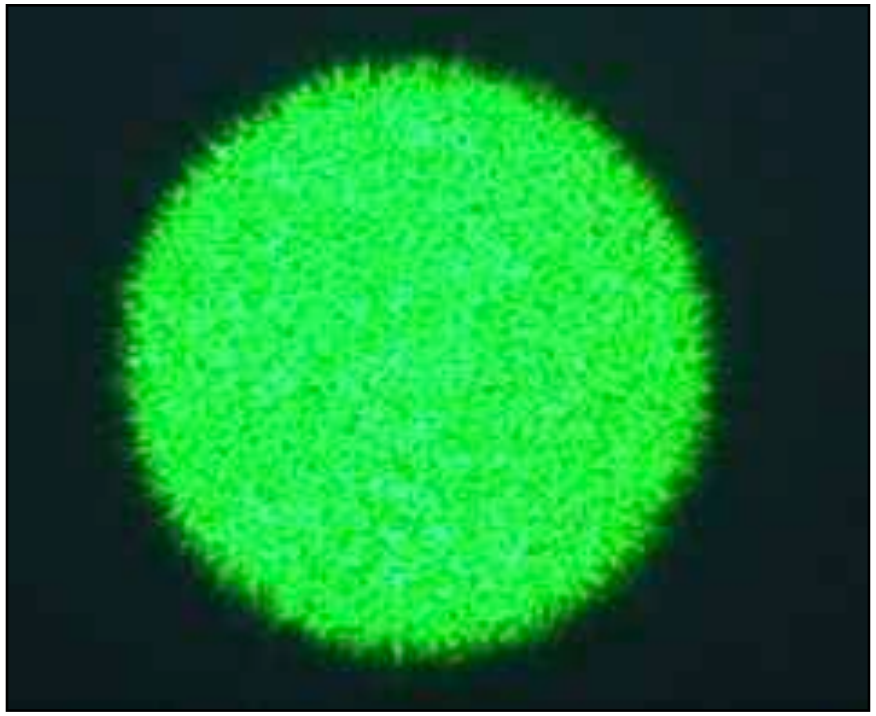
Laser speckles



Are you ametropic?

When a laser falls on a rough surface, a pattern of dark dots is created, which can be used to determine short or long-sightedness. This pattern is called "**laser speckles**".

Basics



The adjacent pattern is created when a laser falls on a rough surface because it is reflected by the various elevations and the light rays reflected from adjacent surface elements interfere.

However, because the bright and dark dots are not dots on the screen, but actually bright and dark "light cylinders", they are always seen in focus, regardless of the distance at which the eye is set.

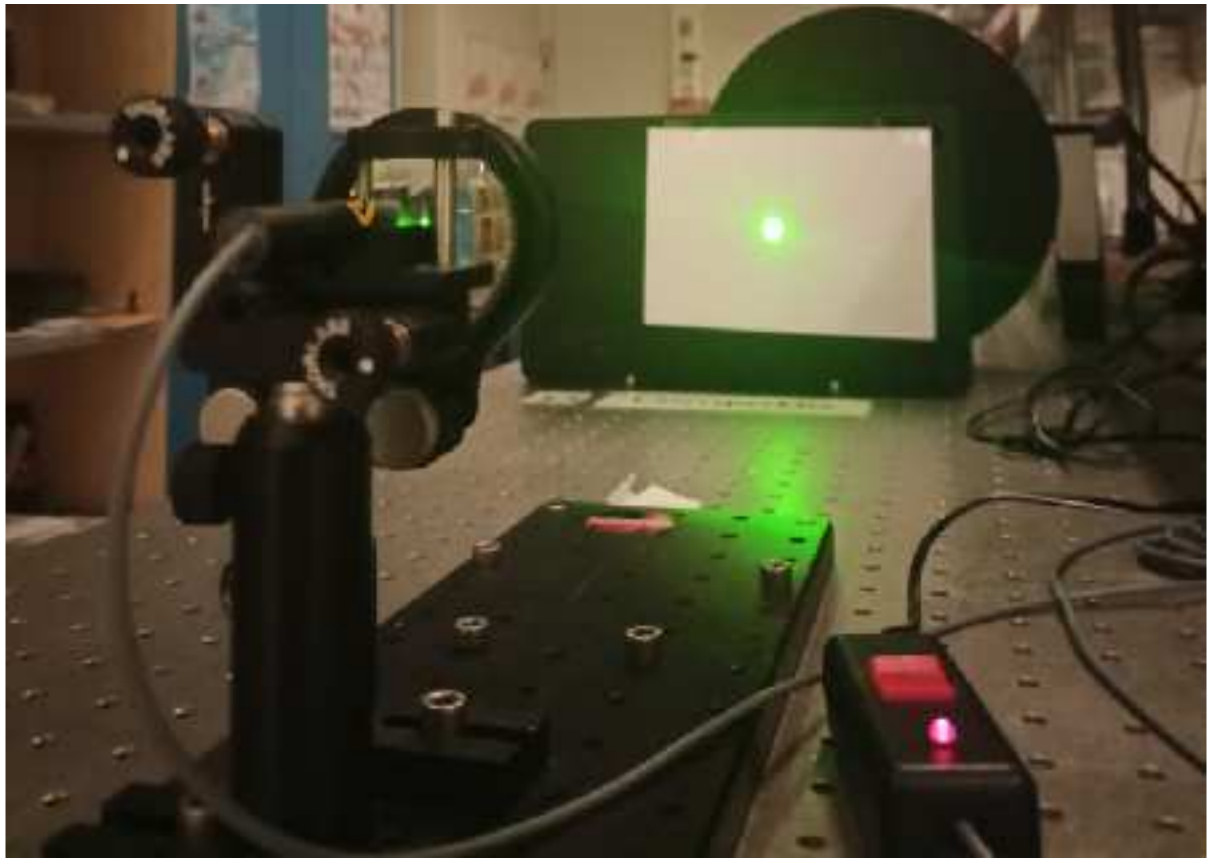
The eye therefore focuses on the screen. If you have defective vision, the image of the screen is in focus either in front of or behind the retina (**defective vision**).

This is why a short-sighted person sees the speckles seemingly in front of the screen and a long-sighted person seemingly behind it.

If you now move your head, the black dots also appear to move in relation to the screen, although this is not the case (parallax effect).

Construction

Arrange the laser pointer, the lens and the paper screen so that the laser is expanded by the lens and then falls onto the screen. The setup should already be set up as shown in the picture.



Disclaimer: The large black spots are defects in the lens.

Procedure

Put on laser safety goggles and switch on the laser pointer!

When you switch on the laser pointer, the speckles appear on the screen. Look at them vertically and then move your head to the right.

If the black dots move in the direction of your head, you are farsighted.

If the black dots move in the opposite direction to the movement of your head, you are short-sighted.

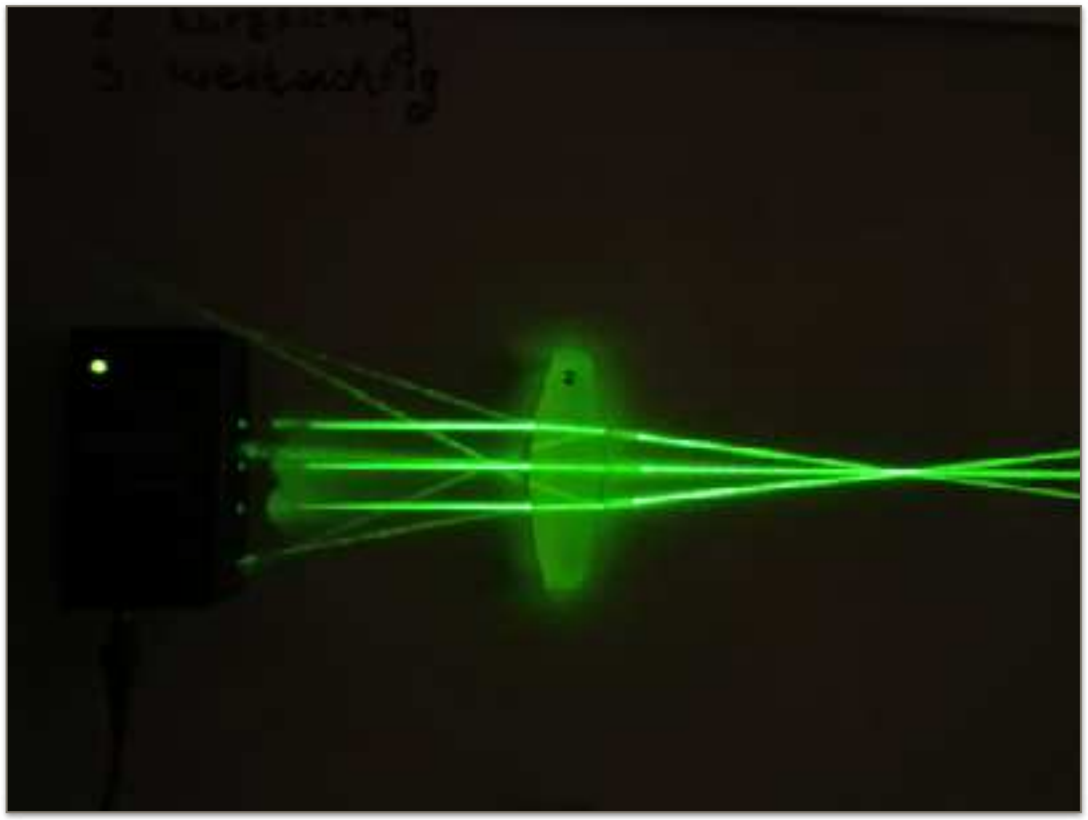
If the black dots **do not move in relation to the screen**, you **do not have defective vision**.

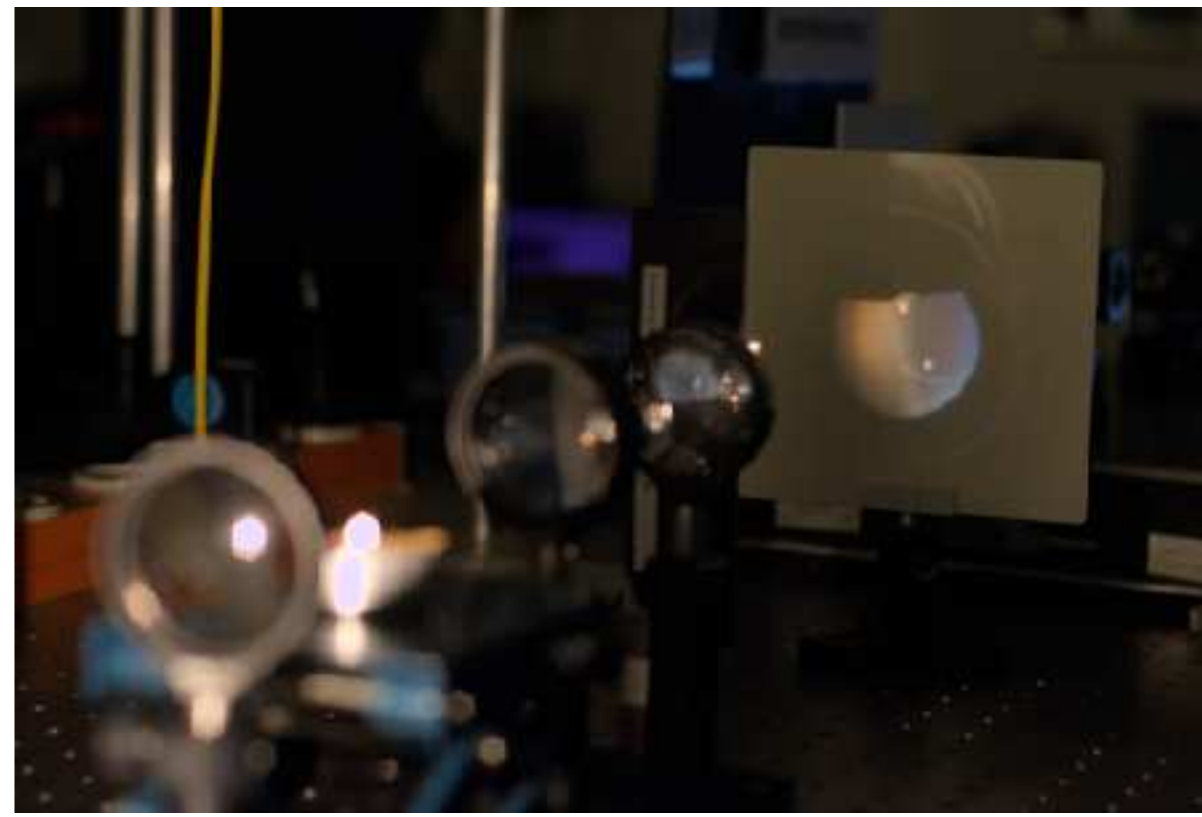
Congratulations! To see the effect anyway, you can hold the given glasses in front of the laser safety goggles.

This test is very precise and any defective vision detected here may also be due to eye fatigue.

Geometric optics

Making the invisible visible?



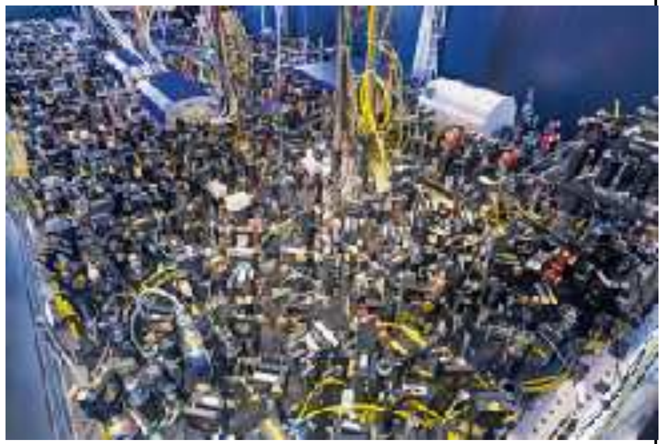


Geometrical optics deals with the purely geometrical part of optics (**ray optics**). It is a model for investigating the formation of **images** in sufficient detail.

Incidentally, if the light rays run at a flat angle close to the optical axis, this is referred to as **paraxial optics**.

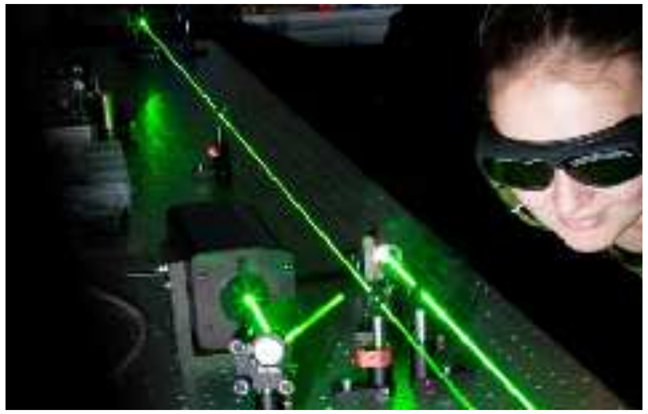
Basics

Optical System
All the equipment that leads to the creation of an image. Such a system can sometimes (here: MPQ) become quite complex.



Lenses
Transparent panes that influence the course of a beam.

Light source
A light source is the origin of the rays (e.g. laser, halogen lamp).



Apertures
A diaphragm is, for example, a disk with a hole. The purpose of a diaphragm is to intercept certain areas of a bundle of light rays.

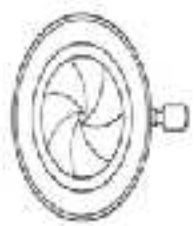


Abb. 197. Eine Iris-blende

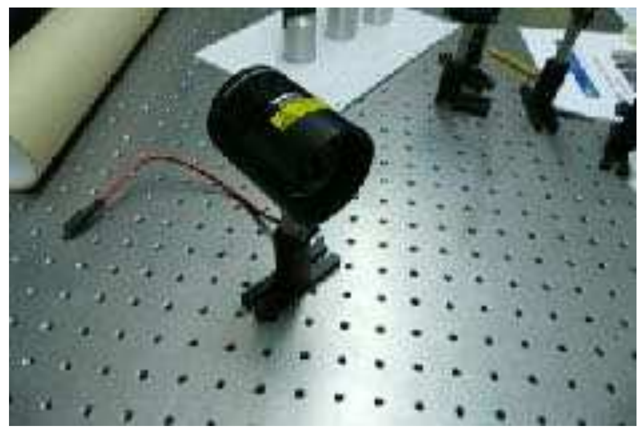
Screen
For example, the images land on a screen after its rays have passed through an optical system.

https://homepages.physik.uni-muenchen.de/Juergen.Giersch/HistorischeSammlung/sammlung_test/08__Optik/1__Geometrische_Optik/d__Mikroskopzubehoer/1905X__Zubehoer__01_006/medien1024.html
https://www.acalbfi.com/de/technologien/photonik/laser-und-lichtquellen

Equipment (overview)

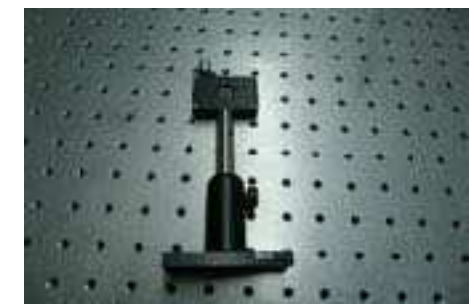
Streaky edge

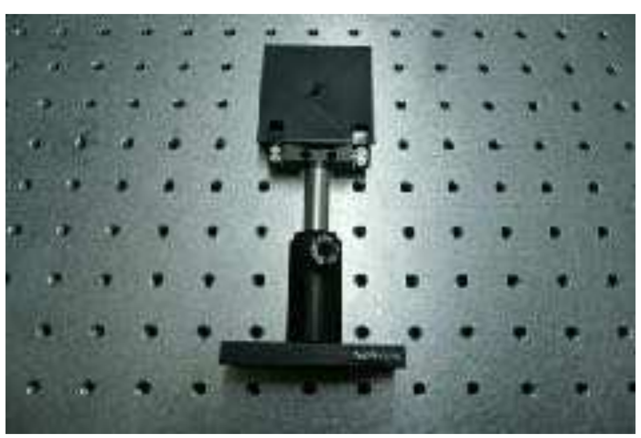
Halogen lamp (light source)



Iris diaphragm (like eye)

Single gap





"Schrödinger cat" (object)

Rails with metric labeling

Red and blue color filter

Lenses (data such as focal length: see lens)

Grid (object)

Experiment 1: Sharp cat claws

Components: Light source (halogen lamp), lens (f=100mm biconvex), screen, Schrödinger cat (object)

1. place the Schrödinger's cat 1 cm in front of the halogen lamp and then switch on this lamp.

2. now place the white screen at a distance of about 60 cm (note the labeling on the rails) from the object (the cat). You should now be able to see the light from the light source on the screen. That's a good start!

3. now use the biconvex lens (focal length f=100mm). Move it back and forth between the object and the screen until you can observe a sharp image of the cat. Important: Now measure the object distance g and the image distance b and enter these values into the lens equation (see below).
If you solve for f, do you get approximately the focal length?

4. (optional) Is there a second object distance (or image distance) at which you obtain a sharp image? (Solution here)

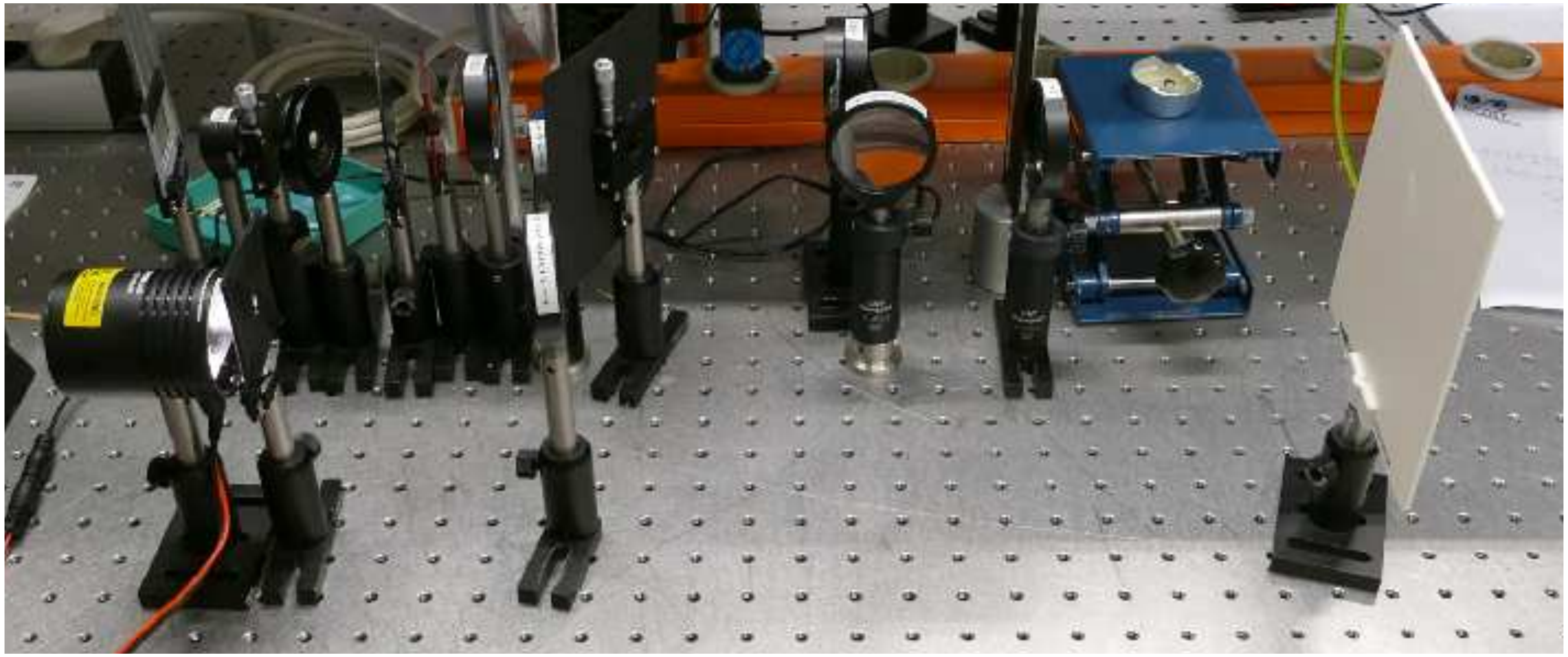
$$\frac{1}{f} = \frac{1}{g} + \frac{1}{b}$$

EXPLANATION

What you see here:

On the left of the picture you can see the light source. Right next to it is the cat (object) and the lens. Does your setup look similar?

Attention! The cat is quickly heated up by the lamp - so don't hold it directly in front of the halogen



That was a one-step illustration. Would you now like to investigate a two-stage image whose aim is to show an enlargement, as in the image on the right? Then click here for this experiment!

Experiment 2: What is the error?

Components: **Light source** (halogen lamp), **lens** (f=100mm) **biconvex**, **shade**, **grid**, **iris diaphragm**

1 First, we use the last setup to create a sharp image on the screen again. This time, however, we are not using the Schrödinger cat as the object, but the grid. When you have an image on the screen, are all areas of the image in focus? No? If you want to know why, take a look at the chapter on spherical aberration.

2. now we want to find out how we can remove the blurred areas of the image, i.e. we want to minimize the aberration. Place the iris diaphragm between the object (grid) and the lens. Then vary the aperture of the iris diaphragm by moving the slider. Try it out!

What can you observe under which conditions?

What you see here:

On the left of the picture you can see the halogen lamp again, next to it the grid, then the iris diaphragm and the lens. Your optical system should look something like this.

If you want to do more experiments on abberation, click here for the chromatic abberation experiment!

HIGHLIGHT

Experiment 3: Schlieren optics

Now comes the highlight of this little series of experiments: you can make the invisible visible here. Or is it all just hot air?

<u>**What you need:**</u> **Light source** (halogen lamp), **2x lens** plano-convex), **lens** (f=150mm, biconvex), **candle**, **Schrödinger's cat**, **screen**, **matches**, **schlieren edge** (ATTENTION! SHARP!)

1. first place one of the two plano-convex lenses directly in front of the **halogen lamp** at a distance equal to the focal length. Make sure that the flat side of the lens is facing the lamp. **Control check**: Use a small piece of paper to check whether the beam diameter remains constant at a variable distance from the light source (then the light beams run parallel).

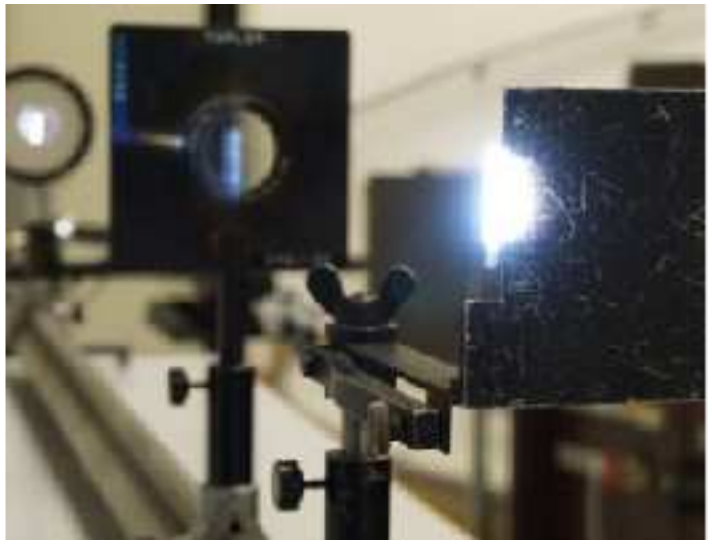
2. now place the **second plano-convex lens** (f=200mm) to the right of the first plano-convex lens just set up. Now place the candle (do not light it yet!) between the two lenses. Again, make sure that the flat side points towards the screen (remember: "the bellies point towards each other"). Note that the distance between the second lens and the shade should be exactly L=50 cm!

www.videoman.gr/wp-content/uploads/untitled301.jpg

Image: The air flow of the hairdryer was visualized with schlieren optics.

HIGHLIGHT

ATTENTION: The schlieren edge is a **razor blade**!!! Extremely sharp and dangerous, do not touch!!!



3. the **last lens** (biconvex with f=150mm) is placed between the screen and the second (plano-convex) lens. You must align this last, biconvex lens in such a way that the image of the candle is displayed sharply on the screen. Tip: Start by using the wick of the candle (or the grid) to create a sharp image! Then you can light the candle carefully.

4. In **the last step**, we place the edge between the 2nd and 3rd lens and move it in the beam so that the point of light is minimal. This is the **focal point**. Now move the edge forwards or backwards so that it covers a large part of the light at the focal point and only the last "hint" passes it (as above right). Now you should be able to observe the **density fluctuations** around the candle on the screen. Otherwise, move the edge a little more forwards or backwards.

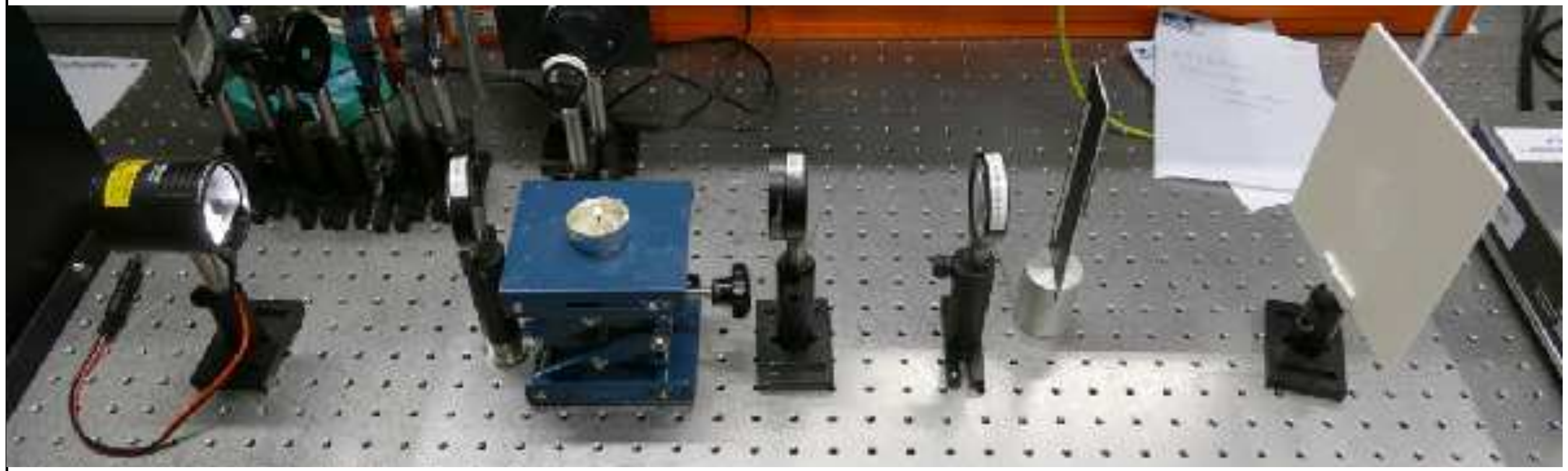
The picture shows a candle in a single-mirror schlieren photographic apparatus, which uses four color filters instead of a razor blade to separate the refracted light. This makes the horizontal and vertical separation of the light visible. This allows you to do more than just separate "dense air from less dense air", but also to make the 3-dimensional form visible

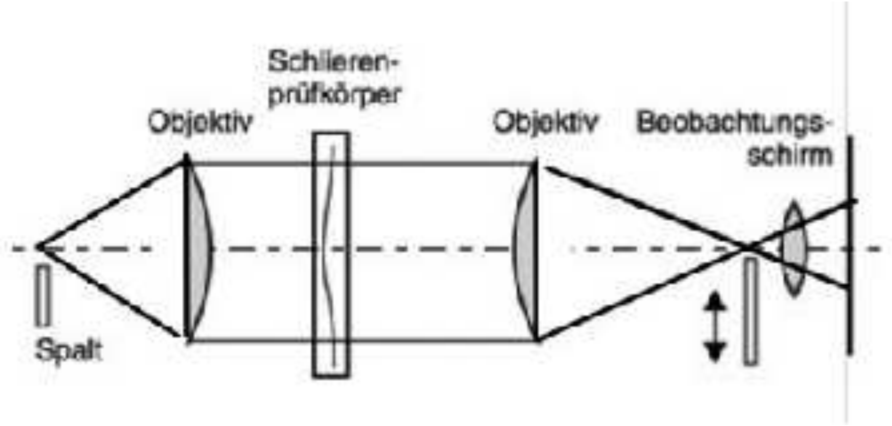
https://expvorl.physik.uni-muenchen.de/versuche_optik/reflexion_beugung/toepler/index.html

EXPLANATION

What you see here:

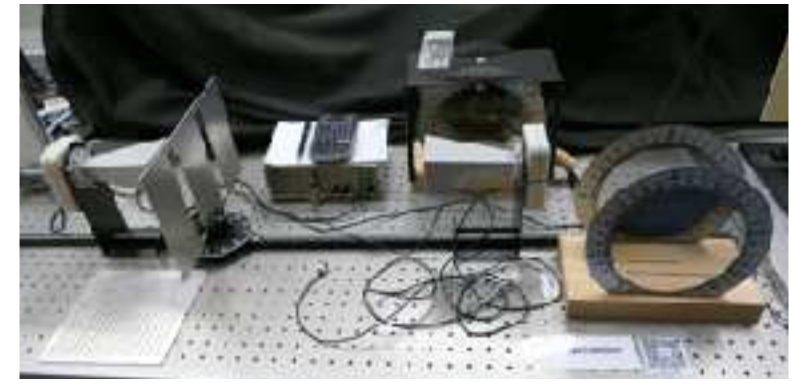
Towards the right, the light source illuminates the two plano-convex lenses, the candle in between, then the edge, the lens and the screen.



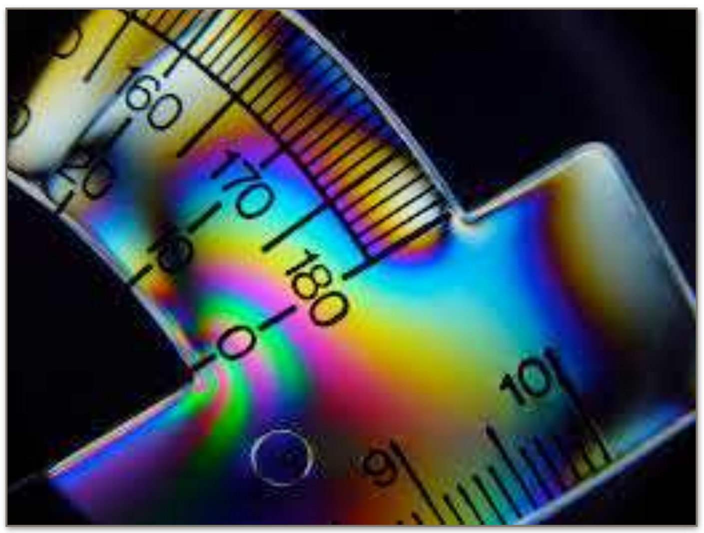


Why a schlieren edge? Air is normally a homogeneous medium. This is where the edge comes into play: it "blanks out" the parallel rays between the first two lenses (plano-convex). With a candle, however, things look different! Due to the differences in density, which you have illustrated with the experiment, not all rays of light are combined at the focal point and can be imaged past the edge.

For pros: Now you've experimented a lot! Now think about how a rainbow is created. You can find the solution here!



Polarization



What do 3D glasses, dazzling colors and lemonade have in common?

One property of light, polarization, comes into play here:
-Polarized light can be used to investigate the stress on materials (e.g. tools).

-With the help of polarized light, you can watch films in 3D in the cinema (experiment: 3D vision).

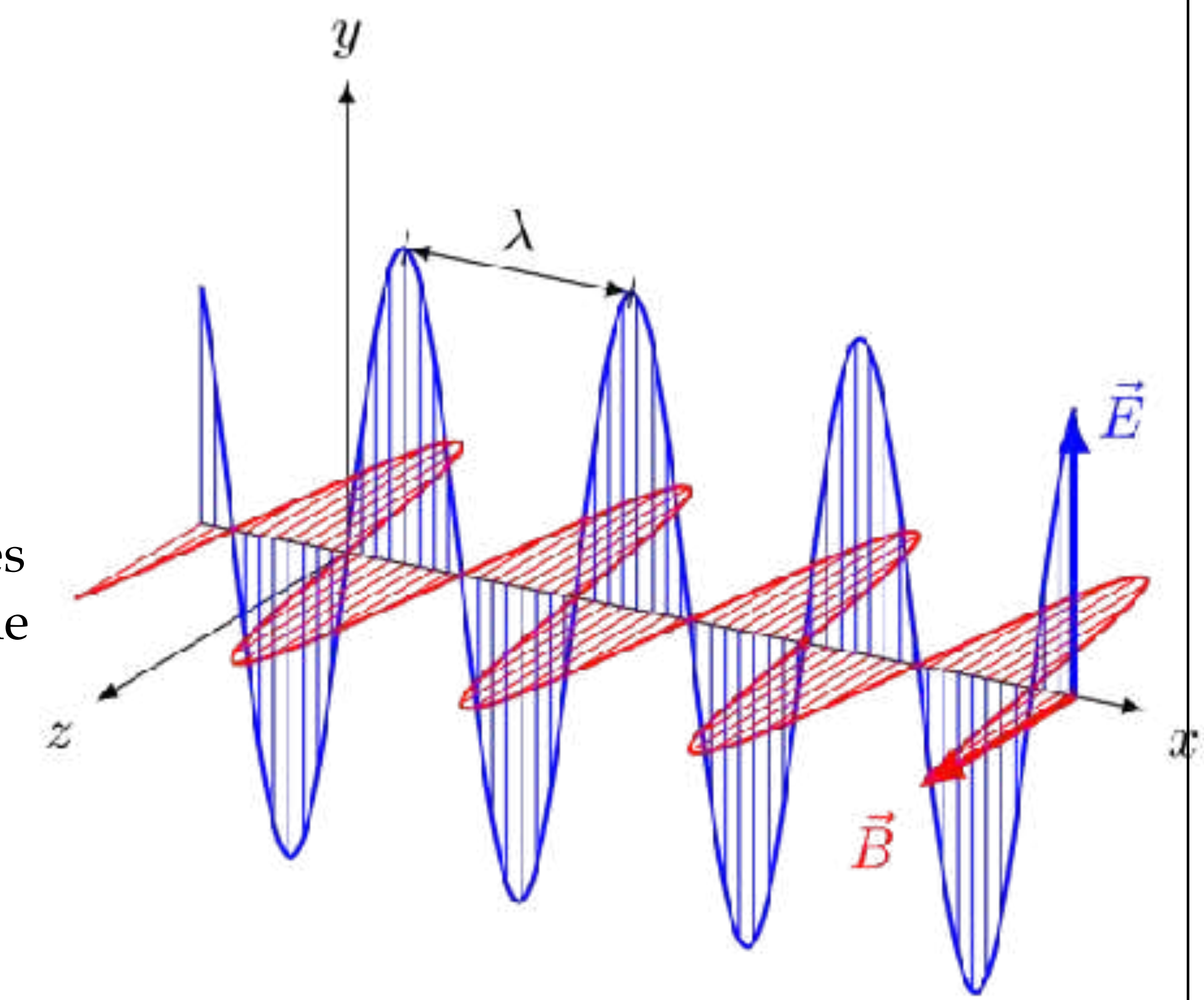
-The manufacturer uses a polarimeter to set the correct sugar concentration in soda.

Basics

Before we take a closer look at polarization, we need to look at the properties of light. Light can be described as an electromagnetic wave.

What are electromagnetic waves?

Electromagnetic waves are so-called transverse waves whose magnetic B-field oscillates perpendicular to the electric E-field. The wave shown here is **monochromatic** (i.e. has a fixed wavelength λ and is "monochromatic") and propagates in the x-direction:



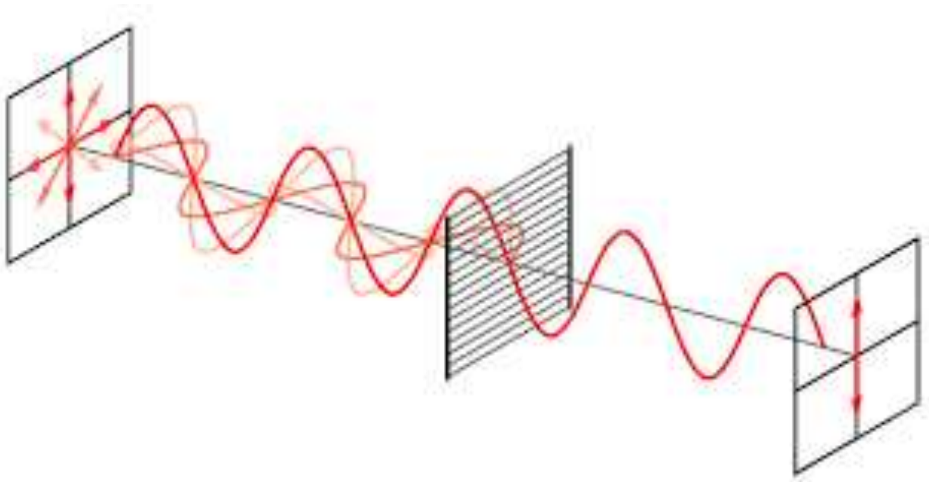
Electromagnetic waves are generated in different ways, for example by bremsstrahlung in the X-ray tube or by oscillating electrons in an antenna (Hertzian dipole).

https://de.wikipedia.org/wiki/Elektromagnetische_Welle

What is polarization?

When we talk about polarization, we mean the **direction of oscillation** of an electromagnetic wave (electrical component in the electric field). If a wave is polarized, its electric and magnetic field vectors oscillate **perpendicular** to each other in one plane. If a wave is **unpolarized**, its electric field vectors oscillate in many different directions (and its magnetic field vectors naturally oscillate perpendicular to each other). An example of this is the unpolarized light of an incandescent lamp (see image on the right).

In general, the **electric** field vector is referred to because the magnetic field vector is always perpendicular to it.
Incidentally, the degree of polarization indicates how "ordered" a wave is. The higher the degree of polarization, the more "ordered" the wave. A linearly polarized wave is therefore a wave with only one direction of oscillation.



(https://de-academic.com/dic.nsf/dewiki/1118700)

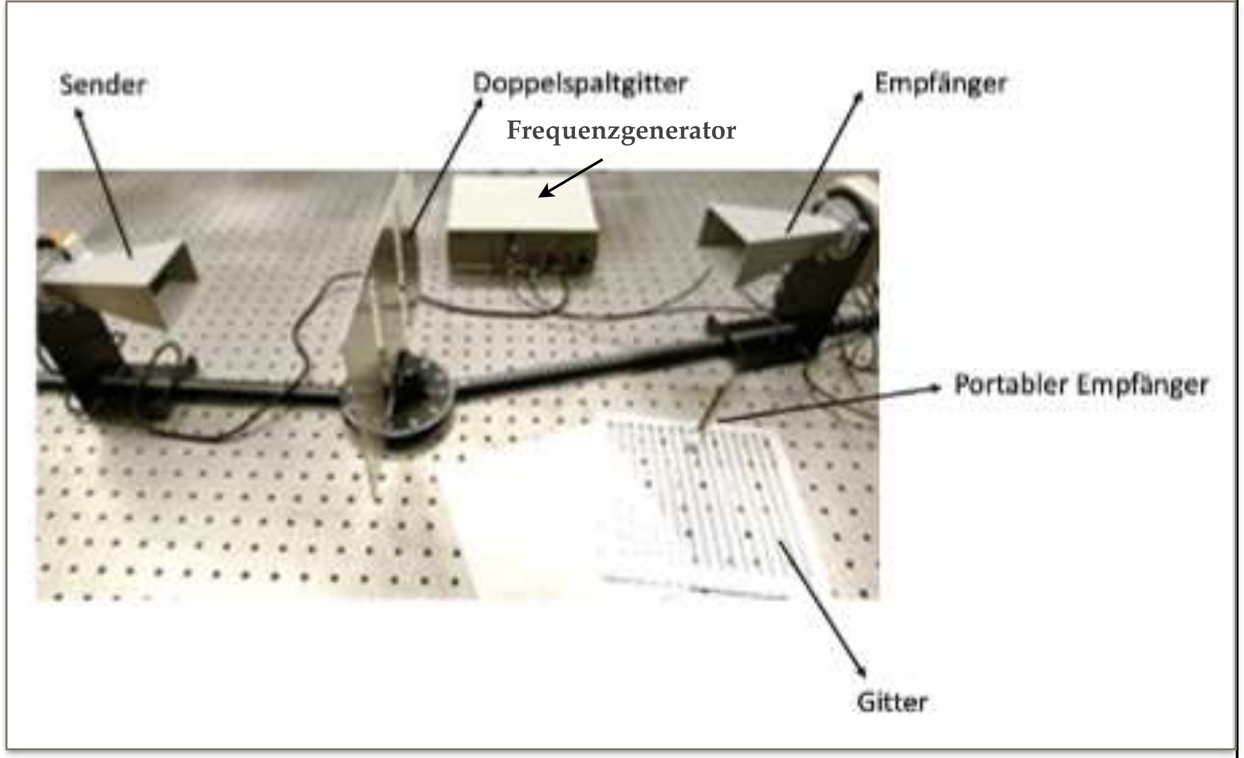
TV1: Microwave experiment

(TV=Subtest 1)

Microwaves, like light, are electromagnetic waves, but have a much longer wavelength in the millimeter to decimeter range. This makes it very easy to carry out experiments on polarization.
The microwave experiment consists of a **microwave transmitter** on the left, which emits linearly polarized microwaves, a **receiver** on the right and a **portable receiver** (device in the middle).

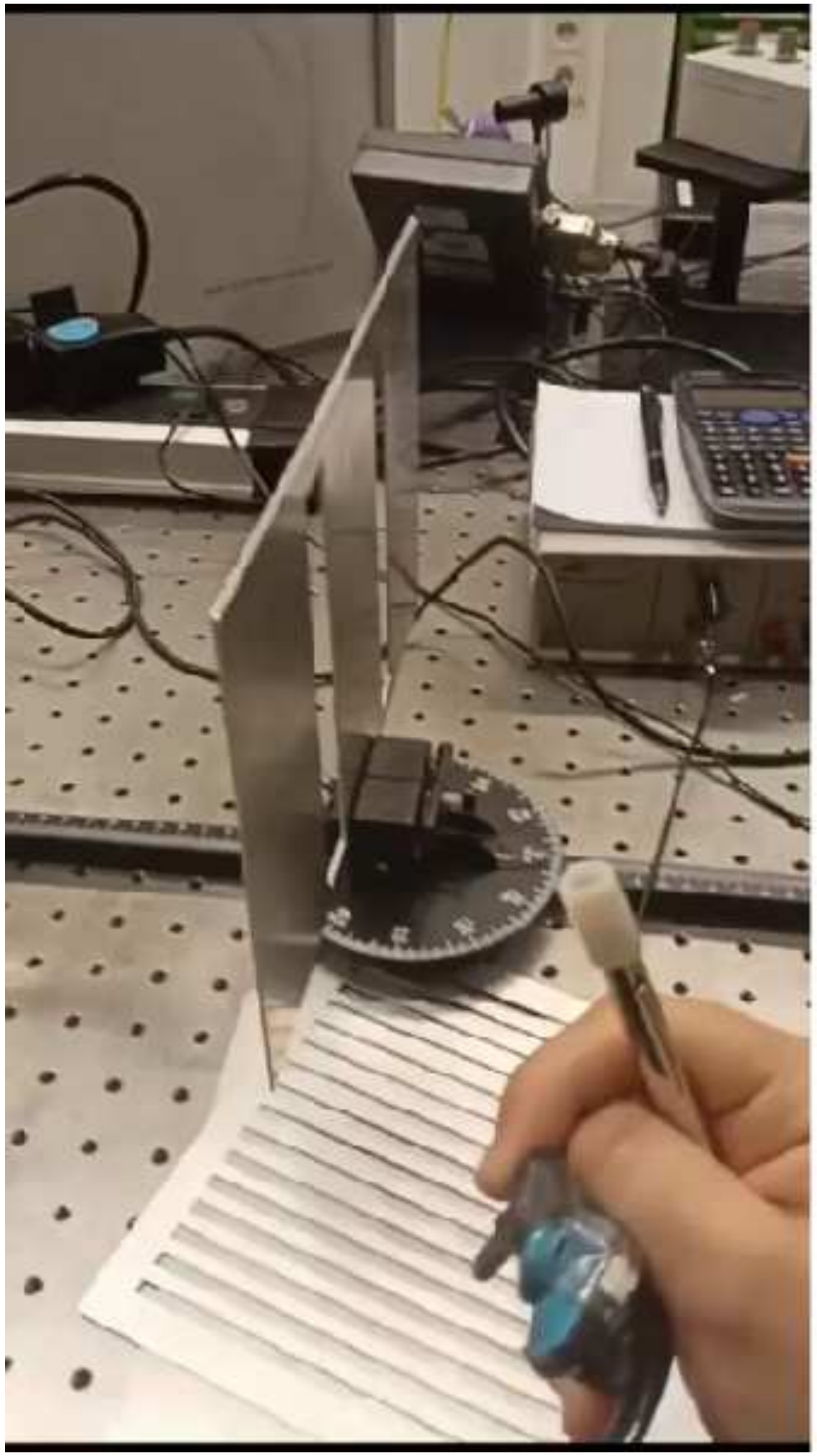
1. transmission and reception

The first experiment is the transmission and reception of microwaves when the transmitter and receiver are directly opposite each other. Connect the thin black cable of the receiver to the frequency generator ("Receiver" socket). Make sure that the "Modulator" switch is set to "INT". You will now hear a tone: the louder it is, the higher the intensity of the measured signal.



2.a: Metal plate

Further research can be carried out using a metal plate with several slits (grid). Place it vertically on the table between the transmitter and receiver. Now turn it 90° in the plane of the grid. What can you hear?



Explanation: The transmitter emits linearly polarized light. This hits the gril-le. Depending on the orientation of the grating, the polarized oscillation is absorbed (no sound) or transmitted (sound is transmitted). The grating here is also known as a polarization filter.

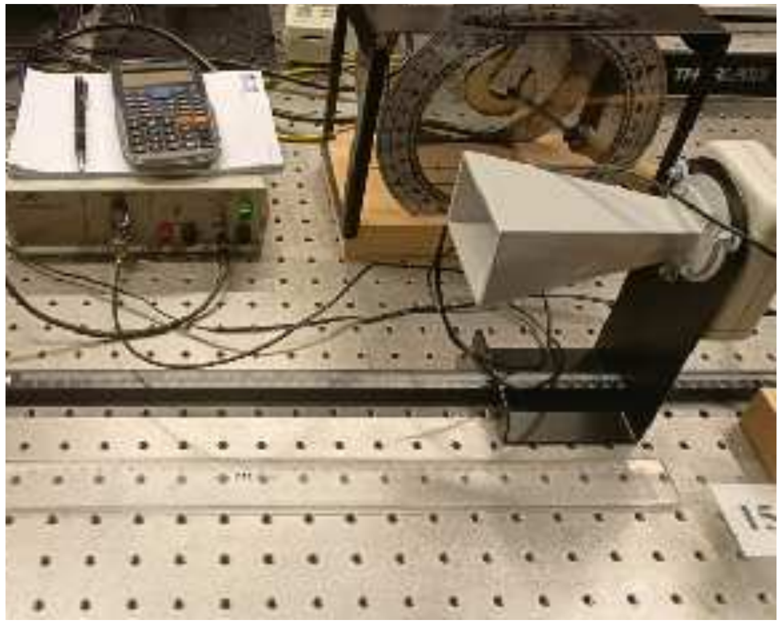
2.b: Double slit

Now replace the grating with the metal plate with the two slits (sound on for the double slit in the video). Use a mobile (portable) receiver to help you. Connect the portable receiver to the frequency generator at the socket where the receiver was previously connected. Using the portable receiver, we can measure or hear the interference pattern created behind the double slit at any position.

Quelle Bild: https://eventelevator.de/storys/funk-schwingungslehre-mit-shure-frequenz-management-interferenz-intermodulation-frequenzspektrum/

Determine the frequency yourself?

Theoretically, we can determine the frequency by the distance between two extremes. To do this, we use the fact that the transmitted and reflected waves are now transmitted to form a **standing** wave. You can hear this: If you slowly push the receiver (on the right in the picture) forward, the sound changes. Ideally, it should become steadily louder and quieter again and describe a sine wave. It is quieter at nodes and louder at the belly. Unfortunately, it is too loud for this in the lab and the setup is too error-prone. You probably can't figure out that the frequency is 9.6 GHz and the distance between two extremes is 1.6 cm (half the wavelength).

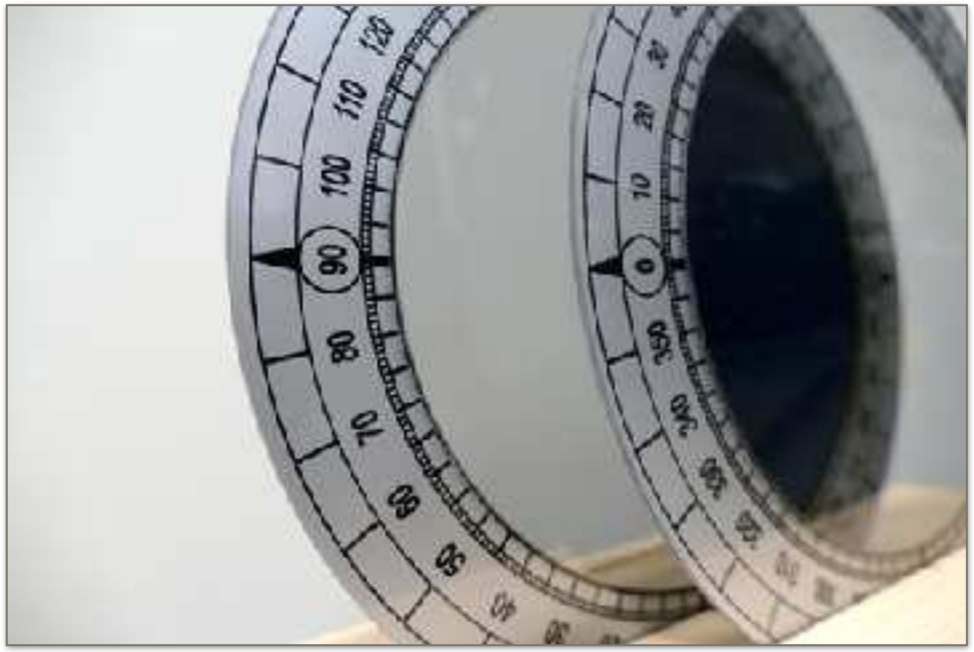


TV 2: Two-filter test

To repeat: A linear polarization filter (polarizing filter for short) is a filter that only allows electromagnetic fields of one direction of oscillation to pass through (pass direction). Light that is polarized perpendicular to it is not transmitted (blocking direction).

Now it's your turn!

Investigate the angle at which the polarizing filters are opaque to each other.
At what angle are the polarizing filters transparent?



If unpolarized light is shone through **two mutually perpendicular polarizing filters,** no light can be transmitted: They appear dark (see previous page).

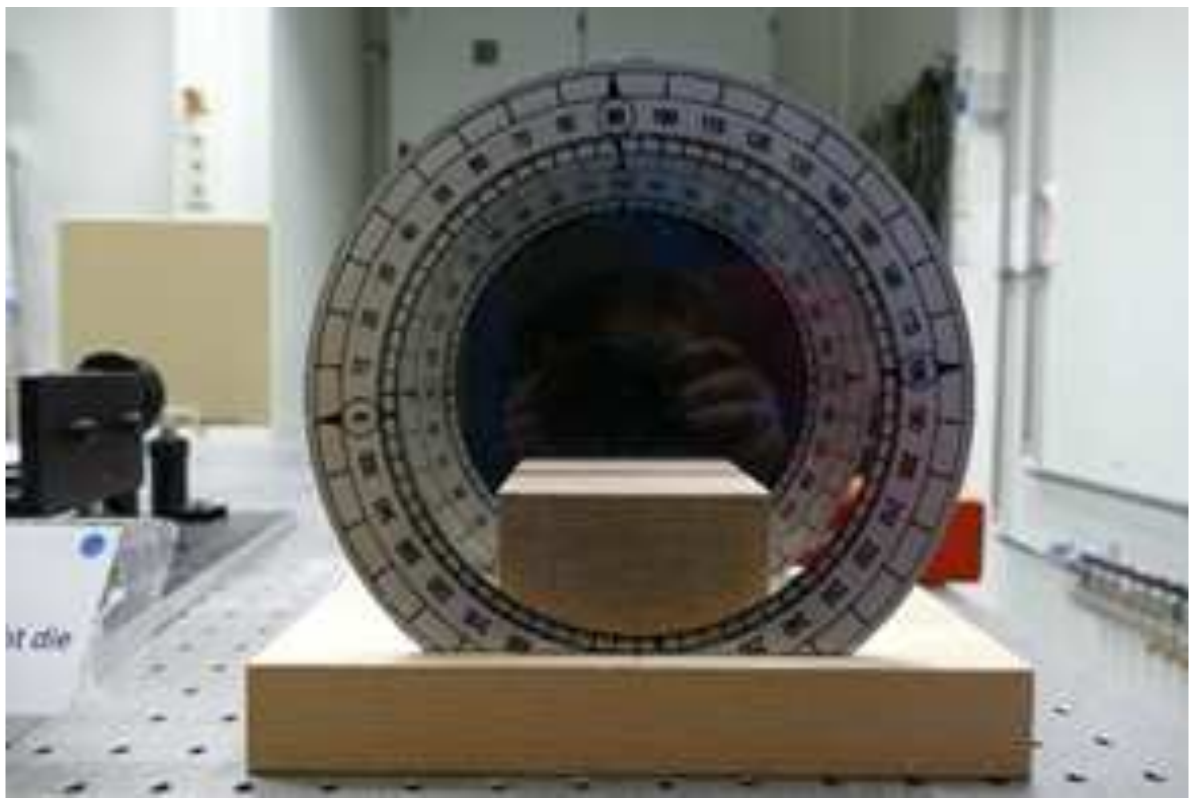
Explanation:
This is because the light **only** oscillates **in one direction** after the first polarizing filter. As soon as this polarized light hits another polarizing filter that is perpendicular to the first polarizing filter, no light is transmitted (**blocking direction**).*

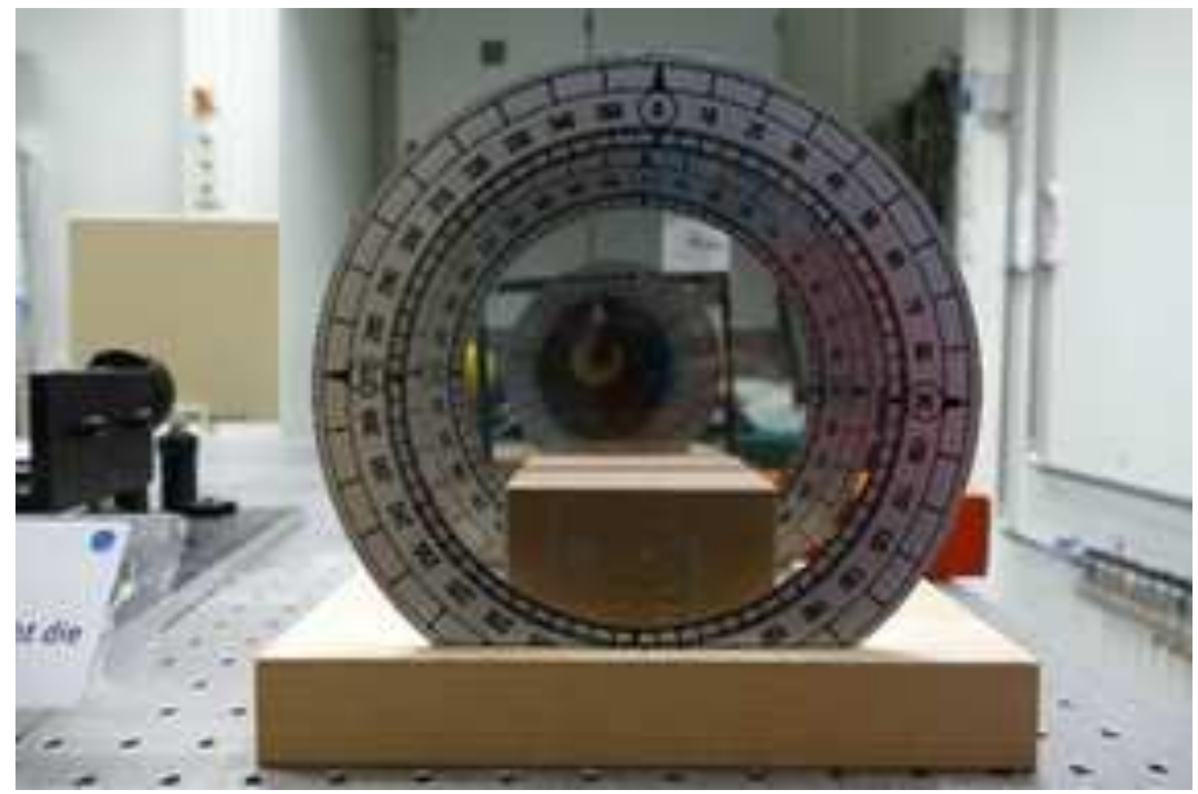
For those interested:
If an electromagnetic wave of intensity I(0) falls on two linear polarization filters arranged at an angle α to each other, the transmitted intensity I can be calculated using Malus' law. The following applies: $I=I(0)*\cos^2(\alpha)$

*Pole filters consist of elongated molecular chains of iodine whose internal charge distribution interacts with the electric field of the light.

Try it yourself!

Reproduce the following pictures! Do you understand your observations?





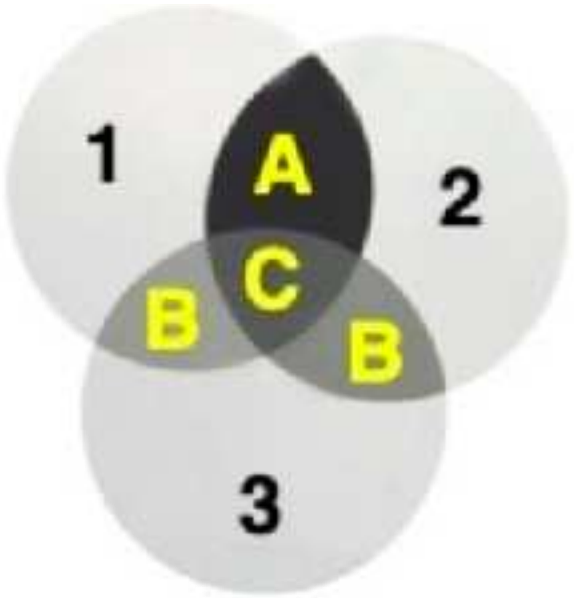
Now change the position of the two filters relative to each other. What can you observe? What happens at 45°?
For those who are interested: How high is the transmitted intensity at 45°?

Solution: 50% of the intensity I(0) is transmitted -> Malus' law.

TV 3: Three-filter test

We start with the familiar two-filter experiment in the blocking direction. Take a third polarizing filter and hold it between the first two. Now rotate the third filter. **WOW!** Although no light was transmitted at first, you have certainly managed to get light through again! How can that be?

You must have observed the following: The closer the third filter is rotated by **45°** relative to the other two, the more light it lets through.



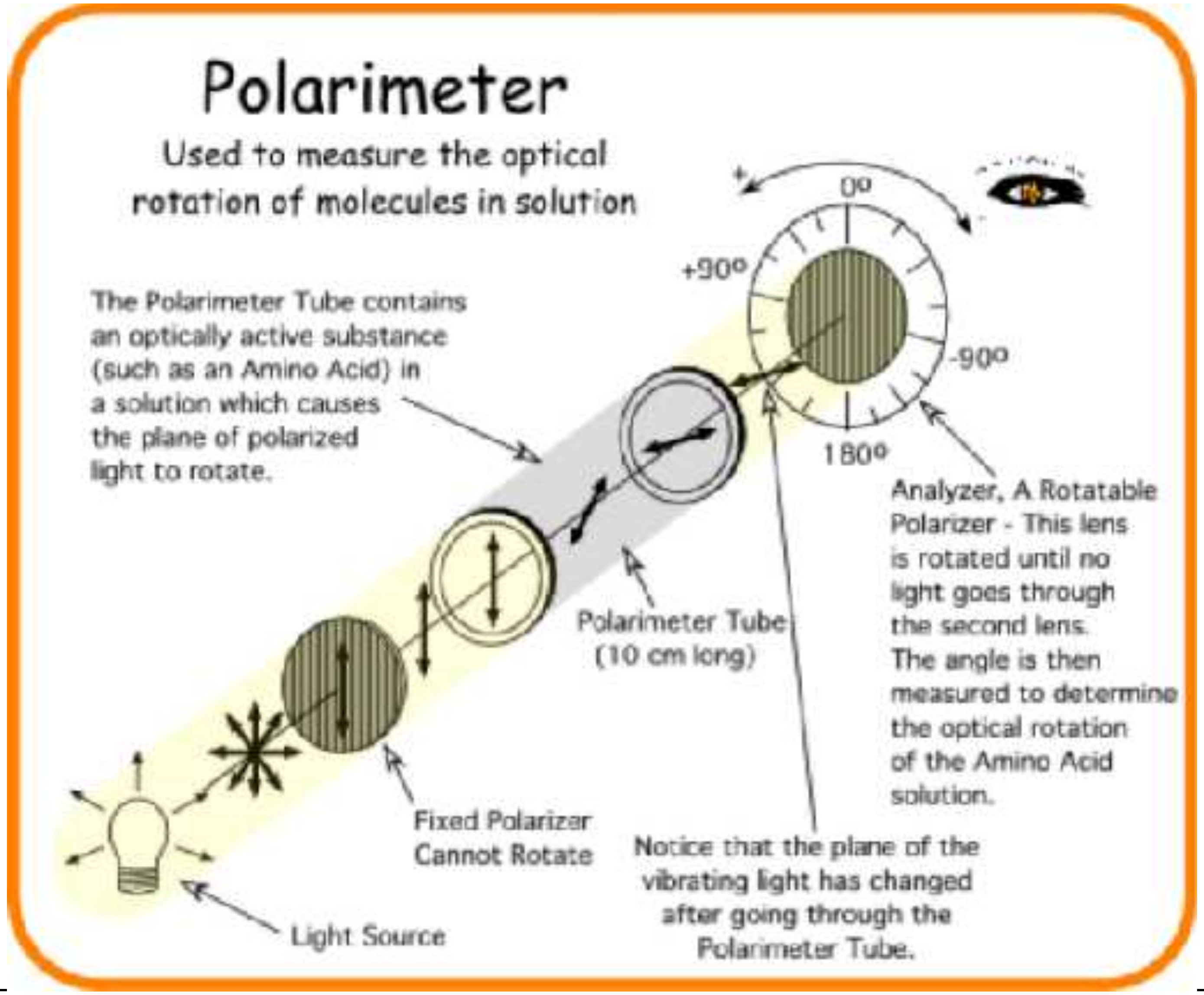
Why is light transmitted again at 45°?

As you have already observed and calculated in the two-filter experiment, according to Malus' law, 50% of the intensity I(0) of the incident light is transmitted at 45°. Since we have three polarizing filters at 45° to each other, the total transmitted intensity is 50% * 50% = 25%.

TV 4: Polarimeter

Switch on the laser by flipping the large red switch. With the help of polarization, we can now measure the sugar concentration with a "polarimeter"! To do this, we first set the polarizers without the cuvette (glass vessel) perpendicular to each other (the rear filter is set to zero: Zero position, as no light falls on the screen). If we now place the cuvette between them, some light must be allowed through again due to the **chirality** of the optically active substances.

We exploit this effect by rotating the analyzer until the screen is dark again. This rotation angle is the **rotation angle α**, which can be used in conjunction with the volume of the liquid in the above formula to determine the concentration of the sugar content (in g).



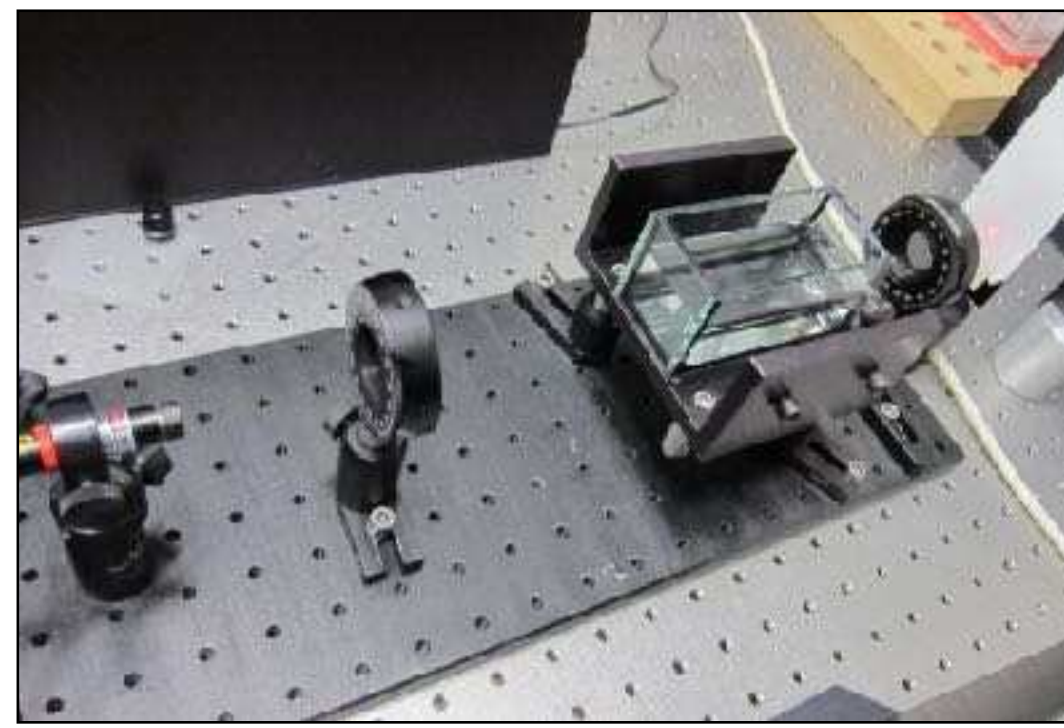
https://www.globalspec.com/learnmore/laboratory_equipment_scientific_instruments/spectrometers_analytical_photometers/polarimeters

The angle of rotation of the polarization direction is directly proportional to the concentration c (i.e. mass m per volume V) of the optically active substance and the length d of the distance travelled (here: the length d of the cuvette). If you measure it, you can measure the concentration of **sugar water**, for example

$$c = \frac{\alpha}{\alpha_0 \cdot d} = \frac{m}{V} \qquad \alpha_0 = 6{,}5 cm^2/g \text{ for household sugar}$$

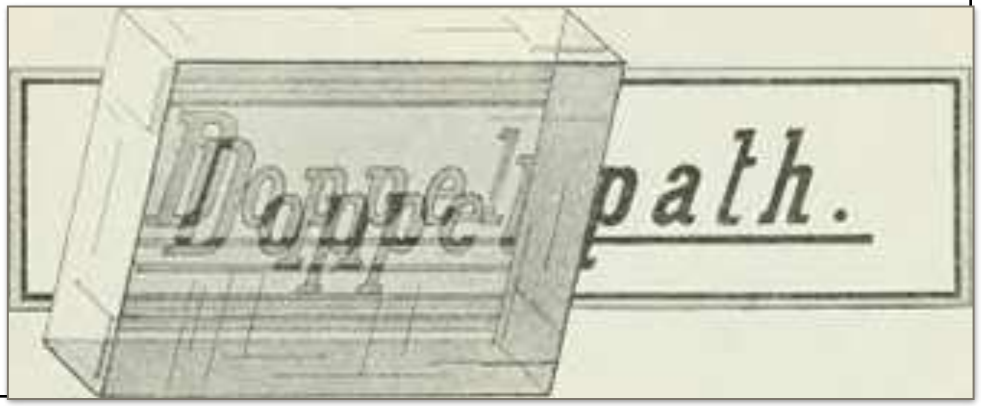
α_0 is called specific rotation capacity and is a material constant.

1. First, the polarizers are set perpendicular to each other **without the** cuvette. This is the zero position in which no light falls on the screen. Tip: It is best to first set the analyzer to zero degrees, then turn the polarizer until no more light falls on the screen.
2. Then place the cuvette between the polarizer and the analyzer and turn the analyzer until the screen is dark again (**less** than 180 degrees!).
3. Now you can read the angle of rotation on the analyzer and calculate the concentration c using the formula on the previous page.
4. Now measure the volume of the liquid and use it to calculate how many g of sugar are in the cuvette.



TV 5: Double refraction

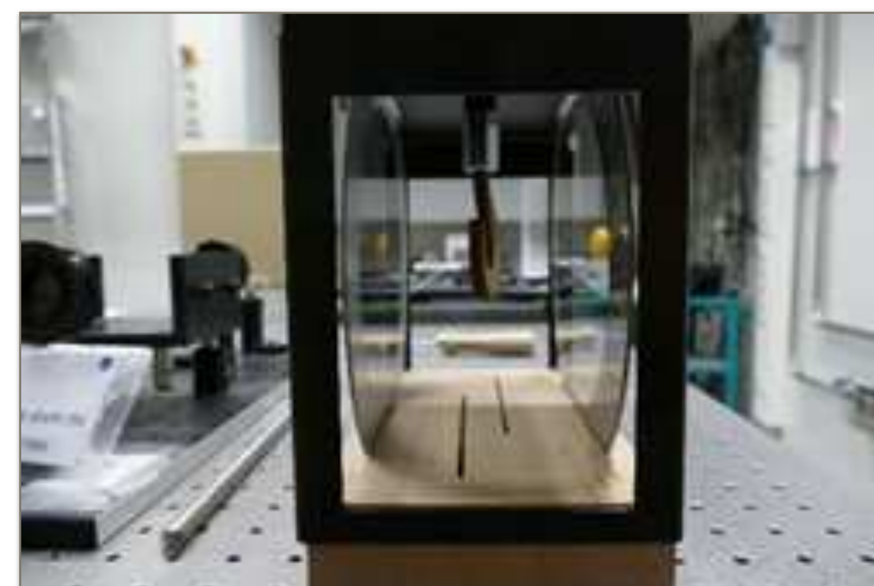
Now comes another cool effect that lets you see double!
Place a picture under the limestone. Here you can see that the light coming from the image under the limestone creates **two** images.
Birefringence is the splitting of a light beam into two mutually perpendicular, polarized **partial beams**.
More precisely, electromagnetic waves of different polarization are refracted to different degrees so that the image under the limestone appears **twice**.
Examine the two images using the polarizing filter. How do they differ?
Explanation: If you place a polarizing filter on the limestone, only one direction of oscillation can be transmitted and observed at a time. You can see the two "different" images when you rotate the polarizing filter.
Try to find both images by rotating the polarizing filter.



TV 6: Voltage birefringence

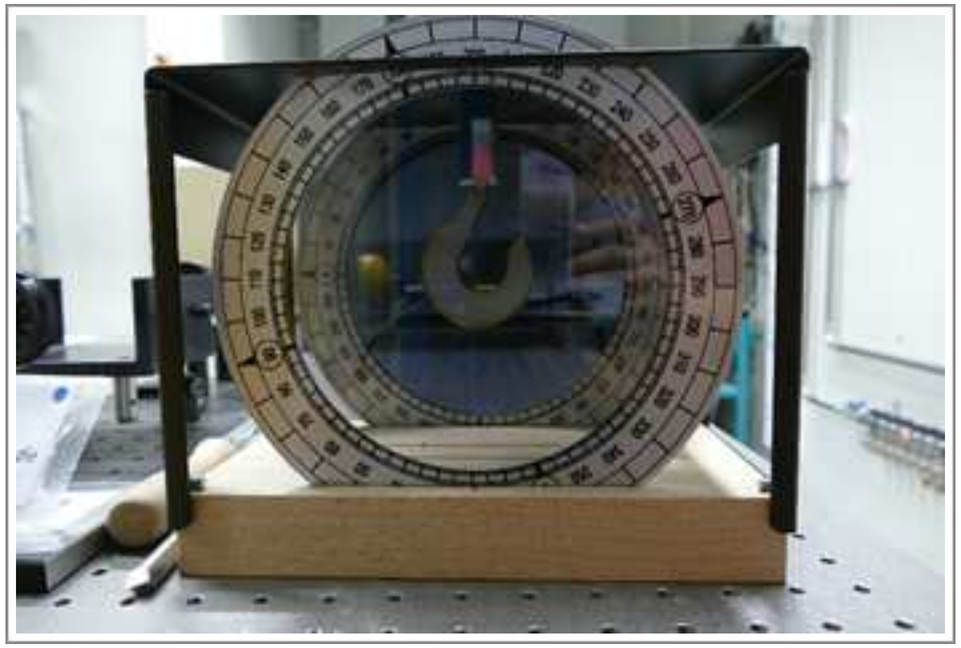
Where does the hook break first under load?
An extension of the **two-filter experiment** can be used to **visualize** mechanical stress* (e.g. the bending of a rubber-like object).

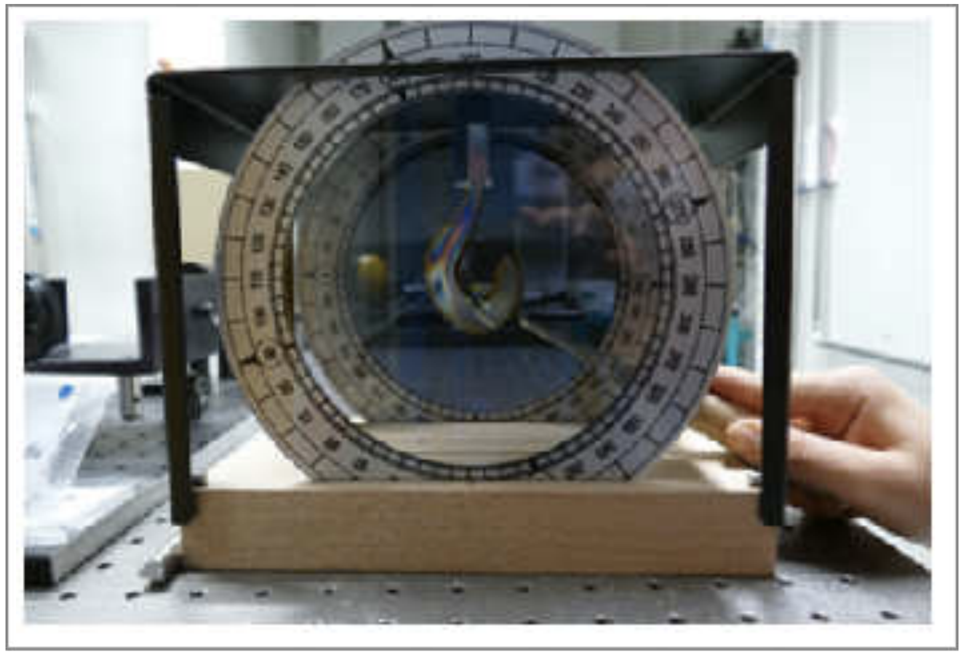
To visualize the bending, the object that bends must be placed between the two polarizing filters set perpendicular to each other (**dark field arrangement**) and then bent. Pull the rubber hook with the wooden hook: you will see colored stripes. These are **isochromats**, which represent lines of the same wavelength or frequency and visualize the mechanical tension. The more isochromats you see in one place, the stronger the mechanical tension.

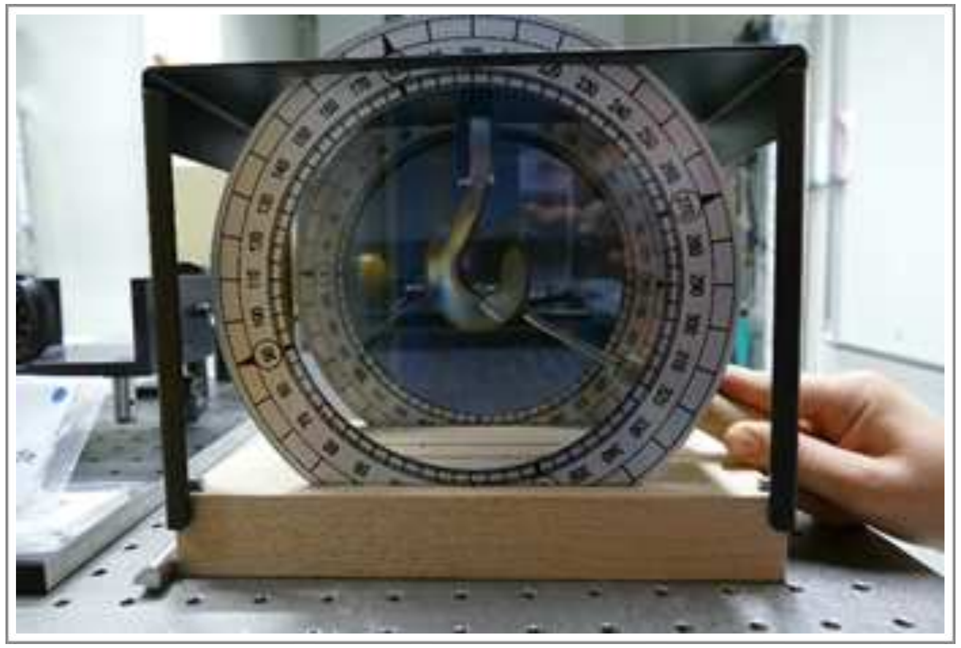


*The mechanical stress σ must not be confused with the electrical stress U: σ is a measure of the internal stress on a body as a result of an external load (force, pressure). It is calculated from the force on a surface and has the unit N/m^2 or Pa. Mechanical stress is therefore only a specifically applied synonym for pressure.

Can you see the stripes when stretching? Try to discover where there is the most mechanical tension without destroying the object!
Explain the following pictures using the information you can gather from the text:







Distance Measurement

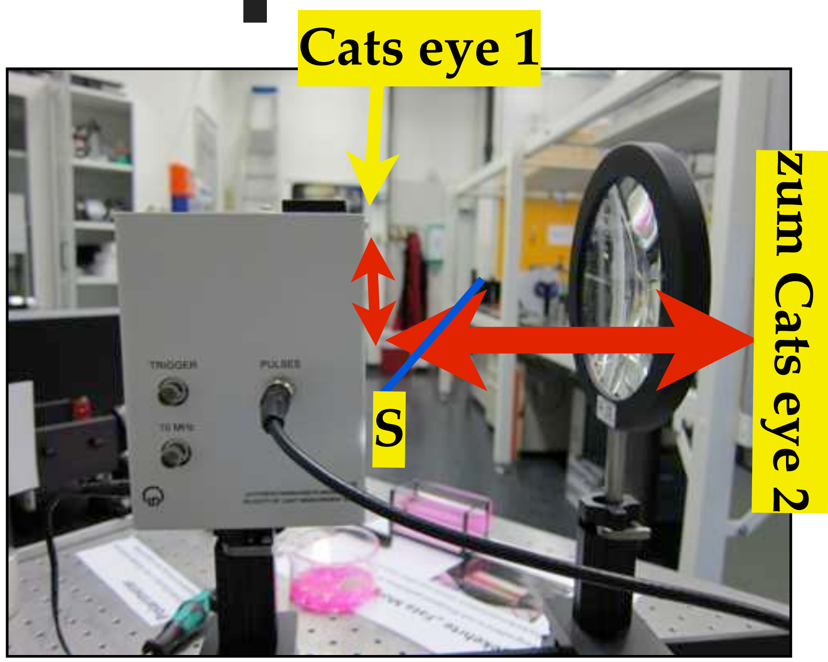
How fast is light?

Light takes about eight minutes and 19 seconds to travel from the sun to the earth. By contrast, it takes 5.5 hours to reach Pluto. Light therefore has a **fixed speed**. This has long been determined at around 300,000 km/s. You can therefore also determine the distance to an object if you know how long it takes light to travel from you to the object. Exactly this method is also used to measure the distance of the moon from the earth. The astronauts on the Apollo missions left these laser reflectors on the moon, which are still used today to measure minimal deviations (in the cm range) in the moon's orbit. Sheldon and his friends also do this in the series "The Big Bang Theory".

Bild von: http://upload.wikimedia.org/wikipedia/commons/b/b8/Solar_System_Template_Final.png

http://de.wikipedia.org/wiki/Lunar_Laser_Ranging#mediaviewer/Datei:Apollo_11_Lunar_Laser_Ranging_Experiment.jpg

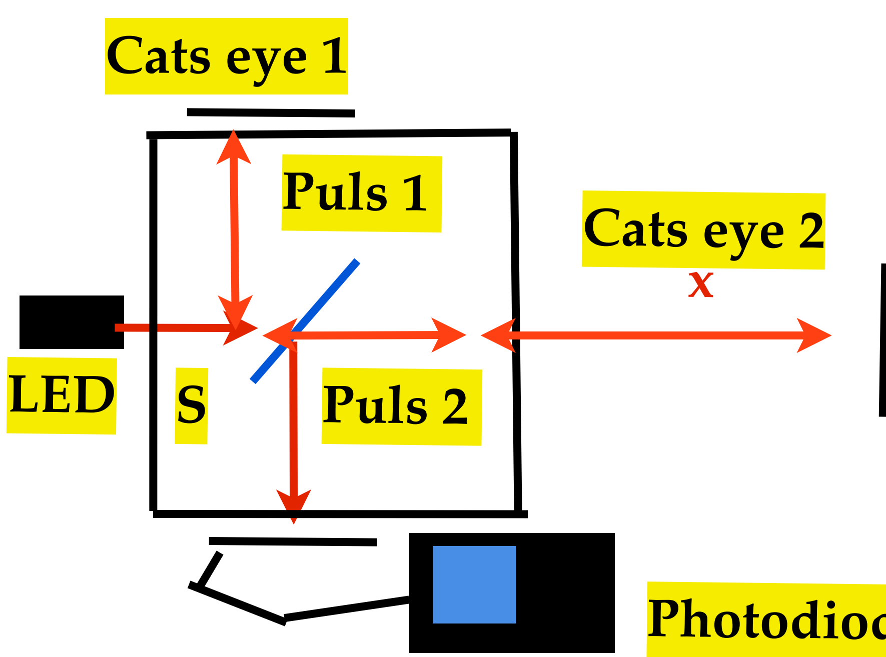
Experimental setup



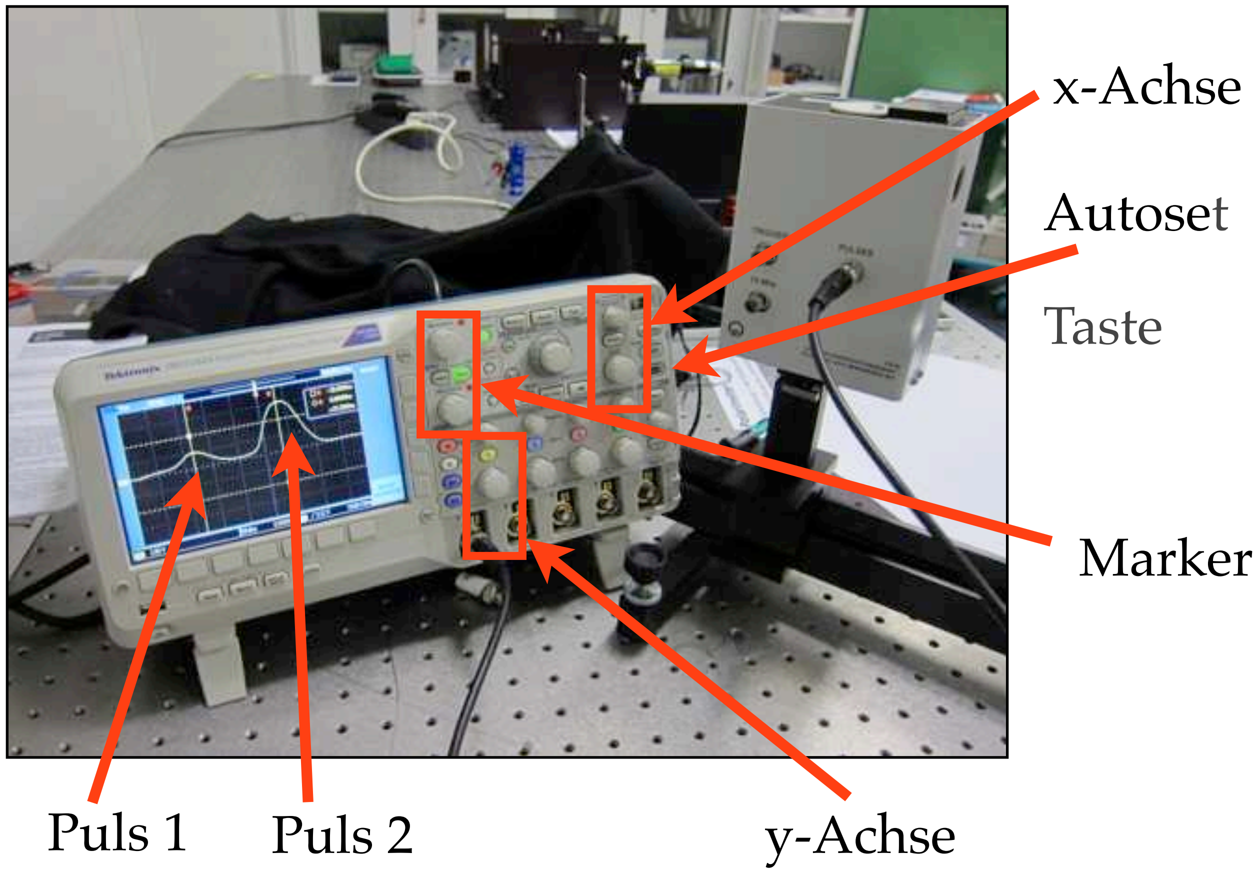
The speed of light measuring device emits very short, red light pulses of around 20 ns in length via a high-power LED. The light pulses are split into two partial beams by the beam splitter S and reflected by the cat's eyes 1 and 2. Pulse 2 covers the distance x to be measured, while pulse 1 only covers the distance in the box as a comparison measurement. This means that the difference in transit time between the two light pulses is exactly the time it takes for the light to travel from the apparatus to cat's eye 2 and back.

After traveling back and forth, the light pulses are converted into voltage pulses using a photodiode and observed with an oscilloscope to measure the transit time difference (this corresponds to 2x). Knowing the speed of light, the distance of cat's eye 2 can be determined from this.

Connect the output of the pulse to channel 1 of the oscilloscope.



Procedure



Press the "Autoset" button so that the oscilloscope finds the signal on its own. Change the x and y scaling by turning the knobs marked in the picture. To make the two pulses the same size, the optical bench with the lens can be shifted slightly (!). However, this should not normally be necessary! On this oscilloscope, the **time is on the x-axis** and the voltage, which corresponds to the intensity of the light beam, is on the y-axis.

Read off the time difference Δt between the two signals and determine the distance x of the "cat's eye" using this measured value and the speed of light (300,000 km/s).

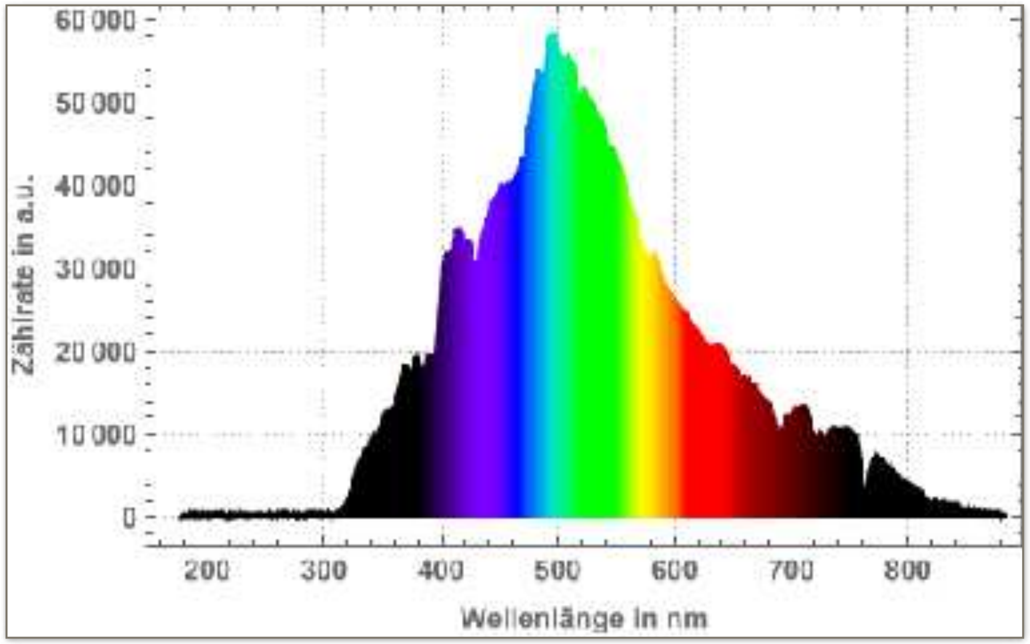
Quiz

How far away is the cat's eye from the measuring apparatus?

1. approx. 4.5 meters
2. approx. 5.2 meters
3. approx. 7.5 meters
4. approx. 8.9 meters

Answer c) is correct.

Spektral Analysis



Which gas is in the ceiling lamp?

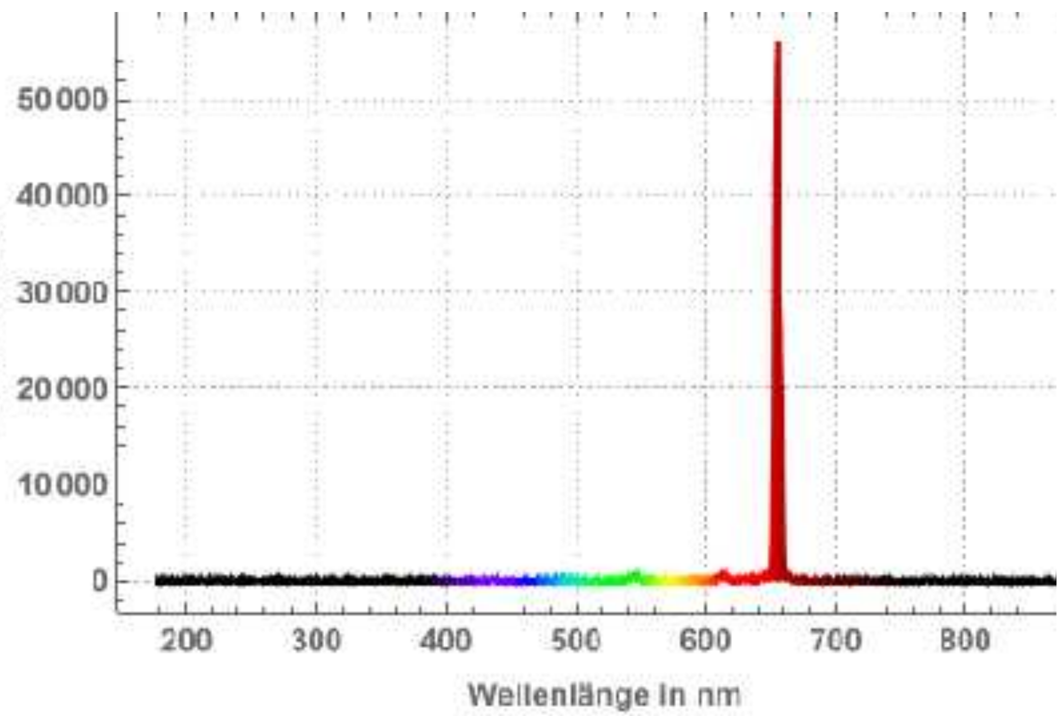
Every substance only emits light of certain wavelengths when it is illuminated. The image of all these wavelengths with the respective intensity is called the spectrum of a light source. Each substance or element has a characteristic, unique spectrum so that it can be identified by its glow. This effect can also be used, for example, to find out what elements the sun is made of.

http://de.wikipedia.org/wiki/Sonne#mediaviewer/Datei:The_sun1.jpg

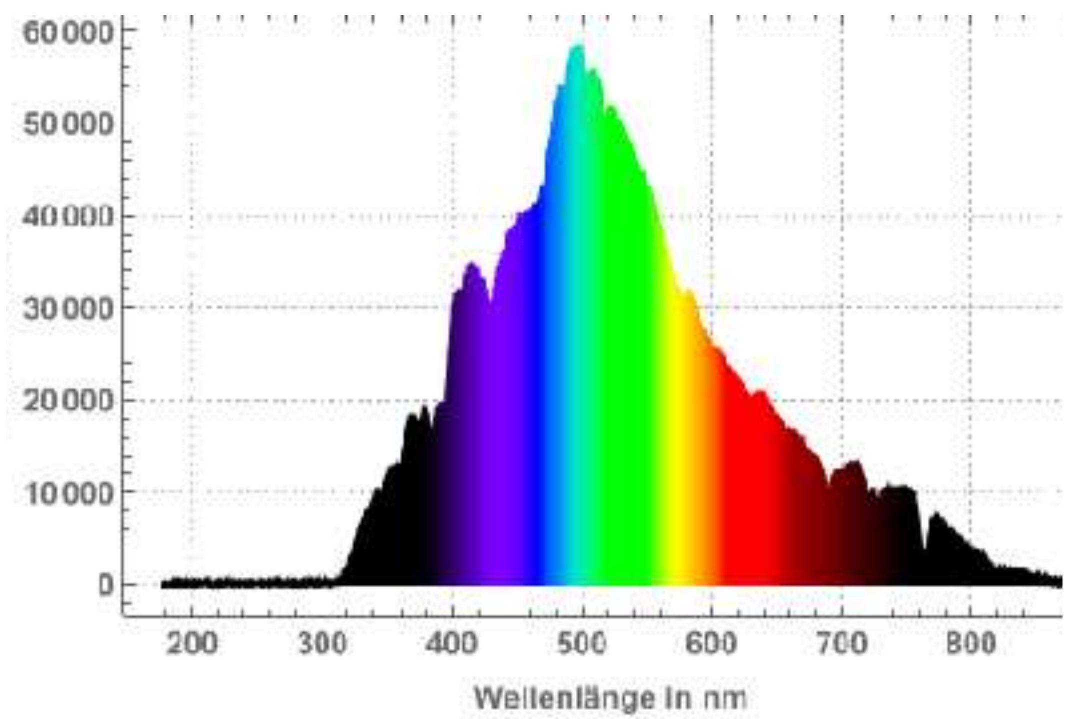
Basics

The wavelength of a light wave determines the color of the light. Because light is usually composed of different colors, the spectrum of light must be determined in order to identify the exact wavelengths, i.e. the intensity with which each wavelength is represented. Two such spectra are shown below. One belongs to a laser that really only emits one wavelength, the other is the solar spectrum.

Because every substance emits a characteristic spectrum when it is excited to glow, it is possible to determine the components of unknown substances or distant objects such as stars.



Red Laser



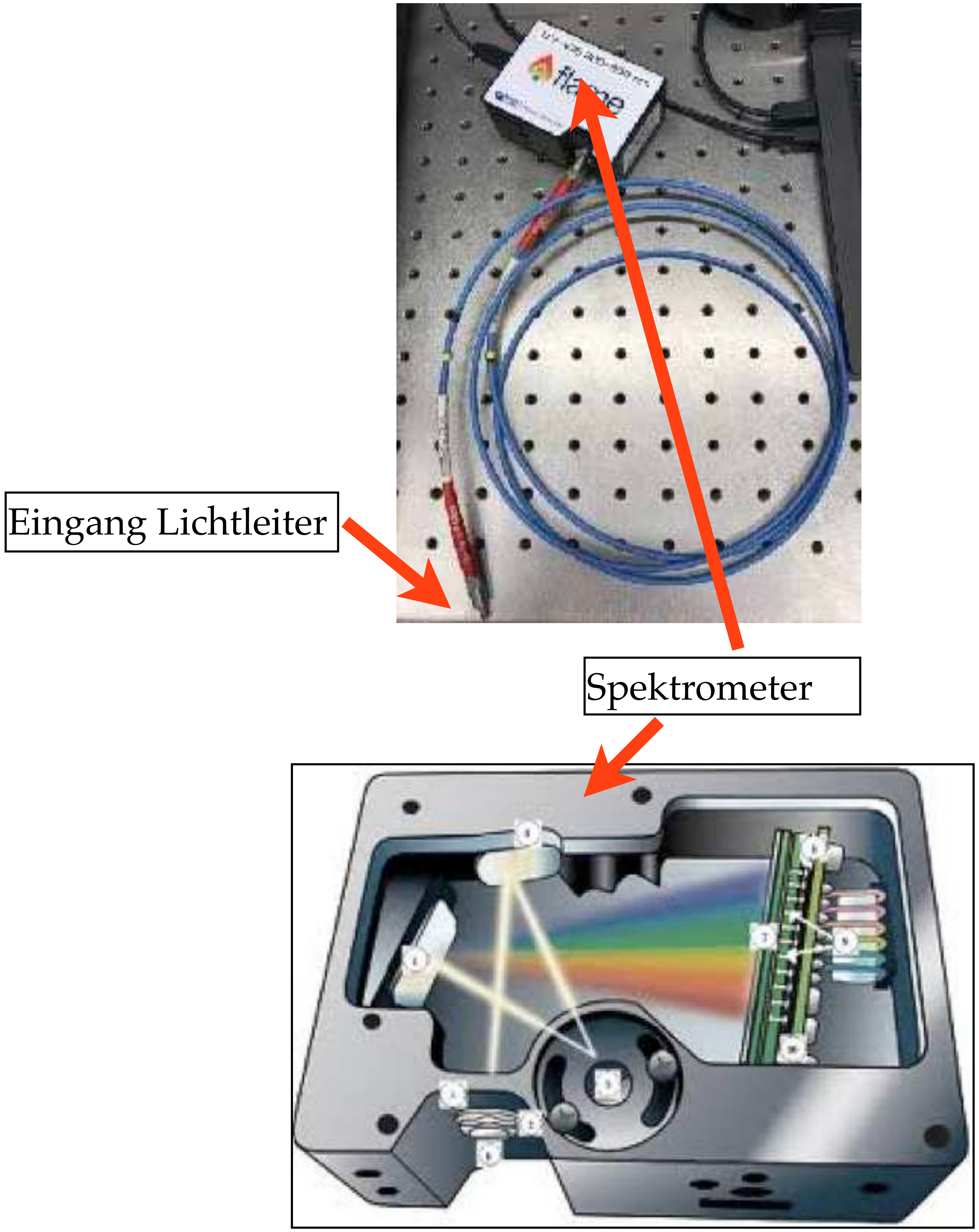
Solar spectrum

Structure

Caution: Do not bend the light guide!!!

A blue/metallic light guide (= glass fiber) is screwed into the input of an Ocean Optics spectrometer. The spectrometer is connected to the laptop. The Ocean-View program should be running, otherwise start it (Quick View). Shine a light source into the front of the light guide (= glass fiber), then you will see the corresponding spectrum on the screen.

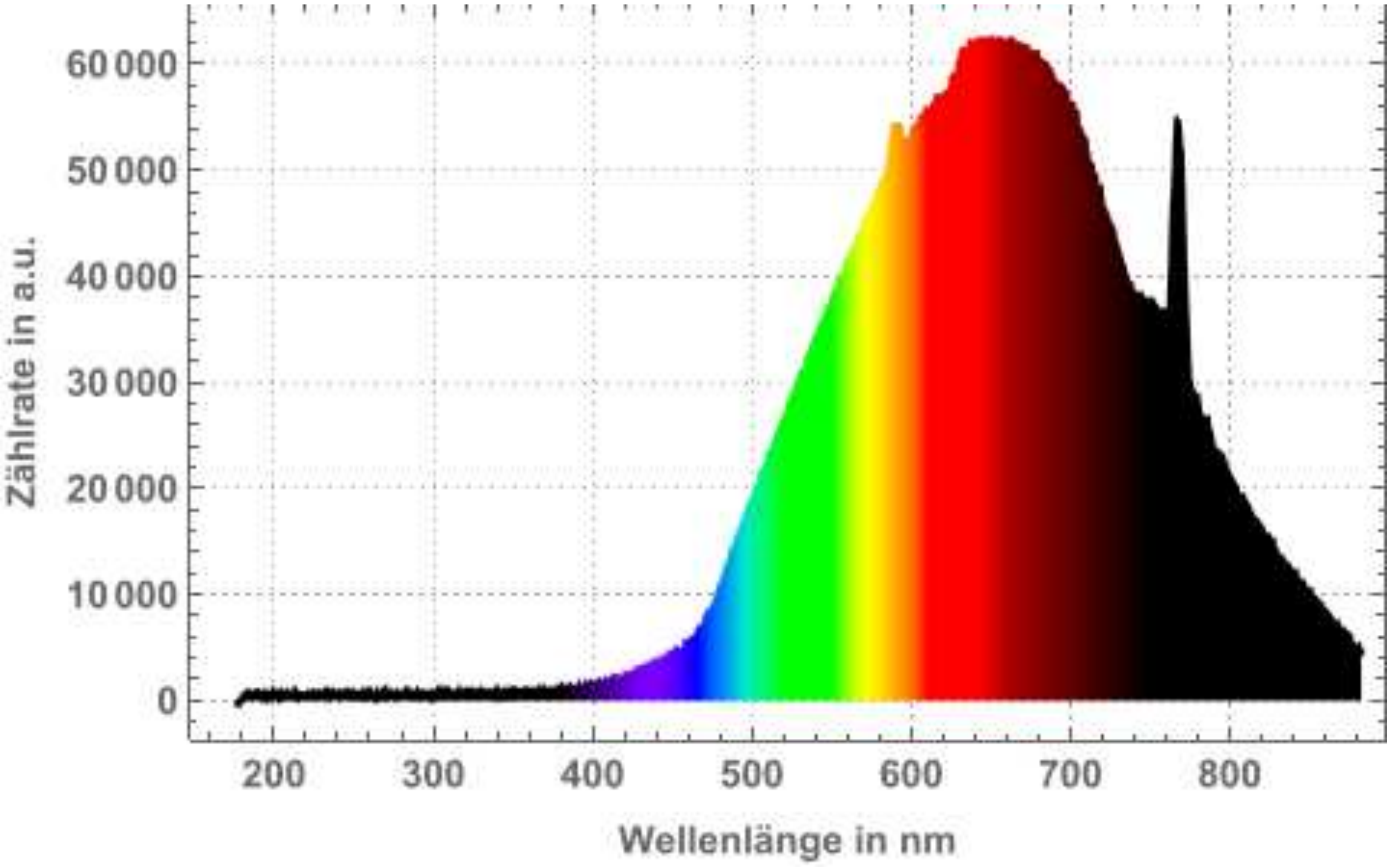
In the picture on the right you can see how the **spectrometer** is constructed from the inside. It splits light into all its wavelengths like a prism and displays the result on the screen.



Task

1. assign these spectra to the light sources in the box!

Solution



1

Possibilities:

- Solar spectrum
- Fluorescent tube
- Red laser
- Candle flame
- UV lamp
- White LED

2. which material is contained in the ceiling lamp?

Use the whiteboard marker and the ruler to draw lines at the points on the spectral chart where you see maxima in the spectrum - but no longer in the red area. Compare the line spectrum of the ceiling lamp with that of the other substances!

a) Neon

b) Mercury

c) Hydrogen

d) Xenon

Solution: B

3. Quality check: Olive oil

The olive oil industry is worth billions and good "extra virgin oil" is expensive. Fraudsters therefore add cheaper oils to olive oil to increase their profits. They often even add chlorophyll and flavorings. It is therefore of great interest to determine the quality of olive oil in a simple way.

Here in the PhotonLab you can measure the absorption of different oils. You will find the program settings on the next page. Then compare your spectra with the image below!

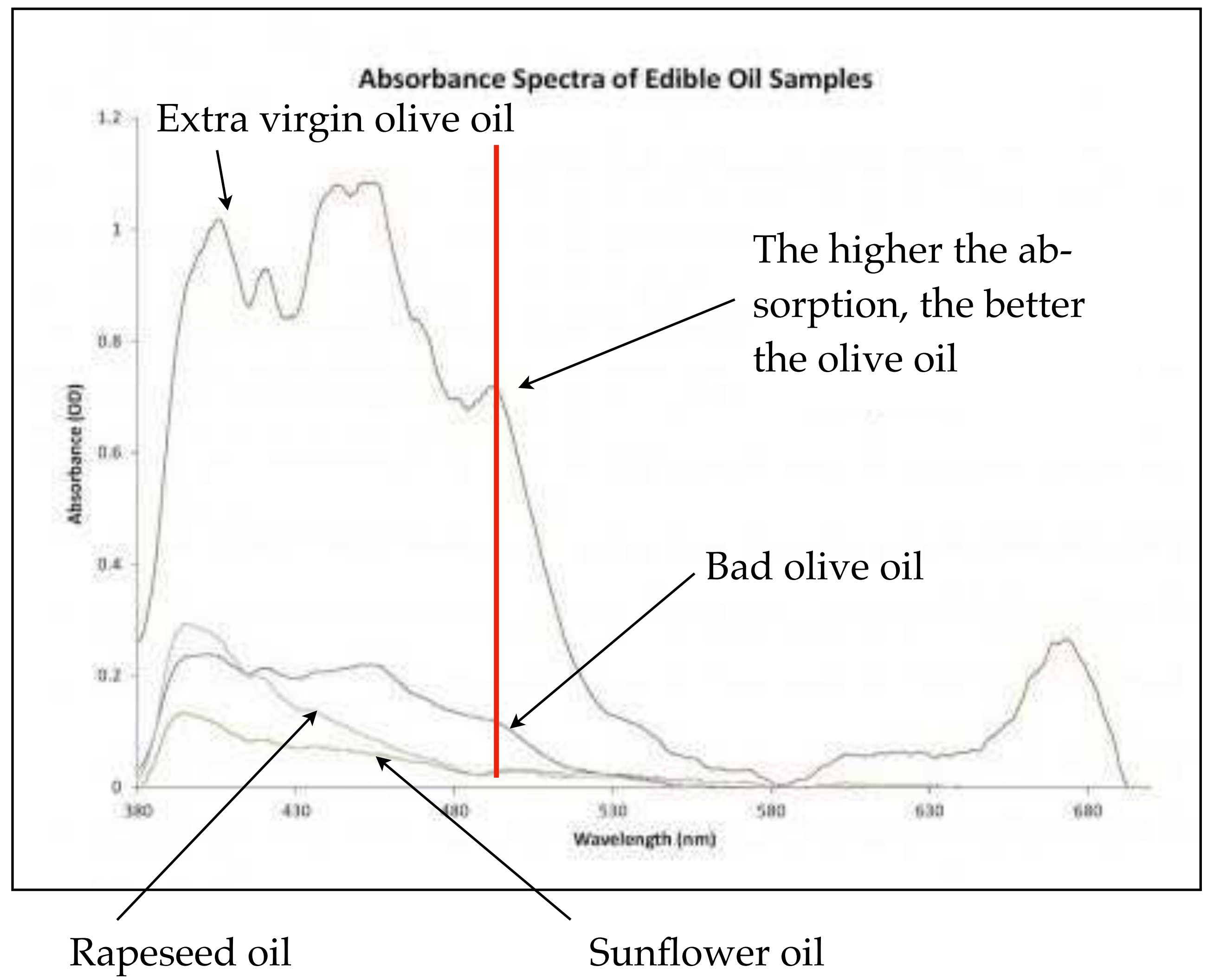
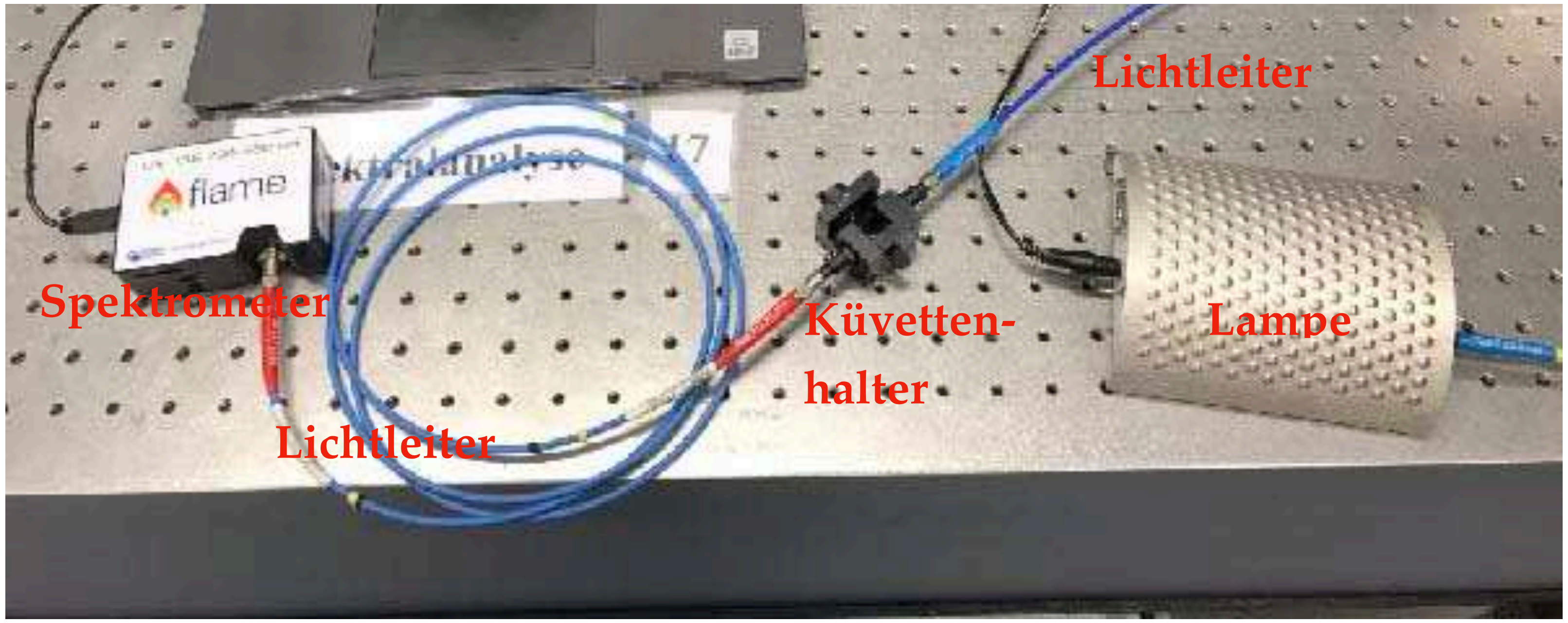


Foto: WikiCommons Rodrigo Nuno Bragança da Cunha

Olive oil quality check

1. To measure, you need two glass fibers/light guides and the silver, semicircular lamp, which is connected to the cell holder via a glass fiber. Screw the light guide coming from the spectrometer into the connection provided on the cell holder. An optical fiber leads from the cell holder to the lamp.



2. Click on "Quick View" in the "OceanView" program and then on the "Ocean View symbol", the "rainbow" at the top left.

Programm „Ocean View“

Links: „Quick View“

Quality check: Olive oil

3. select Absorbance "Absorbance only" -> next
4. set integration time to 3 ms -> next
5. switch on deuterium and halogen lamp, open shutter (On)
6. then click on "Incandescent lamp" -> next
7. close shutter (Off), then click on black "bulb" -> finish
8. open shutter

Then click on "Absorbance"

Click on "Next" here

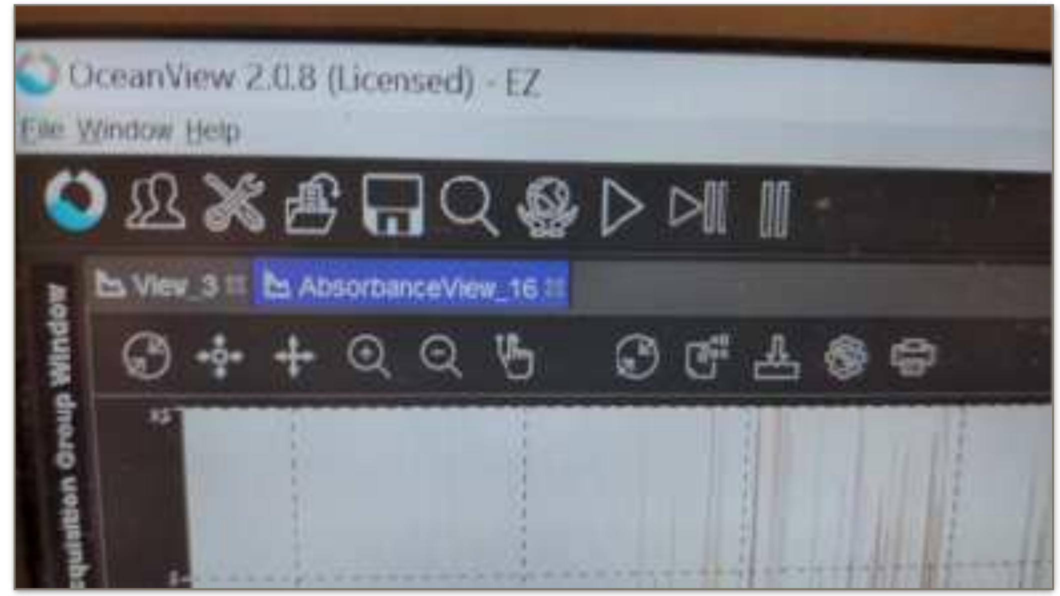
Quality check: Olive oil

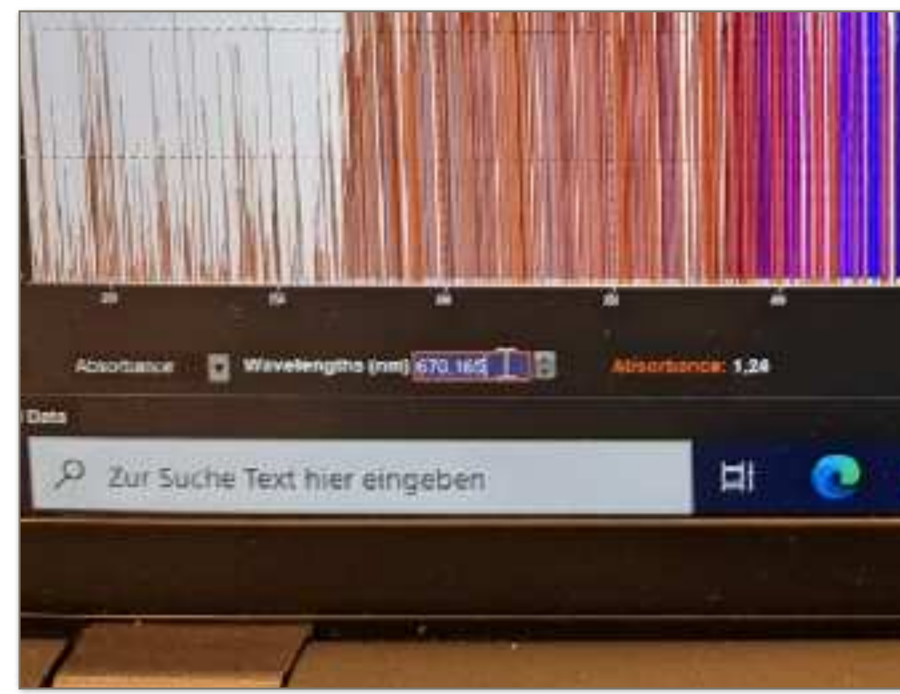
9. select "Absorbance view" on the tab at the top. The spectrum should be jiggling around zero, as there is no sample in the sample holder yet.

10. place the sample in the holder. Attention: The **clear** side of the cuvette should be illuminated!

11. to be able to observe more precisely, press the magnifying glass to **zoom in** and magnify to the range around **670 nm**. To read the exact value, click on "Wavelength (nm)" under the x-axis and enter 670 (nm). This will give you the exact value of the absorption!

12. write down the values of the 5 different olive oils.





Quality check: Tasks

Which cuvette is filled with good/bad olive oil?

The higher the absorption at 670 nm, the better the olive oil. Select the olive oils and arrange them in order of increasing (from worst to best) quality! Check the sequence of numbers!

For professionals: Explain the variation in intensity of the measured values (on the screen).

By the way: The worst olive oil was given to a trainee by a farmer on Crete. Aldi oil is relatively good.

Which number series is correct?

a. 4-3-1-5-2

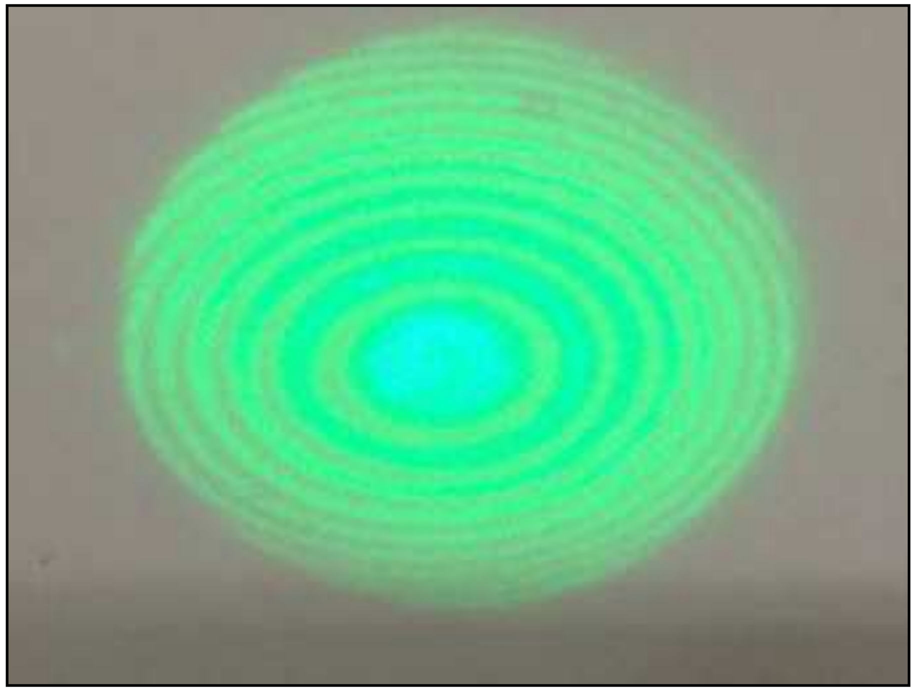
b. 5-1-2-3-4

c. 1-2-3-4-5

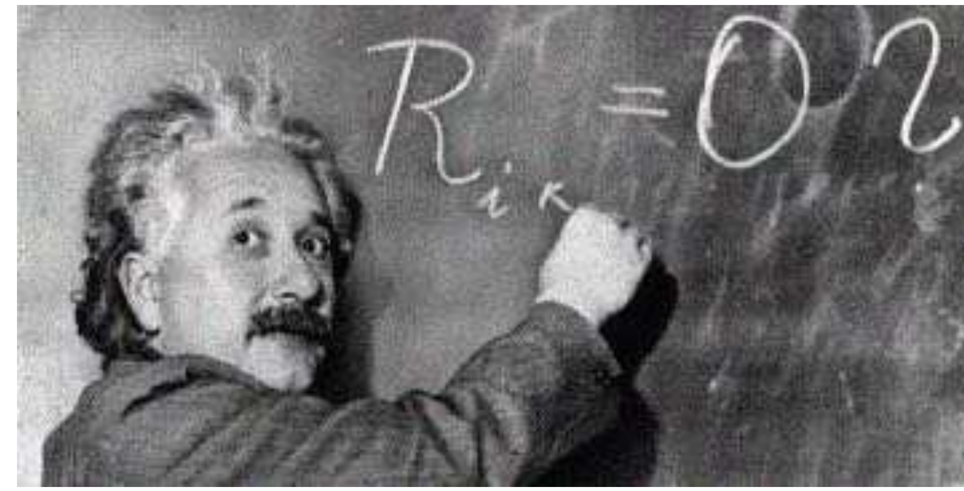
Answer: a

Michelson Interferometer

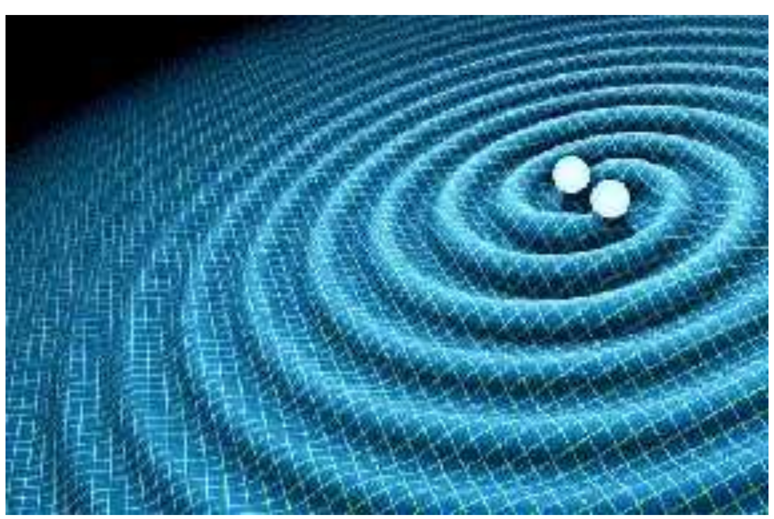
Interference with light - how does it work?



Wanted: Gravitational waves



The discovery of gravitational waves in 2016 made the headlines for quite some time. But how were these waves measured in the first place and what are gravitational waves?
Einstein's theory of relativity was published in 1915. Over 100 years later, one of the consequences of this theory, gravitational waves, was confirmed for the first time.
Tip: You can also find this information and more in the video about gravitational waves on the iPad!

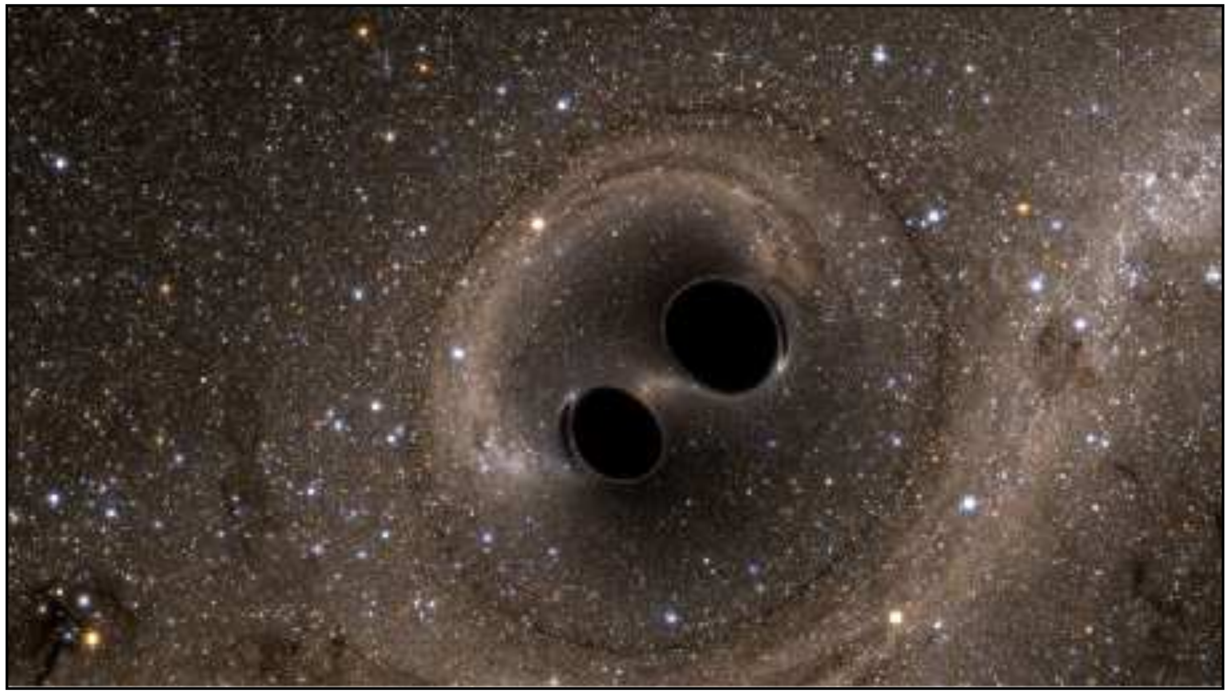


What are gravitational waves?
Gravitational waves are generated by masses that experience acceleration. The larger the masses, the "larger" the wave (i.e. the higher the amplitude).
Why did it take a century to detect these waves? The signals that we have been able to measure with the detectors so far are much larger than the signals triggered by gravitational waves. The detectors have not been accurate enough so far.

http://www.stuttgarter-zeitung.de/inhalt.nachweis-von-gravitationswellen-wir-hatten-unglaubliches-glueck.0bdff3b7-f0d0-4e13-adaf-a2ba55e3e31f.html
http://www.amnh.org/exhibitions/einstein/

Detection of gravitational waves

Gravitational waves cause compressions and elongations of lengths in space through their propagation.
These changes in length can be measured.
be measured.
However, as the differences are very small, 10^{-18}m also 0,000000000000000001m the scientists have to use very precise detectors.



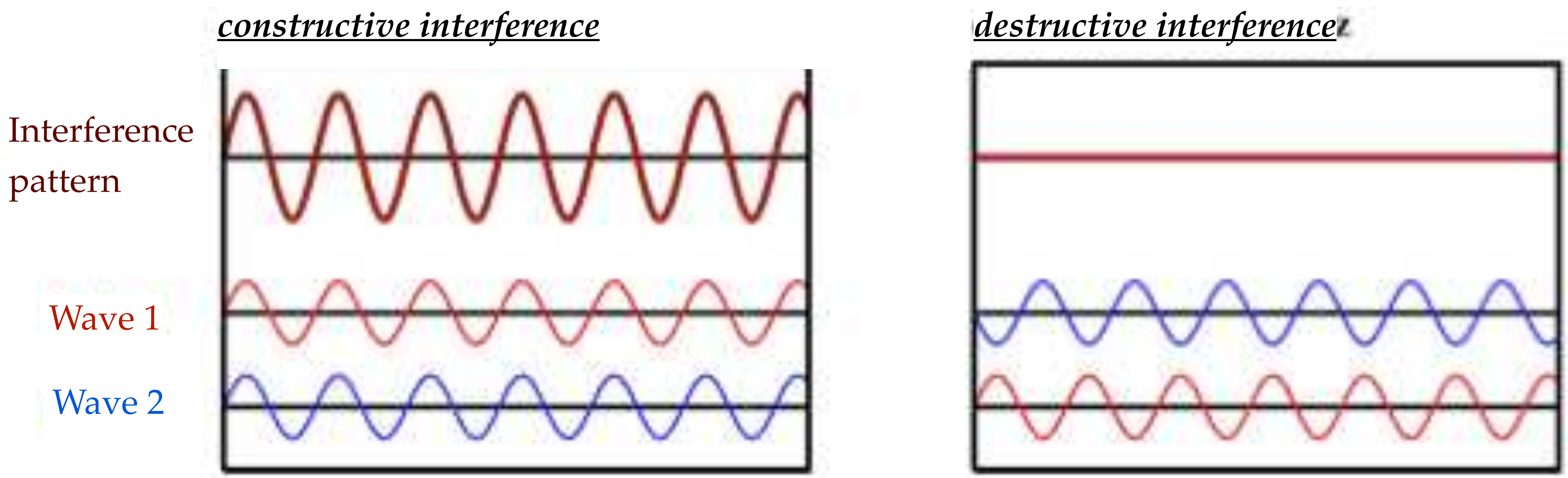
Gravitational waves can be produced, for example, when two black holes merge.

One detector that can be used to measure such small differences in length is the Michelson interferometer, which we use in the PhotonLab.

(Abb.https://www.heise.de/newsticker/meldung/Einstein-hatte-Recht-Forscher-weisen-Gravitationswellen-nach-3099654.html)

What is interference?

In addition to the Michelson interferometer, there are many other optical interferometers. In general, an interferometer is an experiment in which waves are superimposed. They interfere.



If two waves overlap and a maximum meets a maximum, the result is a maximum twice as high (constructive interference)

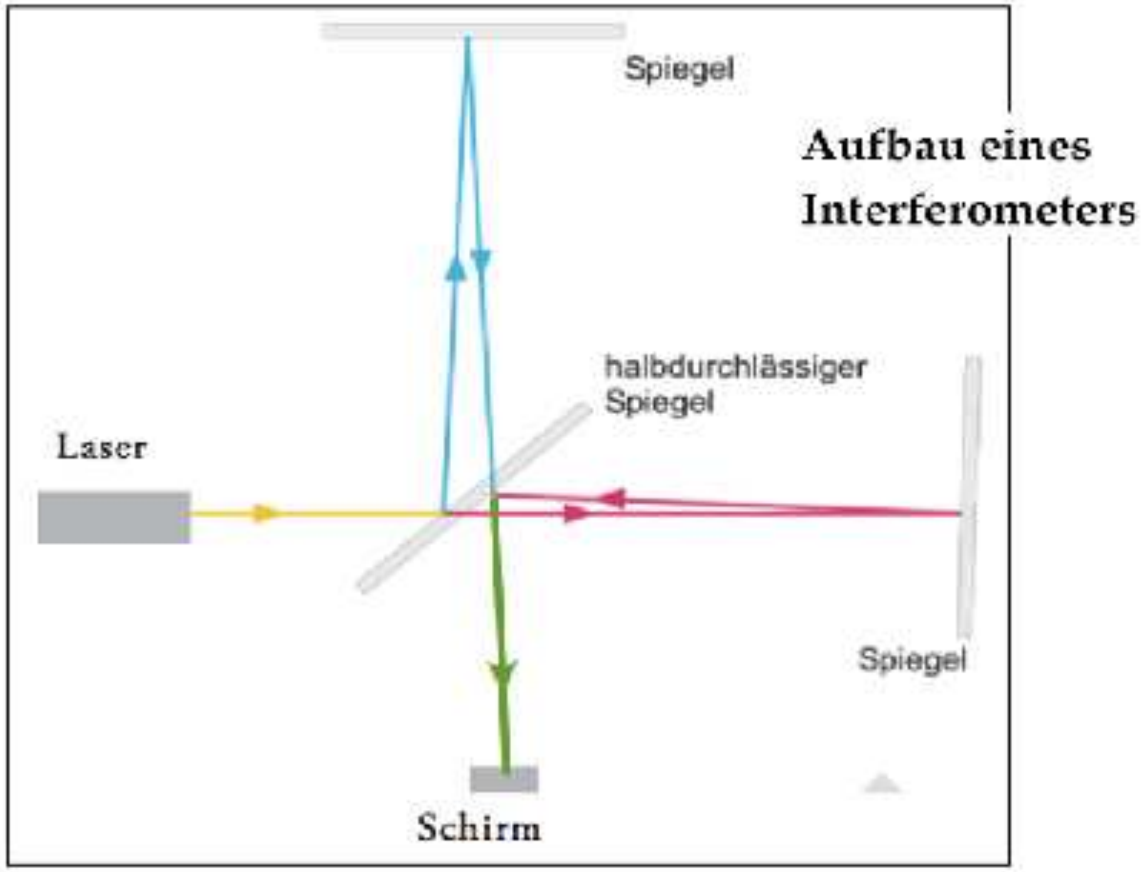
If, on the other hand, a maximum always meets a minimum, the light waves cancel each other out (destructive interference)

Image: Guide Thorlabs

The interferometer

The Michelson interferometer can now be used to determine more than just gravitational waves. There are many applications. Some of these will be examined in more detail in the following experiments.

Experimental setup



For this experiment you need

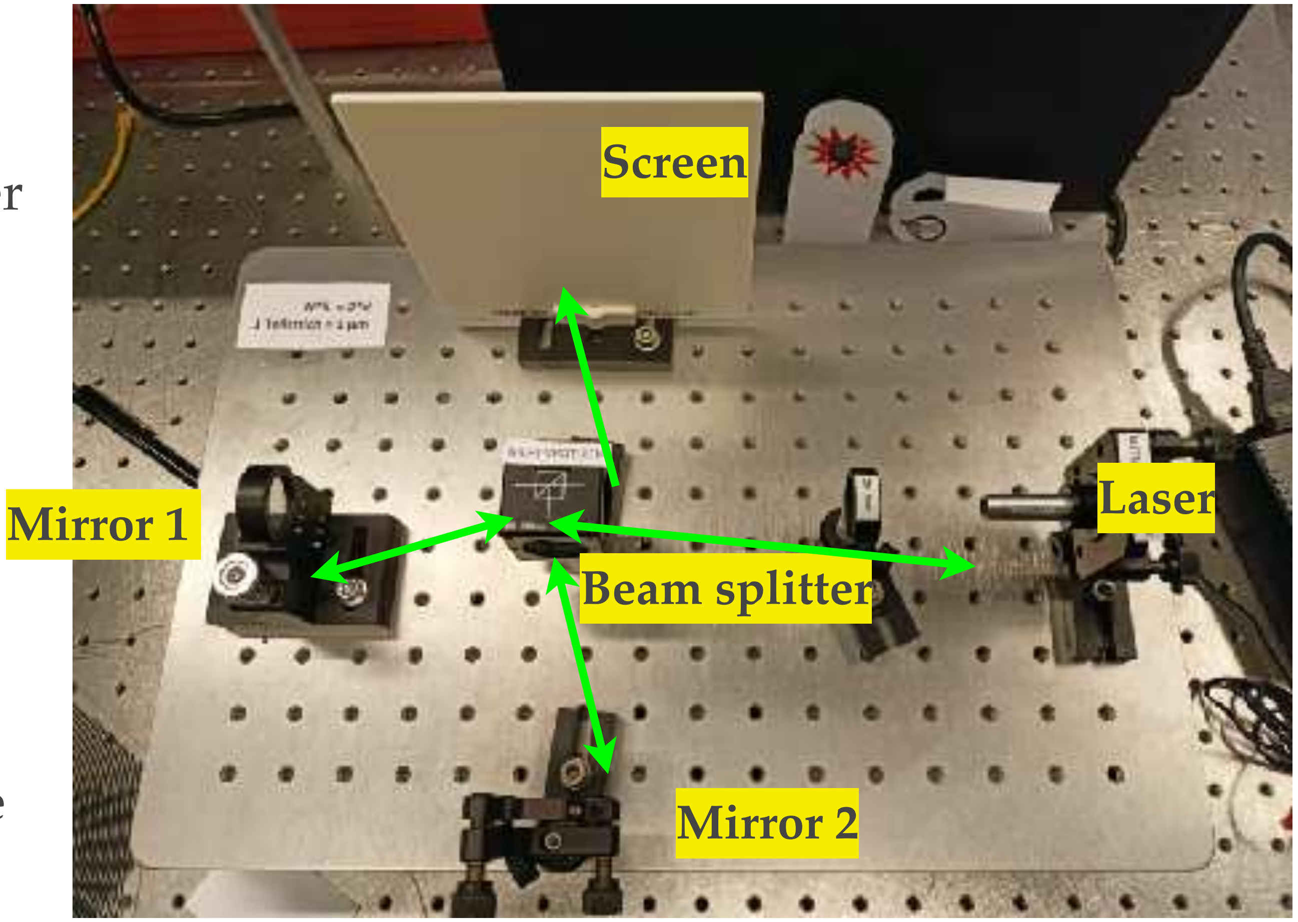
- 2 mirrors
- 1 semi-transparent mirror
- 1 observation screen
- 1 laser

The semi-transparent mirror is often also called a beam splitter. It splits the laser beam into two beams by reflecting 50% of the laser light and allowing the other 50% to pass through. (A more detailed description can be found under the link)

The two beams are reflected by the mirrors and both hit the beam splitter again. There, the two beams overlap and hit the observation screen.

Image: Guide Thorlabs

Procedure



The first challenge is to adjust the interferometer correctly.
Adjustment is the process by which individual components of the experimental set-up (for example the mirrors) are adjusted so that a good result is obtained.
In optics, this is the first step in every experiment. This determines how accurately we we can measure later (and whether we measure measure anything at all).

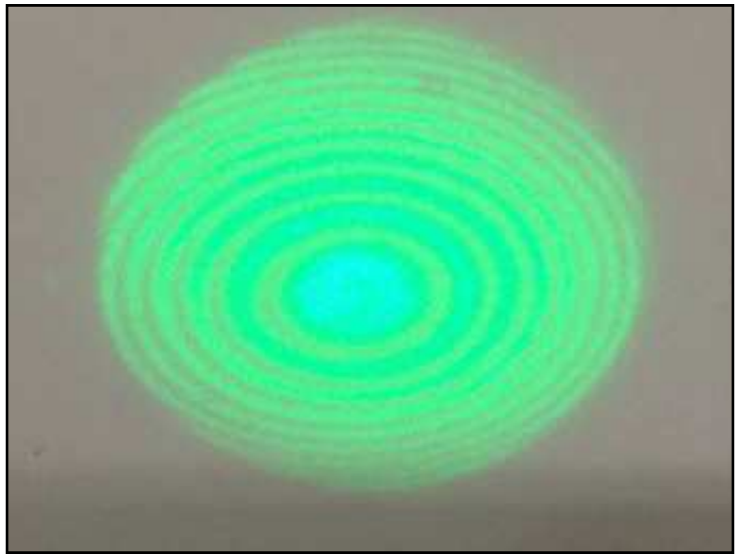
You can see the misaligned experimental setup in front of you. The mirrors and the beam splitter are correctly positioned, but not correctly adjusted.
Put on your laser safety goggles!

Adjusting the interferometer

Listed below are some tips to help with the adjustment:

- All components should be at the **same height**
- The beam path can be traced exactly with the help of a piece of paper
- The laser beam should hit the mirrors or the beam splitter as **centrally** as possible (under no circumstances should part of the laser beam hit the edge of a mirror, for example)
- If only two reflections are visible on the screen, these must be aligned by adjusting the mirrors.

The pattern on the observation screen indicates whether the experiment has been successfully adjusted.



Determine wavelength

In the following experiment, the wavelength of the laser is determined. If the light is in the visible range, its wavelength is between 400 nm and 700 nm (nm= 10^{-9}m). The wavelength gives us the length from which the light wave of the laser repeats itself (i.e. the length of the period).

What our interference pattern looks like depends, among other things, on the wavelength of the light. In general, the closer the interference maxima (the bright stripes) of the pattern are with the same structure, the smaller the wavelength.

Determination of the laser wavelength λ

Make a precise note of the micrometer screw setting. Now slowly adjust the micrometer screw on the translation stage and count the dark rings that disappear. Each disappearing dark band corresponds to a change in path length in the interferometer arm of exactly one wavelength.

1 graduation mark on the rotating part of the micrometer screw corresponds to a displacement distance of

$d = 1\ \mu\text{m} = 1000\ \text{nm}$

Make a note of the number of wavelengths N passed through and the displacement distance of the mirror d.
Then use the following formula to calculate the wavelength of the laser:

Attention: The light covers the displacement distance twice:
on the way there and on the way back!!!

$N\,\lambda = 2 \cdot d\ [\text{nm}]$

Quiz

What is the wavelength lambda of the laser?

1. 532 nanometers
2. 632 nanometers
3. 532 micrometers
4. 632 micrometers

Answer a) is correct.

Recognizing gravitational waves

To determine gravitational waves, you need interferometer arms that are several kilometers long. The interferometer must be large enough to be able to measure such small signals.

Unfortunately, our interferometer in the experiment is too imprecise.
Nevertheless, we can simulate the gravitational waves:

By slightly shaking the experimental set-up (for example by knocking on the experimental table) we can simulate the waves (and of course this signal is much stronger).

What can you observe?

https://www.ligo.caltech.edu/WA/image/ligo20150731e

Evaluation

For the participants of the **quantum physics course**:

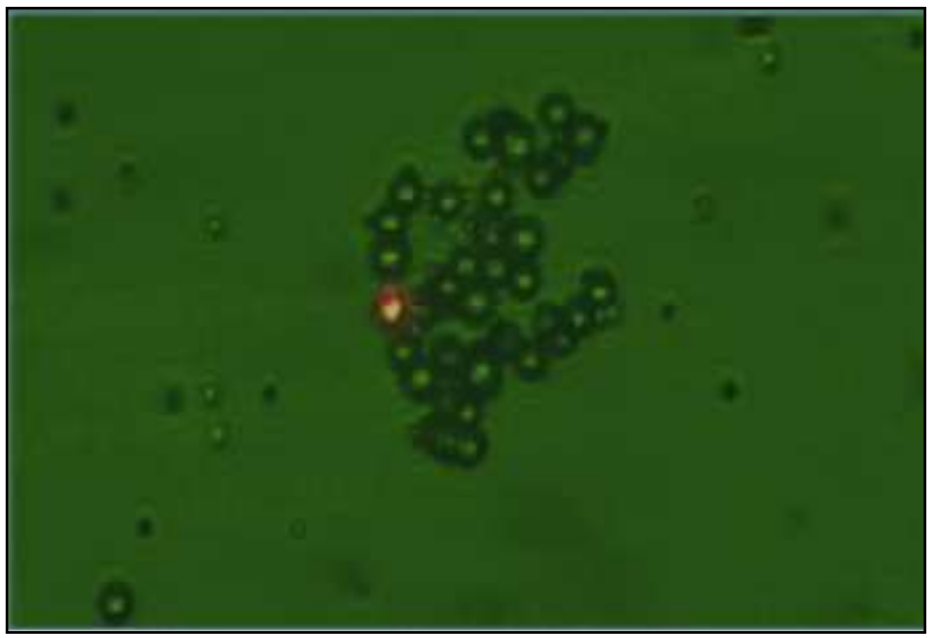
Which pattern could you recognize on the screen after experiment 1 (adjustment of the interferometer)? Make a sketch.

Explain the origin of this pattern. Describe the connection to the wave character of light.

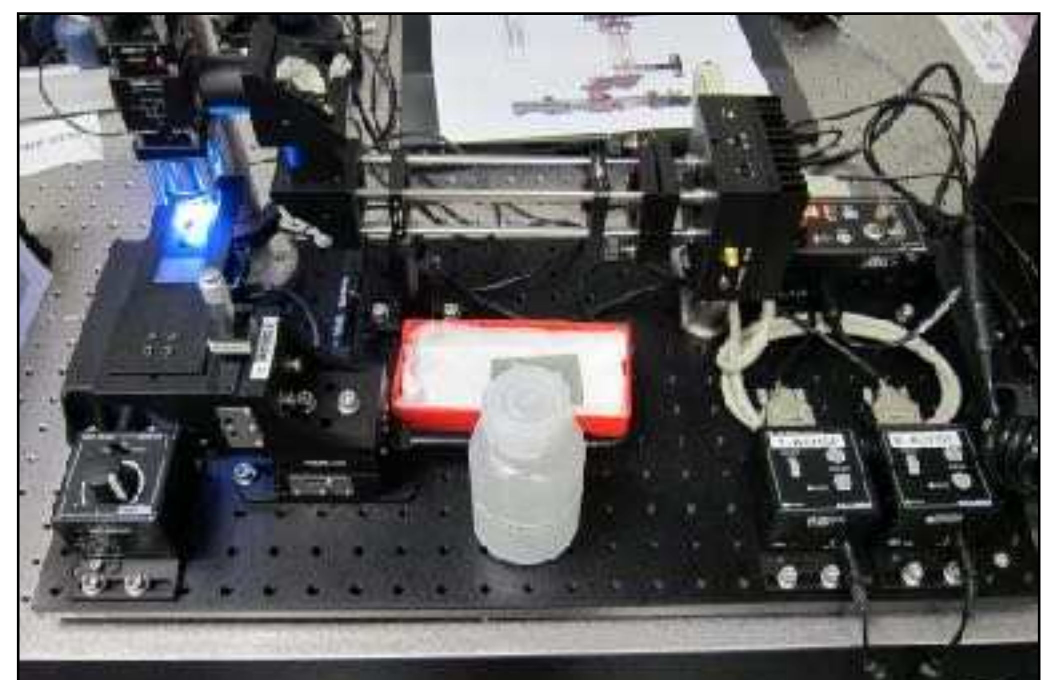
Describe how the wavelength of the laser can be determined using the Michelson interferometer.

Optical tweezers

How can you hold individual cells and move them around precisely?



If you want to push spheres a few μm in size around, any mechanical tweezers are too big. But you can use the momentum transfer of photons, which is just strong enough to hold these spheres in place.

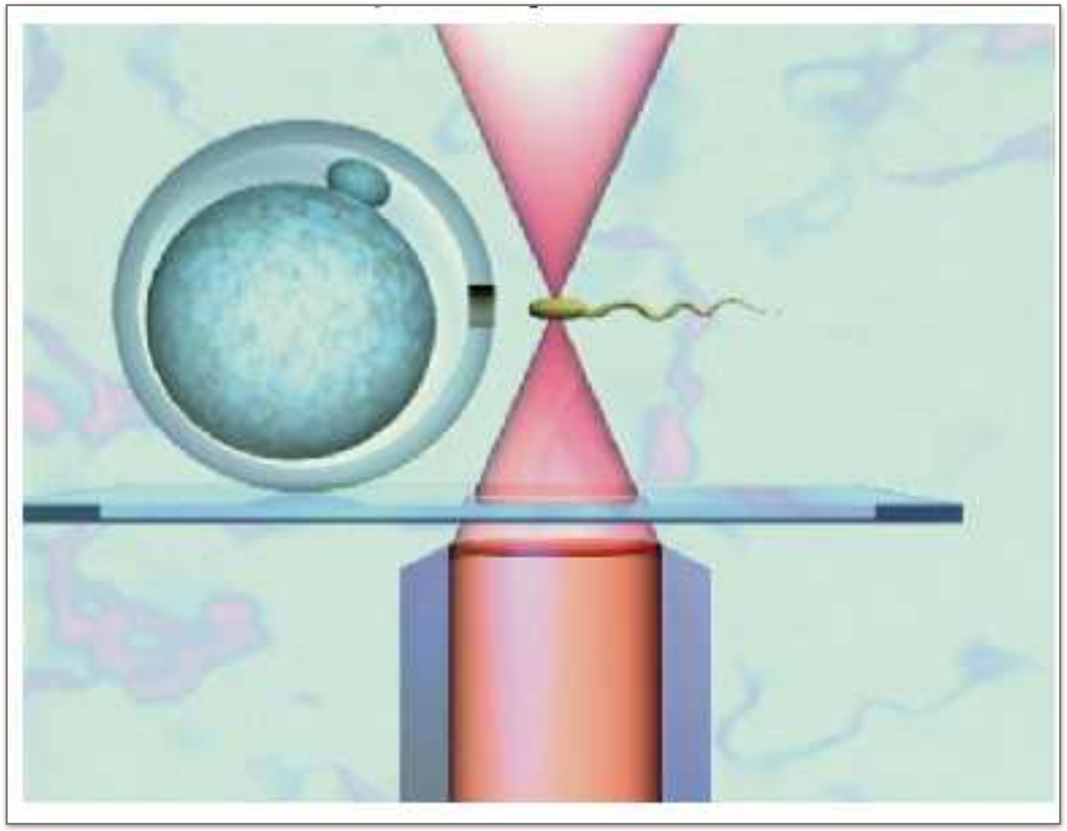


By the way: Arthur Ashkin was awarded the 2018 Nobel Prize for the invention of optical tweezers!

Source: THORLABS

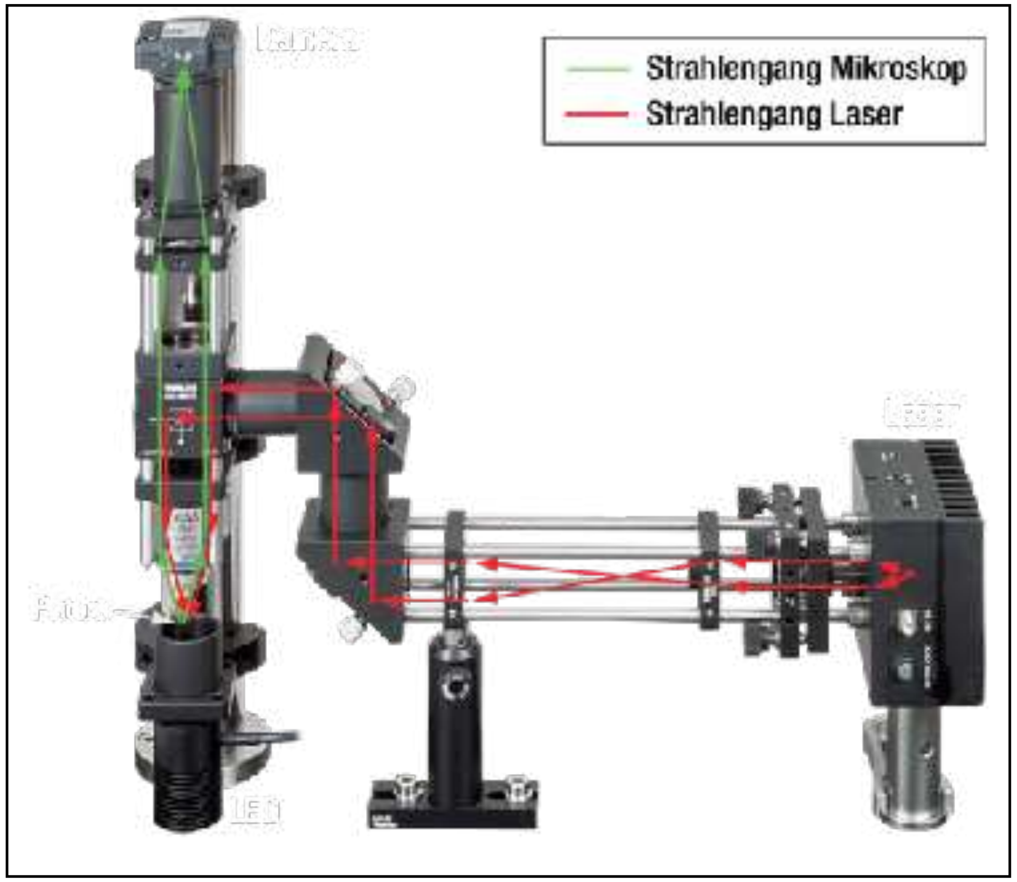
Artificial fertilization

The way optical tweezers work makes it possible to capture and move very small bodies (in this case a sperm) using a laser beam. During artificial fertilization, a small incision is first made in the egg cell using the laser. The sperm is captured by the laser beam and moved to the incision in the cell wall.



http://www.physi.uni-heidelberg.de/~eisele/lehrer/Greulich14.3.09.pdf

Experimental setup



The optical tweezers consist of two components: a microscope and a laser. The beam path of the microscope is marked in green in the adjacent image, that of the laser in red. The laser is located in a cage and is immobile. In order to capture particles, the sample is moved and not the focus of the laser. The laser is focused on the sample.

In our experiment, we will hold and move μm-sized Plexiglas balls.

Source: THORLABS

Basics

How can we hold particles with light?

The laser focus exerts a force on the particles in the sample (in our case, the Plexiglas spheres). The force is attractive and is used to capture the particles, as the particles move towards the laser focus due to this force.

It is called **gradient force** and occurs as soon as a laser beam hits particles whose refractive index is higher than that of the surrounding medium.

What is the refractive index?

The refractive index is a material constant.

Every material has its own **refractive index**, which can be used to calculate how fast light of a certain wavelength travels in this material and how much the light beam is deflected when passing between two materials.

You can find out more about refraction and refractive index **here** or on the next page.

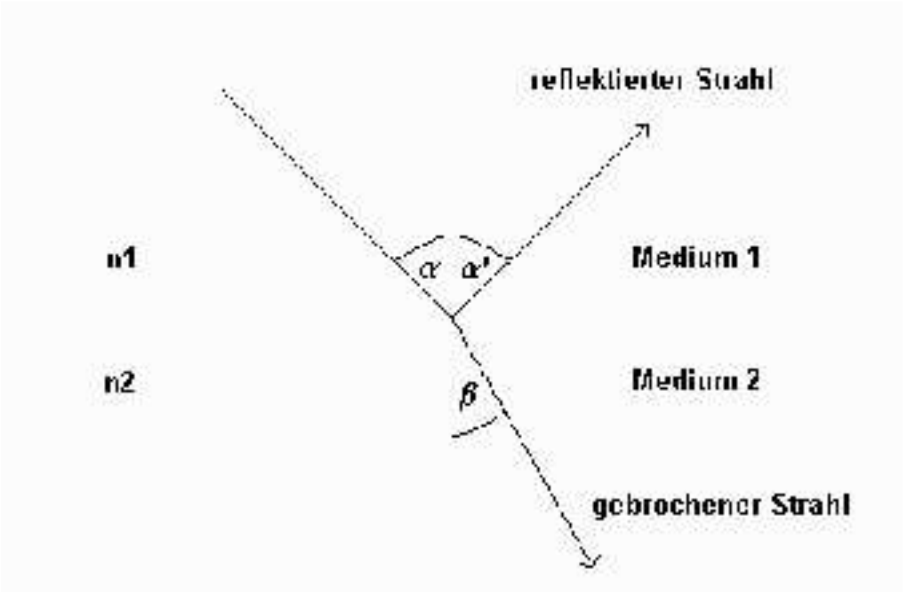
https://www.experimentis.de/site/wp-content/uploads/2013/02/201LoeffelOel500.jpg

Refraction of light

If a beam of light crosses a boundary between two materials with different refractive indices, it is refracted at the boundary, i.e. it changes direction. If the light beam passes from a medium with a low refractive index to one with a higher refractive index, the light beam is refracted towards the perpendicular at the boundary of the media. When entering a medium with a lower refractive index, on the other hand, it is refracted away from the perpendicular.

The strength of the deflection is described by Snellius' law of refraction. n_1 and n_2 are the refractive indices of the two media; α the angle of incidence and β the angle of reflection.

$$n_1 \cdot sin(\alpha) = n_2 \cdot sin(\beta)$$



Material with a low refractive index

Material with high refractive index

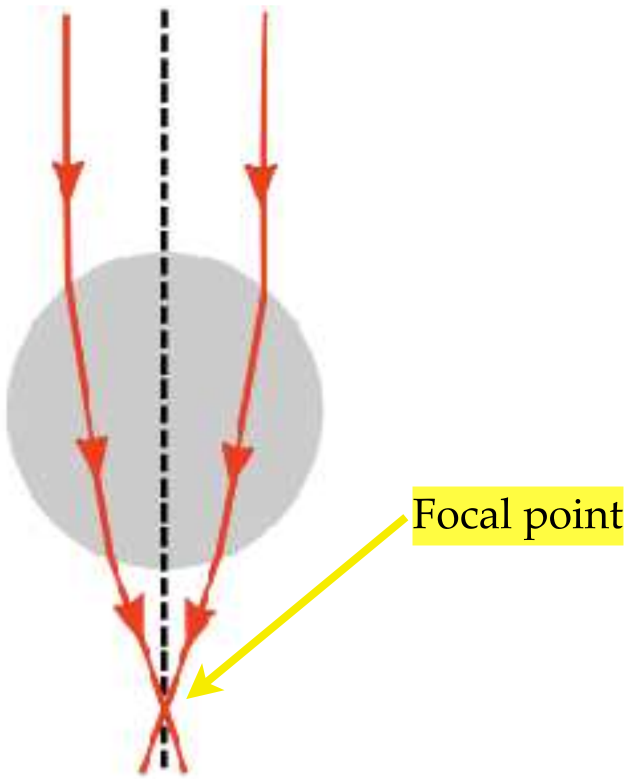
http://www.physik.tu-berlin.de/institute/IFFP/moses/Subsites/themenseiten/brechungsgesetz/applets/brechungsgesetzindex.html

We can explain the effect of the gradient force as follows:

If a beam of light is refracted, it then moves in a different direction. This change in direction of the photons also means a change in momentum.
This change in momentum transfers a counter-momentum to the medium that has refracted the light beam.
This momentum is only minimal, but it exists and is strong enough to move particles with a tiny mass.

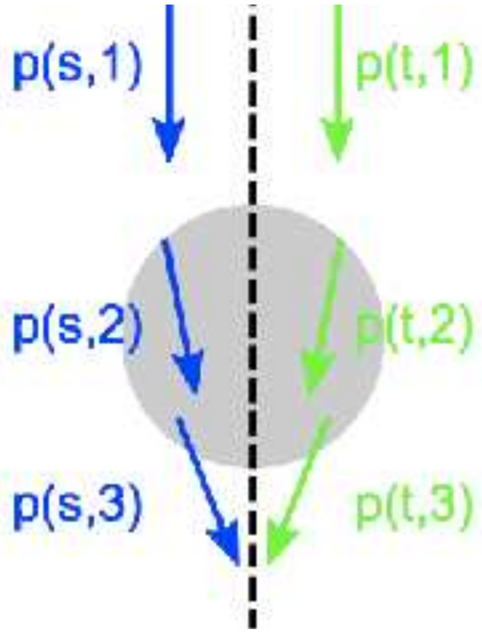
If the laser is focused at one point, the sum of all the pulses transmitted by different light beams always results in a force towards this point. This can be visualized as follows:

The beam path through the sphere when it is above the focal point.

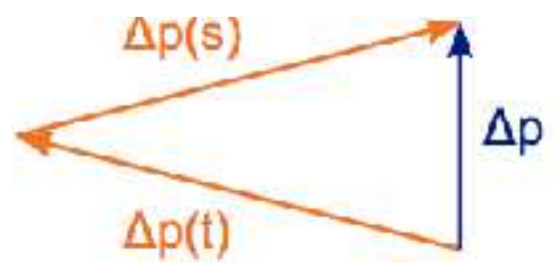


Source: THORLABS

The resulting impulses:



If you determine the differential momentum of the two light beams and add them together, you get the total differential momentum Δp of all photons. Exactly the opposite momentum acts on the sphere. This goes vertically downwards, i.e. exactly towards the focal point.



If you perform this calculation for other positions of the sphere, for example to the left or right of the focal point, you will also always obtain an impulse towards the focal point. The sphere is therefore captured there and can be moved by moving this point.

Source: THORLABS

Experimental procedure

1. Start the camera

If necessary, switch on the computer (not password-protected) and open the "uc480Viewer" program. Then click on the symbol in the top left-hand corner (Open camera). If you now carefully turn up the LED driver on the left in front of you, you will see the live image on the computer.

2. *Preparation of the slide Attention: Read completely first!*

Use the pipette to add a tiny drop from the bottle labeled "Styrofoam beads 1 μm in distilled water" to the furthest field with the depression in the blue slide and then carefully place the cover glass on top. The cover glass is in a box and breaks easily! Risk of injury! Now screw the micrometer screw all the way down and carefully place the slide under the camera.

3. *Setting the laser*

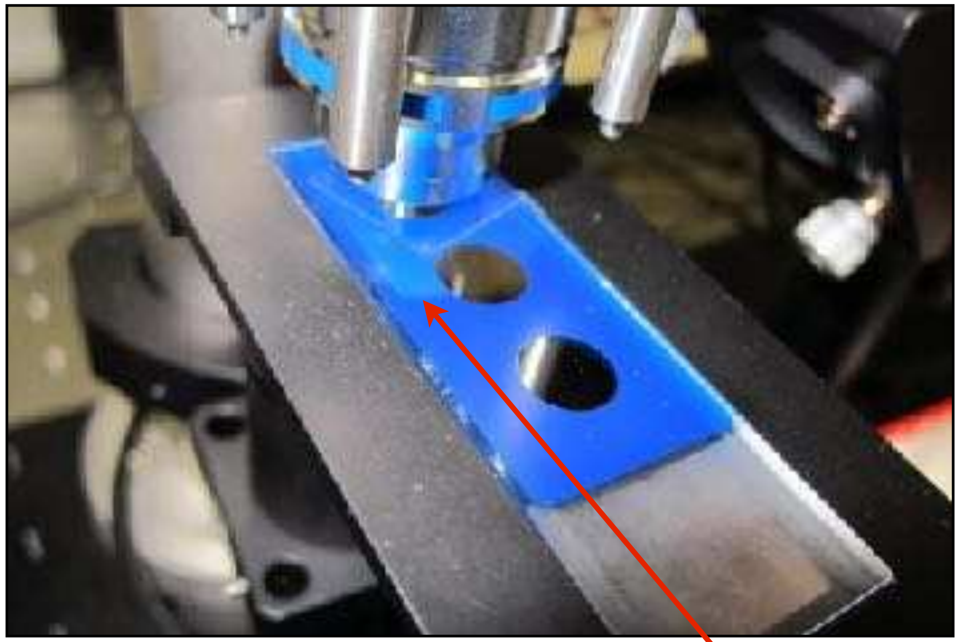
In the next step, ask the lab manager to switch on the laser. She switches the laser on by turning the key switch and pressing the "Laser on" button. **Make sure that there is nothing in the beam path of the laser!**

Procedure

Partial experiment 1: Holding the particles in place

Slowly turn the micrometer screw (the micrometer screw is labeled "down") upwards while observing the image on the computer. Moving structures and a red reflection of the laser will appear on the screen. Stop screwing at the third red flash. Do not turn any further! You can now use the toggle switches on the motors to carefully move the sample and capture small particles.

If a bead stops moving and lights up red, you have captured the bead using the laser. (Note: Initially, the beads may move too quickly as there are still currents present. However, these currents quickly subside).



The object slide

If you now look at the image from the camera, you will see that all the other particles are moving chaotically. This movement is called **Brownian motion**.

By very carefully and slowly pressing the toggle switches on the motors at the bottom right (x-axis; y-axis), you can move the slide while holding the particle.

Quiz

Turn off the laser, lower the sample table and carefully remove the glass slide. Place the **optical grating** on the sample table (plastic foil that shimmers in rainbow colors). Estimate how many **lines per millimeter** this optical grating has by comparing it with the **micrometer beads** (the image scale is the same).

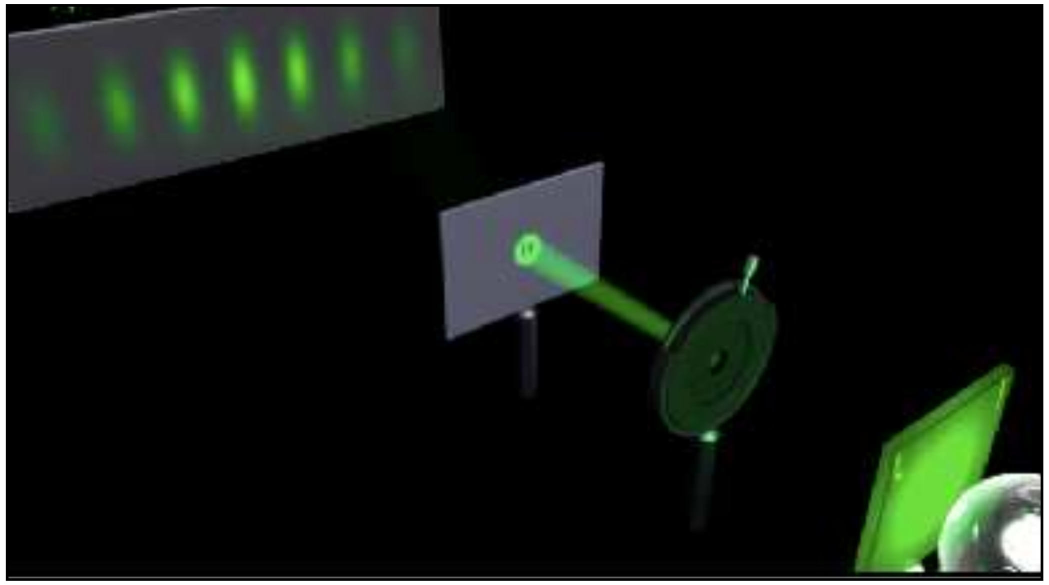
a) 100
b) 1.000
c) 10.000
d) 100.000

Correct: b

Double-slit experiment

Fancy an insight into the world of quantum physics?

The experiment is actually very simple, but it has a lot to offer!
Initially, it only consists of a light source (laser), two small slits (double slit) and a screen (camera). It actually works with **single photons**, but as we cannot generate these, we use a laser with a low intensity. So we are working with an **analogy experiment**!
Perhaps you have already become familiar with the double slit.



https://boule-braunschweig.jimdofree.com/boulelexikon/mannschaft-kommunikation/interferenz-resonanz-d%C3%A4mpfung/
Bild: Screenshot von photonworld.de

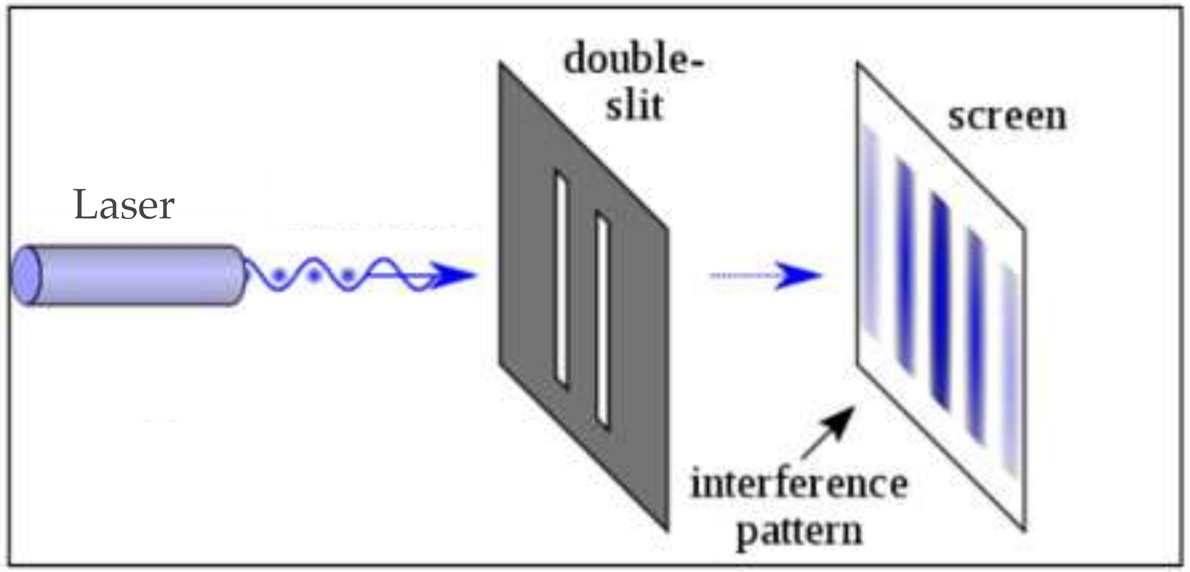
Double slit with single photons

To understand the experiment **in terms of quantum mechanics**, you first need to know how it works "**classically**".
Imagine kicking a soccer ball between two crossbars into the goal. What do you expect? Right, **two piles.** The balls of one have flown through the right-hand gap, the balls of the other through the left-hand gap.

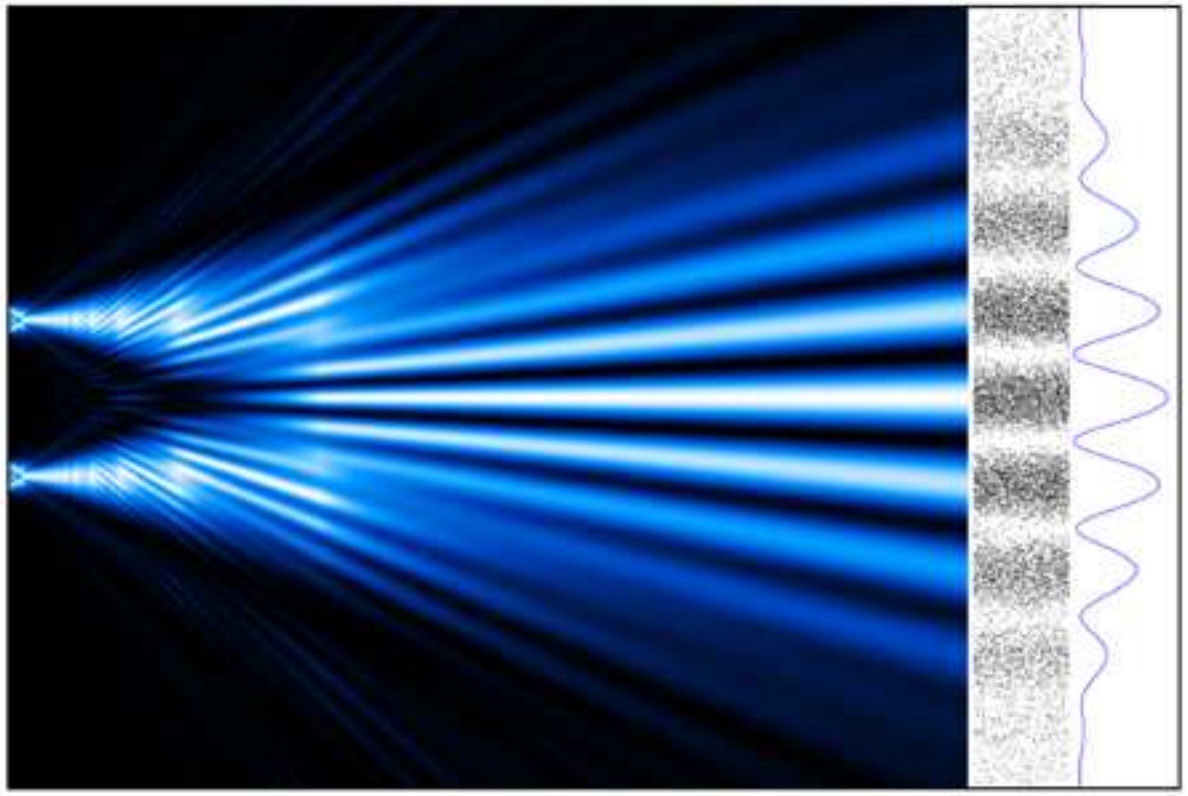
„Normal" footballs

In the double-slit experiment, however, you can see **waves** behind the slit!
This can be explained because light, which we send through the slit, is a wave. You've probably also heard that light consists of **photons**. This is true. Experiments such as the photoelectric effect show that light is **detected** as bundles of energy with very specific energies, which we call **energy packets**. The individual units of discrete energies that together make up an energy packet are called **photons**.
So if we carry out our double-slit experiment with individual photons - **energy packets** - we expect the same result as when playing soccer on the top right. But it looks completely different! You will learn why this is the case in this course.

Light as a Wave



At the top right you can see the setup of the **double-slit experiment**. The source in our case is a laser. On the right of the screen you can see the result of such an experiment.
Normally we would expect to see two stripes. But we observe a whole light/dark pattern, the so-called **interference pattern**.



You can explain it simply by assuming that light is a **wave**. In the dark areas, the light waves cancel each other out (destructive interference), in the bright areas they amplify each other (constructive interference).
You can find out exactly how this works here. You can also do experiment 2 - hair thickness.

Interference Pattern -> Light behaves like a wave

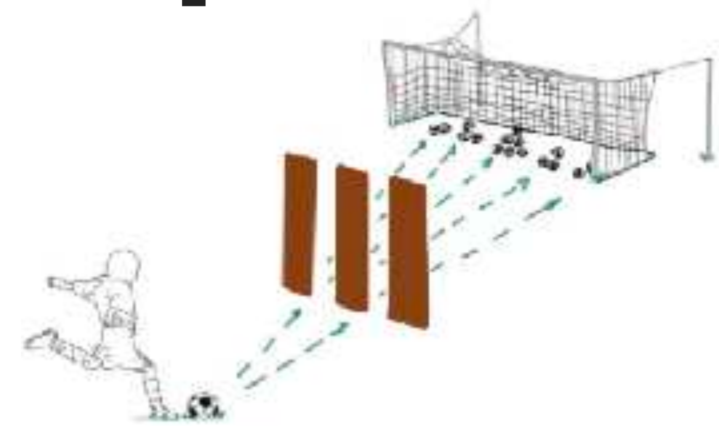
https://de.wikipedia.org/wiki/Doppelspaltexperiment

https://www.spektrum.de/news/was-verraet-die-quantentheorie-ueber-die-realitaet/1592854

Double-Slit with single photons

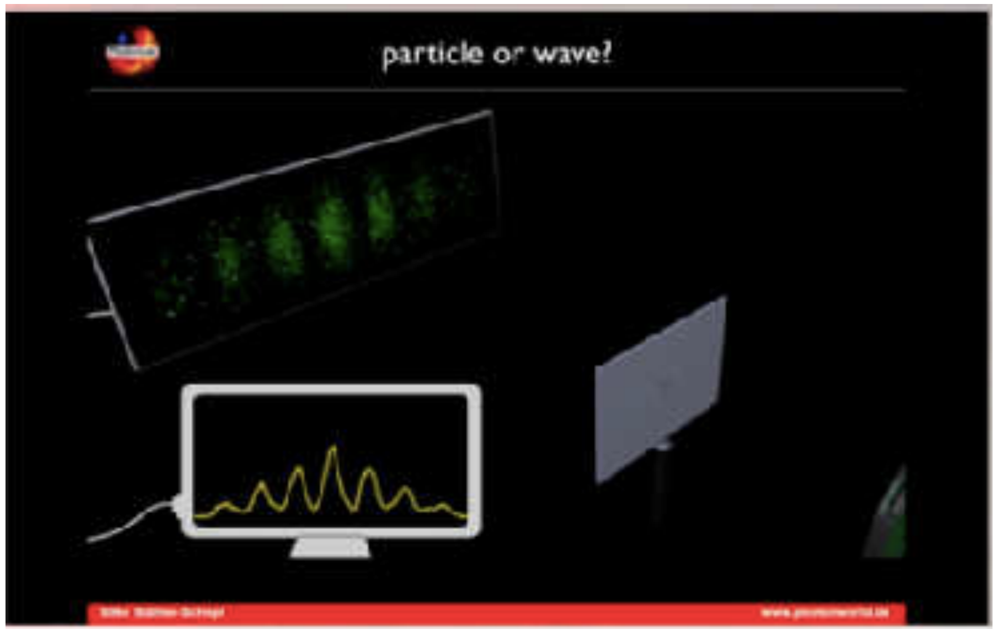
However:

If you now carry out the double-slit experiment with individual quantum particles such as photons, you will observe an **interference pattern** similar to that of waves!



„Quantum“ Footballs

This shows us that photons have both wave and particle properties = **wave-particle duality**.



https://www.youtube.com/watch?v=N7NYLG-OAPU

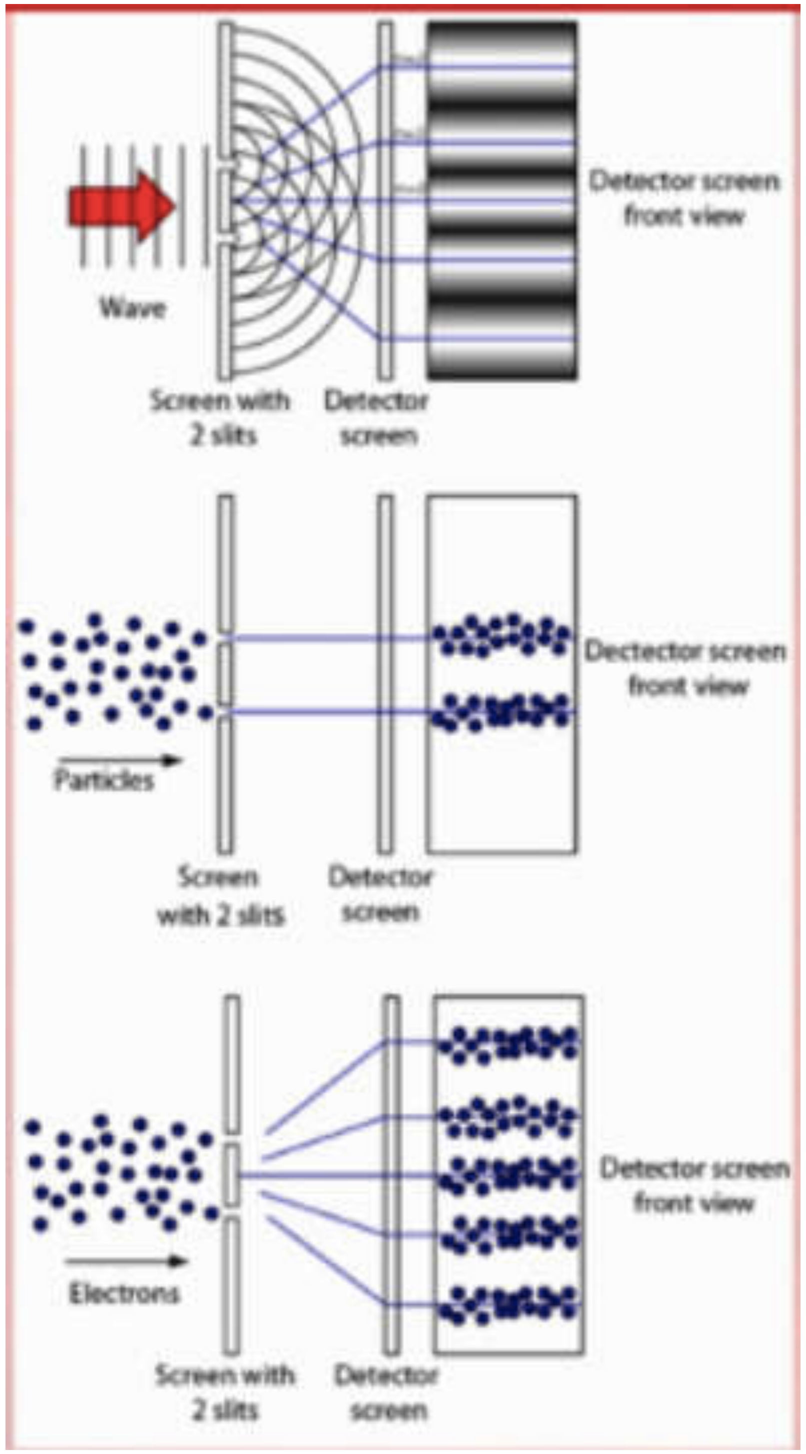
More precisely, the following happens: If we now shoot single photons at the double slit, the photons appear to hit the screen at random. However, the **interference pattern** actually forms again if a sufficiently high number of photons are detected! The photons are quantum particles and hit the screen with a **probability** that corresponds to the interference pattern.

Summary

If a wave (water wave, light wave, sound wave...) hits a plate with two narrow slits, an **interference pattern** is observed after the obstacle (**top**).

If classical particles, such as balls, apples..., hit two slits, they form two areas in which they hit the screen (**middle**).

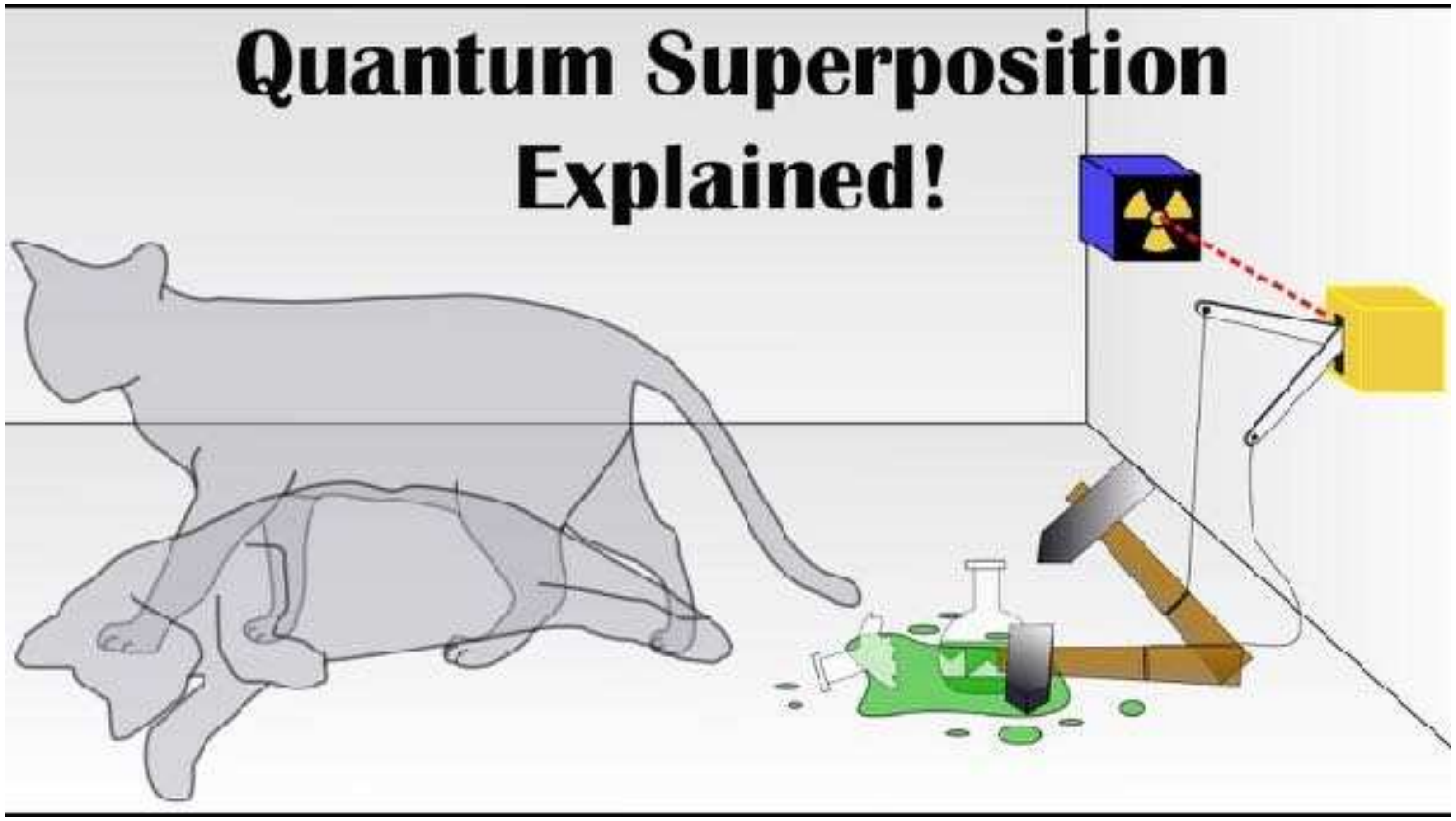
When quantum particles (electrons, photons, atoms...) hit a double slit, an interference pattern is observed (**bottom**). **ALSO:** Classical particles and quantum particles behave differently!



https://www.researchgate.net/figure/Double-slit-experiment-with-a-photons-b-very-large-particles-c-electrons_fig1_349125115

Double-Slit with single photons

Quantum particles propagate like a wave (description with wave front) as long as they are not measured. The photon is then in a superposition state.
We express this state with **position probabilities**. However, if we carry out a **measurement**, they are measured like a particle (**collapse of the wave function**).

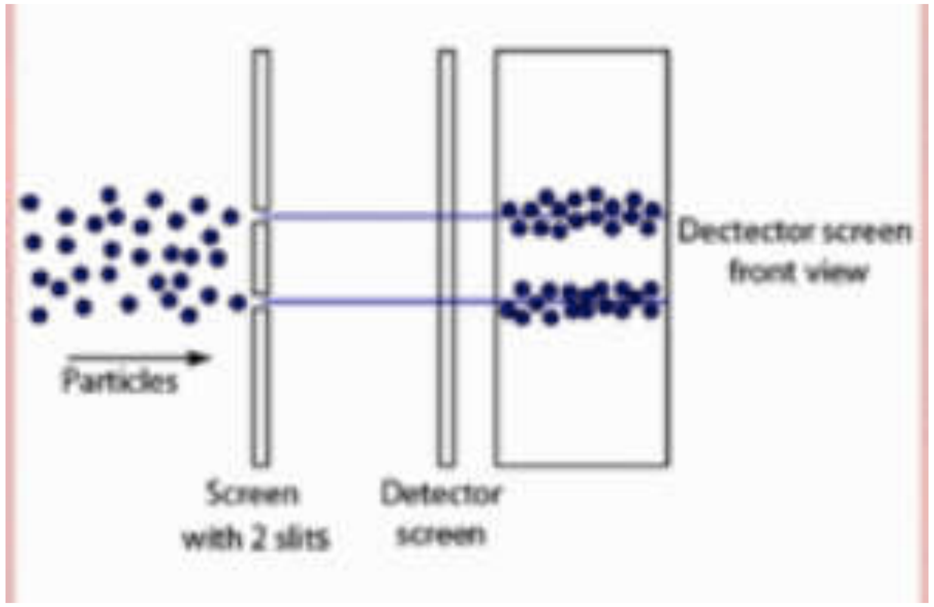


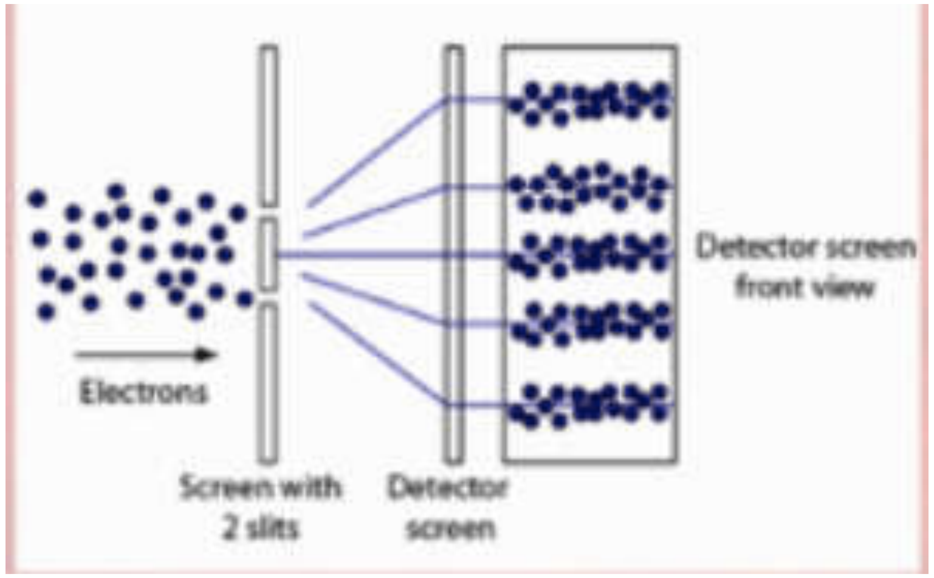
https://de.wikipedia.org/wiki/Schr%C3%B6dingers_Katze

Mystery of the photon's path

In the next step, we want to find out which **path** the photon has taken. To do this, we position two polarization filters perpendicular to each other at the two slits. The photon must therefore have taken **either** the right or the left path in order to be completely in one of the paths (top image).

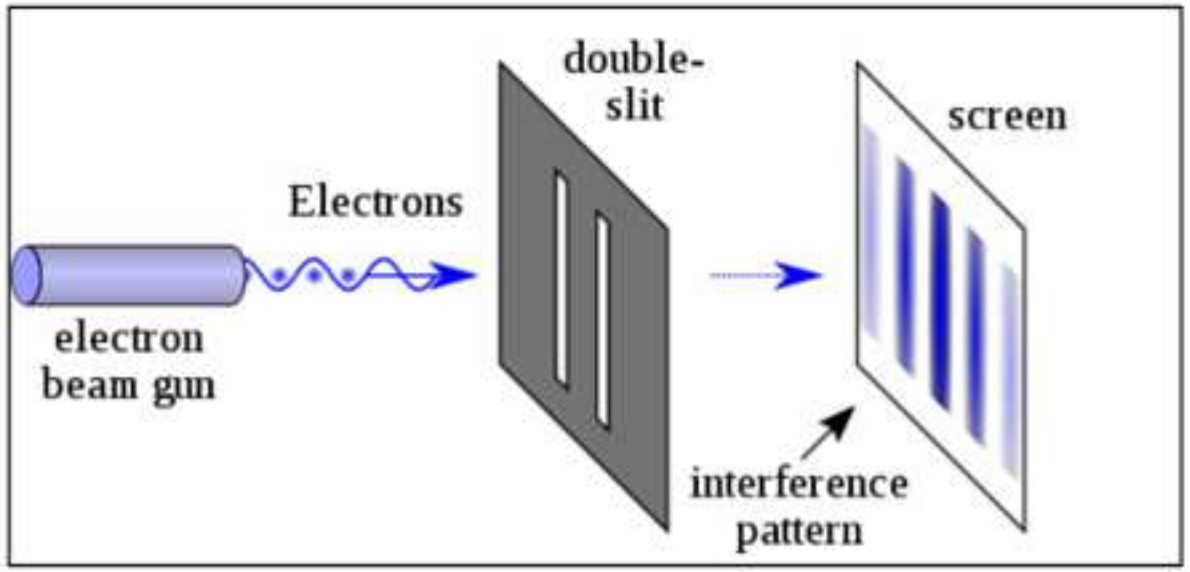
Before the measurement, the photon was in a superimposed state in superposition, according to our explanation. Because we know that it could only take one path, the superposition is destroyed. It is impossible to predict **which** of the two paths the photon will take (bottom image).
So on the screen you can see whether you have interference or not!
If you want to find out more about **which path information** , try the Bomb Tester.



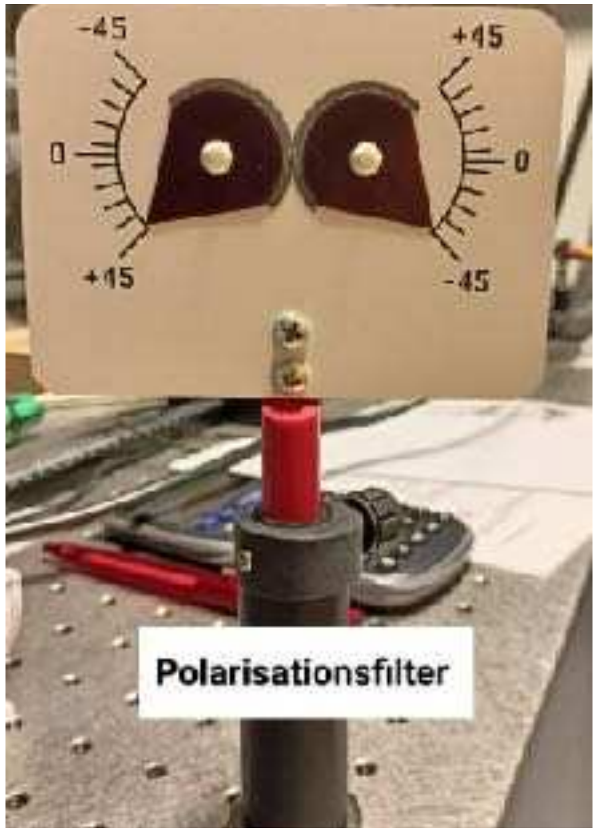


https://www.researchgate.net/figure/Double-slit-experiment-with-a-photons-b-very-large-particles-c-electrons_fig1_349125115

In the lab

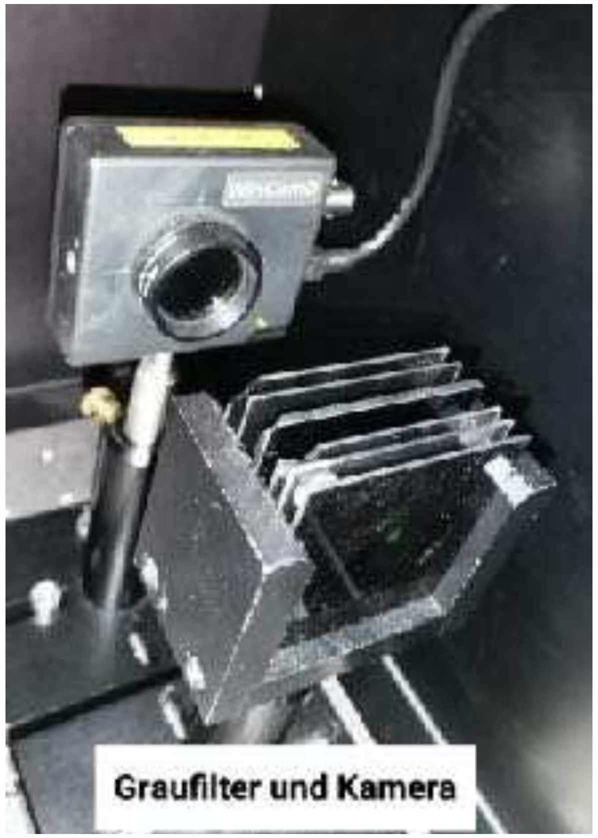


To help you understand the following experiment, the individual **components** and the **setup** are described below.



Polarization filter to determine the influence of polarization on the interference pattern

Laser as a photon source



Grey filter to minimize the irradiated laser power and thus simulate single photons.

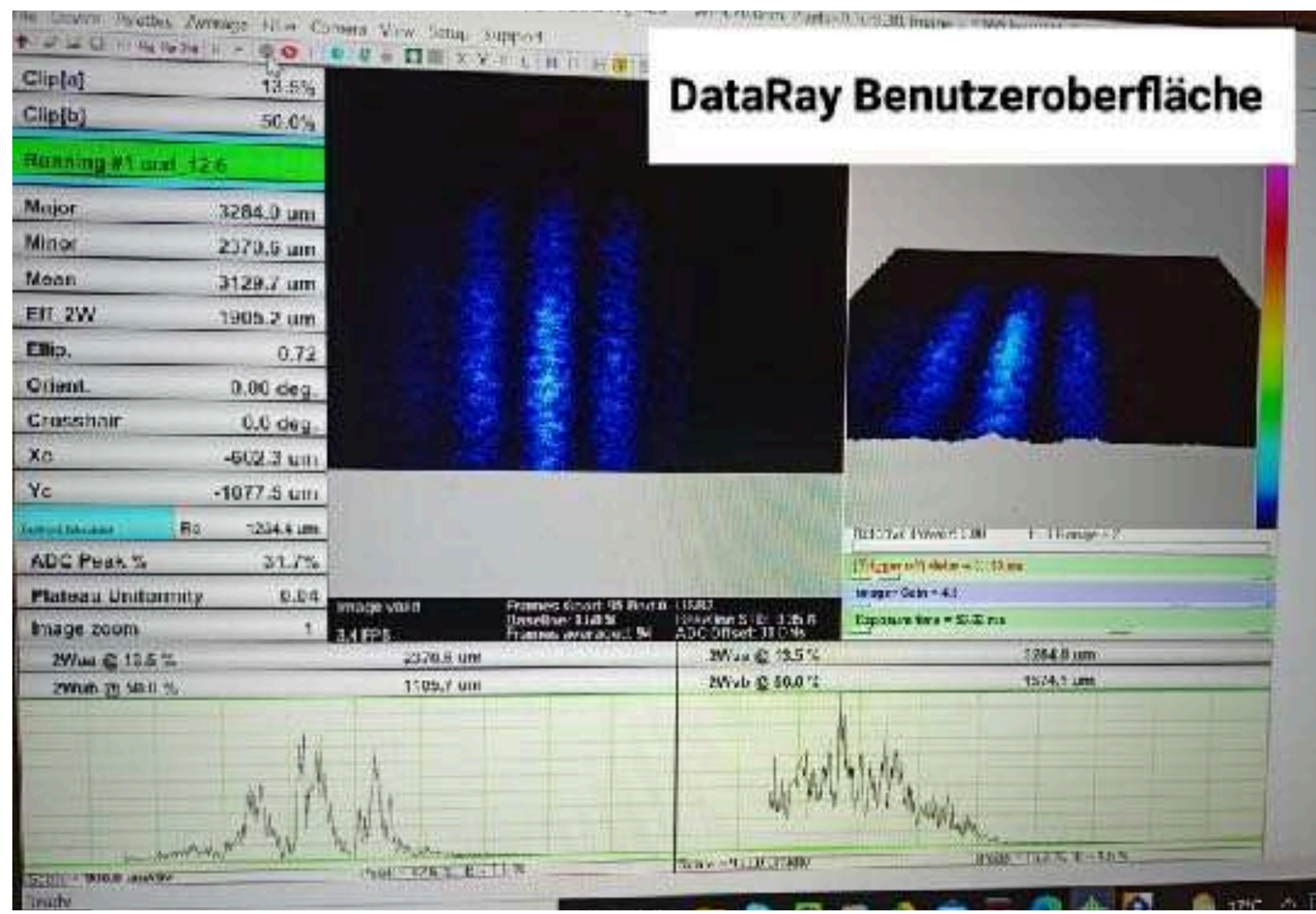
https://de.wikipedia.org/wiki/Doppelspaltexperiment

And now you!

Disclaimer: This is an analogy experiment in the laboratory
Researcher question: How does the existence of which-path information influence the interference pattern?

Put on your laser safety goggles NOW at the latest!

1. Switch on the computer and the laser. !!! DO NOT CHANGE THE SETTINGS UNDER ANY CIRCUMSTANCES!!!
2. Now open the "DataRay" program. Press the green "G" for "Go" in the upper command bar. As you can see, the image is made up of individual pixels. However, these **do not** represent real photons! Since the result looks similar with real single photons, it is an **analogy experiment** (if in doubt, take another look at "Double slit with single photons").



Your result should look something like this.

3. Analyze the detected **intensity distribution** of the oscilloscope on the computer and think about what happens if we repeat the experiment with **single** photons.
4. Now place the polarization filters in the laser beam so that it illuminates the **two single slits** . First set both filters to 0° and photograph the interference pattern on the screen with your smartphone.
   Now change the angles: once -45° to +45° and +45° to +45°.
   Take a photo of the interference pattern, e.g. with your smartphone! How does the interference pattern **change** on the screen?
   Now observe the pattern with **DataRay**. How does the **existence** of which-way information influence the interference pattern?

Schrödingers Cat

(taken from Philip Schwinghammer)

Schrödinger's cat is a famous thought experiment designed to illustrate the strangeness and absurdity of quantum physics and superposition. Suppose we don't care about animal welfare or job security. We could take a cat and put it in a box with a bottle of poison. The bottle of poison would have a significant weakness: it would break as soon as a radioactive decay happens in the box. So far so good, it looks as if we are murdering cats for no reason. But that's only **half** the truth!

Schrödingers Cat

https://www.stupidedia.org/stupi/Schr%C3%B6dingers_Katze

https://www.cosmos-indirekt.de/Physik-Schule/Schr%C3%B6dingers_Katze

Schrödinger´s Cat

Why the concept of quantum particles in superposition amazes us so much

Radioactive decays are **quantum processes**. This means that a radioactive atom can be in a superposition of decay and non-decay until a **measurement** is made. Until the atom has decayed and not decayed at the same time, the bottle is broken and not broken at the same time. In the same way, a single photon passes through the left and right slits simultaneously in the double-slit experiment. If we open the box, we dissolve the **superposition** through the measurement.
The poison has reached the cat, but at the same time it has not, and the cat is therefore in a superposition of dead and alive! The proportions of dead and alive therefore depend on the radioactive atoms. The probability of a radioactive atom decaying can be very different depending on which element we have. If we **open** the box, we dissolve the superposition so that the cat is **clearly** dead or alive.

https://www.redbubble.com/de/i/galeriedruck/Schrödingers-Katze-meme-von-Faeblehoarder/53198779.7Q6GI

QM Bomb Tester

How can I test whether bombs are armed or not WITHOUT blowing them up?

Image: Thorlabs

Shell game

In order to be able to observe something, it must be hit by **at least** one photon. We can easily verify this statement: If we cover our eyes, no photon reaches our eyes and we cannot observe anything.
But in **quantum physics**, this no longer applies.

Let's imagine the following:

In a **shell game**, we have two shells and a marble. The marble is under one of the two cones. We don't know which one it is under. As soon as the marble comes into contact with **light**, it disintegrates into **dust**.

If we lift the little hat under which the marble is, it will crumble into **dust**. So we know where the marble was (**pile of dust**), but we have destroyed it.

In order to find the marble and **not** destroy it, we would lift the hat under which we **do not suspect** the marble to be. If we were right, we now know that the marble is intact under the other hat. We have determined the **location of** the marble **without** it having been touched by a photon.

https://kniffliges.de/de/product_info.php?info=p1564_das-huetchenspiel-mit-roten-huetchen.html

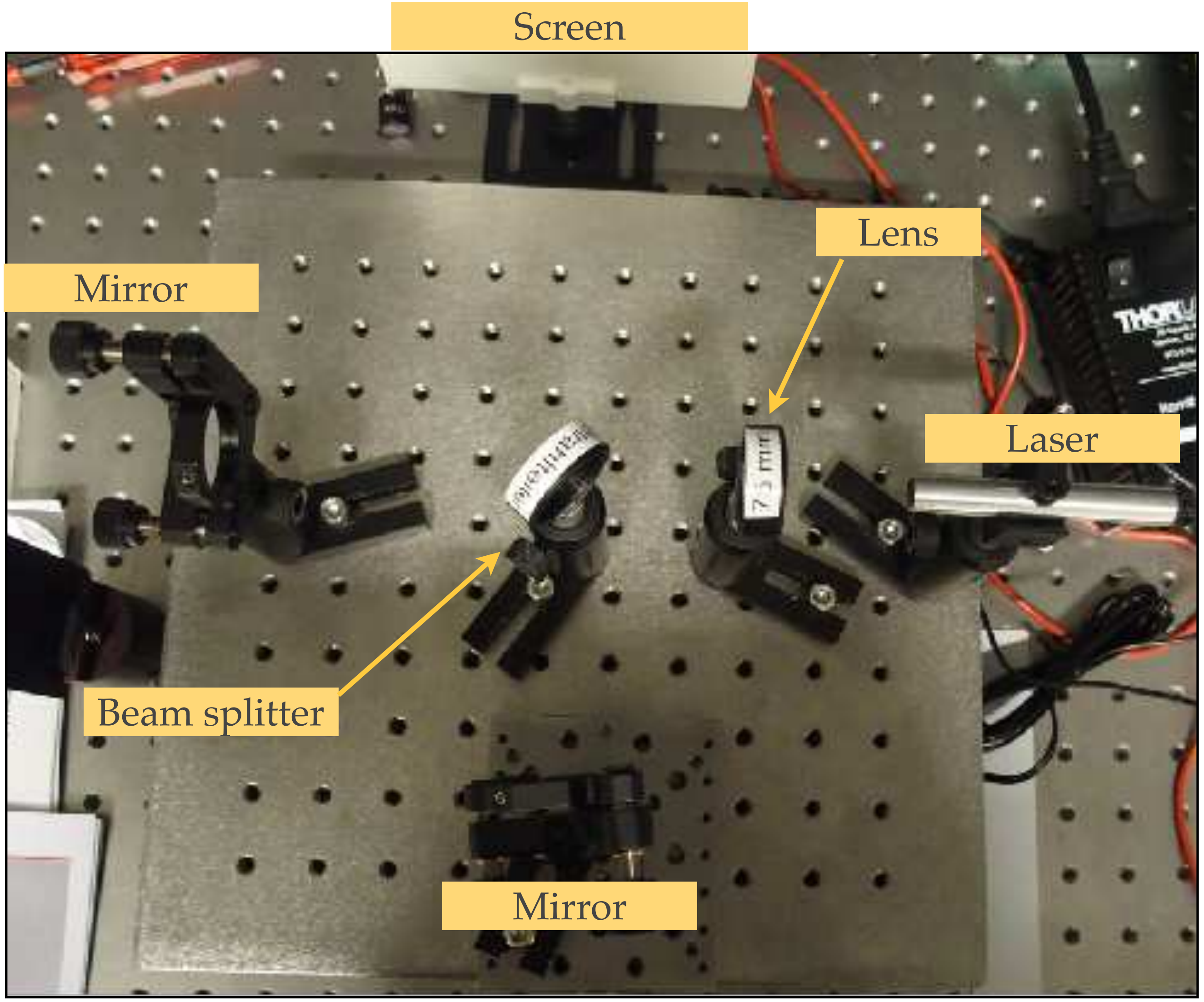
This principle is called **interaction-free quantum measurement**.
In quantum physics, we can therefore **obtain information about quanta without** them **interacting with light**.

The thought experiment:

A large number of bombs lie in front of us. Some of them are **live**, some are **unexploded** (it is not known which proportion is live).
The bombs have a **light-sensitive** trigger.
This means that the live bombs explode as soon as a photon interacts with the trigger.
The unexploded bombs **do not** interact with photons.
In our experiment, we also want to measure **without interaction** in order to find the live bombs without blowing them up.

The experimental setup

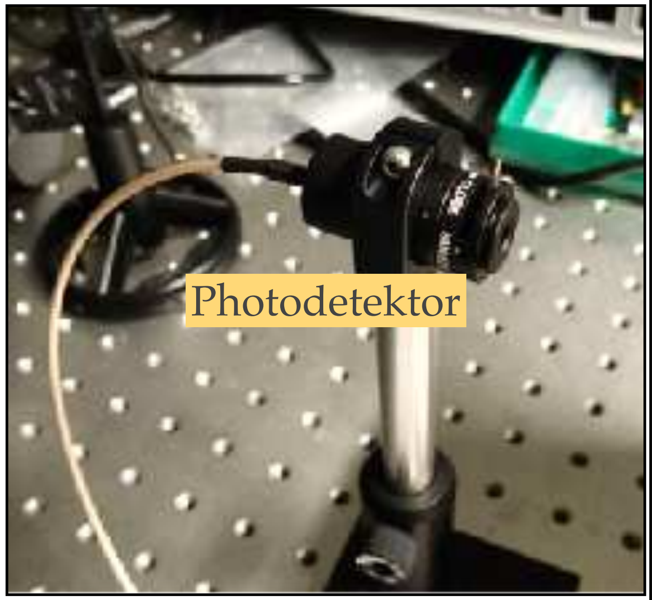
To check the results of our thought experiment, we use the following structure:



The experimental setup is identical to that of the Michelson interferometer (next slide), except that a photodetector is later placed in place of the screen. The photodetector is connected to a voltmeter. You can use the voltmeter display to read the measured voltages.

The setup contains:

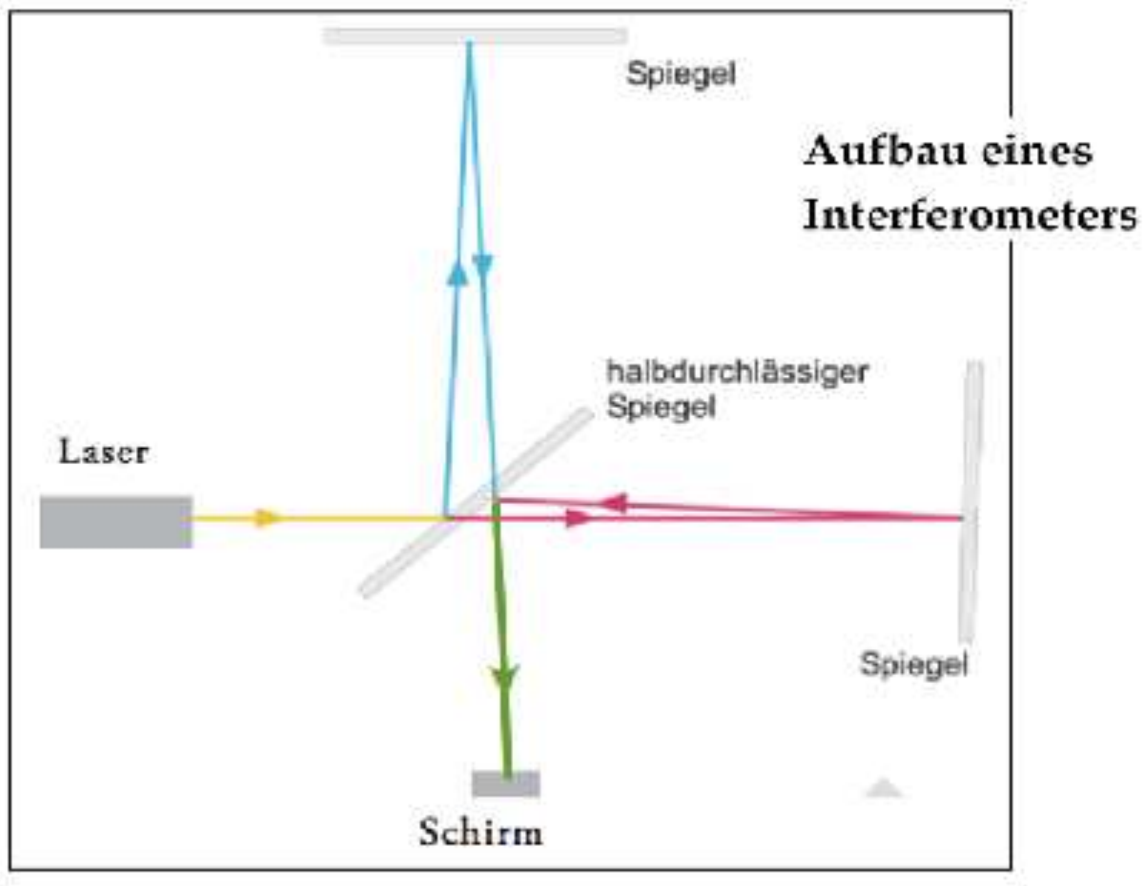
- 1 laser
- 2 mirrors
- 1 lens (75mm)
- 1 beam splitter
- 1 screen
- 1 photodetector
- 1 voltmeter



The Michelson interferometer

The Michelson interferometer is also included in the Photon Lab as a stand-alone experiment. Here you will find some information about the interferometer that you need for the Knaller experiment.

Experimental setup

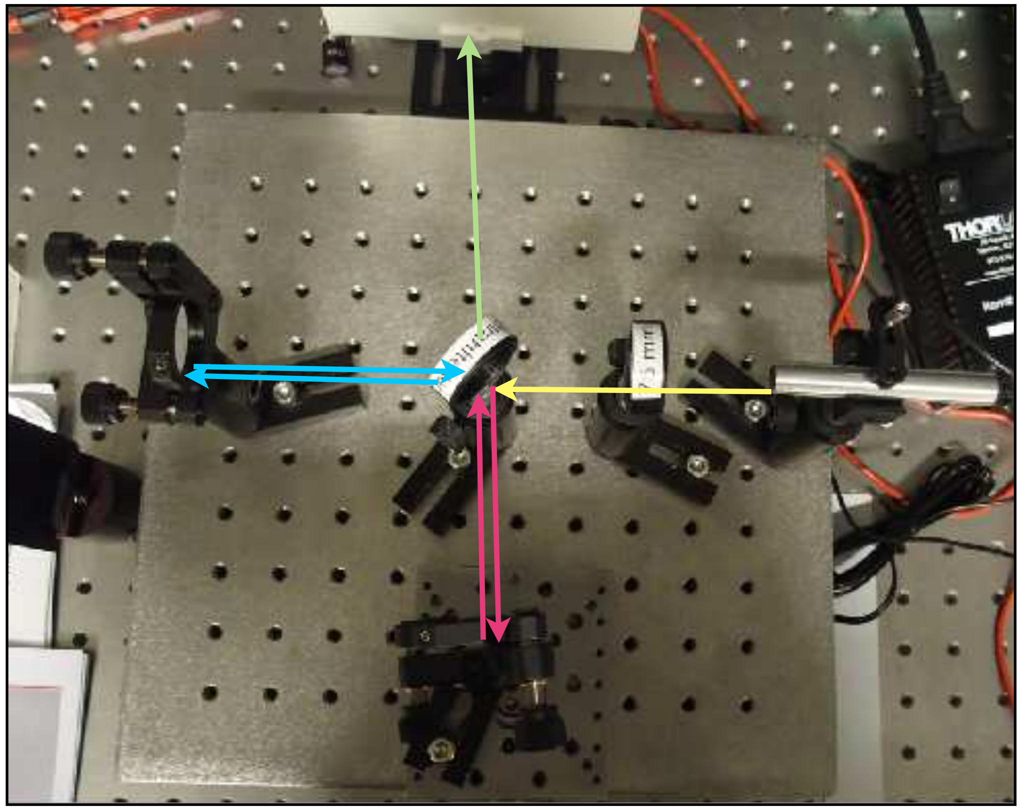


The semi-transparent mirror is often also called a beam splitter. It splits the laser beam into two beams by reflecting 50% of the laser light and allowing the other 50% to pass through. (A more detailed description can be found under the link) The two beams are reflected by the mirrors and both hit the beam splitter again. There the two beams overlap and hit the observation screen.

Image: Thorlabs

Basics

This experiment is an analogy experiment that is normally carried out with single photons, but the result would be the same as with this setup. In the case of a laser beam, however, this experiment can be explained classically, although with single photons you have to fall back on quantum mechanics.

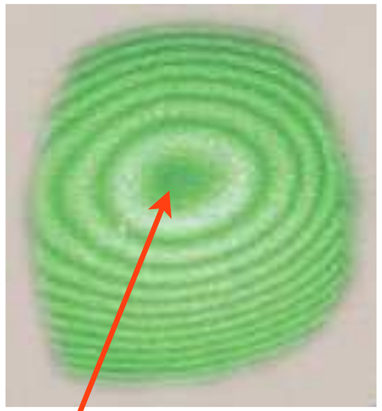


Now it gets a bit abstract:
In the introductory lecture, we have already seen that light has both particle and wave properties.
If we send photons into the experimental setup, we can see an interference pattern on the screen.
The light therefore behaves like a wave.
This is why we can also observe the interference pattern.

In general, we can say that light exhibits wave properties when...

1. There is **more than one possible** path that the light can take (here red and blue path)
2. We **cannot distinguish** which path the light has taken, see the double-slit experiment. If these conditions are not met, we can no longer observe interference.

Bomb or unexploded ordnance?



Minimum of the interference pattern

To be able to distinguish the bombs, we place each bomb in turn in one of the **interferometer arms**. We have previously adjusted the interferometer so that the interference pattern has a minimum at the location of the photodetector.
Now we can distinguish between 2 cases:

Case 1: The bomb is aktive
The trigger of a live bomb **interacts** with the photon. This "marks" this interferometer arm. This is because the paths **can** now **be distinguished**: If the photon takes the path with the bomb, we would notice. As one of the two conditions for interference is no longer fulfilled, the interference pattern **disappears**. The photon behaves like a particle:
It can take the path the bomb is in. This would be the worst case, because now the bomb **detonates** and we would have to start the experiment **all over again**.
Or it can take the other "**bomb-free**" path. Then our photon hits the beam splitter again after it has been reflected by the mirror. This means that it again has a 50% chance of being reflected or transmitted. If it is reflected, it is sent back towards the laser and cannot be measured by our detector. If it is transmitted, the photon is **registered** by our photodetector.

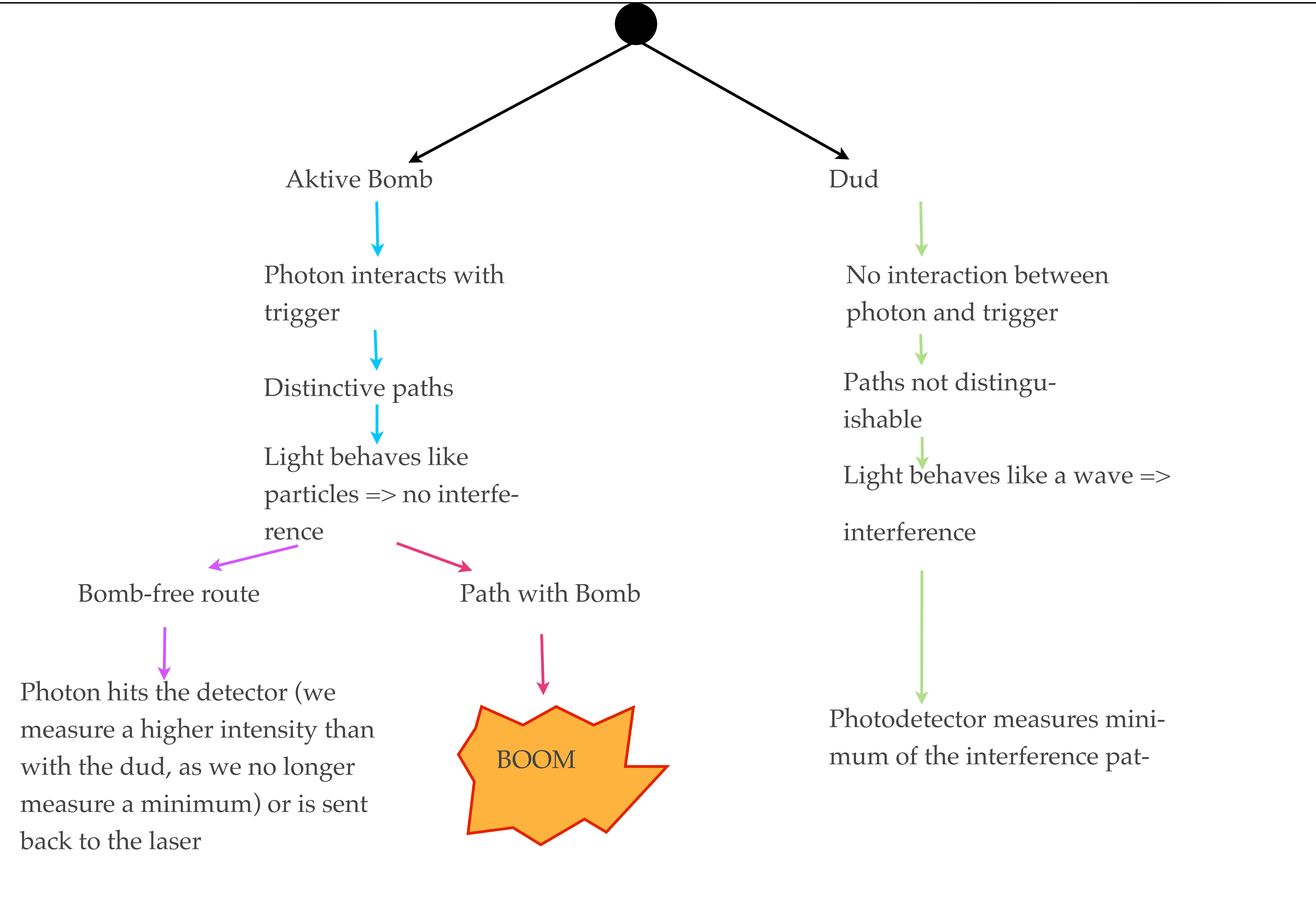
Case 2: The bomb is a dud

In the case of a dud, the photon does not interact with the trigger. We can therefore not distinguish which path the photon has taken. The conditions for interference are not violated.

This means that our photodetector now measures the minimum of the interference pattern (this signal is much weaker than the signal from our photon in case 1).

Suppose 50% of our bombs were aktive. Then we would blow up our lab in about 25% of the trials (P(bomb armed)=50% and P(photon takes path with bomb)=50%. Read P(x) as the probability that x is).

BOMB TESTER


Aktive Bomb
Dud
Photon interacts with trigger
No interaction between photon and trigger
Distinctive paths
Paths not distinguishable
Light behaves like particles => no interference
Light behaves like a wave => interference
Bomb-free route
Path with Bomb
Photon hits the detector (we measure a higher intensity than with the dud, as we no longer measure a minimum) or is sent back to the laser
BOOM
Photodetector measures minimum of the interference pat-

Procedure

Caution: The following part of the experiment is not stable in its execution. Do not spend too much time on it!

As soon as the laser is switched on, an interference pattern should be visible on the screen. If not, carefully turn the screws of the red mirror until the two partial beams overlap exactly and the interference pattern can be seen.

1) Move the photodetector with the screen so that the interference pattern hits the center (!) of the aperture. Check the beam path by holding a piece of paper in front of the photodetector.

2) Carefully turn the **adjustment screw** of the **non-red mirror** to set a minimum in the middle. This minimum should now be exactly centered on the aperture of the detector.

The photodetector measures the light intensity at the location of its aperture. The connected voltmeter indicates the voltage, which is **proportional** to the measured light intensity.

3) You can now use the voltmeter to check whether you are measuring the minimum. Change the position of the detector until you have found the point at which the display shows the lowest value.

3) **Check**: If the light in one arm of the interferometer is blocked, the voltage must increase, as there is no longer any interference and the photodetector no longer measures the minimum.

4) Now adjust the interferometer a little by carefully (!) turning one of the screws on the mirror in the red holder until the ring pattern disappears. Make a note of the value measured by the voltmeter and double it. This value represents half of the total intensity, as half of the light is reflected back to the laser by the beam splitter. We therefore double this value.

Note: The voltage measured by the voltmeter cannot become zero as light from the surroundings is still being measured.

Important: Before each measurement, use a piece of paper to check whether the detector is still measuring the minimum. The laser is unstable. The minimum may therefore need to be reset by turning the adjustment screws on the mirrors.

Procedure

Fall 1: Bomb is aktive

In our experiment, we can only represent the situation in which the photon takes the bomb-free path.

First think about what results you expect for the different cases.
(When will the measured values be higher?)

We can simulate this case by covering one of the interferometer arms. This is the interferometer arm in which the bomb is located. To do this, place the image of the sharp bomb between the beam splitter and a mirror so that the laser beam hits the image. Switch on the voltmeter connected to the photodetector to read the values.

Observe the display of the voltmeter.

What does the photodetector measure? Note your results.

Case 2: Bomb is a dud

Now place the image of the unexploded bomb in one of the interferometer arms (the laser beam should shine through the opening of the image).

Measure again with the photodetector.

Compare your results. Create a table for this (see next page).

Image: Thorlabs

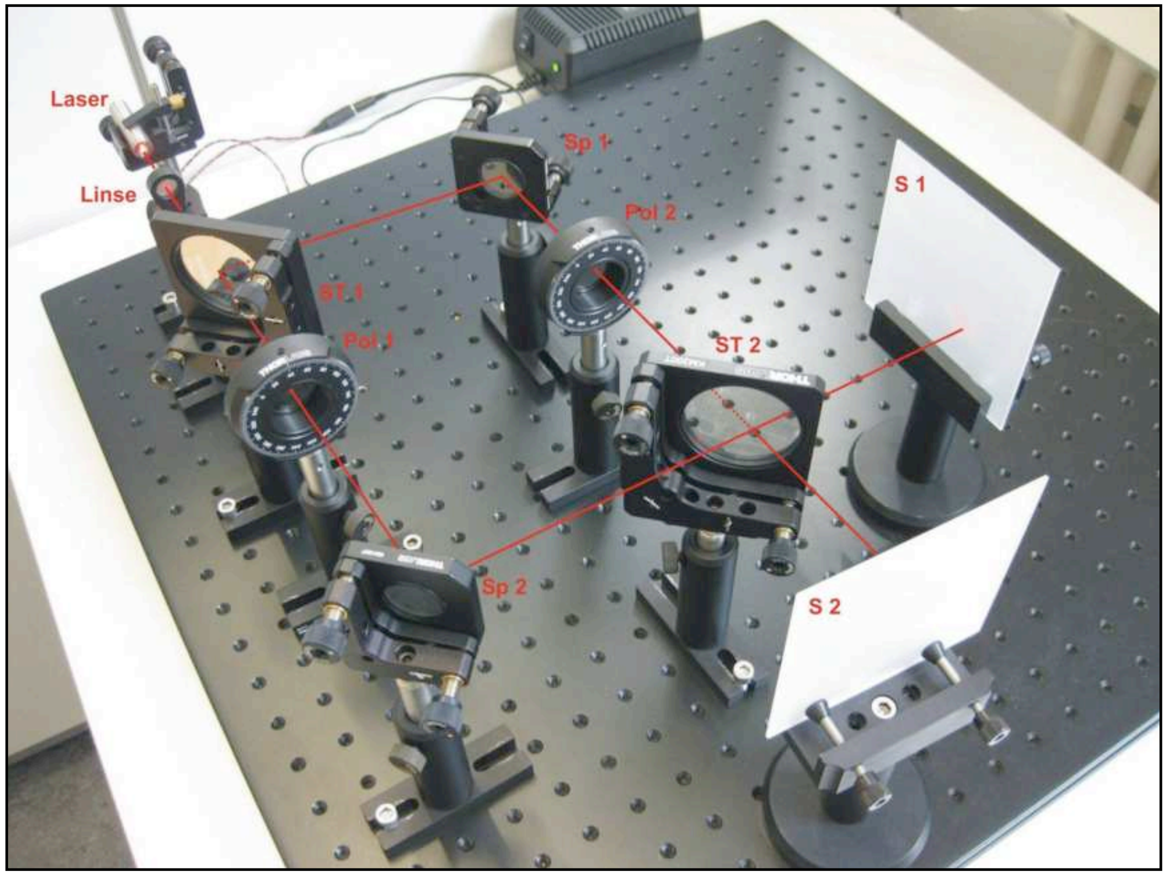
Measurement	Total intensity*	Dud (intensity of the minimum)	Aktive bomb (one arm covered)
1			
2			
3			

Do your results match your expectations? What could be the reasons for deviations if they do not match?

*Here you enter the double measurement of the voltmeter in mV - with a misaligned setup. The voltages reflect the intensities measured by the photodetector.

QM Quantum eraser

Can I make the past invisible?



Please read before you start:

Please NEVER adjust the mirrors or turn the mirror adjustment screws!!!

The same applies to the laser itself. NEVER turn the laser in the anchorage or even remove it!!! The whole experiment is very difficult to adjust.

Once it is misaligned, it can take a really long time to get it working again! If the experiment does not work, please contact the laboratory management.

Take your time to understand the principle before you start the experiment.

Have fun experimenting!

Basics

We have already learned that light sometimes behaves like a wave and sometimes like a particle. This means that light has both wave and particle properties (this is called wave-particle dualism). If this is not yet clear to you, go to the **double-slit experiment** first.

If you send a laser beam onto a double slit, you can observe an interference pattern on the screen behind the slit. The photons therefore behave like a **wave**, i.e. they exhibit wave properties.

Even if we send the photons individually through the slit, we obtain this interference pattern.

We carry out the same experiment again, only this time we observe which path the photons take (does the photon go through the left or right slit?). Now our interference pattern disappears! Two lines appear on the screen, as you would expect with particles. The photons therefore behave like **particles**.

The path information we receive thus destroys our interference. The same phenomenon can also be observed with photons. We will deal with this in the first part of the experiment.

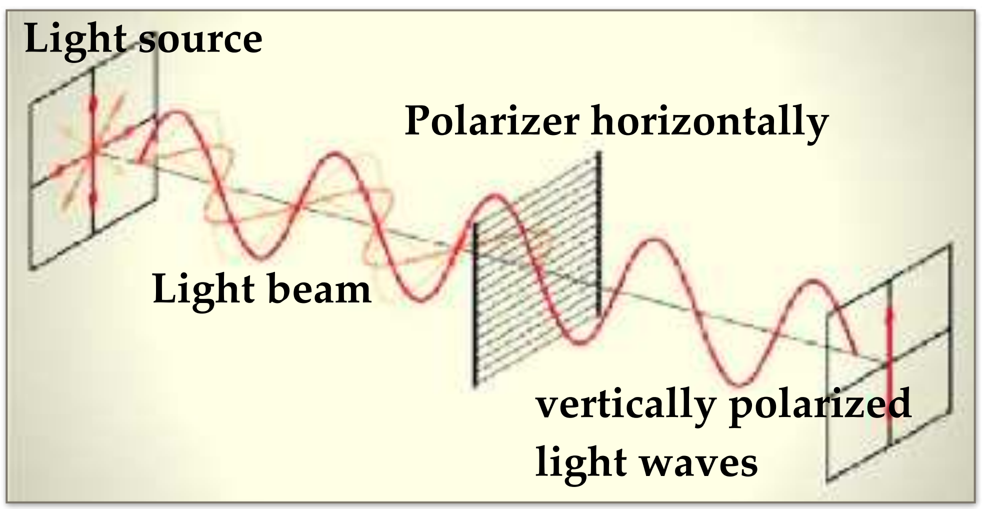
Of course, we cannot sit next to the **double slit** in the experiment and note which photon goes through which slit. We have to obtain the path information in another way.

In our experiment, we want to use polarization to distinguish which photon has taken which path.

To do this, we polarize the light in the different paths in different orientations.

Polarization of Light

Light can be polarized in different directions perpendicular to the direction of propagation. This means that the light wave oscillates in this direction. Our laser emits **unpolarized** light. The photons that leave our laser are therefore all oriented differently. If you hold a polarization filter in the beam path of the laser, it only allows waves of a certain **orientation** to pass through. We can imagine the polarization filter as a grating that only lets through waves that fit through the gaps in the grating.



In the illustration, unpolarized light hits a polarization filter. The light behind the polarizing filter is now linearly polarized.

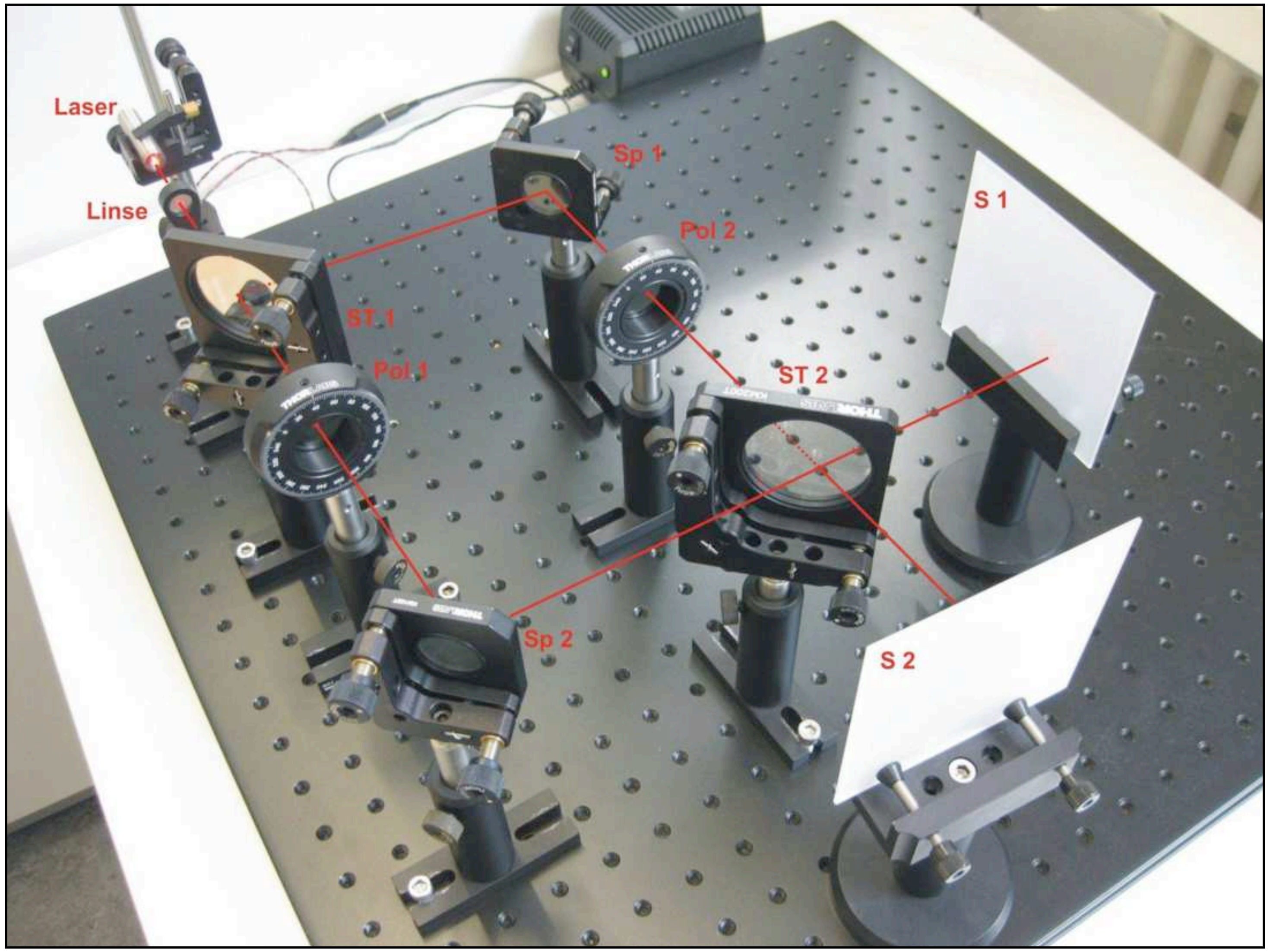
If two filters whose grids are perpendicular to each other are placed one behind the other, they **no** longer allow any light to pass through.

If our polarization filters are not perpendicular to each other, but at an angle of 45°, for example, they still allow some of the light waves to pass through (namely a quarter of the irradiated intensity). In the Photon Lab you will find polarization filters on which you can observe the phenomena just described. Try out different angles and observe how the proportion of light transmitted by the filters changes with the angle. The experimental set-up (next page) initially contains two polarization filters. A **third** filter is added in the second part of the experiment.

https://scoobe3d.com/3d-scan-technologie-neue-scoobe3d-technologie-im-vergleich/

The experimental setup

This experiment is an analogy experiment that is normally carried out with single photons; however, the result would be the same as with this setup. With a laser beam, this experiment can be explained classically, and with single photons you have to fall back on quantum mechanics.



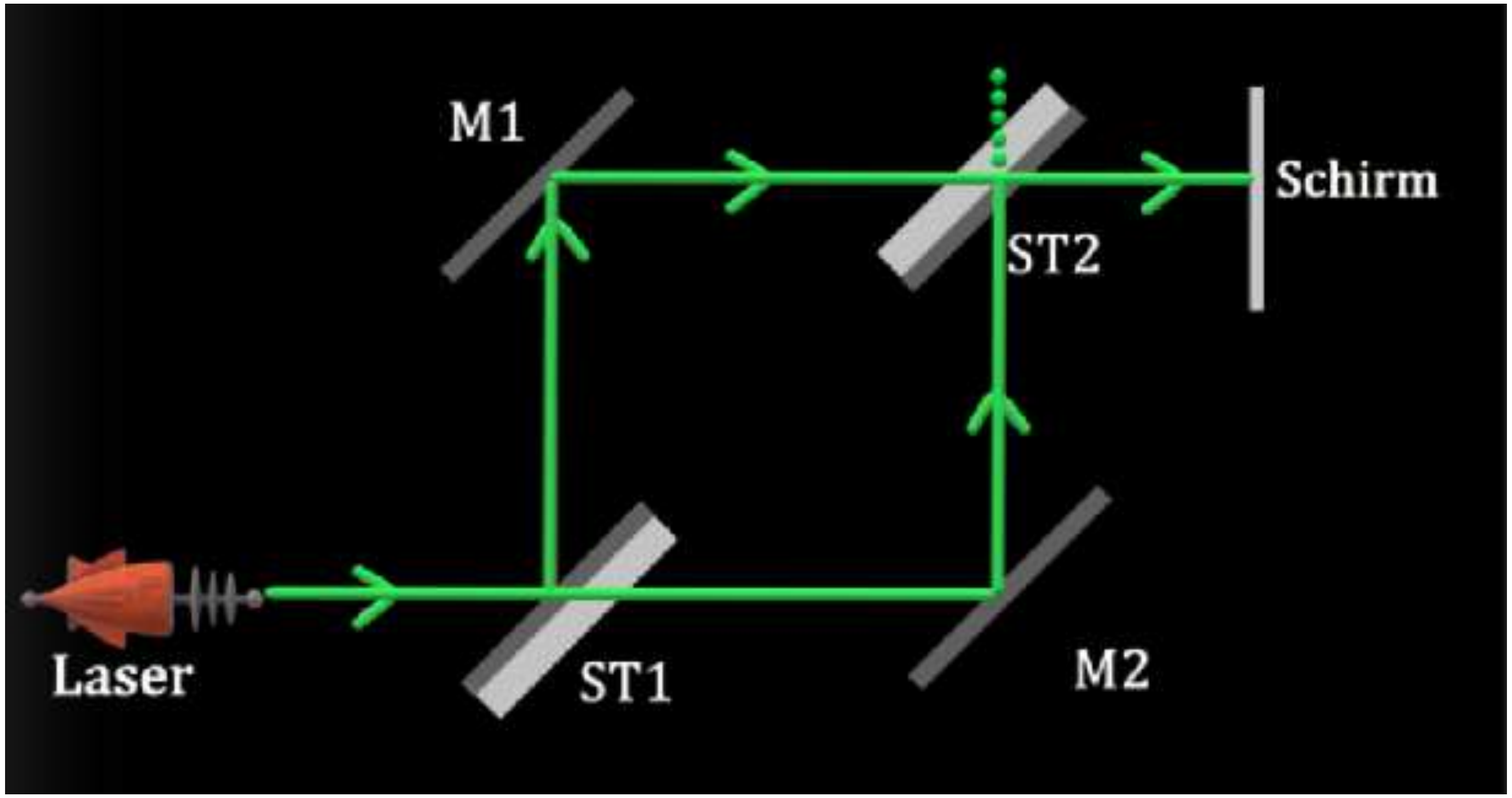
This experiment should already be arranged as shown in the picture. The setup contains

- a laser
- 2 mirrors (Sp)
- 2 beam splitters (ST)
- 2 polarization filters (Pol)
- 2 screens (S)

For the second part of the experiment we need a third polarization filter. (To get information about the beam splitters, click on the link above)

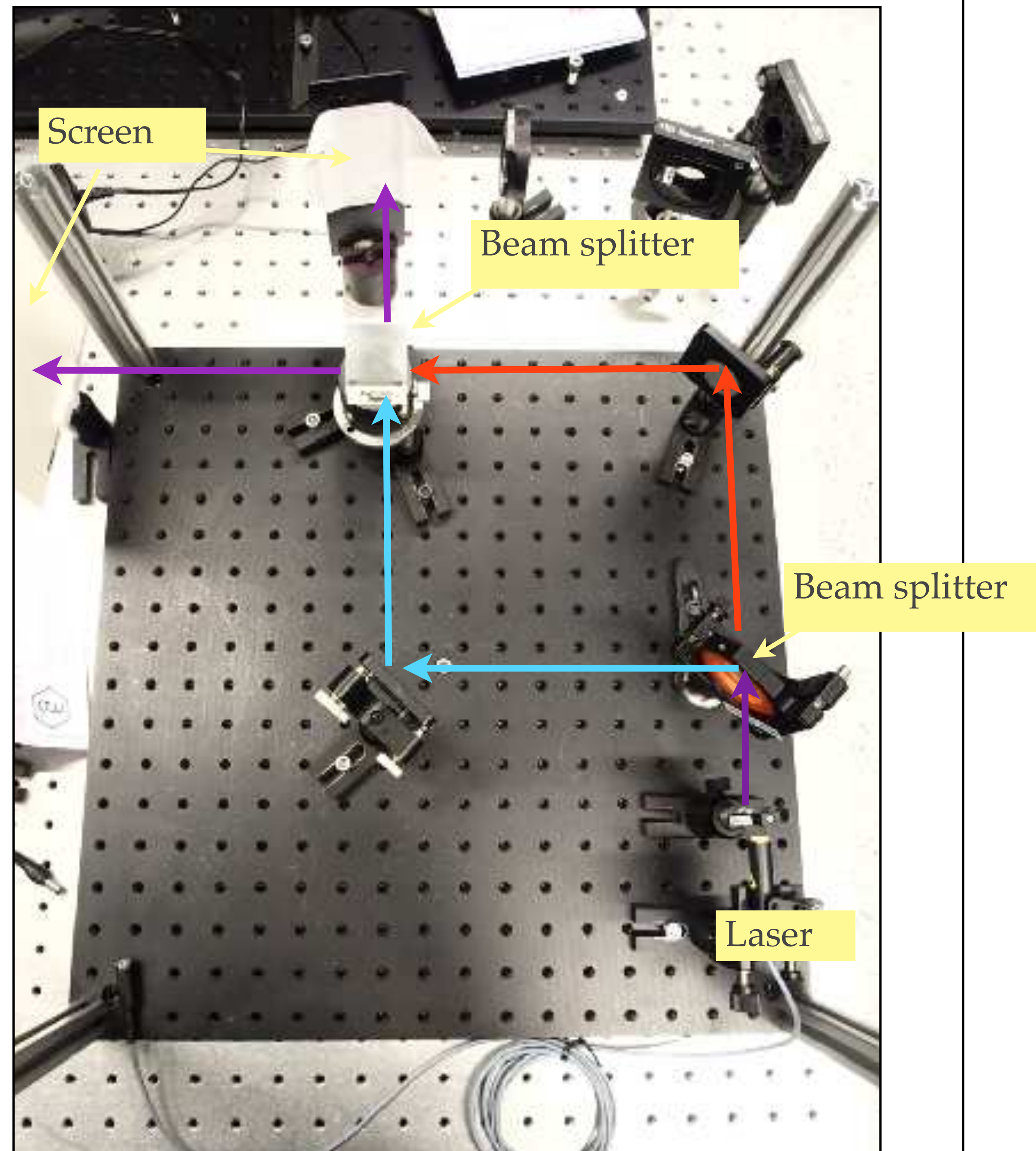
Setup

Here you can observe the beam path: At beam splitter 1, the light beam is split into two parts and then 50 % is transmitted and reflected again at a beam splitter. In the end, 50% of the initial intensity reaches the screen. You are already familiar with this setup from the Mach-Zehnder interferometer.



Subtest 1 (obtaining route information)

Here you can see the setup in the laboratory. In addition to the structure of the interferometer, polarizing filters are added here. The first beam splitter results in two possible paths (blue and red).



The two laser beams overlap as soon as they hit the second beam splitter. The superimposed beam is split by the second beam splitter. The resulting beams hit the 2 observation screens. By superimposing the beams, we obtain an interference pattern.

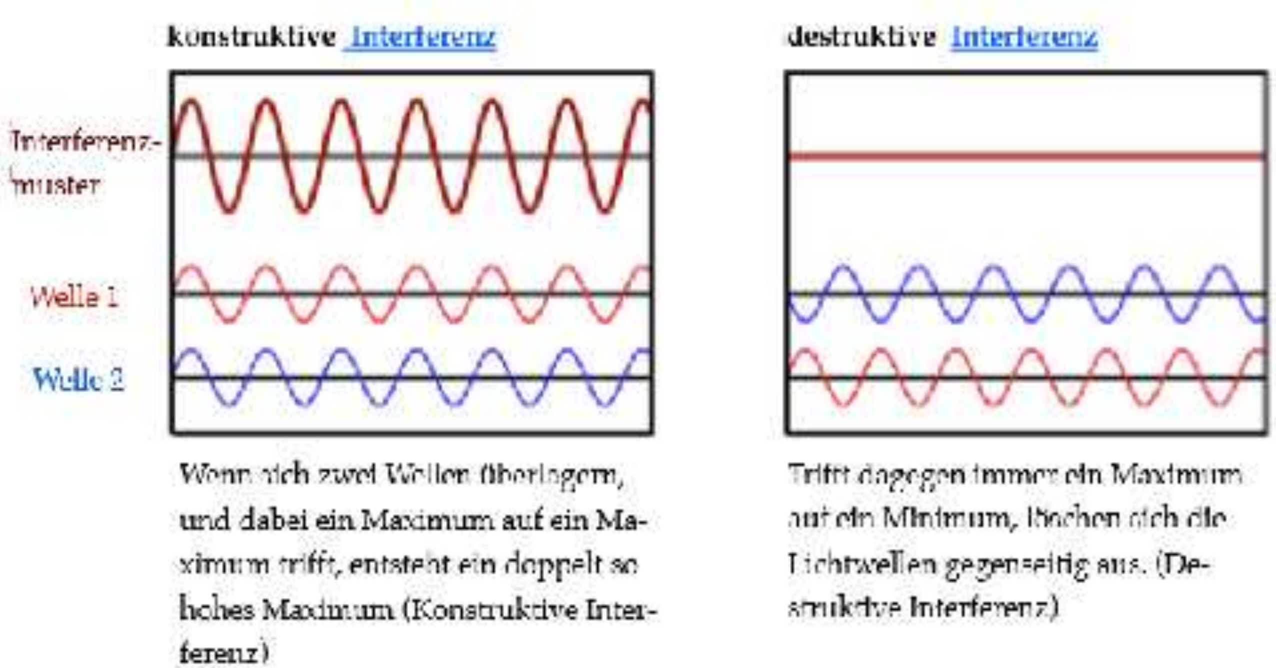


Image: Thorlabs

Subtest 1: Procedure

Put on laser safety goggles!

The experiment is already adjusted! You touch, you die! Please only touch the polarization filters!

First, the polarization filters are set to the same position (for example, both can be set to 0°).

Before you switch on the laser, think about what should now be visible on the two observation screens. You can see the polarization direction of the transmitted beam from the small sticker.

Now switch on the laser and make a note of your observation.

You should now be able to see an interference pattern on both screens (if not, please contact the lab manager).

To destroy the interference pattern, we need to make the paths distinguishable. For this we use the polarization filters:

For one of the polarization filters, the pass direction is now changed by 90°. Based on the polarization of the light, we can now see which photon has taken which path (**path information**). The paths can be distinguished by the different polarization.

Describe your observation.

Do you have problems with the adjustment? Then take a look at the glossary here!

Subtest 2: "Erasing" quanta

Now we come to the actual purpose of the experiment: erasing quanta. This means that we now want to erase the path information obtained. To do this, we need the third polarizer:

The initial situation is the final state from the first part of the experiment. The polarization filters are perpendicular to each other.

Now the third polarization filter is placed with an orientation of 45° between the beam splitter and one of the two screens.

What can be observed on the screens?

Explain your observations from the two partial experiments on the loss and acquisition of **path information** (see previous pages).

Subtest 2: Solution

You have observed on the screen that the interference pattern is now visible again, but still not on the other screen.

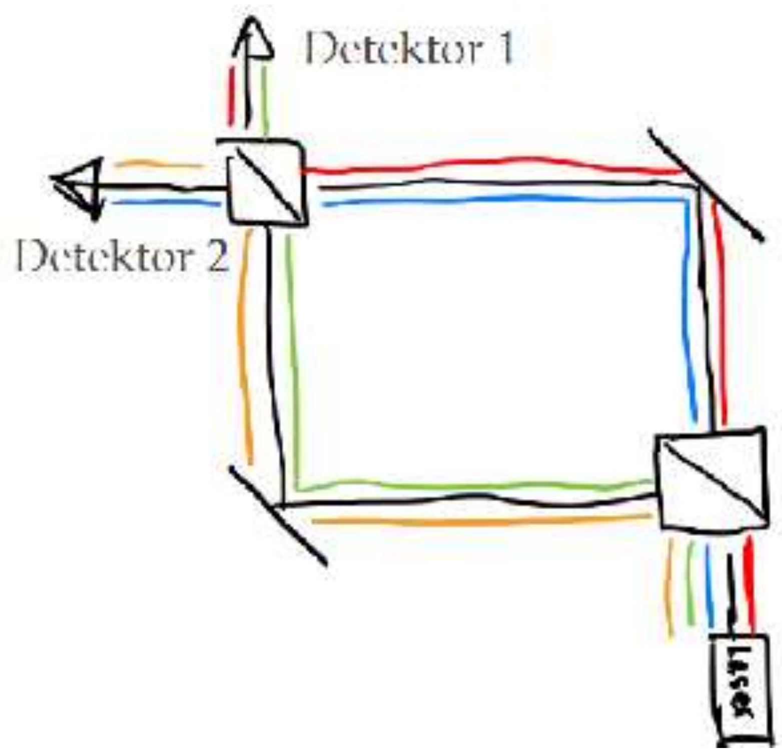
Explanation: By inserting the polarization filter below 45°, it is no longer possible to obtain "which-path information" about the photon. Now it again shows the superposition as one of its quantum properties.

Thought experiment: How does it work with single photons?

In the following, we will consider how the experiment with single photons works. It is important that we now only place single photon detectors exactly in the center of the previously observed interference pattern. So we count single photons!

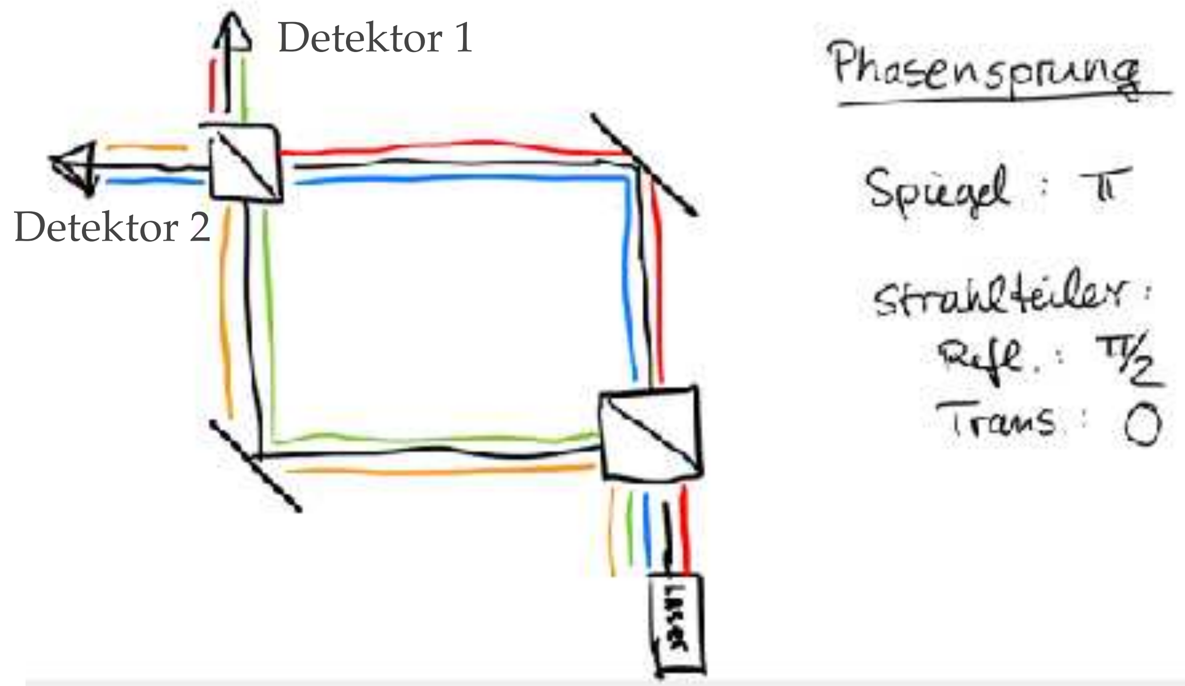
Now imagine that you send 100 photons into the apparatus, first to the first beam splitter, then to the mirrors and then to the second beam splitter. **Where do you expect how many photons?**

Think carefully about your answer!



Classically, we would expect an even distribution of 50:50, but we observe all photons at detector 1 and none at detector 2!

Why is that? In principle, the photons have four possible paths. If a photon has wave properties, we can explain this well:

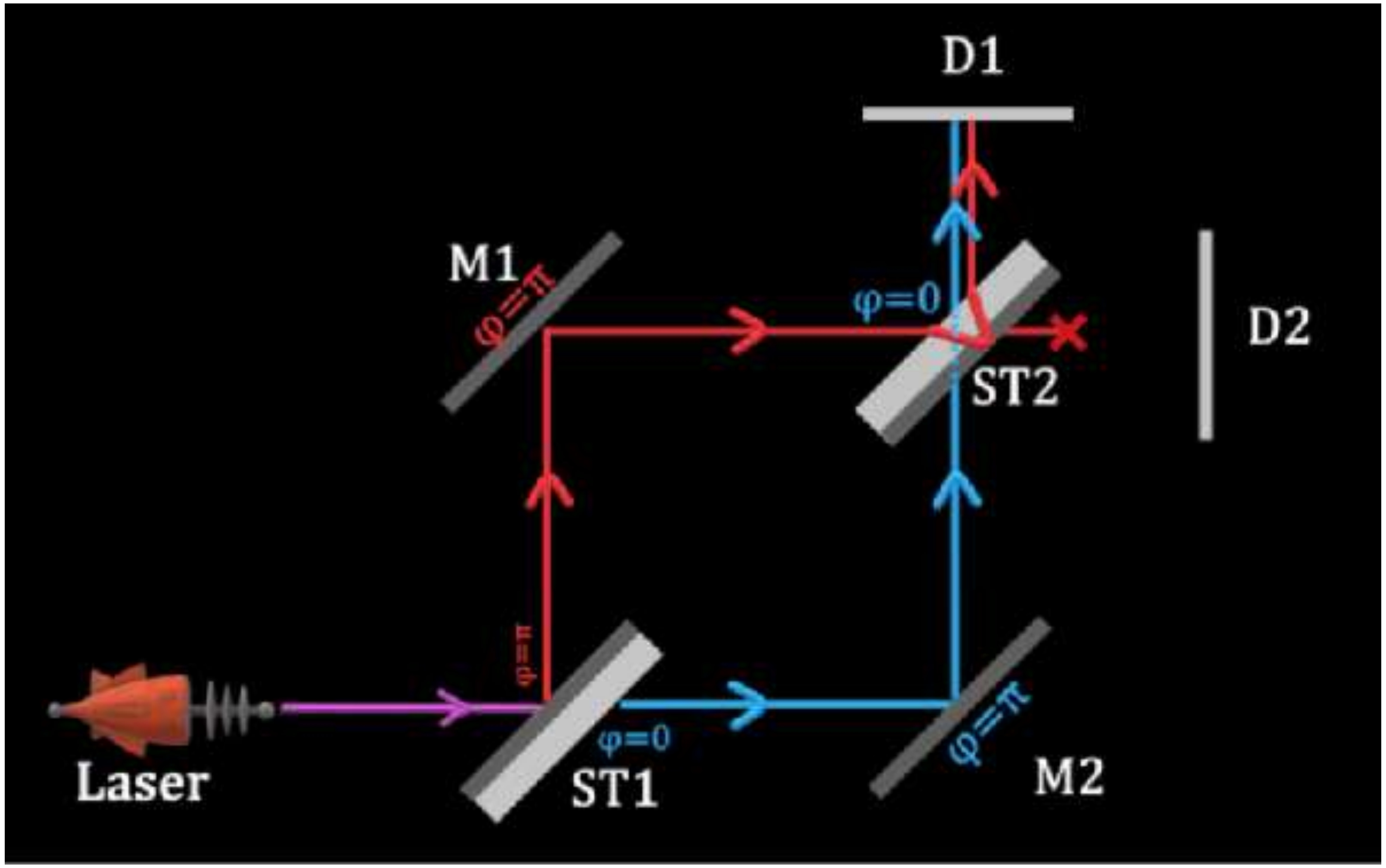


Take the laminated "quantum eraser" sheet and place the blue waves in the same position on the far right in the yellow and blue or red and green areas. Now follow the path for the waves in your mind as follows (here we are doing this for red as an example): At the 1st beam splitter, the red path is transmitted (phase jump 0), then reflected at the mirror (phase jump π) and then reflected at the beam splitter ($\pi/2$). In total, we therefore have a phase jump of $0+\pi+\pi/2=3\pi/2$. So you move the blue wave on the paper to the left by three dashed waves and leave it there. Now do the same for blue, yellow and green! At the end, compare how yellow and blue or red and green relate to each other: Do we have destructive or constructive interference here?

Solution: In the case of yellow/blue, we have destructive interference. Therefore, we do not see an interference pattern at detector 1. Since we have constructive interference at red/green, we see an interference pattern there.

Here you can see this again in the illustration from our interactive book https://photonlab.h5p.com/content/1291414188940105797

You can already guess from our simple experiment that individual photons have wave properties.



The quantum eraser with single photons

You have already carried out the classic experiment under 2.1. But this also works with single photons!

Here, too, **the interference pattern is now destroyed with the 0° and 90° filters**! You can see this in a real single photon experiment from the count rates (Counting rate high: constructive interference, count rate 0: destructive interference, count rate in between: no interference).

Why do I have no interference? The path that the photon has taken is now marked: "A measurement is being carried out". The superposition is therefore destroyed. The polarization of the photon allows you to deduce which path the photon has taken and the wave function collapses. The photon now behaves like a particle.

If the 3rd filter is positioned at 45° in front of one of the detectors, the interference pattern is restored. How can this be?

The 3rd polarizing filter erases the which-path information! You now have a quantum particle again that shows interference. You can see this again in the count rates.

"Den Weg" löschen und damit auch die Vergangenheit?

QM Quantum cryptography

How can I securely encrypt messages?

The NSA affair in particular made it clear how important the secure and secret transmission of information is for us. Banks, governments and especially the military rely on secure ways of transmitting information. Cryptography (encryption) is therefore an important topic in today's world.

Modern BND wiretapping facilities

The art of encryption consists of encoding messages in such a way that they can only be read if a key is known. The most modern method of encrypting data is to use quantum mechanical laws to transmit messages securely. You can learn about the principle of this method here!

You can also make a preliminary test with the QeyGen at the beginning.

https://www.spiegel.de/netzwelt/netzpolitik/bad-aibling-bundesnachrichtendienst-enttarnt-eigene-abhoerstation-a-973134.html

Please read before you start:

Please NEVER adjust the setup!!! You may only turn on the laser, go into the adjustment/measurement mode and turn the polarizers and rotators. DO NOT TOUCH the rest!

The same applies to the laser itself. NEVER turn the laser in the anchorage or even remove it!!! The whole experiment is **very difficult** to adjust.

Once it is misaligned, it can take a really long time to get it working again! If the experiment does not work, please contact the laboratory management.

Take your time to understand the principle before you start the experiment.

Have fun experimenting!

Basics of quantum mechanics

Quantum objects are generally objects that are very small and very light, such as electrons or photons. The behavior of these objects can no longer be explained by classical physics; in most cases it even contradicts it. It is not possible to determine the exact location of an object at a specific point in time, but it is possible to make a statement about the probability of the location of many particles.

How can this be used for cryptography?

It is particularly important for the properties that they cannot be "copied" (no-cloning theorem).

For our experiment, this means that an eavesdropper cannot listen to the message and then copy it without changing it.

Basics of information transfer

Nowadays, information is transmitted via binary codes (consisting only of 0 and 1).

For example, the letter F in binary notation means 00101. The enemy could intercept, read and understand such a binary code and then send it on.

A key must therefore be defined in advance to make the message unreadable for the enemy.

Only the **sender unit** (from now on always called Alice) and the **receiver unit** (Bob) know the key, but not the **eavesdropping unit** (Eve).

The key is also a sequence of zeros and ones. Message and key are added together in binary form to "hide" the message.

Binary edition: 0+0=0 1+1=0 1+0=1 0+1=1 Green is finally sent.

You can find an example of this on the next page.

Here is an example:

The letter F, i.e. 00101, is to be sent.

Alice and Bob meet and secretly exchange a previously randomly generated key.

This should be 10110. The key must be the same length as the message sent (!!!).

Alice therefore encrypts and sends: 0+1=1 0+0=0 1+1=0 0+1=1 1+0=1

Only green is sent: 10011 is definitely not equal to 00101, i.e. not equal to F. Not readable without knowledge of the key!

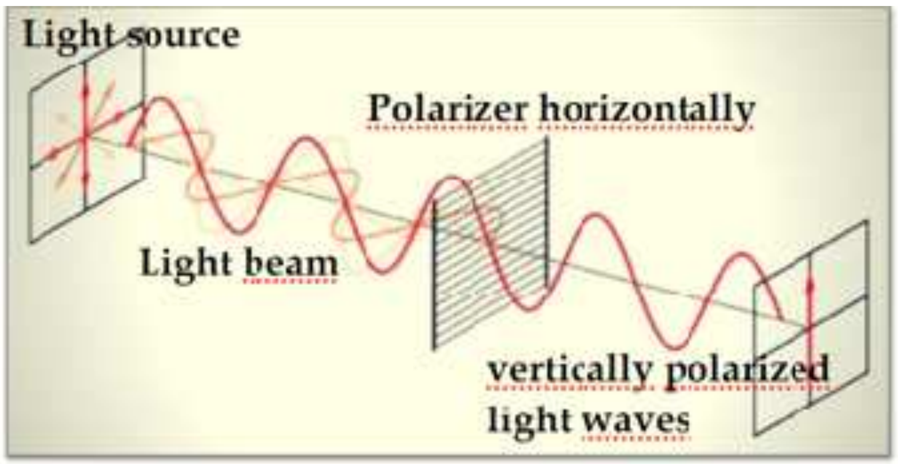
Bob knows the key and decodes by binary addition:

1+1=0 0+0=0 0+1=1 1+1=0 1+0=1 Bob receives 00101, i.e. F.

This principle of the key is called "one-time pad".

The following must apply: The key is only used once, it is as long as the actual message, the key is absolutely random and it is only known to Alice and Bob.

Polarization of light



In the illustration, unpolarized light hits a polarization filter. The light behind the polarizing filter is now linearly polarized.

If two filters whose grids are perpendicular to each other are placed one behind the other, they no longer allow any light to pass through.

If our polarization filters are not perpendicular to each other, but at an angle of 45°, for example, they still allow some of the light waves to pass through (namely a quarter of the irradiated intensity). In the Photon Lab you will find polarization filters on which you can observe the phenomena just described. Try out different angles and observe how the proportion of light that the filters let through changes with the angle. In our experiment, we transmit the information (0 or 1) via polarized laser light. Normally, lasers emit unpolarized light. This means that light of any orientation is emitted by the laser. Our laser in the experimental setup emits (almost completely) linearly polarized light. The light therefore only leaves the laser in one orientation and can now be rotated by any angle by so-called polarization rotators (see experimental setup).

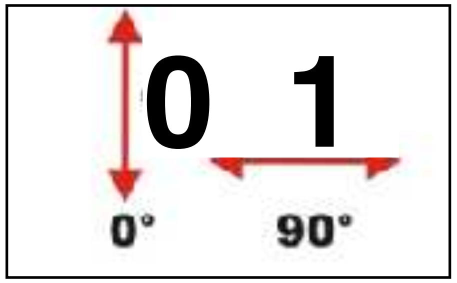
In our experiment, we use -45°, 0° (horizontal), 45° and 90° (vertical) polarized light.

https://scoobe3d.com/3d-scan-technologie-neue-scoobe3d-technologie-im-vergleich/

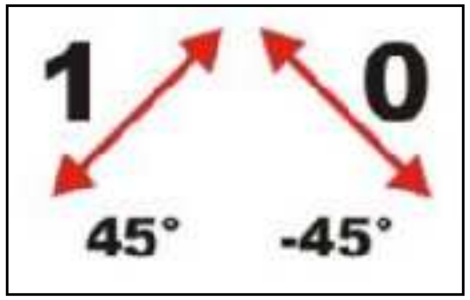
Key and code in the experiment

Two different bases + and x are available for information transmission. Within each base there is a polarization angle for 1 and a polarization angle for 0.

Base + Base x



0° polarization is bit: 0



45° polarization is bit: 1

90° polarization is bit: 1 -45° polariz. is bit:0

So if Alice (the sender) wants to send a bit (e.g. 1), she first selects a base (e.g. x).

If you want to send 1 in base x, you send light that is polarized at 45°. If Bob now knows that Alice is sending in base x, he can receive the 1 without any problems. If he has the wrong base, he cannot do anything with the information, just as before with the binary addition.

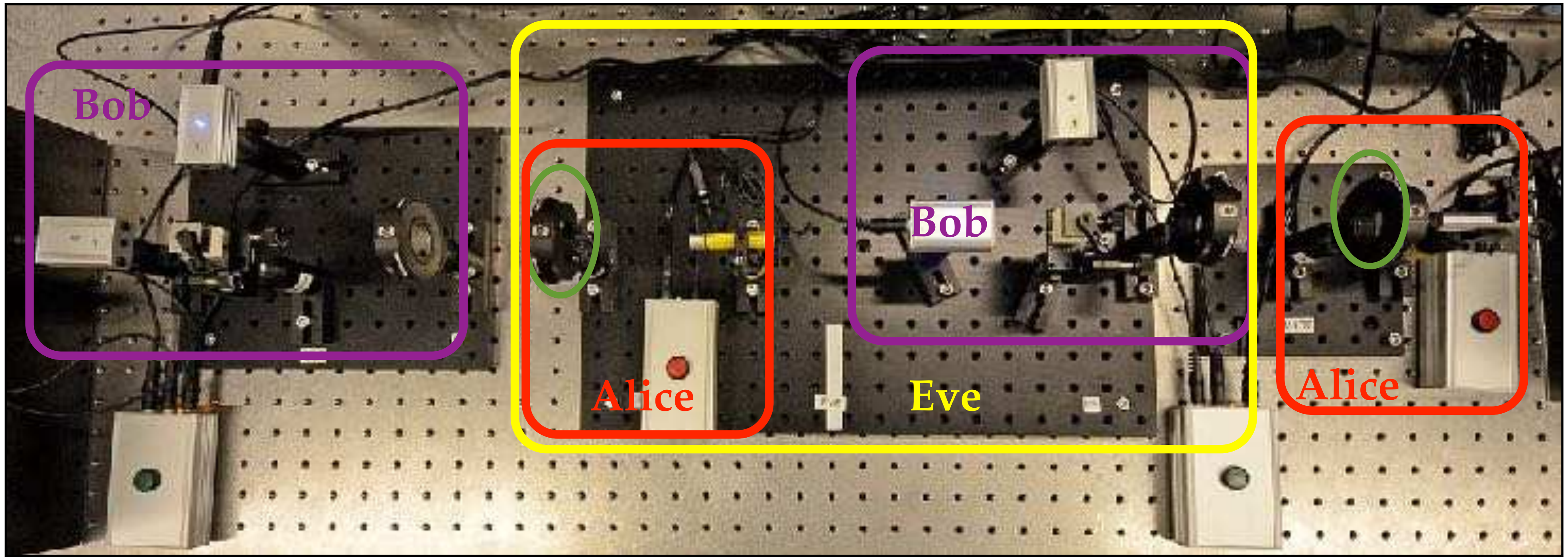
Although the bases encrypt the message, they are not sufficient. A person who knows the binary code could easily intercept the message. This is why you need to create a key from 0 and 1, which is only known to the sender and receiver and is therefore secure.

You can better understand the principle of the bases here using the QeyGen.

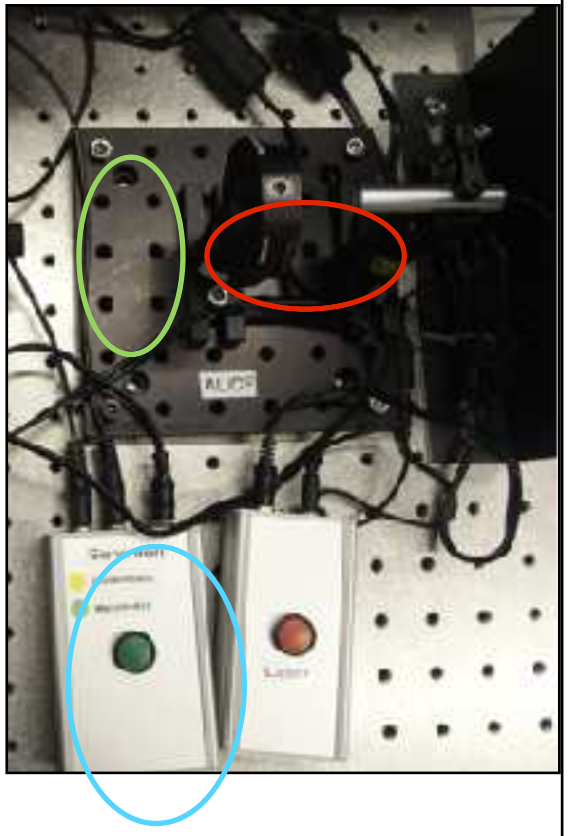
Image: Thorlabs

Experimental setup

The experimental setup consists of two identical halves:



On the left is the receiver unit Bob, on the right is Alice and in the middle is Eve, which actually consists of 1x Alice and 1x Bob.



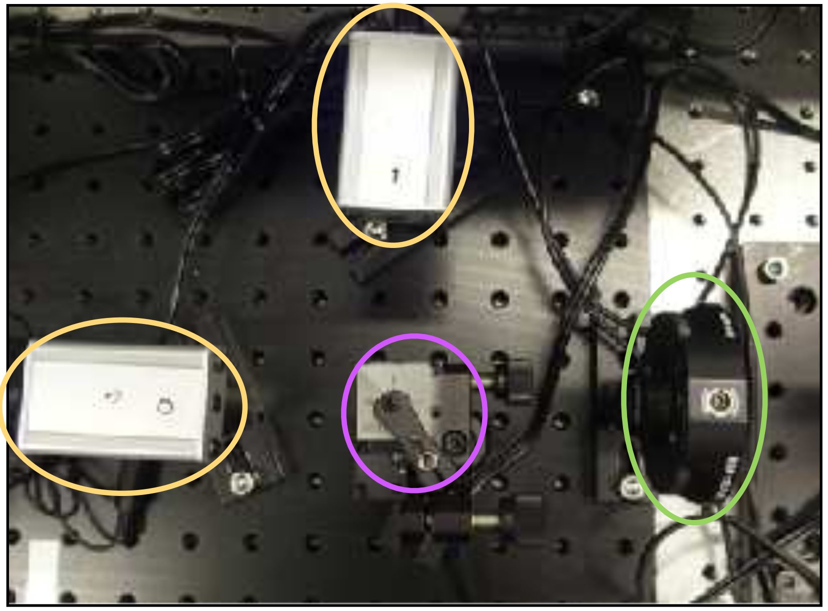
Alice consists of:

- a laser

- the corresponding fire button (short press to transmit a bit (0 or 1), long press: laser permanently on for adjustment)

- a polarization rotator (with the settings -45°, 0°, 45° and 90°)

The polarization rotator rotates the polarization of the light by the desired angle. This determines which bit (0 or 1) is sent in which base.



Bob consists of:
- a polarization rotator (with 0° and 45° settings)
- a polarizing beam splitter
- two detectors

The beam splitter transmits 0° polarized light to the 0 detector and reflects 90° polarized light to the 1 detector (+direction). Light that is polarized at 45° or -45° (x-direction) is transmitted at 50% and reflected at 50% in **adjustment mode**, i.e. **both detectors light up**. In **measurement mode**, one of the two detectors lights up **randomly** (50:50), thus electronically simulating the measurement with individual photons. The beam splitter can therefore only reliably sort +, x gives a random result.

So if both detectors light up, our result is not clear.

For example, if Bob wants to receive x in the base, his rotator is set to 45°. There is now a clear result if Alice sends 45° or -45°. As Bob's rotator now rotates another 45° and thus generates a total of 0° or 90° polarized light (45°+45°=90° or -45°+45°=0°), only one sensor responds at a time.

Data transmission is therefore only possible with the same base.

BASE	+	+	X	X
Bit	0	1	1	0
Angle on the rotor	0°	90°	45°	-45°

If you want to send a bit, move the turner to the desired polarization and then press the fire button. Alice then sends the bit to Bob.

The following options are available:

ANGLE WITH ALICE	0°	0°	90°	90°	-45°	-45°	45°	45°
Sent bit with Alice	0	0	1	1	0	0	1	1
Basis with Alice	+	+	+	+	x	x	x	x
Angle with Bob	0°	45°	0°	45°	0°	45°	0°	45°
Basis with Bob	+	x	+	x	+	x	+	x
Result at the sensor	0	None	1	None	None	0	None	1

Note: Before you start the experiment, try out all possibilities on both halves of the setup. In adjustment mode, both detectors light up if you do not get a clear result (in the table "no result on sensor").

If you do not always get the right result, contact the laboratory management.

Generation of the key

Alice and Bob now want to generate a key for the message - initially without Eve (select one half of the test setup). If you haven't already done so, switch from adjustment mode to measurement mode.

1. Alice randomly selects a base and a bit, sends it to Bob and notes the bit and base.

2. Bob chooses a base at random beforehand. In **measurement mode**, Bob always receives a **clear** result. However, he does not know whether the result was measured in the correct **base**. Bob has a 50% probability of choosing the correct base (0° or 45°).

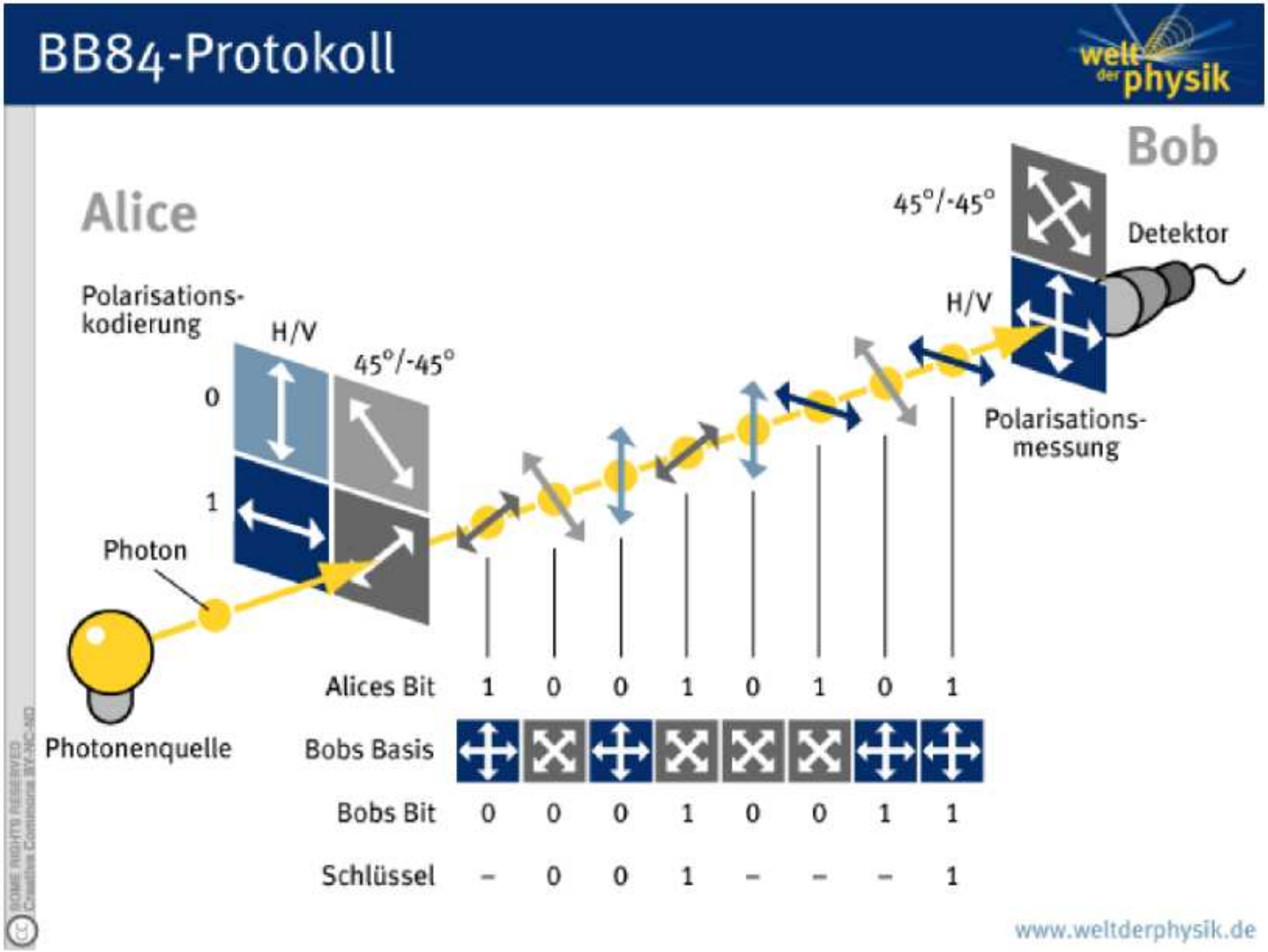
So if you want a 10-bit long key, you have to carry out the process approx. 20 times.

3. Bob makes a note of the results.

Then both compare publicly, e.g. via a telephone line.

Bob tells Alice which bases he has chosen, but not which bit he has received. Alice then tells him which bases he got **right**. So only the **bases** are made public, but not the bits that Bob received! The wrong bases are **crossed out**, the sequence of **bits** that were transmitted through the correct bases is the key that is then applied to the message according to the **binary addition** (see section 2).

The diagram illustrates the same principle once again.



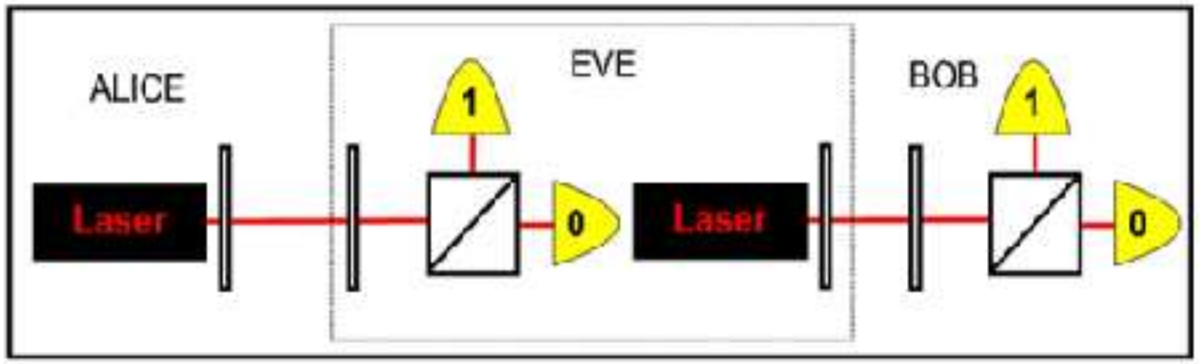
https://epb.bibl.th-koeln.de/frontdoor/deliver/index/docId/1002/file/Daten+Teleportation+mit+Hilfe+der+Quantenphysik+%e2%80%93+Patrick_Plamper.pdf

Now Alice can encrypt the message as in section 2 and send it publicly. Bob receives the encrypted message and can understand it using the key.

Caution! There is a significant difference between this experiment in adjustment mode and real quantum cryptography! In reality, a **single photon source** would be used. This means that the photon of an incorrect base would still be assigned to a "unique" sensor in the beam splitter (50% 1 and 50% 0). This is simulated in **measurement mode**. In **adjustment mode**, you can tell that the two bases do not match simply by the flashing of both sensors.

Discover the eavesdropper Eve

As before, a key is generated.



1. Alice randomly selects a base and a bit; Bob randomly selects the receive base.

2. Eve also chooses a receive base at random (as with Bob, only 0° or 45° is possible on Eve's right-hand dial, as it is used for receiving).

3. Eve now receives a 0 or 1, but she does not know whether she has received in the correct base. Due to the "no-cloning theorem", she cannot send the same photon on to Bob.

Eve always transmits in the same base in which she receives. If Eve is in the same base as Alice, she can forward the bit correctly. If not, she sends the randomly received bit to Bob in the wrong base.

If Bob and Alice now compare their bases, they must also compare some bits in order to detect Eve. If there are differences (e.g. Alice sends 1 in x, Bob receives in x but gets 0), then there is an eavesdropper on the line! Only the bits for which Bob and Alice have the same base are compared.

Procedure

Carry out the experiment as a role play. To do this, set the detector to **measurement mode**.

Assign the roles of Alice, Bob and Eve.

Do not talk to each other during the experiment, except during the "**public phone calls**", and do **not** look at each other's notes!

Then transfer three letters (e.g. LMU or MAP or FCB) with the help of the instructions and the laminated tables. **Discover** Eve in the process!

Of course, there is no "solution", as some steps are based on chance. If you get stuck, here is a short step-by-step guide.

QM Quantum random generator

How can I generate random numbers? - No, Google Random Number is not meant.

https://www.golem.de/sonstiges/zustimmung/auswahl.html?from=https%3A%2F%2Fwww.golem.de%2Fnews%2Fsichere-kommunikation-sk-telecom-stellt-chip-fuer-quantenverschluesselung-vor-1703-126468.html&referer=https%3A%2F%2Fwww.google.com%2F

Encryption using random numbers

FACEBOOK UND WHATSAPP

Die geheime Macht der Metadaten

Sichere Kommunikation ist nur eine Seite der Medaille. Was Facebook und Whatsapp trotzdem über uns wissen.

Michael Spehr

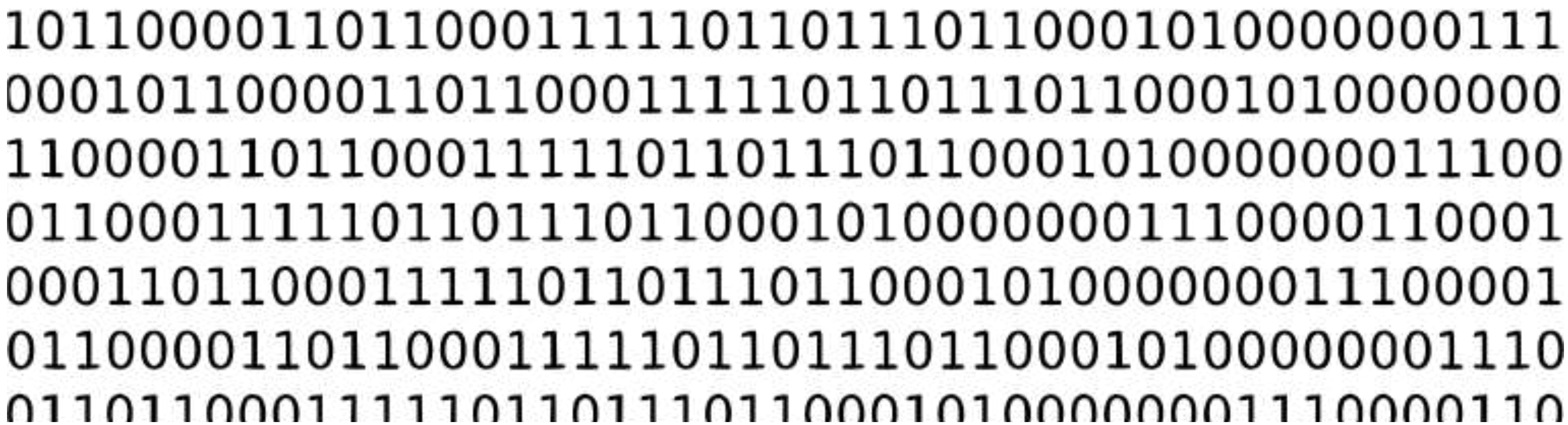
11.05.2020, 16:00 Uhr

Die Verschlüsselung von Informationen, ist von großer Bedeutung in der heutigen Kommunikationstechnologie, da sie einen sicheren Austausch von Daten ermöglicht. Die dabei verwendeten **Zufallszahlen** müssen hohen Anforderungen genügen. Sie müssen optimalerweise „echt" zufällig sein. (Chen et al. 2011).

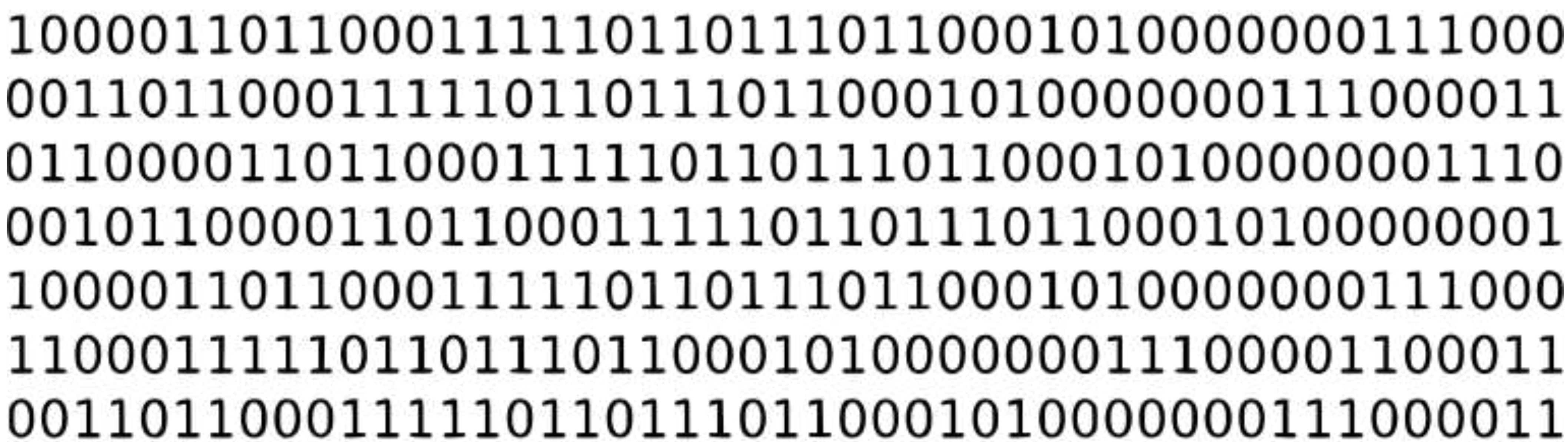
13. November 2013, 11:35 Uhr Verschlüsselung bei Smartphones

Sicher telefonieren mit dem Krypto-Handy

https://www.faz.net/aktuell/technik-motor/digital/facebook-und-whatsapp-die-geheime-macht-der-metadaten-16762262.html
https://www.sueddeutsche.de/digital/verschluesselung-bei-smartphones-sicher-telefonieren-mit-dem-krypto-handy-1.1817398
http://www.fim.uni-linz.ac.at/lva/Web_Security/Abgaben/Schuerz-RNG.pdf



Unser Ziel: Gute Zufallszahlen selber erzeugen!



Ist ein Würfelexperiment zufällig?

This is a box with exactly 100 dice. These cubes are special because they have 6 sides, but only 0 or 1 can be used as a solution.

Now shake the box so that you get a random sequence of 0s and 1s, a so-called binary number chain.

How random are the zeros and ones really?

Chain length test: How random is the diced binary number chain?

A chain length is a block consisting of digits of the same type. It can also consist of just a single digit.

Example:

001010010001010101000101010001010100101010101110

Divided into chain lengths:

0-1-0-1-00-1-000-1-0-1-0-1-0-1-000-1-0-1-0-1-000-1-0-1-0-1-00-1-0-1-0-1-0-1-0-11-0

The characteristic that can be used here to distinguish **random** from **non-random** is the length of the longest chain length.

With 100 dice, the probability is very high, approx. 95%, that at least 4 zeros or 4 ones occur in succession, i.e. a chain of length 4 occurs. (see glossary)

Chain length test: How random is the diced binary number chain?

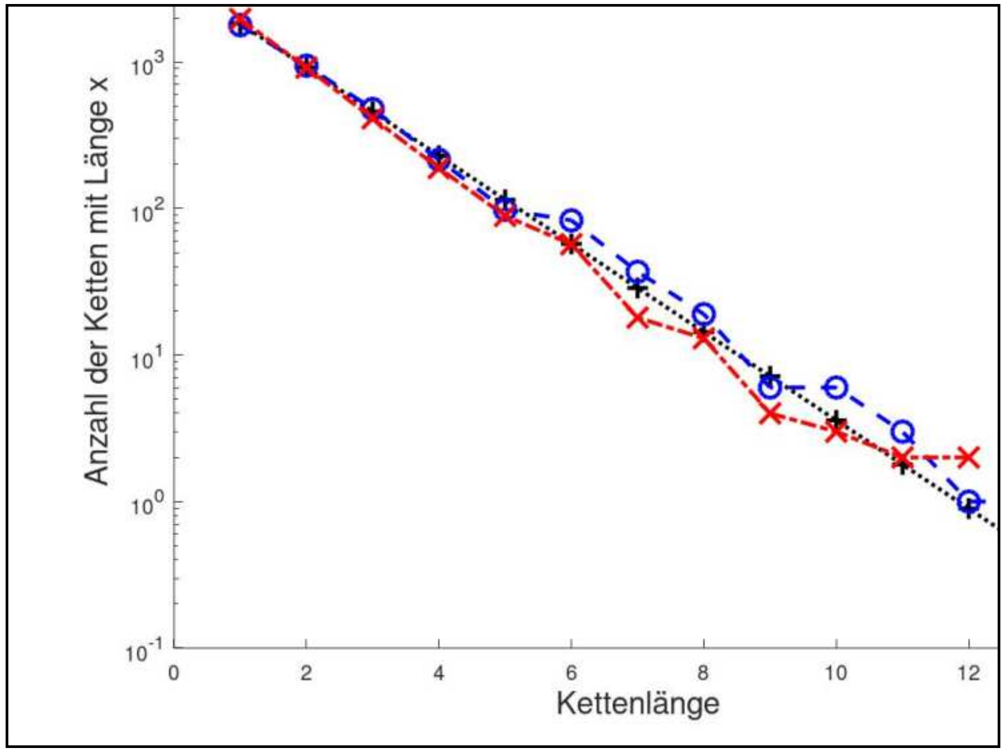
- The length of the number chain with the same number sequence is a very good distinguishing feature, because true randomness is very likely to produce relatively long chains even with short sequences.
- The chains of poorly generated random sequences are often not so long because an attempt is made to ensure an even distribution of 0 and 1. However, this means, for example, that there are less often four consecutive identical numbers, which increases the number of "short" chains. **The number of available chain lengths can therefore be used to make statements about the randomness of random number sequences.**

We have established that if we have many "short" chains, it can be assumed that the randomness is rather low.

Chain length test: How random is the diced binary number chain?

Here is the graphical representation of 10,000 random numbers that are analyzed for chain lengths.

On the x-axis you can read the possible chain lengths (here up to a maximum of 12) and on the y-axis you can read the frequency of the existing chains.



In the figure on the right you can see that, for example, the frequency of a chain of length 6 occurs approx. 80 times (based on the red measured values, i.e. the 1 chains) and approx. 90 times for the 0 chains (blue graph).

The chain can either look like 111111 or like 000000. It doesn't matter whether there are zeros or ones, the important thing is the repetition of the same number (0/1) one after the other. So for 10,000 random binary numbers, chains of length 6 occur approx. 170 times. Many "long chains" are therefore by no means improbable.

Would you do the same?

Dice: Coincidence?

You can generate random numbers with the dice - but what if we were rolling the dice and we knew the exact parameters such as air resistance, mass of the dice, drop height and angle of inclination etc. when rolling the dice?

Are the numbers that are rolled still random?

Although it is impossible to know all the parameters at the same time, we are not talking about randomness in the case of so-called physically generated random numbers, because the laws of classical physics can be clearly determined in essence (Anton Zeilinger).

Another well-known alternative is computer-generated random numbers. Whether these are suitable for "good random numbers" will be shown in the following slides.

Computer-generated random

Computer-generated random numbers are possible, but they are usually called **pseudo-random numbers**.

These pseudo-random numbers are realized using complex mathematical models.

(Example: Von Neumann method)

Computer-generated random numbers are usually mathematical formulas (see glossary for von Neumann method) based on a specific algorithm. If the starting value is known, the entire random number series generated can be traced so that each individual number no longer appears random.

Although it is difficult to arrive at the exact starting value, it is possible, which is why we cannot speak of "real" random numbers here either (= pseudo-random numbers).

Random number generation: Overview

Here is a brief overview of the previous topics Generate random number

Physical random number

Pseudo-random number algorithmic random numbers

(no real randomness)

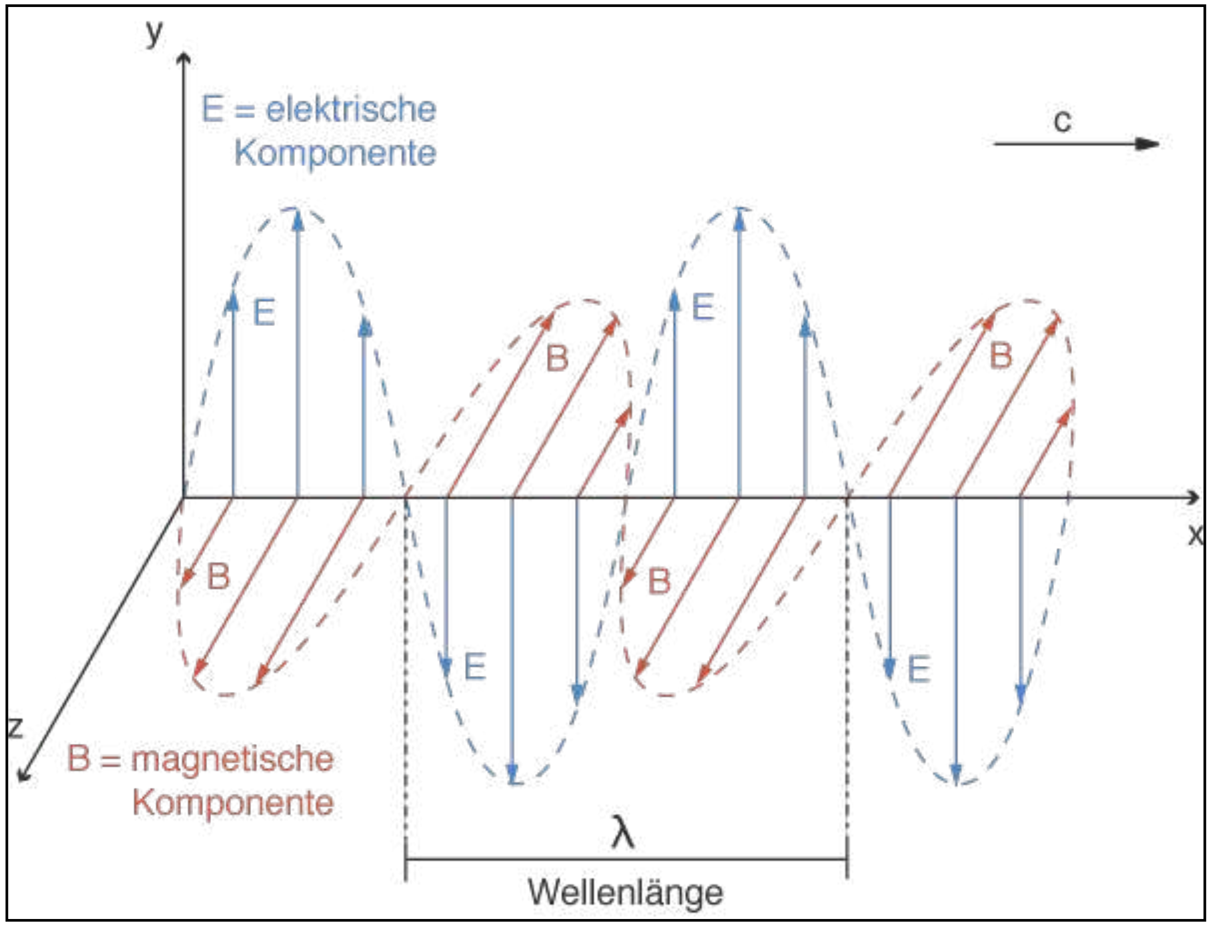
Random number according to classical physics

(no real randomness)

only apparently random due to the difficulty of determining the parameters

Quantum physical random number (special rules apply in quantum physics)

Fundamentals of optics: electromagnetic wave



Light is an **electromagnetic wave**, i.e. it consists of electric and magnetic fields that oscillate perpendicular to the direction of propagation (= transverse wave).

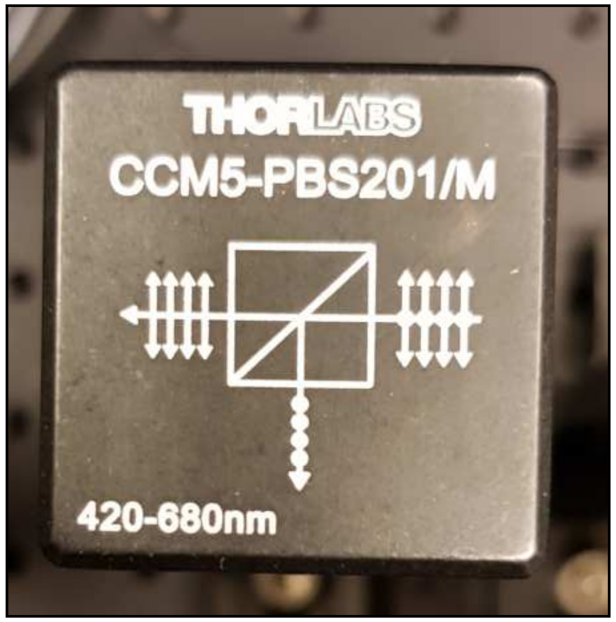
http://www.chemgapedia.de/vsengine/vlu/vsc/de/ph/14/ep/einfuehrung/emwellen/ausbreitung.vlu.html

Basics: Optics

Polarization:

A light wave oscillates perpendicular to its direction of propagation. If the electric field only oscillates in one plane, the light wave is linearly polarized.

Polarizers are filters that only allow light of a certain direction of oscillation, i.e. polarization, to pass through. In our case, the light is always linearly polarized in the same direction after it has passed through the polarized beam splitter cube. Here the light is polarized horizontally or vertically.



This is the beam splitter from the experiment:

Photons that are reflected (see arrow with the **dots**) are polarized perpendicular to the plane of the table and photons that are transmitted (see arrow with the long **parallel double arrows**) are polarized horizontally to the plane of the table.

https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=6056

Basics: Light has wave and particle properties

It is important to understand that light propagates like a wave, but also consists of individual photons (wave-particle duality). The wave property of light can be seen, for example, in interference. Interference means that when two waves are superimposed, they either strengthen (=constructive interference) or weaken (=destructive interference).

However, light also has particle properties. It can be described by individual energy packets, so-called photons (see, for example, the **Taylor experiment = double-slit experiment with single photons**)

What are quanta?

Quantum objects (e.g. photons, electrons) are neither small spheres nor waves or clouds. They are nothing like what we know from our everyday experience. There is no classical picture that can be used to describe or explain all the properties of quantum objects. (Copenhagen interpretation)

Quantum particles propagate like waves - interact with matter like a particle. Even if photons cannot be split, they appear to interact (interfere) with themselves.

The smallest quantum of energy has the size that can be calculated by multiplying Planck's effective quantum "h" by the frequency. E=h∗f

Planck's quantum of action 6.626 ∗10^(-34) Js is a natural constant, such as the speed of light 299,792,458 m/s (for glossary)

Basics: Light has wave and particle properties

Photons

-are quantum objects.

-are elementary particles, they are indivisible.

-carry electromagnetic energy and momentum

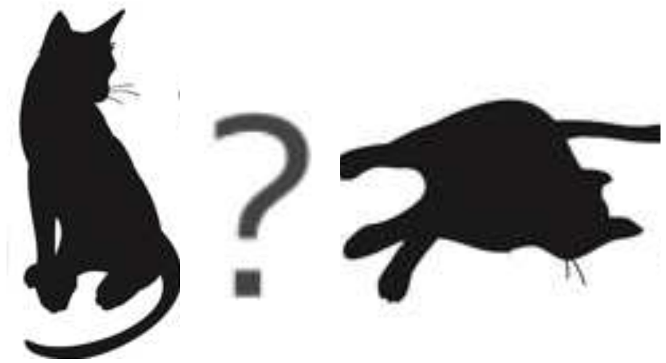
-can be polarized.

For quantum objects (photons), only probability statements can be made about their states.

- Wave-particle dualism describes light from today's perspective.
- It is important that both characteristics "light as a wave" and "light as a particle" are equally important. (Wave-particle dualism)

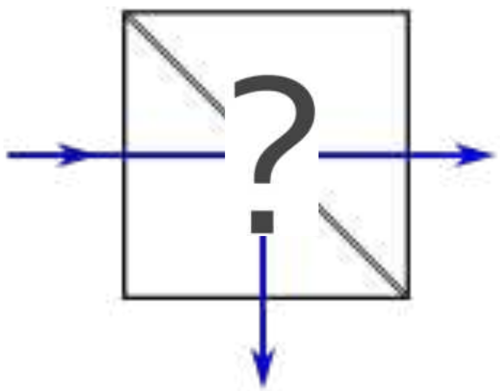
Basics of quantum physics

The fascinating thing about quantum objects is that you can use probabilities to make good predictions for a large number of photons, but never for a **single** one. Quantum physics succeeds in finding a description for the sometimes contradictory behavior of quantum objects using stochastic methods.



Individual quantum objects are in superimposed states, also known as **superposition**. The best-known example is Schrödinger's cat, in which the cat can be alive and dead at the same time.

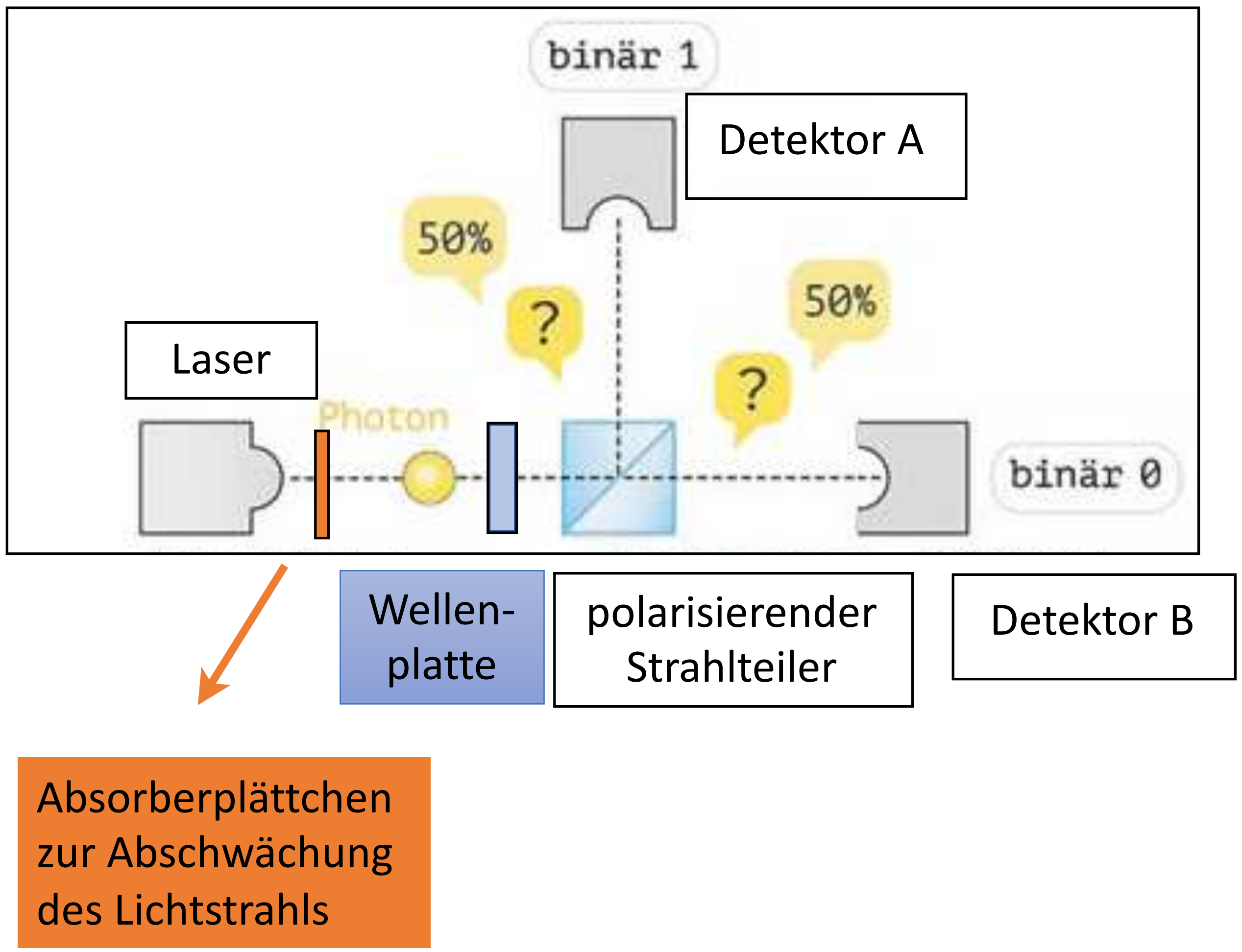
Whether a single photon decides to be reflected or transmitted at a beam splitter remains random. In the beam splitter cube, the photon is in superimposed states (reflection/transmission), just like Schrödinger's cat.



For a **large** number of photons, however, one can (on average) make probability statements of 50% for reflection and 50% for transmission.

https://www.google.de/url?sa=i&url=http%3A%2F%2Fwww.mathisintheair.org
https://commons.wikimedia.org/wiki/File:Beam_splitter.svg,

Sketch: Structure

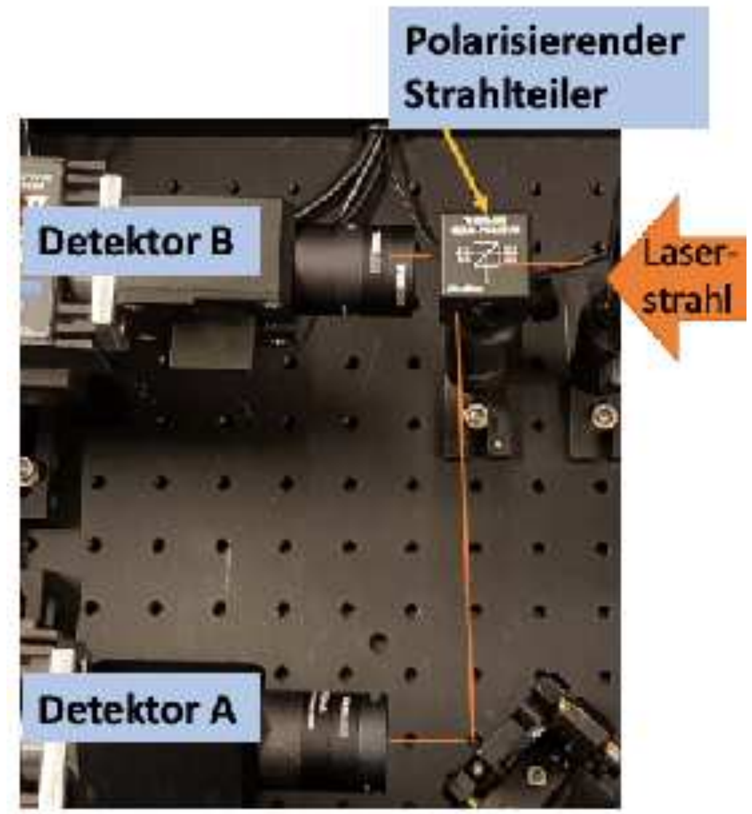


Laser light is very strongly attenuated by the dark filter plates so that only a few photons reach the beam splitter. As soon as the photon at the polarizing beam splitter decides on either horizontal (horizontal) or vertical (vertical) polarization, there is a signal at detector A or B.

Detector A is used for binary number 1 and detector B for binary number 0. We cannot know which detector the photon will choose. This results in a binary number sequence that cannot be predicted, i.e. is truly **random**.

Das Quanteninternet Seite 42 Abb. 1.2

Beam splitter cube: where chance begins

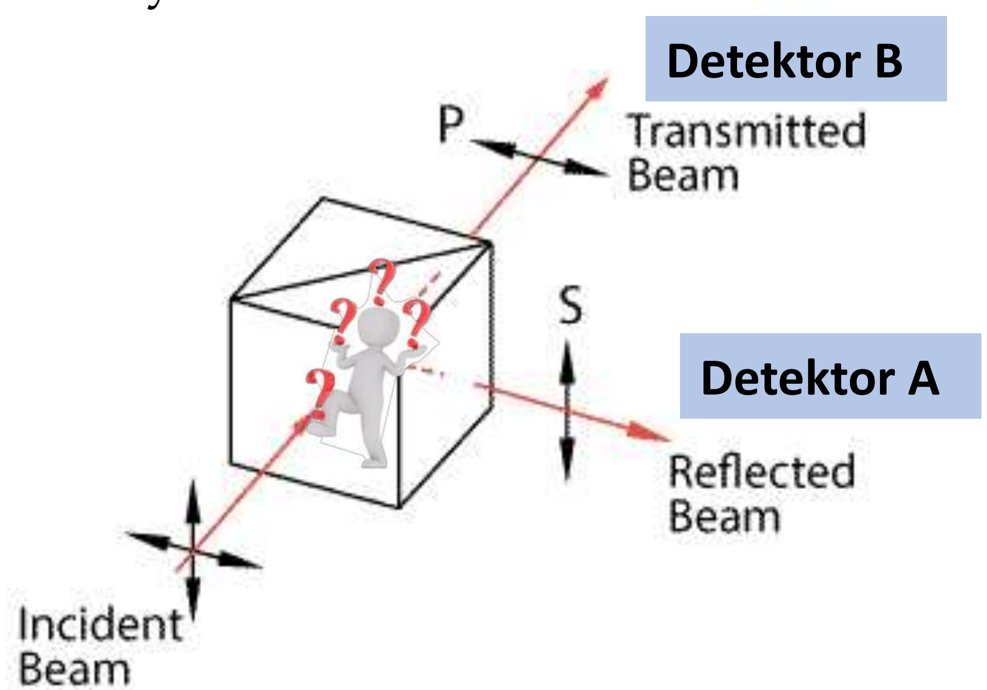


The photons in our laser are all oriented differently. The polarizing beam splitter divides the photons into vertical and horizontal polarization based on their polarization.

There are therefore two possible paths for a photon, transmission with horizontal polarization or reflection with vertical polarization - each with a probability of 50 %.

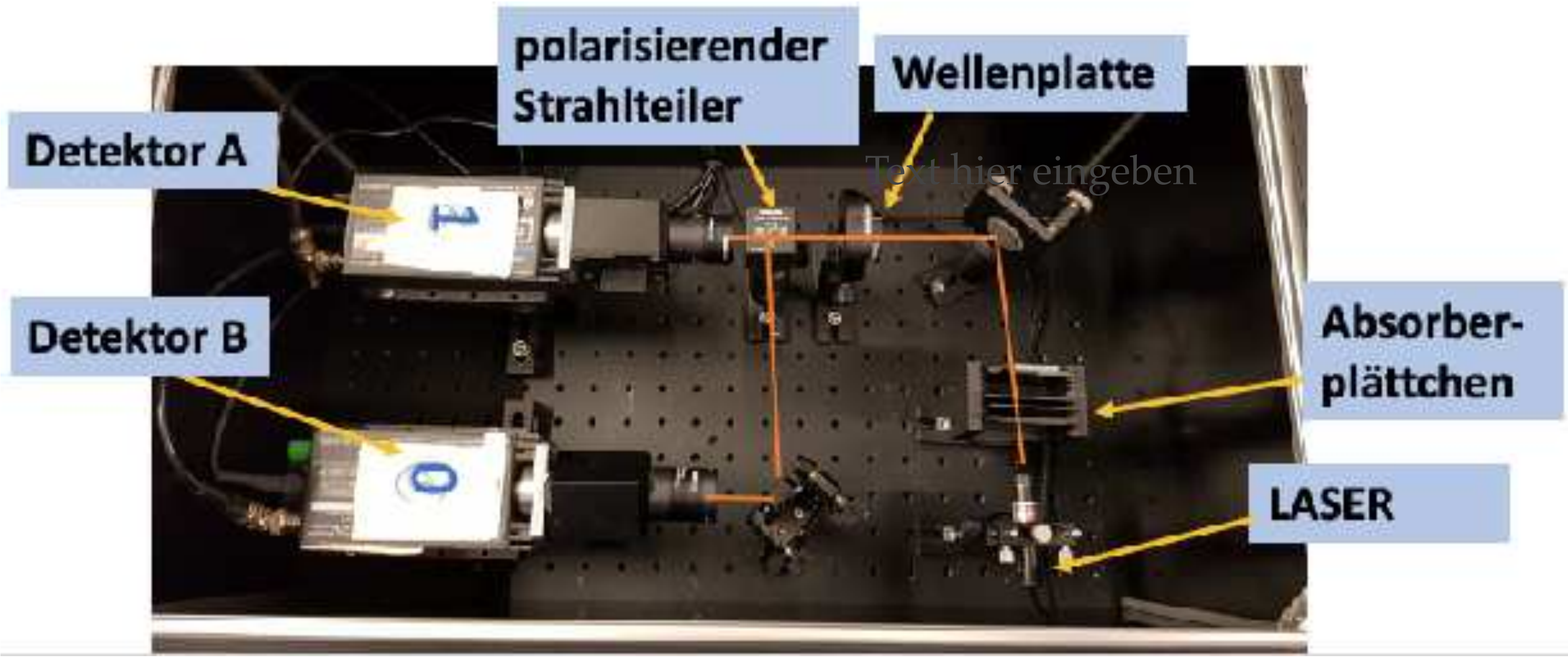
Which path the individual photon

chooses is purely **random**.



http://rmico.com/high-power-polarizing-cube-beamsplitters

Real setup: quantum random number generator



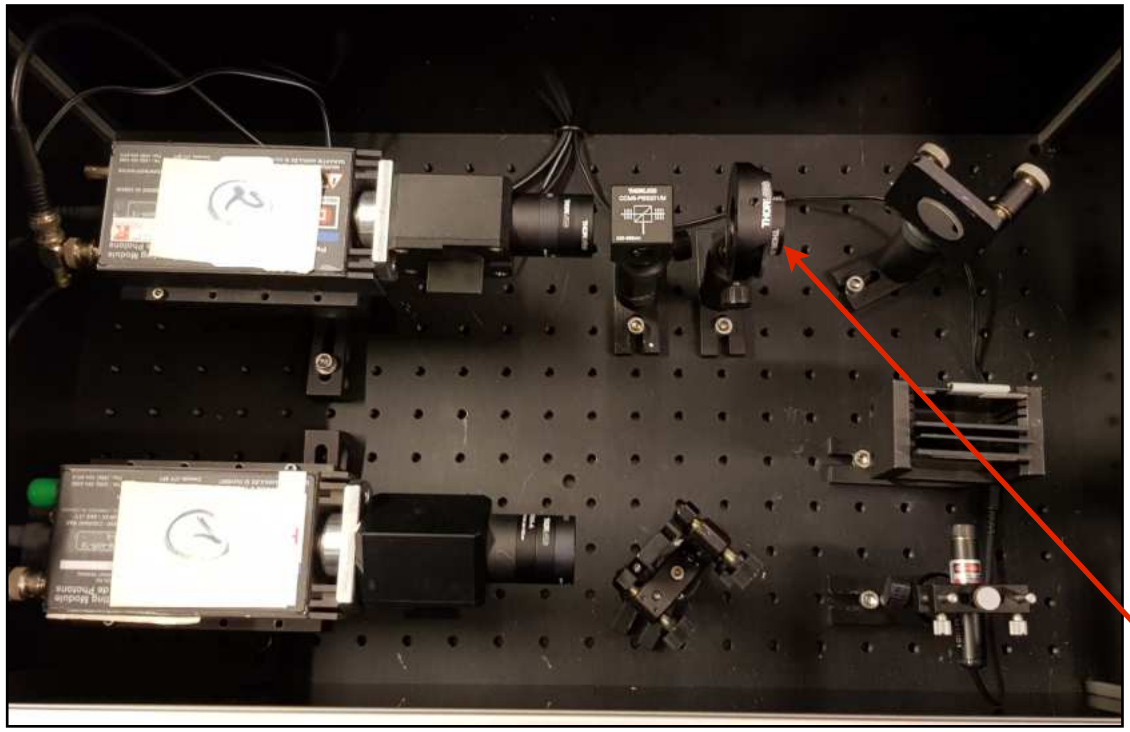
The randomness of individual photons is utilized in the quantum random number generator.

We need a laser for the experiment. To ensure that only a few photons reach the single photon detectors, the laser light must be strongly attenuated with the aid of filters that are attached directly to the single photon detectors (the absorber plates are not necessary). (The absorber plates are not necessary.) The photons are either reflected with vertical polarization or transmitted with horizontal polarization purely by chance at the polarizing beam splitter. By setting the detectors

Transmission → binary 0, reflection → binary 1

the result is a completely random bit sequence.

Setup: Quantum random number generator



There are lasers that emit linearly polarized light, but this only has a certain preferred direction in which it is more polarized. A wave plate $\lambda/2$ is positioned in front of the beam splitter, which ideally enables a 50:50 beam distribution. Using the wave plate, we delay the preferred direction of the laser in which it oscillates more strongly, so to speak, and achieve the same intensity in both detectors.

The $\lambda/2$ wave plate is an optical component that changes the polarization of light, thereby achieving the same intensity in both detectors.

Use quantum random number generator

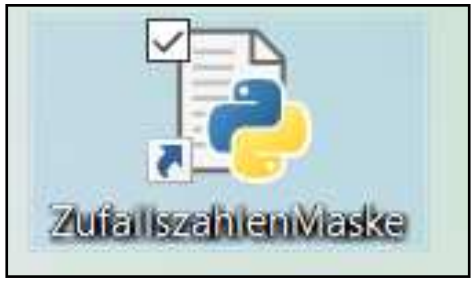
Step 0: Switching on the voltage devices: First press the black button on the right and then the silver switch on the left

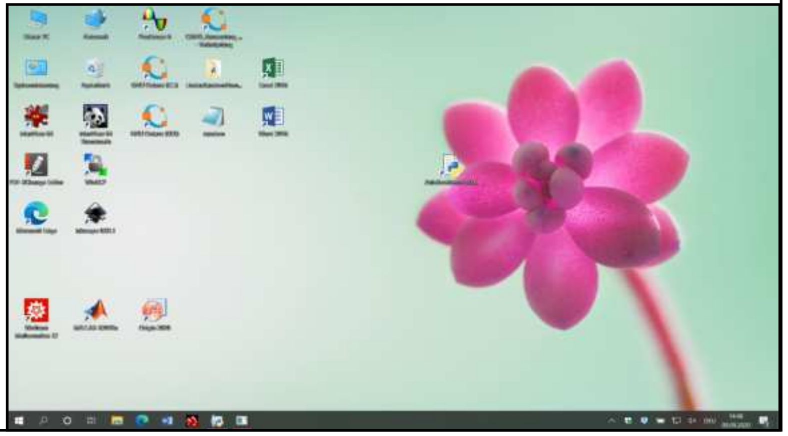
Step 1: Switch on the voltage generators for the single photon detectors (if these are already switched on, go to step 3)

Step 2: Lift off the lid of the experiment and get an overview of the experiment. Close the lid. **IMPORTANT**!

Step 3: Start the Python program (password from laptop: PhotonLab) and press Start. As soon as you press Stop, the random numbers are determined.

The upper device belongs to detector A and the lower one to detector B



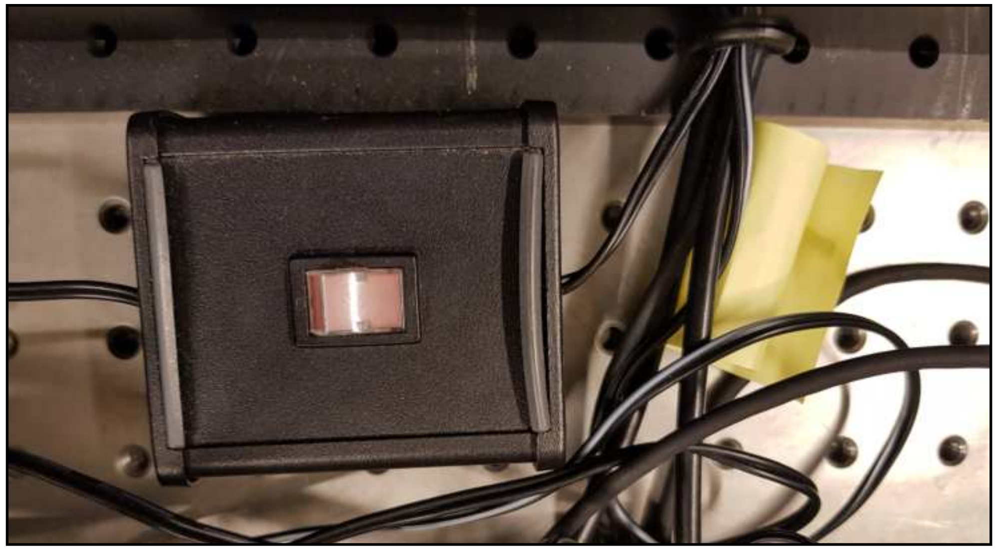


Picture Desktop

Use quantum random number generator

Caution!

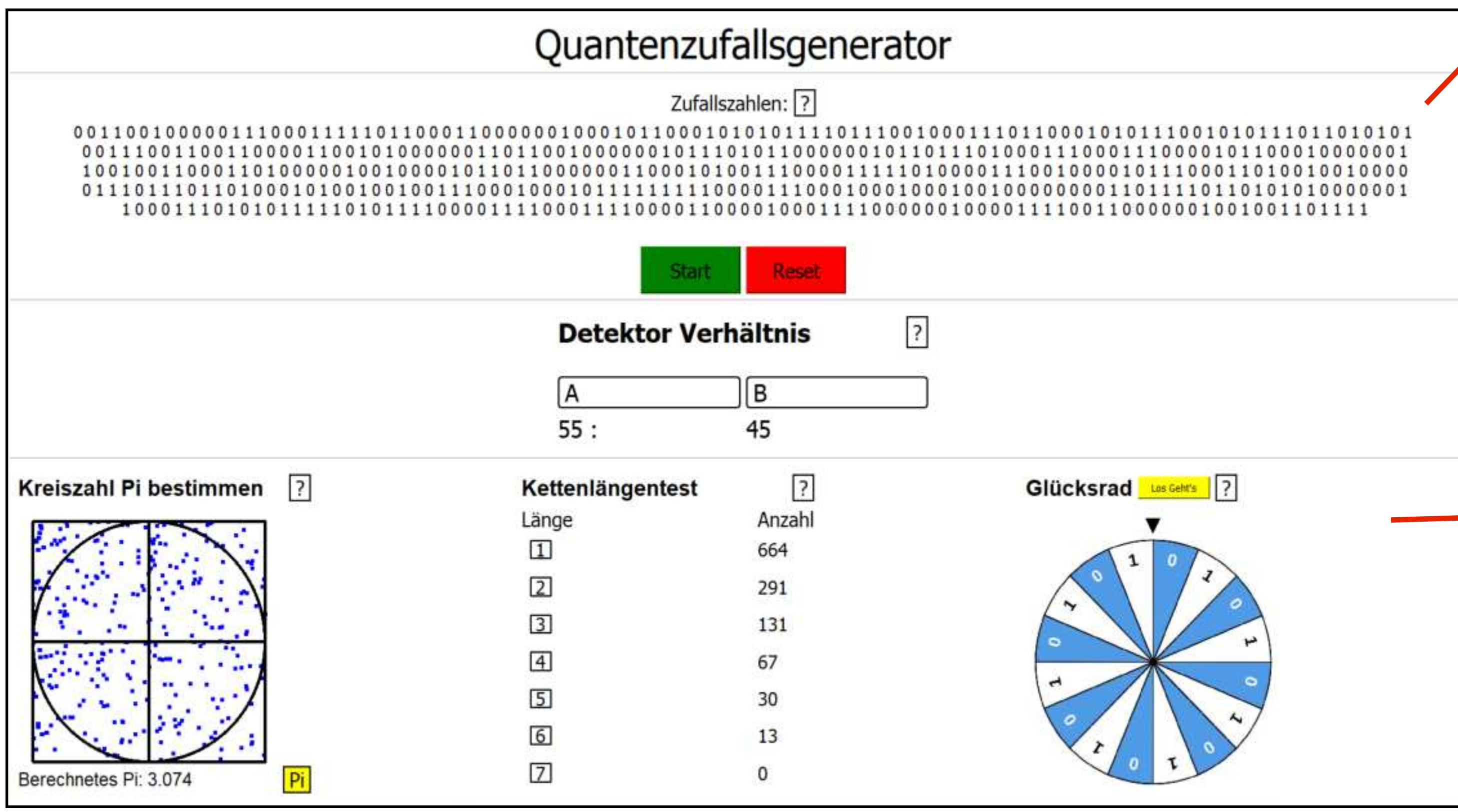
As soon as the laser is switched on, the cover must be put on. The single photon detectors are very sensitive and react to all light irradiation and can therefore be destroyed very quickly.



Step 4: Switch on the laser (switch is behind the box)

Explanation of the program

There are question mark tools in the program, where the area is explained and mostly how we use the random numbers from the quantum random number generator.

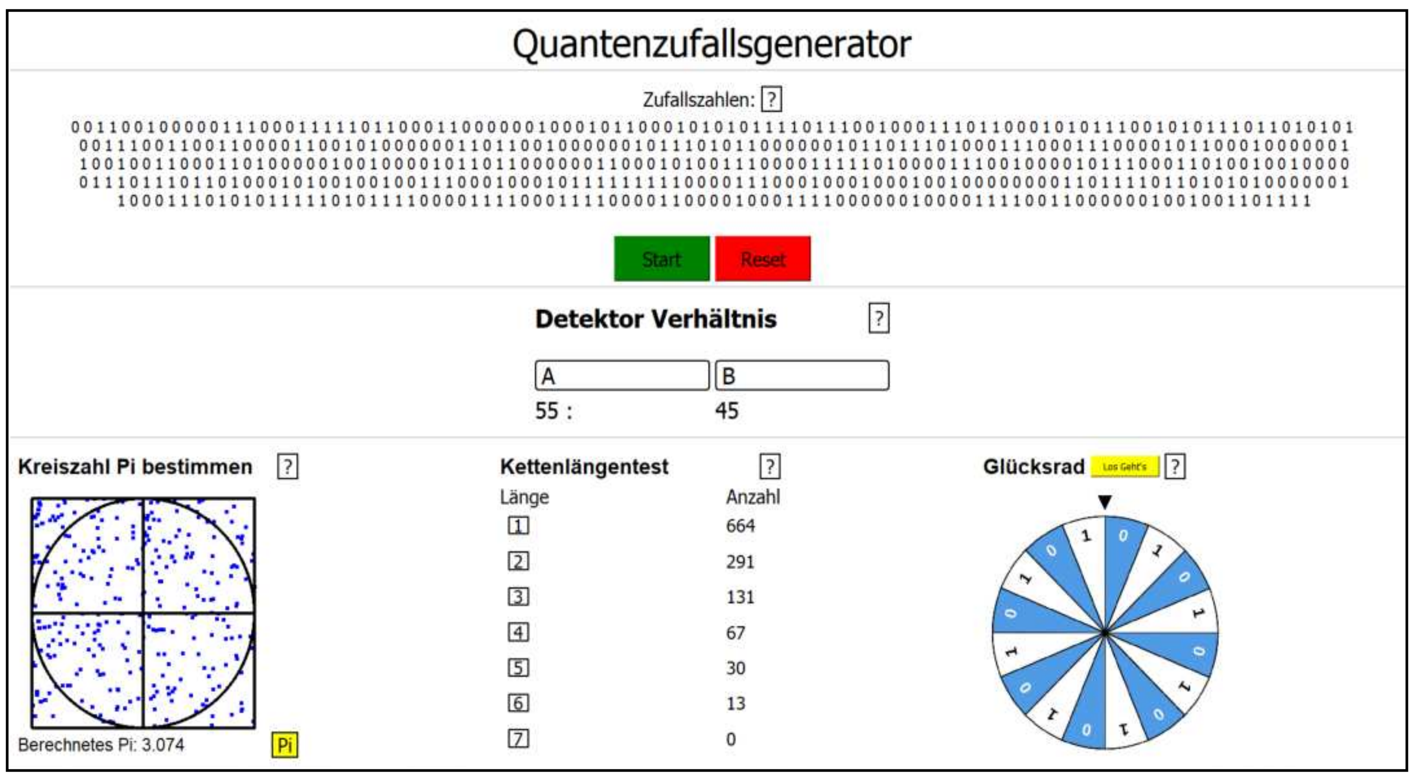


You can find a detailed description of how pi is calculated in the question mark tool.

Photons generate voltage pulses on the detectors; these are displayed as a binary number 1 for detector A and 0 for detector B. The image on the oscilloscope is discussed in more detail in the glossary.

Random numbers can be used to correctly calculate the number π to very many decimal places. However, random numbers can also be used to encrypt sensitive data à see quantum cryptography

Use quantum random number generator:



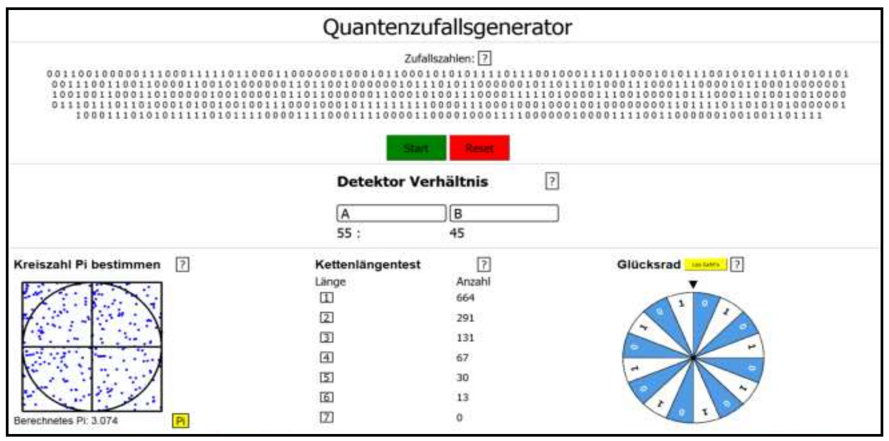
Step 5: Now use the program to check the ratio of the detectors.

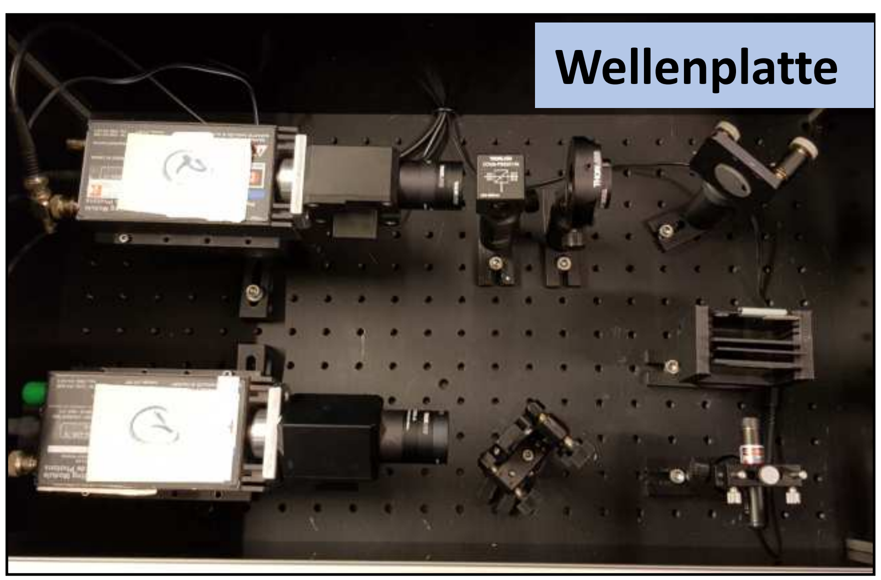
Step 6: Now it is important to achieve as equal an intensity distribution as possible with the wave plate positioned in front of the beam splitter.

The work order is described in detail in the next slide.

Your task: Adjust the wave plate

Your task is now to adjust the ratio of the two detectors as evenly as possible using the wave plate.





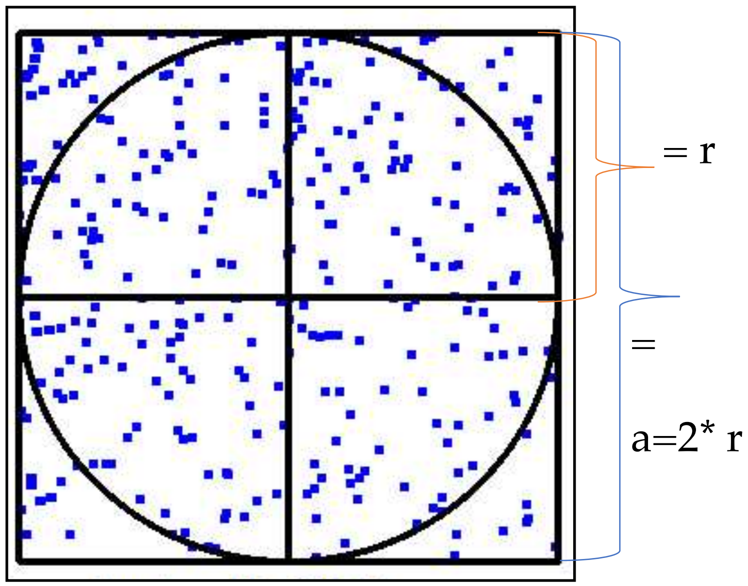
To do this, you will (probably) have to carry out the following steps several times:

1. Switch off the laser again
2. Open the cover
3. Adjust the corrugated plate
4. Close the cover again
5. Switch on the laser and then restart the program

As soon as you have pressed Restart and Start, you can see on the program how changing the polarization by rotating the $\lambda/2$ plate affects the 50:50 emission of the photons and thus directly affects the quality of your generated random numbers.

It is very difficult to produce a uniform distribution. Good luck with that!

Quality of the random numbers



There are many tests for the statistical analysis of random numbers. You can tell whether your random numbers are good or bad, for example, by determining the circle number Pi.

We can determine the circle number using the so-called Monte Carlo method. The random numbers are distributed evenly in the square. This uniform distribution is crucial, because the ratio of the random numbers (marked here as points N_K) in the circle to the total number of random numbers in the square (N_Q) is equal to the ratio of the area of the circle (πr^2) and the square (a^2), where a=2$*$r.

$$\frac{A_{Kreis}}{A_{Quadrat}} = \frac{r^2 * \pi}{a^2} \text{ weil } (a = 2r) \Rightarrow \frac{r^2 * \pi}{(2 * r)^2} = \frac{\pi}{4} = \frac{N_K}{N_Q} \Rightarrow \pi = \frac{N_K}{N_Q} * 4$$

Quality of the random numbers

The chain length test looks at the frequency of certain chain lengths in a randomly generated binary chain. These are displayed by the program. Chain length is the number of consecutive identical characters.

Kettenlängentest [?]

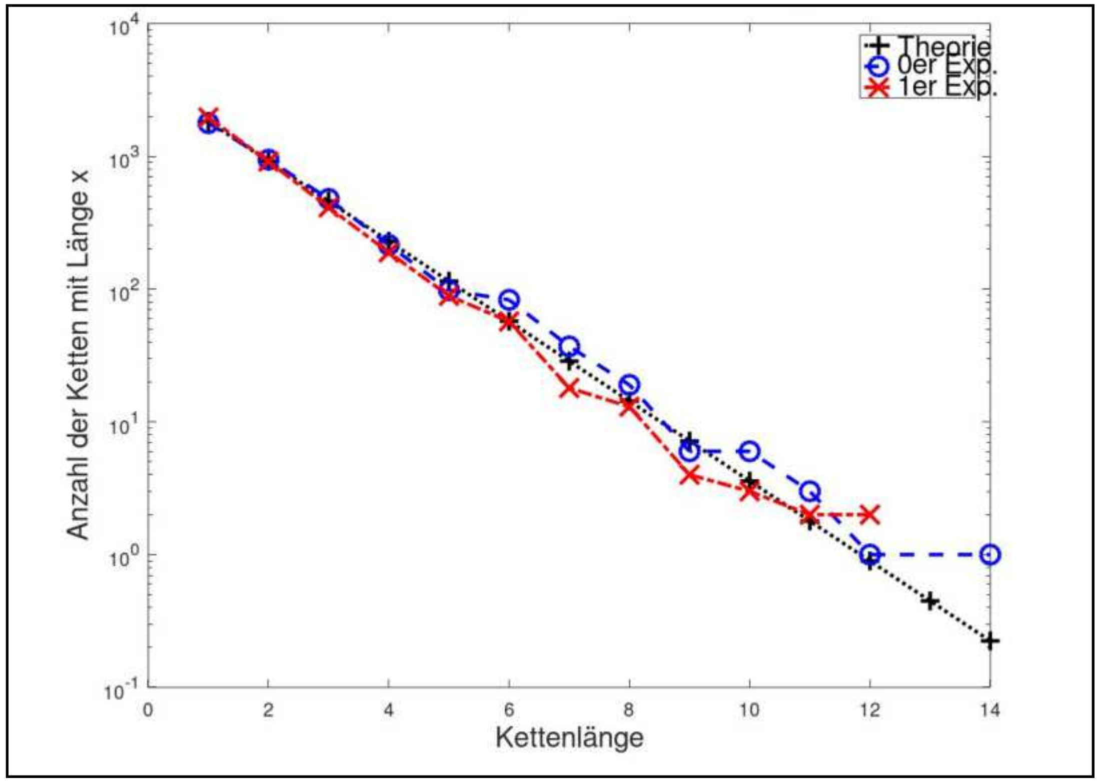
Länge	Anzahl
1	1646
2	1128
3	786
4	488
5	360
6	260

1. example from the program

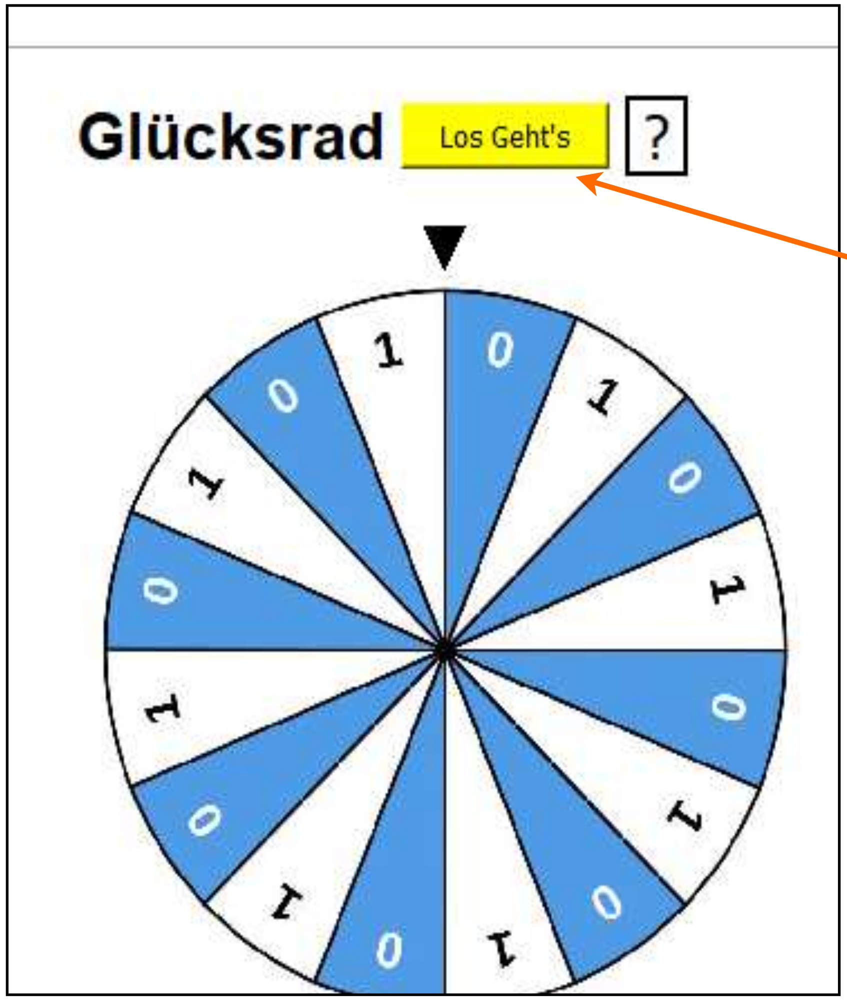
Mathematically, you can determine the probability of certain chain lengths occurring, see glossary.

However, you can also make a qualitative statement. The fewer chains there are, the less likely it is that a **long chain** (greater than 3) will occur. You can see from the first example that the random numbers are rather poor here.

2. example from the program of good random numbers



Generating random numbers



The rotation speed of the wheel of fortune can be changed using the random numbers determined. This allows you to generate your personal quantum random number series, which is truly random provided your detector ratio is even.

To do this, click on „Los Geht's“

End of the experiment:

At the beginning you tried to generate random numbers by rolling dice and realized that you reach your limits with the "random", but with the quantum random generator you have discovered a good way to generate "truly" random numbers, but only if you set a uniform intensity distribution of the laser.

Quantum for beginners

Bundesministerium für Bildung und Forschung

What is quantum physics?

-In this course you will get to know the terms "state" and quantum system.

-We will also examine the following phenomena:

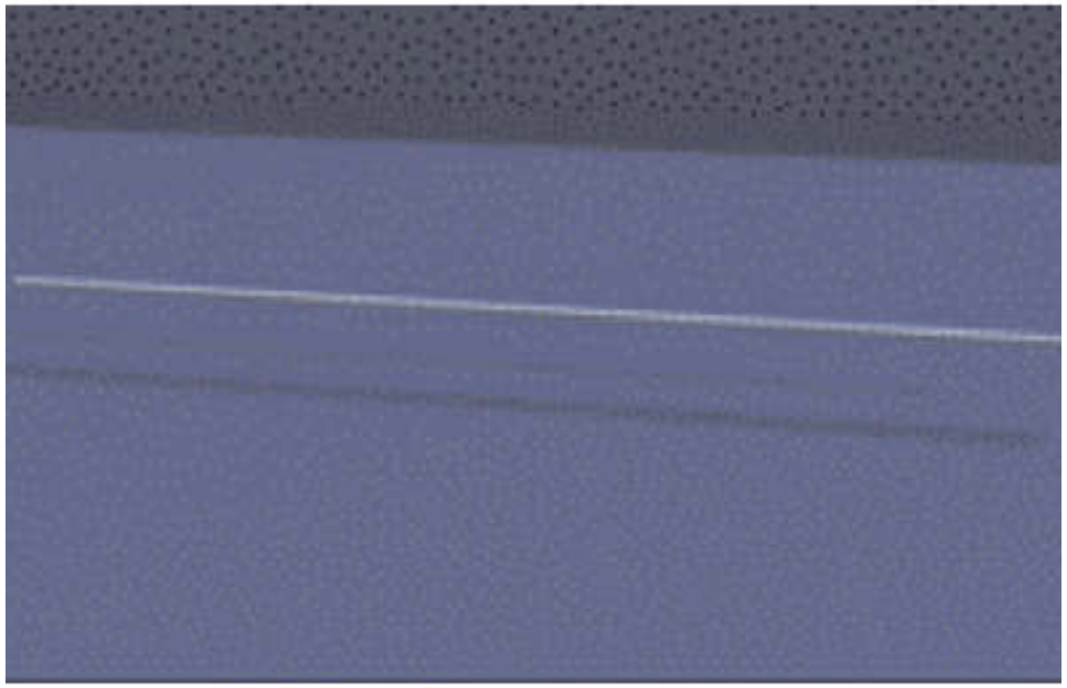
- superposition
- measurement process
- Measurement in different bases
- Schrödinger's cat
- Classical bit and QuBit
- Quantum computer
- Entanglement

Phenomena in quantum physics

After clarifying the basic concepts, we will now look at specific phenomena in quantum physics and how they can be made as clear as possible. We start with **superposition**!

What is superposition?

Superposition is a superposition of physical quantities that do not influence each other. In the case of waves, this is called interference. The superposition of two waves can have a canceling or amplifying effect, but the two original waves then separate again without being influenced by each other.



https://commons.wikimedia.org/wiki/File:Standing_waves1.gif

Examples of interference

- Interference of water waves, e.g. raindrops on the water surface

- Interference of light waves, e.g. in feathers, insects and soap bubbles. In insects, the interference is caused by the superposition of thin layers on the chitin shell, and the constructive interference, for example, enhances the shimmering green of the beetle in the picture. A bird's feather has a grid-like structure that is created by the gap separation of main branches and hairs. This allows you to observe the same effects as with an optical grating and to detect diffraction.

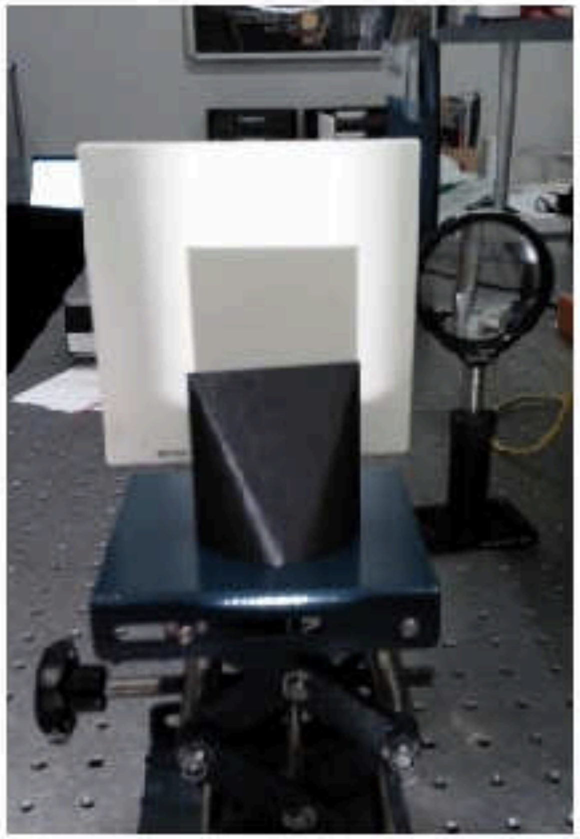


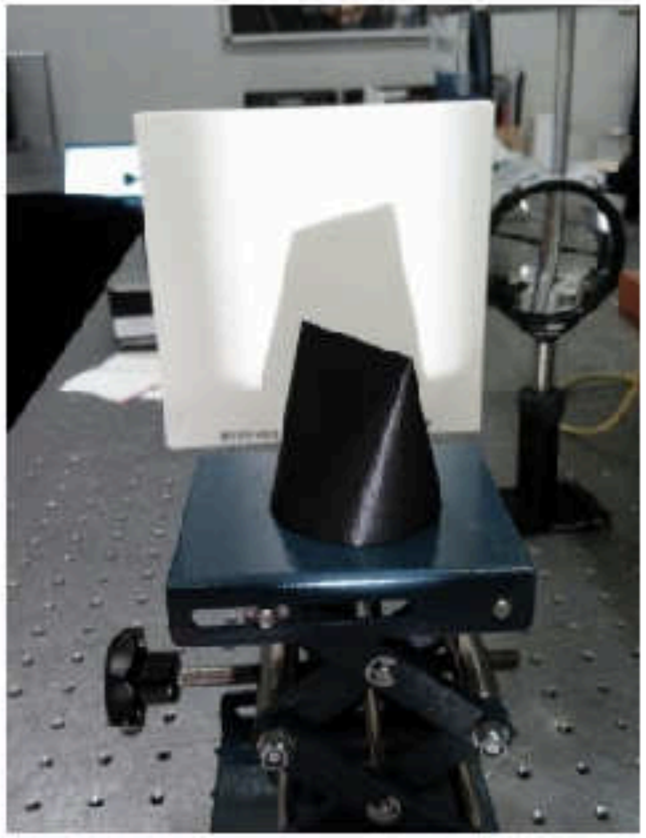
https://pixabay.com/de/photos/regen-regentropfen-interferenz-65484/
https://pixers.de/lichtdurchlassige-fenstervorhange/detail-der-pfau-federn-auge-32892014
https://www.itp.uni-hannover.de/fileadmin/itp/emeritus/zawischa/static_html/vielstrahl.html

Shadow = quantum mechanics??

- Because it is difficult to imagine a superposition of states, here is a classic illustration: the shadow image. Depending on how you position the shape that casts a shadow, the shadow looks circular, triangular or cuboid-shaped. But if you position the shape at an angle, you see a superposition of states: something in between (right image).
- In contrast to quantum mechanical superposition, however, the measuring element is missing here. Before the measurement, you never know which state it is.

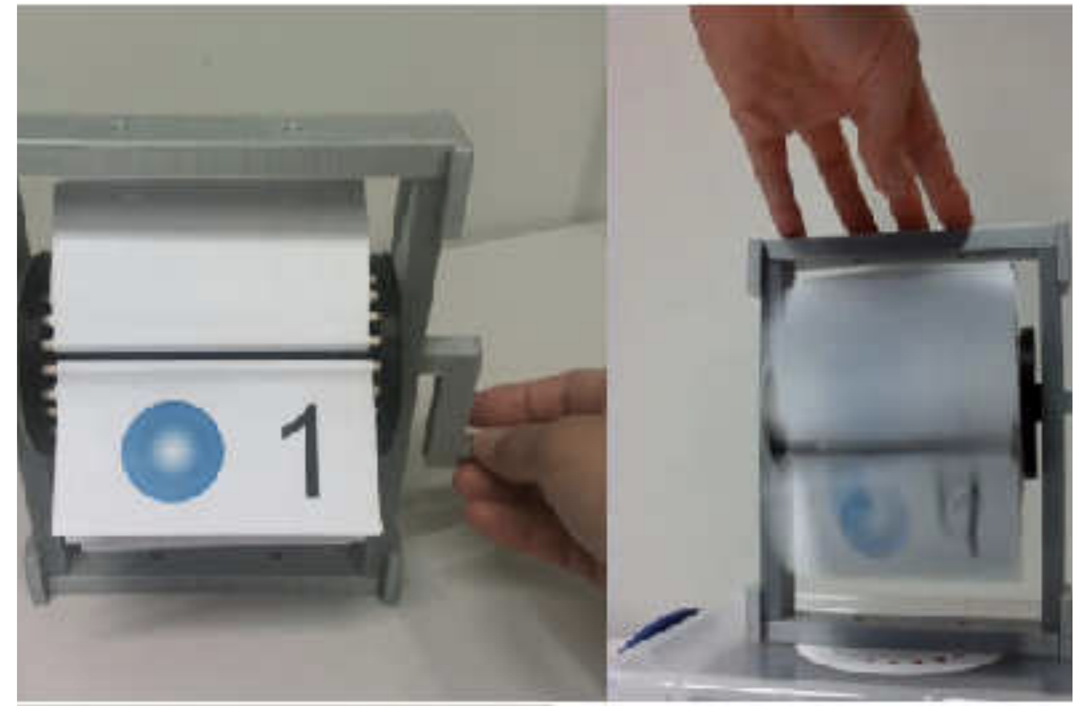

Dreick


Quadrat


irgendwas dazwischen

Superposition and measurement process

- A quantum mechanical measurement removes the superposition and the wave function **collapses**. The result of the measurement is clear, but random and can only be predicted with a certain probability. Examples are crank/flip books.
- **Crank cinema**: The superposition of 0 and 1 exists as long as the crank is turned. The states 0 and 1 are indicated as an atom in the ground state (small circle) or in the excited state (large circle). If a measurement is carried out, this corresponds to stopping the crank. The result is then clearly 0 or 1, but each with a probability of 50%.
- You can take a closer look at this in the YouTube video: https://youtu.be/680PfVH8nUw



Crank cinema

Superposition and measurement process: Example of a flip book

Flip book: The flip books work according to the same principle. The cat is in a superposition of dead and alive until the flip book is stopped. Then the state is clearly defined, but which state was measured is random. The flip books are equipped with a different number of dead and alive cats. This influences the probability of the result of the measurement.

Flipbook

Schrödinger's cat (adapted from Philip Schwinghammer)

Schrödinger's cat is a famous thought experiment that is intended to illustrate the strangeness and **absurdity** of quantum physics and superposition. Let's assume we are not concerned about animal welfare or job security: we could take a cat and lock it in a box with a bottle of poison. The poison bottle would have a significant weakness: it would break as soon as radioactive decay occurred in the box. So far so good, it looks as if we are murdering cats for no reason. But that is only half the truth!

Schrödingers Cat

https://www.stupidedia.org/stupi/Schr%C3%B6dingers_Katze

https://www.cosmos-indirekt.de/Physik-Schule/Schr%C3%B6dingers_Katze

Schrödinger's cat thought experiment: Why the concept of quantum particles in superposition amazes us

Radioactive decays are quantum processes. This means that a radioactive atom can be in a superposition of decay and non-decay until a measurement is made. Until the atom has decayed and not decayed at the same time, the bottle has broken and not broken at the same time. In the same way, a single photon in the double-slit experiment goes through the left and right slit at the same time. If we open the box, we resolve the superposition through the measurement.

The poison has reached the cat, but at the same time it has not, and the cat is therefore in a superposition of dead and alive! The proportions to which it is dead and alive therefore depends on the radioactive atoms. The probability of a radioactive atom decaying can be very different: depending on which element we have. If we open the box, we resolve the superposition, so that the cat is clearly dead or alive.

https://www.redbubble.com/de/i/galeriedruck/Schrödingers-Katze-meme-von-Faeblehoarder/53198779.7Q6GI

Entanglement

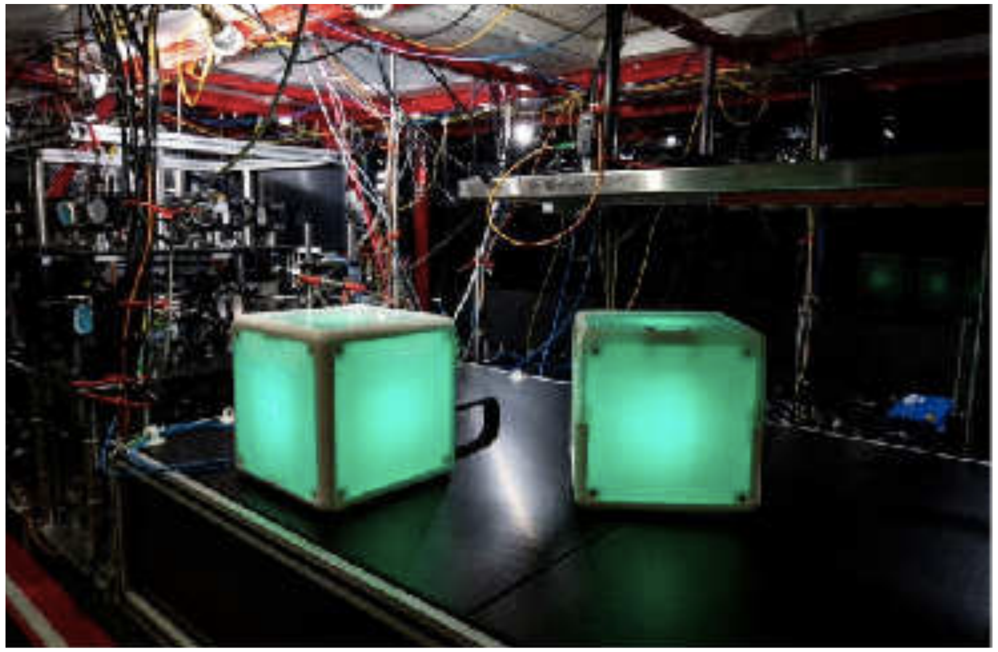
Entanglement can be thought of as the superposition of two systems. Two entangled particles can then no longer be described as separate particles, but form a complete system. As a result, their measurement results are no longer independent of each other. This means that once you have measured one particle, you know what the measurement of the other will reveal. Quantum cubes serve as an example:

Entanglement with quantum cubes

The quantum cubes clearly show how entanglement works.

The cubes correspond to two quantum particles that are brought together to form a quantum system by entangling them. In this case, this works simply by pressing a button.

Unentangled, the cubes work like normal cubes: you can roll them (carefully move and rotate them and put them down again) and they randomly display one of six different colors. Rolling the dice describes the **measuring process**.



Quantum cubes

Entanglement with quantum cubes

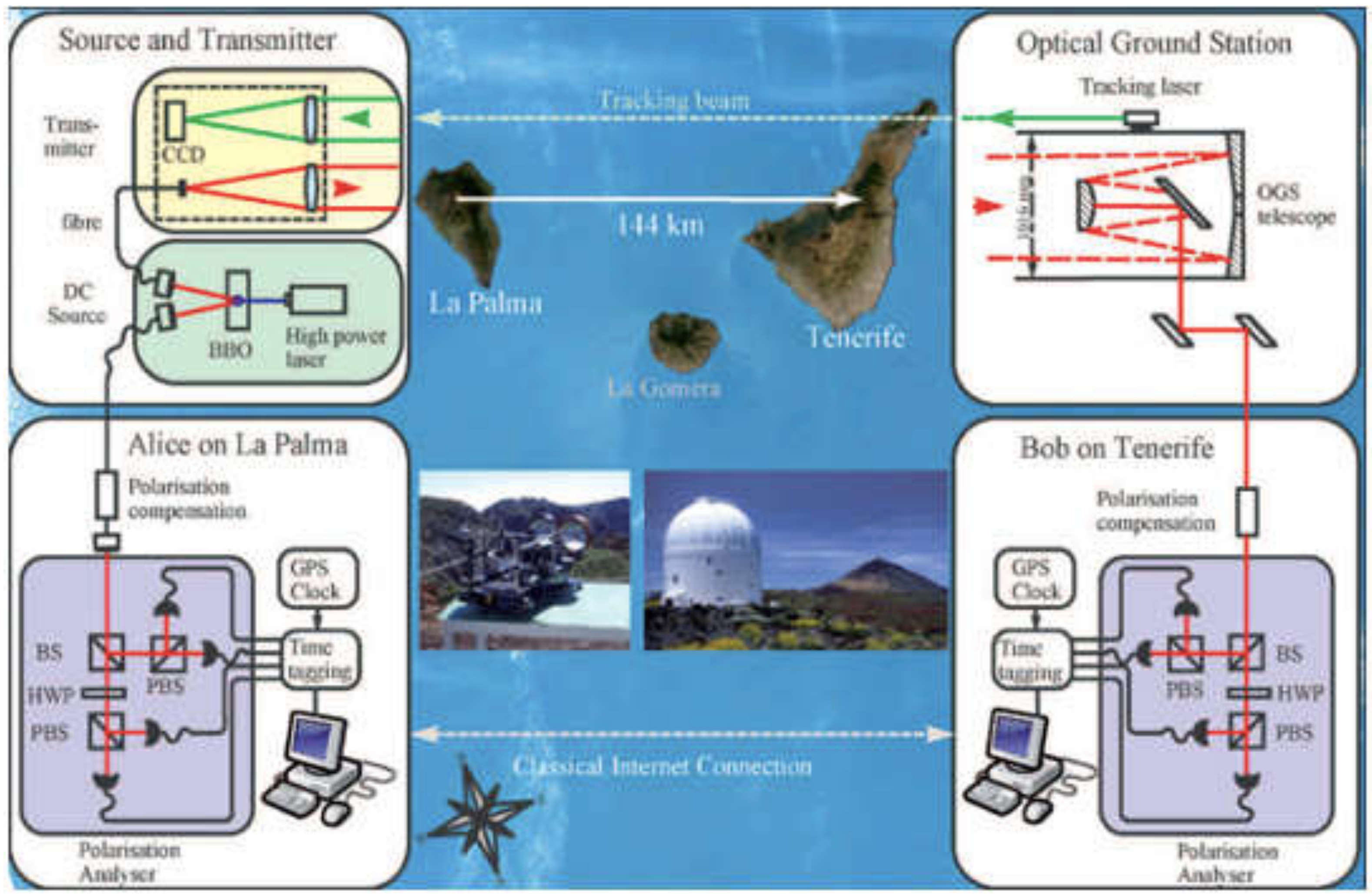
If they are entangled by pressing the entanglement button, they initially flash wildly as their status is not fixed. If one of them is rolled and receives a random color, this is transferred to the other die. It doesn't matter which die was rolled first, they always have the same **random** color.

If you roll the dice again, the entanglement is canceled and both dice are back in the "classic" initial state and can be entangled again. The "entanglement", which is represented by Bluetooth in our analogy system, works up to a distance of approx. 50 m. Real quantum systems, on the other hand, are still entangled with each other if they are at opposite locations in the universe.

Merkel and Söder in the MPQ with the quantum cubes

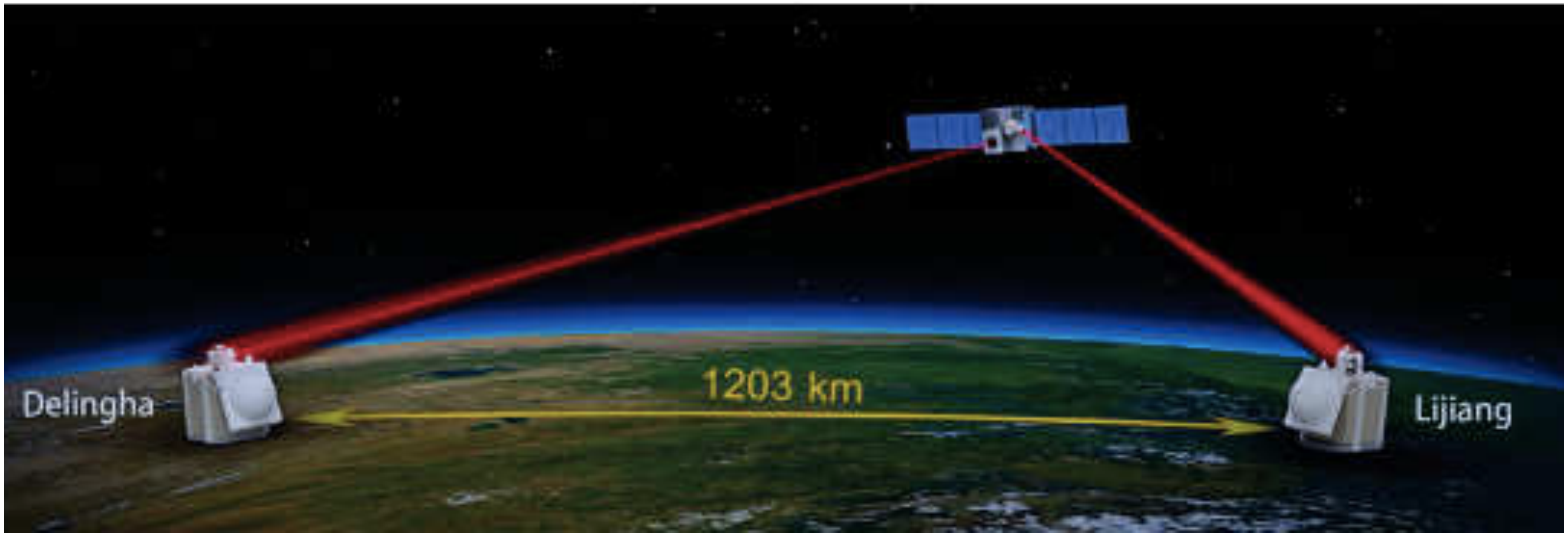
Entanglement: Experimental verification (as of 2009)

Further examples of entanglement: entangled photons can be generated in a **non-linear** optical crystal and are entangled in their direction of emission (parametric down-conversion), state after collision processes, spins of electron and proton in the ground state of the hydrogen atom, atoms excited with a laser emit two photons with entangled polarization when returning to the ground state.



Entangled photons measured between the Canary Islands of Tenerife and La Palma over a distance of 144 km through the atmosphere.

Entanglement: Experimental verification



In 2017, entanglement was detected over a distance of 1200 km by sending entangled photons from Earth to a satellite and from there to another ground station.

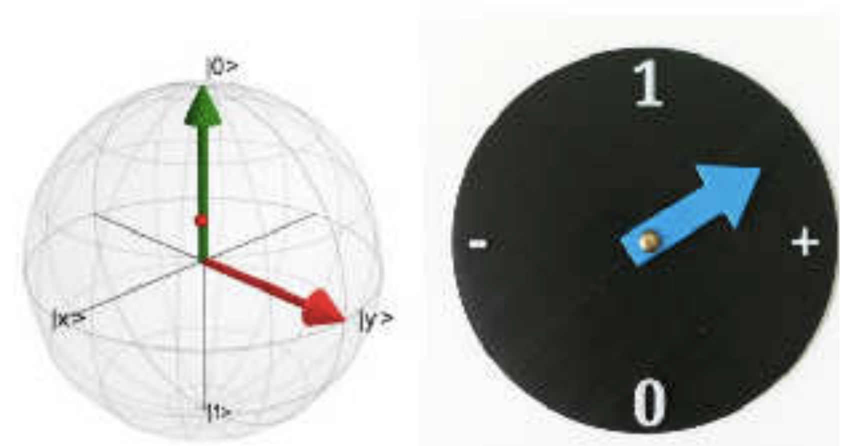
Classic bit and QuBit

The classic bit, which all our computers use to calculate, can always be in one of two states. In this example, it is set to 2 o'clock, i.e. the probability of receiving a 1 during the measurement is greater than receiving a 0.

Switch

This can be technically realized in various ways, e.g. current on and off, such as with a switch:

In contrast to the classical bit, the qubit can assume any point on the spherical surface of the Bloch sphere.



Bloch ball and Bloch clock

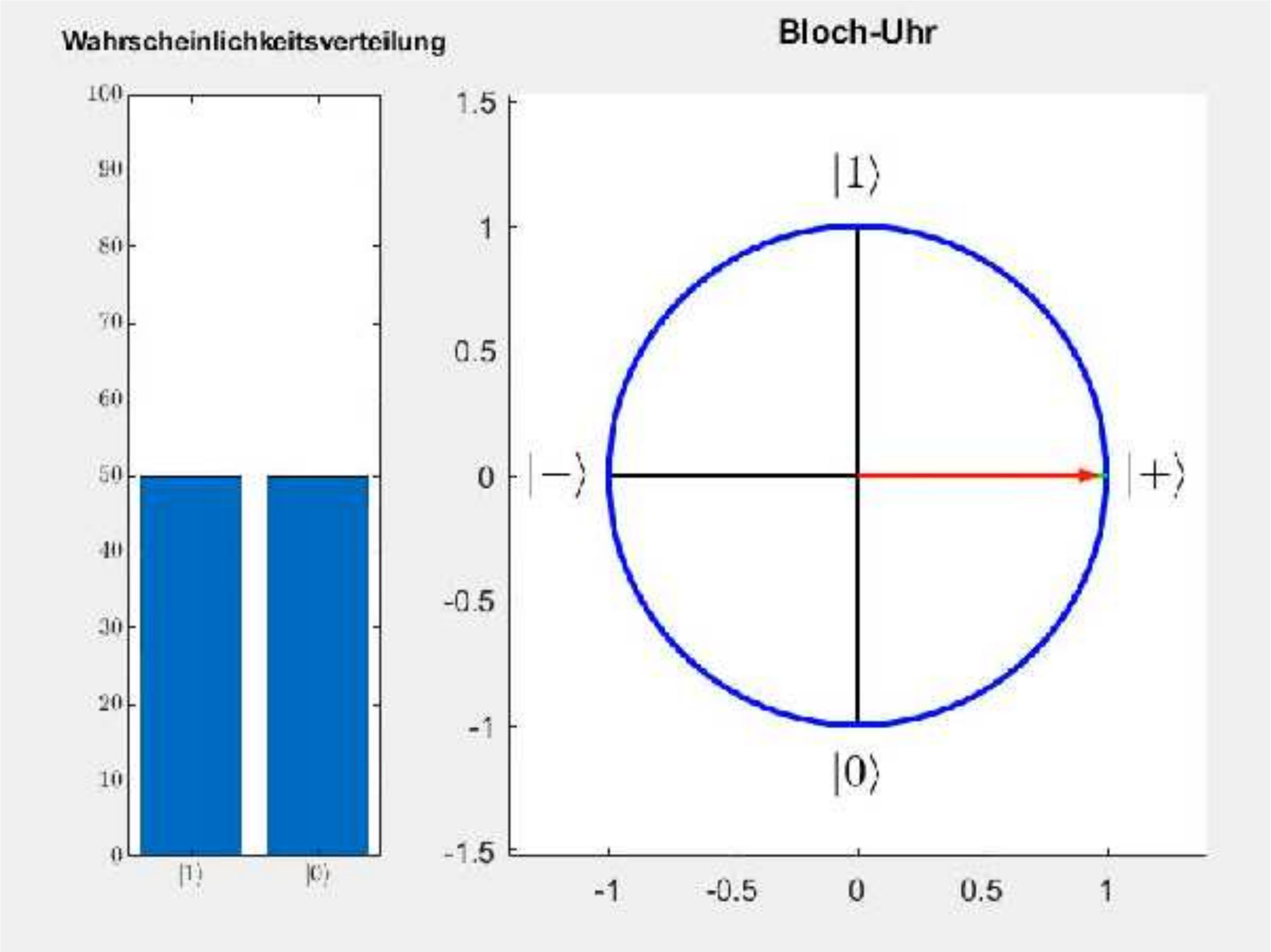
To simplify the representation, the sphere is reduced to a circle and referred to as a Bloch clock. Mathematically, this means that we omit the imaginary component and the measurement in the z-basis. In the case of the classic bit, only the settings 0 or 1 are permitted on the Bloch clock, while the QuBit can display **all** "clock times". The position of the arrow can be freely selected here. In this example, it is set to 2 o'clock.
You can watch an animation of the Bloch clock in the YouTube video: https://youtu.be/McWqLIP6AuE

Classic bit and QuBit

A single measurement in this configuration gives a probability of 1 with 66% and 0 with 33%.

However, a single measurement only results in 0 or 1, and only after repeating the same measurement several times can it be calculated back to the initial state.

The same applies to all other arrow positions: The probability for the results 0 and 1 changes depending on the position. The animation clearly shows how the probabilities change depending on the arrow position:



Quantum computer

A quantum computer calculates with qubits instead of bits. This gives it some enormous advantages over classical computers and enables it to solve problems for which classical computers require extremely long computing times.

Quantum computers have great advantages, particularly in the field of optimization problems such as financial mathematics, logistics and molecular simulations.

If you would like to find out more, you can take a look at this interactive book on quantum computers:

https://photonlab.h5p.com/content/1291417877260690287

https://www.spiegel.de/netzwelt/netzpolitik/ibm-quantum-system-one-deutschlands-erster-quantencomputer-kostet-11-621-euro-monatsmiete-a-eb402a65-d78a-41f7-9411-047bc99db079

Black Box/ Black Box

A black box is a good analogy for a quantum system, e.g. an atom or a photon. It is just as difficult for us to look inside it as it is to look inside an atom. Only through a measurement can we find out something about it, e.g. whether it is in an excited state or how its electrons are arranged. However, we only ever get the answer that our measurement asks for. The overall system remains inaccessible to us and in a superposition of all possible states (e.g. Schrödinger's cat: dead and alive).

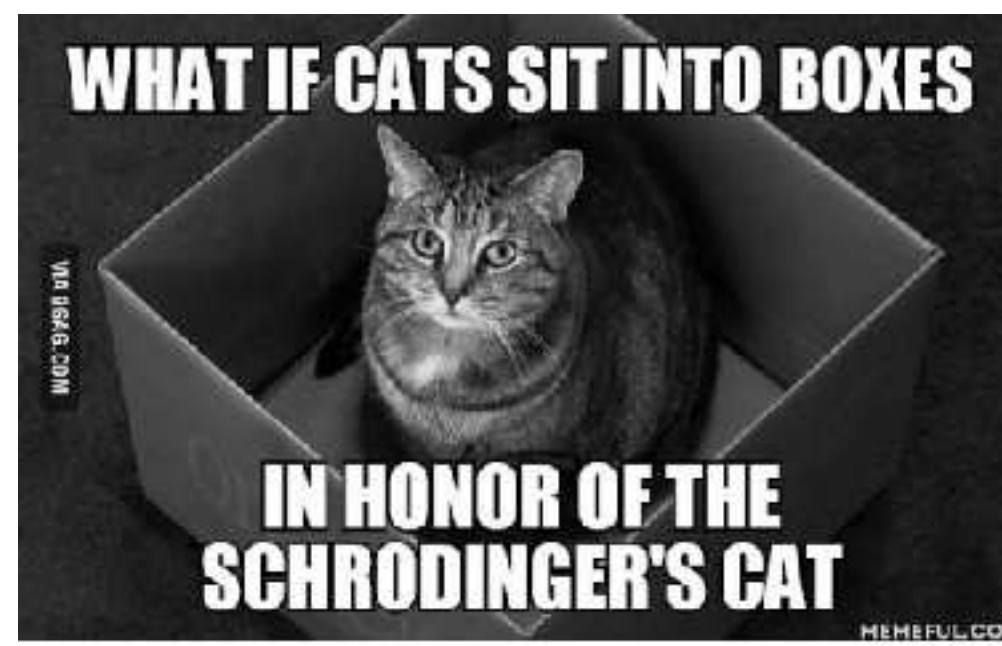
Likewise, the result of the measurement depends on the basis in which we measure, i.e. in which "direction" we project the state of the system. The black box works in a very similar way. If it is closed, our system is indeterminate and is in a superposition of all possible states. Opening a door corresponds to a measurement in a certain base.

But even if we open the box, we do not immediately learn everything about the system, but only a projection into a base. Opening another door then corresponds to the measurement in another base. So the same system can give different results depending on which base you measure it in.

In the same way, the result can be different even if you always measure in the same base, as there are always different probabilities for a measurement result per base.

And what does this have to do with Schrödinger's cat?

The state of the system is represented by the liveliness of the cat. Like a QuBit, the cat can assume several states and be either dead or alive. Unopened, the cat is in a superposition of dead and alive, but we cannot see this. We can only look at the system by measuring it, but in doing so we collapse the superposition into one of the two states. However, since we can measure in different bases, we can determine the superposition! Unlike in reality, the system always returns to its original state after a measurement and can be measured again.



https://www.onlinesprache.de/memes/crying-cat/
https://www.pinterest.de/pin/402157441713561401/

Quiz: Black Box

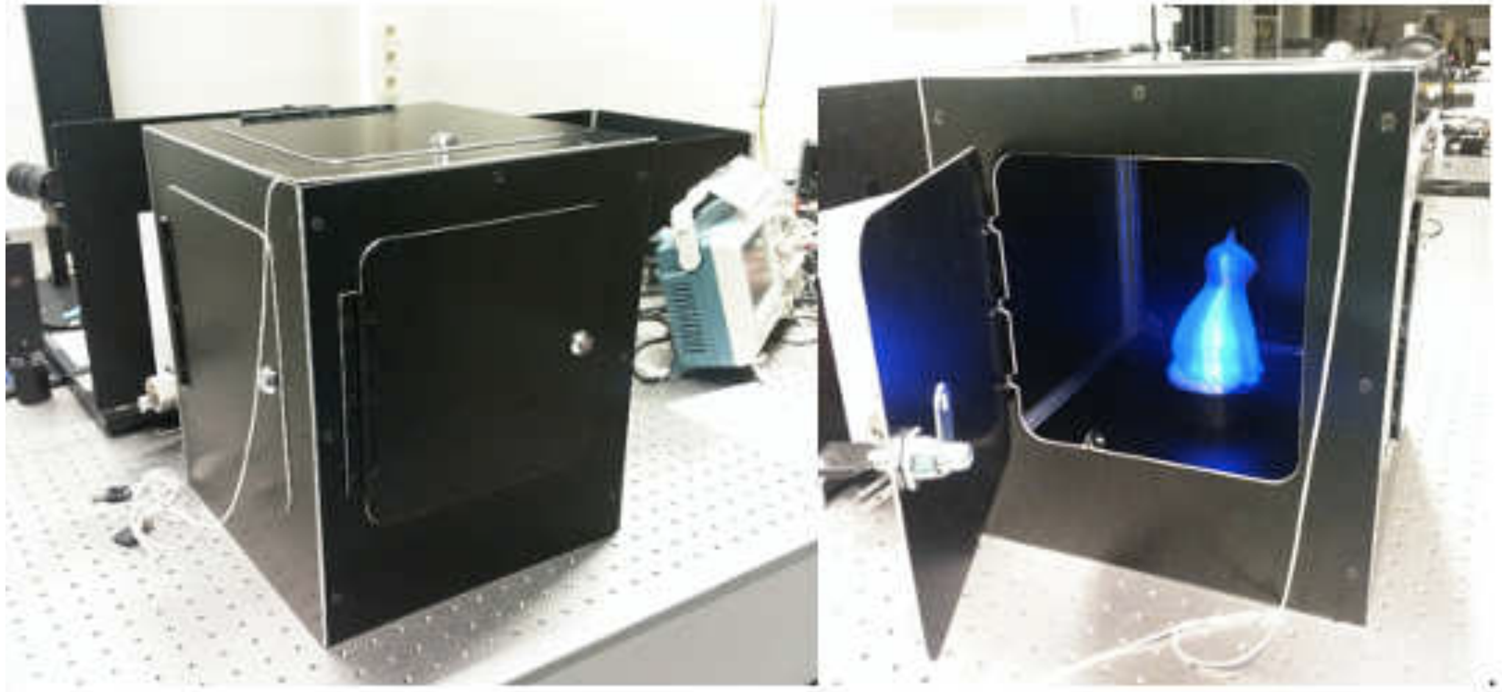
What happens when you open doors A, B and C one after the other? What colors do you see?

What happens if you open the same door several times in succession?

How many times in a row do you have to open a door to be able to make a reliable statement about the outcome of the measurement?

How can you draw conclusions about the state of the system from the measurements?

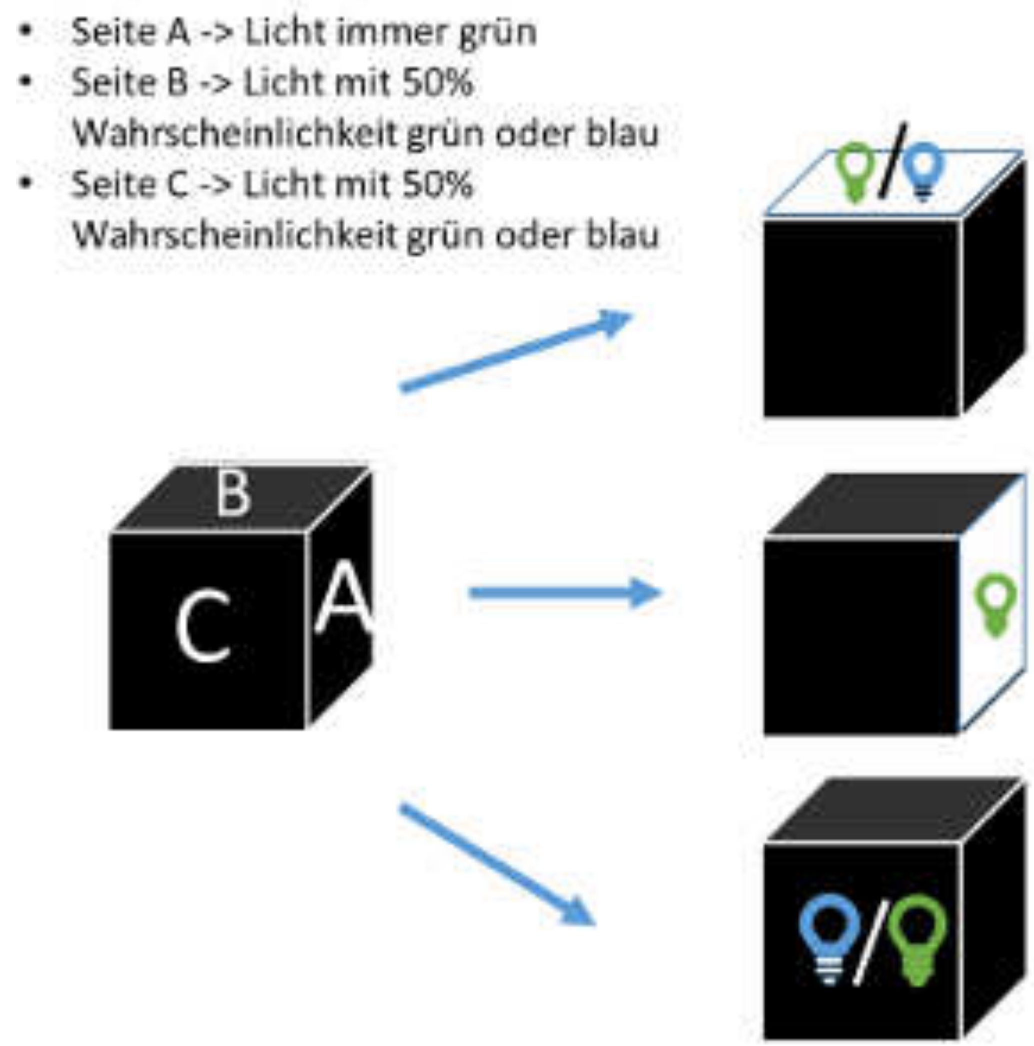
What state is the system in?



Untertitel

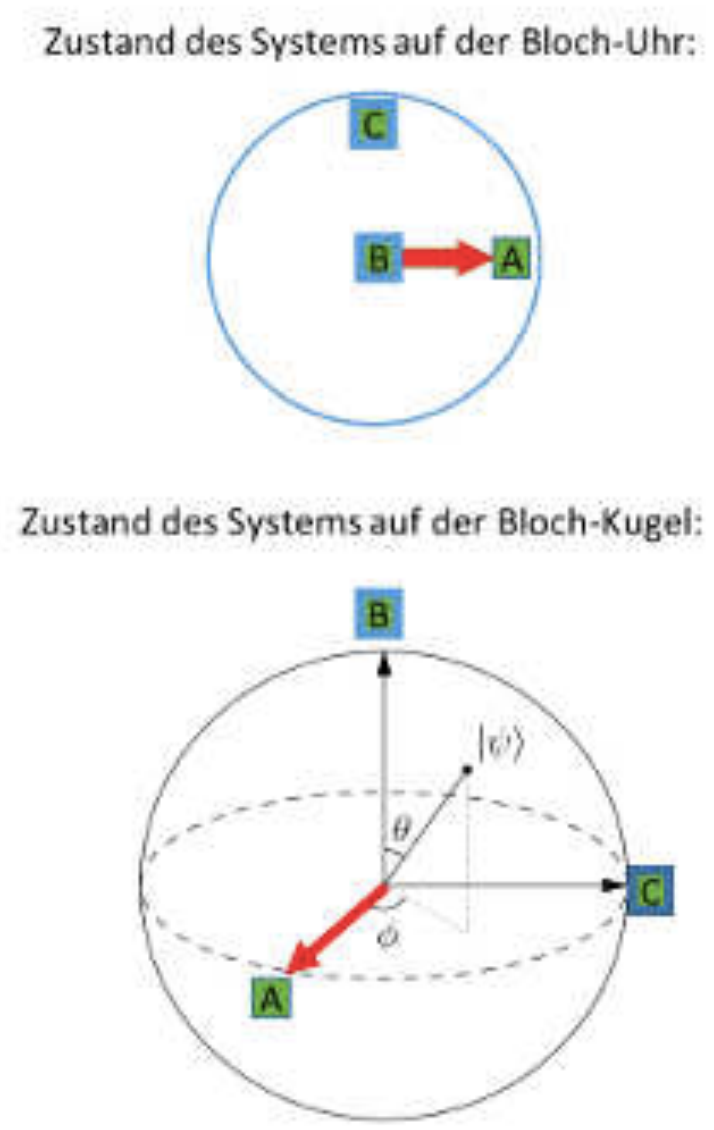
Quiz: Black Box solution

The superposition set here is always green in one base and blue or green in the other two bases with 50% probability in each case. This can be determined by repeated measurements (= opening doors). In reality, you would always have to prepare your quantum system again in the same state after a measurement in order to carry out such an experiment. Here you can see the principle again:



Untertitel

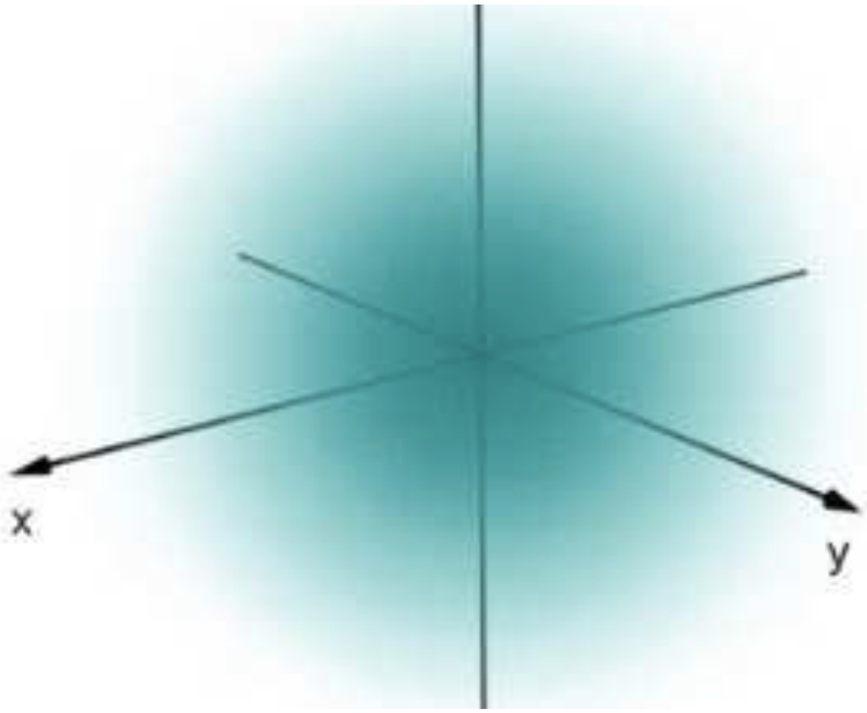
Quiz: Black Box solution



Basics

A quantum system is a delimited unit that obeys the laws of quantum physics. Examples are atoms, elementary particles such as photons and electrons, but also crystals and molecules.

The state of a (quantum) system is the sum of all parameters by which it can be described. In classical states, these are the relevant parameters such as the position and speed of a ball or the angle and angular velocity of a spinning top. In quantum mechanics, the state is also described by the relevant parameters, e.g. the location and velocity of an electron in a hydrogen atom. The difference to classical mechanics, however, is that quantum mechanical states are determined by the superposition of the associated classical states. These superpositions are not exactly known, but can only be specified with a certain probability. You can find an example on the right.

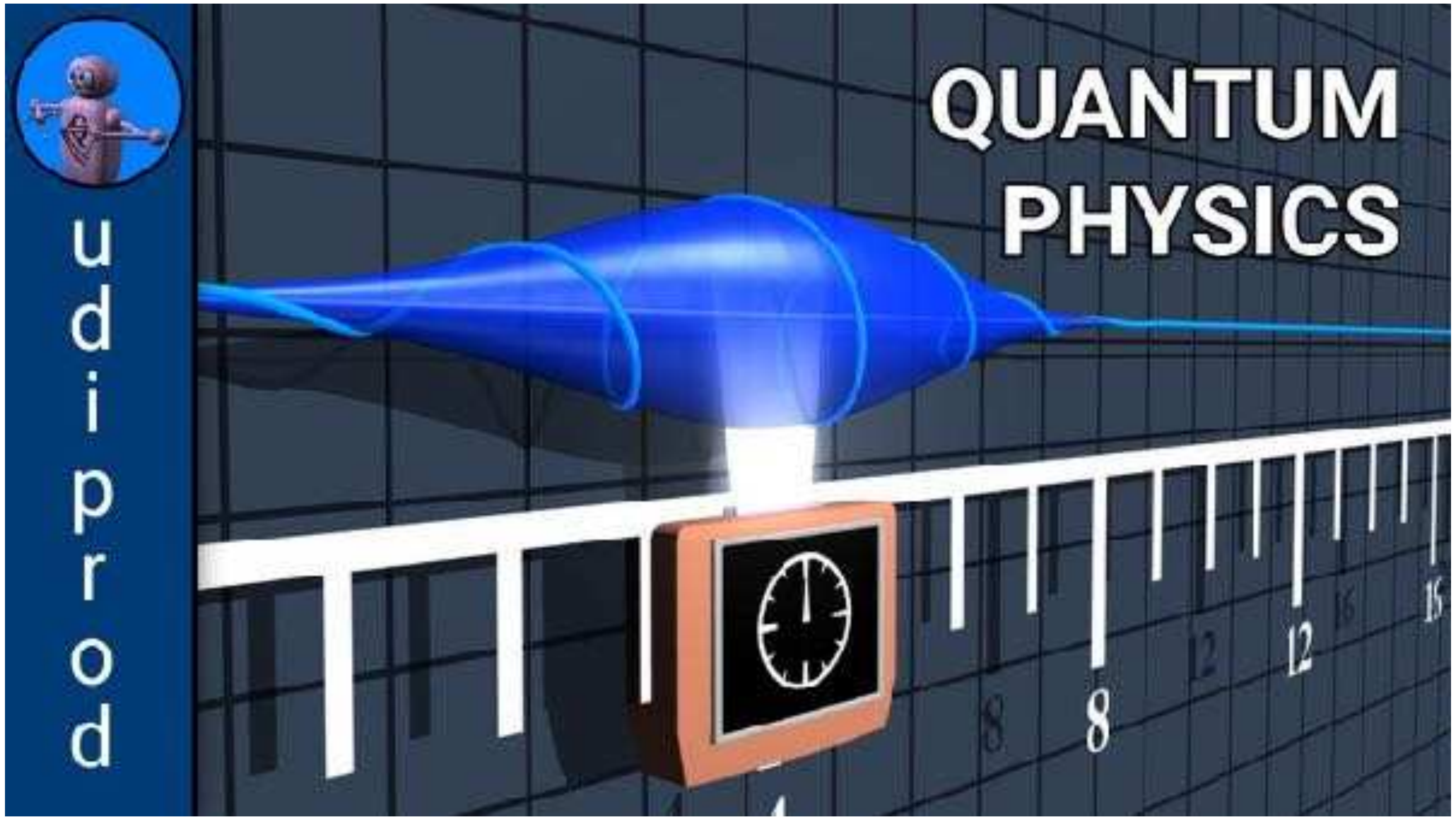


Point cloud in 3D.
The probability of finding an electron in the ground state of the hydrogen atom is shown here as a point cloud. The denser the points are, the higher the probability of finding an electron.

Basics

Probability of location (probability that the particle is at this location) of a point particle in one-dimensional space. The location is distributed over a distance (x-axis) and is only visible as a probability distribution. The greater the amplitude (y-axis), the greater the probability. The spiral is the sum of all possible probability amplitudes for each location on the x-axis. During a measurement, the state collapses to a concrete but random result.

Source: Youtube-Video https://www.youtube.com/watch?v=p7bzE1E5PMY



Glossary

17-BITS PER BYTE

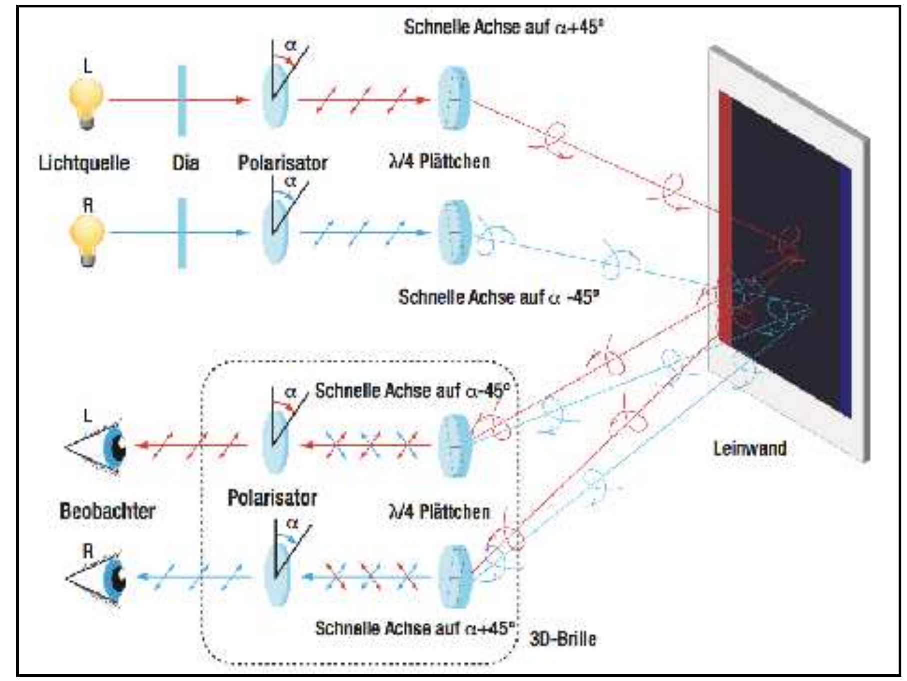
On the CD, the one is written by a change in height and the zero by a constant height. In order for two consecutive ones to be written to the CD, each one must be followed by two zeros. As more zeros are written on a CD than ones, the total length of the information can be shortened. The smallest recess on the CD therefore consists of the sequence of digits: "1001". On average, a byte is thus stretched from 8 to 17 bits.

Related Glossary Terms

Index

3D TECHNOLOGY IN THE CINEMA (REALD)

The glasses that we put on our noses in the cinema consist not only of linear polarization filters, but also of a retardation plate (or $\lambda/4$ plate).



First, the light from the projector or our lamps hits a polarizer, which polarizes the light linearly in the same direction for each eye.
Then comes the $\lambda/4$ plate or retardation plate. It turns linearly polarized light of a certain wavelength into circularly polarized light (and vice versa). Depending on the orientation of the platelet, the transmitted beam is left- or right-handed. Steps one and two are then carried out in reverse order.
When the beam hits the coated screen, it is reflected and undergoes a phase shift of 90°. This means that the previously clockwise rotating beam is now counter-clockwise and vice-versa.

http://psi.physik.kit.edu/img/3D_Brille_Aufbau.png

When it hits the glasses, the first two steps are reversed. This ensures that we only ever receive one of the images in the eye intended for it. This technology also allows us to move our head in the cinema, as it does not matter from which angle the light hits the glasses.

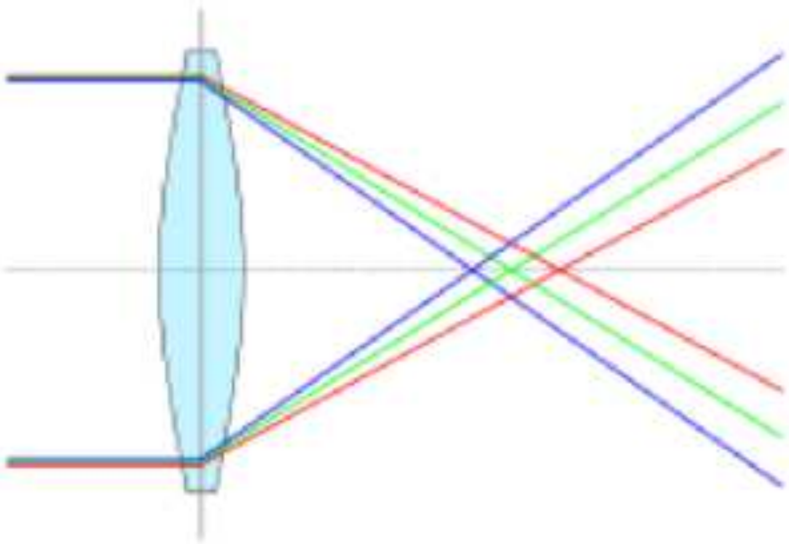
Verwandte Glossarbegriffe

Das λ/4- Plättchen, Zirkulare Polarisation

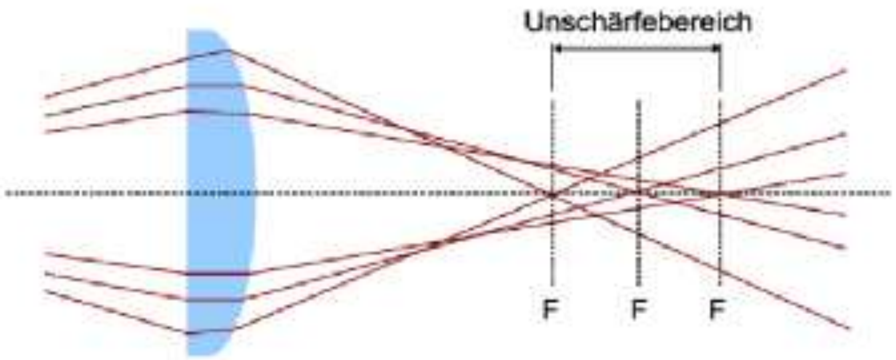
Index

ABBERATIONS

An abberation is an imaging error. A rough distinction is made between
- Chromatic aberration
- Spherical aberration
- Image field curvature
- Astigmatism
- coma
- ...



Here you can see **chromatic aberration**.
This occurs when **light** of different **wavelengths** (colors) passes through a lens. This is because different **colors** are **refracted** to different degrees.



Here you can see spherical aberration. Different focal points can be seen here, i.e. a blurred image. This is because the rays hit the lens at different heights.

https://de.wikipedia.org/wiki/Abbildungsfehler

What is image field curvature?

If an object is imaged and you focus on the center (e.g. with a camera), the background appears blurred because the object is not imaged as a flat (plane) surface, but as a curved surface.

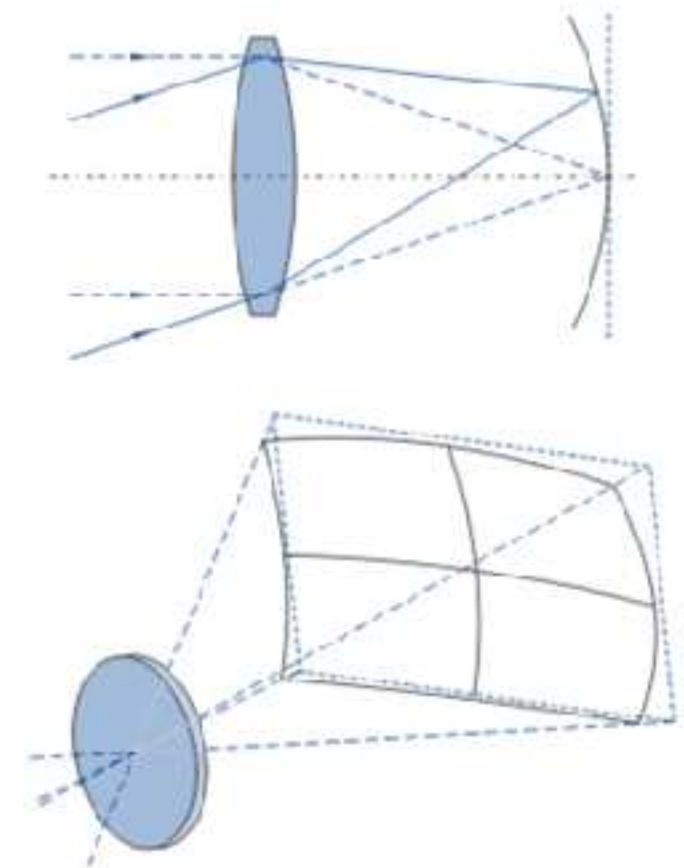
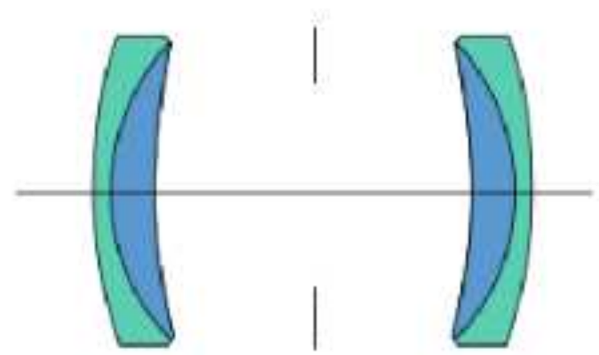


Illustration: Why is the non-focused part of the image out of focus?
The screen is curved, not flat (see image).

What can be done to correct this?
For example, you can use an aplanatic lens, a combination of convex and concave lenses, to correct the error.
Incidentally, this principle was invented by Carl August Steinheil.
Here you can see an Aplanat!



Related Glossary Terms

Index

https://olypedia.de/index.php?title=Datei:Bildfeldw%C3%B6lbung_Wikimedia.png

https://upload.wikimedia.org/wikipedia/commons/thumb/5/56/Rapid_rectilinear.svg/240px-Rapid_rectilinear.svg.png

INSTRUCTIONS FOR ADJUSTING THE QUANTUM CRYPTOGRAPHY EXPERIMENT

1. Sensors

If the sensors are misaligned, the following occurs: You press the fire button on the laser, but the sensor does not respond, although it should respond if the polarization is set.

Procedure:

- Unscrew the sensor and look into the hole where the photodiode is located. This does not necessarily have to be exactly in the center of the hole. The laser must hit the diode exactly.
- Screw the sensor back into the holder and set the laser to continuous operation (press the button for 2 seconds, then release it quickly). Loosen the screws on the sensor (NOT ON THE RADIATOR, unless completely misaligned) and roughly position the sensor so that the laser dot disappears into the hole. Caution: Wear laser safety goggles!

Now the fine adjustment begins.

- Tighten the sensor in the rough position so that it no longer wobbles, but you can still move and turn it by hand.
- One person now stops continuous operation of the laser (press once) and fires the laser every second (press briefly). Another person moves the sensor slightly until it responds to the signal. (Attention: Set the polarization on the turner correctly!!). If the sensor responds, tighten the screws.

2. Lasers/ Polarizers: "Symptoms"

There are essentially three cases in which the sensors can respond. 1, 0 or both. How they respond depends on the polarization of the laser light (e.g. 45° for Alice and 45° for Bob gives a 1). If the polarizer and/or the laser is misaligned, either none of the rotation angles will work correctly, or some cases or sometimes just one case will not work. For example: Alice 45° and Bob 0° correctly returns no result, Alice 90° and Bob 0° correctly returns 0, but Alice 0° and Bob 0° does not return 1 as desired, but no result or even 0.

Procedure: There are now two ways in which the error can occur. First, always try to correct the error using adjustment a). If this does not help, you must try the very time-consuming option b). But be sure to contact the laboratory management first!

a) <u>Only the polarizer is misaligned</u>

On the back of the stands of both polarizers you will find information on the angle at which the polarizer was positioned and worked when the experiment was first put into operation. Set the polarizer to this angle again. If this does not help:

Take one/the case that is not working and set the rotators to the appropriate angles. For example, Alice 45° and Bob 45° gives no result instead of 1.

- Now loosen the screw on top of the polarizer
- One person fires the laser every second.
- Turn the wheel with the scale carefully (usually only very little, approx. 2°-5°) (try both directions) until the sensors deliver the correct result for the rotation settings.
- Screw the polarizer into position and try out all other cases or combinations of rotators. Always compare the result in the table. (It should also be laminated on the table).

- If another case does not work, repeat the procedure described above for this case. Then try all the other cases again. One case may not work again... The whole process must be repeated until you find an angle on the polarizer for which all the cases in the table work.

b) Polarizer and laser are misaligned

Although the laser does not provide linearly polarized light, it does have a preferred direction. The alignment of the laser is therefore important.

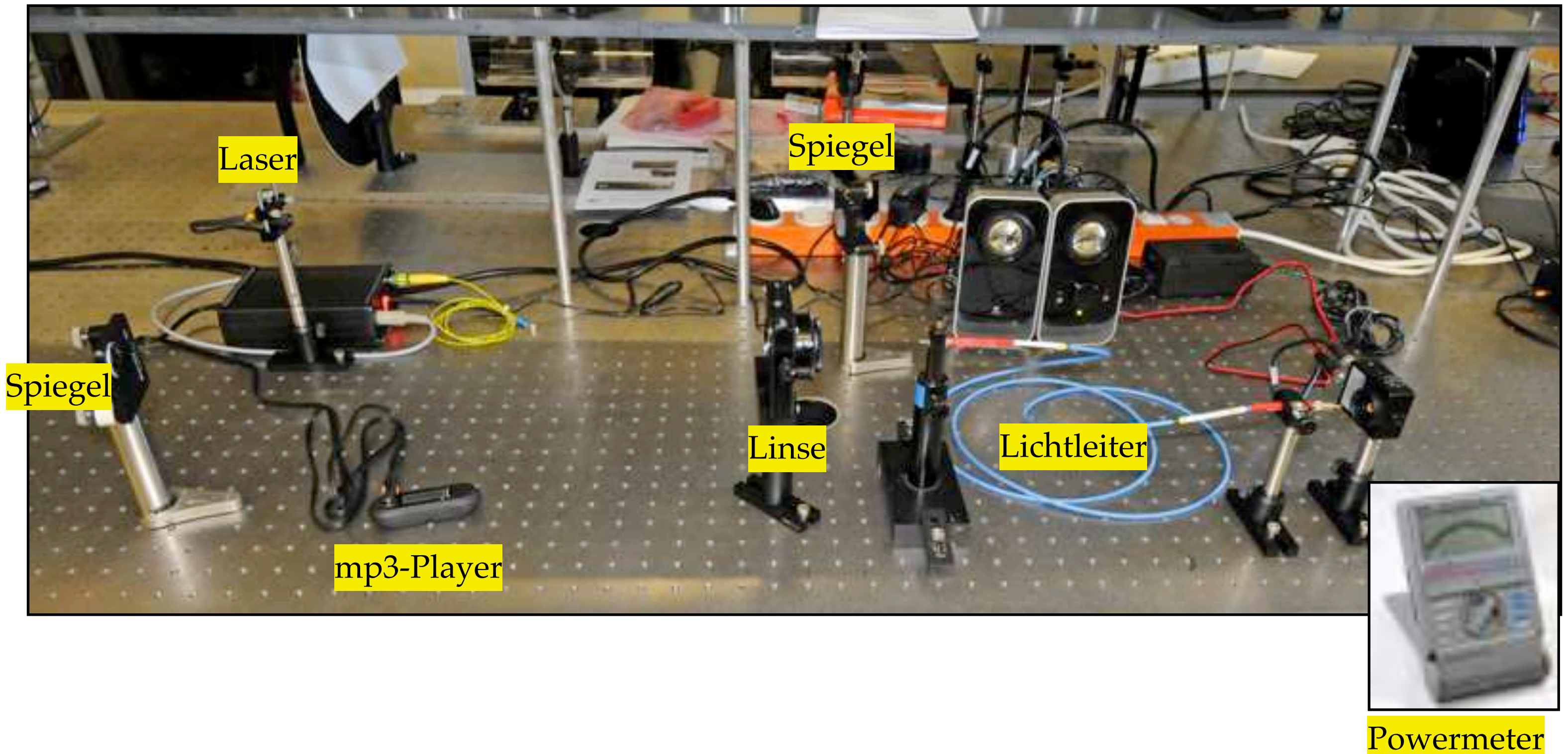
- Remove the polarizer from the setup.
- Set the laser to continuous operation. The beam should fall through the two polarization rotators and the beam splitter cube. Place a sheet of paper in front of the sensors so that both laser points are visible on the paper.
- Set Alice's (or Eve's) rotator to 0° and Bob's (or Eve's) to 90°.
- Loosen the laser holder and turn the laser (without removing it, of course). If you look closely, the intensity of a laser dot on the paper will change slightly. Turn the laser so that the intensity is MINIMUM.
- Screw the laser into this position. The laser is now correctly aligned.
- Now to the polarizer:
- Put the polarizer back into the setup and leave the laser on continuous operation.
- Hold a sheet of paper behind Alice's (or Eve's) polarizer.
- Loosen the screw of the polarizer (see picture above) and turn it until the laser dot on the paper shows a MINIMUM. This is now very clear compared to the laser adjustment just now.
- Note the number of degrees the polarizer is now at and turn it by -90°. For example, if it is at 120°: 120°-90°=30°

- You can now try out all the options in the table. However, it is very likely that an adjustment as in a) is still necessary.

Verwandte Glossarbegriffe

Index

STRUCTURE OF LIGHT GUIDE



Arrange the components as shown in the picture. Make sure that the mirrors are at sharp angles and that they are hit in the middle. The beam height should be 15cm.

Caution:

Do not bend the light guide too much!!!!

Do not touch the light guide, the mirrors or the receiver!!!!

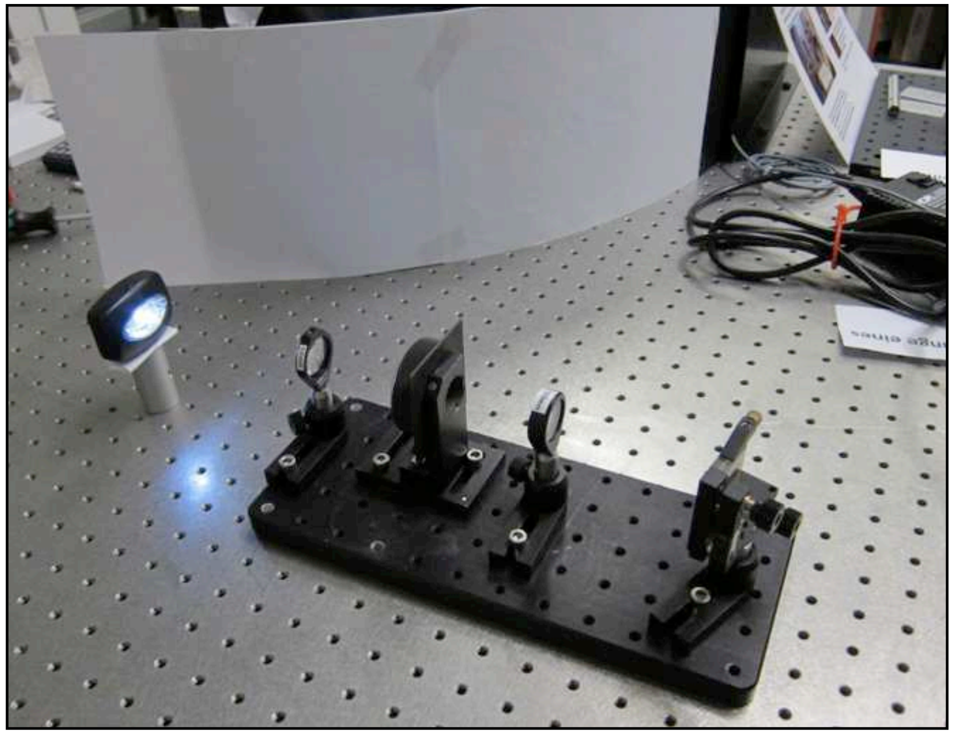
Fix the output of the light guide!

Related Glossary Terms

Index

CONSTRUCTION OF SPECTROMETER

First set the lamp so that only one LED lights up. Position the LED so that the focus is on the slit, check this with a white sheet of paper and trace the further path of the light. When the light hits the center of the lenses and the grating, the first spectra should be visible on the screen. To avoid stray light, you can now place the black sheet between the LED and the screen.



Three spectra should now be visible on the screen if the grating is correctly adjusted. The white one is the 0th order spectrum, the most intense is the 1st order spectrum. Weaker spectra are of higher orders. To achieve the best possible results, you can vary the slit thickness. It may also be necessary to rotate a few lenses or change the distance between the LED and the first lens.

Related Glossary Terms

Index

DIFFRACTION AT THE SINGLE SLIT

For a single slit of thickness h, which is scanned by a laser of wavelength λ (red: λ =633nm, green: λ = 532 nm)* illuminated, the angle α at which the maxima appear is given by the following formula

$$\mathbf{h \cdot \sin(\alpha) = (m + \frac{1}{2})\lambda}$$

(m=1,2,... Order of Maxima)

(Formula for diffraction at a single slit)

For small values, the first maximum is (m=1):

$$\mathbf{h = \frac{3}{2}\lambda\frac{D}{d}}$$

It is interesting that the diffraction pattern (interference pattern) of the single slit and the hair in the far field (i.e. as in our setup) do not differ. This is Babinet's theorem.

Verwandte Glossarbegriffe

Fresnelsche-Zonenplatte

Index

BROWNIAN MOTION

Brownian motion is a random thermal movement of small particles in liquids and gases that are not held in place by a force. The movements performed are statistical and their intensity depends on the temperature. The cause is the permanent movement of the invisible water molecules that collide with the visible polystyrene beads.

Related Glossary Terms

Index

CHROMATIC ABERRATION

What you need: Light source (halogen lamp), lens (f=100mm biconvex), blue (as in the picture) or red color filter, iris diaphragm, screen, grid (object)

1. in principle you use the same setup as for spherical aberration. This time, however, we want to look at chromatic aberration! If you don't know exactly what this is, click here.

2. to correct the chromatic aberration, we now insert one of the two color filters into the system (between the iris diaphragm and the lens). What can you observe?

Now you should only see the image of the grid in the color of the color filter. What we have done is that we have "faded out" all but one of the colors. This reduces the chromatic aberration!

Research question: How does the image width b vary depending on the color of the filter?

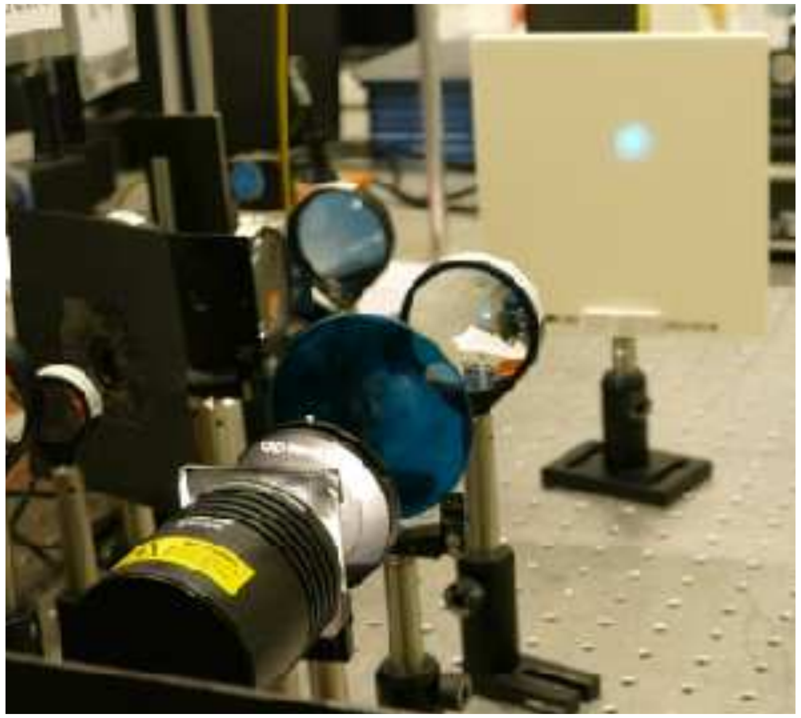
Tip: To always get a sharp image with different colors, move the screen minimally.

A little hint: The image becomes sharper with the blue color filter when the image width is reduced. The opposite is true for red!

CHROMATIC ABBERATION

What you see here:

On the left of the picture is the halogen lamp, right next to it is the grid, next to it is the iris diaphragm and between the lens and the iris diaphragm you can see the blue color filter! On the far right of the picture, at the end of the system, as in the previous experiments, is the screen.



THE $\Lambda/4$ PLATE

This "plate" is also called a retardation plate and is an essential component of RealD glasses. Only this plate enables the use of circular polarization.
The plate turns linearly polarized light into circularly polarized light.
When linearly polarized light hits the plate, which is mounted at an angle of 45° to the optical axis, the vector of the electric field (E vector) is divided into two equal components (vertical and horizontal).

Within the platelet, however, the propagation speed of the light is different, so that a phase delay of a quarter of the wavelength (λ) has occurred between the two parts of the e-vector when leaving the platelet. Whether the light is left- or right-circular depends on the orientation of the retardation plate (+ or - 45°). The cinema glasses contain not only linear polarizers, but also $\lambda/4$ plates. Both polarization filters are aligned in parallel, however one plate lets only right-circular light through, while the other only lets left-circular light through. (You can find a detailed illustration under "3D technology in cinemas (RealD)“.

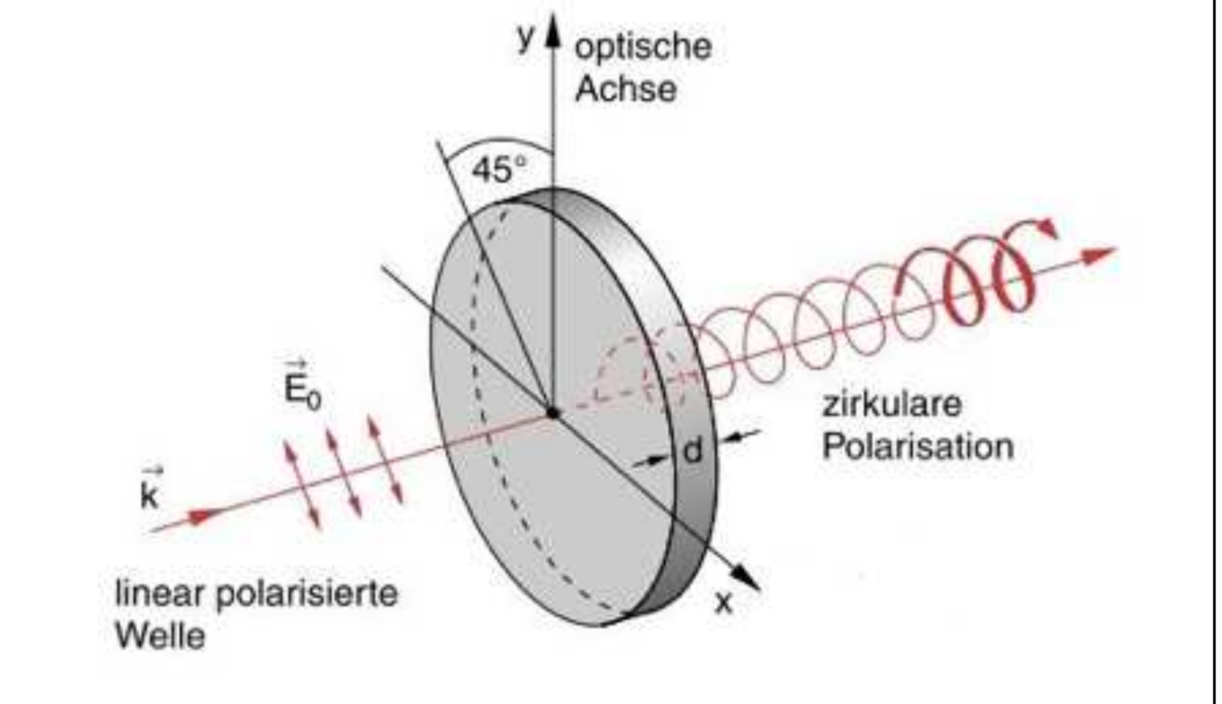


Abb. 2: Erzeugung zirkularer Polarisation

Verwandte Glossarbegriffe
3D-Technik im Kino (RealD)
Index

http://psi.physik.kit.edu/334.php

RULE OF THREE

Distance a ≙ 17 piece of sugar

Distance b ≙ x piece of sugar

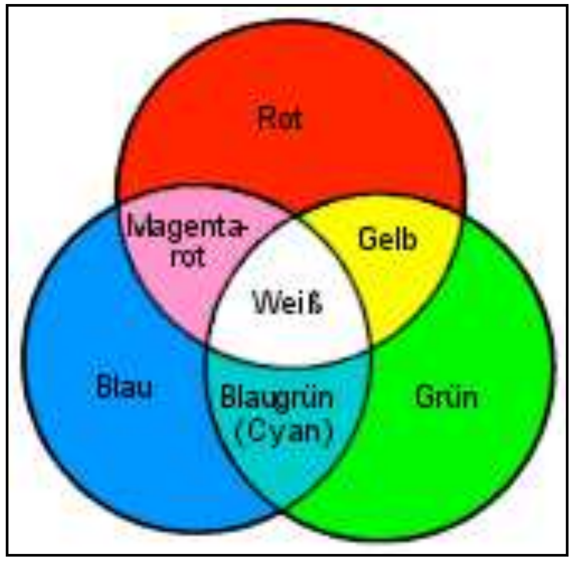
$x = \frac{17 \cdot b}{a}$ piece of sugar

Related Glossary Terms

Index

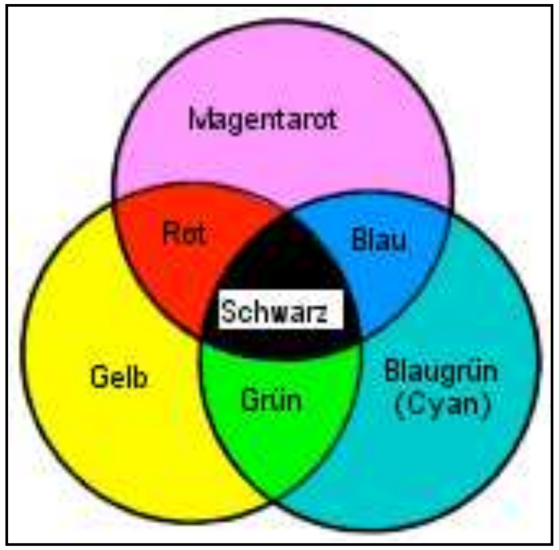
COLOR THEORY FOR PROFESSIONALS: ADDITIVE AND SUBTRACTIVE COLOR MIXING

We all know how easy it is to create our own shade of green from yellow and blue using a watercolor box. But how does this work with light?



In our case, we use the properties of additive color mixing. Here, other colors are created by adding or adding the three basic colors red, green and blue. If you mix all three together, you get white light. (You will need flashlights in the right colors to try this out yourself).

Subtractive color mixing works a little differently: here, different colors are extracted or subtracted from a white light source, such as the light from an overhead projector, using filter foils. The color filters used are magenta, cyan and yellow. If all these components are filtered out of white light, only black or "darkness" remains.



Subtractive color mixing is also used in our printers at home, which is why we need ink cartridges in magenta, cyan and yellow.

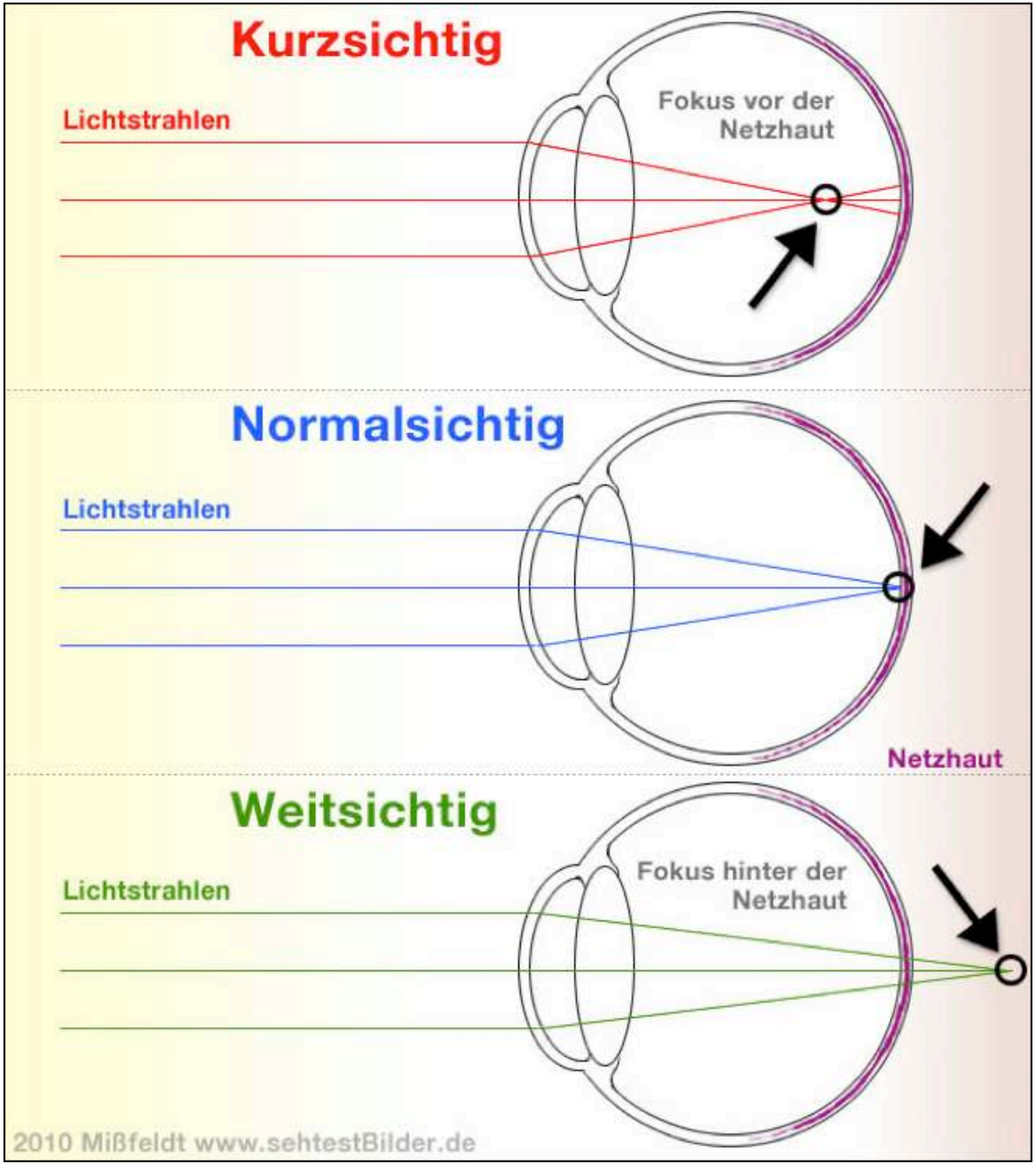
http://www.geoinformatik.uni-rostock.de/images/Subtraktive_Farbmischung.gif
http://www.geoinformatik.uni-rostock.de/images/Additive_Farbmischung_c.gif

Both of these processes are of great importance for the anaglyph technique. Different color filters (red/cyan) are used, which only allow part of the light in the appropriate color to pass through. The other color is blocked in this eye, as the selected colors are complementary colors.
If, as in our experiment, a red and cyan image are superimposed, only one of the half-images is recorded by each eye, as the filters in the glasses block the 'wrong' image.
The biggest disadvantage of this technique is the color representation. The coloring of the individual partial images results in a loss of color, as all colors except red and cyan must be formed by subtractive color mixing.

Verwandte Glossarbegriffe

Index

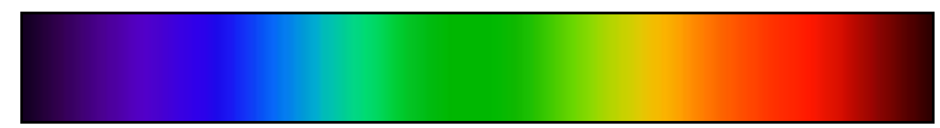
AMETROPIA


Kurzsichtig
Lichtstrahlen
Fokus vor der Netzhaut
Normalsichtig
Lichtstrahlen
Netzhaut
Weitsichtig
Lichtstrahlen
Fokus hinter der Netzhaut
2010 Mißfeldt www.sehtestBilder.de

FRAUNHOFER LINES

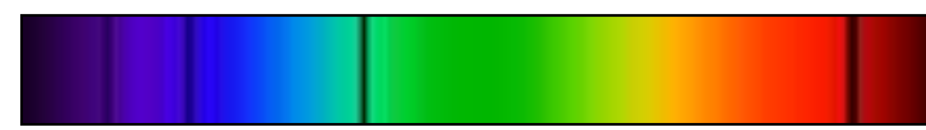
In order to determine the elements of the sun, the spectrum of this light source is also observed. In this case, however, the sun shines in all wavelengths, but due to the absorption and re-emission of certain wavelengths by elements on the surface, these wavelengths do not appear in the spectrum. These dark lines in the spectrum are called Fraunhofer lines. They are the spectrum of the elements that make up the sun.

Continuous spectrum: Complete spectrum



Emission lines: The wavelengths at which an element shines

Absorption lines: The lines that are missing in the solar spectrum



Related Glossary Terms

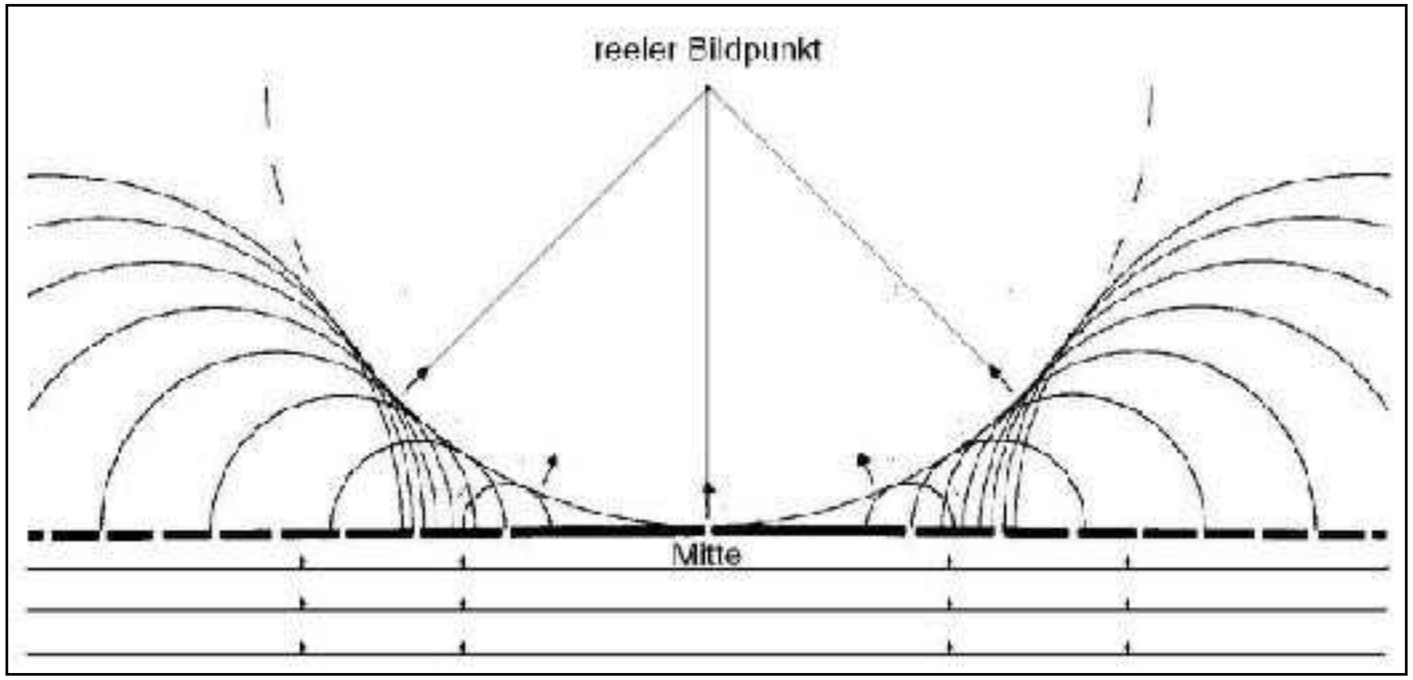
Index

http://de.wikipedia.org/wiki/Spektrallinie

FRESNEL ZONE PLATE

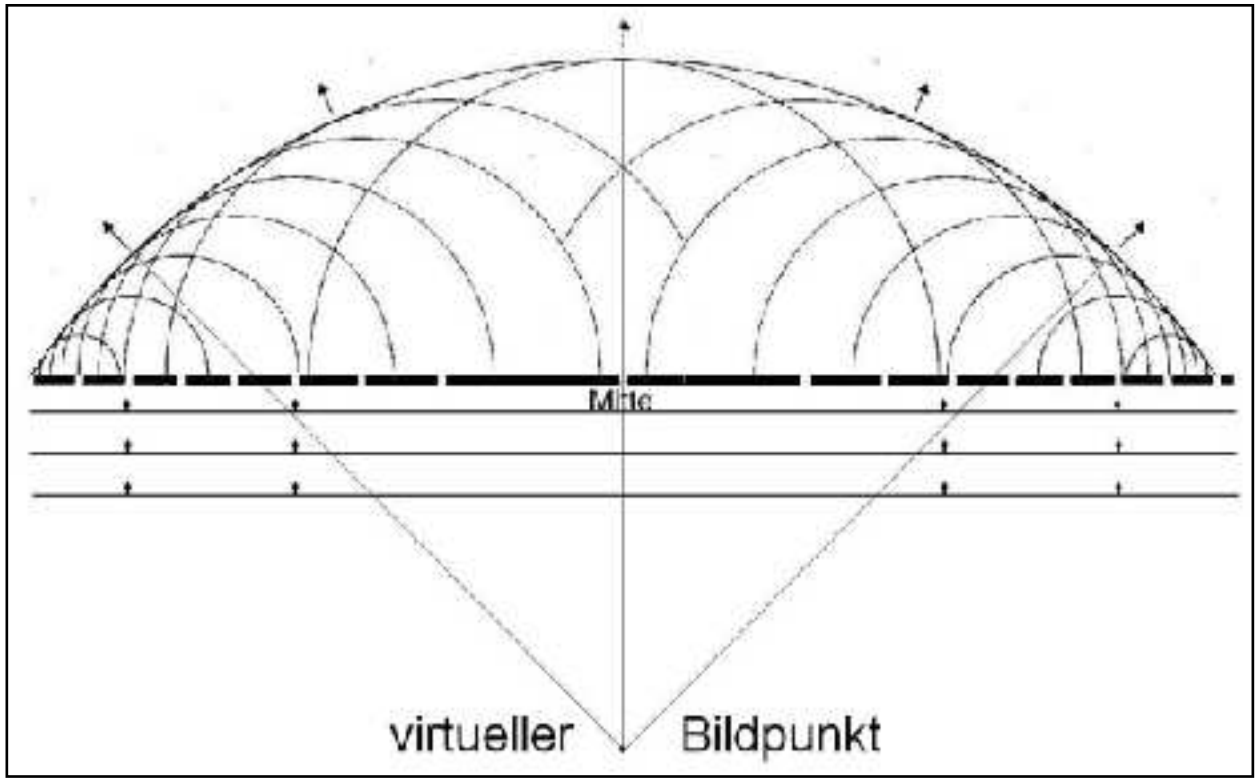
A Fresnel zone plate is an arrangement of concentric zones whose radii are defined by the formula $r_n = \sqrt{n\lambda \frac{gf}{f+g}}$ and are alternately translucent and opaque. This slit pattern can diffract light and therefore functions like a lens with focal length f ; object width g ; wavelength ; n=1,2,3,4.....

If a plane wave hits the Fresnel zone plate, whose object width is infinite, it is bundled at the focal point. This creates a real pixel at a distance f from the plate.



The wave front that runs towards the real image point can be constructed by drawing individual elementary waves. The elementary wave at time T0 is drawn in the middle slit. If you go one slit outwards, an elementary wave is drawn there that was created at a time “-T”, i.e. exactly one period earlier.

If you go three slits outwards, the Elementary wave drawn at time "-2T". If you continue this, these elementary waves complement each other to form a wave front that runs towards the real image point.
However, if you draw the elementary waves outwards at a later period instead of an earlier one, i.e. "+T", a different picture emerges. A wave front is created that comes from a virtual image point behind the plate. (This point is the position of the object when reconstructing a hologram.)



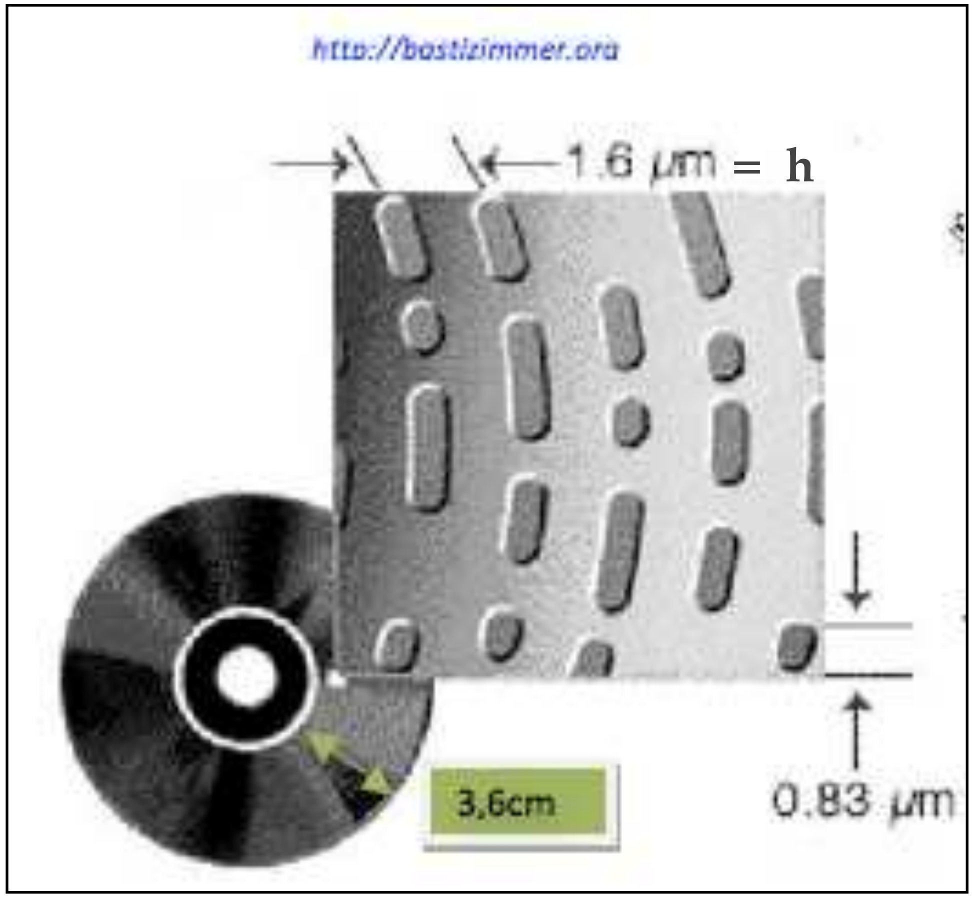
The Fresnel zone plate therefore has the properties of a **converging lens** and a **diverging lens**.

Verwandte Glossarbegriffe
Beugung am Einfachspalt, Interferenz, Interferenz am Doppelspalt

---

Index

Hair thickness: CD or DVD?



Light can also be diffracted by other structures. On a CD, DVD or Blue-Ray disc, the data is stored in grooves. These grooves act like an optical grating for incoming light, reflecting it. The closer the grooves are to each other (the smaller the grating spacing), the more storage space is available. A DVD has more storage space than a CD.

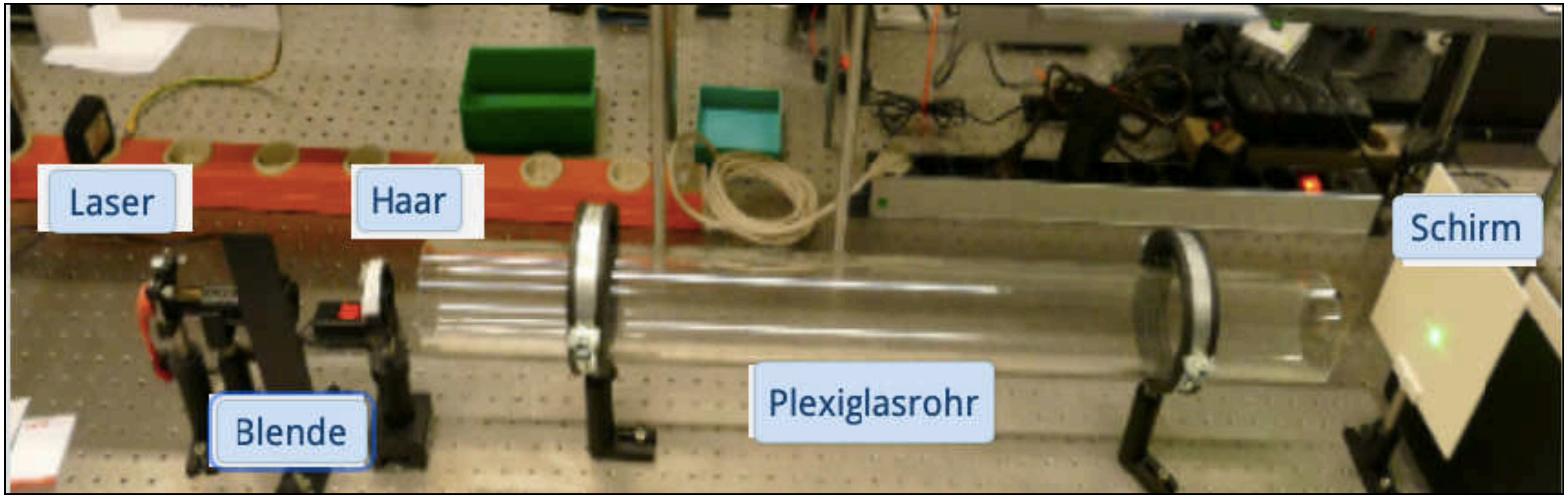
The same formula applies to the reflection of light from an optical grating as for diffraction at a double slit, except that here h is the grating spacing (distance between two grooves).

Now take another look at the formula for diffraction at a grating. This time it is solved for the deflection of the light beam, i.e. d:

$$d = \frac{\lambda D}{h}$$

How must the grid spacing (h) change to increase the deflection?

Solution



Set up the experiment as shown in the picture. The laser beam reflected from the CD or DVD should hit the back of the screen.

Test which of the test objects deflects it more and use this experiment to answer the question on the next page. How can you use the conclusions from the preliminary experiment?

For profis:

Why doesn't this experiment work with a Blue-Ray disc? Can you explain why the Blue-Ray disc was given this name?

Which disc is the DVD?

Which answer is correct?

1. No. 1
2. No. 2
3. Neither
4. They are both DVDs

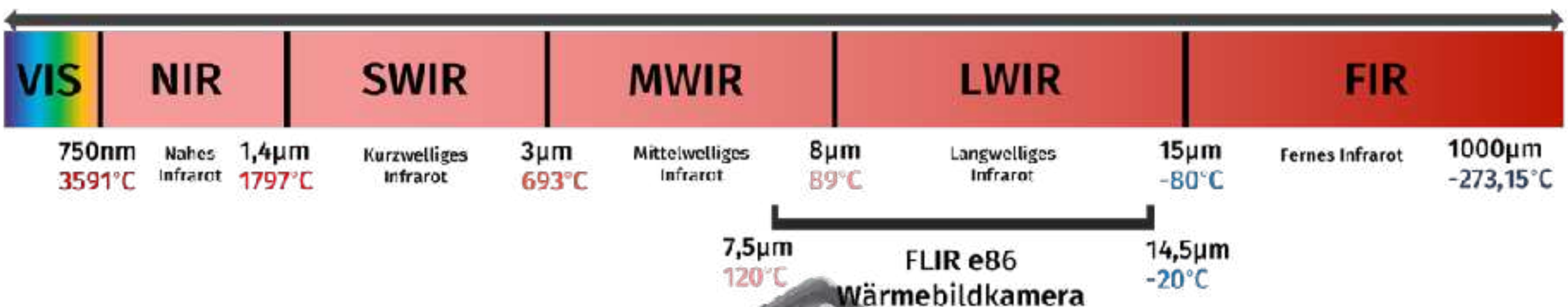
Related Glossary Terms
Index

Answer 1) is correct.

The spectrum of infrared radiation is very large and is divided into several areas.

The thermal imaging camera that you will use is also tied to a specific area.

The emission spectrum together with the properties of the material can be assigned to a temperature. The thermal imaging camera can therefore only determine temperatures in the visible range.



Important! Thermal image does not mean infrared image.

The thermal image is only a representation of the temperatures based on infrared radiation. The actual infrared emission can be different.

Since the thermal imaging camera can only see from 7.5μm to 14.5μm, it is limited to temperatures between -20°C and 120°C.

INTERFERENCE

When waves can meet, they amplify or weaken each other. This effect is called interference. If a maximum meets a maximum, a maximum that is twice as high is created. If, on the other hand, a maximum meets a minimum, the waves cancel each other out. In this way, complicated interference patterns can arise from points of mutual cancellation and amplification.

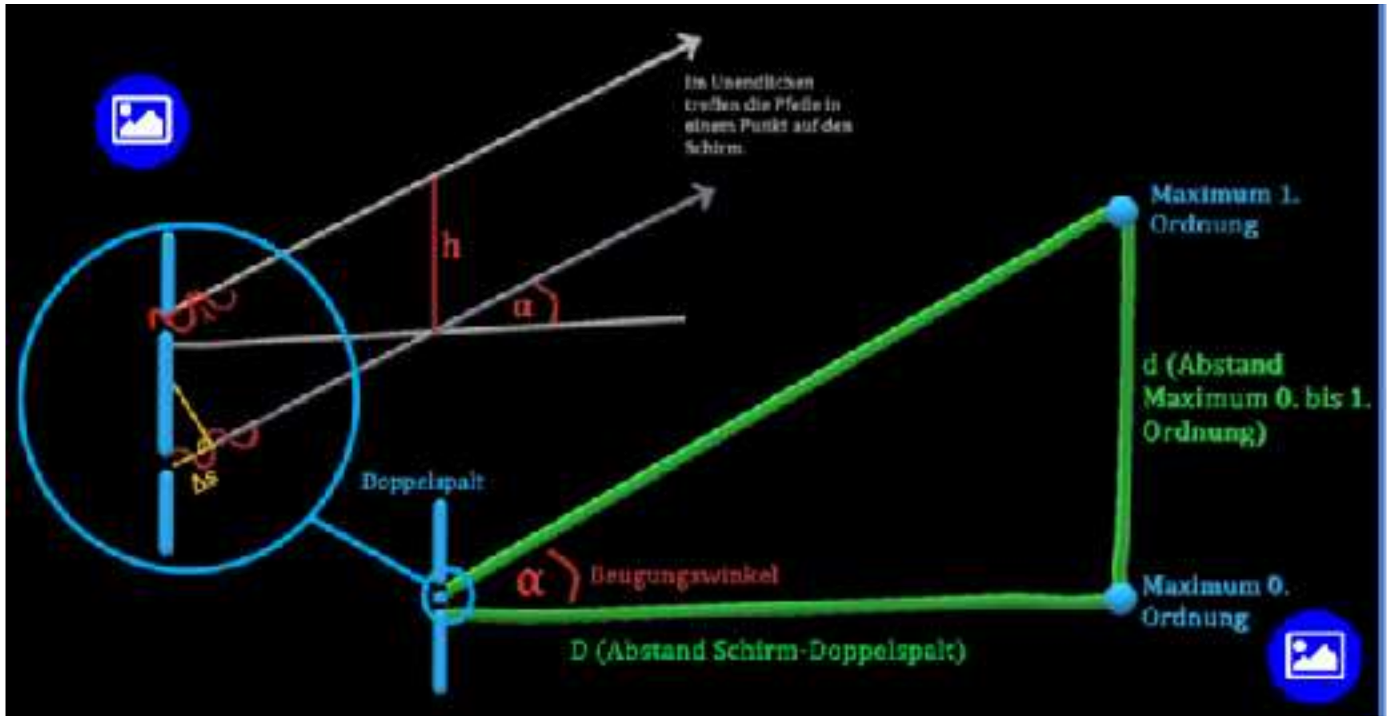
Related Glossary Terms

Fresnelsche-Zonenplatte, Interferenz am Doppelspalt

Index

INTERFERENCE AT THE DOUBLE SLIT

Because the derivation of diffraction at a single slit, such as a hair, is very complicated, the formula for interference at a double slit is explained here, which produces a similar interference pattern. If the difference in length between one slit and a point on the screen and between the other slit and the same point is exactly one wavelength, we get the first maximum.



The two angles in the drawing are equal because they have only been rotated by 90°. Because the distance between the slits is extremely small compared to the distance from the screen, the two lines in the left image can be considered parallel. The adjacent side of the triangle is therefore perpendicular to both lines. Therefore, the other side is exactly the difference in length of the lines. As a reminder: if this is exactly one wavelength ( ), this is the angle at which the 1st maximum appears. The following applies:

$sin(\alpha_1) = \frac{\lambda}{h}$ (from the left image section) und $sin(\alpha_1) = \frac{d}{D}$ (from the right picture section)

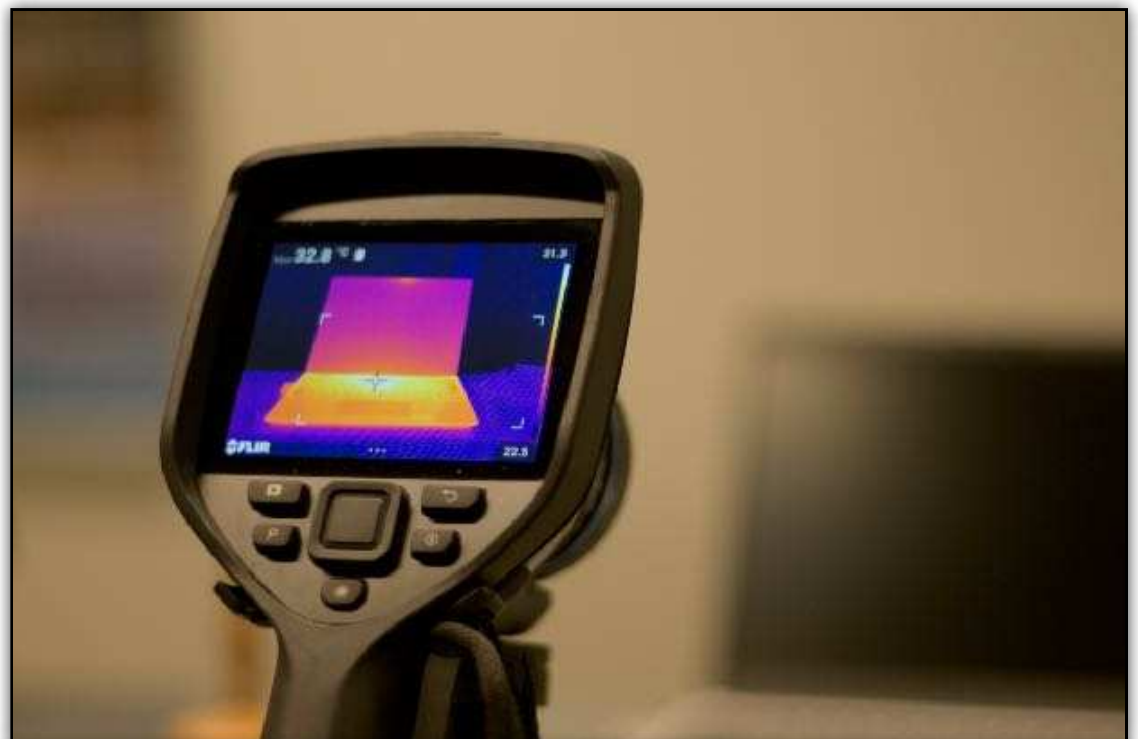
Since both formulas are used for calculation, they can be equated. Solving for the gap distance or the hair thickness (h) results in: $h = \lambda \frac{D}{d}$

As you can see, this formula differs only in a prefactor from the original formula.

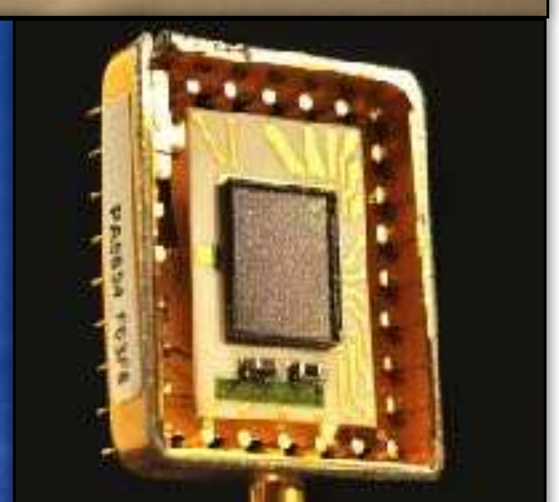
Related Glossary Terms

Fresnelsche-Zonenplatte, Interferenz

Index



Germanium (Source: https://www.flir.com/discover/rd-science/what-are-ir-camera-lenses-made-of/)



Microbolometer (Source: https://en.wikipedia.org/wiki/Microbolometer)

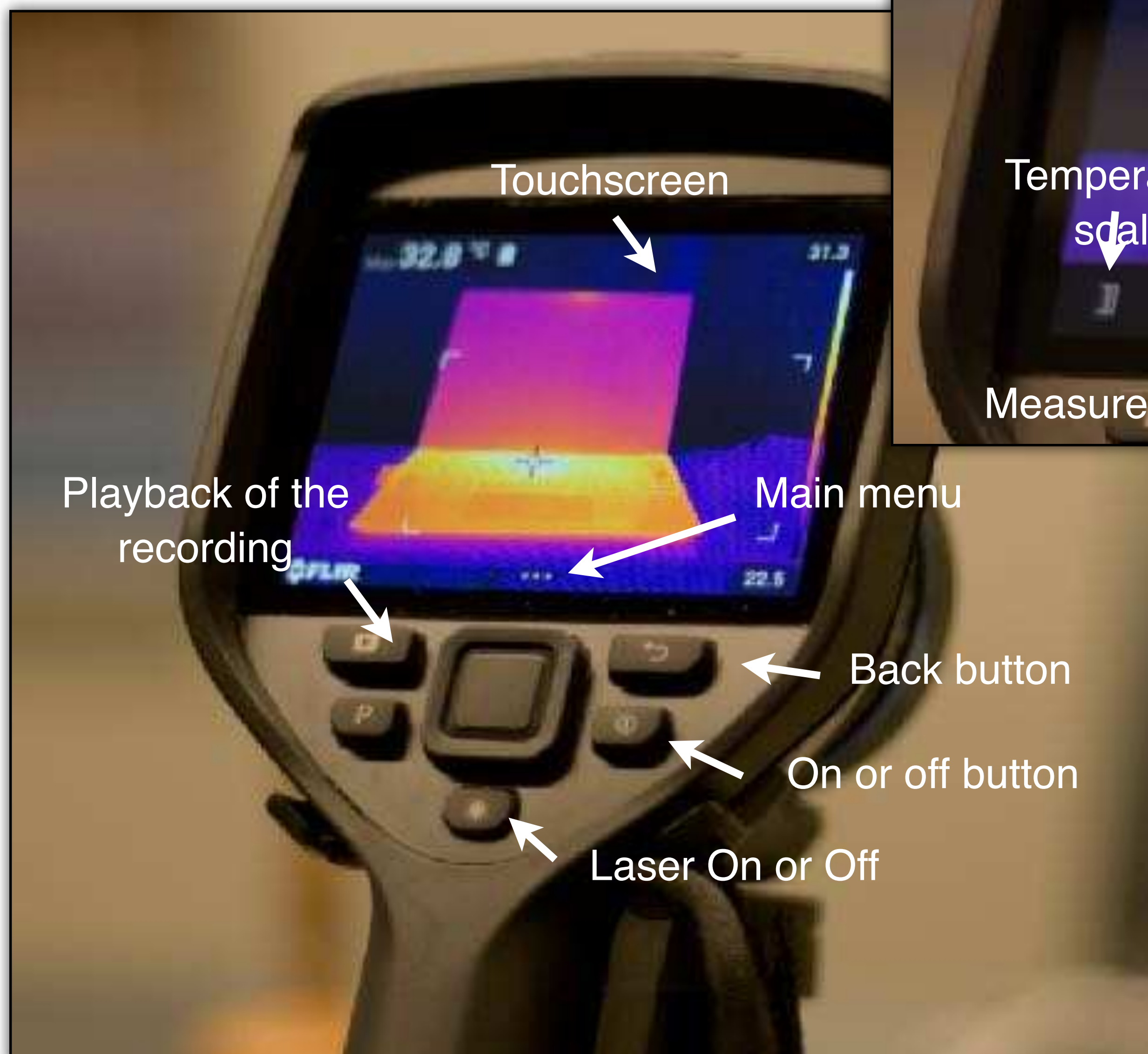
An infrared camera works very similarly to a normal optical camera, collecting infrared light using geometric optics and a sensor.

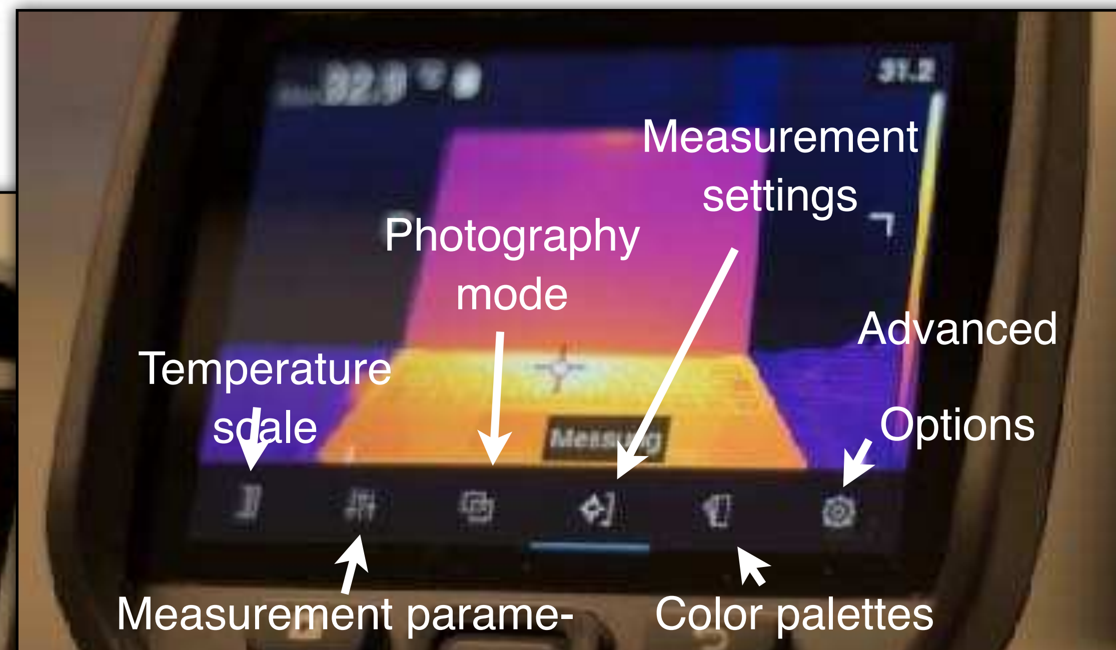
The difference is that it uses a special microbolometer sensor to take the pictures. The lenses for focusing the infrared light are not made of normal glass either. They are made of germanium because it is transparent to infrared light.

These infrared images are then displayed on the screen in false colors.

There is more information on how to use it on the next page.

ADVANCED OPERATION





There are a few options available in the main menu. You can calibrate the camera or just change the false color palette.

Please do not play with the advanced settings. Everything else can be changed, but please undo it after use.

Durch die Absorption der thermischen Strahlung der Erdoberfläche steigt die Temperatur der Atmosphäre und sie beginnt nun ihrerseits in Richtung Erdoberfläche ($I_{\text{Atm.}\rightarrow\text{Erdob.}}$) und in Richtung Weltall ($I_{\text{Atm.}\rightarrow\text{Weltall}}$) abzustrahlen. Da die Atmosphäre in keine Richtung bevorzugt abstrahlt, gilt in diesem einfachen Modell:

$I_{\text{Atm.}\rightarrow\text{Erdob.}} = I_{\text{Atm.}\rightarrow\text{Weltall}}$ (2)

Da sich die Atmosphäre auch im Strahlungsgleichgewicht befindet, muss die eingestrahlte Leistung der absorbierten entsprechen, also:

$I_{\text{Erdob.}\rightarrow\text{Atm.}} = I_{\text{Atm.}\rightarrow\text{Erdob.}} + I_{\text{Atm.}\rightarrow\text{Weltall}}$ (3)

Mit den Erkenntnissen (1), (2) und (3) folgt insgesamt:

$$\underbrace{I_{\text{Erdob.}\rightarrow\text{Atm.}}}_{\substack{\text{von der Atmosphäre}\\ \text{aufgenommene Energie}}} = 0{,}8 \cdot I_{\text{Erdob}\rightarrow} = \underbrace{I_{\text{Atm.}\rightarrow\text{Erdob.}} + I_{\text{Atm.}\rightarrow\text{Weltall}}}_{\substack{\text{von der Atmosphäre}\\ \text{abgestrahlte Energie}}} = 2 \cdot I_{\text{Atm.}\rightarrow\text{Erdob}}$$

Und damit:

$I_{\text{Atm.}\rightarrow\text{Erdob.}} = 0{,}4 \cdot I_{\text{Erdob.}\rightarrow}$ (4)

40 % der von der Erde emittierten Strahlung werden also von der Atmosphäre wieder in Richtung Erde zurückgeschickt. Und hier liegt der grundlegende Unterschied zwischen einer Erde mit Atmosphäre und der Felsenerde:

Die Erdoberfläche wird von der Atmosphäre als weitere Strahlungsquelle bestrahlt!

Auch hier wird sich ein Strahlungsgleichgewicht einstellen und so muss die Erdoberfläche diese zusätzlich eingestrahlte Energie auch wieder abstrahlen. Es gilt also:

$$\underbrace{I_{\text{Erdob.}\rightarrow}}_{\substack{\text{von der Erdoberfläche}\\ \text{abgestrahlte Energie}}} = \underbrace{I_{\text{Sonne}\rightarrow\text{Erdob.}} + I_{\text{Atm.}\rightarrow\text{Erdob}}}_{\substack{\text{von der Erde aufgenommene}\\ \text{Energie}}} = \underbrace{I_{\text{Sonne}\rightarrow\text{Erdob.}} + 0{,}4 \cdot I_{\text{Erdob.}\rightarrow}}_{\text{mit Gleichung (4)}}$$

Aufgelöst nach $I_{\text{Erdob.}\rightarrow\text{Atm.}}$ ergibt sich:

$$I_{\text{Erdob.}\rightarrow} = \frac{1}{1-0{,}4} \cdot I_{\text{Sonne}\rightarrow\text{Erdob.}} = \frac{1}{1-0{,}4} \cdot 238\,\frac{W}{m^2} = 397\,\frac{W}{m^2}$$

ADJUSTING THE MIRRORS

Attention: Do not touch the mirrors when adjusting!

Adjustment is done by turning the screws on the mirror holder. This deflects the laser beam vertically or horizontally. Fine adjustment is done by turning the adjustment screws, which tilts the mirror and deflects the laser beam horizontally or vertically.

Rough adjustment of the height: Loosen the screw on the post (=rod of the holder).

Rough adjustment on the side: Loosen the screw that secures the holder to the laser table.

Related Glossary Terms

Index

ADJUSTING THE POLARIZATION FILTERS

Attention: Do not touch the mirrors when adjusting!

The polarization filters are often misaligned. Here are a few tips on how you can try to solve the problem:

-Place a filter in each arm and turn it until the interference disappears: The filters are now perpendicular to each other.

-Then place the 3rd filter between the beam splitter and the screen and turn it until the interference is as strong as possible. The 3rd filter is now at a 45° angle to the other two!

Related Glossary Terms
Index

ADJUSTMENT MODE - MEASUREMENT MODE QUANTUM CRYPTOGRAPHY

The sensor electronics have a green button that switches between adjustment mode and measurement mode. In adjustment mode, the LED on the side lights up yellow. If this mode is activated, BOTH blue LEDs on the sensors light up when a laser pulse of the same intensity arrives at them - this corresponds to the cases where Alice and Bob's bases do not match.
The measurement mode, in which the LED lights up green, behaves differently in the case of different bases: It randomly selects one of the two blue LEDs and lights it up. This simulates the path of a single photon that is randomly transmitted or reflected at the beam splitter with 50% probability.

Verwandte Glossarbegriffe

Index

CHAIN LENGTH TEST: HOW RANDOM IS THE RANDOMLY THROWN BINARY CHAIN?

We ask ourselves how likely a chain of ones of length "at least 4" is with 100 dice.
1 ≤ run length (here 4) ≤ 100) is satisfied in a bit sequence of length 100, so we can now calculate the probability.
To determine the probability, we divide the 100 numbers (0s and 1s) into 25 blocks of 4. Now the probability that a chain of length 4 is created is exactly 2/16 and that it does NOT happen is 1-2/16=7/8 (= counter probability).
Now it is necessary to raise to the power of 25, since we divided the 100 at the beginning, but we want to look at the length of the probability "at least one block of 4 with 100 random numbers".
To do this, we raise the probability of the opposite event $(7/8)^{25}$= 0.0354... to a power and round up a little (since this calculation is an estimate).
With a probability of about 95%, there is a chain length of 4 for good random numbers. With only 100 dice, the probability is very high that four numbers will appear in succession without changing. Check the numbers you have rolled yourself.

Related Glossary Terms
Index

COPENHAGEN INTERPRETATION

Avoiding a clear idea of how quantum objects behave "on the move" is also called the Copenhagen interpretation.

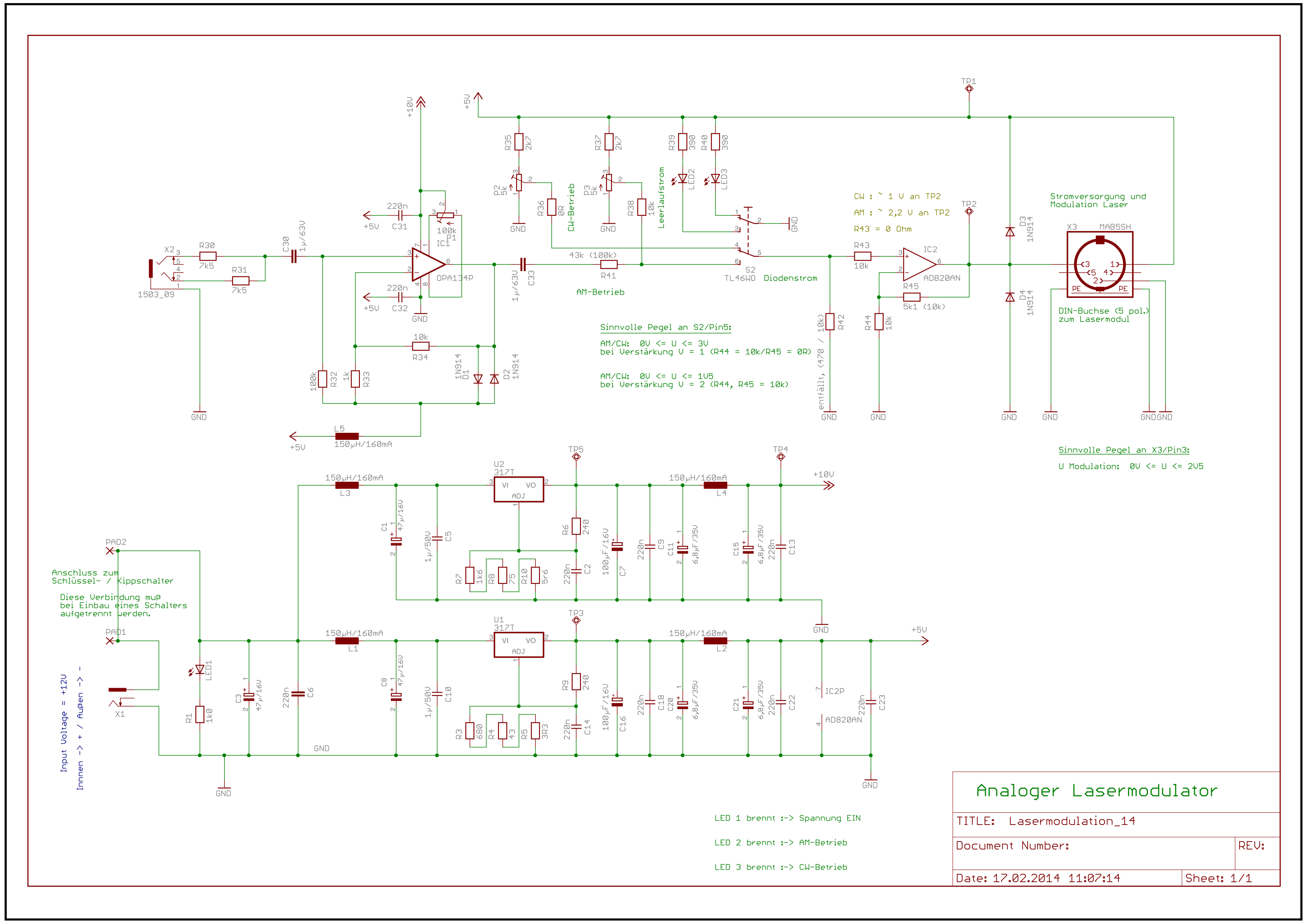
The Copenhagen interpretation is an explanation of how the world of tiny particles works in quantum mechanics. It states that these particles, like electrons, are not really in a specific place or state before we measure them. Instead, they are in a kind of "fuzzy" or "smeared" state in which they could be anywhere and have different properties at the same time. Only when we make a measurement does this state "collapse" and the particle shows us a specific place and property. This means that quantum mechanics is very probabilistic, since we cannot predict exactly what will happen in a measurement in advance.

Related Glossary Terms

Index

Laser modulator

Circuit diagram of the laser modulator used in the student laboratory.

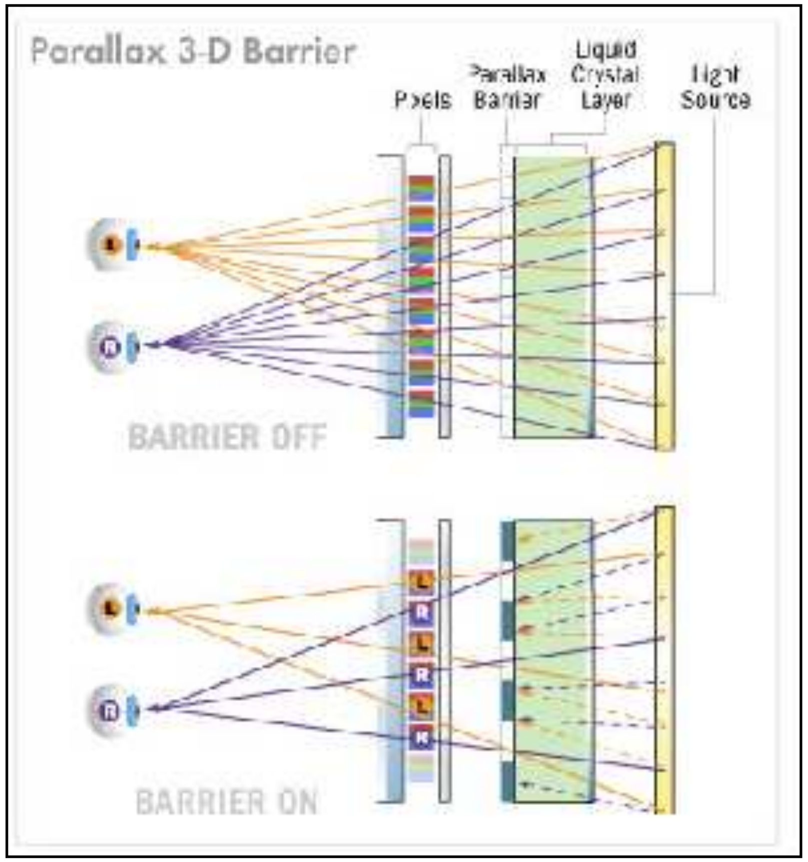


Related Glossary Terms

Index

LAYER DISPLAYS / PARALLAX FUNCTION

This technology works without glasses. The prime example of this is the Nintendo 3Ds, televisions or smartphones.
The device has several *layers* built in its display. Each layer has a very specific function.
The first layer only gives us the background light (source light).



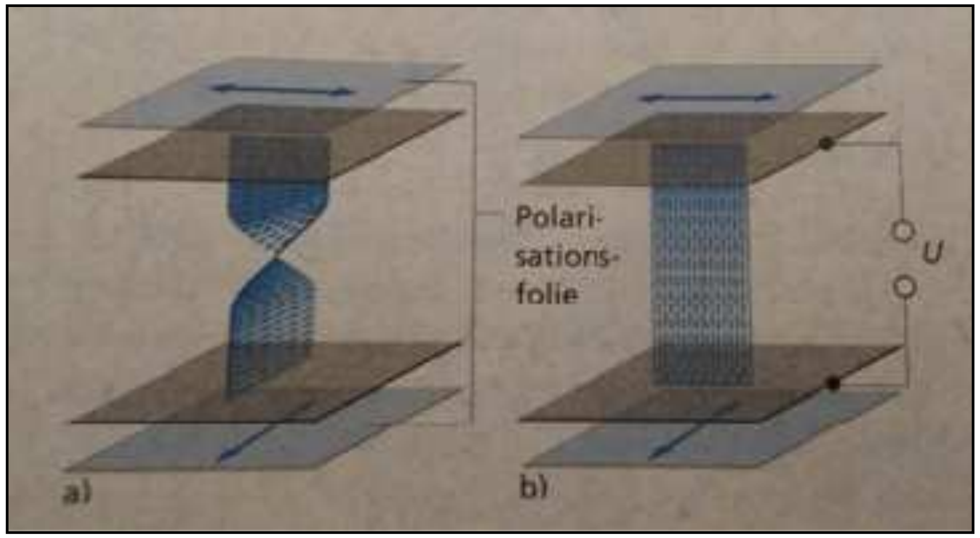
The second consists of an LCD display, which sends out the images we can see.
The third layer is called a parallax barrier. When activated, it ensures that only one image from one angle reaches one of our eyes. A good comparison are old wobbly images: here, you change the angle and thus the image you see by tilting it. In the displays, all of this happens electronically.
The so-called 'sweet spot' can only be found by calibrating beforehand. At this point, only one image really hits the right eye. This is also the big disadvantage of this technology, as the user has to remain relatively static in his position in order to enjoy the effect.

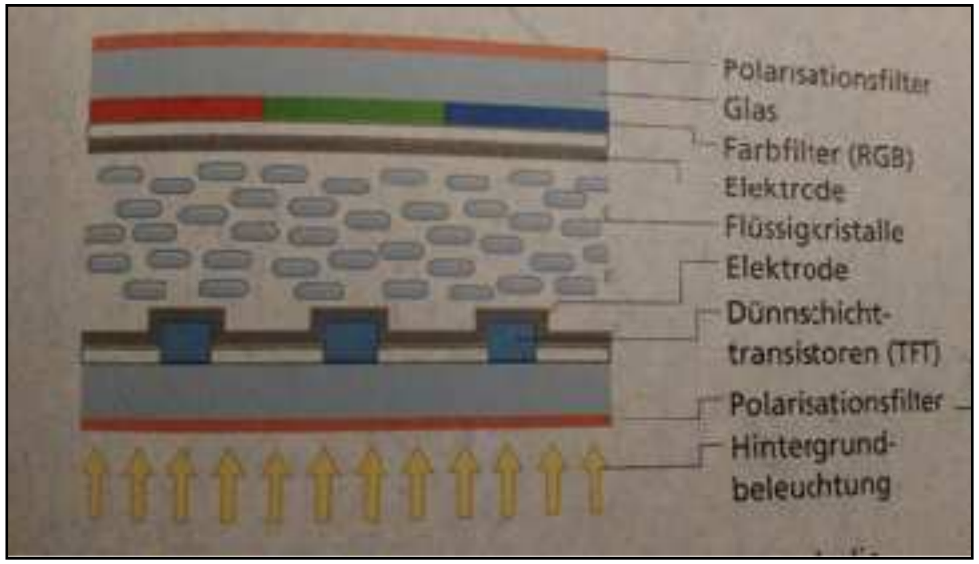
Related Glossary Terms

Index

https://www.nintendo.de/Nintendo-3DS-Familie/Nintendo-3DS/Nintendo-3DS-Funktionen-114646.html

LCD-DISPLAYS





We are all familiar with liquid crystal displays (LCD) from our homes, as they are built into televisions and computers. But how do they work and why do they emit polarized light?

The displays consist of a layer of long-chain, molecular liquid crystals sandwiched between two specially polished glass plates. These can move freely against each other at room temperature. The glass plates are covered on the outside with polarization films whose transmission directions are perpendicular to each other.

The crystals are aligned by the special production of the glass plates so that they are perpendicular to each other on opposite sides. A kind of spiral staircase is formed between them (see adjacent illustration).

When a beam of light hits the cell from below, it is directed towards the molecules by the polarizer. When the light passes through the crystal cell, an extraordinary interaction occurs. The direction of polarization rotates by 90° as it follows the orientation of the molecules.

By applying a voltage to the cell, its ability to transmit light can be influenced. In an LCD display there are cells in the colors red, green and blue. These can be controlled with the help of transistors. The cells can be switched on and off individually. This gives us an image composed of pixels. As the light coming from the backlight undergoes the polarization process just described, an LCD display emits polarized light.

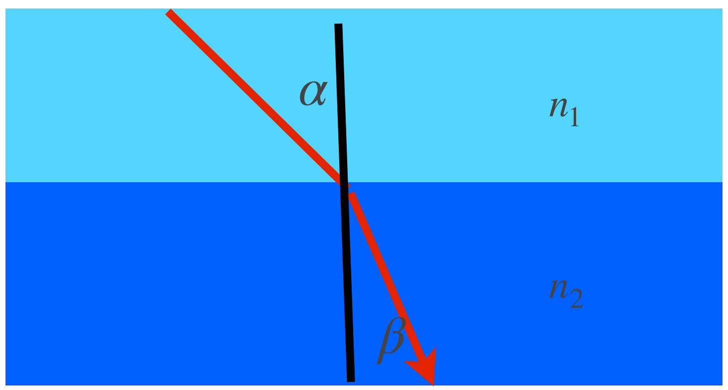
Illustrations from: Diehl Bardo, Erb Roger, Harri Heise und Kotthaus Udo, eds. 2009. *Phyisk Oberstufe-Gesamtband*. Berlin. Cornelsen Verlag.

Verwandte Glossarbegriffe

Index

REFRACTION OF LIGHT

Summary:
If a beam of light hits the boundary between two materials with different refractive indices, it is refracted at the boundary, i.e. it changes direction. If the light beam passes from a medium with a low refractive index (e.g. air) to one with a higher refractive index (e.g. water), the light beam is refracted towards the perpendicular at the boundary of the media - when it enters a medium with a lower refractive index, on the other hand, it is refracted away from the perpendicular. This spoon therefore has a kink due to the phenomenon of refraction!



Material with a low refractive index

So what is refraction?

Refraction is a change of direction of an incident light beam onto another medium with a different refractive index. This happens because light propagates at different speeds in different materials. If you want to express this as a formula, it looks like this: c(n) is the speed of light in the medium, c_0 is the speed of light in a vacuum and n is the refractive index.

$$c(n) = \frac{c_0}{n}$$

More details can be found on the next page.

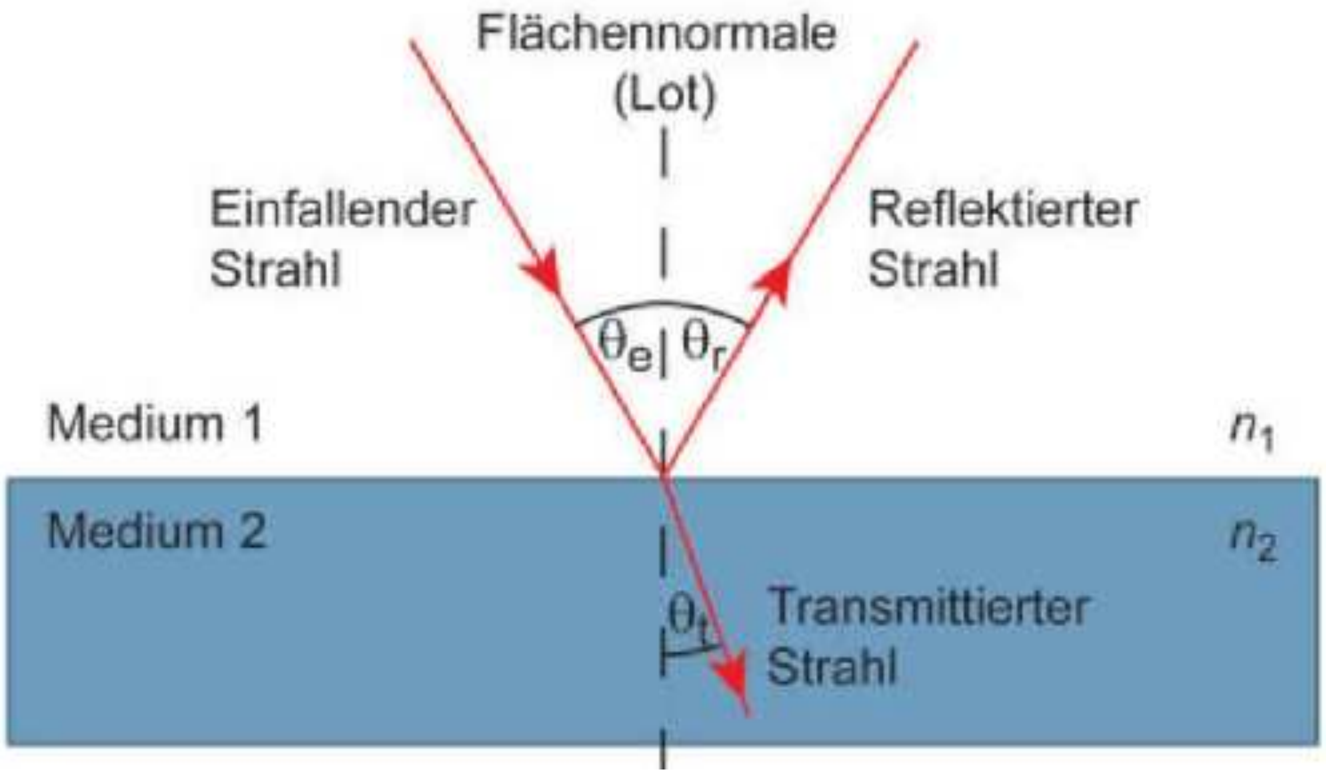
https://de.123rf.com/photo_20391393_beispiel-des-wassers-brechung-mit-einem-glas-und-l%C3%B6ffel-.html

REFRACTION OF LIGHT

The image shows the refraction and reflection of a ray: An incident ray from the homogeneous medium 1 hits the surface of medium 2. n is the refractive index, i.e. a unitless number that describes how strongly or weakly the light is refracted/reflected.
The angles (e=incidence angle, r=reflection angle and t=transmission angle) describe the path of the rays.

The change in direction of the refracted ray can be described by the law of refraction (Snelli's law):

$$n_1 \sin(\theta_c) = n_2 \sin(\theta_t)$$



Geometrische Optik, Lehrbuch zur Exprimentalphysik, Joachim Heintze (Quelle)

LENS EQUATION

If the object to be imaged emits light and this light, after passing through an optical system, collects in a point on a screen, then we have an image!

In this case, three representative auxiliary rays emanate from the object with object distance g (distance from object to lens). Path 1 first runs parallel to the optical axis (axis of symmetry) and then through the focal point F_b. Path 2 first runs through the focal point F_g and then parallel to the axis. Path 3 passes directly through the center of the lens (center beam). The distance from the lens to the image is called the image width b.

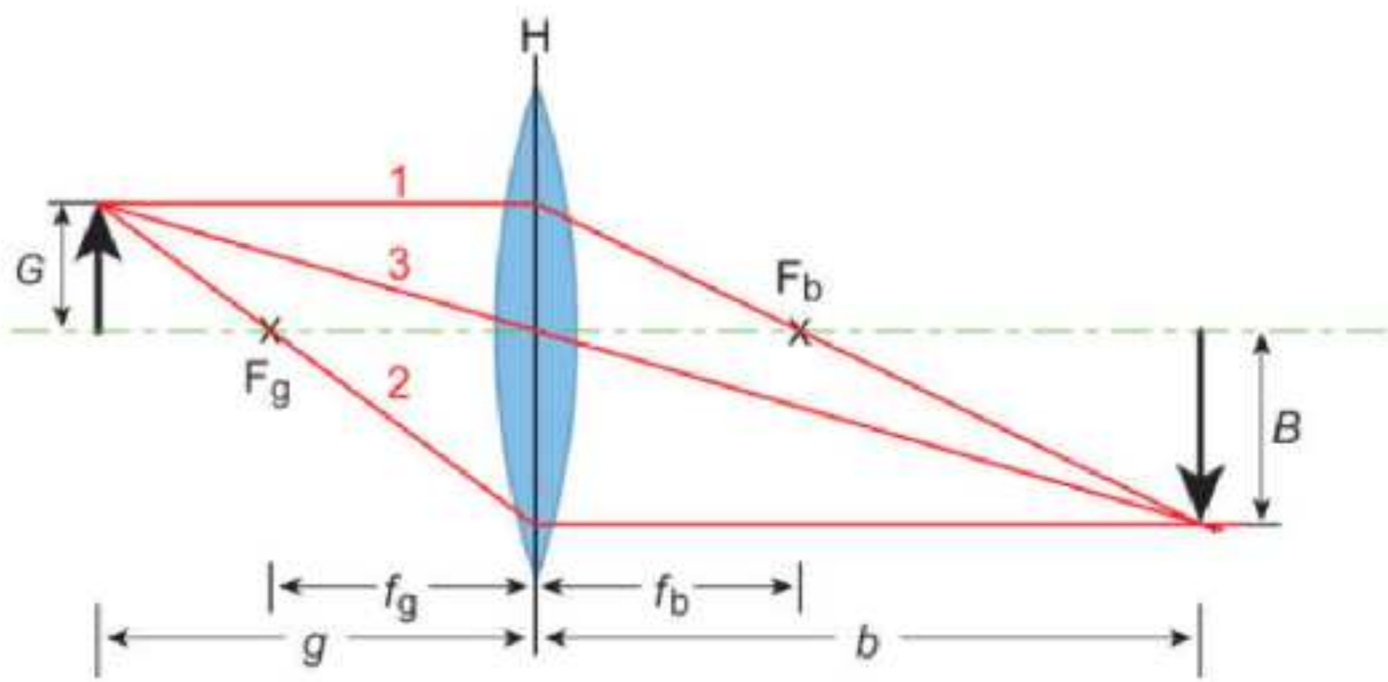
Disclaimer: In reality, of course, many more rays are emitted from the object than in the picture.

Also important is the focal point F of the lens, where rays incident parallel to the axis meet.

The famous **lens equation** or imaging equation

describes the relationships between these variables:

$$\frac{1}{f} = \frac{1}{g} + \frac{1}{b}$$

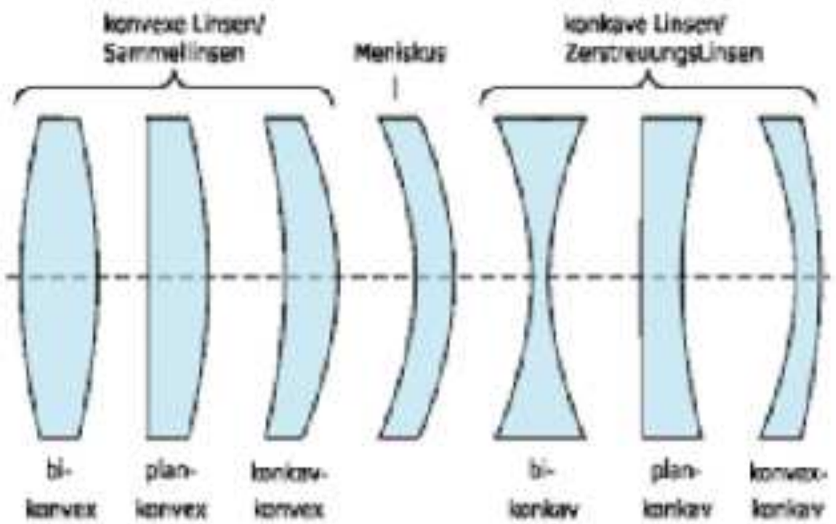


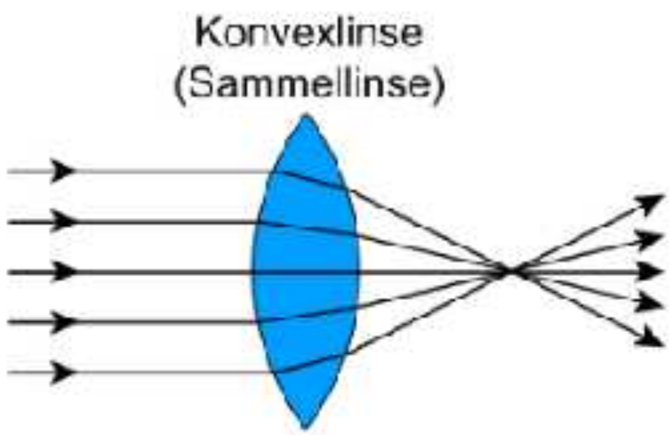
https://de.wikipedia.org/wiki/Geometrische_Optik

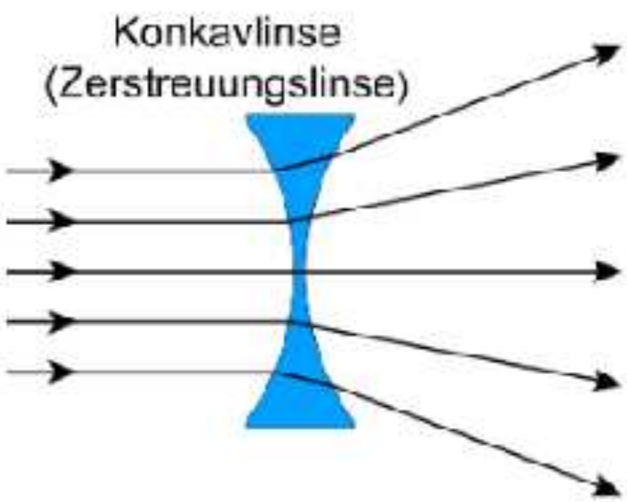
LENSES

Lenses change the **beam path** by **dispersing** (concave lenses) or **collecting** (convex lenses) light. They do this by refracting the light rays at the **entrance** and **exit surfaces** in accordance with the law of refraction described above. The rays do not change direction in the lens itself.

A biconvex lens collects the incident light rays, a biconcave lens disperses them.







https://www.leifiphysik.de/optik/optische-linsen/grundwissen/linsenformen

https://de.wikipedia.org/wiki/Linse_%28Optik%29

SOLUTION GEOMETRICAL OPTICS, EXPERIMENT 1

Question: Is there a second object width (or image width) at which you get a sharp image?

Solution: In the experiment, the second sharp image point is very difficult to localize. This is because the image is very small. Mathematically, the case is also something for professionals because the equation is complex to solve. The equation is quadratic and solving it with the midnight formula can result in two solutions.

SOLUTION BLUE-RAY-DISC

Because the track groove spacing on a Blue-Ray disc is much smaller than on a DVD (0.32 m), green light is no longer reflected by this grating. Light of a smaller wavelength (e.g. blue) is needed to resolve these structures. The Blue-Ray is named after the color of the laser needed to read it.

Related Glossary Terms

Mikrometer

Index

SPECTROMETER SOLUTIONS

Below you will find the resolutions of the various spectra under the glossary chapter "Spectrum 1-5", or here: Page 335

Related Glossary Terms

Spektrum 1, Spektrum 2, Spektrum 3, Spektrum 4, Spektrum 5

Index

MICROMETER

$1\ \mu m = 1$ Micrometer $= 10^{-6} = 0.000001$ m

Related Glossary Terms

Lösung Blue-Ray-Disc, Nano

Index

NANOMETER

1 nm (Nanometer)= 10^{-9}m = 0.000000001 m

1 ns (Nanoseconds) = 10^{-9}s = 0.000000001 s

Related Glossary Terms

Mikrometer

Index

OPTICALLY ACTIVE SUBSTANCES

All molecules have centers of charge, and therefore also an electric field, which is generated by the electrons. As light also has an electric field, the field of the molecules interacts with the light - the wave is deflected. However, the molecules are statistically distributed in a solution. So why is the wave in the sugar solution not also deflected in the opposite direction, so that it emerges unchanged at the end of the cuvette? The reason for this is chirality. Glucose is chiral, i.e. it has no axis of rotation and no exact mirror image that could reverse the deflection. It is therefore optically active. The light in the glucose solution is therefore always deflected in the same direction. Glucose deflects to the right, other substances (e.g. fructose) deflect to the left - depending on the respective molecular structure.

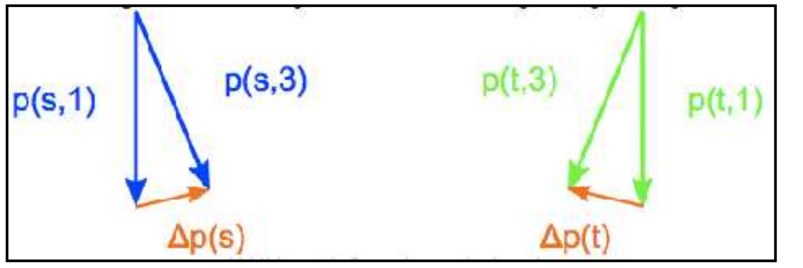
Related Glossary Terms

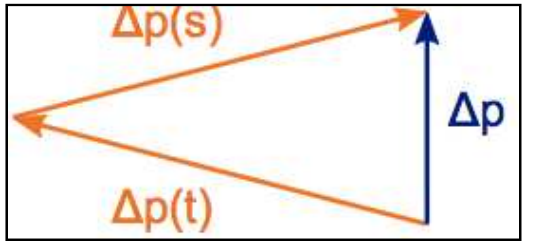
Polarisation

Index

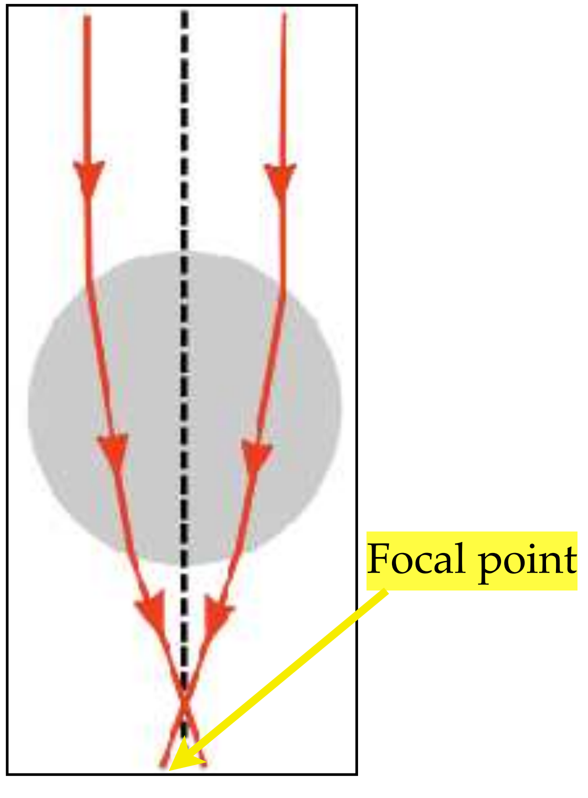
OPTICAL TWEEZERS

When a tiny sphere is captured with the optical tweezers, it is always impacted by an impulse towards the focal point. Why this is the case is explained here.

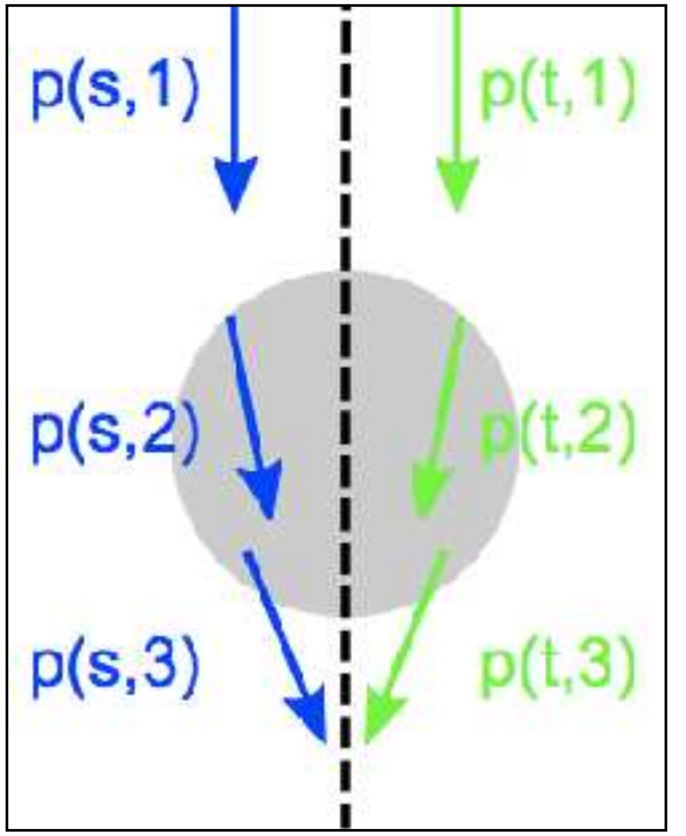




The beam path through the sphere when it is above the focal point.

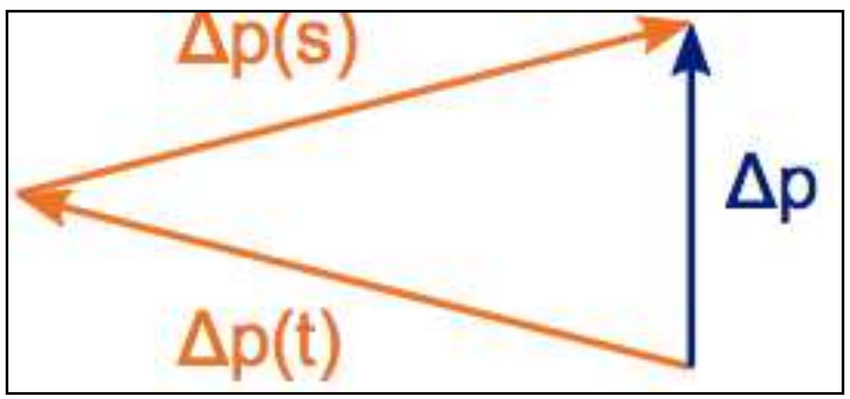


The resulting impulses:



If you carry out this calculation for other positions of the sphere, you will also always obtain an impulse towards the focal point. The sphere is therefore captured there and can be moved by moving this point.

If we determine the differential momentum of the two light beams (upper figure) and add them together (lower figure), we obtain the total differential momentum p of all photons. An exactly opposite momentum acts on the sphere. This goes vertically downwards, i.e. exactly towards the focal point.



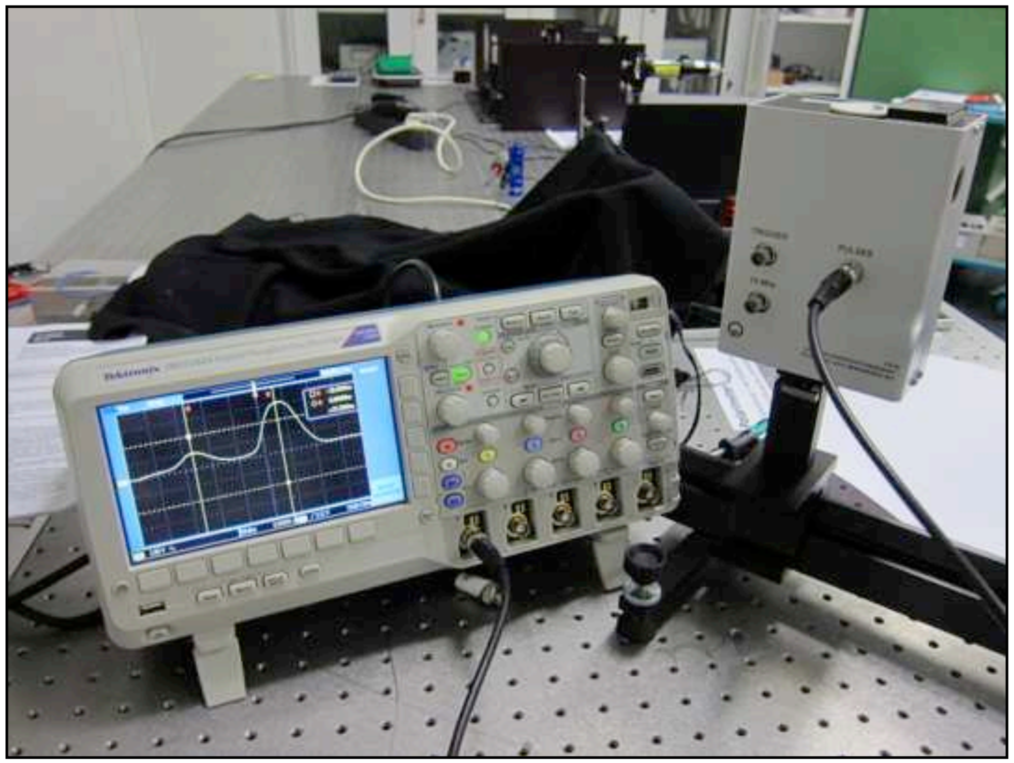
If you carry out this calculation for other positions of the sphere, you will also always obtain an impulse towards the focal point. The sphere is therefore captured there and can be moved by moving this point.

Related Glossary Terms

Index

OSCILLOSCOPE

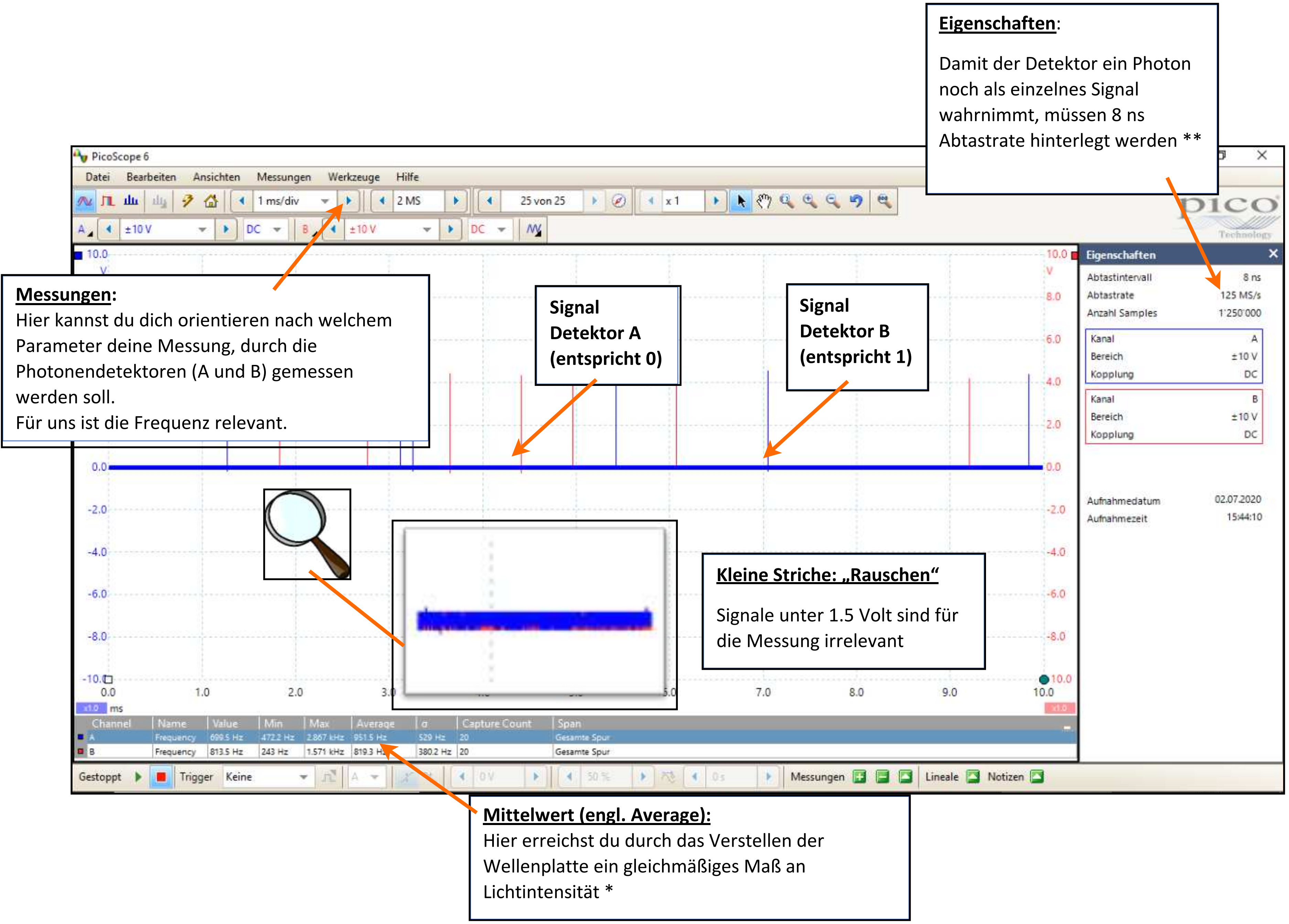
An oscilloscope is an electrical measuring device that displays a voltage curve in a diagram. The time is usually shown on the X-axis and the voltage intensity on the Y-axis.



Related Glossary Terms

Index

INTERPRETING THE OSCILLOSCOPE IMAGE



Related Glossary Terms

Index

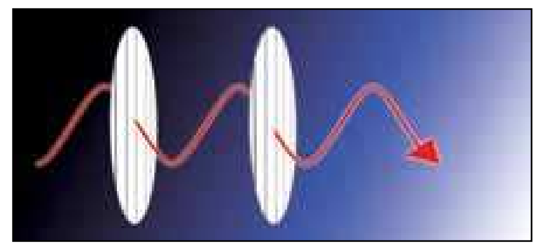
Rätselhaftes Licht !

PhotonLab

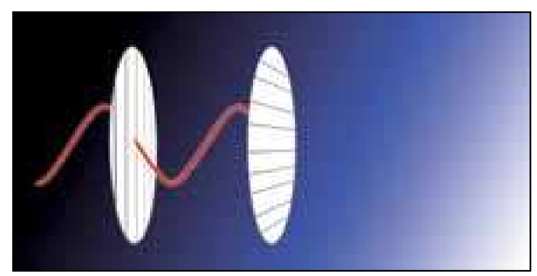
In der Hand hälst Du drei gleiche Folien, so genannte Polarisationsfolien.
(Auf beiden Seiten klebt noch eine Schutzfolie.)
Anwendung finden solche Folien im 3D-Kino, in der Fotografie oder in Flüssigkristall-Bildschirmen.

a) Lege zunächst zwei Folien übereinander und halte sie gegen eine Lichtquelle. Verdrehe nun die Folien gegeneinander. Was beobachtest Du?
b) Suche nun die Position, in der kein (kaum) Licht durch die beiden Folien dringt.
Nun wird es spannend! Nimm die dritte Folie und stecke sie **zwischen** die beiden auf dunkel gestellten Folien. Die mittlere Folie wird nun gedreht, ohne die beiden anderen gegeneinander zu verschieben. Was beobachtest du? Kannst Du das erklären?

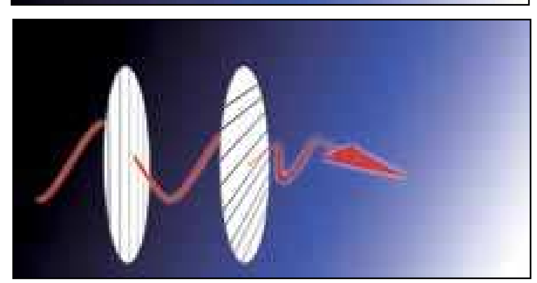
Erklärung:
Licht verhält sich wie eine Welle; die Teilcheneigenschaften wollen wir hier außer Acht lassen. Eine Lichtwelle schwingt senkrecht zu ihrer Ausbreitungsrichtung. Licht einer normalen Lampe ist unpolarisiert. Polarisatoren sind Filter, die nur Licht einer bestimmten Schwingungsrichtung, d.h. Polarisation durchlassen. In unserem Fall ist das Licht, nachdem es den ersten Polarisator durchquert hat, stets in diesselbe Richtung linear polarisiert.



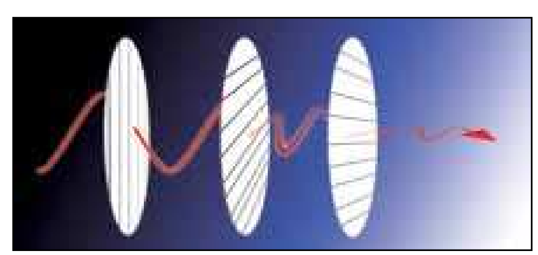
Parallele Polarisatoren:
Der zweite Polarisator lässt das vom ersten Filter polarisierte Licht passieren. (Achtung: Hier ist der magnetische Anteil des Lichtes skizziert!)



Senkrechte Polarisatoren:
Der zweite Polarisator lässt kein Licht durch!



Schräge Polarisatoren:
Der zweite Polarisator lässt einen Anteil* des Lichtes durch!
** Bei 45° sind es 50% (Gesetz von Malus). Man kann sich auch die Amplitude des Lichts als schrägen Vektor vorstellen und diesen in zwei zueinander senkrechte Anteile zerlegen. Einen in Durchlassrichtung und einen in Sperrrichtung.*



Drei jeweils schräg zueinander stehende Polarisatoren:
Der zweite Polarisator lässt einen Anteil des Lichtes durch, der dritte ebenfalls. Und das, selbst wenn der erste und der letzte senkrecht aufeinander stehen.

Besucht uns auf Facebook unter PhotonLab

The Munich-Centre for Advanced Photonics www.munich-photonics.de

---

Verwandte Glossarbegriffe

Optisch aktive Substanzen

Index

POLARIZING BEAM SPLITTER

This works exactly like a normal beam splitter, except that the polarization direction is the criterion for whether the light is transmitted (transmitted) or reflected. For the quantum cryptography experiment, this means that

0° polarized light is reflected

90° polarized light is transmitted

Verwandte Glossarbegriffe

Strahlteiler, Strahlteilerwürfel

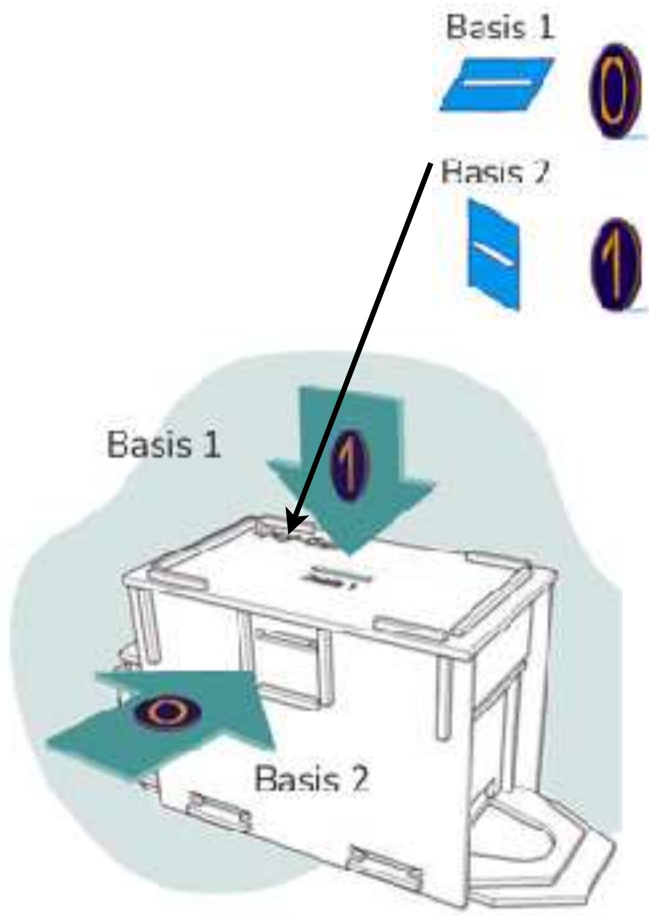
Index

QEYGEN

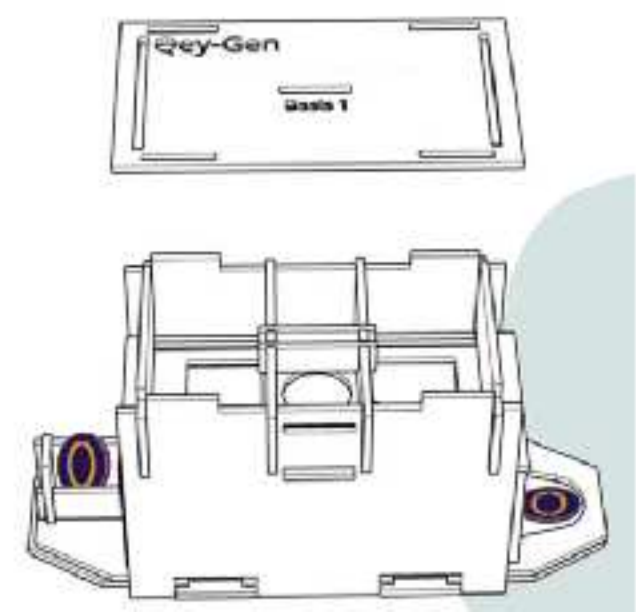
The "QeyGen" is a quantum key generator that allows you to understand the principle of the bases. Let's start with how the box works.

The box has two slots into which you can insert a 50-cent coin. If we choose one and insert the coin, it is prepared in "base 1 or base 2".

In our experiment, the bases describe which type of photons Alice sends out. So vertically or horizontally, with the value 1 or 0, just like our box.



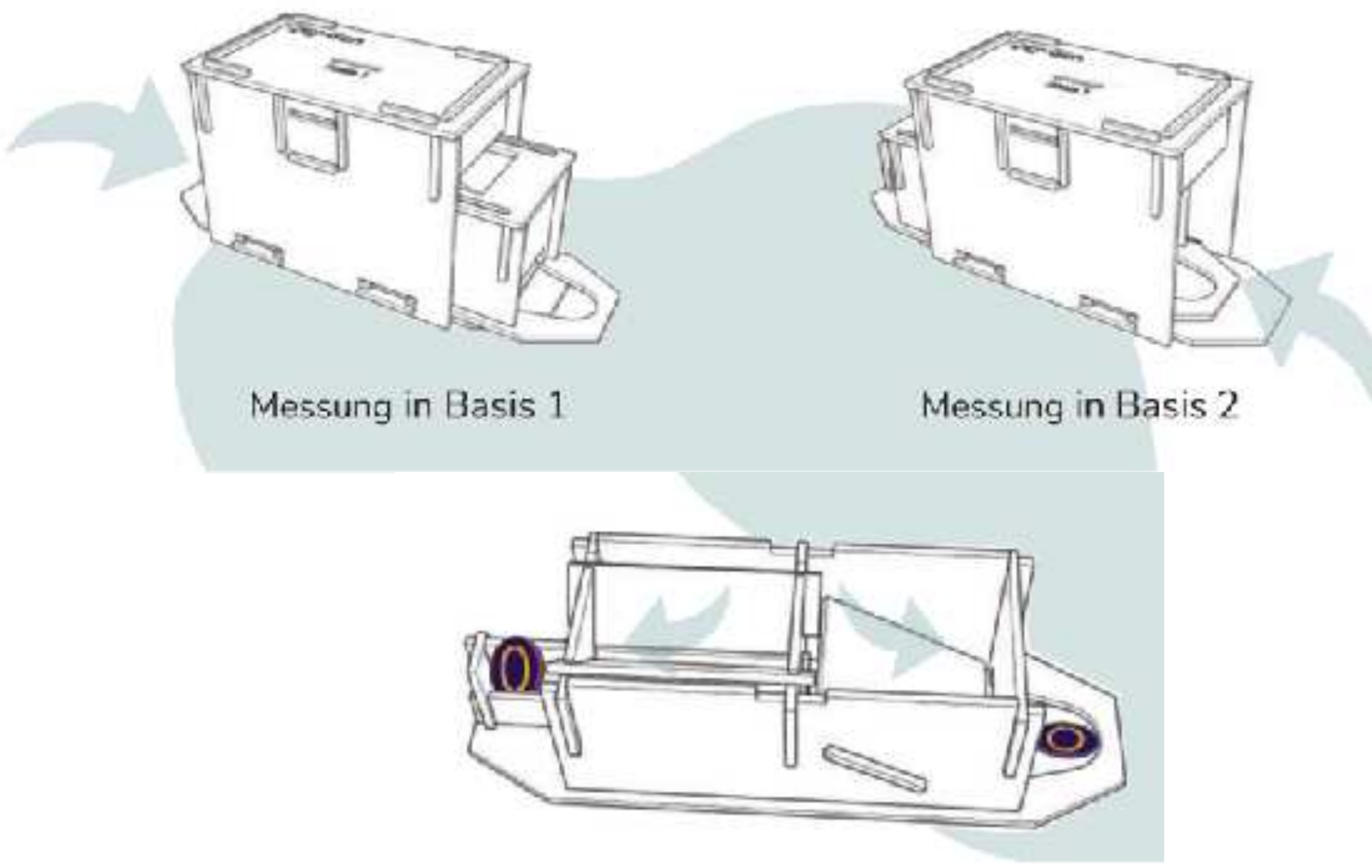
When we open the Qey-Gen, we see that the coin is held in a device depending on which base we insert it into. The inner box can be moved to the left or right, whereby the coin either slides down a ramp and remains flat on the floor, or falls down a kind of funnel and ends up on the edge. Similar to the insertion, this is called a measurement in base 1 (horizontal) or in base 2 (vertical).



https://tueftelakademie.de/wp-content/uploads/2023/03/qey-gen-anleitung-v2-small.pdf

QEYGEN

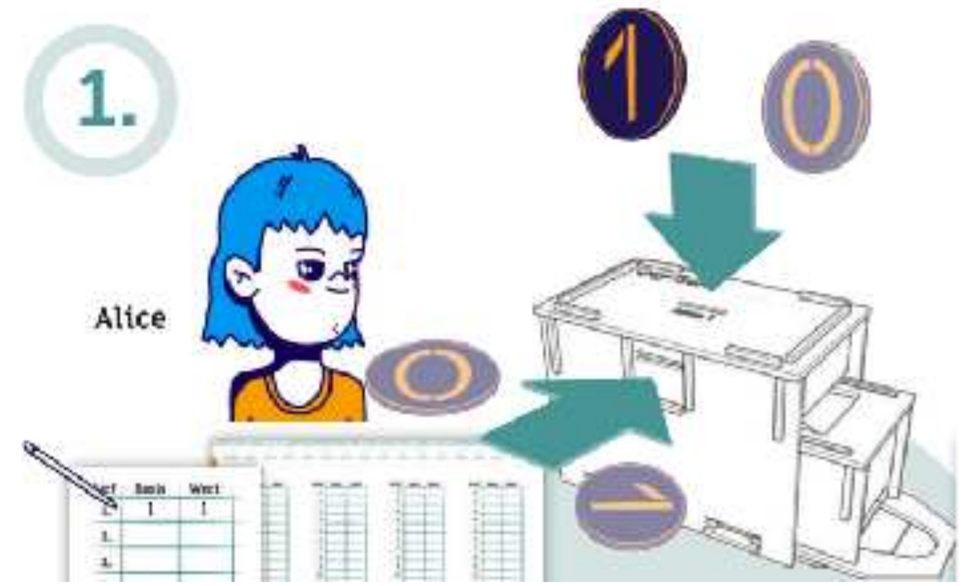
So if you insert a coin into base 2 and also measure it in base 2, the state of the coin remains unchanged. If tails are pointing upwards, tails will also point upwards when measuring. However, if you measure in base 1, the coin will tilt to one edge and 50% of the coin will show 0 and 50% will show 1. This produces exactly the same effect as with quanta. If the bases are the same, the value remains the same; if they are different, the value is determined by chance.



https://tueftelakademie.de/wp-content/uploads/2023/03/qey-gen-anleitung-v2-small.pdf

QEYGEN: PRE-EXPERIMENT

Creating tap-proof keys is actually not that easy to understand. However, we have provided you with a step-by-step guide as an example. In our example, we will call player 1 "Alice" and player 2 "Bob" for the sake of simplicity.



1. Alice secretly moves the coin into base 1 or 2 and notes the base and the value of the coin on her spreadsheet. The "value" of the coin is which number points towards you (if base 1) or which number points upwards (in the case of base 2). While Alice inserts her coin, Bob has to look away!

2. Now Bob carries out a measurement and notes down the result. If he wants to measure to base 1, he has to move the inner box to the right. For base 2, he has to move the inner box to the left until the coin falls down. Alice must of course look away!

3. Alice always inserts the coin and Bob reads it. They repeat this process 12 times. But wait a minute. How can you be sure that no one has been eavesdropping? In the next steps you use your values to build a key and test for eavesdroppers.

Wurf	Basis	Wert
1.	1	1
2.	1	0
3.	2	1
4.	1	1
5.	1	1
6.	1	1
7.	2	1
8.	1	0
9.	2	0
10.	2	1
11.	2	1
12.	1	0

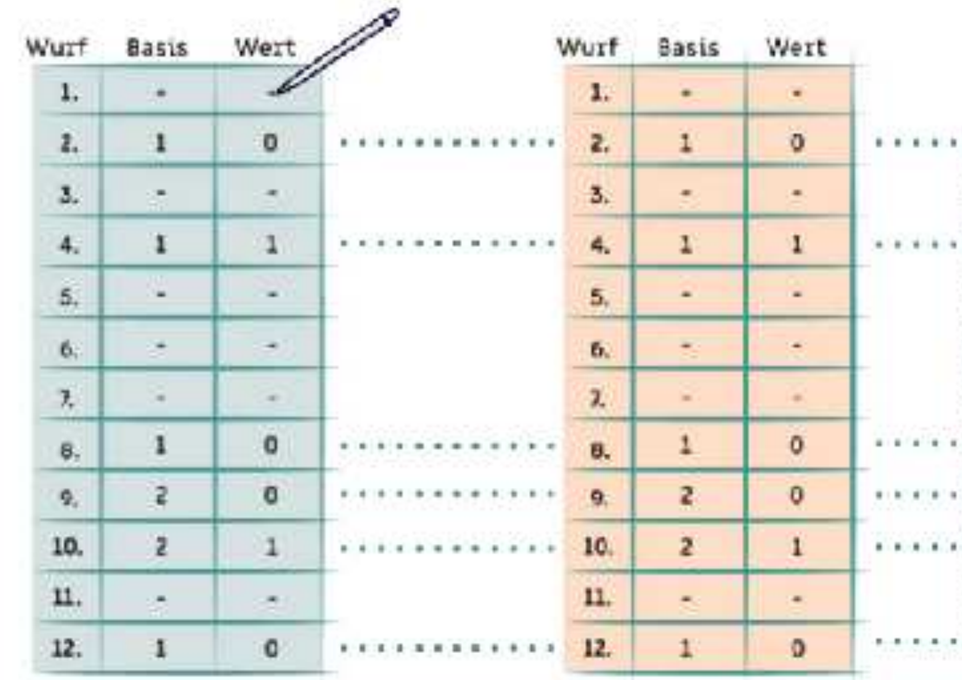
Wurf	Basis	Wert
1.	2	0
2.	1	0
3.	1	1
4.	1	1
5.	2	0
6.	2	1
7.	1	1
8.	1	0
9.	2	0
10.	2	1
11.	1	0
12.	1	0

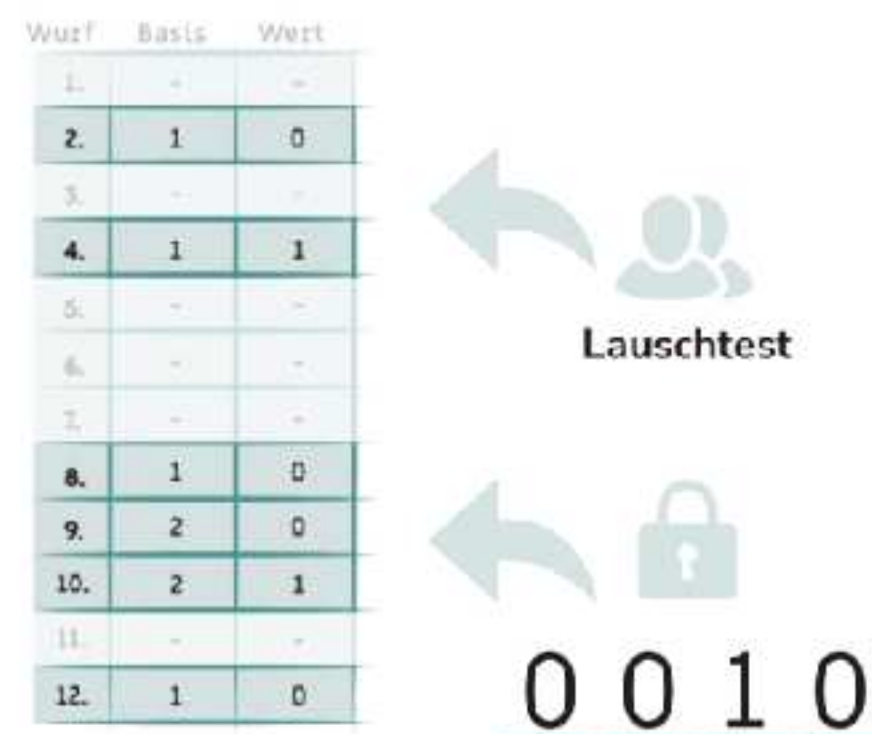
https://tueftelakademie.de/wp-content/uploads/2023/03/qey-gen-anleitung-v2-small.pdf

QEYGEN: PRE-EXPERIMENT

4. Now Alice and Bob openly discuss which base they chose for which roll without revealing the value. They cross out all throws with different bases. You use this to build your key and carry out the louse test.

5. But wait a minute. How can we be sure that no one has been eavesdropping? Alice and Bob only need four values for the key. As long as they never say the value out loud, they can freely choose together which ones they want to use (here 8, 9, 10 and 12). They can discuss the other values out loud (here 2 and 4). They must be correct, i.e. the same. If they are not the same, someone has been eavesdropping. The more values they compare, the more certain it is that no one has been eavesdropping. You could also do more than twelve coin tosses to have more values for the eavesdropping test.





Verwandte Glossarbegriffe

Index

https://tueftelakademie.de/wp-content/uploads/2023/03/qey-gen-anleitung-v2-small.pdf

QUANTUM PARTICLES

We know that the world around us is made up of atoms. What is not so obvious, however, is that the rules of physics are different for the smallest particles than in our large, macroscopic world.

We describe objects in our everyday world by determining their "state": This is made up of the object's momentum and velocity. For small particles, such as subatomic particles, we cannot measure the state and properties directly. This is because the individual states overlap as a so-called "superposition"! Experiments show that quantum particles occur in two different states at the same time: However, we cannot measure both states at the same time!

Measurements: Another important aspect in the quantum world is the measurements of a state. Unlike in our world, we cannot simply measure the speed - no! In the quantum world, instead of a result, we get a probability for this result. For example, when we try to determine the state of a quantum system, we detect our quantum particle in a certain position with a probability that depends on how strongly the location is influenced by the superposition.

Verwandte Glossarbegriffe

Superposition

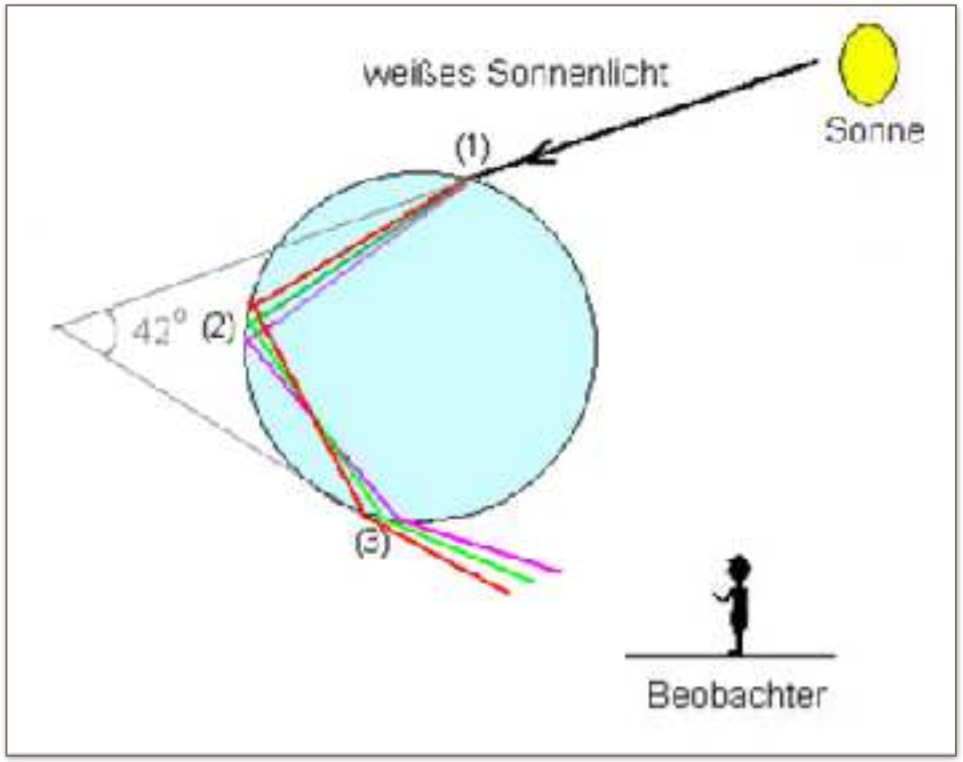
Index

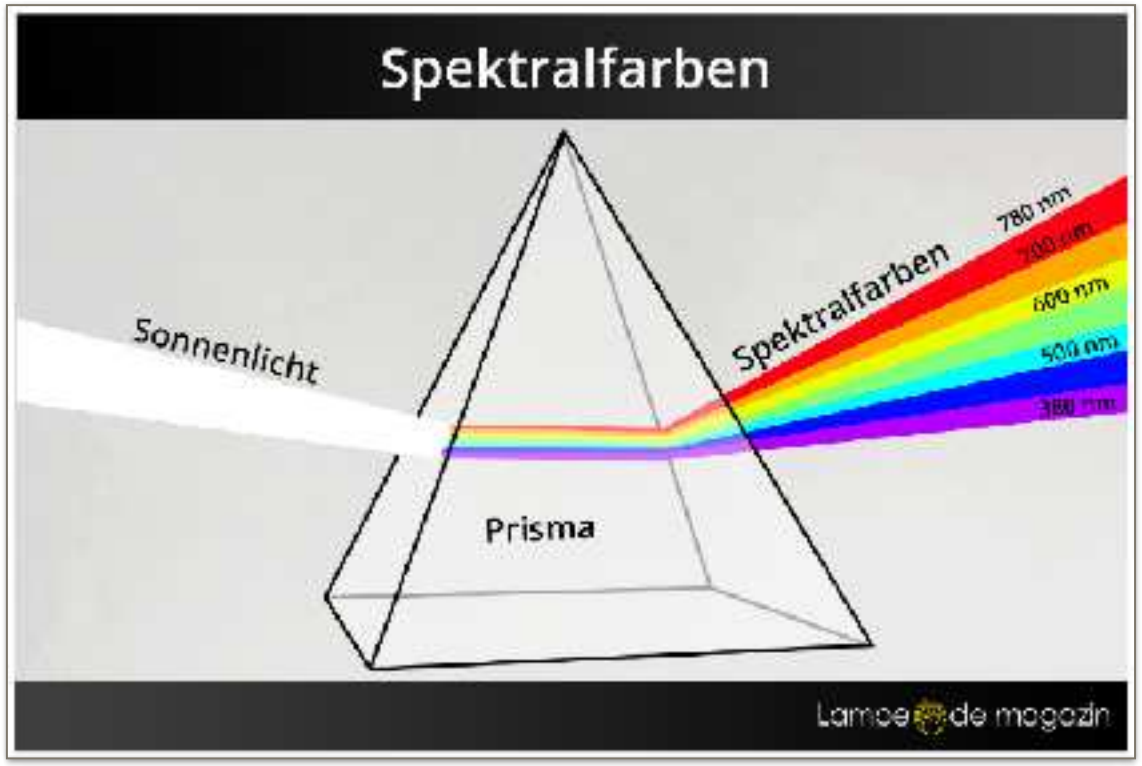
RAINBOW

How does a rainbow actually work?

The cause of a rainbow is the color separation or dispersion of light through refraction. If white sunlight, which contains all spectral colors, hits raindrops, it is refracted when it enters the raindrop (transition from air to water).

Here is some geometrical optics: After using Snellius' law twice, the angle between the observer, the drop and the sun is about 42°. The refractive index of air is about 1 and that of water about 1.5.

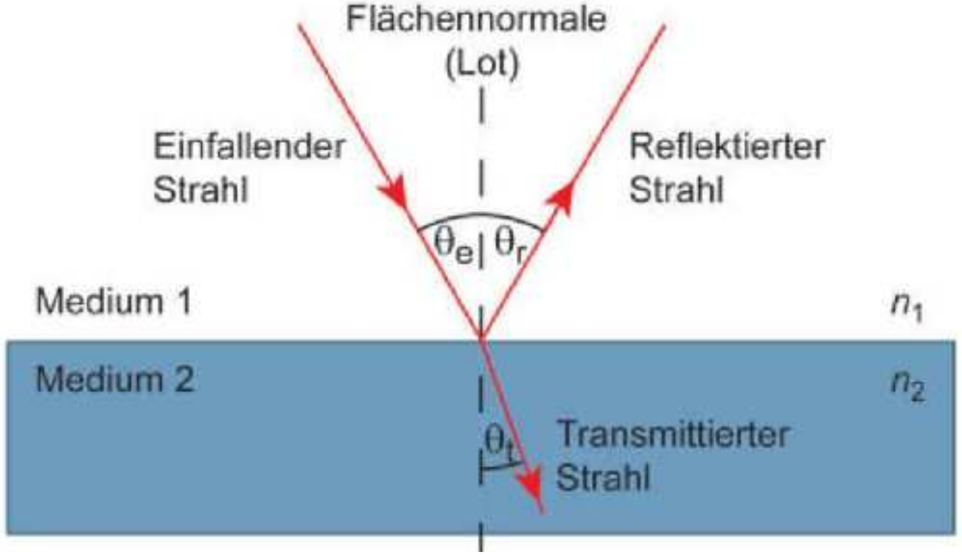




https://www.schule-bw.de/faecher-und-schularten/mathematisch-naturwissenschaftliche-faecher/physik/unterrichtsmaterialien/optik/brechung/regenbogen.htm

REFLECTION

The image shows the refraction and reflection of a ray: An incident ray from the homogeneous medium 1 hits the surface of medium 2. n is the refractive index, i.e. a unitless number that describes how strongly or weakly the light is refracted/reflected.
The angles (e=incidence angle, r=reflection angle and t=transmission angle) describe the path of the rays. The angle of incidence is equal to the reflected angle:



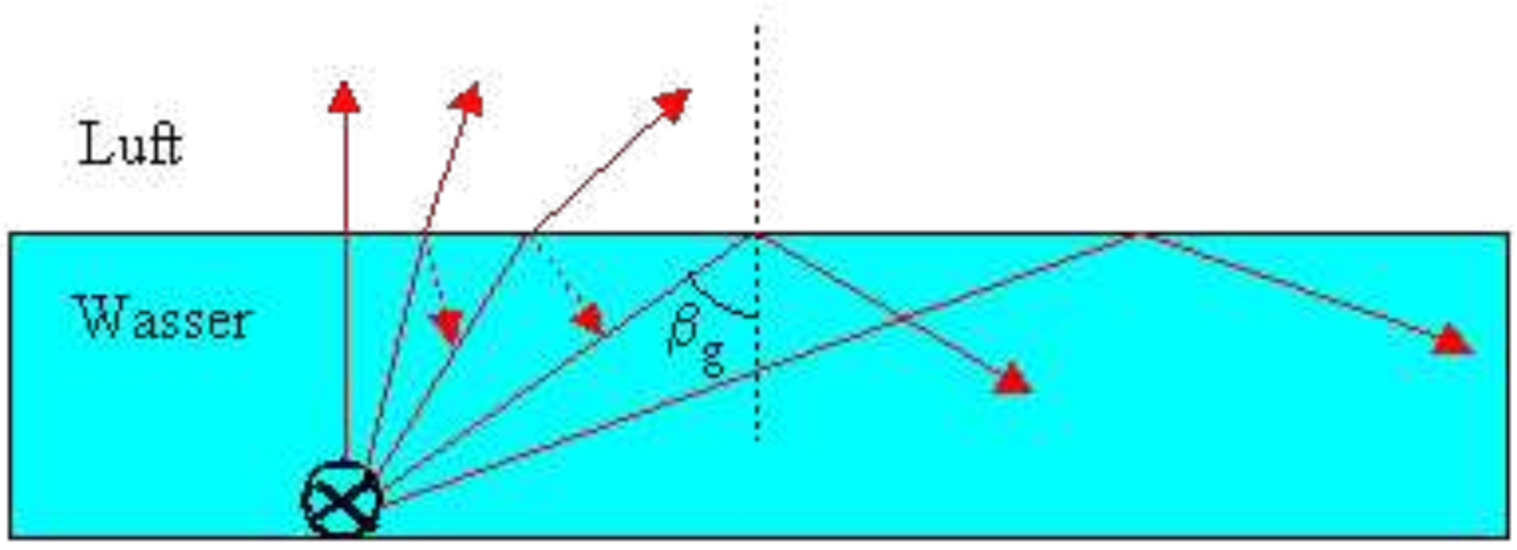
$$\theta_e = \theta_r$$

Total internal reflection is the complete reflection of an incident beam. According to Snellius' law, there is an angle of incidence at which the angle of refraction is 90°. Beyond this angle, light can no longer be refracted, but only reflected. Exactly THEN one speaks of total reflection!

https://www.leifiphysik.de/optik/lichtreflexion/grundwissen/reflexionsgesetz

REFLECTION

If light hits the boundary of two media with different refractive indices, a certain proportion is always reflected. Unlike on the previous slide, light from the medium with the higher refractive index is reflected into a medium with a lower refractive index. The flatter the angle, the greater the proportion reflected. Above a certain critical angle, all the light is reflected. This is called **total internal reflection**.
Below you can see the different rays that are not reflected at all, partially reflected or totally reflected. The following sketch serves as an illustrative explanation for the experiment "Water as a light guide"!



CORRECT ANSWER CHAPTER 22 EXPLANATION

The polarizing film only allows one direction of polarization to pass through. Due to the absence of the second filter directly on the monitor, every polarization direction comes out. Therefore, if you turn the filter, you will not only see the polarization direction that you are supposed to see, but also parts of the other polarization directions. This results in false color mixtures.

Verwandte Glossarbegriffe

LCD-Displays

Index

Kapitel 22 - Durchführung/Aufgabe

STEP-BY-STEP INSTRUCTIONS

First, the three letters are translated into binary codes using the tables.

Schritt 1	Schlüssel-übertragung	• Alice wählt zufällig eine Basis (also x oder +) und ein Bit (also 0 oder 1). Bob wählt zufällig seine Basis (also x oder +). Beide stellen ihre lambda/2 Platten entsprechend ein. Dann wird das Photon durch den Aufbau geschickt (bei uns der Laserpuls). • Bob schreibt auf, ob er eine 0 oder eine 1 oder nichts eindeutiges gemessen hat.
Schritt 2	Löschung falscher Basen	Alice und Bob gehen die Messungen durch und sagen sich gegenseitig, welche Basen Sie genommen haben. Sie behalten die Ergebnisse, bei denen die Basen gleich waren (den Rest streichen sie durch).
		Dabei verraten beide nur die Basen und nicht die übertragenen und gemessenen Bits. Der Witz: sie wissen jetzt, beide, welche Bits übrig bleiben (haben also einen geheimen Schlüssel), haben sich aber nur über die Basen ausgetauscht.
Schritt 3	Test auf Spion	Alice und Bob vergleichen einige der übertragenen Bits mit der gleichen Basis. Bei Fehlern war ein Spion in der Leitung und der übertragene Schlüssel wird gelöscht. Die Bits zum Testen der Anwesenheit eines Spions werden aus dem eigentlichen Schlüssel gelöscht.
Schritt 4	Verschlüsseln der Nachricht	Erst jetzt verschlüsselt Alice die eigentliche und sensible Nachricht mit dem generierten Schlüssel über die binäre Addition.
Schritt 5	Versenden der Nachricht	Die verschlüsselte Nachricht wird nun öffentlich von Alice an Bob verschickt.
Schritt 6	Entschlüsseln der Nachricht	Bob entschlüsselt die geheime Nachricht mit seinem Schlüssel über die binäre Addition. Mit dem oben eingehaltenen Prozdere war die Verschlüsselung zu 100% sicher.

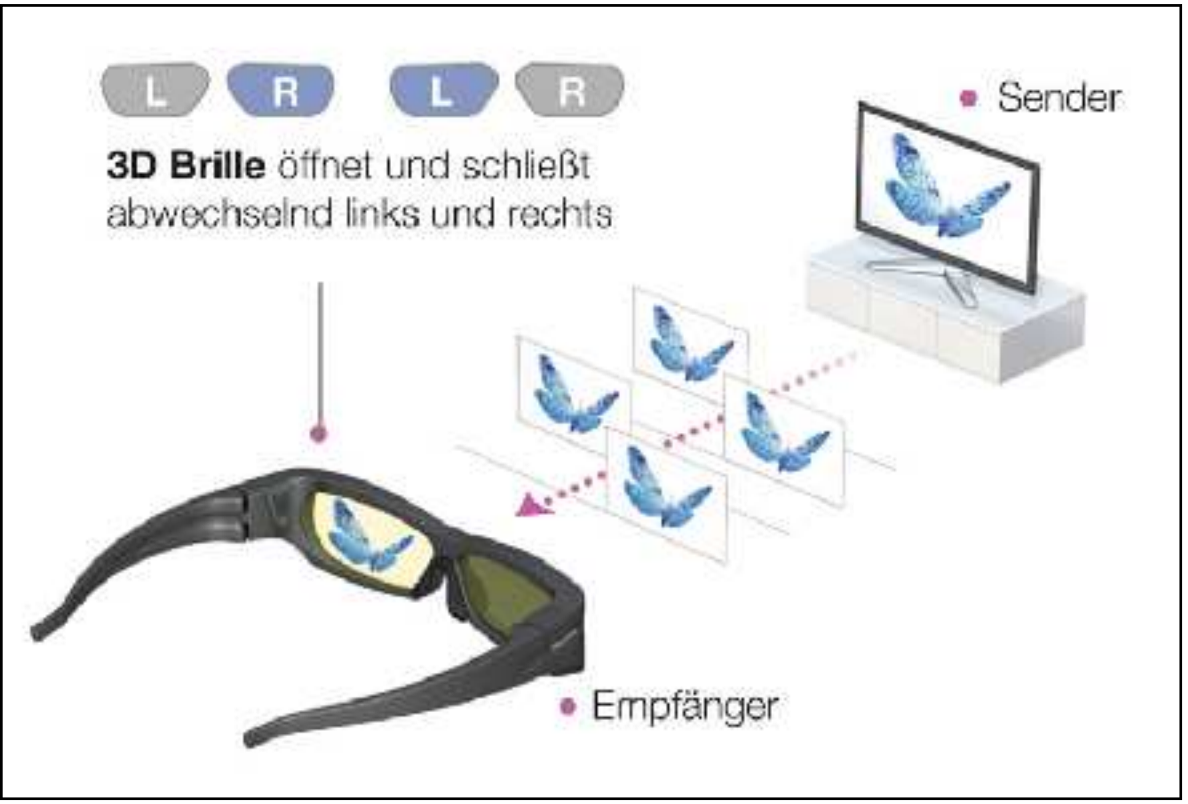
Verwandte Glossarbegriffe

Index

SHUTTER GLASSES

The English word '**shutter**' means, among other things, 'roller blind' or 'gate'. The verb 'to shut' means, among other things, "to close something".

The glasses contain special materials that alternately darken the right or left eye glass (like a roller blind in front of a window). In the same second that the left eyeglass is closed, for example, the television sends the image to the right eye.



This process happens so quickly that we as viewers are not even aware of it. The change between the individual images usually takes place at approx. 100 Hz, which corresponds to approx. 50/60 images per second per eye. The television/projector used must emit 100/120 images in the same time. The electronics inside the glasses control everything fully automatically.

This technology is only used in a few cinemas (Arri Kino in Munich) as the cost of the glasses is comparatively high. In addition, they must always be charged.

Verwandte Glossarbegriffe

Layerdisplays/Parallaxenfunktion

Index

http://www.chip.de/artikel/3D-TVs-im-Technik-Duell-Polarisation-versus-

SAFETY INSTRUCTIONS

Lasers (approx. 1 mW) are used in the laboratory, which can cause eye damage if handled incorrectly. The following rules are for your own safety when visiting the laboratory. If they are not followed, you must leave the laboratory. The signature confirms that the rules have been read and will be applied.

Never look directly into the laser beam!

The eyes must never be at the height of the optical table.

Always look at the experiment at an angle from above.

Do not wear rings, bracelets or watches on your hands because of the reflection of the laser light. Long chains must also be removed.

The laser beam must never shine beyond your own optical table during the experiment. Black metals are used to intercept the laser beam.

When starting the experiment: put on laser safety goggles.

Do not eat or drink in the laboratory.

In an emergency, press the emergency stop switch near the entrance or by the fuse box at the window.

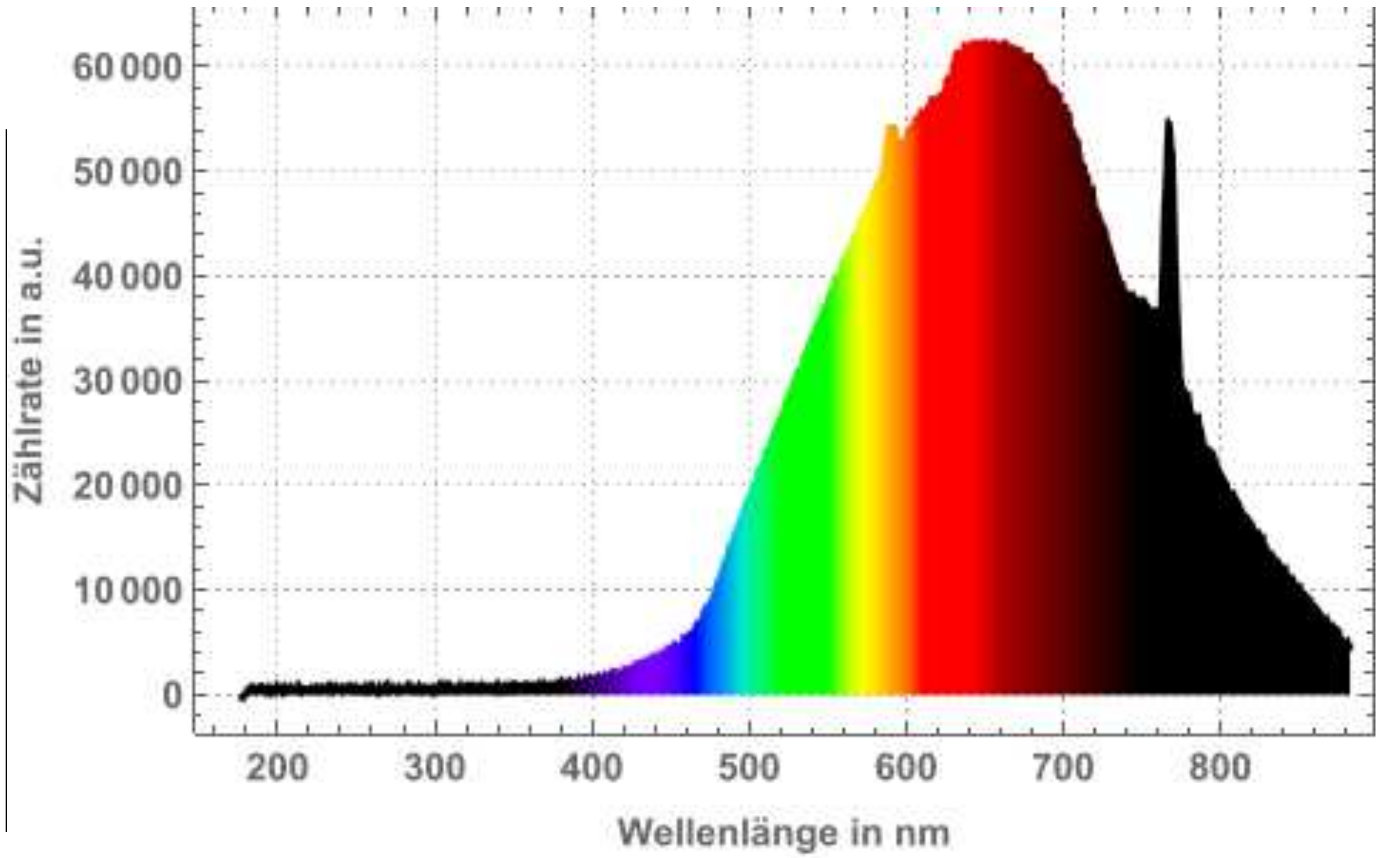
I agree to the publication of photos of myself on the Internet.

Related Glossary Terms

Index

Kapitel 1 - Lasersicherheit

SPECTRUM 1



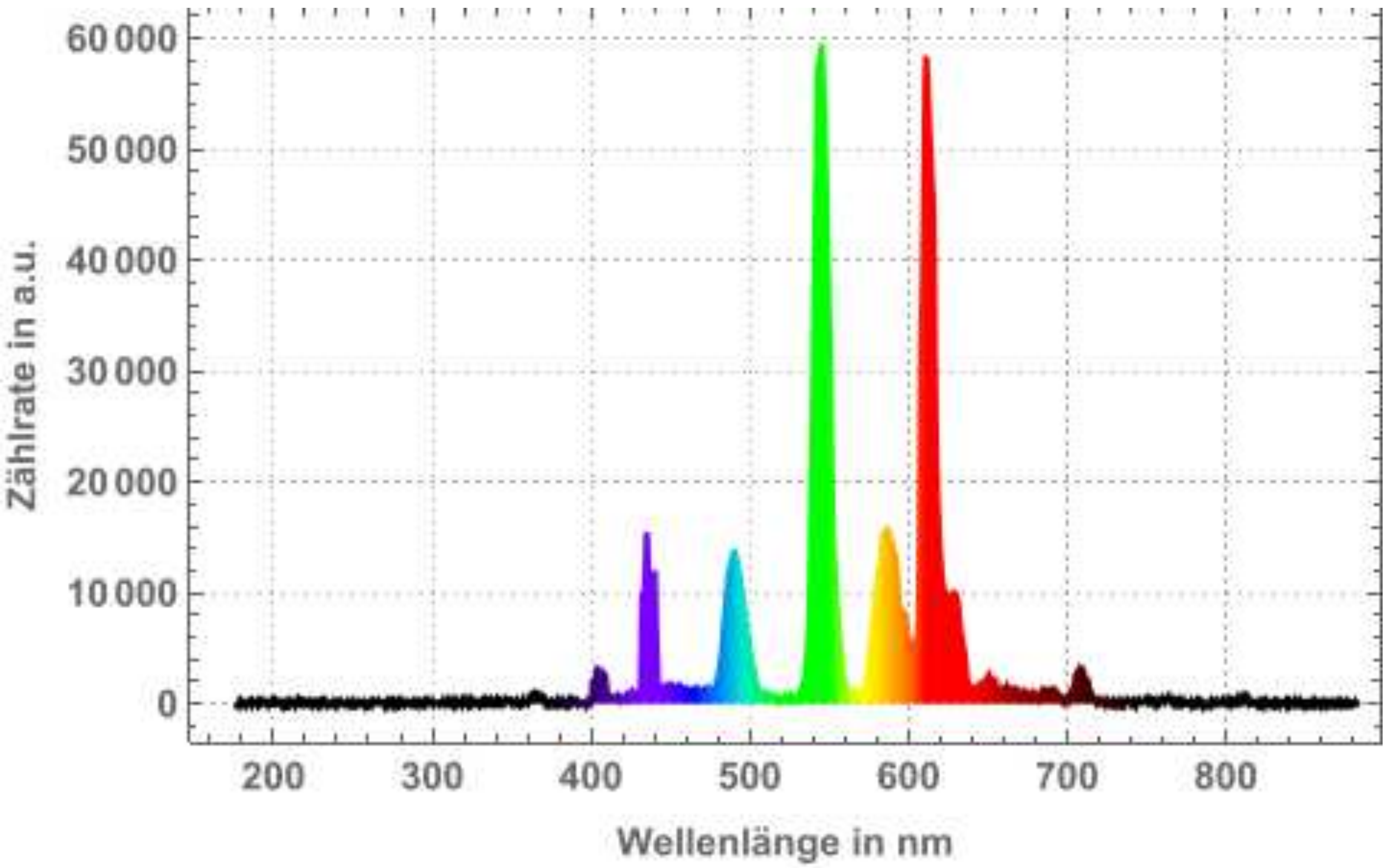
Candle flame

Related Glossary Terms

Lösungen Spektrometer, Spektrum 2

Index

SPECTRUM 3



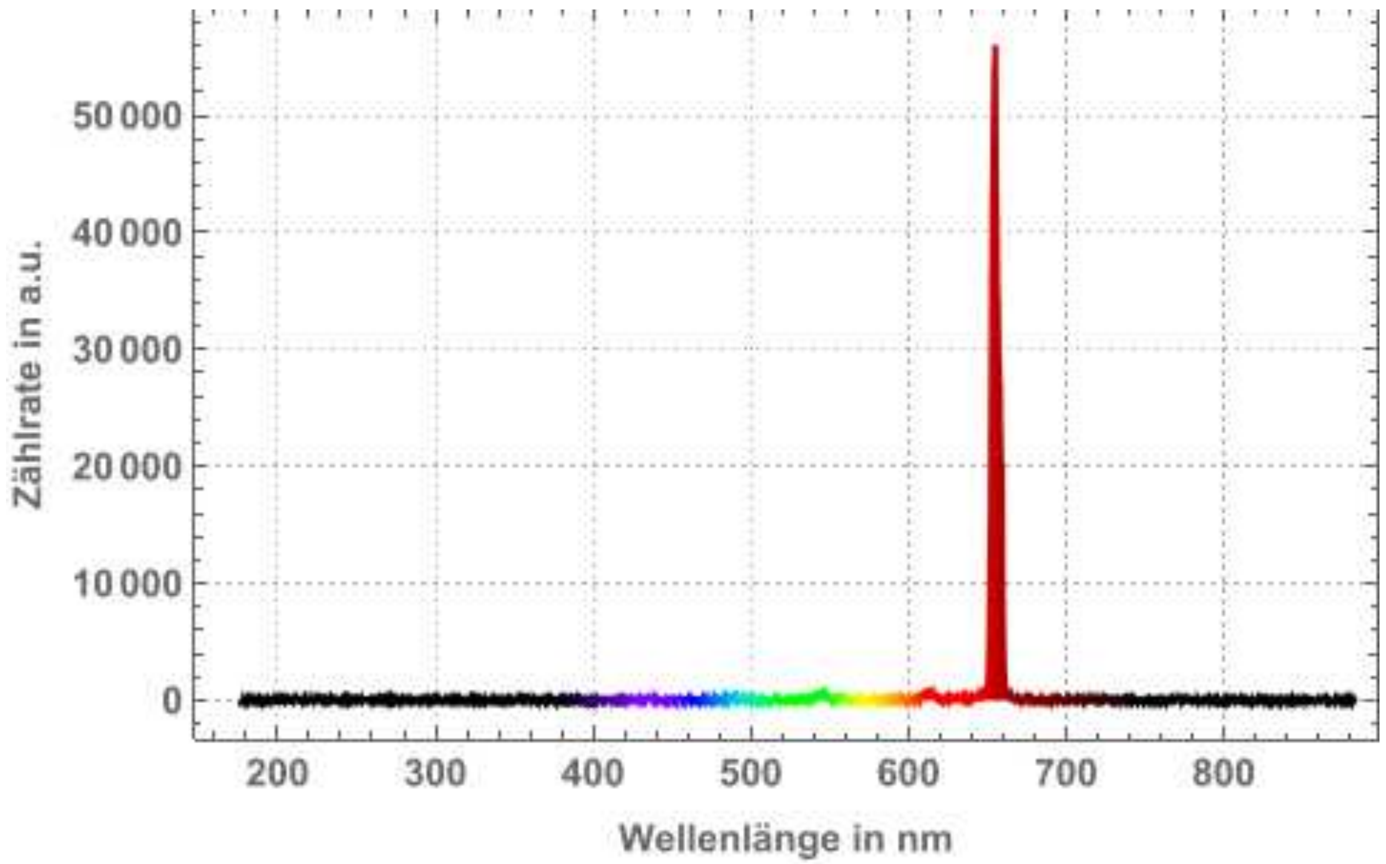
Fluorescent tube

Related Glossary Terms

Lösungen Spektrometer

Index

SPECTRUM 2

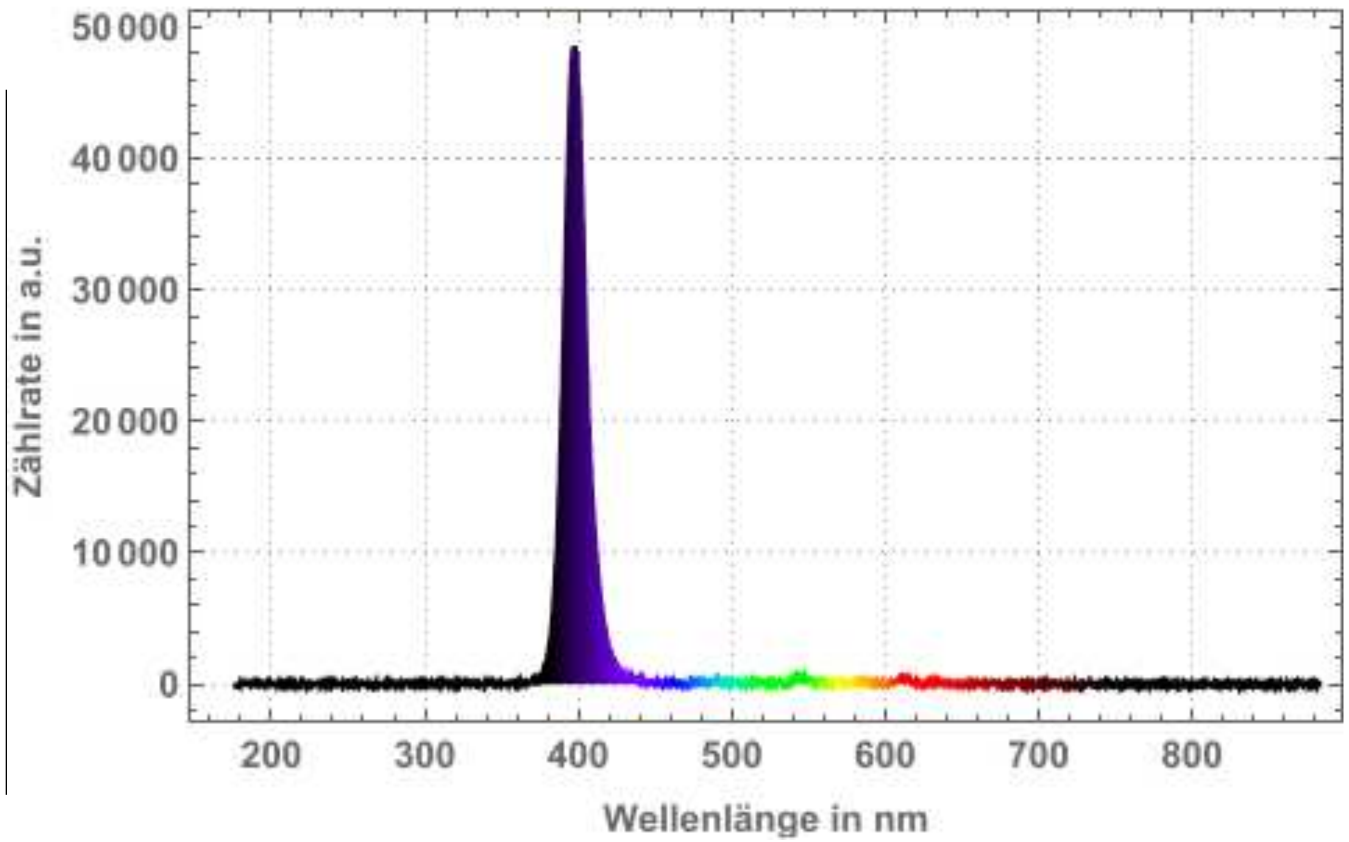


Laser red

Related Glossary Terms
Lösungen Spektrometer, Spektrum 1

Index

SPECTRUM 4



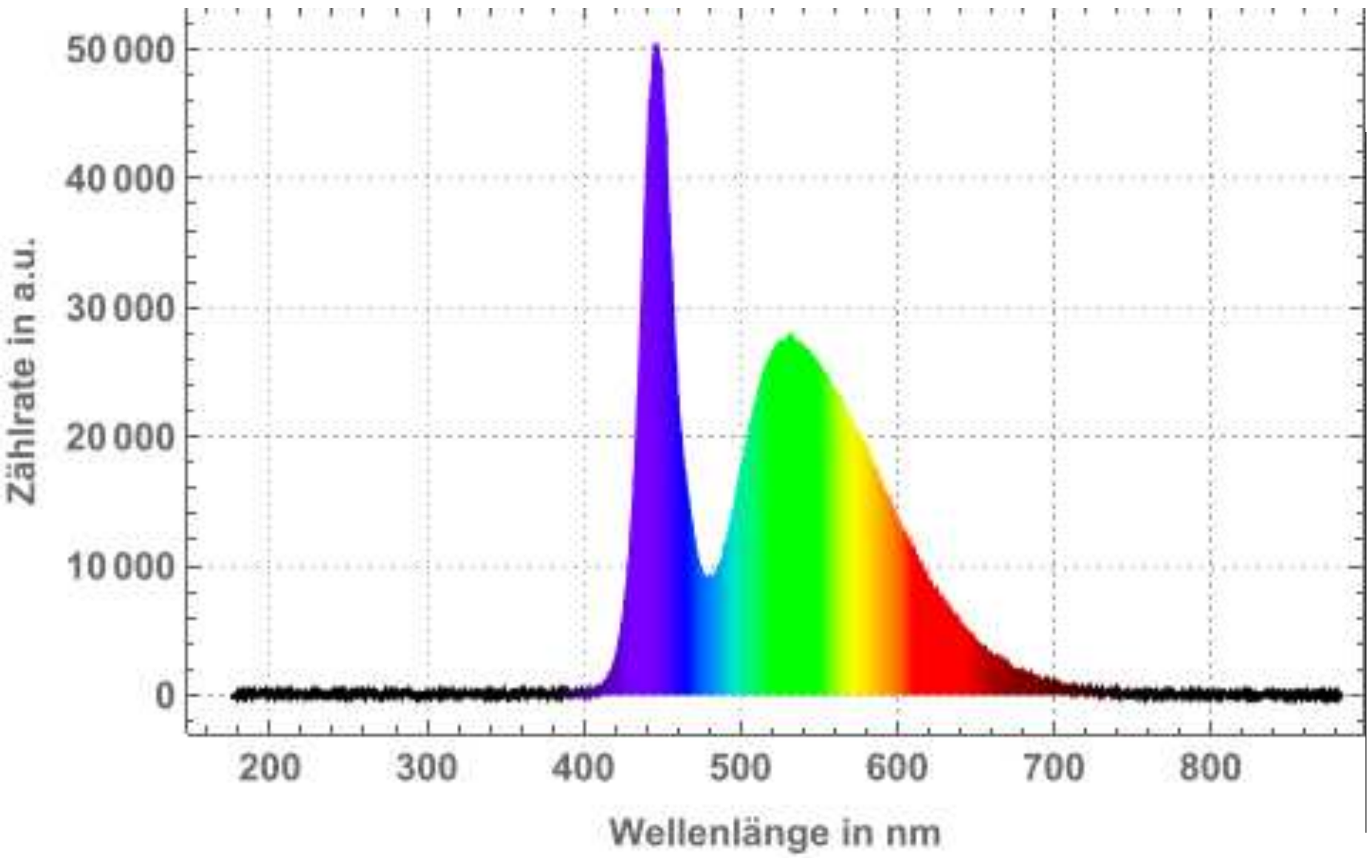
UV-Lamp

Related Glossary Terms

Lösungen Spektrometer, Spektrum 5

Index

SPECTRUM 5



White LED

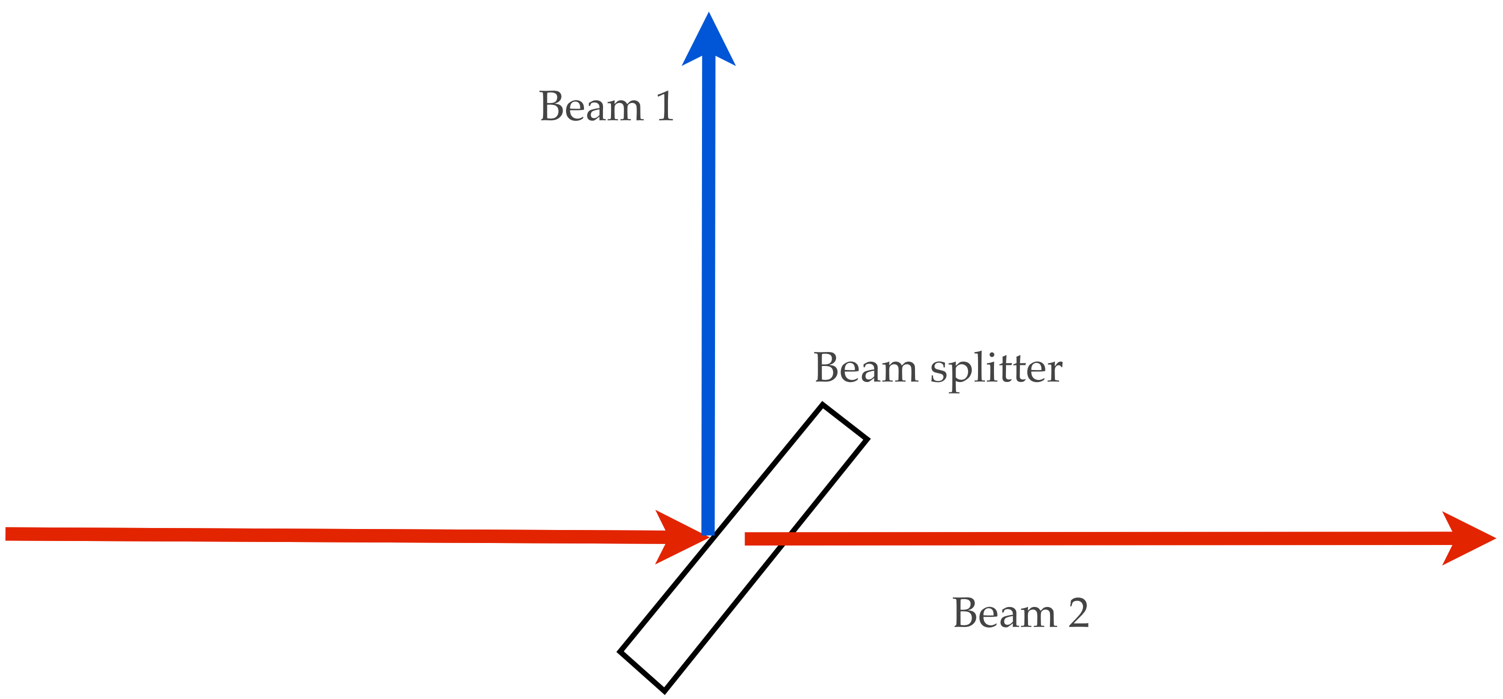
Related Glossary Terms

Lösungen Spektrometer, Spektrum 4

Index

BEAM SPLITTER

A beam splitter splits a laser beam into two partial beams. A common design is an inclined, partially transparent mirror. One part of the light beam is reflected at a 90° angle, while the other part continues straight ahead through the partially transparent mirror.



Related Glossary Terms

Polarisierender Strahlteiler, Reflexion, Strahlteilerwürfel

Index

BEAM SPLITTER CUBE

A beam splitter cube splits a beam of light into two partial beams, just like a beam splitter, which then travel in different directions.

However, the beam splitter cube consists of two prisms that are connected at one edge with a resin.

At the boundary of the prisms, one part of the light is reflected, while the other penetrates the second prism.

Related Glossary Terms

Polarisierender Strahlteiler, Reflexion, Strahlteiler

Index

SUPERPOSITION

Superposition processes are very important in (quantum) physics. There is even a superposition principle, also known as the superposition principle.

The **superposition principle** describes the phenomenon of interference, which you already know from the interferometer experiment. It can become visible through the interference pattern on a screen.

In contrast to the superposition of electromagnetic waves, quantum objects, such as photons, can be in a superposition of states. Unlike an interference pattern, this cannot be made visible.

Superposition of states

Quantum states can be added ("superposed") and the result is another quantum state and, conversely, a quantum state can be represented as the sum of two or more different states. An example from everyday life should give you a better understanding of the term "state".

In a coin toss, there is the possibility for the coin to assume the state heads or tails. The state of the coin that can be assumed is considered as a whole system. As long as the coin is rotating in the air, both states of heads and tails exist simultaneously. When the coin falls and we look at which result has actually occurred, there is only one state.

Of course, this is not a description of a quantum state. It is just an analogy.

Light in superposition

There are two possible states for a photon at the double slit: either it goes through path 1 or path 2. These are assumed simultaneously. So when we are not measuring, the photon (quantum object) is in a superposition (superposition) of the two possible states. This superposition of states can be **nicht** sichtbar gemacht werden. Die

Suppose a beam of light is passed through an interferometer so that it is split into two components which then interfere. How would this work with single photons?

To see this, let's look at an experiment. We shoot a laser beam whose intensity is so low that about one photon hits a double slit at a time. Now consider the following results of the experiment, as shown in the figure.

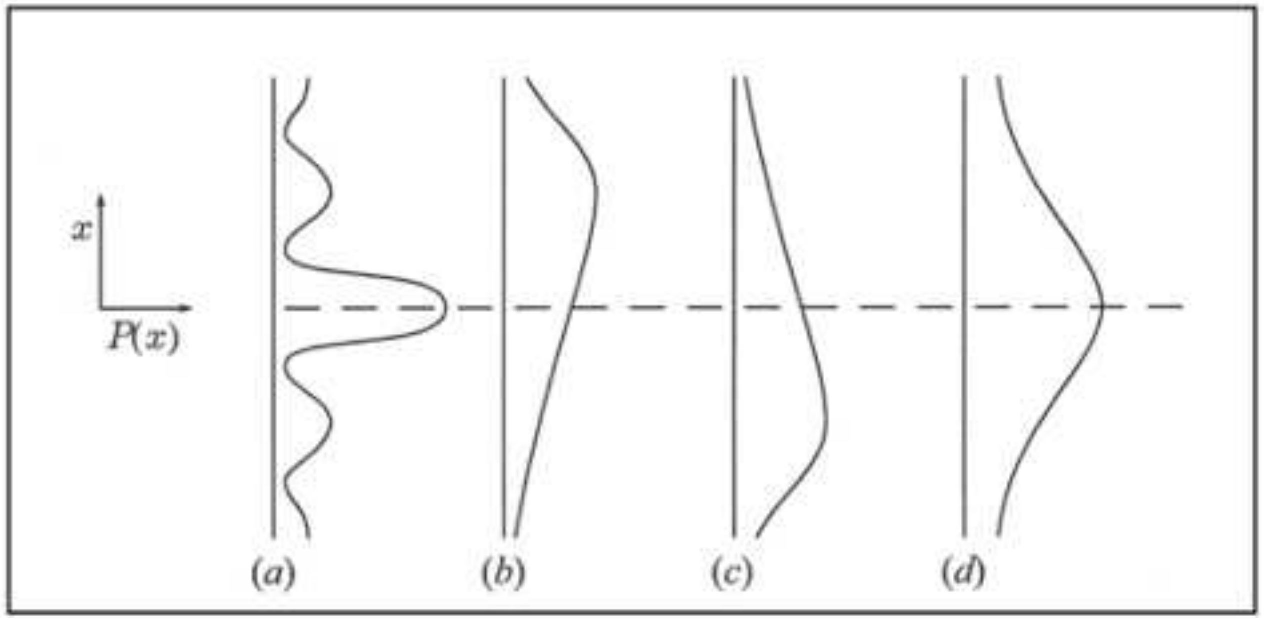
Which answer is correct?

a) Both slits are open

b) Hole 2 is closed so that the photon can only pass through hole 1

c) Hole 1 is closed

d) Sum of the distribution when holes 1 (result b) and 2 (result c) are open.



Answer a) is correct. We can see that the pattern differs considerably from a), where both slits were open!

A single quantum particle thus behaves like a wave that passes through both slits simultaneously and interferes with itself!

Related Glossary Terms

Polarisierender Strahlteiler, Reflexion, Strahlteiler

VON NEUMANN METHOD

Take any six-digit decimal number. Next, square this number. Now take the middle decimal places. This is the first pseudo-random number. Then repeat the process again and again:

$675248^2=455\underline{959861}504$

$959861^2=921\underline{333139}300$

$333139^2=110981593300$

…

…

This method does not work with every starting number, but with certain starting values the results look really chaotic.

Related Glossary Terms

Index

WHY DO WE NEED QUANTUM MECHANICS?

The answer is quite simple: it is the theory that explains how everything works, the nature of the particles that make up matter and the forces with which they interact. If you want to look at current research in almost all areas of basic research, you need quantum mechanics. Quantum physics is the basis for how atoms work and why chemistry and biology symbiotize the way they do. From how lasers work to how the sun burns due to the fusion reactions at its core, quantum mechanics is everywhere.

But why is it so difficult to understand? The difficulty of quantum mechanics lies in the fact that most of the concepts of the quantum world are inaccessible without mathematics. Mathematics provides results about how particles behave that seem very strange compared to what we are used to in the real world! One of these strange ideas is wave-particle duality: quantum objects can behave like particles that are in a single place; or they can behave like waves that are spread out all over space or in several places at once.

Related Glossary Terms

Index

ZWEISTUFIGE ABBILDUNGEN

Objective: To enlarge the object.

What you need: **Light source** (halogen lamp), **lens 1** (f=35mm) plano-convex and **lens 2** (f=150mm) biconvex (the large lens), **Schrödinger's cat**

How to proceed:

Step 1: This is a variation of the first attempt, only now a little more difficult! So be sure to look at the picture of the experimental setup on the next slide while you read these instructions!

Step 2: Now place the plano-convex lens 1 between the object and the screen, with the flat side facing the object.

Tip: The intermediate image should be sharp exactly in the middle of the system!

Step 3: Now the second lens comes into play: Place the biconvex lens 2 between lens 1 (f=35mm, plano-convex) and the screen.

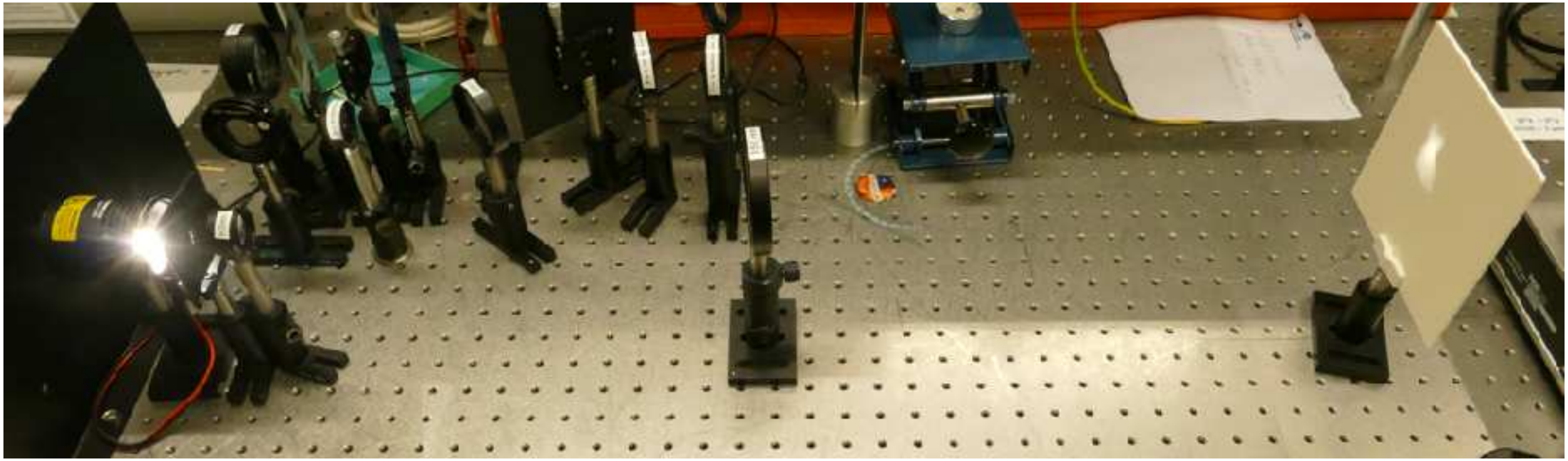
Step 4: Now comes the complicated part of the experiment: You have to align lens 2 so that you get a sharp image on the screen.

TWO-STAGE IMAGES

Research question: What can you tell about the size of the image? This setup shows how a microscope works!

What you see here:

On the left of the picture you can see the lamp. Towards the right is the cat, lens 1, then lens 2 and then the screen. On the screen you can see the image of the cat, enlarged!



CIRCULAR POLARIZATION

In linear polarization, the direction of oscillation of the electric (and also the magnetic) field is aligned in a specific plane. The figure shows the course of the oscillating wave along the z-axis in simplified form. The E-field is represented by vectors.

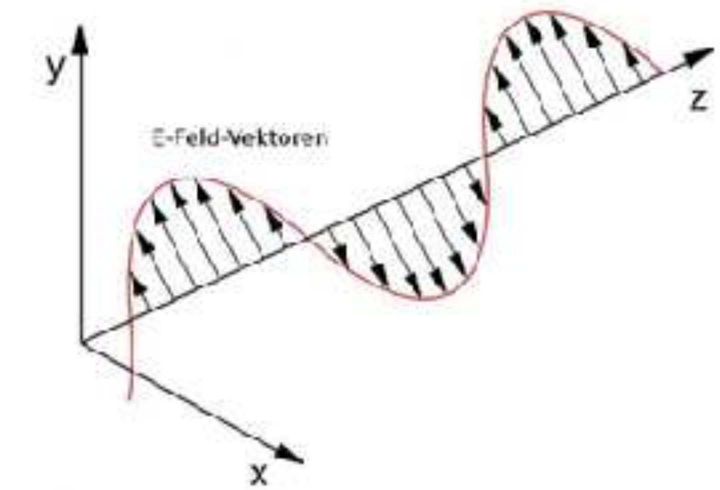


Abb. 1: Lineare Polarisation: Die Feldvektoren (hier eingezeichnet das elektrische Feld) an verschiedenen Orten schwingen alle in derselben Richtung

This state can be achieved by passing the light through a polarizer. Only the parts that oscillate in the plane 'matching' the polarizer are allowed to pass through. Now to circular polarization: If you look at the vector of the electric field, it rotates at a constant angular velocity and describes a circle along the z-axis. If you look at the propagation after penetrating the platelet, a screw/spiral is created that can rotate to the right or left. Circular polarization occurs when linearly polarized light strikes a $\lambda/4$ platelet (also known as a retardation platelet). You can find out exactly how the plate works in the entry "The $\lambda/4$ plate".

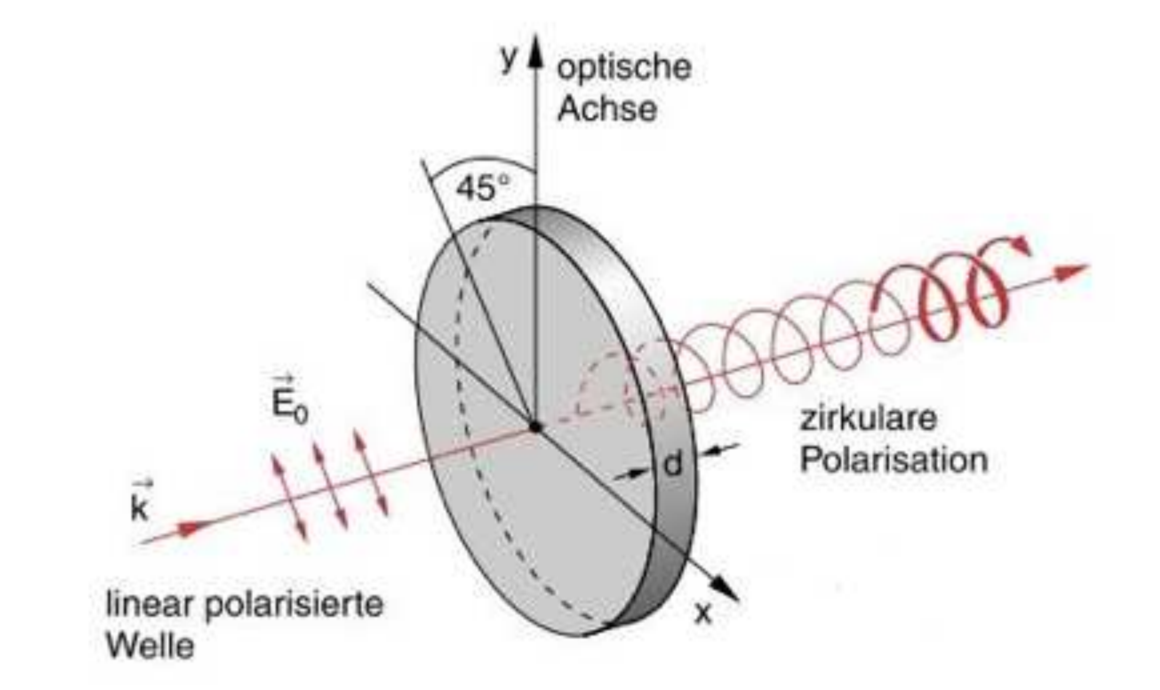


Abb. 2: Erzeugung zirkularer Polarisation

For professionals:

If you would also like to carry out the experiment with circular polarization, follow the instructions for polarization (circular). Ask the lab supervisor for suitable glasses and $\lambda/4$ plates if these are not available at the experiment station.

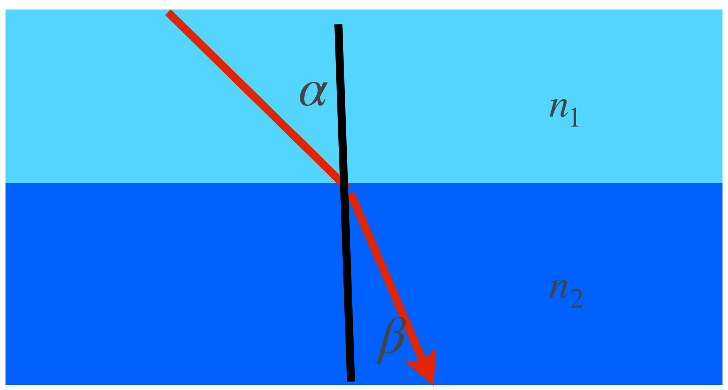
Verwandte Glossarbegriffe

3D-Technik im Kino (RealD)

Index

REFRACTION OF LIGHT

Summary:
If a beam of light hits the boundary between two materials with different refractive indices, it is refracted at the boundary, i.e. it changes direction. If the light beam passes from a medium with a low refractive index (e.g. air) to one with a higher refractive index (e.g. water), the light beam is refracted towards the perpendicular at the boundary of the media - when it enters a medium with a lower refractive index, on the other hand, it is refracted away from the perpendicular. This spoon therefore has a kink due to the phenomenon of refraction!



Material with low refractive index

Material with high refractive index

So what is refraction?

Refraction is a change of direction of an incident light beam onto another medium with a different refractive index. This happens because light propagates at different speeds in different materials. If you want to express this as a formula, it looks like this: c(n) is the speed of light in the medium, c_0 is the speed of light in a vacuum and n is the refractive index.

$$c(n) = \frac{c_0}{n}$$

More details can be found on the next page.

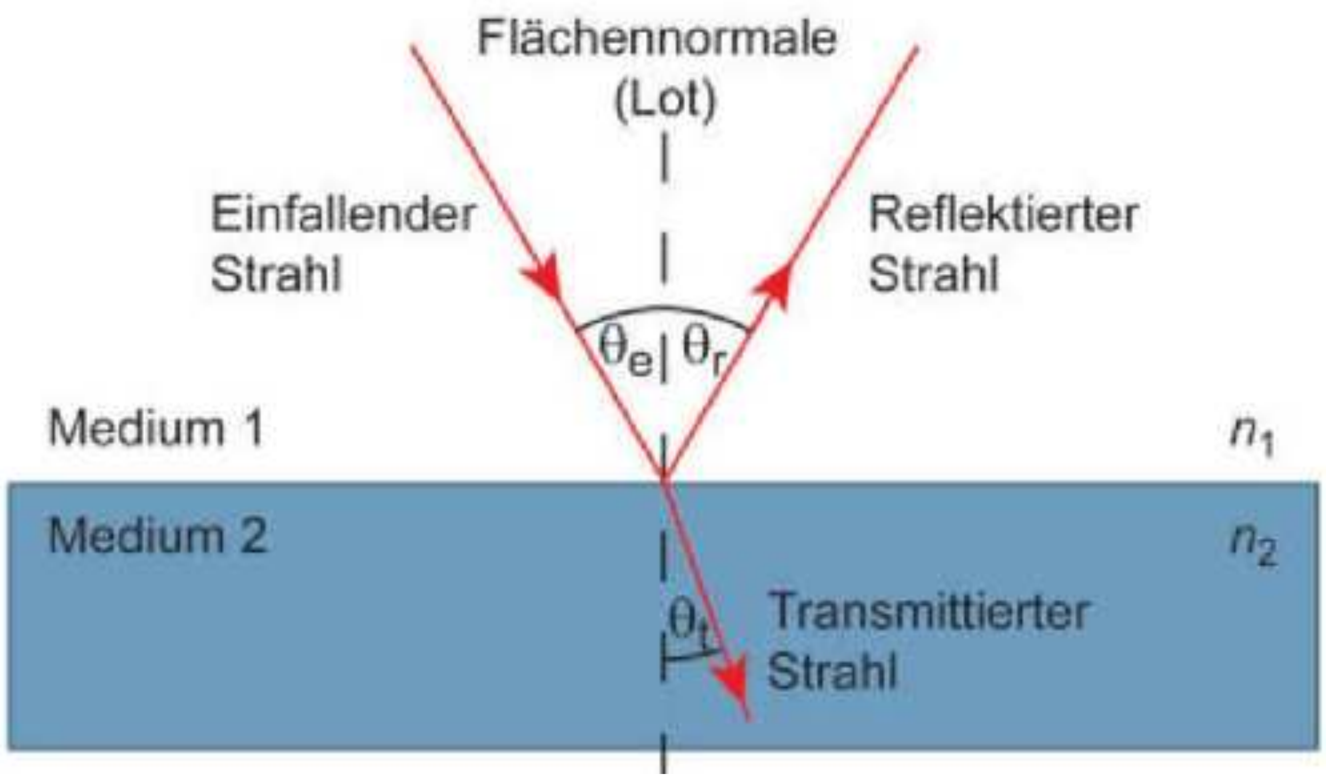
https://de.123rf.com/photo_20391393_beispiel-des-wassers-brechung-mit-einem-glas-und-l%C3%B6ffel-.html

REFRACTION OF LIGHT

The image shows the refraction and reflection of a ray: An incident ray from the homogeneous medium 1 hits the surface of medium 2. n is the refractive index, i.e. a unitless number that describes how strongly or weakly the light is refracted/reflected.
The angles (e=incidence angle, r=reflection angle and t=transmission angle) describe the path of the rays.

The change in direction of the refracted ray can be described by the law of refraction (Snelli's law):

$$n_1 \sin(\theta_c) = n_2 \sin(\theta_t)$$



Geometrische Optik, Lehrbuch zur Exprimentalphysik, Joachim Heintze (Quelle)

LENS EQUATION

If the object to be imaged emits light and this light, after passing through an optical system, collects in a point on a screen, then we have an image!

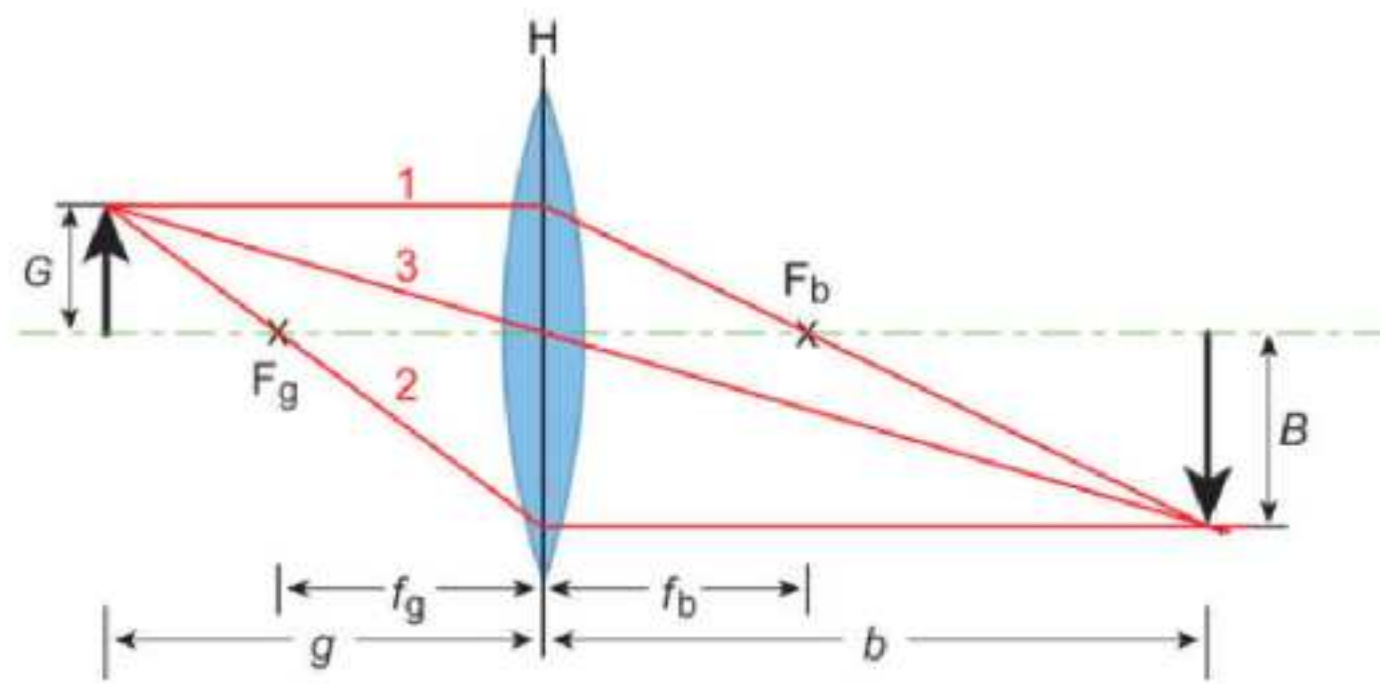
Here, three representative auxiliary rays emanate from the object with object distance g (distance from object to lens). Path 1 first runs parallel to the optical axis (axis of symmetry) and then through the focal point F_b. Path 2 first runs through the focal point F_g and then parallel to the axis. Path 3 passes directly through the center of the lens (center beam). The distance from the lens to the image is called the image width b.

Disclaimer: In reality, of course, many more rays emanate from the object than in the picture.

Also important is the focal point F of the lens, where rays incident parallel to the axis meet.

The famous lens equation or imaging equation describes the relationships between these variables:

$$\frac{1}{f} = \frac{1}{g} + \frac{1}{b}$$

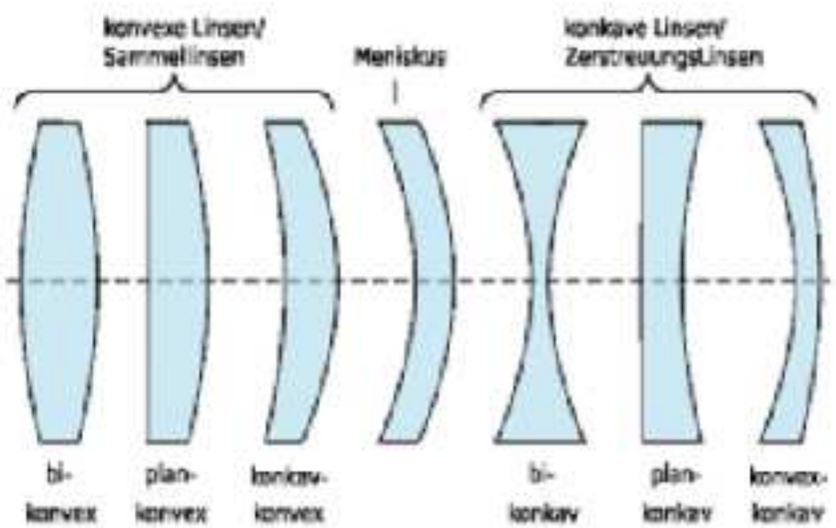


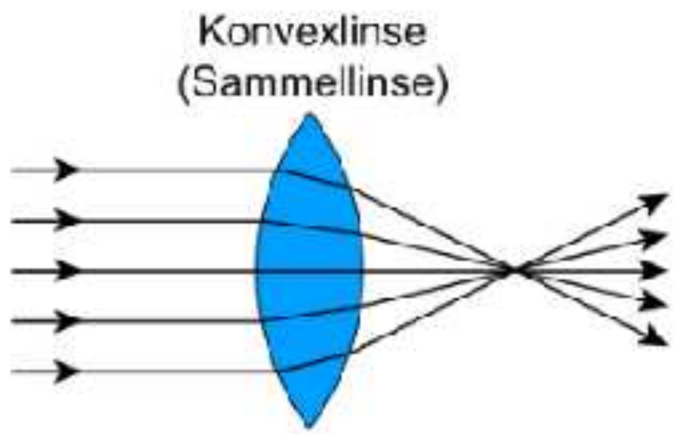
https://de.wikipedia.org/wiki/Geometrische_Optik

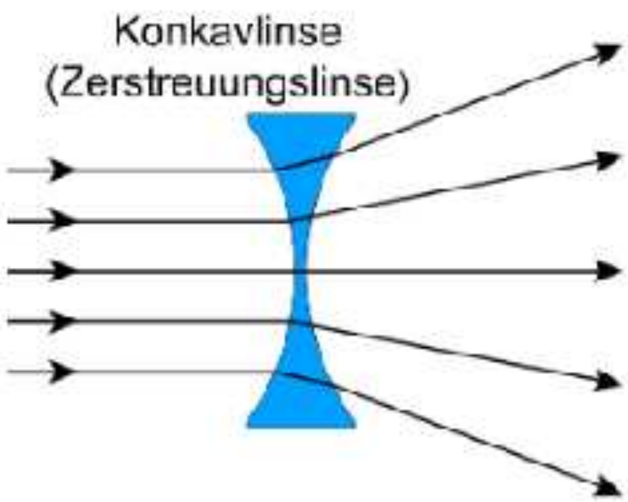
LENSES

Lenses change the beam path by dispersing (concave lenses) or collecting (convex lenses) light. They do this by refracting the light rays at the entrance and exit surfaces in accordance with the law of refraction described above. The rays do not change direction in the lens itself.

A biconvex lens collects the incident light rays, a biconcave lens disperses them.







https://www.leifiphysik.de/optik/optische-linsen/grundwissen/linsenformen

https://de.wikipedia.org/wiki/Linse_%28Optik%29

SOLUTION GEOMETRICAL OPTICS, EXPERIMENT 1

Question: Is there a second object width (or image width) at which you get a sharp image?

Solution: In the experiment, the second sharp image point is very difficult to localize. This is because the image is very small. Mathematically, the case is also something for professionals because the equation is complex to solve. The equation is quadratic and solving it with the midnight formula can result in two solutions.