PHY127 FS 2026

Prof. Ben Kilminster
Lecture April 24th, 2026

I was asked to show this slide.

Looking for volunteers for a study.

Universität Zürich[UZH]

Institut für Evolutionäre Anthropologie
Department of Evolutionary Anthropology

HEEP
Human Evolutionary Eco-Physiology

Looking for participants!

Help us discover how forests and cities influence human biology

Our team studies how the environments in which humans evolved have shaped *Homo sapiens* biology and how modern 21st-century settings affect key biological functions including stress, the immune system and physical performance;
and we want you to be a part of our research!

What are we doing this summer?

In Summer 2026, we're running a unique experimental study exploring how living in different environments influences human health and biology.

You will spend **5 consecutive days** taking part in guided activities in one of two environments:
- Züriberg forest
- Zürich City Centre

What will participants do?

You will take part in:
- Guided walks and light physical activities
- Physiological and psychological measurements
- Group meals and discussions

What you get in return:
- Lunch and dinner provided each day
- Learn how your body responds to the environment
- The chance to contribute to cutting edge research on how our environment affects our health

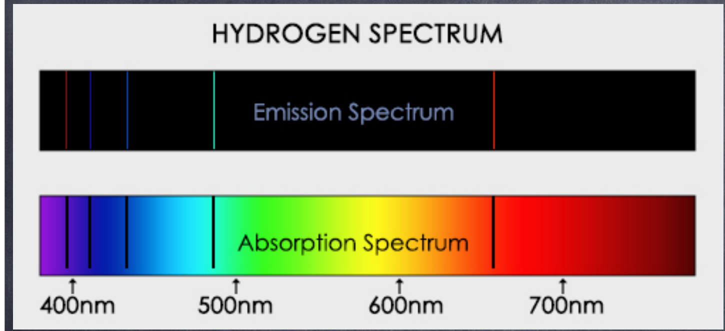
Get involved! Scan the QR code to learn more and sign up!

If you want to earn credits for your participation (BIO 548) contact: colin.shaw@iea.uzh.ch

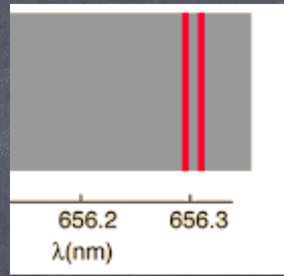
Principal Investigator
Dr. Colin Shaw
colin.shaw@iea.uzh.ch
www.heepresearchgroup.com

Last week:

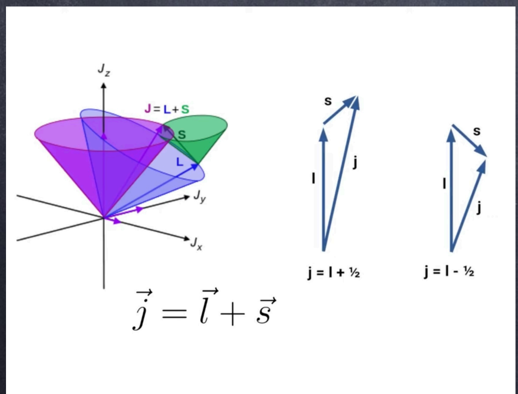
Fine structure is due to 4th quantum number, m_s



correspond to either $m_s = +\frac{1}{2}$ or $-\frac{1}{2}$



visible without a magnetic field.



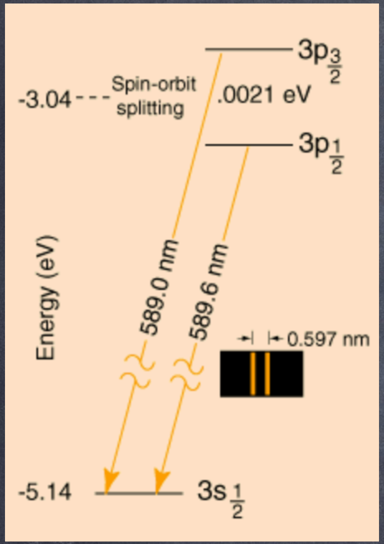
Two lines because of "spin-orbit coupling"

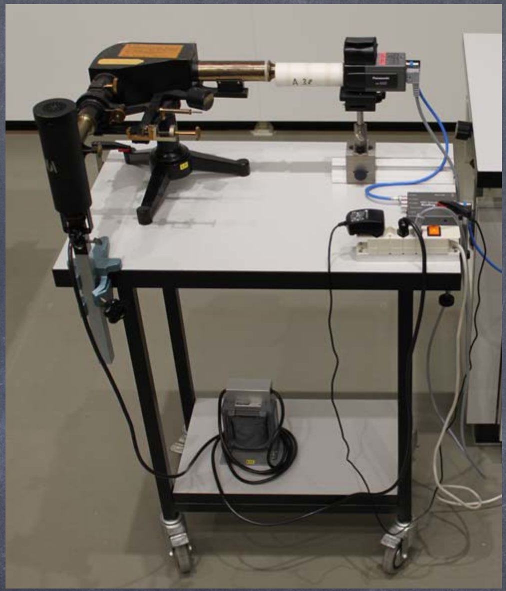
orbital angular momentum : ℓ quantum number

$+$

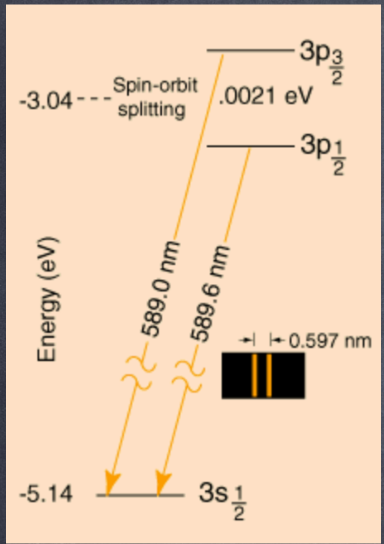
spin : s quantum number

Experiment to see the effect of electron spin-orbit coupling on the energy spectrum of Sodium (Na).



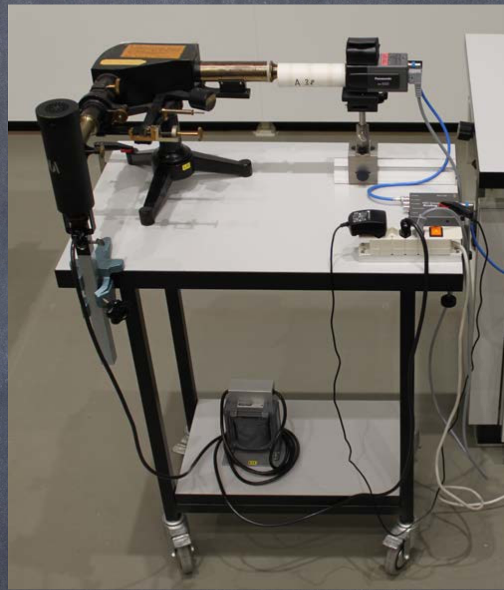


Experiment to see the effect of electron spin on the energy spectrum of Sodium (Na).



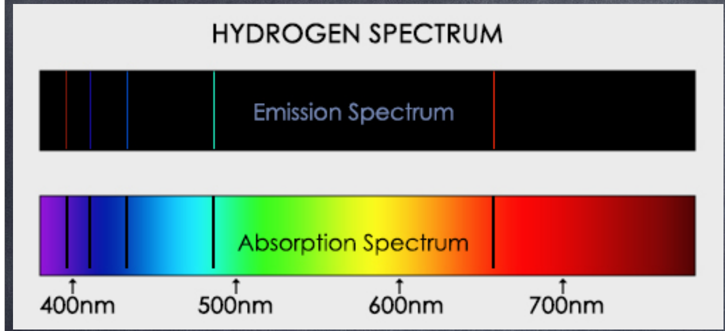
2 states for l = 1

1 states for l = 0

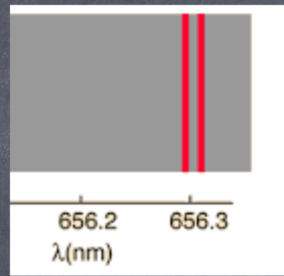


Last week:

Fine structure is 4th quantum number, m_s
from spin of electron

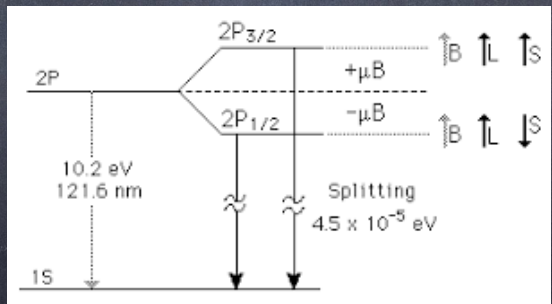


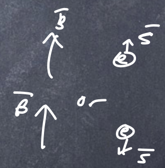
Coupling of spin with orbital angular momentum causes two lines:
$2p_{\frac{3}{2}} \rightarrow 1s_{\frac{1}{2}}$
and $2p_{\frac{1}{2}} \rightarrow 1s_{\frac{1}{2}}$



visible without a magnetic field.

In a magnetic field, splitting increases (Zeeman effect)



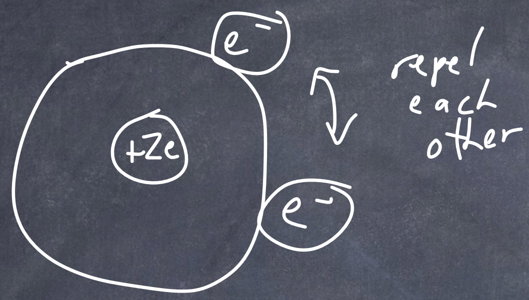


"hyperfine"

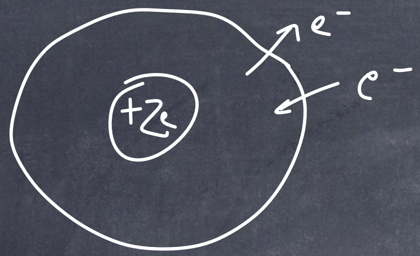
Note: there are other effects that further split spectral lines into more than one visible line. (such as the Stark effect – not covered here)

Atoms with many electrons:

He

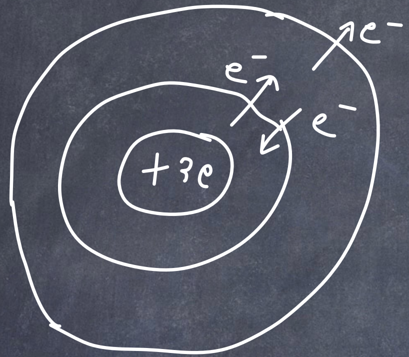


Applied to the hydrogen atom (with one electron)
ground state:

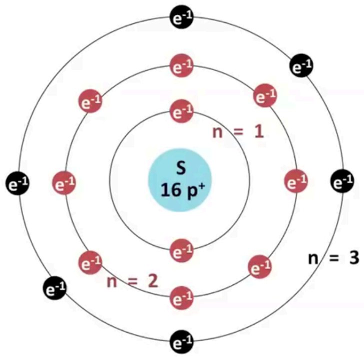

+Ze
e⁻
e⁻

n	ℓ	sub-shell	sub-shell capacity	total electrons in all sub-shells
1	0	1s	2	2
2	0	2s	2	4
2	1	2p	6	10
3	0	3s	2	12
3	1	3p	6	18
4	0	4s	2	20
3	2	3d	10	30
…	…	…	…	…

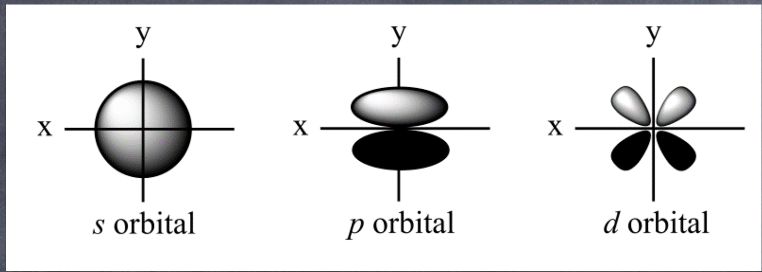
Screening :



What is the effective nuclear charge felt by an electron in the n = 3 shell of sulfur?



Aside : screening is a bit more complicated than this due to shape of orbits :



4p
3d
4s
3p
3s
energy 2s
1s

Note: 4s is bound with less energy than 3d

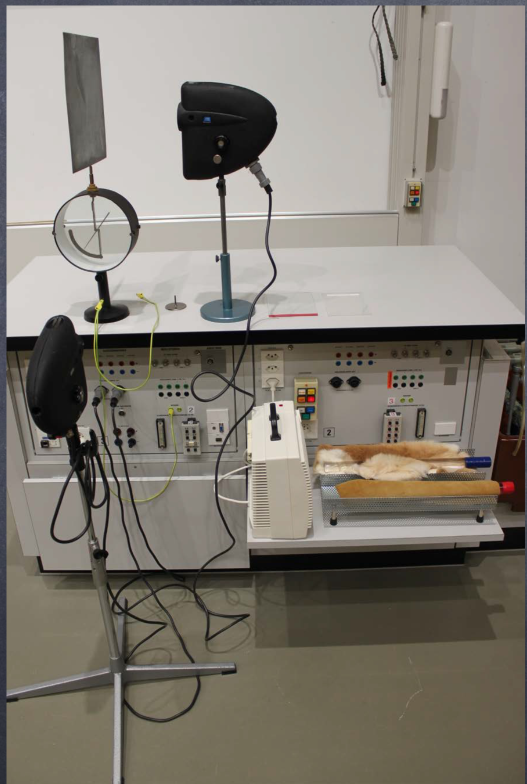
This is because of the shape of the electron orbit, which changes the amount of screening that happens.

Electrons with higher ℓ are more screened.

Lower-ℓ orbits are less screened because the orbits are more eliptical.

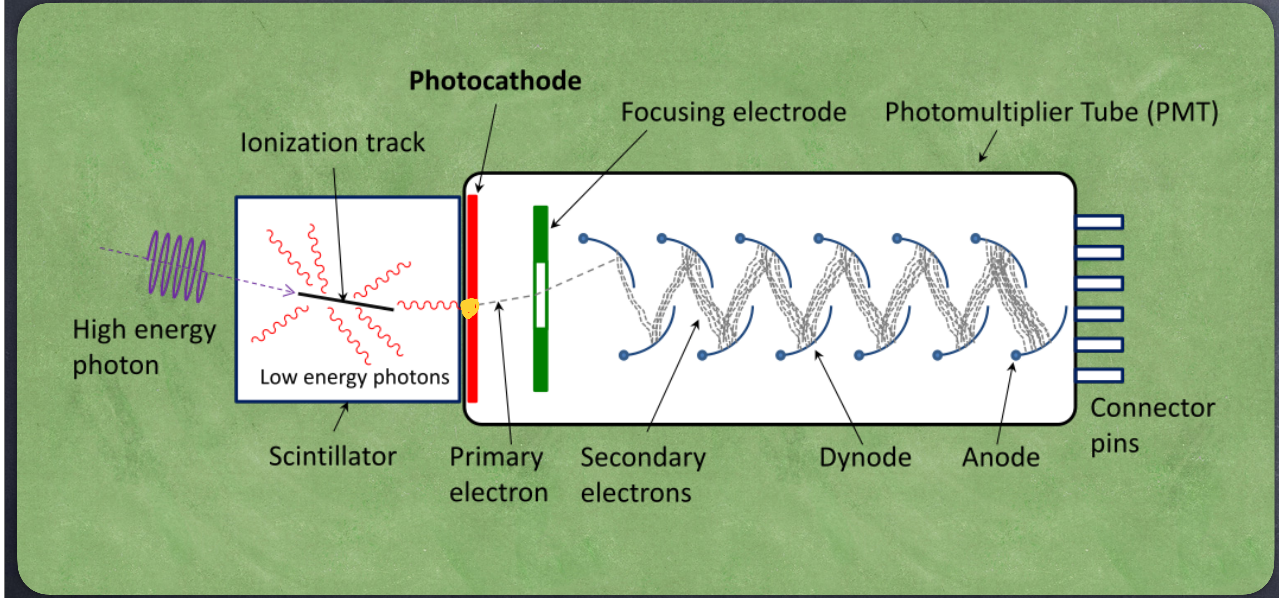
A bit of a detour on detecting radiation

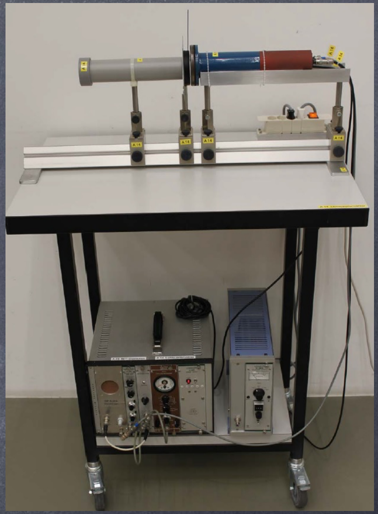
Photoelectric effect we already learned :



Light can free electrons if photons have enough energy to overcome binding energy

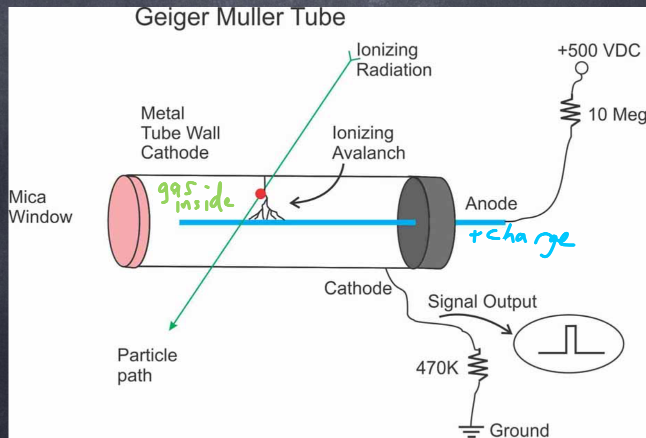
Radiation: we start with visible light detection





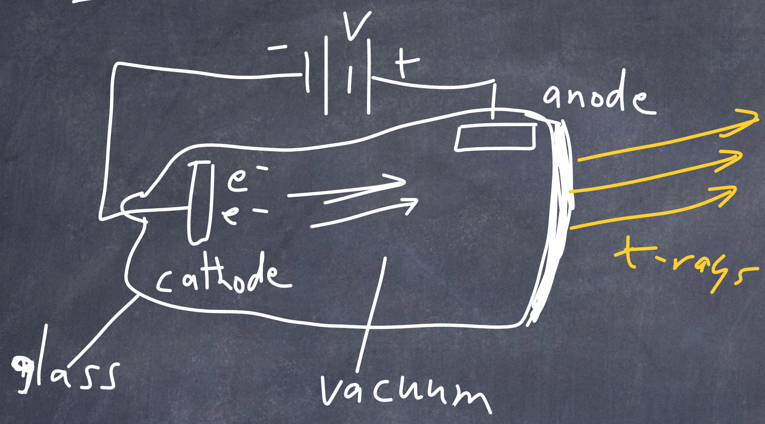
Charged particle radiation

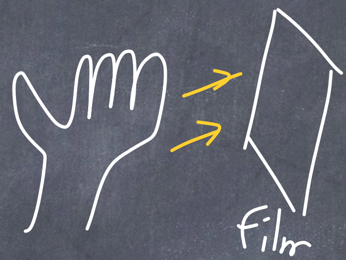
Geiger counter:

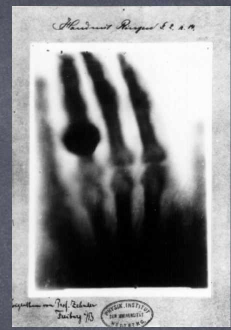


Discovery of the x-ray

Roentgen, 1895

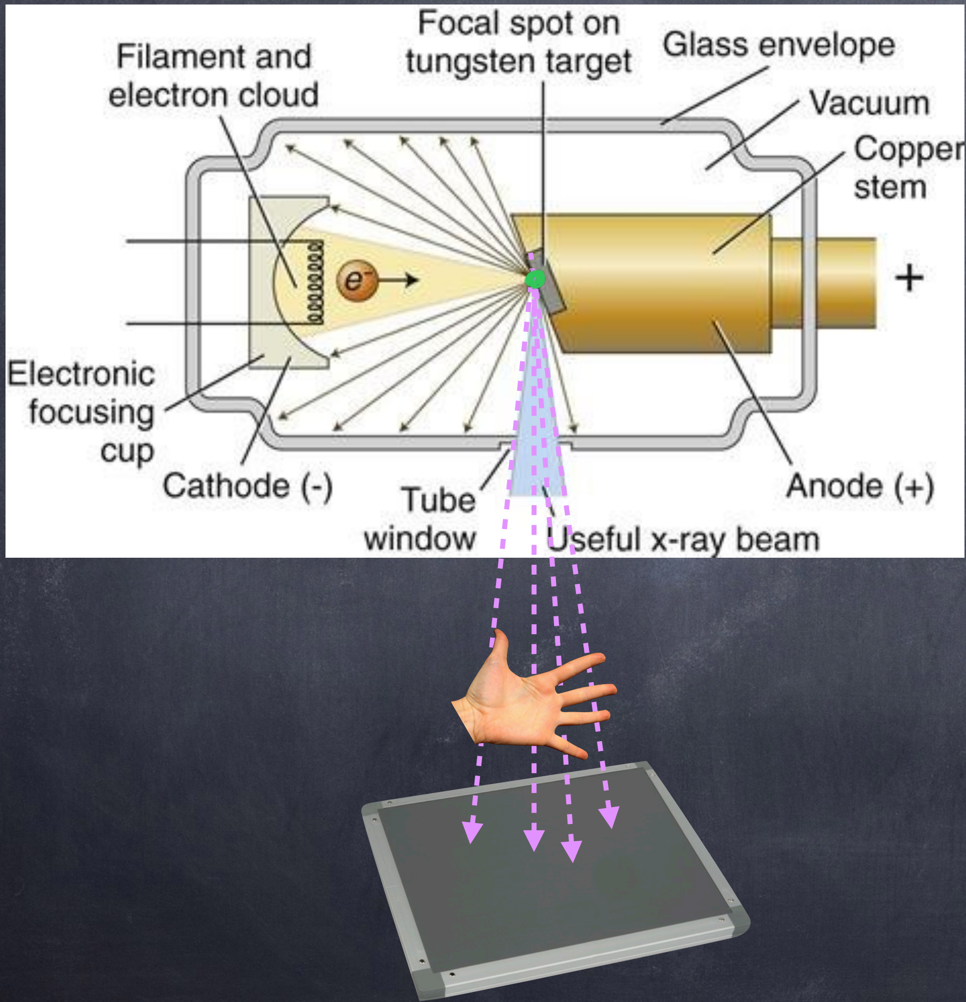




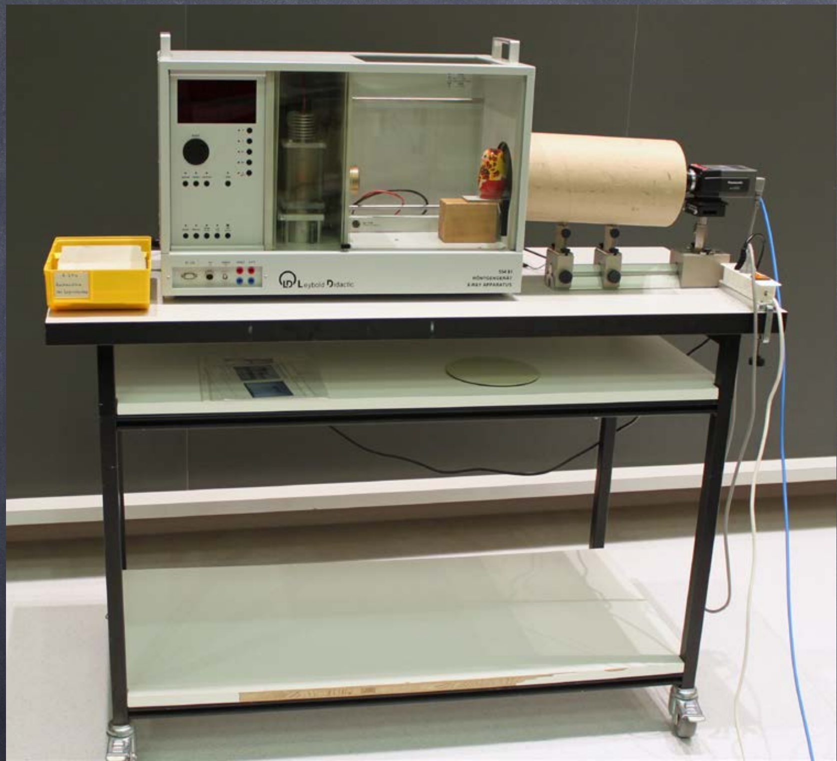


First "medical x-ray"

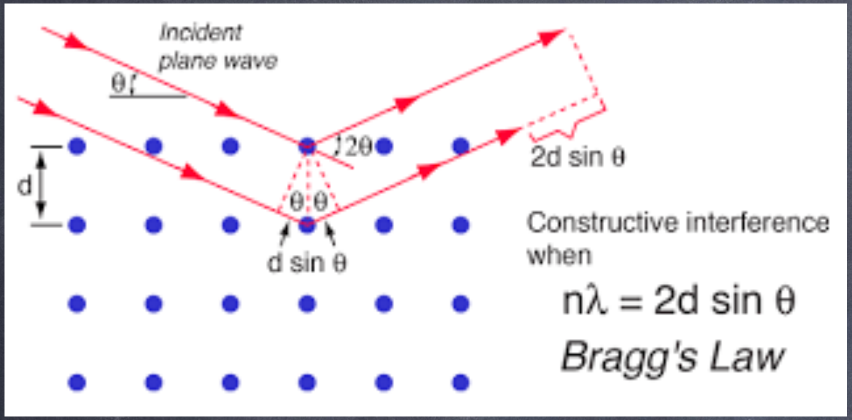
Modern x-ray tube:

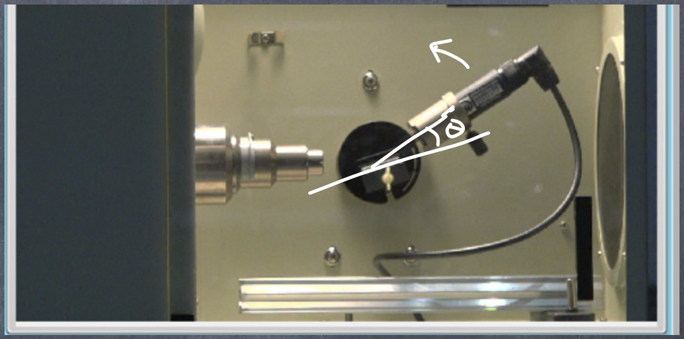


Fun with x-rays in class :



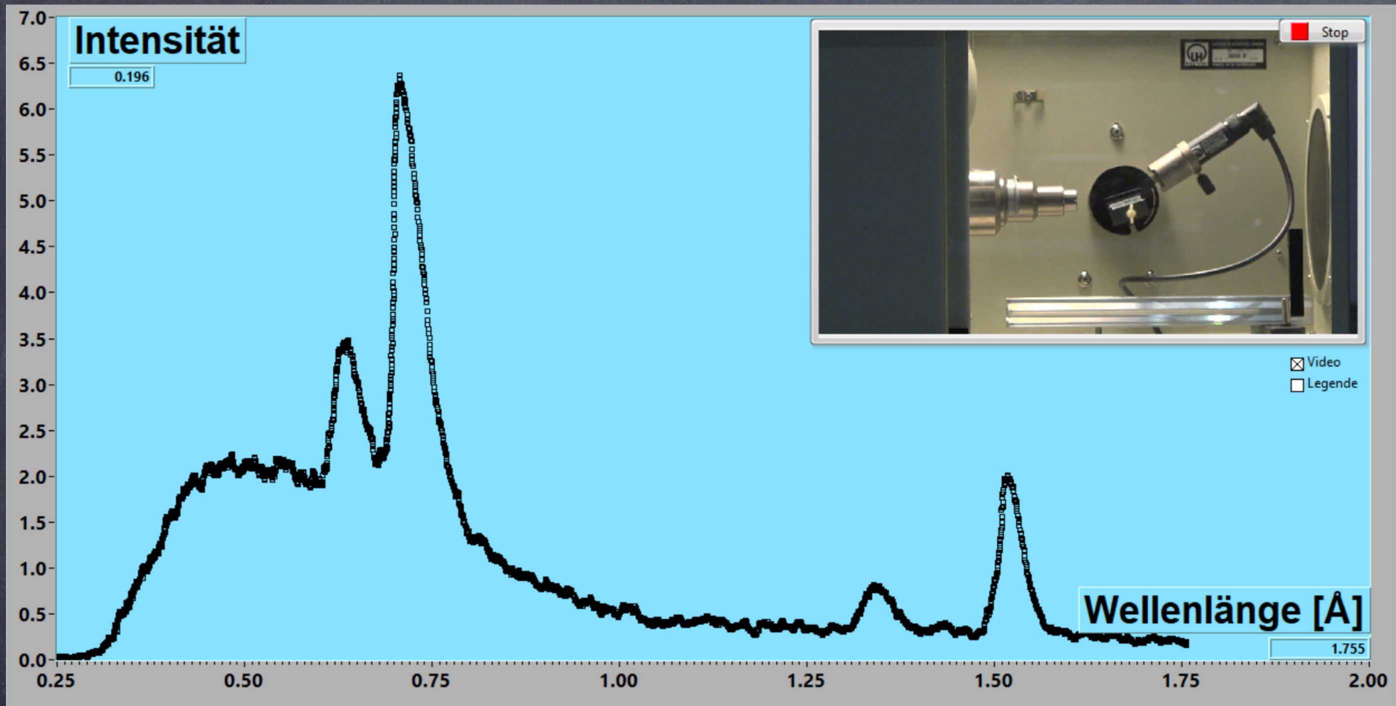
Bragg's Law:



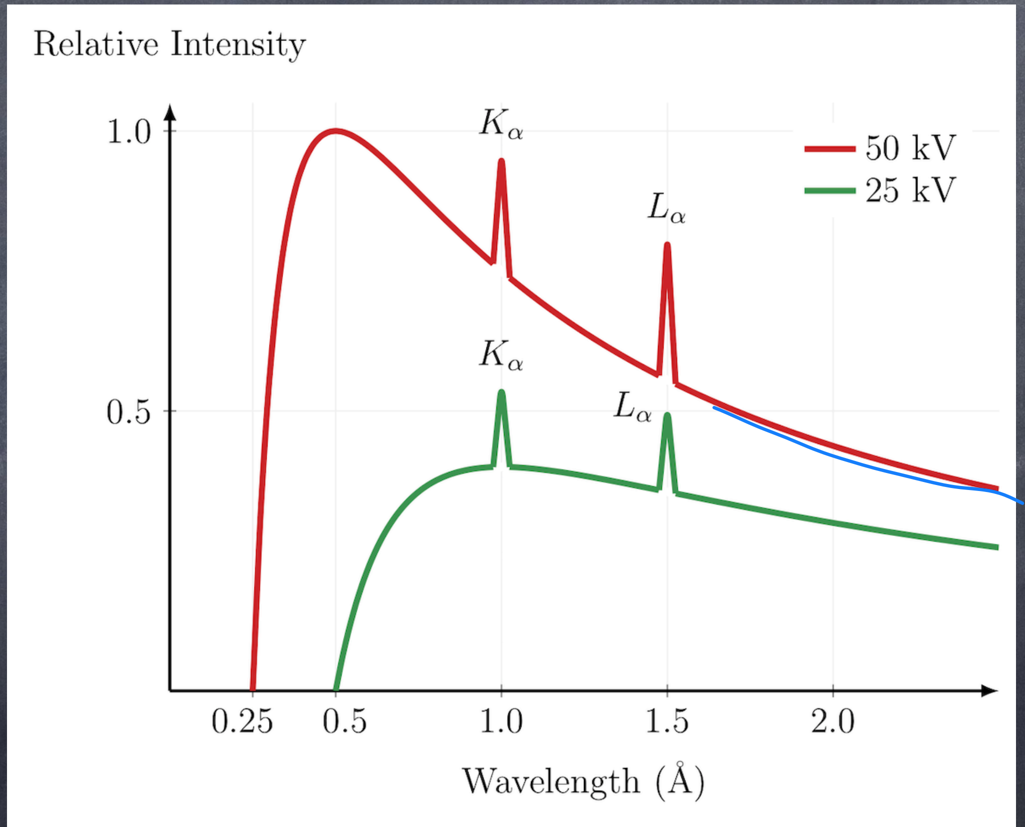


Experiment in class:

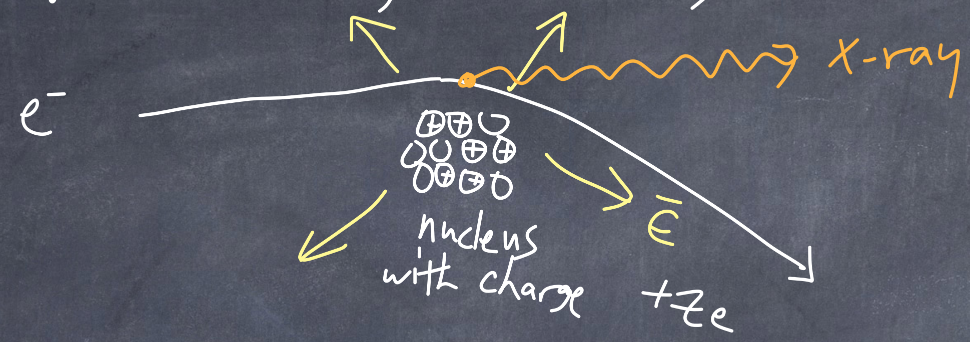
Crystal: Natrium-Chlorid:
Netzebenenabstand 282 pm
Reflexionswinkel für die Molybdän-K α-Strahlung der Wellenlänge 71 pm: $\sigma_B = 7.24°$.


Intensität
0.196
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Stop
Video
Legende
Wellenlänge [Å]
1.755
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

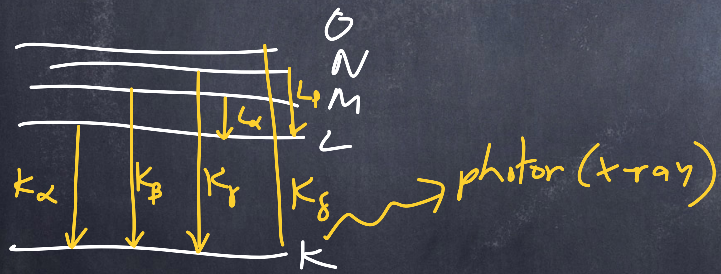
X-ray production:



1) Bremmstrahlung "braking radiation"

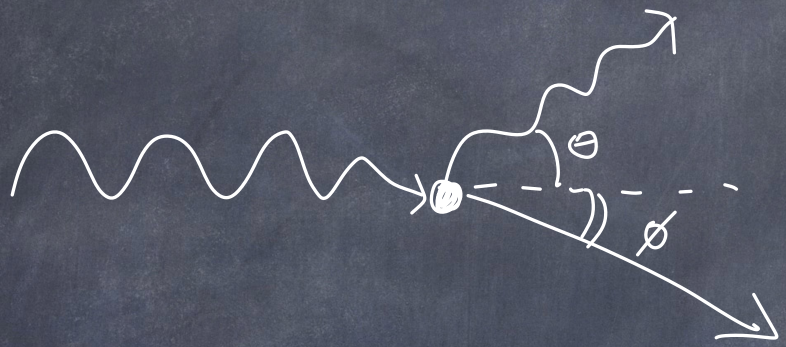


② characteristic x-rays:

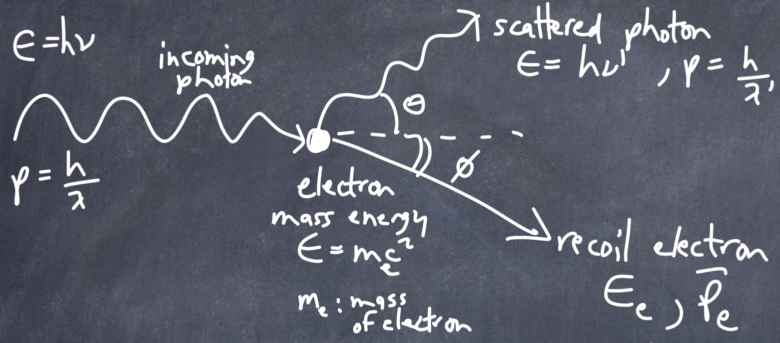


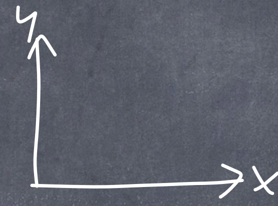
X-rays

Compton scattering – process that makes the wavelength larger (reduces the energy & frequency of the t-ray)



Supplementary: how to derive the Compton effect formula:





we do it using momentum + energy conservation.

	Initial state	Final state
photon energy	$h\nu$	$h\nu'$
photon momentum in x-direction	$\frac{h}{\lambda}$	$\frac{h}{\lambda'}\cos\theta$
photon momentum in y-direction	0	$\frac{h}{\lambda'}\sin\theta$
Electron energy	mc^2	$E_e = m_e c^2 + K$ ← kinetic energy
Electron momentum in x-direction	0	$P_e \cos\phi$
Electron momentum in y-direction	0	$P_e \sin\phi$

Relativistically, the energy of a massive particle is $\boxed{E^2 = (mc^2)^2 + (cp)^2}$ ⓪ True in general!

$\underbrace{(mc^2)^2}_{\text{from rest mass}}$ $\underbrace{(cp)^2}_{\text{from momentum}}$

For our problem

Energy conservation means $E_{initial} = E_{final}$

$$\boxed{h\nu + m_e c^2 = h\nu' + E_e} \quad ①$$

Momentum conservation in x direction:

$$\boxed{\frac{h}{\lambda} = \frac{h}{\lambda'}\cos\theta + p_e\cos\phi} \quad ②$$

in y direction:

$$0 = \frac{h}{\lambda'}\sin\theta - \underbrace{p_e\sin\phi}_{-y\text{ direction}}$$

$$\boxed{\frac{h}{\lambda'}\sin\theta = p_e\sin\phi} \quad ③$$

Now we solve this. First, square ② + ③ and add. This removes ϕ:

$$p_e^2(\cancel{\sin^2\phi + \cos^2\phi}^{\,1}) = \left(\frac{h}{\lambda}\right)^2 + \left(\frac{h}{\lambda'}\right)^2(\cancel{\cos^2\phi + \sin^2\phi}^{\,1}) - 2\frac{h}{\lambda}\frac{h}{\lambda'}\cos\theta \qquad ④$$

Now substitute E_e from ① + p_e from ④ into ⓪:
(setting $\lambda = \frac{c}{\nu}$)

$$\left[h(\nu-\nu') + (mc^2)\right]^2 = m_e^2c^4 + (h\nu)^2 + (h\nu')^2 - 2h\nu(h\nu')\cos\theta$$

Do the squaring of the left side + cancel terms to get:

$$m_ec^2(\nu-\nu') = h\nu\nu'(1-\cos\theta)$$

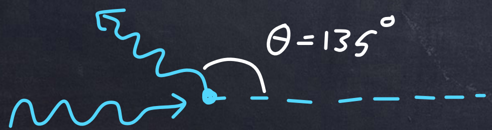
rearranging: $\frac{h}{m_ec^2}(1-\cos\theta) = \frac{\nu-\nu'}{\nu\nu'} = \frac{\frac{c}{\lambda}-\frac{c}{\lambda'}}{\frac{c^2}{\lambda\lambda'}} = \frac{1}{c}(\lambda'-\lambda)$

end: or $\boxed{\Delta\lambda = \lambda' - \lambda = \frac{h}{m_ec}(1-\cos\theta)}$

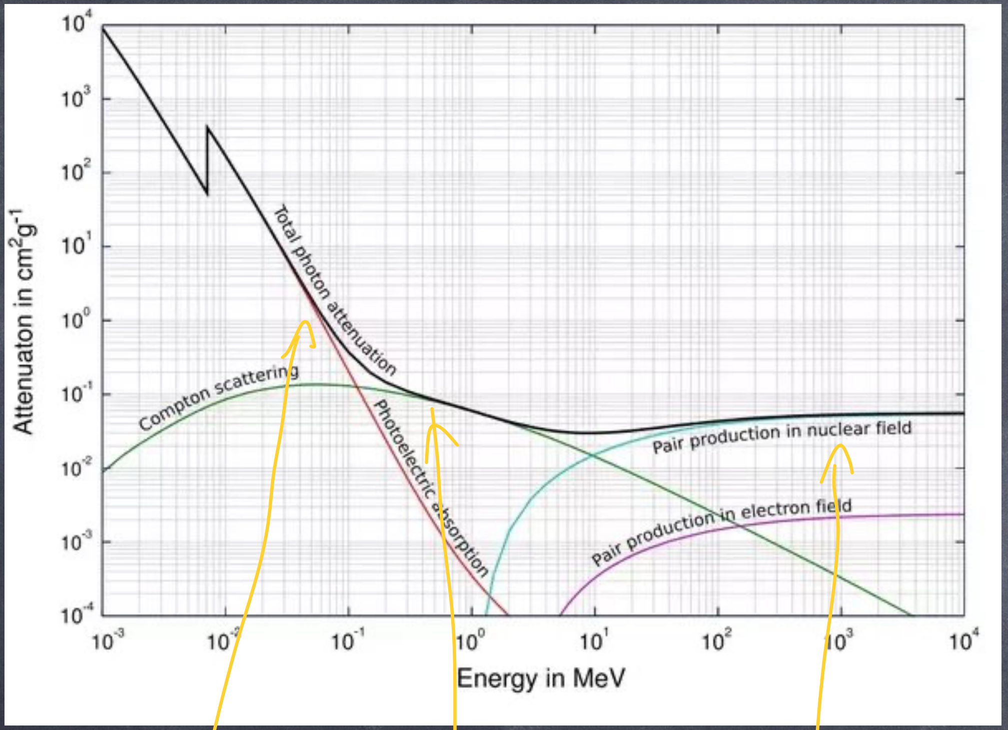
Done!

Back
to
notes ...

Compton effect experiment



Attenuation is $\frac{I}{I_0}$: how the photons lose energy as a function of their initial energy.



Attenuation units $\left[\frac{cm^2}{g}\right]$

if you multiply by the density $\left[\frac{g}{cm^3}\right]$

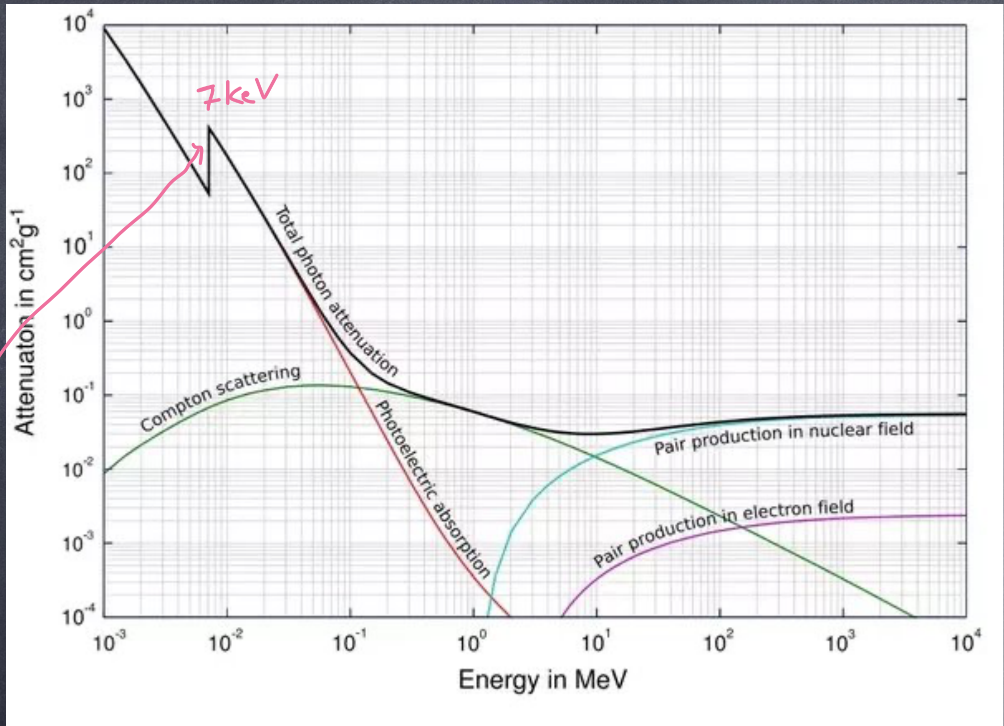
you get attenuation in units cm^{-1}

photoelectric absorbtion (produces ionization

Compton effect

pair production $\gamma \to e^+ e^-$

How photons lose energy as a function of their initial energy.



photoelectric absorption edge (higher interaction rate if photon has almost the same energy as an atomic energy shell.) Here we see the K-shell absorption edge.

From this plot, the K-absorption edge is ~7 keV. use this website to find out what material this is.

Database of K-absorption edges for different materials here :

http://skuld.bmsc.washington.edu/scatter/AS_periodic.html

Follow-up clarification: If energy levels for atoms with a spin-up or spin-down electron are the same, then why is there splitting of energy levels due to fine structure?

To be clear, energy levels are only the same when $\ell = 0$, such as the <u>ground state</u>, where $n=1, \ell=0$.

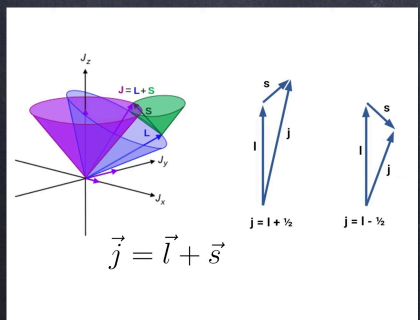
This is because the splitting of energy levels comes from adding the orbital angular momentum (quantum number, ℓ) with the spin, s. (A non-zero ℓ is required)

To add $\bar{\ell} + \bar{s}$, we add or subtract the magnitudes:

$j = |\ell| + |s|$ and $j = |\ell| - |s|$

the total magnitude is $|j|$:

Adding $\bar{\ell} + \bar{s}$



Examples:

If one adds $\ell = 1$ and $s = \pm\frac{1}{2}$,

we get $j = |1| + |\pm\frac{1}{2}| = \frac{3}{2}$ and $j = |1| - |\frac{\pm 1}{2}| = \frac{1}{2}$

So $|j| = |\frac{3}{2}| = \frac{3}{2}$ and $|j| = |\frac{1}{2}| = \frac{1}{2}$

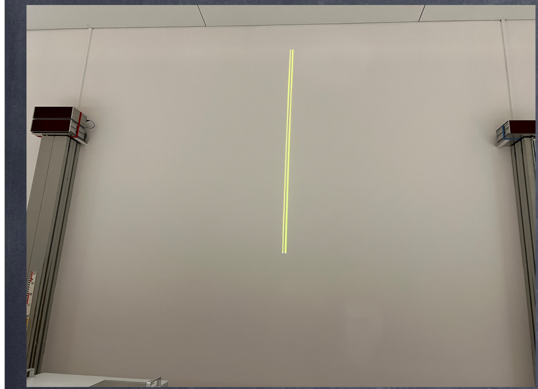
These different $|j|$ have different energy levels.

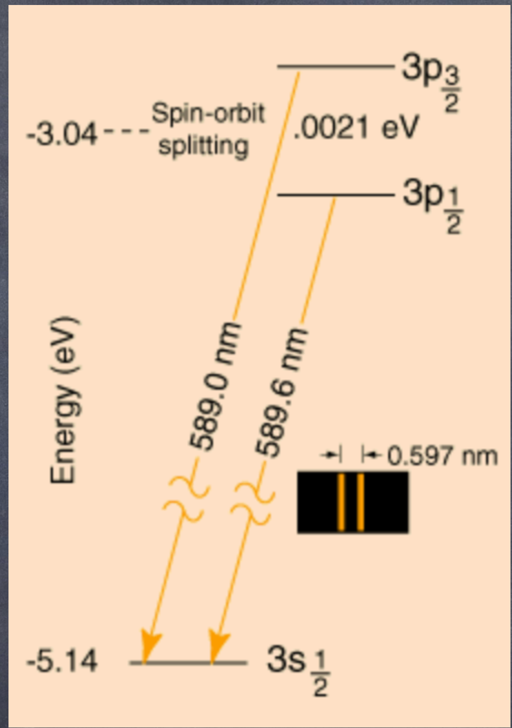
If one adds $\ell = 0$ and $s = \pm\frac{1}{2}$,

we get $j = |0| + |\pm\frac{1}{2}| = \frac{1}{2}$ and $j = |0| - |\pm\frac{1}{2}| = -\frac{1}{2}$

These same $|j| = \frac{1}{2}$ have the same energy levels.

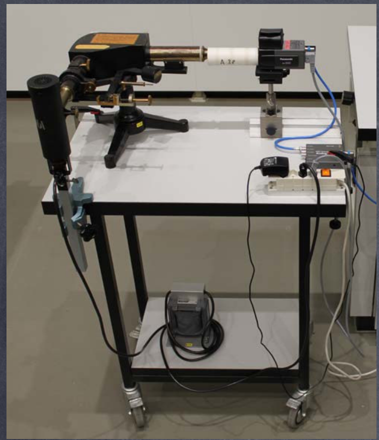
Sodium doublet



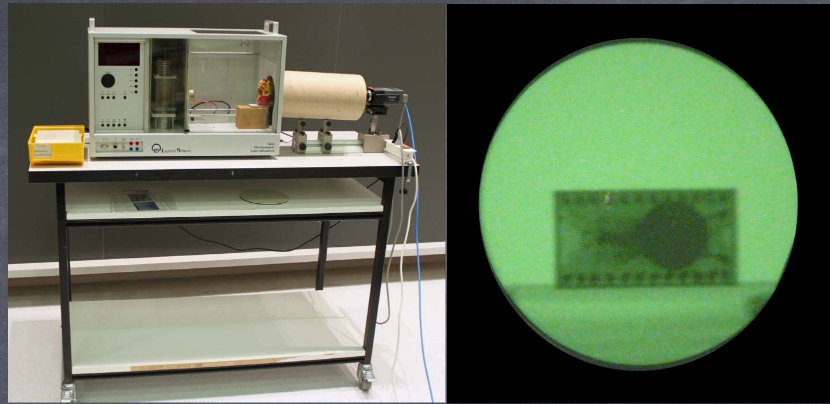


2 energy levels for $\ell=1$ (p subshell)

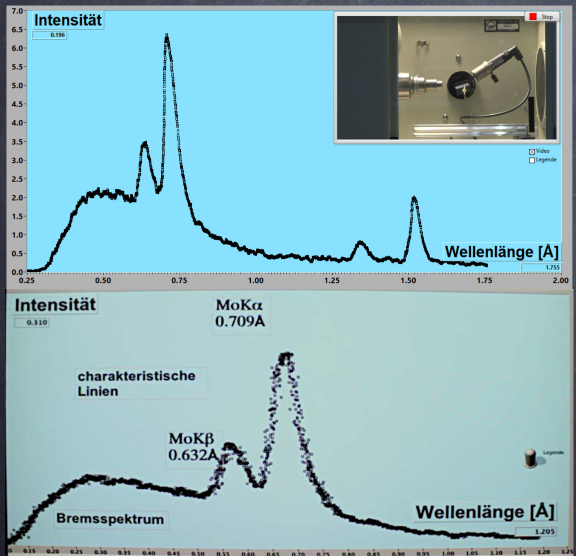
1 energy level for $\ell=0$ (s subshell)



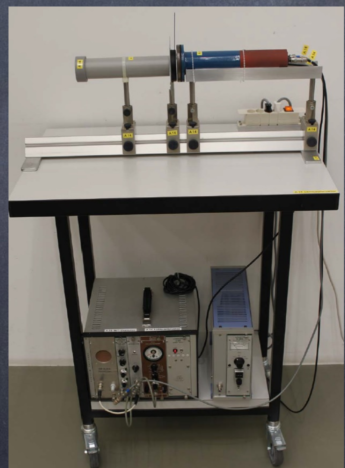
A38



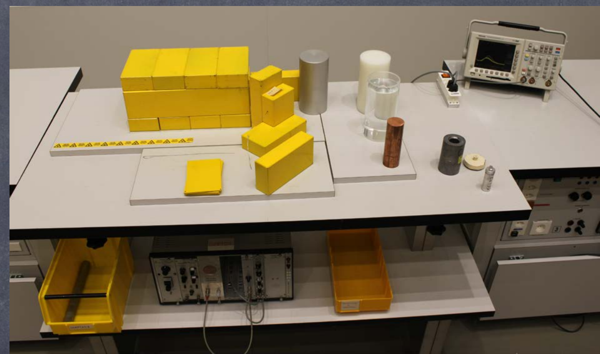
A24



A25



A14



A3

ES90