Introduction to the quantum world

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Image from MudassarIqbal on Pixabay

With funding from the:

Federal Ministry of Research, Technology and Space

https://qufablab.de/
https://quantumminilabs.de/

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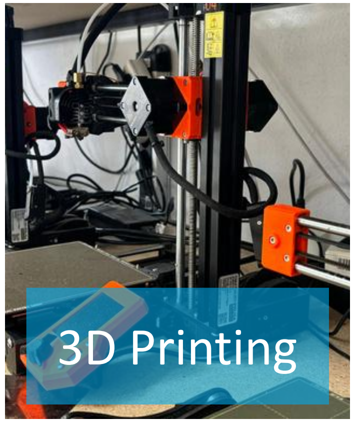

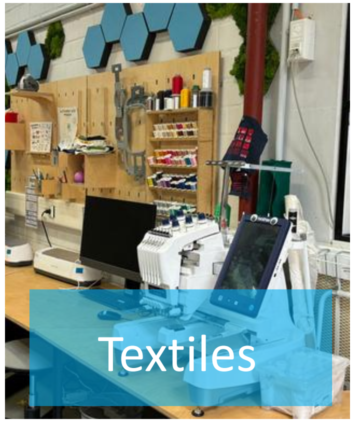

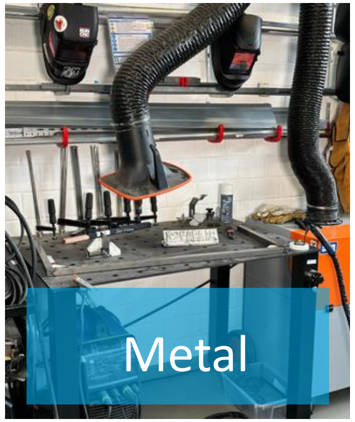

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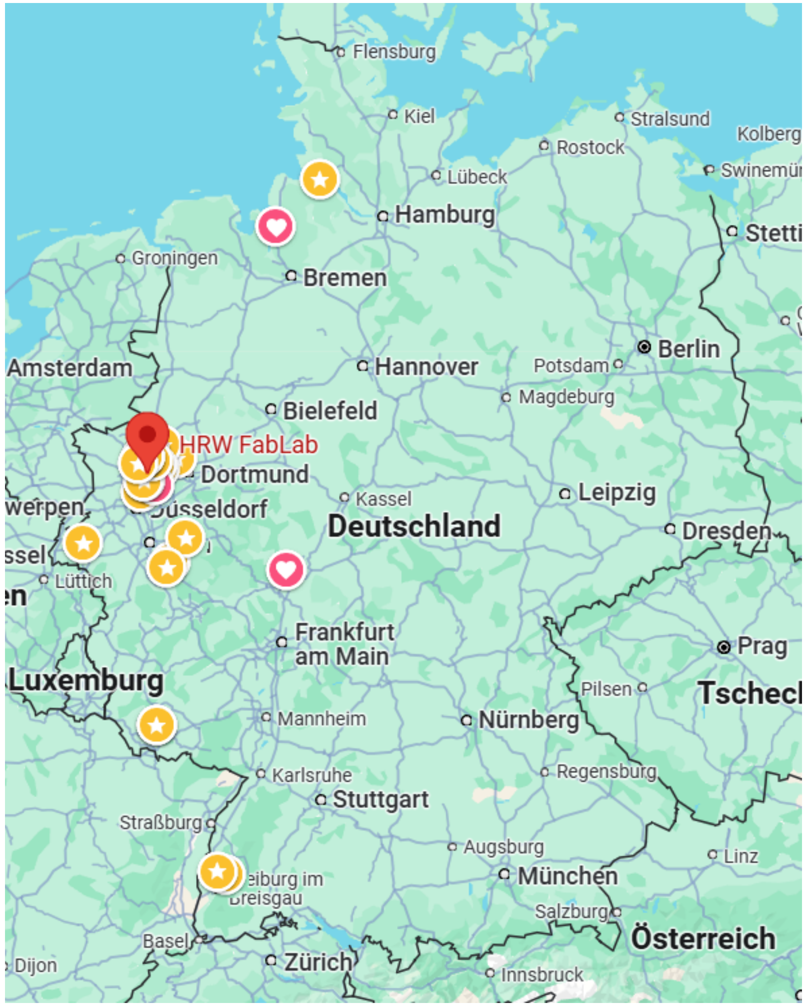
Open workshop (free of charge)
Wednesdays 3.30 - 7.30 pm
Registration:
https://hrw-fablab.de/anmeldung/

HRW - FabLab



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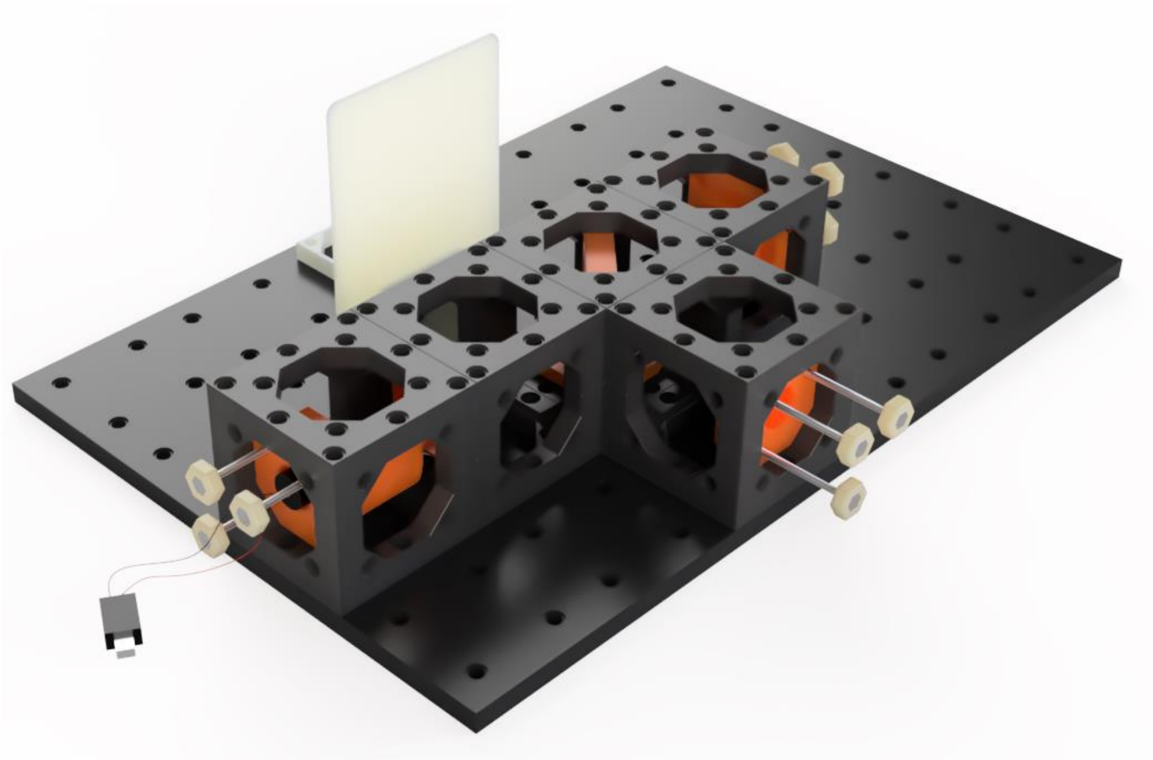
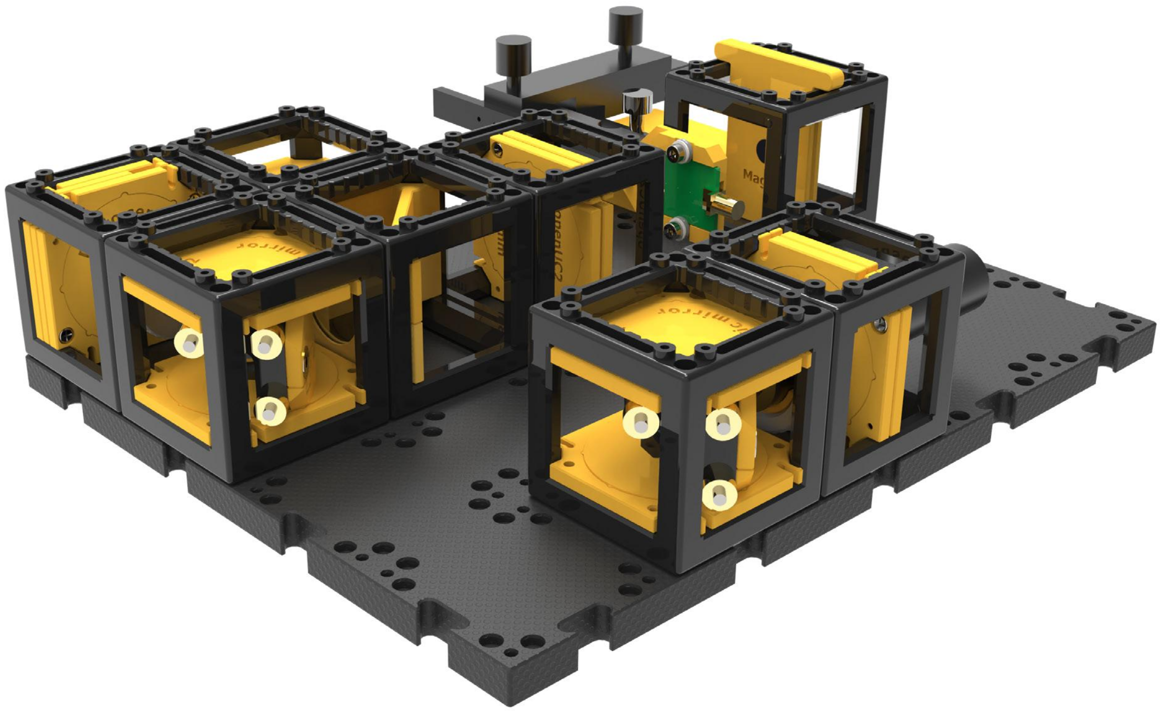
QuFabLab-Kit and Quantum MiniLabs





https://qufablab.de

Files to **3d print the kit**:
https://qufablab.de/wuerfelsystem

https://quantumminilabs.de

Learning centres in Germany can **apply for a free kit.**
https://quantumminilabs.de/bewerbung/
available to order at https://openuc2.com/ from ~2027 on

Experiments that can be carried out

- Spectrometer
- Double slit experiments
- Band gap in LEDs
- Determine the Planck constant
- Michelson interferometer
- Mach Zehnder interferometer
- Optically Detected Magnetic Resonance (ODMR)
- Quantum eraser
- BB84
- Polarizer

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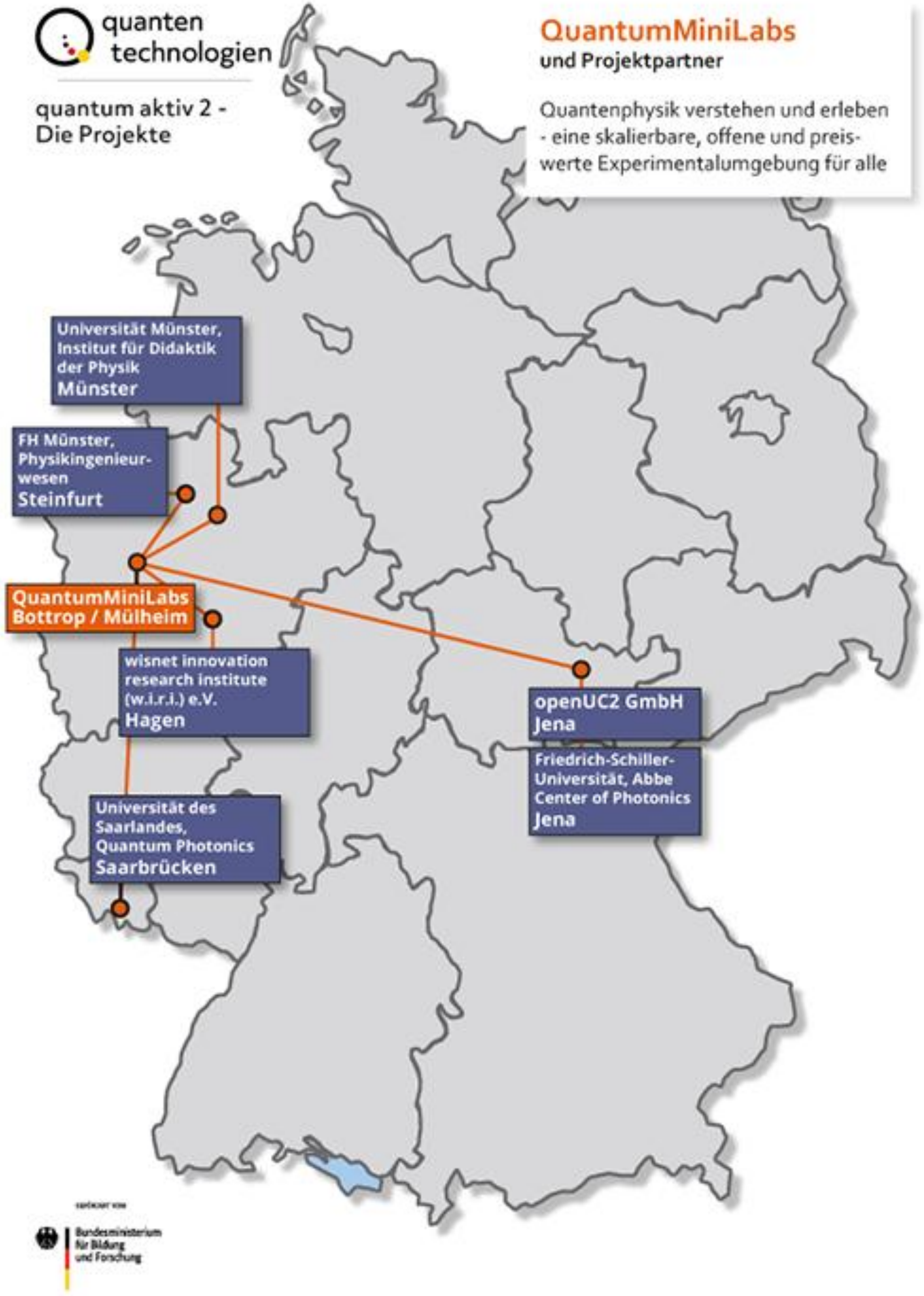
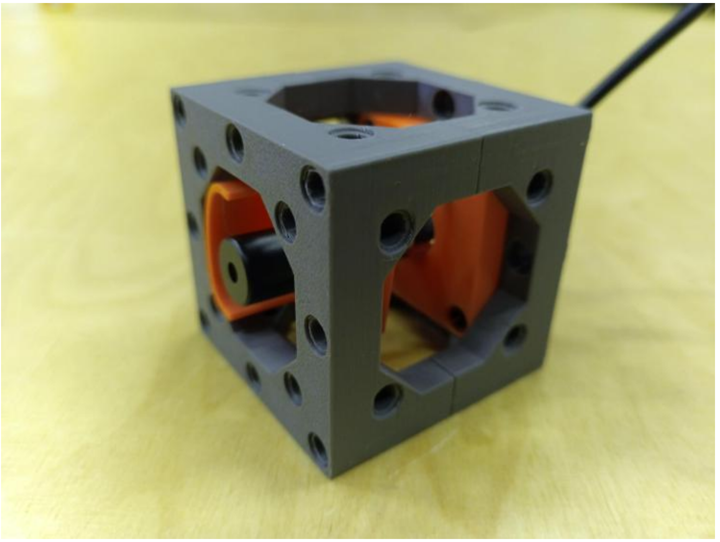


Our partners
in the Quantum MiniLabs project

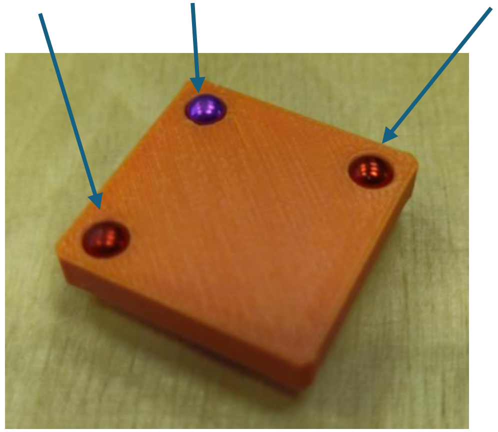
Laser safety

Attention: Laser class II



- Do not look into the laser
- only supply the laser with power when it is in the experimental setup
- only look at the experimental setup from above and not from the side
- Do not point the laser at people or animals
- Do not unintentionally point the laser at reflective objects
- Remove watches, rings, bracelets
- Do not hold cell phones in the beam path of the laser
- Before you switch on the laser, think about where the laser will go and whether there are people, animals or reflective objects in its path
- switch off the laser before introducing new objects into the laser beam
- Do not disassemble the laser

Strong magnets



- Please let us know if you have a cardiac pacemaker or a Cochlear implant carried.
- Cell phones, tablets, computers, EC cards, etc. can be damaged by strong magnets - do not bring these items near the experimental setup.
- Please let us know if a magnet comes loose.

What are quanta?

Everything consists of quanta!

They are the **smallest known units of matter and energy.**

That means:

if you keep zooming in on anything, you always end up finding quanta.

Image from Lumina Obscura on Pixabay

Examples of quanta: electrons, quarks and photons

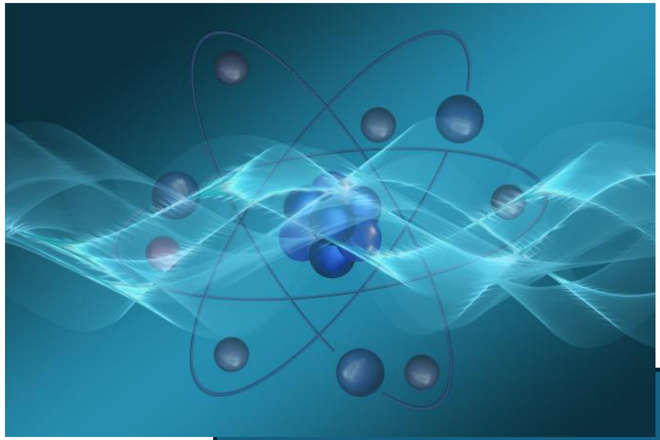


image from
Gerd Altmann on Pixabay

- **electrons** are the negatively charged elementary particles

- The subatomic particles protons and neutrons are made up of **quarks**

Science television magazine:
Quarks and Co

image from
myshoun on Pixabay

- Light consists of **photons**

atoms consist of electrons, protons and neutrons → atoms consists of quanta

Why quantum physics is relevant?

Without quantum physics no...

Image from Clker-Free-Vector-Images on Pixabay

Transistor=
Computer =
Smartphone

Laser =
DVD drive =
Playstation etc.

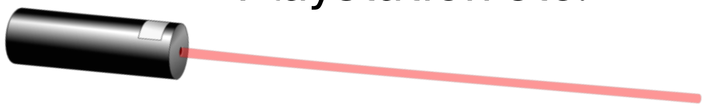


Image from OpenClipart vectors on Pixabay

Led= as in televisions, smartphones etc.

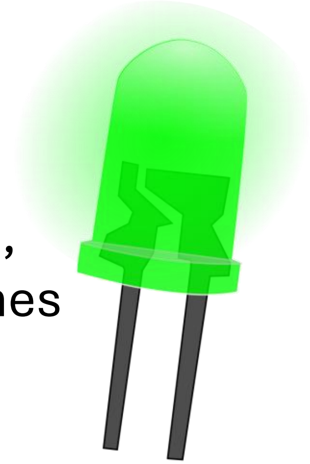
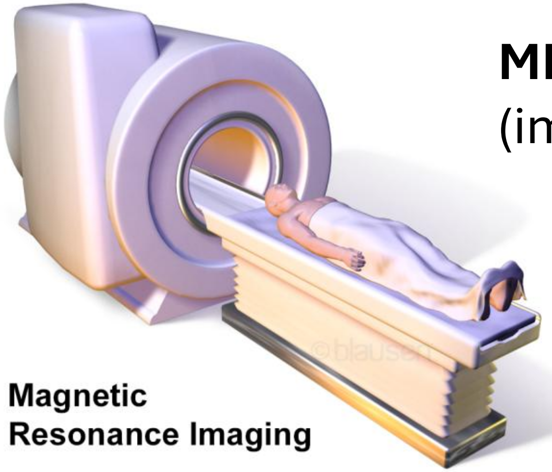


Image from OpenClipart vectors on Pixabay



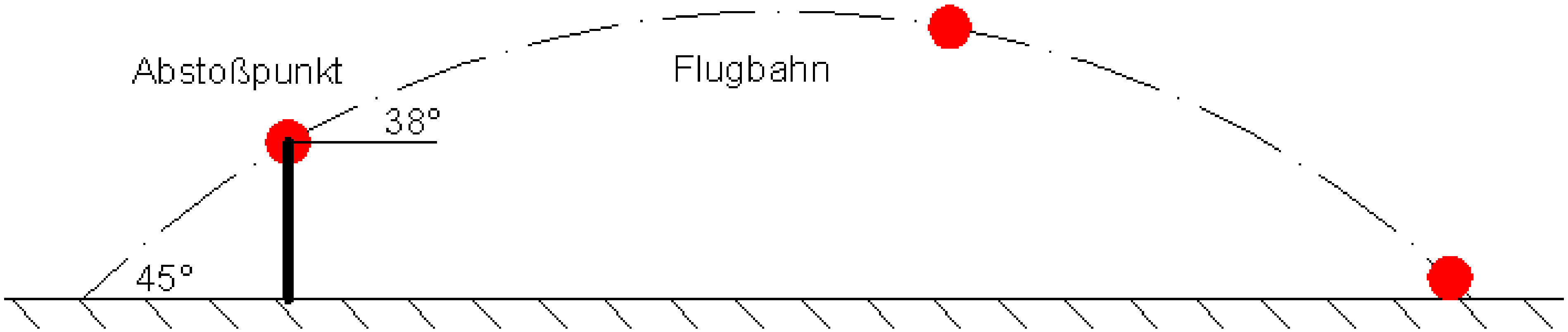
MRI
(important medical diagnostics)

Atomic clock =
Navigation via GPS

What are the differences between quantum physics and classical physics?

Classical physics

- If you throw a ball and know the **drop angle**, the **starting speed** and the **mass** of the ball, you can precisely predict the **position** and **speed** and the **meeting point** of the ball.



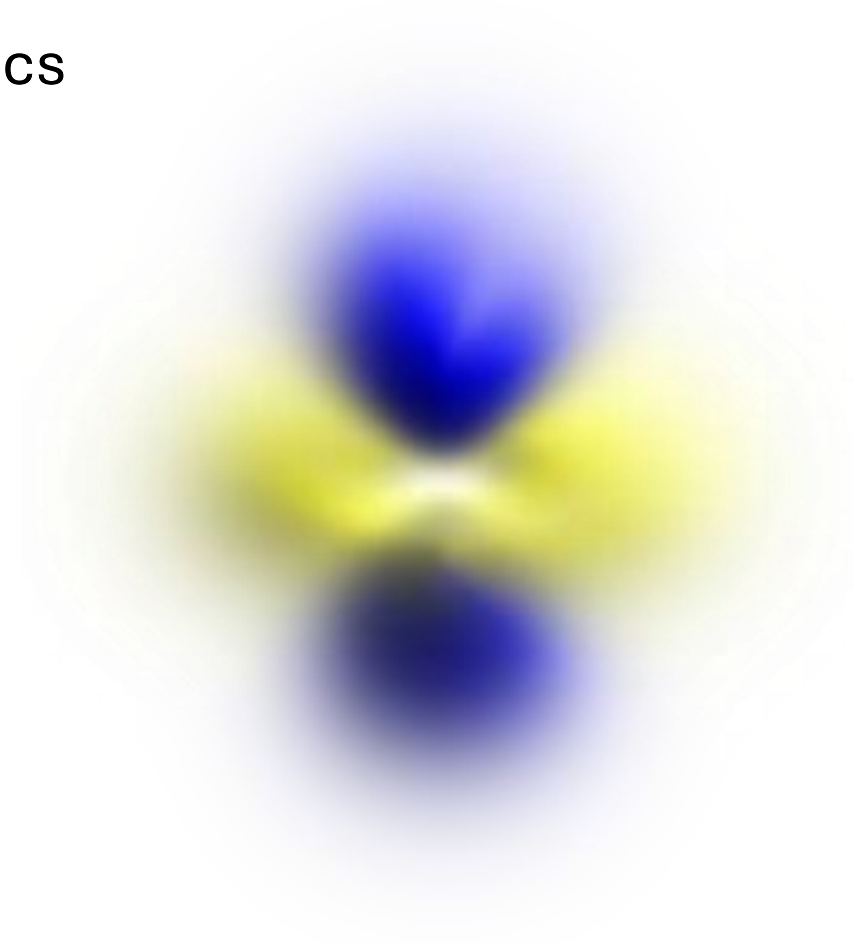
Robert Kropf (https://commons.wikimedia.org/wiki/File:KugelFlug.png), „BallFlight“, https://creativecommons.org/licenses/by-sa/3.0/legalcode

What are the differences between quantum physics and classical physics?

Quantum physics

- In quantum mechanics it is **not possible to precisely predict** the **movement** and **location** of quanta.

- For electrons in an atomic nucleus, the **place of residence** can be specified only to some **probability**. In the figure on the right, the probability of finding an electron is represented by the intensity of the colour. The areas in which electrons are found are called orbitals.



Example of an orbital

Quanta have special properties

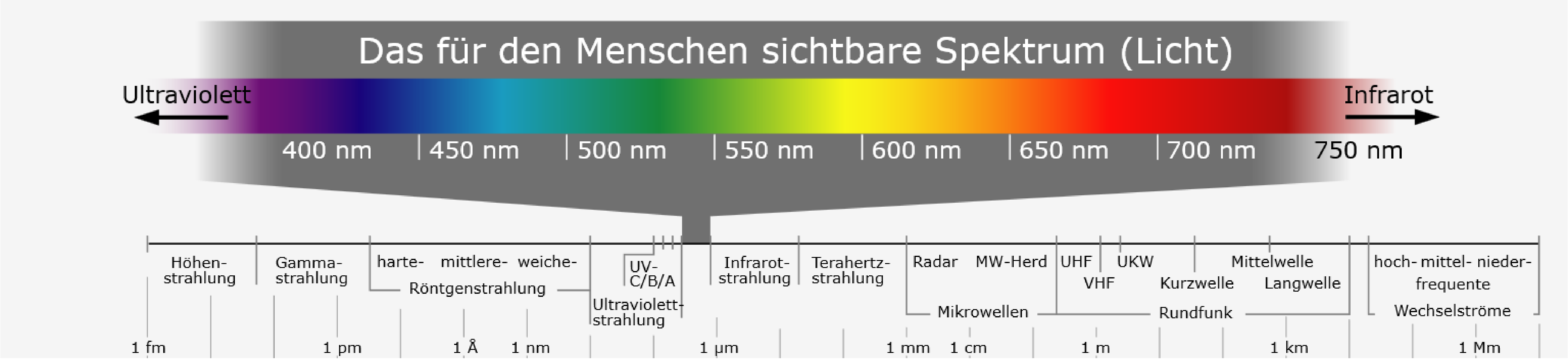
Quanta…

- … usually have particle and wave properties.
  This is referred to as **wave-particle duality**.
- … are indivisible.
- … have a spin.
- … can have superpositions.
- two or more quanta can be entangled with each other.

➢ But: the more quanta there are in one place, the fewer quantum properties they exhibit. This is due to interactions between the quanta.

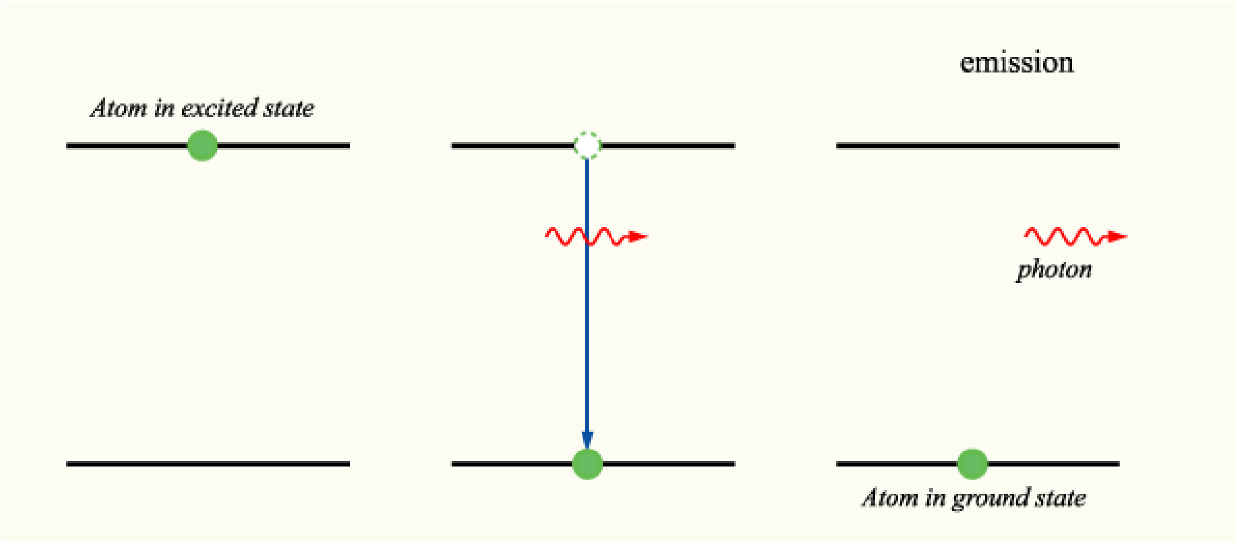
Light spectrum - all photons! - i.e. quanta

In this quantum workshop, we only deal with photons



When you mix red, green, and blue light, it appears white to us.

Where does photons come from?



Modified after: User:(Automated conversion),User:DrBob, CC BY-SA 3.0 <http://creativecommons.org/licenses/by-sa/3.0/>, via Wikimedia Commons

Electrons can jump to a state with a higher energy level when excited by...

- light
- electricity
- heat

This is referred to as a **quantum jump**.

When electrons jump back to the state with the normal energy level the excess energy is emitted in the form of a **light quantum (photon)**.

flame colouring - photons due to excitation of electrons by heat

copper

lithium

sodium

Different atoms show different large gabs between the energy levels in which electron can stay.

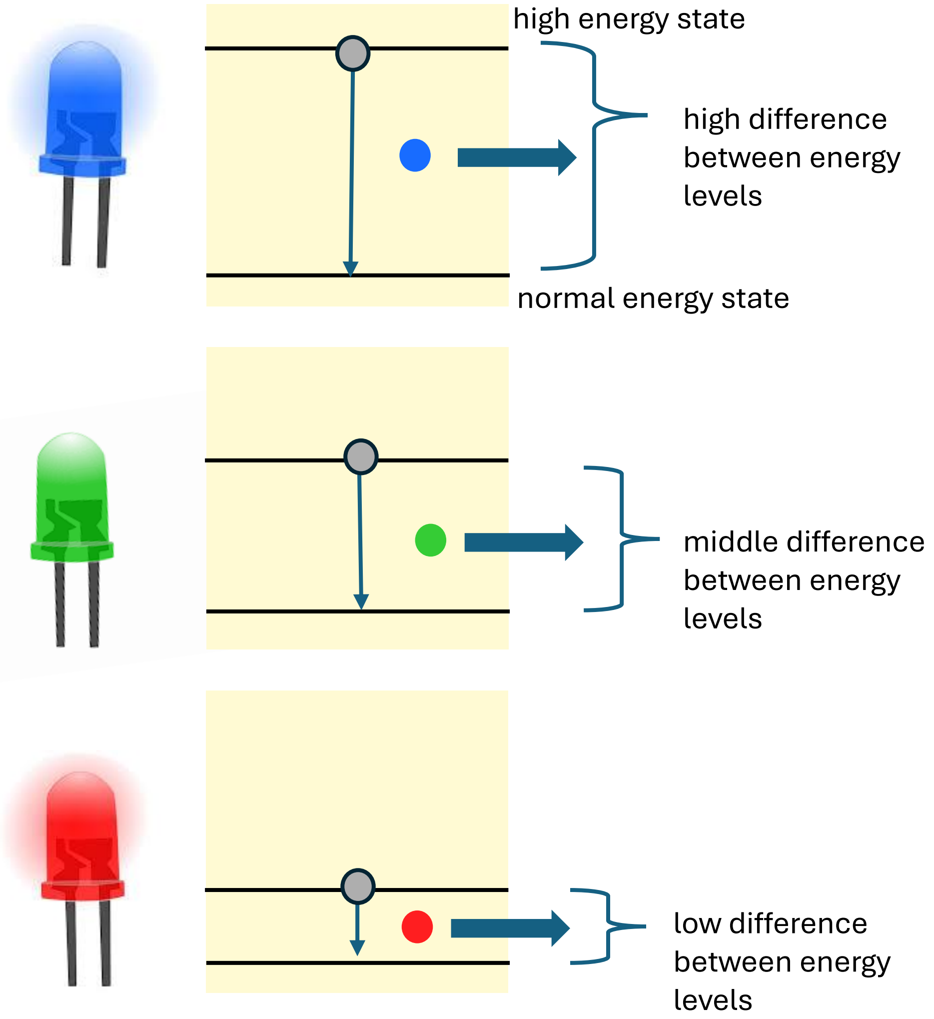
When electrons fall down to the normal energy state, they emit photons.

The larger the gab - the shorter the wavelength of the photon.

This phenomenon can be used to identify atoms.

https://commons.m.wikimedia.org/wiki/User:S_k_y_r

Leds - photons due to excitation of electrons by electricity



LEDs contain semiconductors with a precisely defined chemical composition.

The electrons in the semiconductor are excited by electricity and jump to a higher energy state.

When the electrons jump back, photons are emitted.

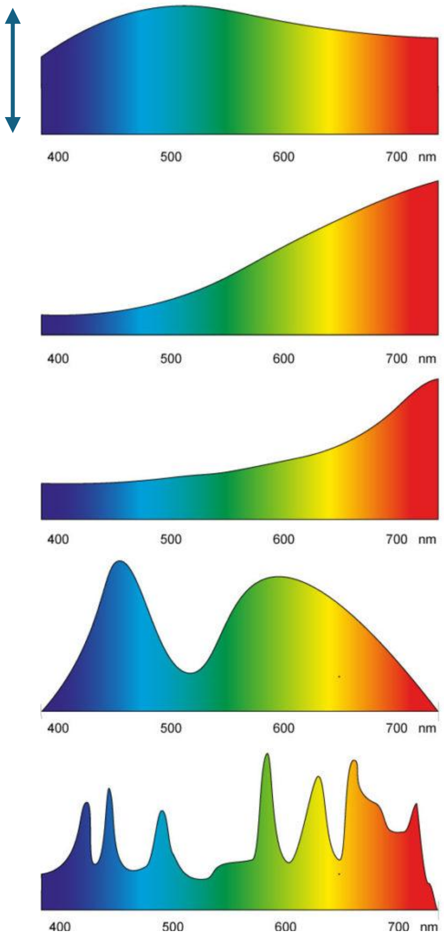
The wavelength of the emitted photon depends on the chemical composition of the semiconductor material.

The greater the difference between the energy levels, the shorter the wavelength.

https://openclipart.org/detail/248021/red-led-lamp-on // green // blue //

Spectral analysis

Intensity



daylight

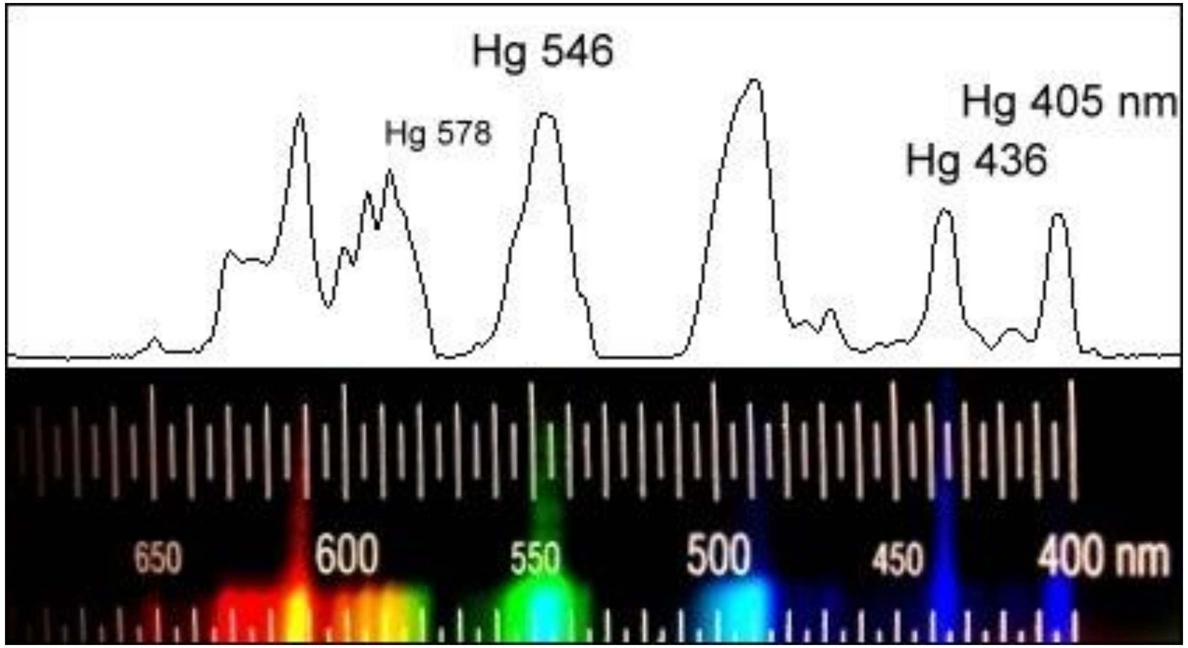
light bulb

halogen light

led light

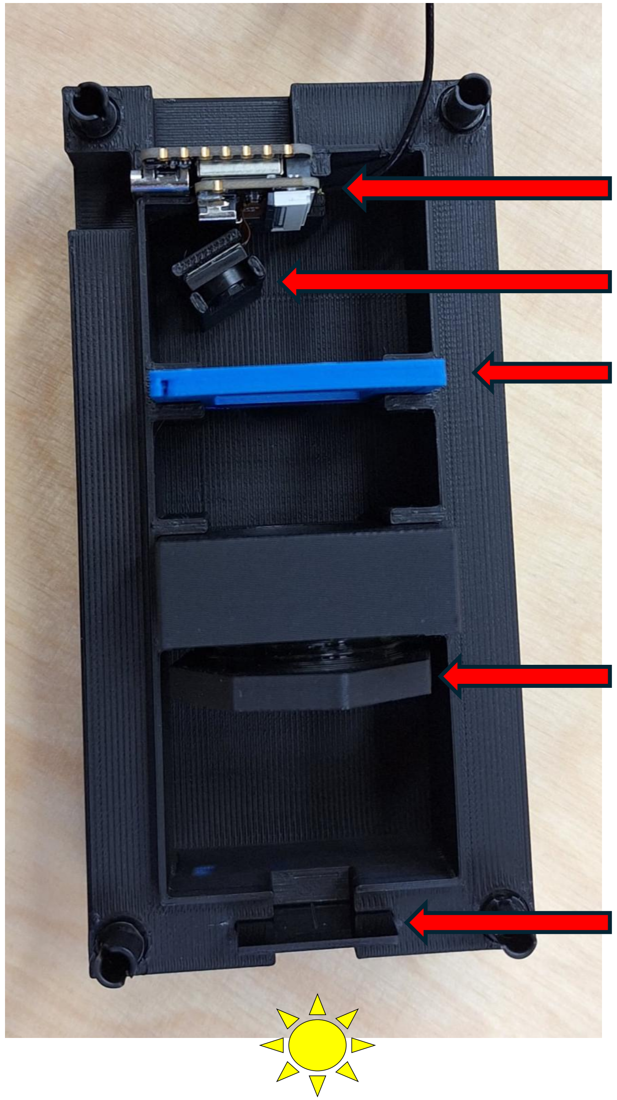
energy saving lamp
with mercury

“white light” of different sources have different spectra – you can analyse the spectrum with a spectrometer.



https://emv-plus.com/aktuelles/leuchtmittelvergleich-im-gesundheitscheck/

Our low-cost spectrometer



Usb connector of the camera

camera sensor

diffraction grating
(1000 lines/mm)

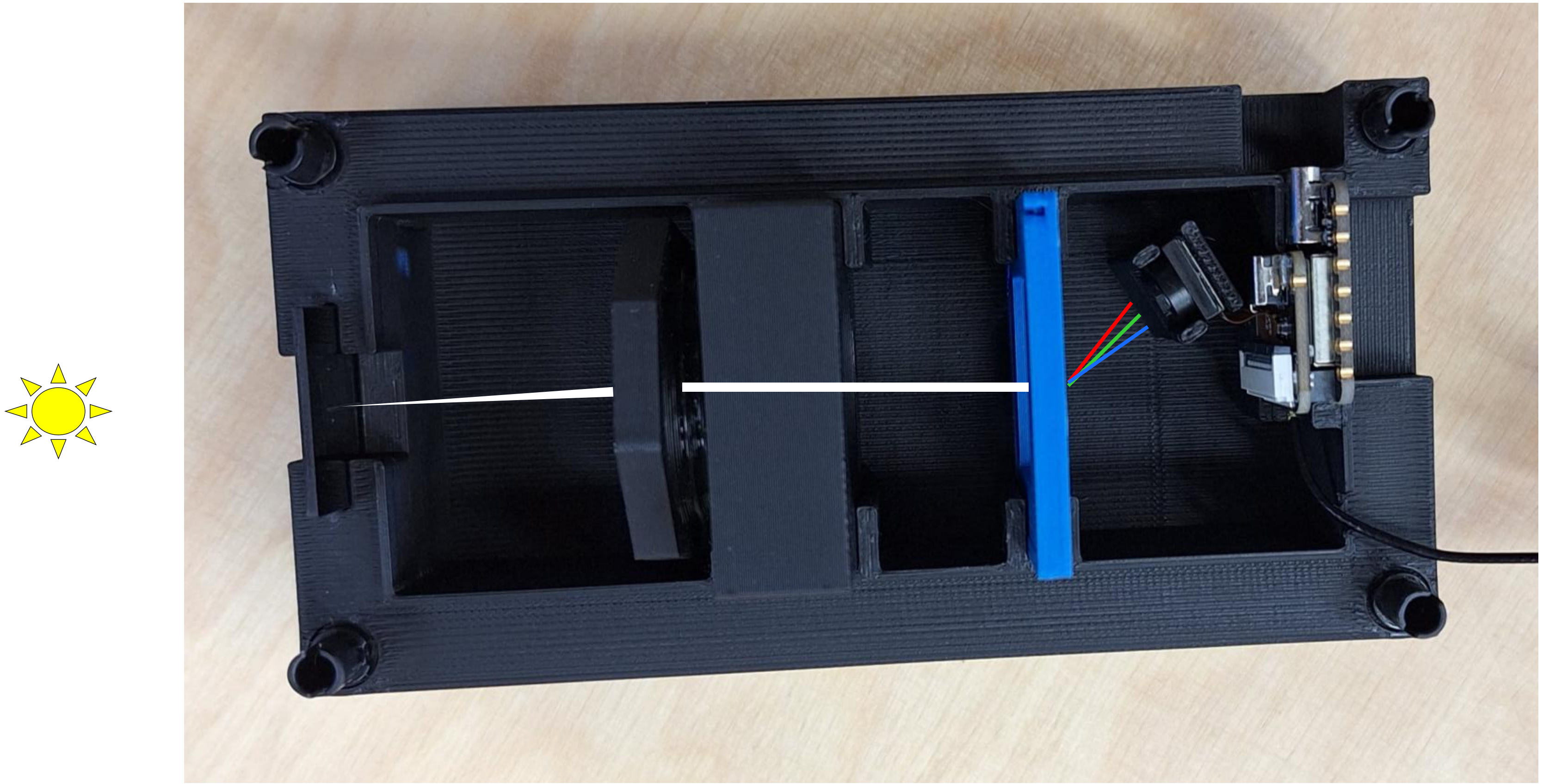
lens

slit aperture (150 μm)
laser-cut from black acrylic glass

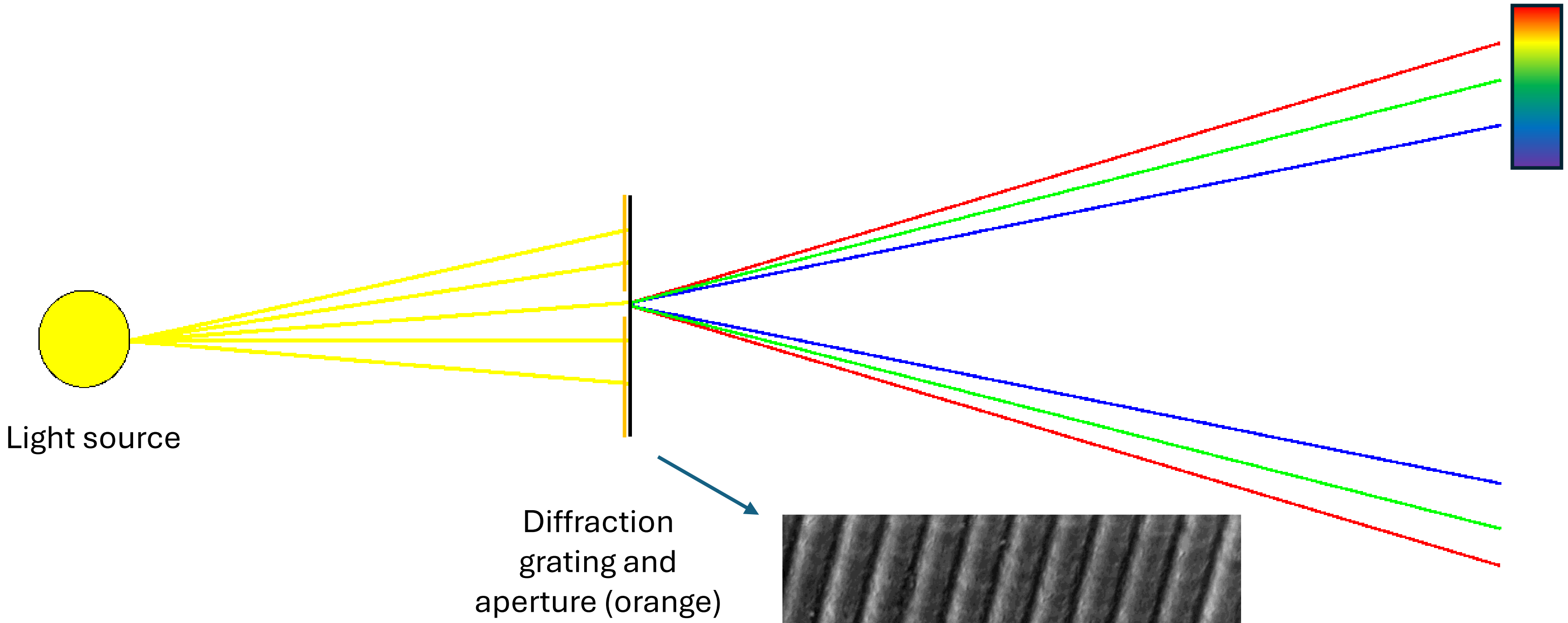
with a spectrometer you can analyse which wavelengths are contained in light from different light sources.

and analyse if there are special atoms in the light source.

Our low-cost spectrometer

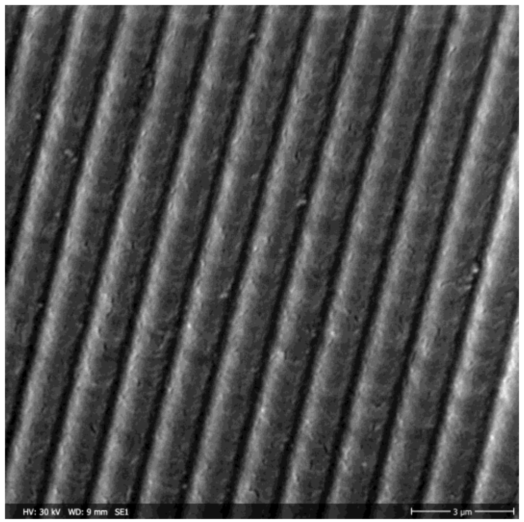


diffraction at the grating



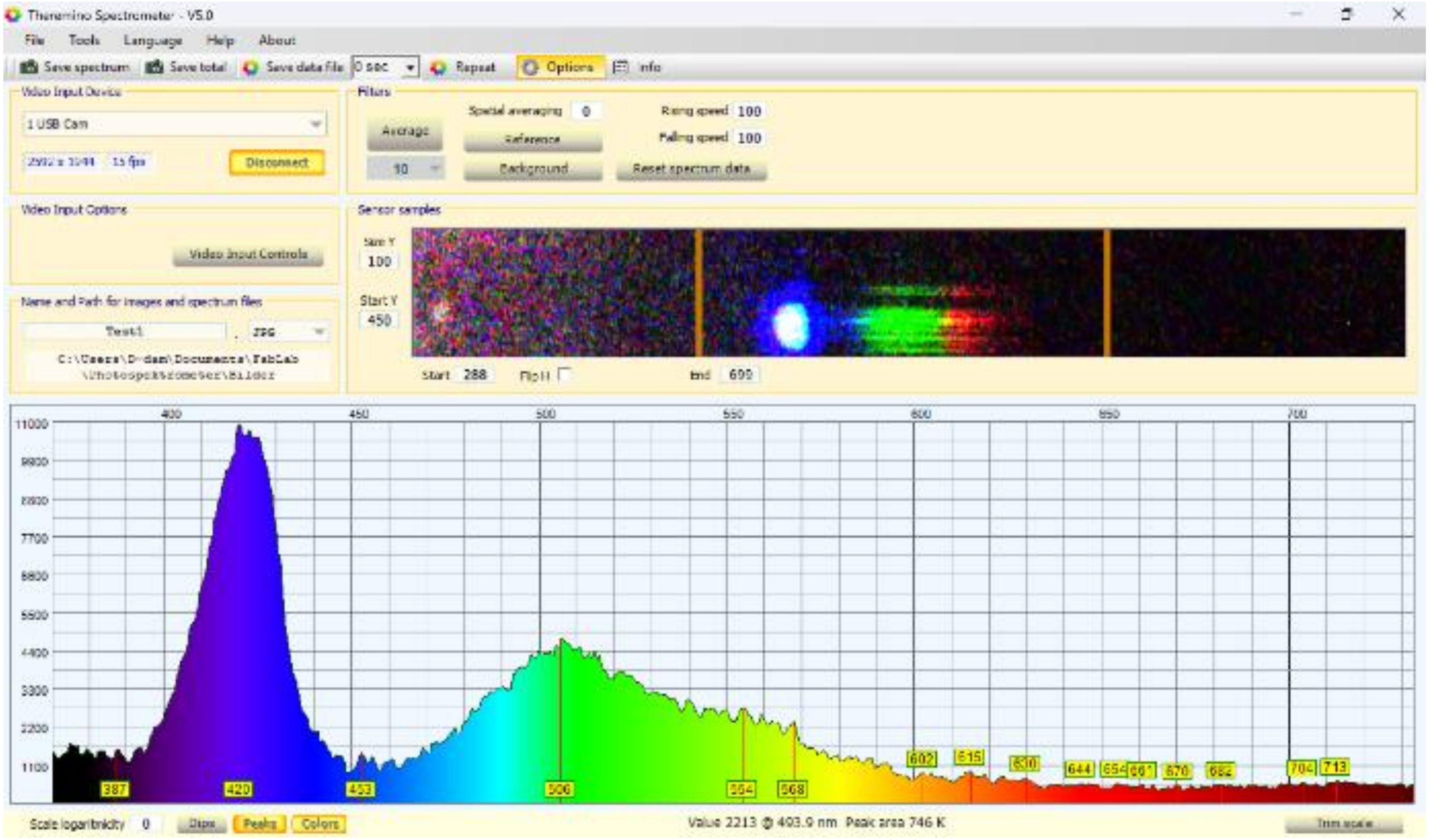
Spectrum:
light is separated into its individual wavelengths

The longer the wavelength, the more the light beam is diffracted



SEM image of a diffraction grating
distance between the grooves: 1000 nm

Software: Theremino Spectrometer



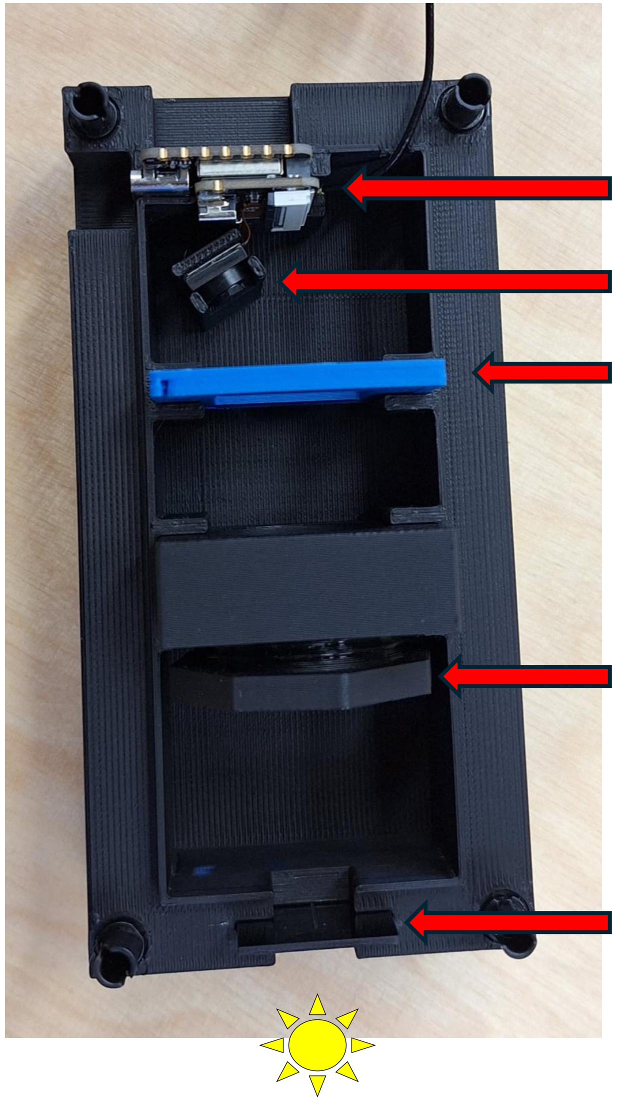
https://www.theremino.com/de/downloads/automation

to calibrate the software go to Tools – Trim points – and select the wavelengths you have available:

436 nm (blue) und 546 (green) oder 692 (red)

move the sliders to the corresponding wavelengths.

Our low-cost spectrometer



Usb connector of the camera

camera sensor

diffraction grating
(1000 lines/mm)

lens

slit aperture (150 µm)
laser-cut from black acrylic glass

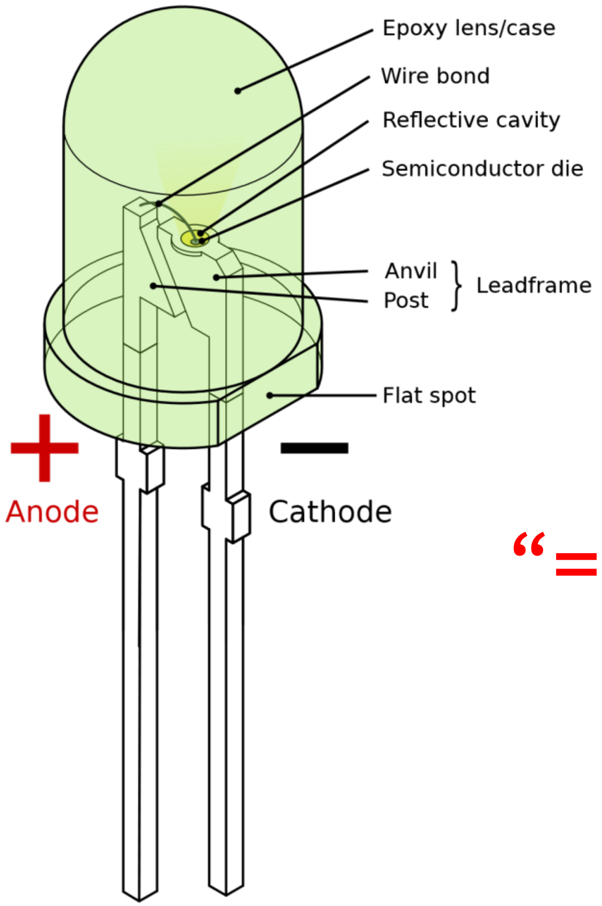
Experiment 1

point the spectrometer at different light sources (light bulbs, LED lamps, if available: energy-saving lamps, cell phone display, sun).

➔ **with a spectrometer you can analyse which wavelengths light is composed of**

you also can use the app screen flashlight

Photoelectric effect



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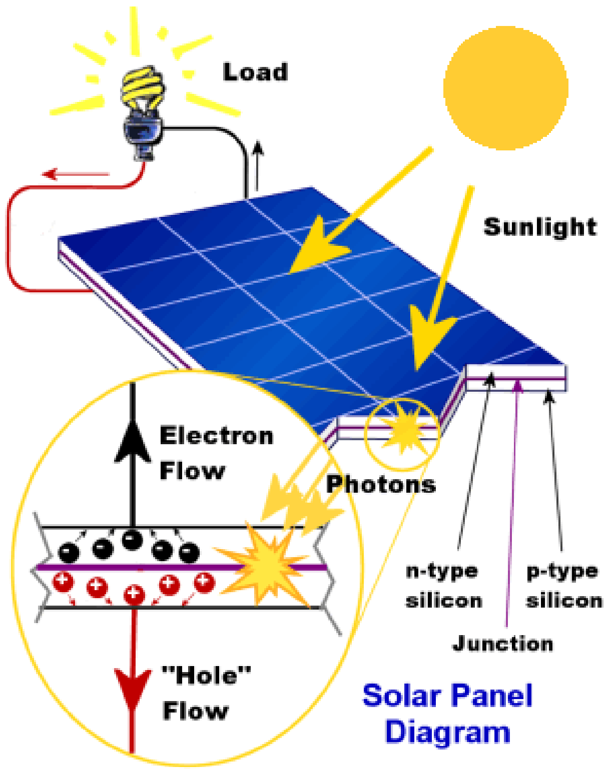

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- The process in LEDs of generating photons through excitation with electricity **can be reversed**.
- Irradiation with photons can therefore generate electricity in LEDs.
- This is the same process as in solar cells and is called the **photoelectric effect**.
- But the energy = wavelength of the incoming light **has to be high enough** to push an electron out of the (semi-)conductor.

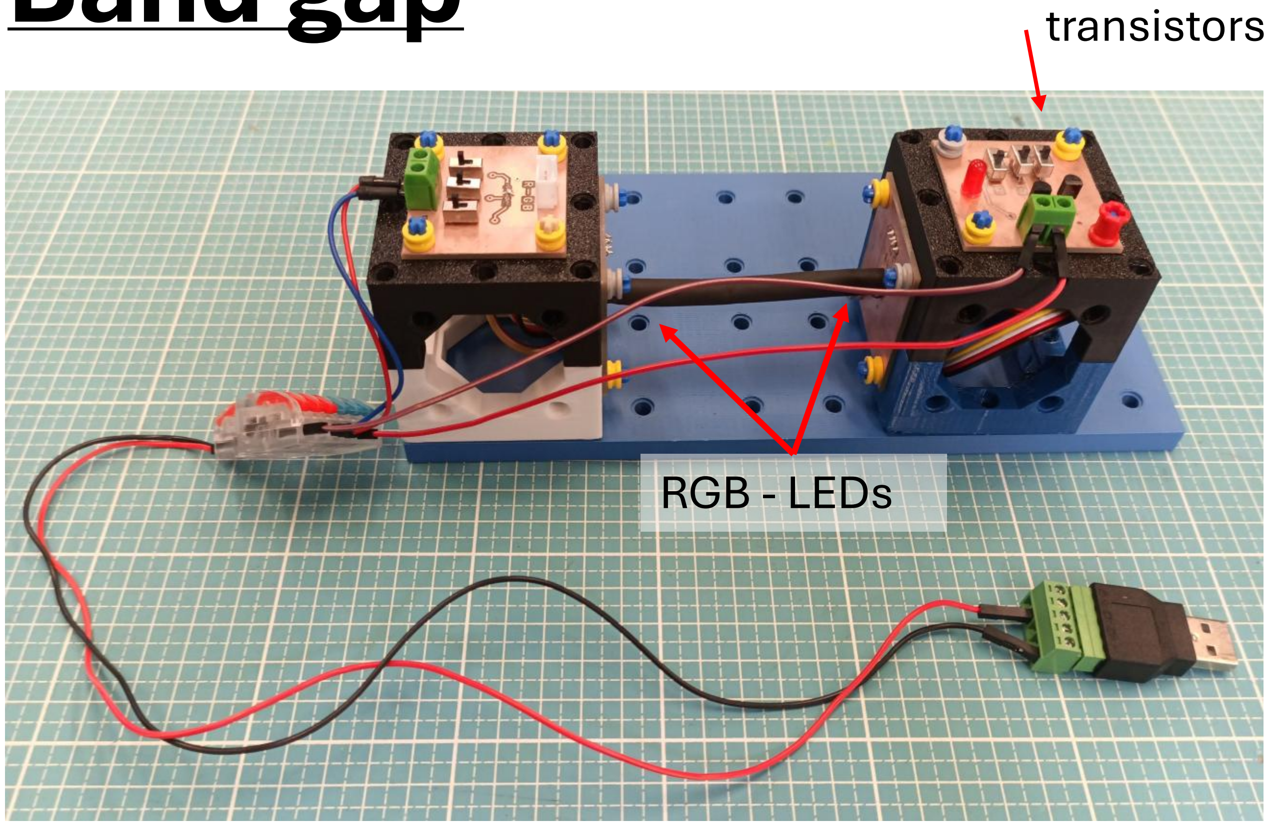
Important findings by Albert Einstein (1905):

Light consists of energy packets (photons).

Only the energy per photon counts, not the number of photons.

This was key evidence for the particle nature of light → and a foundation of quantum physics.

Band gap



		„solar cell“ (right pcb)		
		red	green	blue
light source (left pcb)	red	?	?	?
	green	?	?	?
	blue	?	?	?

Experiment 2

- Place the two cubes shown on the base plate.
- Connect the two protruding RGB LEDs with heat-shrink tubing.

We use the left-hand RGB LED to generate light of different wavelengths, which hits the right-hand RGB LED. We use this as a "solar cell". If current is generated in the "solar cell", it is amplified via transistors and lights up a red LED on the top of the right-hand circuit board.

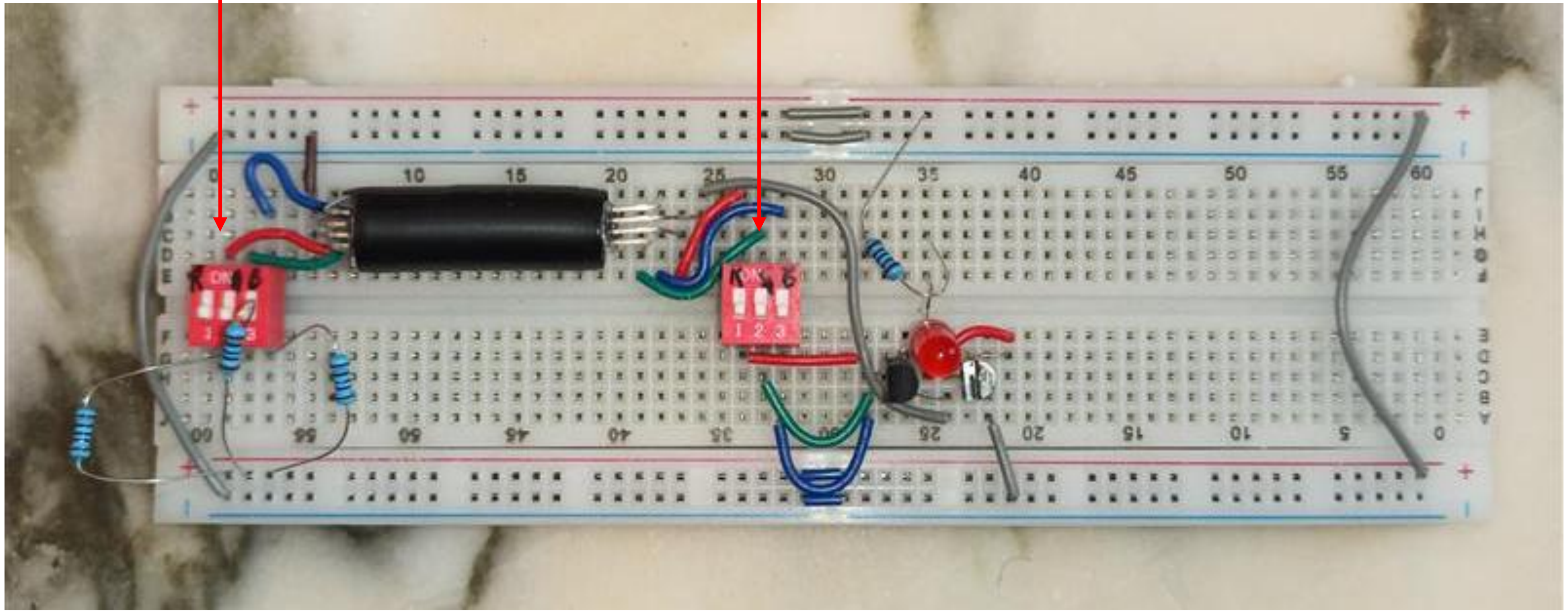
- Connect the USB port to a power supply unit (laptop or smartphone charger).
- Switch on a LED colour of the RGB LED on the left circuit board.
- Switch on the R, G and B channels on the right-hand circuit board one after the other.

<- With which combination does the red LED at the top of the second circuit board light up?

Alternative experimental set up

RGB Light

“RGB-solarcell”



You should have come to the following conclusion:

		„solar cell“ (right pcb)		
		red	green	blue
light source (left pcb)	red			
	green			
	blue			

Fluorescence - photons due to excitation of electrons by light

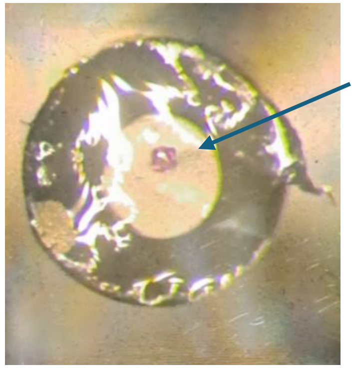
Maxim Bilovitskiy, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

Quinine makes bitter lemon bitter

Vitamin B2 (Riboflavin) also shows a fluorescence under UV-light

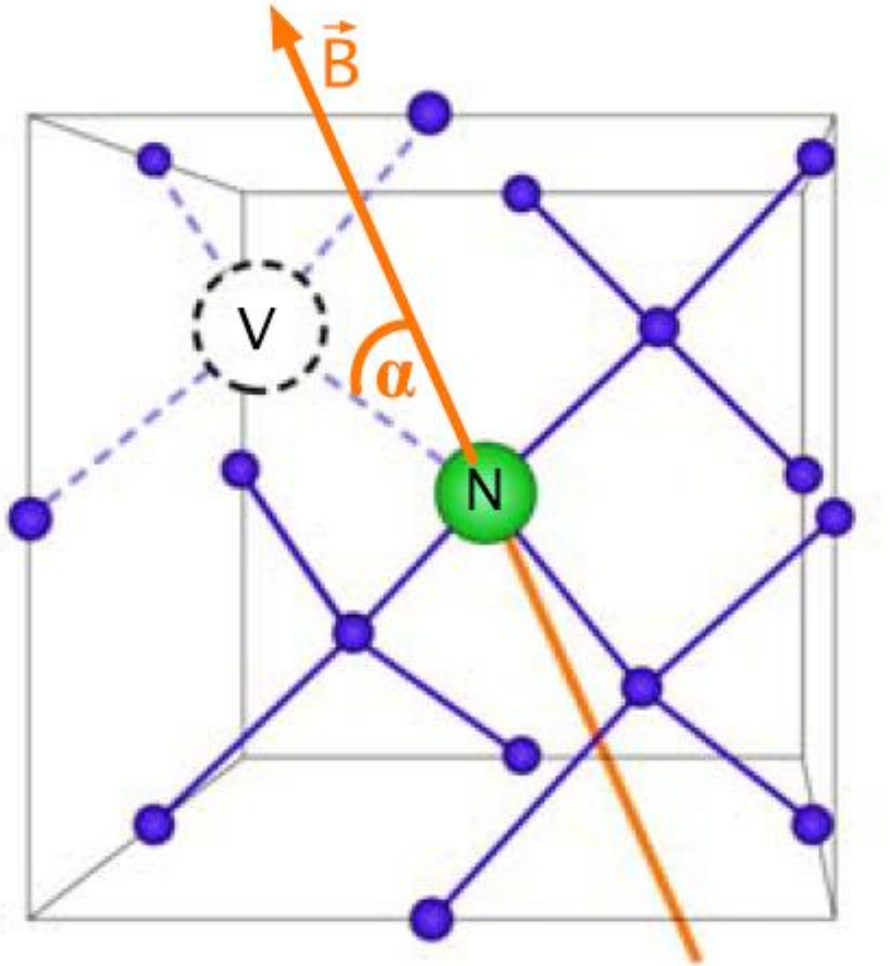
https://www.flickr.com/photos/28617364@N04/32792346483

and diamonds with a NV-centre:



these diamonds glow red,
when you shine a green light on it

What does NV-diamonds look like?

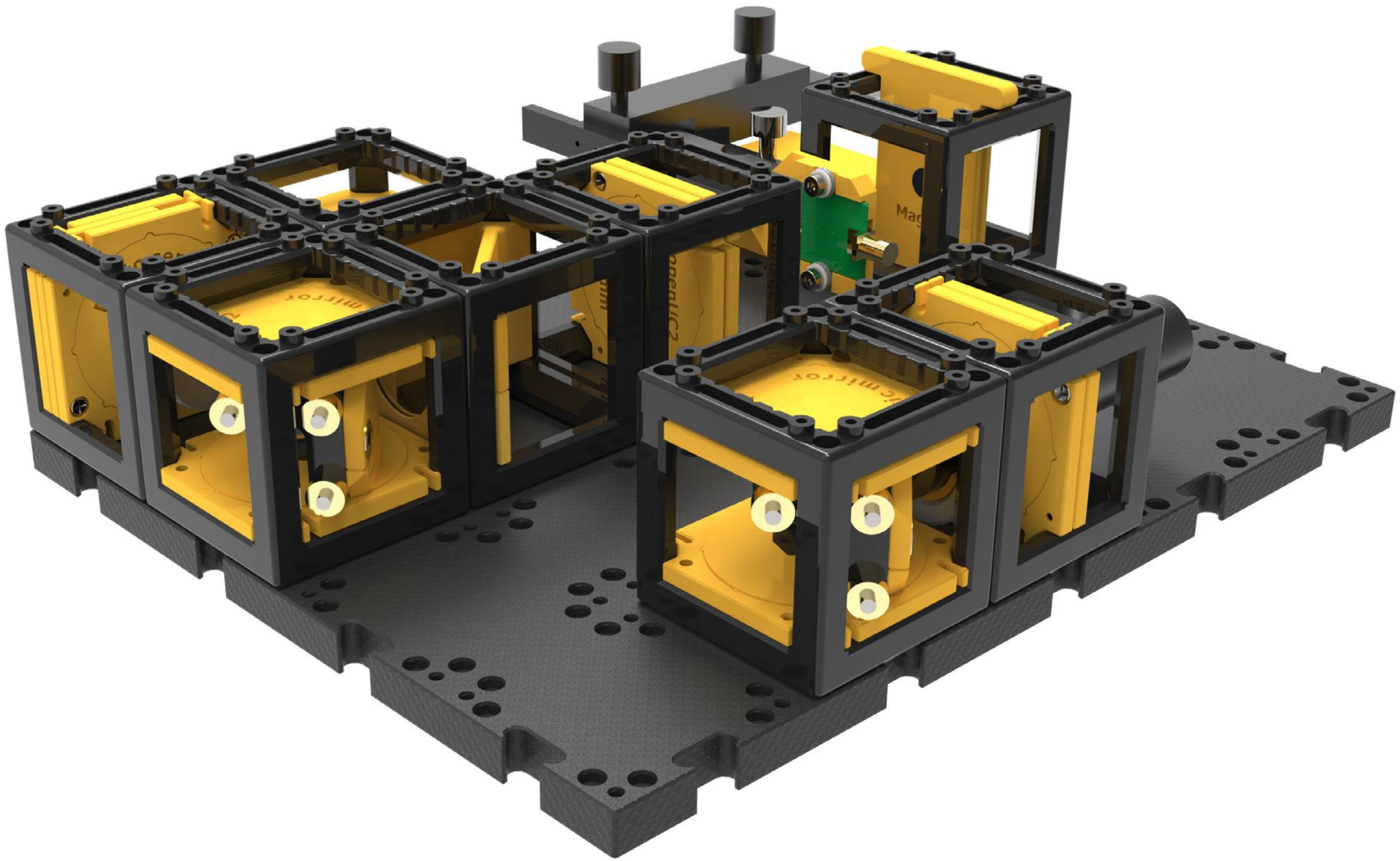


In a normal diamond one carbon atom is replaced by a nitrogen atom (N) and a neighbouring atom is missing (V).

in some quantum computers diamonds with NV-centres are used as single qubits.

Stegeman, Jan & Peters et al (2023). Modular low-cost 3D printed Setup for Experiments with NV centers in Diamond. European Journal of Physics. 44. 10.1088/1361-6404/acbe7c.

OMDR: Optically Detected Magnetic Resonance

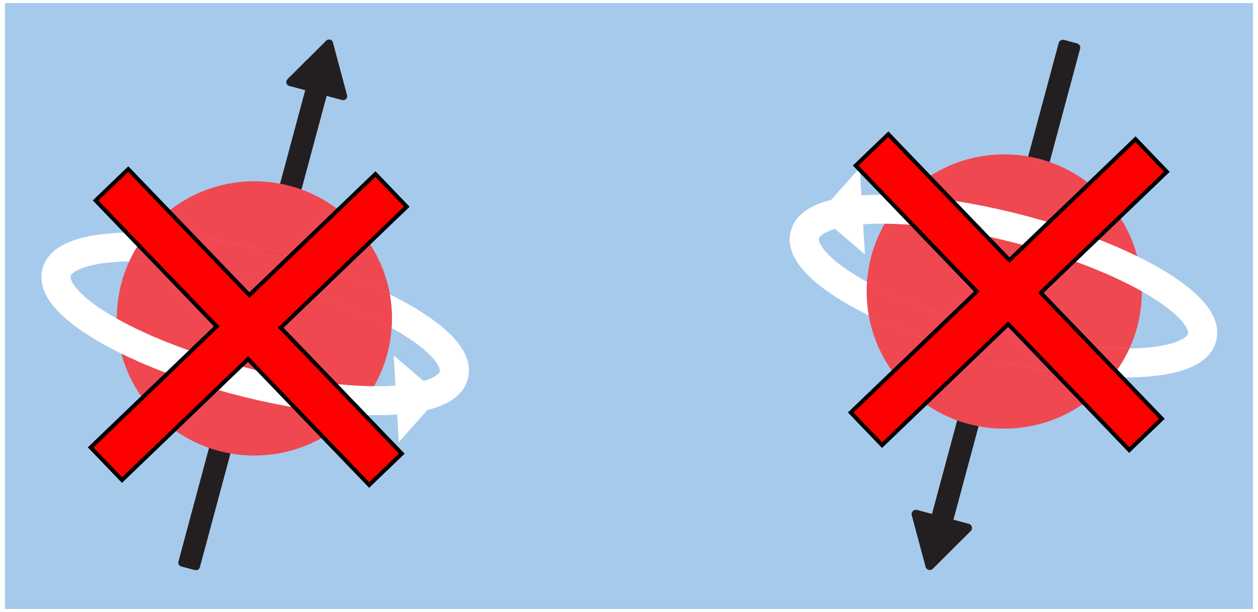


with this principle you can measure very small magnetic fields

for example the magnetic field of your heart or your brain!

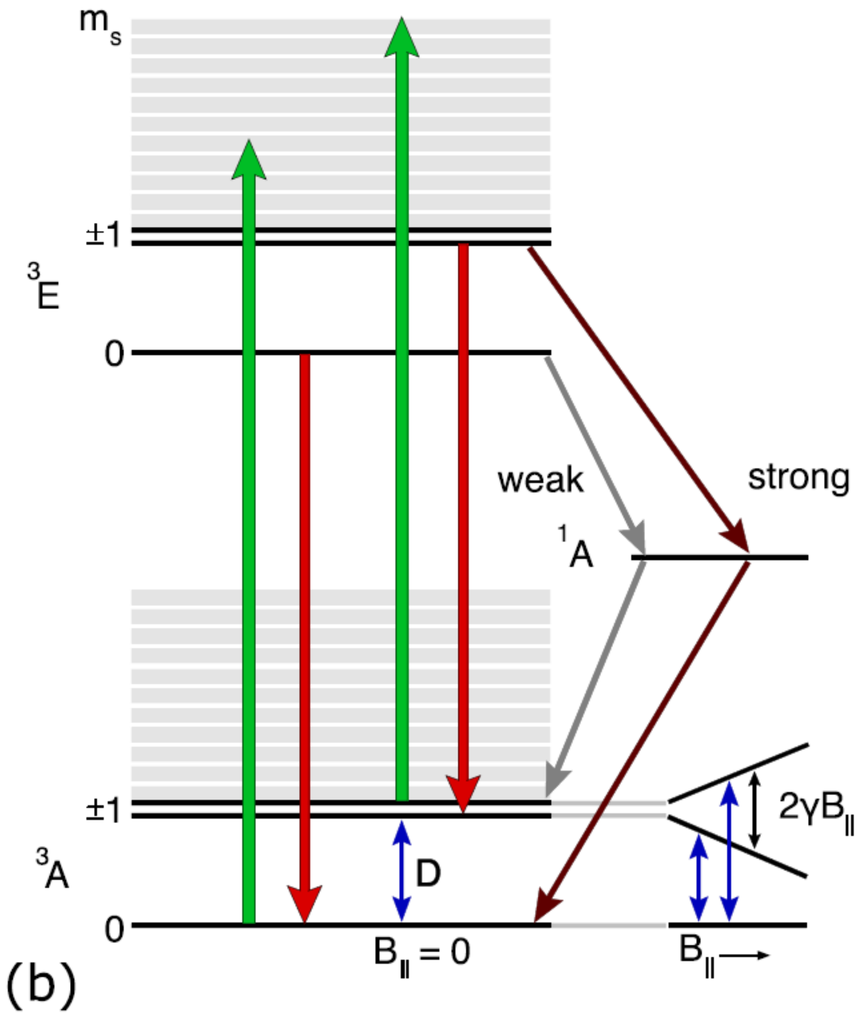
our set up is for educational purposes and does not have this capability

What is spin?



- In classical analogies, spin is often described as the intrinsic rotation of a quantum particle.
- However, the reality is somewhat more complicated, as **quanta do not rotate**.
- It is **a property of quantum objects**, alongside mass and electric charge, that is used to describe them.
- But this spin has parallels with intrinsic rotation, such as the induction of a magnetic field.
- What exactly spin is, is still being researched.
- **A spin can be -1, 0 and +1.**
- **The spin is often used to save the information in quantum computers.**

How does it work?



By shining a green light on the NV centers of the diamond, an electron is excited from the ground state to the excited state while maintaining its spin.

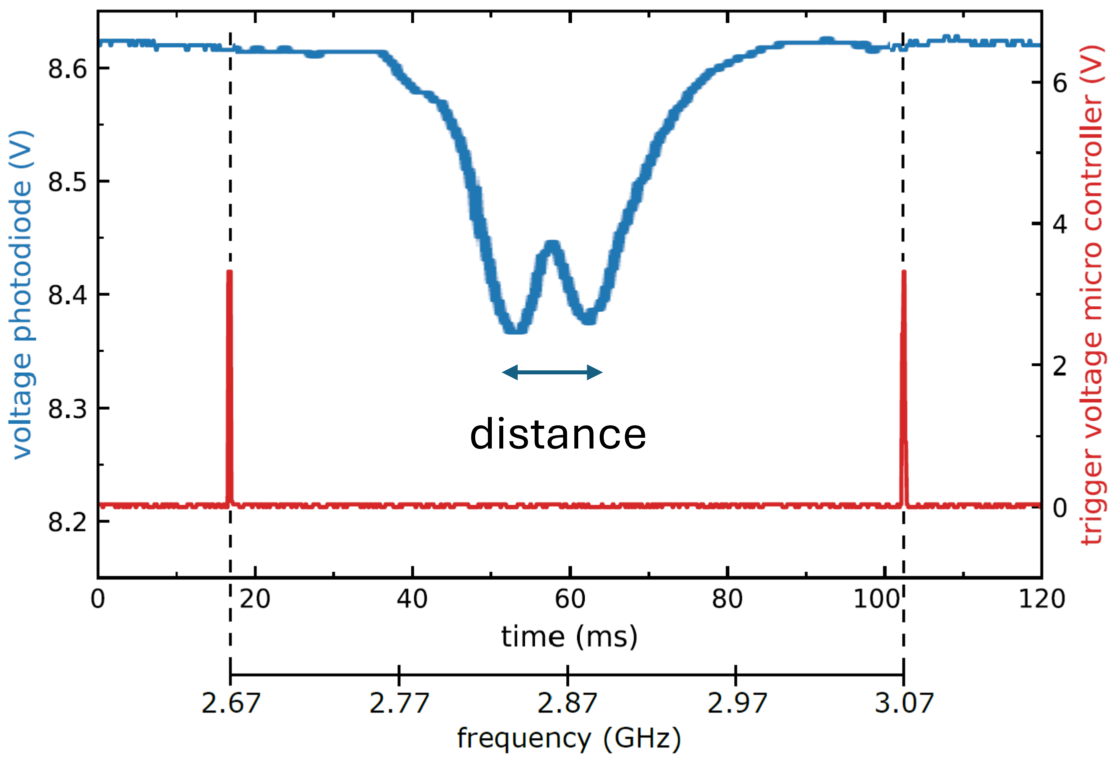
This excited state decays by emitting red light (650 -750 nm) or infra-red light (1042 nm).

The electrons with spins ms = +1 / -1 decay more strongly by emitting **infrared light**.

As a consequence, electrons that fall through this channel reduce the intensity of the red fluorescence.

Stegeman, Jan & Peters et al (2023). Modular low-cost 3D printed Setup for Experiments with NV centers in Diamond. European Journal of Physics. 44. 10.1088/1361-6404/acbe7c.

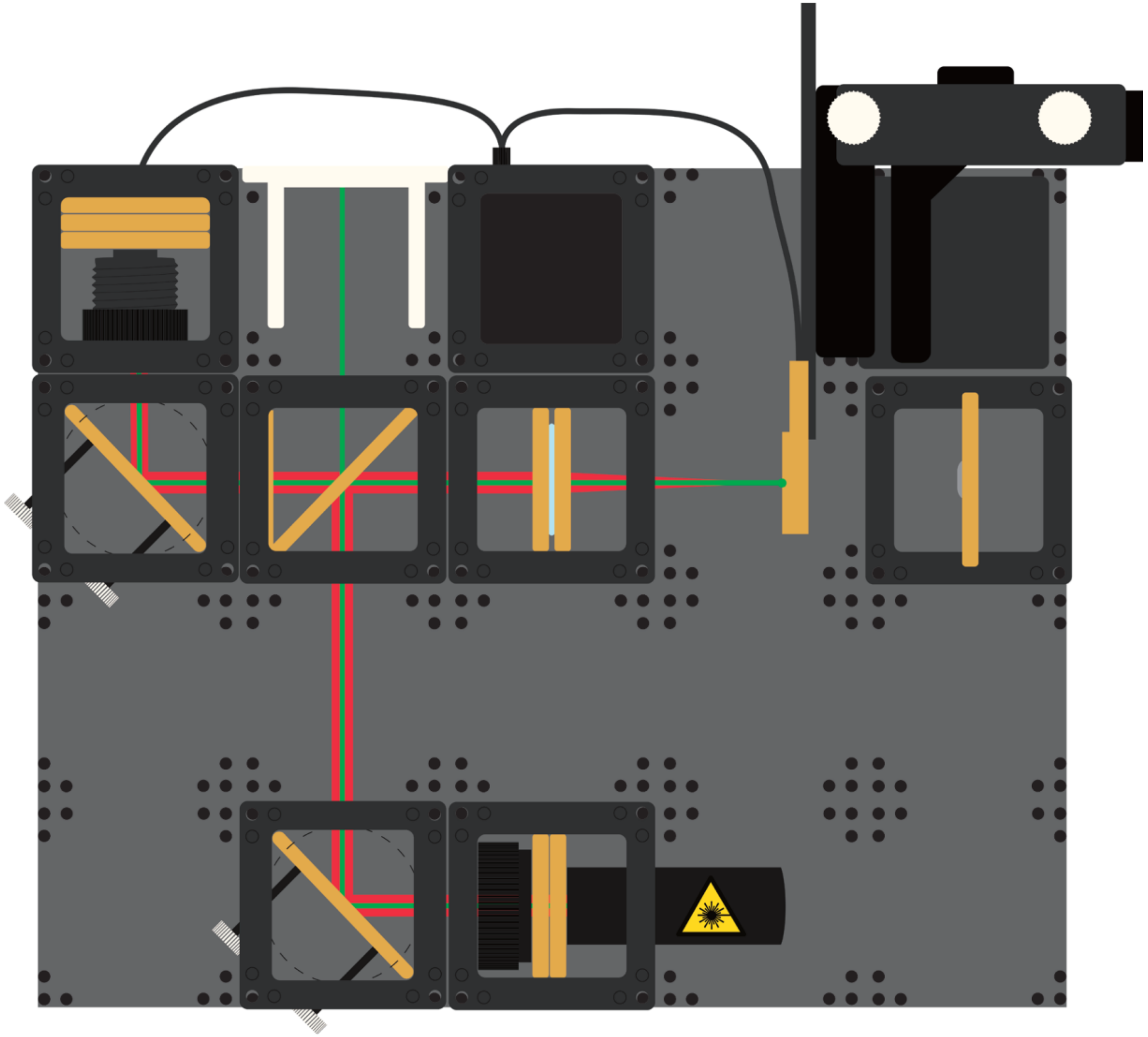
How does ODMR work?

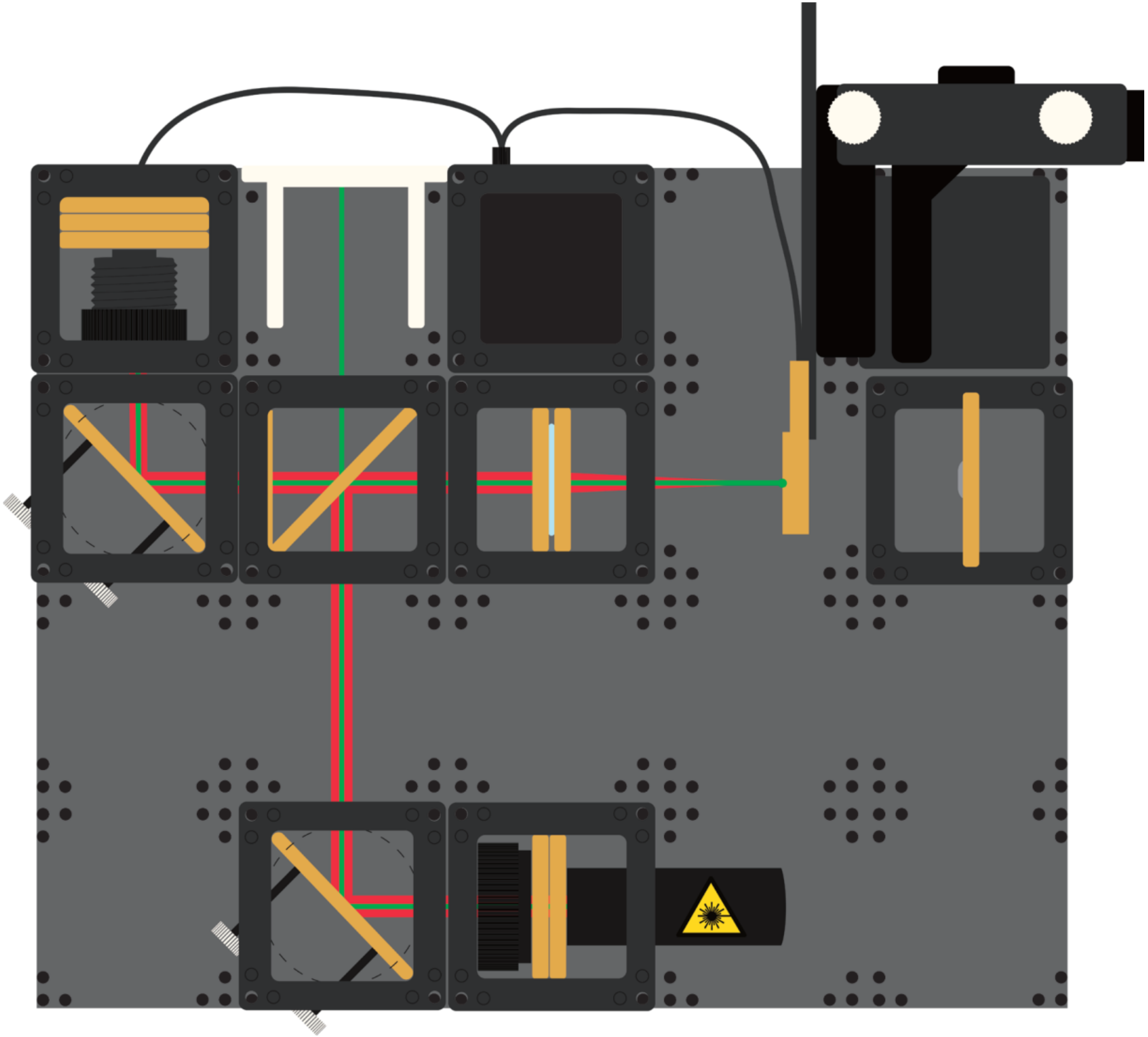


- With a microwave radiation, which has the resonant frequency of the NV-centre, you can change the spins from ms= 0 to ms= +1 / -1
- microwave radiation is applied to the diamond with frequencies from 2.67 to 3.07 GHz
- at two certain frequencies the red fluorescence is lower
- **An external magnetic field** shifts the frequency in which the NV-centers are in resonance.
- the larger the distance between the dips in fluorescent intensity, the larger the magnetic field

Stegeman, Jan & Peters et al (2023). Modular low-cost 3D printed Setup for Experiments with NV centers in Diamond. European Journal of Physics. 44. 10.1088/1361-6404/acbe7c.

What do we need to build our own?





Operation via browser

Our ODMR experiment is controlled by a microcontroller.

This provides a website.

To access the website, you need to connect to the microcontroller's Wi-Fi: ODMR_47A50

and enter the following URL in a browser: 192.168.4.1.

Thank you for your attention