Karlsruher Institut für Technologie

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Note gesamt + 0 -

Anerkannt: ________________
(Datum Unterschrift)

Datum Rückgabe: ________________

Bemerkung:

Inhaltsverzeichnis

4. Experimental tasks

ATTENTION!

- BEFORE switching on the X-ray tube, make sure that the RED is never in the direct beam.

- Always set the current, voltage and aperture settings on the X-ray unit so that the intensity of the measured radiation does not exceed 300 pulses/s (except for task 4.2).

- To suppress the low-energy background, use an "offset" of 8 - 10 % on the VKA.

4.1 Calibration of the X-ray energy detector (RED) - instruction TEP 5.4.40

(a) Record a spectrum of the radiation from the tungsten tube and assign the corresponding channels to the position of the characteristic lines (Lα and Lβ).

Settings: 25 kV, 0.01 mA, aperture diameter 1 mm, Θ = 0°, 2Θ = 0.2° , V = 2.

(b) Record spectra of the standard samples (Fe, Cu, Ni, Zn, Pb, Ag (optionally)) and identify their characteristic lines. Compare to literature values and use them to evaluate your calibration.

Settings: 35 kV, 0.5 mA, aperture diameter 2 mm, Θ= 45°, 2Θ = 90°, V = 2, measuring time 400 s.

Determine the pulses/s in each case. Fit the measured intensity distributions to a scaled normal distribution (Gaussian distribution) and note the curve parameters a, b, c.

4.2 Determination of the energy resolution of the RED - instruction TEP 5.4.41

Measure without aperture the K-line of the Zn standard sample for different emission currents.

Settings: 35 kV, currents 0.01, 0.05, 0.1, 0.2, 0.5, 1 mA, no aperture, V = 2, 30,000 events.

Note the measurement duration and number of pulses. Determine the centre of gravity and half-width of the intensity distribution (fit with curve parameters a,b and c, scaled normal distribution). Plot both values vs. the rate #/s.

4.3 Quantitative X-ray fluorescence analysis, Moseley constant - instruction TEP 5.4.45

Plot the energy of the K lines of the standard samples from 4.1 suitably against the atomic number Z. Determine the Rydberg constant and the screening constant from Moseley's law.

4.4 Determination of the layer thickness of thin foils - instruction TEP 5.4.52

Measure the Fe standard sample covered with 0, 1, 2, 4, 6 layers of Al foil. In addition, take one measurement where one layer of Al foil is located only in the incident beam.

Settings: 35 kV, 0.4 mA, aperture diameter 2 mm, Θ = 45°, 2Θ = 90°, V = 2, measuring time 300 s.

Plot the intensity of the Fe signal (sum of the events in the channels belonging to the Kα-line) against the number of foils and determine the thickness of the foil using the absorption law.

4.5 Qualitative X-ray fluorescence analysis on alloys - instruction TEP 5.4.50

Measure 4 alloy samples: Solder (optionally sample A, B, C), constantan (sample D), carbide cutter for metalworking (sample E), a sample of your own choice (ring, coin, bangle, wristwatch, or similar).
Settings: 35 kV, 0.5 mA, aperture diameter 2 mm, Θ = 45°, 2Θ = 90°, V = 2, measuring time 400 s.

Fit the measured intensity distributions with a scaled normal distribution and note the curve parameters a, b, c. Identify the alloy constituents by comparing the characteristic lines with already known spectra and plausible other elements. A quantitative analysis of the composition is not possible here.

5. End of experiment

- Reset the high voltage and emission current of the X-ray tube to low values (20 kV; 0.01 mA).
- Remove the samples from the holder.
- Close the radiation protection housing and switch off the equipment.

Preperation

0.0.1 Introduction

In the experiment we will analyse materials with X-Ray. But to understand the experimental outcome we have to understand some basics of atom structures and X-Rays.
For the experiment we will use Bohr's atom model to describe the structure of an atom.

0.0.2 Bohr's atom model

In Bohr's atomic model the electrons are rotating around the nucleus with an radius r and an velocity v those are set to fix values by the wave properties of the electrons and the prerequisite of stationary states of the same. Because this requires the scope of the orbit l to be $l = 2\pi r$ and $l = \lambda \times n$ where n is part of the natural numbers and λ is the so called de Broglie wavelength. [Dem16]

0.0.3 atomic energy levels

These fixed states result in fixed energy levels for the electrons.
$E_n = -Rhc\frac{Z^2}{n^2}$, where $R = \frac{\mu e^4}{8\epsilon_0^2 h^2}$ is the Rydberg constant, and Z is the number of positive charges in the nucleus.
The formula gives us the binding energy of an electron to an atom.

0.0.4 X-Rays

X-Rays are commonly generated by usage of an vacuum tube which releases electrons from an so called hot cathode, cause of the high voltage, that is used, the electrons have a high velocity when they collide with the metal anode. Out of this collision there are two phenomena which occur:

characteristic X-ray

Characteristic X-ray occur, when the electron with the high velocity has enough energy to knock an electron of an inner sphere out.
Where the electron was is then a hole, which is filed by an electron out of an outer sphere.
There are two for us important transitions that can occur.
The first one, a transition from an electron of the second sphere to the first, produces the so called K_α line, the transition form the third to the first the so called K_β line.

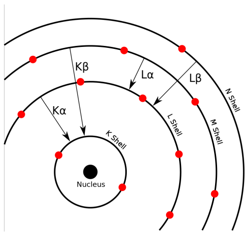

Abbildung 1: Different characteristic X-Rays [?]

Both of them are (by Moseley's law) connected to the positive charge of the nucleus, which determines the energy an electron gets from changing there sphere (because an higher charge means an stronger electromagnetic field) and therefore specific for every material, which is why they are called characteristic X-rays.

Bremsstrahlung

If the electron gets near to the nucleus, without knocking out an bound electron the interaction with the electric field of the latter, it deflects and brake the first. This deceleration means a transformation of the kinetic energy of the electron into radiation. The frequency of this radiation is limited by the energy of the electron, but because the electron can be deflected and decelerated in many ways the radiation exists on an continuous spectrum. [Wika]

0.0.5 Moseley's law

The Moseley Law describes the energy of K_α line, an radiation (in the x-ray spectrum) that is send out from an electron which changes from the L state into the K state.
Or in an more general formula. The radiation of an electron that changes its state form the n_2 state to the n_1 state.

$$f = \frac{c}{\lambda} = f_R(Z-S)^2(\frac{1}{n_1^2} - \frac{1}{n_2^2})$$

where S is the shielding constant, an constant which describes the isolation of the charge of the nucleus by the electrons between the switching electrons an the nucleus and $f_R = r\frac{1}{1+\frac{m_e}{M}}$ and M is the mass of the nucleus.
For $n_1 = 1$ this constant gets $S \approx 1$ and Moseley's law becomes

$$f_{K_\alpha} = f_R(Z-1)^2\frac{3}{4}$$

[Wikb]

0.0.6 X-ray absorption

An X-ray interacts with matter in three ways.

photoelectric effect

The photoelectric effect describes the phenomena of an em-wave knocking out an bound electron. For this to be possible the energy of the em-wave $E_{em} = h\nu \ > E_n$ the binding energy of the electron. The rest of the energy $E_{kin} = E_{em} - E_n$ results in the velocity of the knocked out electron.
If the knocked out electron was one in an inner sphere an outer electron will take its place, an the atom will send out an X-ray.
[Wika] [Dem17a]

Compton scattering

If the X-Ray hits the electron with an angle φ the wavelength of the scattered radiation λ_s follows Compton's scattering formula.

$$\lambda_s = \lambda_0 + 2\frac{h}{m_0 c}\sin^2\varphi/2$$

where $m_0 = m_e v = 0$ or the mas of an other scattered particle. [Dem17a]

Rayleigh scattering

The Rayleigh scattering describes the scattering of the X-ray at particles that are small in comparison to the wavelength λ of the X-ray. Where the energy of the X-Ray is less than the binding energy of the atom. The Rayleigh scattering is proportional to ν^4. And the total scattering amplitude is proportional to Z^2
[Dem17b]

0.0.7 semiconductor detector

A semiconductor detector is build by an detector material which is arranged between two electrodes. If the radiation interacts with this material, it produces free electrons and electron holes, which by the electric field between the electrodes travel to them, both free electrons and holes, or rather the pulse in that they result, can be measured by an outer circuit. Important is that cause of the electric field in the used detector all the free electrons and holes arrive at the same time at the electrodes (holes and electrons at different), so the measured pulse is proportional to the energy of the X-ray.
[Wikc]

0.0.8 multichannel analyser

An multichannel analyser sorts the values of the measurable variable into intervals which get each one channel. Every pulse that is in the interval will increase the value of the channel by one. So if like in our experiment the measured variable is proportional to the energy of the X-ray we are able to register how many x-rays of which energy are produced by our sample.

0.0.9 determination of the thickness of an foil layer

To determine the thickness of the thin foil layers, we have to take in account that the angle in which the x-ray hits the layer is not zero but 45 ° so that the length of the Al that the x-ray has to go thru x is not d the layer thickness but $x = \sqrt{2}d$.
For the intensity of an characteristic fluorescence thru a layer $I_{Fx} = I_{F0}e^{-\mu\rho x}$ where $\mu\rho$ is the mass attenuation coefficient of the material, which depends on the atomic number of the element and the energy of the radiation. For aluminium the value of this coefficient is $\mu = 92\,8\mathrm{cm}^2/\mathrm{g}$ and the density is $\rho = 2.7\mathrm{g}/\mathrm{cm}^3$ with $\mu_\rho = \frac{\mu}{\rho}$
Now we can separate the way of the x-ray thru the foil into to parts. One, before it is reflected by the iron, one after this.

$$I_{p_1} = I_0 e^{-\mu\rho x} \tag{0.1}$$

$$I_{p_2} = I_{ref} e^{-\mu\rho x} \tag{0.2}$$

We assume an linear relation between I_{p_1} and I_{ref}

$$I_{ref} = a \times I_{p_1} \tag{0.3}$$

so

$$I_{p_2} = a \times I_0 e^{2\mu\rho} \tag{0.4}$$

without the foil, I_{ges_0}

$$I_{ges_0} = I_0 \times a \tag{0.5}$$

$$d = \log(\frac{I_{p_2}}{I_{ges_0}})\frac{-1}{\mu\rho 2\sqrt{2}} \tag{0.6}$$

The I_0 and I_{p_2} are evaluated by measuring the intensity of the peaks with different foil layers.

1 experimental goal , theoretical principles

1.0.1 experimental goal

The goal of the experiment is to learn some basics of material analysis with X-rays. Namely energy resolution (how to identify an element by the energy of the X-rays it produces) quantitative and qualitative X-ray fluorescence analysis (), and layer thickness determination ().

1.0.2 characteristic lines of X-ray

element	$E(K_\alpha)/keV$	$\Delta E_{FWHM}/keV$
Fe	6,39	0,360
Ni	7,46	0,369
Cu	8,03	0,371
Zn	8,62	0,377
Zr	15,78	0,420
Mo	17,50	0,429
Ag	22,17	0,512
Sn	25,30	0,552

Tabelle 1.1: characteristic X-ray: source [MAX22]

2 experimental set-up

The experiment is build out of an goninometer (to measure the degrees), with an left and an right arm. At the left arm the X-ray detector is mounted, at the right arm the sample in an crystal holder.
The experiment will be evaluates with the MEASURE program.
The evaluation will also be done with the MEASURE program and an python normal function fit.

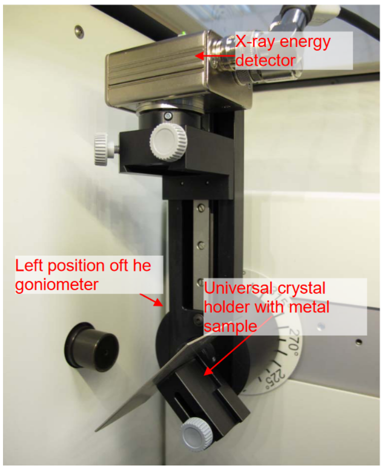

Abbildung 2.1: experimental set-up

3 Durchführung

3.0.1 4.1

a) Calibration of the X-ray energy detector

At first the detector had to be calibrated, for which we measured the radiation from the tungsten tube without an sample and took the theoretical values to assign the characteristic lines of tungsten to the peaks in the measure.
This was done with two different gain levels two and four.
Choosing an other gain level than 1 is needed, because, the multichannel analyser only registers pulses between 0 to 4 V, but the peak of the X-ray spectrum had been expected to be around 35 keV.
The gain level uses the preamplifier, main amplifier, and offset stage to get the pulses of the X-Ray generator in the right magnitude for the multichannel analyser.
The angle of the detector was set to 0.2° without an sample, and measured for 5 minutes. The chosen offset was 10%.
However we did not note down the channel numbers of the characteristic lines, which was not needed for the other tasks, because we changed the channel number in the MEASURE program to the concrete energy values. The name of our calibration was: 102 Tungsten Gate 2/4

b) characteristic spectra of the standard samples

With the calibration of the first task we measured the characteristic lines of different elements. But because we needed more time for the experiments than anticipated we measured only some of them. The values of the fit function (a normal function with $c * N(a, b^2)$) can be seen in 4.1
The settings where as in the instructions, but the gain level was set to 4 after measuring the characteristic lines iron with gain two without being able to measure the K_β line.
However this change did not solve the problem.
It has to be said that the different lines did overlap each other which made it hard to get the peaks right or in case of iron even get an value for the K_β line. Because of this the data was also evaluated with python, with an fit of two normal functions to identify the peaks in a more precise way.
The first try was to fit a double Gaussian fit function over the data. But because the double peaks aren't easy to distinguish, most fits just recognise the higher peak and ignored the lower one. To fix this a simple Gaussian function was used to determine the high peak and then subtract the fitted values from the original data. Because the original data is the sum of both peaks, the reduced data (after smoothing subtracted data from data fluctuation around fit) was then again fitted into a single Gaussian function.
over this a new normal function was fitted (3.2)
At last both of them where displaid together with the data. (3.3)

3.0.2 4.2 Determination of the energy resolution of the RED

In this section we measured the K_α line of Zn for different emission currents (4.2, 4.3) for an equal amount of around 30000 pulses and gain 2.

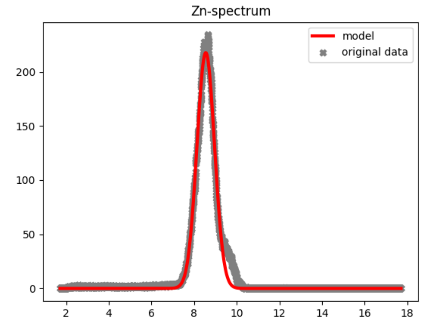

Abbildung 3.1: Zn-spectrum with an normal function fit for the first peak

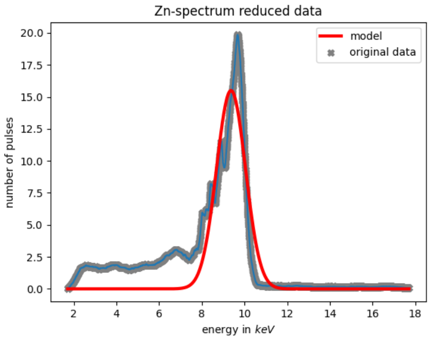

Abbildung 3.2: the data minus the normal function of the first peak.

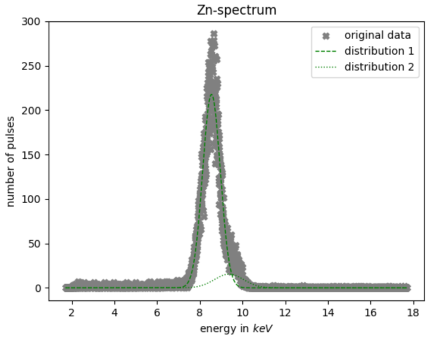

Abbildung 3.3: Zn-spectrum with an normal function fit for the first peak

The parameters have been evaluated with the same two methods like before.

3.0.3 4.3 Quantitative X-ray fluorescence analysis, Moseley constant

Now we use the values out of section 4.1 to plot the energy of the samples against there atomic numbers.

3.0.4 4.4 Determination of the layer thickness of thin foils

We did measure the K_α lines of an iron plate covered in different layers of Al foil, by covering the iron sample into Al foil, where we attached the foil as close as possible to the plate.
However we did not measure the layer of Al foil in the incident beam.
The evaluation of the data was done like before with MEASURE and python.

3.0.5 4.5 Qualitative X-ray fluorescence analysis on alloys

We measured the characteristic lines of different objects to find the elements they are build of 4.8. So we put different thing in the x-ray beam. An unidentifiable object (uo), a coin and a bottle cap.

4 Auswertung, Fehlerrechnung und Diskussion der Messergebnisse

4.0.1 4.1 Calibration of the X-ray energy detector (RED)

b) characteristic lines of standard samples

With our two measuring methods we got different values for the characteristic lines (4.1). Out of our data we got, with the evaluation by python, new values for the energy of the characteristic lines of Fe, Ni, Zn. However even with python the $K_{\beta\mathrm{Fe}}$ could not be evaluated, cause the two peaks where to close together for being recognised properly.
The Cu-sample we could not evaluate with python, because our measurement data only got a few values, because something was marked while saving it.
Like it can be seen in table 4.1 the percentage derivation was in range of 0.2 to 1.9 for the Measure program and 0.6 to 3.9 for the python evaluation.
Overall the percentage derivation from the theoretical value seamed fine, the difference can be explained by the fitting of two separate normal functions instead of one. (Which is probably mostly the reason why the K_β- lines in the python evaluation differ the most, because there peaks where smaller that the K_α-lines and the influence on them is therefore bigger)
Other reasons for deviations are inaccuracies in the calibration of the energy to channel calibration in (4.1 a)

Tabelle 4.1: 4.1 b) characteristic X-ray of different Elements measured with python

line	Theo	V4	V4 %	V2	V2 %	V4 python	V4 python %
$K_{\alpha FE}$	6.4	6.4	0.6	6.3	1.1	6.4	0.6
$K_{\alpha Ni}$	7.5	7.4	0.8	0.0	100.0	7.4	0.8
$K_{\beta Ni}$	8.3	8.3	0.2	0.0	100.0	7.9	3.9
$K_{\alpha Zn}$	8.6	8.5	1.0	0.0	100.0	8.6	0.9
$K_{\beta Zn}$	9.6	9.4	1.9	0.0	100.0	9.4	2.1
$K_{\alpha Cu}$	8.0	0.0	100.0	7.9	1.4	0.0	100.0
$K_{\beta Cu}$	8.9	0.0	100.0	8.7	1.8	0.0	100.0

For V4 and V2 being the different multiplication settings, and V4 python being the evaluation of the V4 multiplication with python

4.0.2 4.2 Determination of the energy resolution of the RED

To get the energy resolution A we had to know $A = \frac{E_0}{FTHW}$ with $FTHW = 2\sqrt{2\ln 2}\sigma$ being the full at halve maximum for an normal function.
With $b = \sigma$, A can be calculated. In 4.1 the energy resolution is plotted over the emission current. In the same way the center of gravity 4.3 and the half width of the intensity distribution 4.5 can be presented. The same has been done for the python measurement 4.3 in 4.2, 4.4, 4.6.
All six of them show the same result, the energy resolution is better for impulse rates from $0\,\mathrm{s}^{-1}$ to $1500\,\mathrm{s}^{-1}$ and gets exponentially worse, if the impulse rate gets higher.
So the detector should only be used for lower impulse rates up to $1500\,\mathrm{s}^{-1}$.

Tabelle 4.2: 4.2 (MEASURE)

U	element	a (Peak) in keV	b	c in #	gate	Imp per sec	Messdauer	ges Imp	A
0.01	Zn 1	8.52	0.414	211	2	139.2	224	30002	8.74
0.05	Zn 1	8.49	0.425	211	2	828.1	35	30021	8.48
0.1	Zn 1	8.46	0.44	212	2	1475.4	21	30002	8.17
0.2	Zn 1	8.36	0.466	211	2	2003	15	30093	7.62
0.5	Zn 1	8.07	0.546	220	2	2956.8	11	31744	6.28

Tabelle 4.3: 4.2 (Python)

U	peaks E_0	sigma σ	FWHM	A
0.01	8.53	0.43	1.02	8.74
0.05	8.49	0.44	1.04	8.48
0.1	8.46	0.46	1.08	8.16
0.2	8.37	0.48	1.14	7.62
0.5	8.07	0.56	1.32	6.28

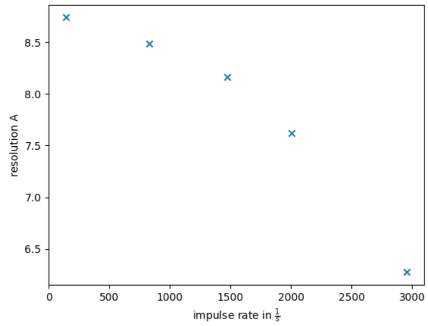

Abbildung 4.1: energy resolution (MEASURE)

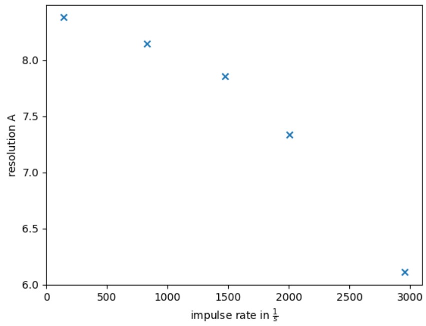

Abbildung 4.2: energy resolution (python)

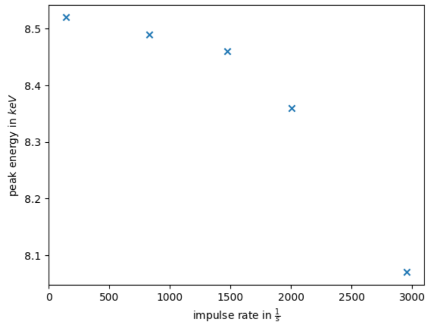

Abbildung 4.3: peakenergy in keV (MEASURE)

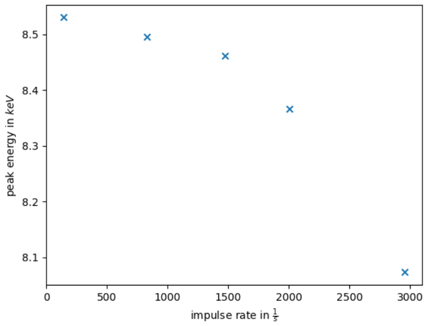

Abbildung 4.4: peakenergy in keV (python)

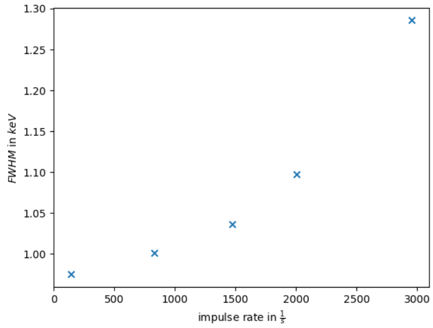

Abbildung 4.5: $FWHM$ in keV (MEASURE)

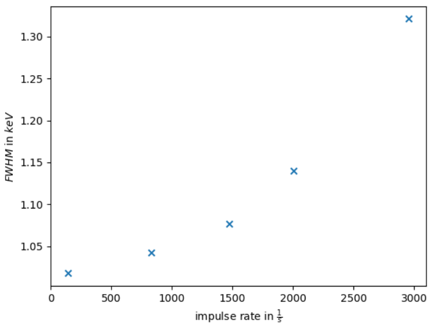

Abbildung 4.6: $FWHM$ in keV (python)

4.0.3 4.3 Quantitative X-ray fluorescence analysis, Moseley constant

The experimental procedure involves the measurement of X-ray emission spectra for a range of elements, and the K_α line energies are determined. For this exercise the data from 4.1 is used. Plotting the square root of these energies against the corresponding atomic numbers yields a linear relationship, the slope of which provides a determination of the Rydberg constant. Simultaneously, the y-intercept of the plot allows for the extraction of the screening constant given by Moseley's law.

$$E = R_\infty \cdot c \cdot h \cdot (Z - \sigma)^2 \cdot \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) \tag{4.1}$$

For the K_α-lines follows:

$$n_1 = 1, n_2 = 2 \tag{4.2}$$

Therefore the linear fit $y = m \cdot x + C$ gives:

$$R_\infty = \frac{4 \cdot m^2}{3 \cdot c \cdot h} \tag{4.3}$$

$$\sigma_{1,2} = \frac{2 \cdot C}{\sqrt{3 \cdot R_\infty \cdot c \cdot h}} \tag{4.4}$$

$$R_{\infty,\text{theo}} \approx 10973731.568160 \frac{1}{m} \tag{4.5}$$

linear fit with Measure data:

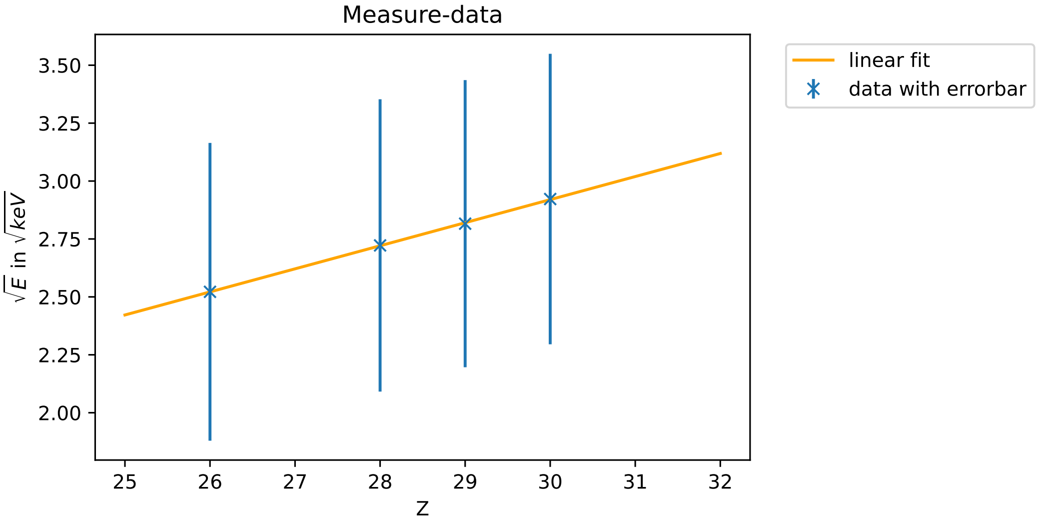

Abbildung 4.7: Measure fit

linear fit with Measure data:

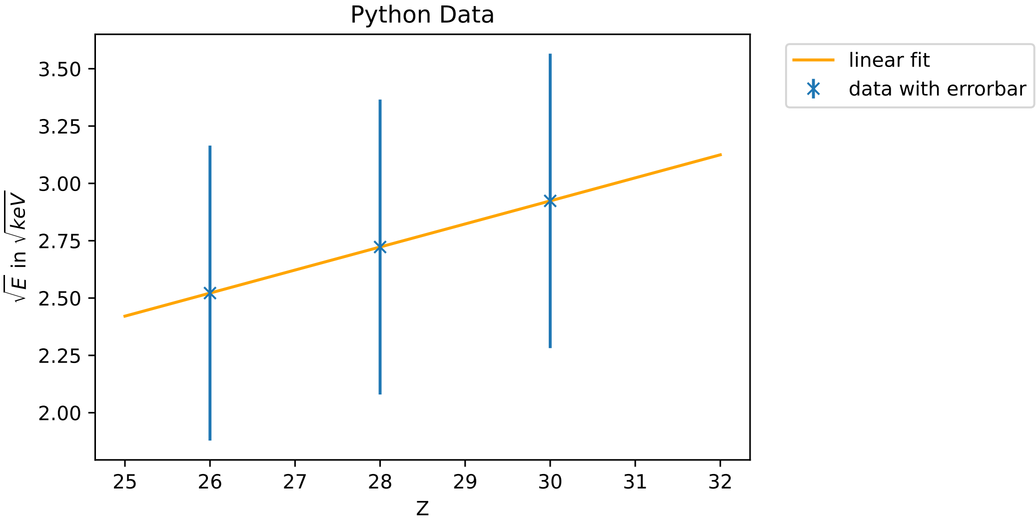

Abbildung 4.8: Python fit

programm	R_∞ in $\frac{1}{m}$	$R_{\infty,\text{err}}$ in $\frac{1}{m}$	%	$\sigma_{1,2}$	$\sigma_{1,2,\text{err}}$
Measure	10662013.04	3.36	2.84	-0.67	0.35
Python	10862707.09	1690.20	1.01	-0.91	0.02

Tabelle 4.4: results

Although the detector has a rough resolution and the peaks are not quite distinguishable, the values of the K-lines of each element and the proportional relationship to the atomic number results in an accurate value for the Rydberg constant. The deviation from the theoretical value is in both data lower than 5%.

4.0.4 4.4 Determination of the layer thickness of thin foils

To detect the intensity I we used the parameter c out of the normal function, which is proportional to I. The center of gravity and the sigma of the normal function differed over the hole measure over 0.1 (keV /) (4.54.6), which is little enough to be approximated constant.
The parameter c was plotted over the numbers of layers to get the proportionality between the intensity and the number of layers (4.9, 4.10)
To detect the thickness of the foil layers, we used the formula in the preparation.

$$d = \log(\frac{I_{p2}}{I_{ges_0}})\frac{-1}{\mu\rho 2\sqrt{2}}$$

and fitted it (4.11, 4.12).
Which gave us for the thickness of the foil layer two values.

In comparison to the average thickness of an aluminium foil from 4×10^{-6} m to 2×10^{-5} m ([Wikd]), both results seem to be possible.
However the two results differ, just like the two measures for the height of the normal function differ. The python values are always below the MEASURE values. This seems to be an systematic offset. But which of the heights are the better ones, could not be decided. Out of which follows that the better result for the thickness can not be decided.

layers	element	a (Peak) in keV	b	c in #	V/gate
0	Fe	6.29	0.423	171	2
1	Fe	6.31	0.436	88.3	2
2	Fe	6.32	0.441	43.2	2
4	Fe	6.34	0.469	14.6	2
6	Fe	6.31	0.501	6.89	2

Tabelle 4.5: iron threw n layers of aluminium foil (MEASURE)

layers	peaks E_0	sigma σ	c I
1	6.30	0.43	160.19
2	6.31	0.45	80.00
3	6.32	0.46	38.48
4	6.35	0.49	12.17
5	6.36	0.50	5.48

Tabelle 4.6: iron threw n layers of aluminium foil (python)

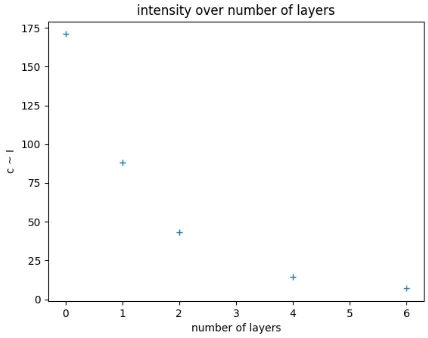

Abbildung 4.9: c was plotted over the numbers of layers (MEASURE)

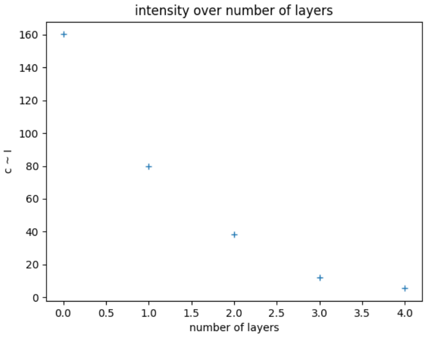

Abbildung 4.10: c was plotted over the numbers of layers (python)

MEASURE	python
8.05×10^{-6} m	1.17×10^{-5} m

Tabelle 4.7: thickness of the Al-layer

4.0.5 4.5 Qualitative X-ray fluorescence analysis on alloys

Alloys, complex metallic substances composed of two or more elements, play a crucial role in modern engineering and materials science. Analyzing alloys, especially in terms of the percentage of elements present, is a fundamental aspect of understanding their properties and performance. One powerful technique employed in this analysis is X-ray spectroscopy.
The X-ray spectrum of an alloy provides valuable information about the types and amounts of elements present. Each element has a unique set of X-ray emission lines, allowing researchers to identify and quantify the elements within the alloy. The percentage of each element in the alloy can be determined by measuring the peak intensities and comparing them to calibration standards with known compositions. Here all peak intensities get summed up and the portion to this sum is used as percentage of the element.
In the following, the X-ray spectrum of a bottle cap, a coin and an unknown material get

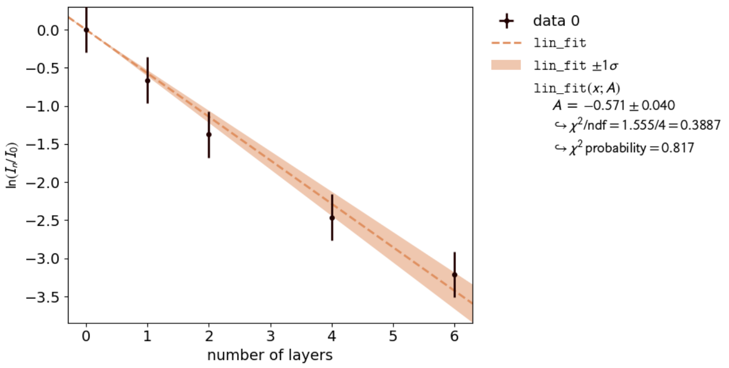

Abbildung 4.11: fit of intensity over number of layers (MEASURE)

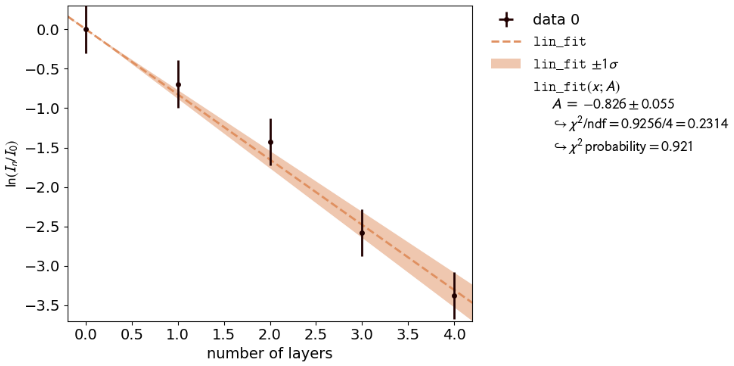

Abbildung 4.12: fit of intensity over number of layers (python)

evaluated by identifying the characteristic Lines of elements and comparing their intensities.

peak	material	a (Peak) in keV	b	c in #	V/gate
1	uo	7.94	0.414	220	2
2	uo	8.71	0.393	43	2
3	uo	10.4	0.421	14	2
4	uo	12.4	0.478	10.5	2
5	uo	14.4	0.561	2.21	2
6	uo	24.7	0,399	1.5	2
1	bottle cap	6.30	0.436	239	2
1	coin	7.99	0.459	444	2
2	coin	8.79	0.332	53.1	2
1	key	8.05	0.603	347	2

Tabelle 4.8: 4.5 characteristic lines for different things

In 4.13, the X-ray spectrum of the unknown object the characteristic lines of copper, zinc and lead were identified. Additional, two very small peaks (under 10 pulses) are not assignable and could be measurement error. By look at the elements the object is most likely a chunk of brass with approximately 75.54% copper, 17.17% zinc and 6% lead.

In 4.14, the X-ray spectrum of the bottle cap only the characteristic line of iron is identified. In contrary to the expectation, there are no characteristic lines of zinc. Normally these metallic bottle caps are coated with tin (Sn), but no L-lines were found around $4keV$. So our bottle cap

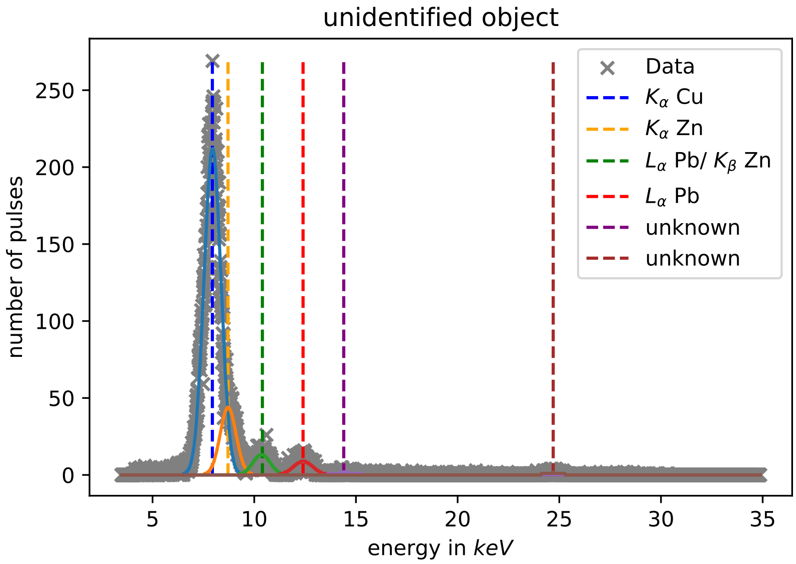

Abbildung 4.13: X-ray spectrum of brass with characteristic line

is no alloy, but made out of iron. Though it could be the case, that the resolution of our detector is too inaccurate and the coat of tin is too thin to be measured in X-ray.

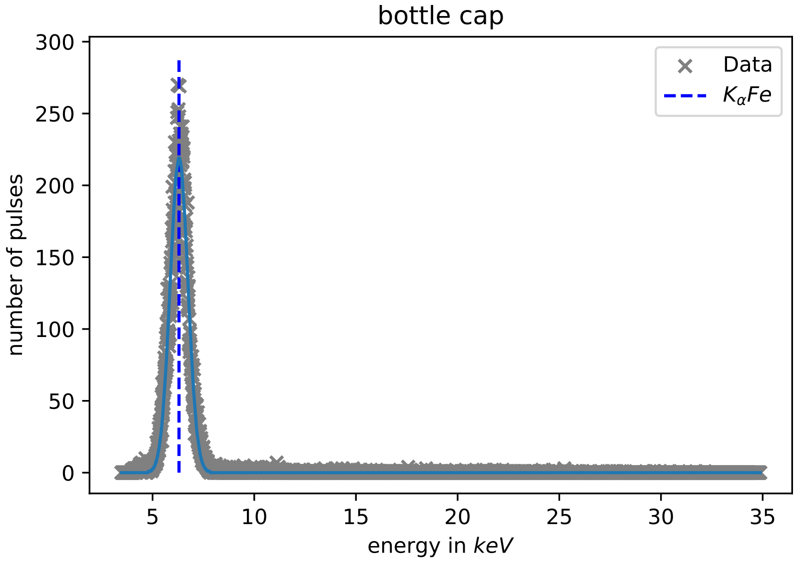

Abbildung 4.14: X-ray spectrum of a bottle cap with characteristic line

4.15, shows the X-ray spectrum of the coin and the characteristic lines of copper. These coins are internal made out of iron and a thick copper coat on the outside. Therefore, sadly we only get the elemental structure of the surface and no information of the inside of the copper coin.

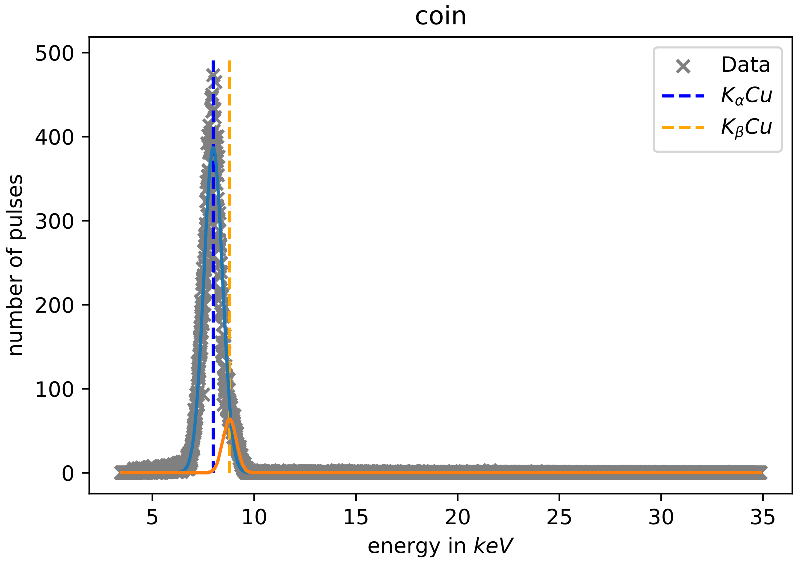

Abbildung 4.15: X-ray spectrum of a coin with characteristic lines

Overall we are able to identify characteristic lines and compare them for the percentage of element. But because of the inaccuracy and resolution, only a rough evaluation of the materials is possible.

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	energy in $\sqrt{keV}$	Z
0	2.521685	26
1	2.722499	28
2	2.923701	30

Tabelle 4.9: Measure - peak energy and atomic number

	energy in $\sqrt{keV}$	Z
0	2.521685	26
1	2.722499	28
2	2.923701	30

Tabelle 4.10: Python - peak energy and atomic number