Radioactive Decay

Michael Goerz, Anton Haase

Introduction

a) dosimetry

~~Dose~~ Rates can be measured using a Geiger-Müller-counting-tube.
The Geiger-Müller-counter gives a measurement for radioactive activity, which is defined as number of decays per second: $[A] = 1\frac{\text{decay}}{\text{sec}} = 1\,\text{Bq}$
When radiation passes through the counter, it creates an avalanche of ionized (i.e. charged) atoms which in turn creates a short current. The device counts the number of these electric impulses and thus measures activity.
The effect of radiation on matter and tissue can be described with several terms:

- "energy dose": e.d. is defined as the absorbed radiation energy per unit mass; $[D_E] = \frac{1\,\text{Joule}}{\text{kg}} = 1\,\text{Gy}$
- "ionic dose": i.d. is defined as the charge created by ionisation per mass of air $[D_Q] = 1\frac{C}{\text{kg}}$
- "equivalent dose": e.d. is defined as the product of the ionic dose and a constant factor that depends on the type of radiation ("relative biological effect")

All these terms have corresponding dose rates, i.e. doses per unit time.
In general, we have to take into account the back-

ground radiation in all measurements.

b) radioactive activation and decay

When some isotopes are exposed to neutron radiation, they can be ionized into an unstable isotope, which decays to a daughter nucleus and emits radioactive radiation (usually β-rays and neutrons). The daughter nuclei can decay in turn, if they are unstable.

For example, silver (Ag) can decay into cadmium (Cd):

$$^{107}Ag\,(n,\gamma)\,^{108}Ag^{*} \longrightarrow {}^{108}Cd^{*} + \beta^{-} + \bar{\nu}$$

$$^{104}Ag\,(n,\gamma)\,^{110}Ag^{*} \longrightarrow {}^{110}Cd^{*} + \beta^{-} + \bar{\nu}$$

If the activating neutron radiation is kept ~~up~~ constant, the number of unstable nuclei, and thus the activity, will first rise and then reach a constant maximum level, according to the following law:

$$dn = dn|_{pr} + dn|_{dec} = \sigma \cdot \phi \cdot N\,dt - \lambda n\,dt$$

$$\Rightarrow n(t) = \frac{\sigma\phi N}{\lambda} \cdot \left(1 - e^{-\lambda t}\right)$$

, where σ is the cross section, ϕ is the neutron stream density, ~~and~~ λ is the decay constant, and N is the number of initially stable nuclei.

The activity is $A(t) = \lambda \cdot n(t)$

$$\Rightarrow A(t) = \sigma\phi N\left(1 - e^{-\lambda t}\right)$$

The saturation activity is the limit of this function for $t \to \infty$, thus $A_S = \sigma\phi N$

When the sample is no longer exposed to the activating neutron radiation, i.e. $dn|_{pr} = 0$ the decay will decrease exponentially, according to the standard law of decay:

$$A(t) = A_0 \cdot e^{-\lambda t}$$

Assignments

1) Measure the natural ionic dose rate and the ionic dose rate at the outside of the neutron emitter, using an ionic dose rate meter. Convert the result to equivalent dose per year (mSv/year) and mrem/year)

2) Measure the background radiation using a Geiger-Müller-counter

3) Activate the radioactive isotopes ^{108}Ag and ^{110}Ag. Measure the time dependancy of the decay rate for different activation periods. Determine the decay constant and the half-life of both silver isotopes

4) Find the saturation counting rate for both isotopes and the ratio of their cross sections for neutron capture reactions. Compare your results to the literature values

Experiment

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Tutor: Michael Hammann
02/25/05 start 10^{45} end

Assignment 1:

distance	dose rate:
0 m	~~9 μr/h~~ 0,09 mrem/h ±0,01
1 m	0,03 ± 0,01 mrem/h
5 m	15,0 ± 5 μrem/h

1 rem = 0,01 Sv

conversions:

dist	original value	mSv / year	mrem/year
0 m	0,09 ± 0,01 mrem/h	7,88 ± 0,88	788,4 ± 87,6
1 m	0,03 ± 0,01 mrem/h	2,63 ± 0,88	262,8 ± 87,6
5 m	15, ± 5 μrem/h	1,31 ± 0,44	131,4 ± 43,8

1 Sv/h = 8760 Sv/y

additional measurement: background radiation in room 0,092 μS/h

Assignment 2:

background effect without sample:

device ~~error~~:
Δt: ± 0,03 s

Δt	counts
10 s ±0,03 s	5
20 s	1
30 s	4
40 s	2
50 s	3

Assignment 3:

activation time 1 min → 60sec ± 1sec

Δt	counts	Δt	counts	Δt	counts		
10s	(168)	240	26	470	9		
20s	958	250	20	480	14		
30s	775	260	19	490	9		
40s	565	270	21	500	8		
50s	428	280	26	510	6		
60s	339	290	16	520	6		
70s	287	300	16	530	5		
80s	194	310	10	540	12		
90s	145	320	10	550	3		
100 s	132	330	19	560	7		
110 s	106	340	19	570	9		
120s	89	350	14	580	10		
130s	65	360	12	590	7		
140 s	52	370	16	600	7		
150 s	43	380	10~~5~~	610	10		
160 s	50	390	9	620	8		
170 s	30	400	11	630	7		
180s	36	410	11	640	6		
	24	420	16	650	3		
	40	430	7	660	10		
	23	440	3	670	5	700	9
	26	450	14	680	7	710	9
	27	460	9	690	3	720	4

✓

activation time 12 min → 720 ± 1 sec

Δt	counts	Δt	counts	Δt	counts
10s	249	250	75	490	24
20	1345	260	70	500	15
30	971	270	61	510	17
40	783	280	63	520	21
50	644	290	59	530	23
60	500	300	62	540	17
70	423	310	52	550	20
80	343	320	32	560	16
90	296	330	59	570	19
100	229	340	49	580	15
110	210	350	47	590	13
120	206	360	46	600	17
130	188	370	50	610	12
140	141	380	32	620	13
150	142	390	46	630	11
160	144	400	43	640	11
170	123	410	26	650	10
180	109	420	30	660	12
190	113	430	29	670	8
200	93	440	25	680	14
210	80	450	31	690	9
220	79	466	33	700	10
230	165	470	29	716	6
246	87	480	26	726	12

Second measurement activation time 12 min

Δt	counts	Δt	counts	Δt	counts
10s	343	250	76	490	19
20	1288	260	77	500	34
30	1012	270	54	510	33
40	771	280	69	520	25
50	647	290	58	530	25
60	525	300	52	540	21
70	396	310	51	550	22
80	335	320	37	560	16
90	285	330	57	570	25
100	201	340	46	580	10
110	215	350	53	590	16
120	196	360	29	600	17
130	160	370	39	610	15
140	157	380	44	620	12
150	112	390	36	630	17
160	143	400	22	640	15
170	144	410	35	650	21
180	105	420	25	660	10
190	113	430	46	670	11
200	93	440	25	680	10
210	78	450	25	690	14
220	89	460	28	700	11
230	85	470	24	710	9
240	81	480	17	720	8

Second measurement activation time 1 min

Δt	Count	Δt	Count	Δt	count
10s	380	250	26	490	5
20	1018	260	15	500	7
30	758	270	19	510	5
40	585	280	18	520	5
50	471	290	14	530	7
60	334	300	17	540	5
70	264	310	22	550	9
80	192	320	17	560	7
90	142	330	11	570	8
100	126	340	16	580	2
110	112	350	16	590	6
120	81	360	16	600	5
130	69	370	12	610	5
140	68	380	17	620	3
150	44	390	6	630	10
160	34	400	14	640	7
170	43	410	9	650	8
180	29	420	16	660	4
190	31	430	12	670	3
200	28	440	8	680	5
210	30	450	8	690	4
220	36	460	11	700	11
230	22	470	11	710	6
240	21	480	6	720	4

Analysis:

Assignment 1:

See table of conversions in the Experiment section.

The distances are rough approximations, 0m is measured right next to the neutron source emitter, 1m is one large step away and 5m is five steps away.

For comparison, the normal background radiation is around 1,1 mSv/year, so the value at 0m is approx. 8 times higher, but quickly decreases to the standard value after some meters. The decrease, however, does not quite follow the $\frac{1}{r^2}$ law that we might expect.

Nicht?
Seltsam!

Assignment 2:

From the five measured values we derive the average-value of 3 counts with an error of $\pm \frac{1}{2}$ (standard deviation)

The device error is irrelevant here, just as in the following measurements.

Assignment 3:

See tables and plots on next pages.

The background effect was substracted from all values

The values for λ, taken from the slope of the fit plot (and the error fit plot), is:

$\lambda_{1min}(Ag-110) = (2,48 \cdot 10^{-2} \pm 0,26 \cdot 10^{-2})\, s^{-1}$

$\lambda_{1min}(Ag-108) = (4,95 \cdot 10^{-3} \pm 1,19 \cdot 10^{-3})\, s^{-1}$

$\lambda_{12min}(Ag-110) = (2,22 \cdot 10^{-2} \pm 0,21 \cdot 10^{-2})\, s^{-1}$

$\lambda_{12min}(Ag-108) = (5,39 \cdot 10^{-3} \pm 1,25 \cdot 10^{-3})\, s^{-1}$ ✓

From λ, we can find the half life as

$$T_{1/2} = \frac{\ln(0.5)}{\lambda}$$

$T_{1/2}^{1min}(Ag-110) = (27,95 \pm 2,89)\, s$

$T_{1/2}^{1min}(Ag-108) = (139,00 \pm 33,55)\, s$

$T_{1/2}^{12min}(Ag-110) = (31,19 \pm 2,82)\, s$

$T_{1/2}^{12min}(Ag-108) = (128,49 \pm 29,73)\, s$

[illegible] [illegible] [illegible] [illegible] [illegible]

For comparison, the literature values are

$T_{1/2}(Ag-110) = 144,6\, s$

$T_{1/2}(Ag-108) = 24,6\, s$ ✓

Assignment 4:

The saturation counting rates taken from the fitplot at 12 min saturation time are

300 ± 150 for Ag-108

2000 ± 300 for Ag-110

2000 – 300 !

At 1 minute ~~saturation~~ irradiation time saturation was not reached, so we cannot get results from that plot.

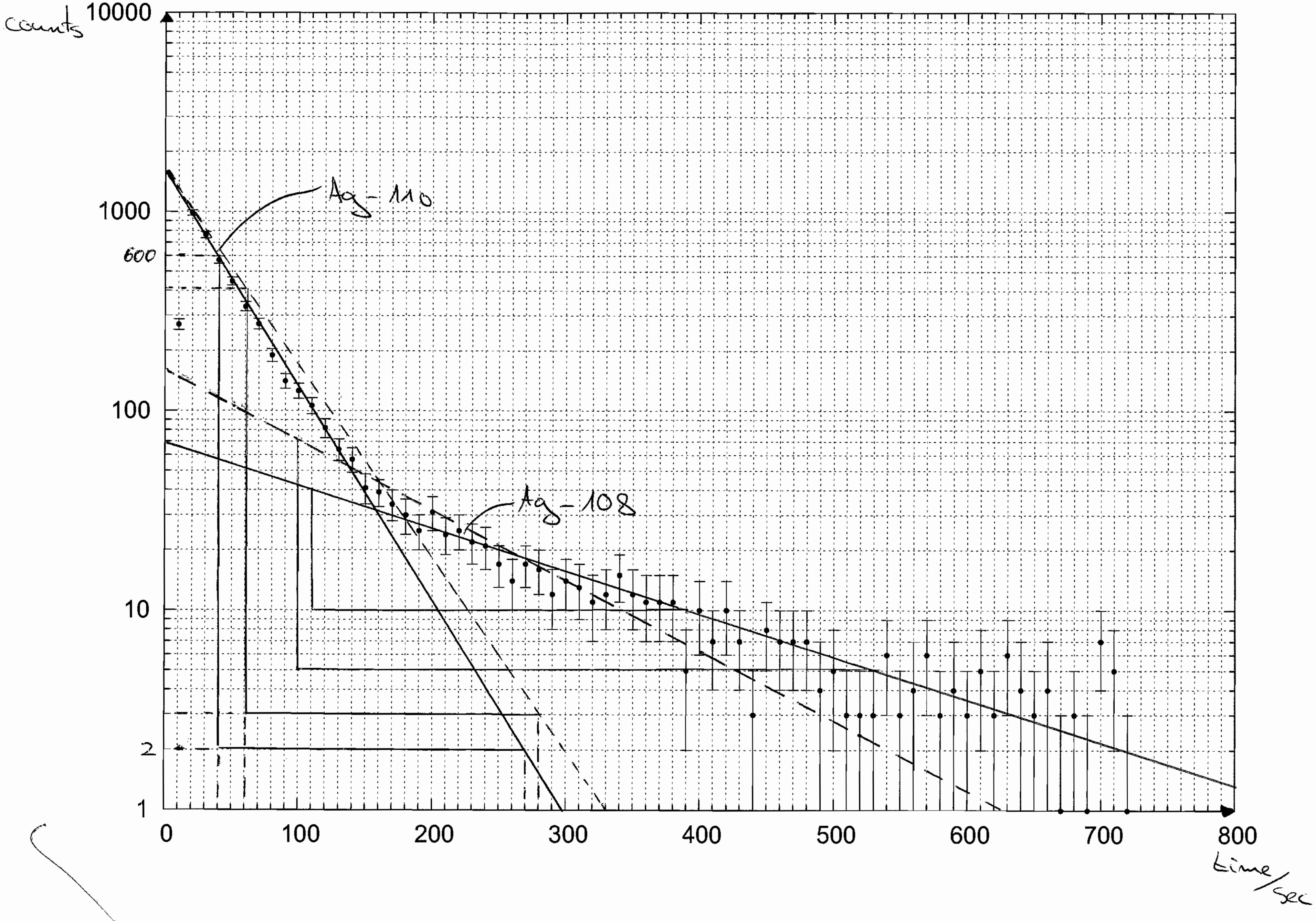
[illegible] for Ag 110 correct

The reading error was not taken into account.

On Assignment 3: Table for Activation Time 1 Minute

time	count1	count2	average	error av.	background	bg. error	total	total error
10	168	380	274	17	3	0,5	271	17
20	958	1018	988	31	3	0,5	985	31
30	775	758	767	28	3	0,5	764	28
40	565	585	575	24	3	0,5	572	24
50	428	471	450	21	3	0,5	447	21
60	339	334	337	18	3	0,5	334	18
70	287	264	276	17	3	0,5	273	17
80	194	192	193	14	3	0,5	190	14
90	145	142	144	12	3	0,5	141	12
100	132	126	129	11	3	0,5	126	11
110	106	112	109	10	3	0,5	106	10
120	89	81	85	9	3	0,5	82	9
130	65	69	67	8	3	0,5	64	8
140	52	68	60	8	3	0,5	57	8
150	43	44	44	7	3	0,5	41	7
160	50	34	42	6	3	0,5	39	6
170	30	43	37	6	3	0,5	34	6
180	36	29	33	6	3	0,5	30	6
190	24	31	28	5	3	0,5	25	5
200	40	28	34	6	3	0,5	31	6
210	23	30	27	5	3	0,5	24	5
220	26	30	28	5	3	0,5	25	5
230	27	22	25	5	3	0,5	22	5
240	26	21	24	5	3	0,5	21	5
250	20	20	20	4	3	0,5	17	4
260	19	15	17	4	3	0,5	14	4
270	21	19	20	4	3	0,5	17	4
280	20	18	19	4	3	0,5	16	4
290	16	14	15	4	3	0,5	12	4
300	16	17	17	4	3	0,5	14	4
310	10	22	16	4	3	0,5	13	4
320	10	17	14	4	3	0,5	11	4
330	19	11	15	4	3	0,5	12	4
340	19	16	18	4	3	0,5	15	4
350	14	16	15	4	3	0,5	12	4
360	12	16	14	4	3	0,5	11	4
370	16	12	14	4	3	0,5	11	4
380	10	17	14	4	3	0,5	11	4
390	9	6	8	3	3	0,5	5	3
400	11	14	13	4	3	0,5	10	4
410	11	9	10	3	3	0,5	7	3
420	10	16	13	4	3	0,5	10	4
430	7	12	10	3	3	0,5	7	3
440	3	8	6	2	3	0,5	3	2
450	14	8	11	3	3	0,5	8	3
460	9	11	10	3	3	0,5	7	3
470	9	11	10	3	3	0,5	7	3
480	14	6	10	3	3	0,5	7	3
490	9	5	7	3	3	0,5	4	3
500	8	7	8	3	3	0,5	5	3
510	6	5	6	2	3	0,5	3	2
520	6	5	6	2	3	0,5	3	2
530	5	7	6	2	3	0,5	3	2
540	12	5	9	3	3	0,5	6	3
550	3	9	6	2	3	0,5	3	2
560	7	7	7	3	3	0,5	4	3
570	9	8	9	3	3	0,5	6	3
580	10	2	6	2	3	0,5	3	2
590	7	6	7	3	3	0,5	4	3
600	7	5	6	2	3	0,5	3	2
610	10	5	8	3	3	0,5	5	3
620	8	3	6	2	3	0,5	3	2
630	7	10	9	3	3	0,5	6	3
640	6	7	7	3	3	0,5	4	3
650	3	8	6	2	3	0,5	3	2
660	10	4	7	3	3	0,5	4	3
670	5	3	4	2	3	0,5	1	2
680	7	5	6	2	3	0,5	3	2
690	3	4	4	2	3	0,5	1	2
700	9	11	10	3	3	0,5	7	3
710	9	6	8	3	3	0,5	5	3
720	4	4	4	2	3	0,5	1	2

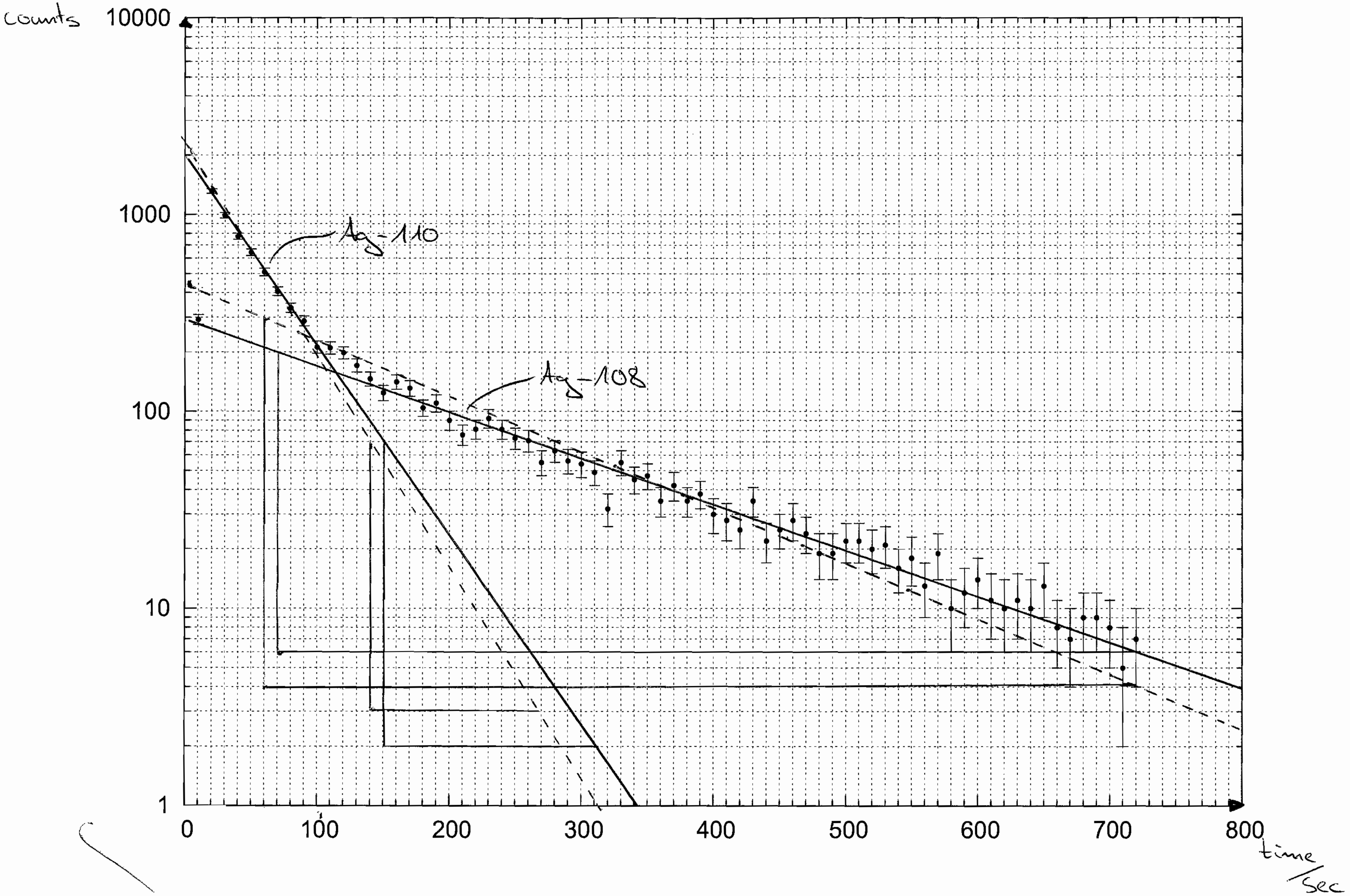
On Assignment 3: Decay of Silver After Activation Time 1 Minute



On Assignment 3: Table for Activation Time 12 Minutes

time	count1	count2	average	error av.	background	error bg.	total	total error
10	249	343	296	17	3,0	0,5	293	17
20	1345	1288	1317	36	3,0	0,5	1314	36
30	971	1012	992	31	3,0	0,5	989	31
40	783	771	777	28	3,0	0,5	774	28
50	644	647	646	25	3,0	0,5	643	25
60	500	525	513	23	3,0	0,5	510	23
70	423	396	410	20	3,0	0,5	407	20
80	343	335	339	18	3,0	0,5	336	18
90	296	285	291	17	3,0	0,5	288	17
100	229	201	215	15	3,0	0,5	212	15
110	210	215	213	15	3,0	0,5	210	15
120	206	196	201	14	3,0	0,5	198	14
130	188	160	174	13	3,0	0,5	171	13
140	141	157	149	12	3,0	0,5	146	12
150	142	112	127	11	3,0	0,5	124	11
160	144	143	144	12	3,0	0,5	141	12
170	123	144	134	12	3,0	0,5	131	12
180	109	105	107	10	3,0	0,5	104	10
190	113	113	113	11	3,0	0,5	110	11
200	93	93	93	10	3,0	0,5	90	10
210	80	78	79	9	3,0	0,5	76	9
220	79	89	84	9	3,0	0,5	81	9
230	105	85	95	10	3,0	0,5	92	10
240	87	81	84	9	3,0	0,5	81	9
250	75	76	76	9	3,0	0,5	73	9
260	70	77	74	9	3,0	0,5	71	9
270	61	54	58	8	3,0	0,5	55	8
280	63	69	66	8	3,0	0,5	63	8
290	59	58	59	8	3,0	0,5	56	8
300	62	52	57	8	3,0	0,5	54	8
310	52	51	52	7	3,0	0,5	49	7
320	32	37	35	6	3,0	0,5	32	6
330	59	57	58	8	3,0	0,5	55	8
340	49	46	48	7	3,0	0,5	45	7
350	47	53	50	7	3,0	0,5	47	7
360	46	29	38	6	3,0	0,5	35	6
370	50	39	45	7	3,0	0,5	42	7
380	32	44	38	6	3,0	0,5	35	6
390	46	36	41	6	3,0	0,5	38	6
400	43	22	33	6	3,0	0,5	30	6
410	26	35	31	6	3,0	0,5	28	6
420	30	25	28	5	3,0	0,5	25	5
430	29	46	38	6	3,0	0,5	35	6
440	25	25	25	5	3,0	0,5	22	5
450	31	25	28	5	3,0	0,5	25	5
460	33	28	31	6	3,0	0,5	28	6
470	29	24	27	5	3,0	0,5	24	5
480	26	17	22	5	3,0	0,5	19	5
490	24	19	22	5	3,0	0,5	19	5
500	15	34	25	5	3,0	0,5	22	5
510	17	33	25	5	3,0	0,5	22	5
520	21	25	23	5	3,0	0,5	20	5
530	23	25	24	5	3,0	0,5	21	5
540	17	21	19	4	3,0	0,5	16	4
550	20	22	21	5	3,0	0,5	18	5
560	16	16	16	4	3,0	0,5	13	4
570	19	25	22	5	3,0	0,5	19	5
580	15	10	13	4	3,0	0,5	10	4
590	13	16	15	4	3,0	0,5	12	4
600	17	17	17	4	3,0	0,5	14	4
610	12	15	14	4	3,0	0,5	11	4
620	13	12	13	4	3,0	0,5	10	4
630	11	17	14	4	3,0	0,5	11	4
640	11	15	13	4	3,0	0,5	10	4
650	10	21	16	4	3,0	0,5	13	4
660	12	10	11	3	3,0	0,5	8	3
670	8	11	10	3	3,0	0,5	7	3
680	14	10	12	3	3,0	0,5	9	3
690	9	14	12	3	3,0	0,5	9	3
700	10	11	11	3	3,0	0,5	8	3
710	6	9	8	3	3,0	0,5	5	3
720	12	8	10	3	3,0	0,5	7	3

On Assignment 3: Decay of silver After Activation Time 12 Minutes



The ratio of cross sections can be determined as follows:

$$C_0 \sim A_0 = \sigma \cdot \phi \cdot N$$

$$\Rightarrow \frac{C_0^{Ag108}}{C_0^{Ag110}} = \frac{\sigma_{108}}{\sigma_{110}}$$, C_0 being the saturation counting rate

$$\frac{\sigma_{108}}{\sigma_{110}} = 0{,}15 \pm 0{,}08$$ $\left(\frac{300}{1500} = 0{,}2 \text{ [illegible] [illegible]} \right)$

The literature value is 0,39

Conclusion

The purpose of this experiment was to observe the radioactive decay of two different silver isotopes after different activation time. The plots show the expected superposition of both isotope's decays.

agreement / within error

The half lifes are in ~~correspondance~~ ~~with~~ the literature values (within one and two error intervalls, respectively) identical

Apart from the statistical error there is no significant error in the counting rates from devices or reading

However, the results obtained for the saturation counting rates are not very satisfactory.

The ratio of cross sections is close to being significantly different from the literature value.

? The errors made in this part do not really allow any meaningful calculation.
In addition to the large statistical error, there is also a large reading error from the logarithmic scale, which was not even taken into account in all parts of the calculation. Also, there might have been an error introduced by the delay between the activation and the start of the measurement. It is not guaranteed that the full activation was reached in the 12 minute period. well written

ok
4.3.25