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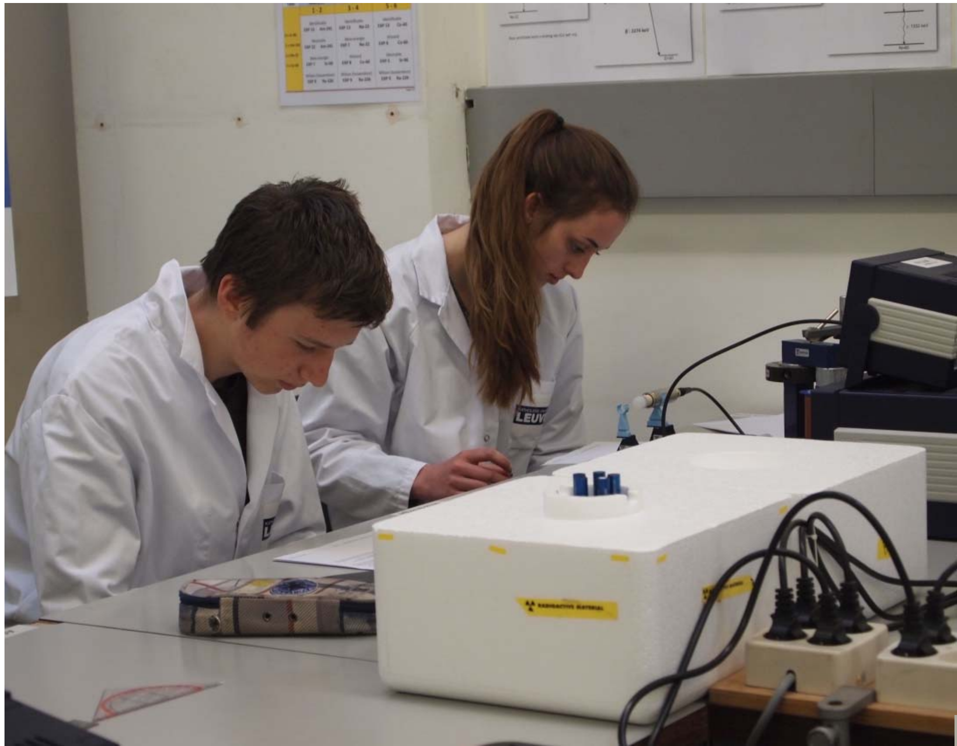
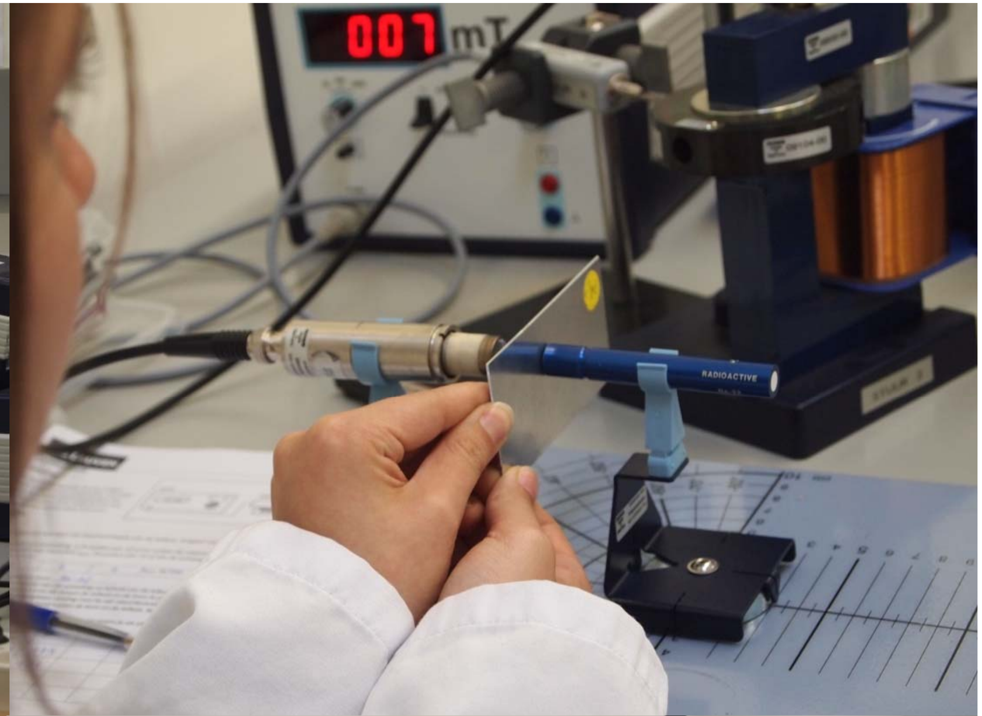
Education project in Ionizing Radiation

STUUR - Nuclear Physics

G. Janssens, B. Boeykens, M. De Cock,

KU Leuven, Departments of Physics & Astronomy




007 mT
RADIOACTIVE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1. Nuclear Physics in secondary school
2. STUUR-project at KU Leuven
3. Actual organization
4. Special attention to safety
5. The experiments
6. Results
7. Conclusion

1. Nuclear Physics in secondary school

- Compulsory in all curricula
- Strict regulations for radioactive sources
  - only theoretical descriptions and calculations are possible
- Students have no idea of the complexity of ionizing radiation :
  - stochastic behavior of radiation
  - different types and energies in one source
  - the actual realization of protection

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2. STUUR-project at KU Leuven

- Student experiments
  for class groups
  with their physics teacher
- Focus on
  measurements in the lab
  and working out at home
- 2 teachers with certificate
  present at each session

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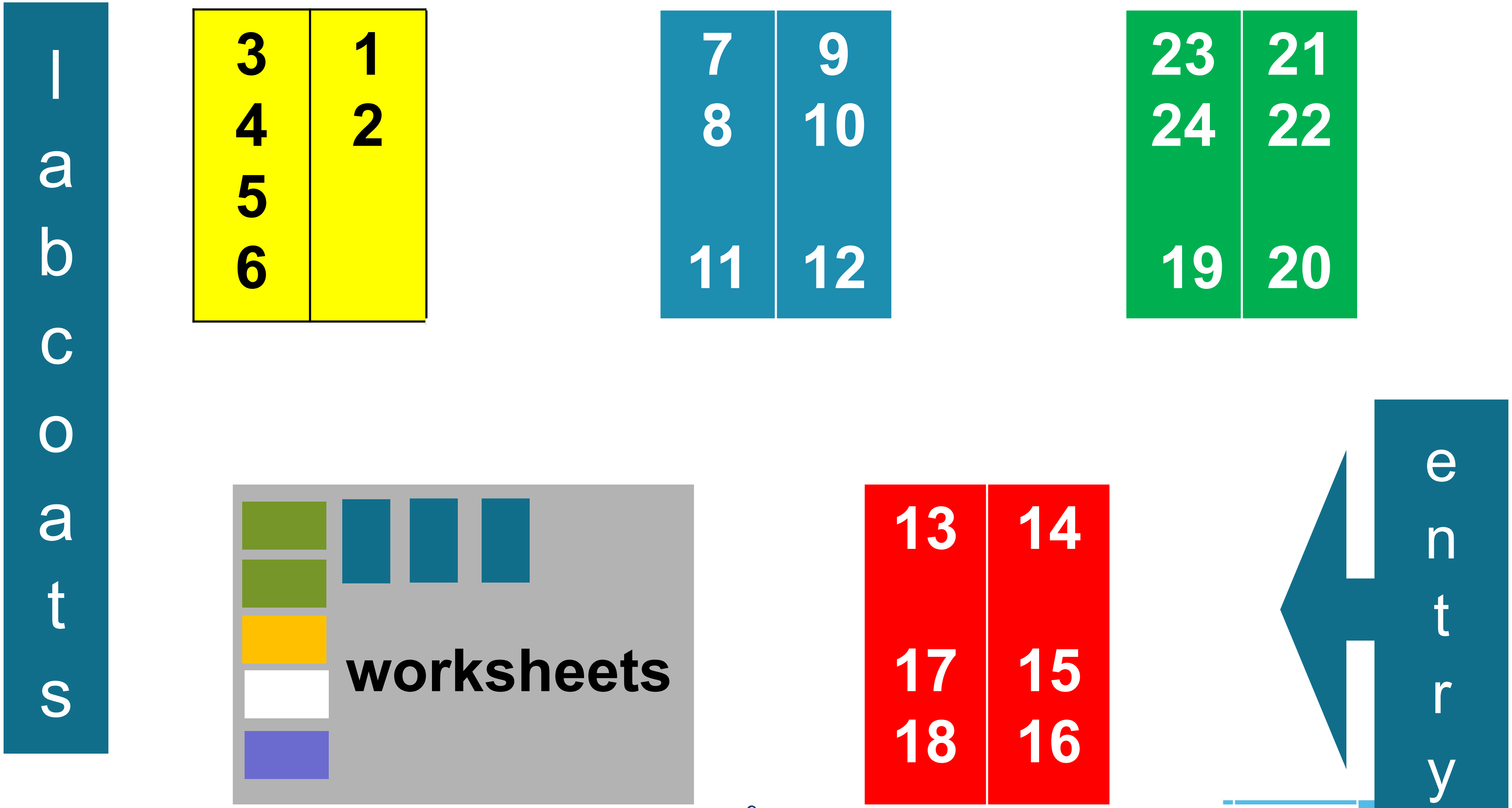
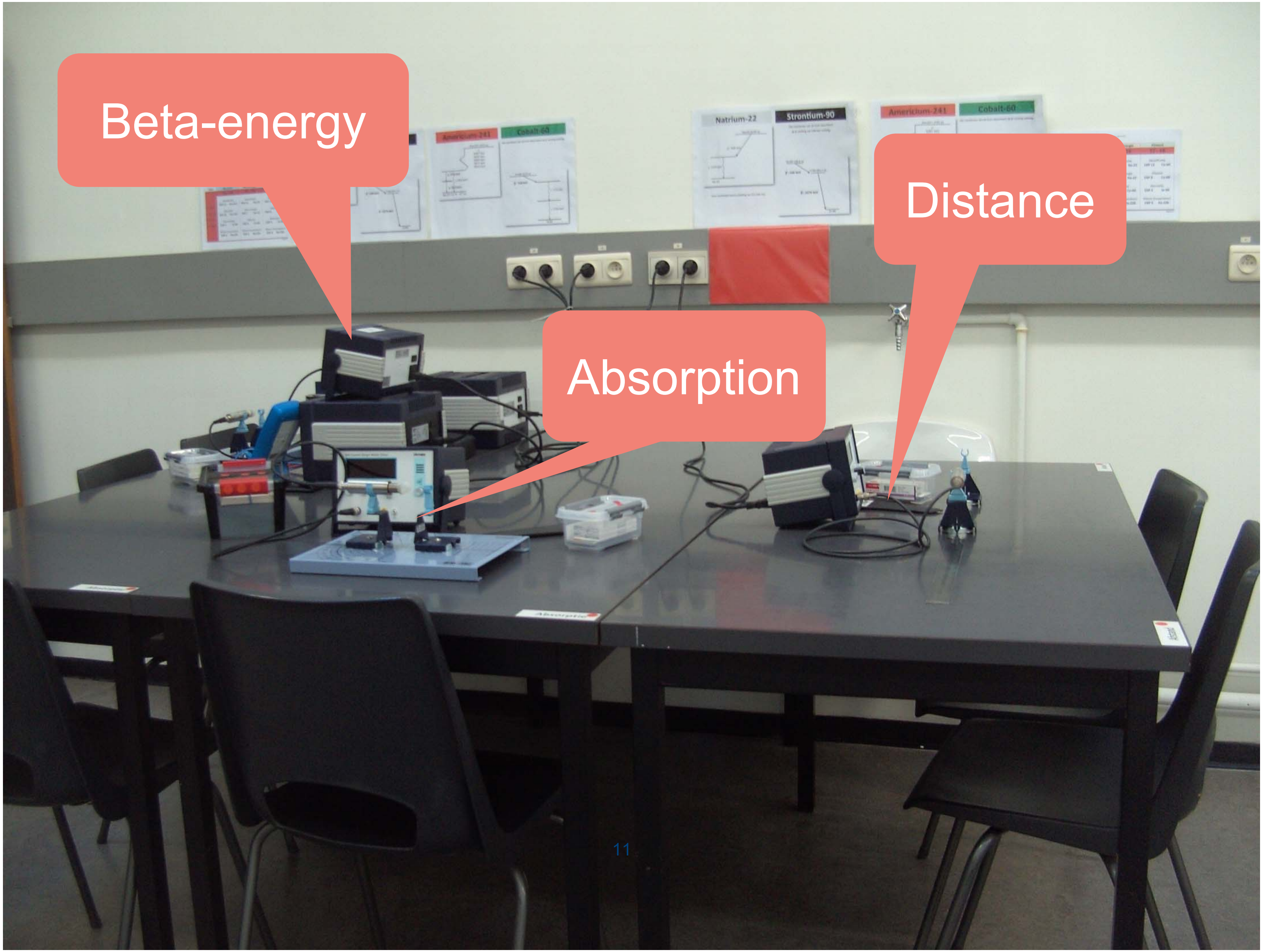
Strontium-90
Americium-241

- 3 different experiments on one table,
- 3 groups of 2 students are working together.




Natrium-22
Strontium-90
Americium-241
Cobalt-60
Natrium-22
Strontium-90
Americium-241
Cobalt-60


Beta-energy
Absorption
Distance
Natrium-22
Strontium-90
Americium-241
Cobalt-60

Distance	Absorption
5 - 6	**13 - 14**
Identification	Identification
EXP 13 Co-60	**EXP 13 Am-241**
Distance	Absorption
EXP 8 Co-60	**EXP 22 Am-241**
Absorption	Beta-energy
EXP 5 Sr-90	**EXP 7 Sr-90**
Wilson chamber	Wilson chamber
EXP 9 Ra-226	**EXP 9 Ra-226**

In between times

- Experiment 9:
  tracks of α-rays in Wilson chamber.

- Working out of measurement results

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Worksheets available

Worksheets available

- a worksheet for each student
- with comprehensive, complete information
- strict instructions
- problem solving questions
  - on measuring strategy
  - number of measurements
  - measuring intervals
- solutions are given to the physics teacher

Worksheets available

- We are much indebted to J. Kortland of the European Science Education Research Association (ESERA) for his kind and valuable support on our project.
- www.fisme.uu.nl/isp
- Bibliography: Eijkelhof H.M.C. (1996) ‘Radiation risk and science education.’

Universiteit Utrecht

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Planning
• Inleiding + praktische afspraken
• Verplaatsing naar STUUR-lab
• Uitvoeren experimenten
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Safety in the lab:

practical directives for manipulation of devices

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Geiger-Müller counter (GM-counter)

counts the number of pulses *I* (= *intensity*)

- start/stop
- reset
- time interval
  - (pulses/10 s)
  - (p/10 s) automatic

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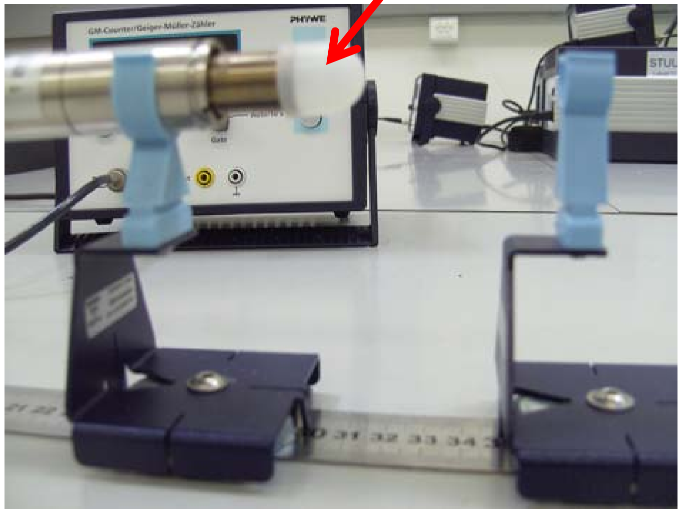
Counter tube



- membrane is very vulnerable
- be careful with sharp objects
- protect with cover when ready

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Safety in the lab:

practical directives for manipulation of sources

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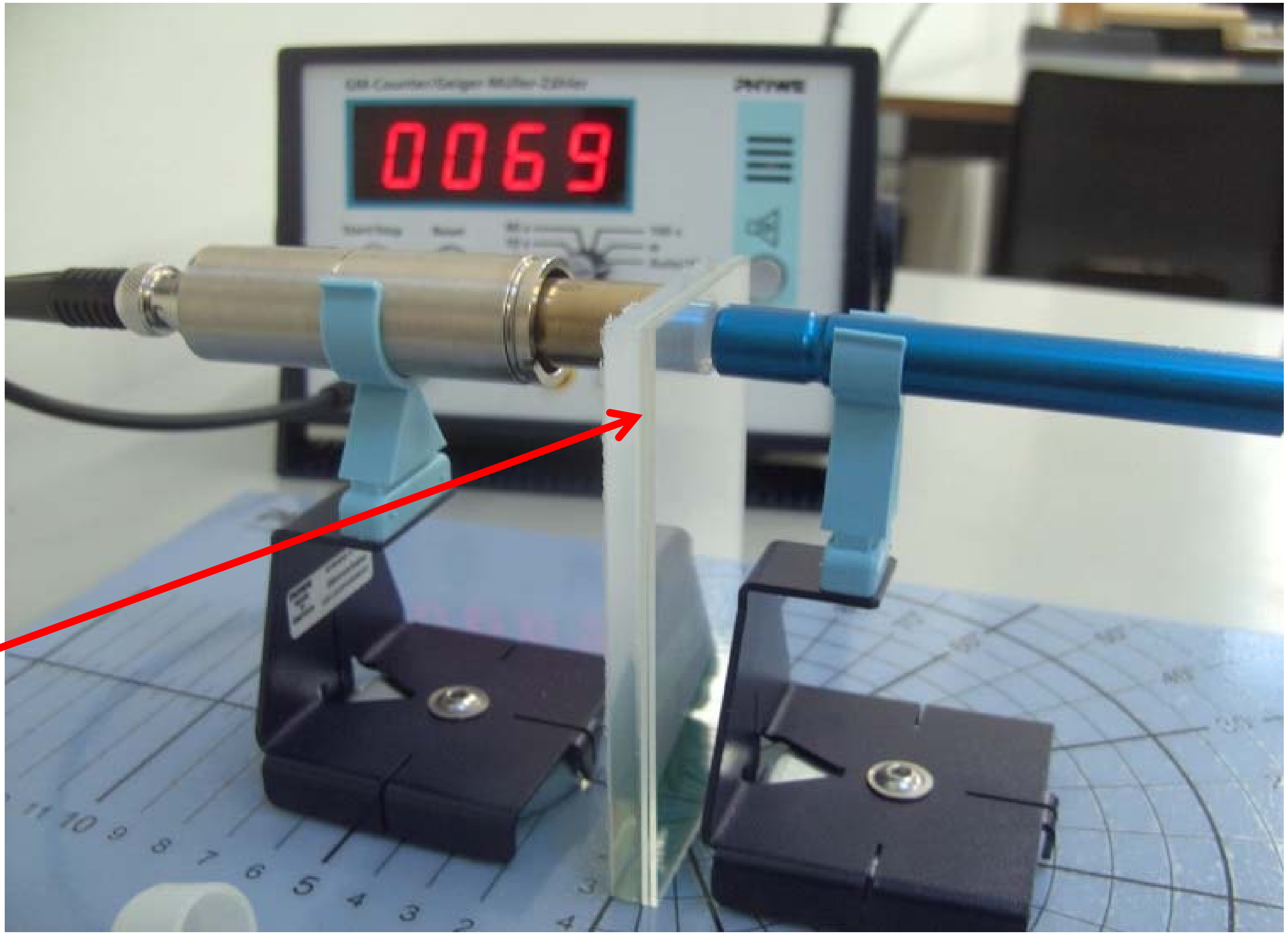
alignment of counter tube and source



spacing element of 1 cm

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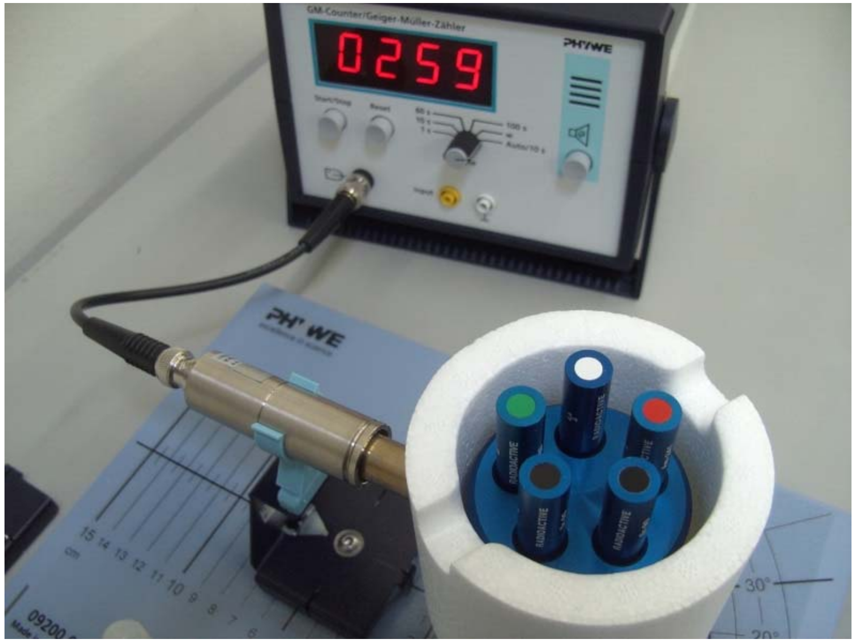
sources



- in container
- take source just before measurement
- be careful with sharp objects
- put source in container immediately after measurement

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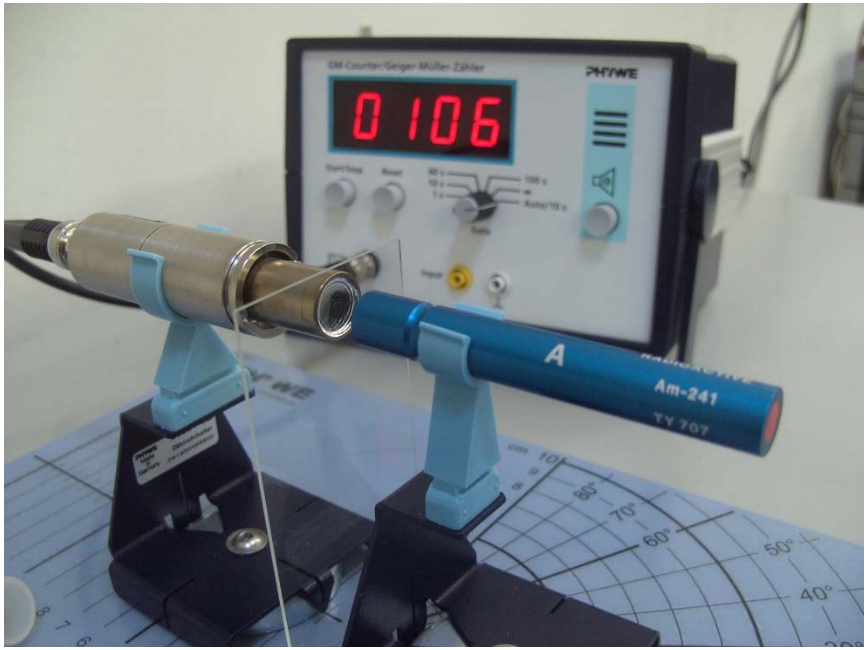
sources

- limit contact time
- keep distance
- use shielding



according to the ALARA-principle

As Low As Reasonably Achievable

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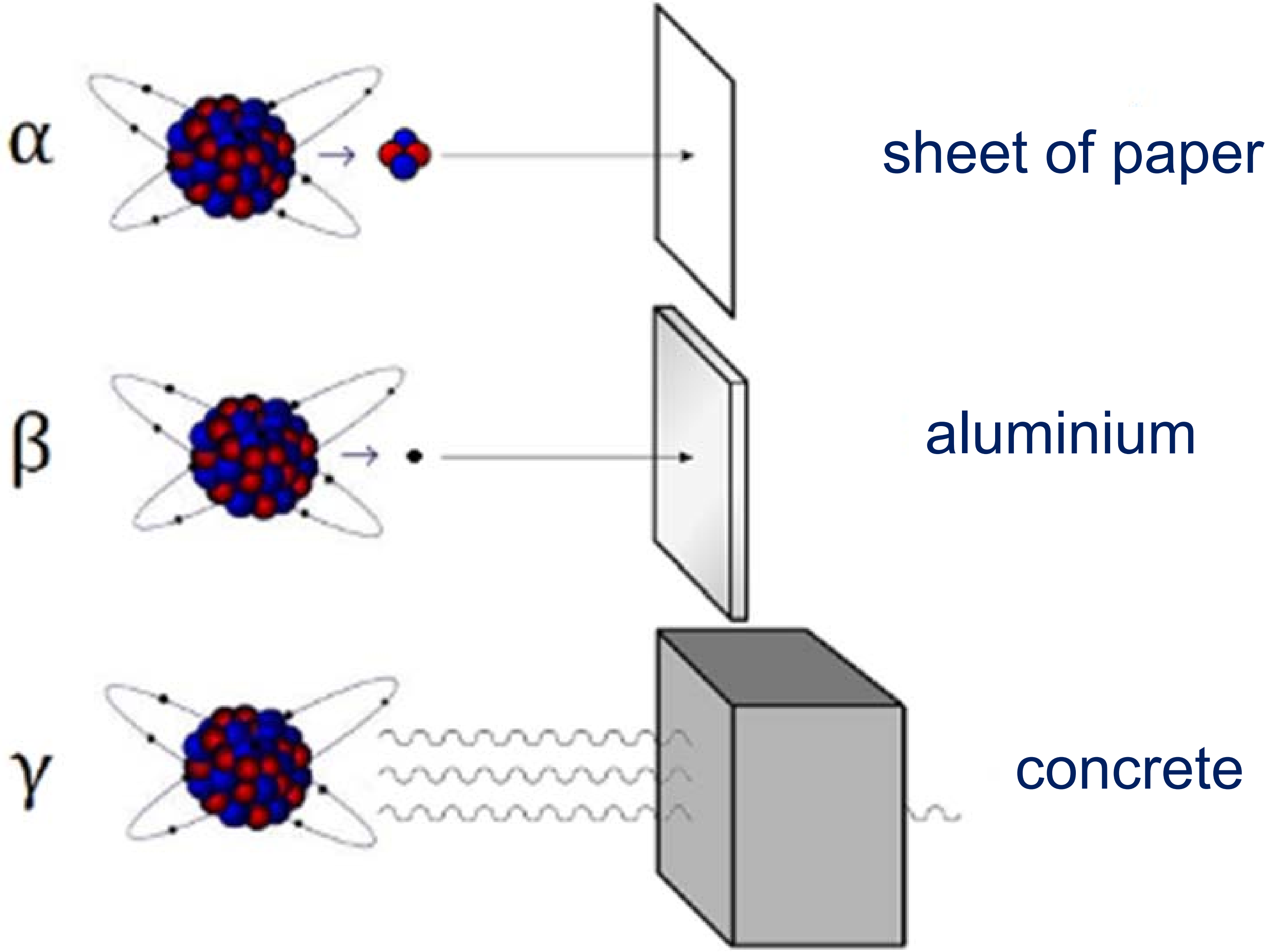
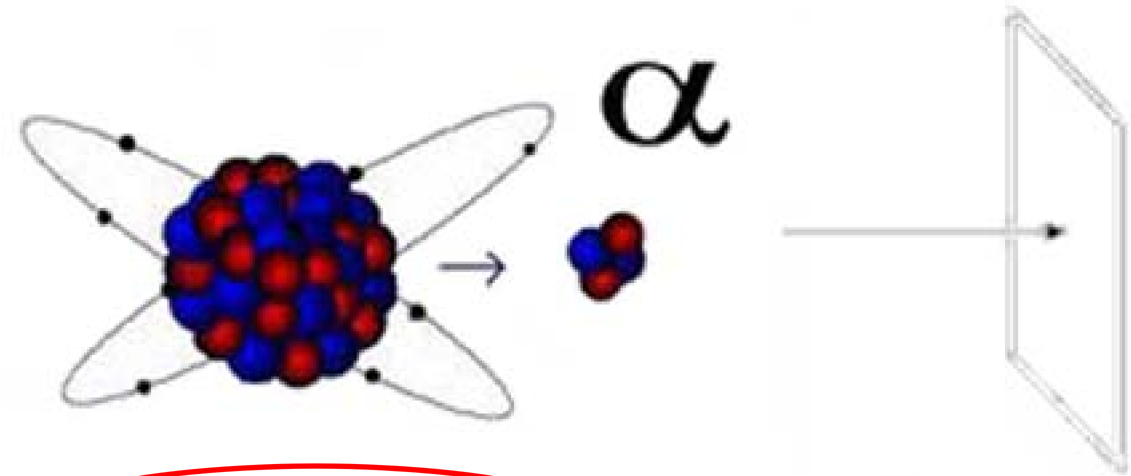
Identification

of radiation type(s) in a source by means of absorption sheets

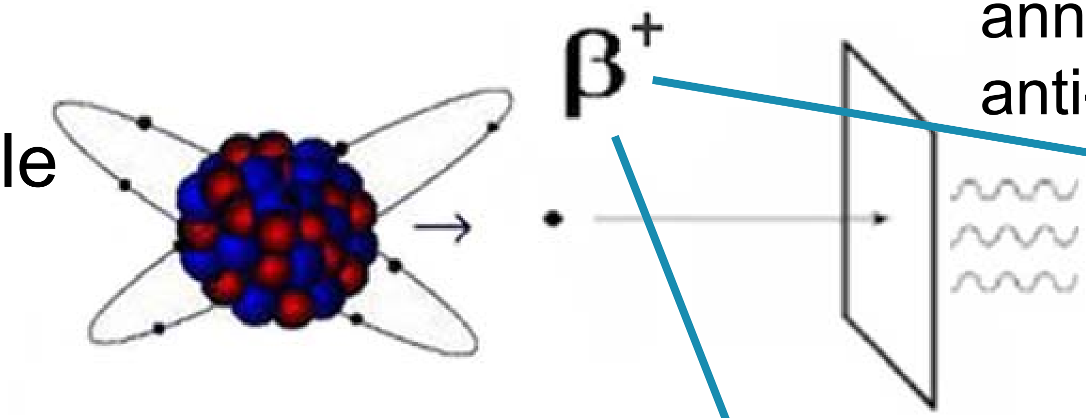

α
β
γ
sheet of paper
aluminium
concrete

alfa particle 2 neutrons and 2 protons



completely stopped by a thin paper foil

beta^{+}-particle
positron

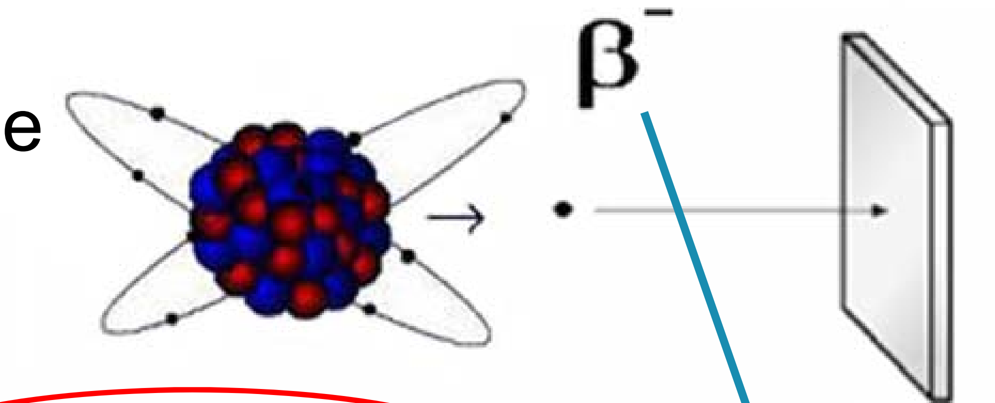


annihilation of anti-particle

γ-radiation

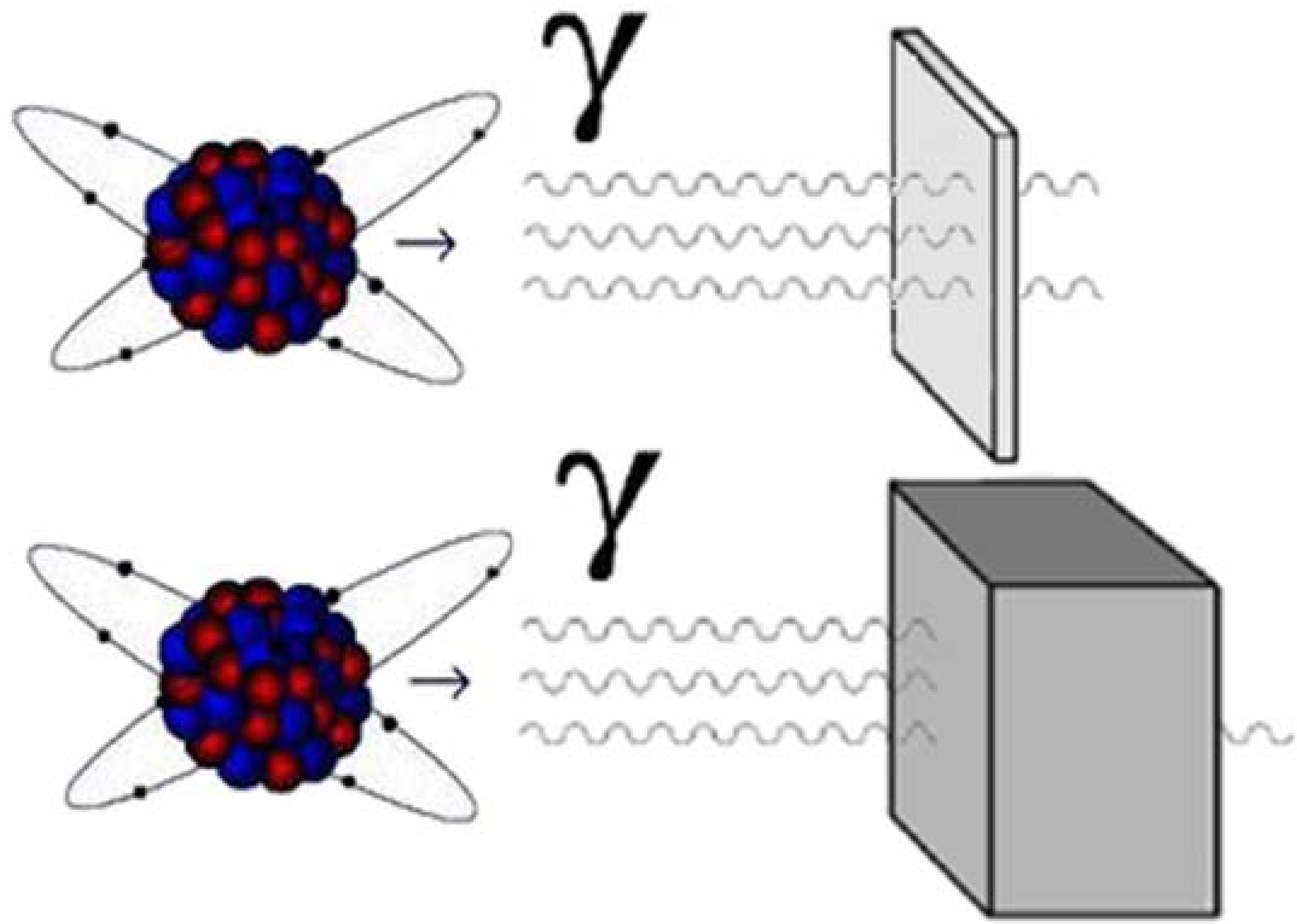
completely stopped by 1 mm aluminium

beta^{-}-particle
electron



completely stopped by 4 mm aluminium

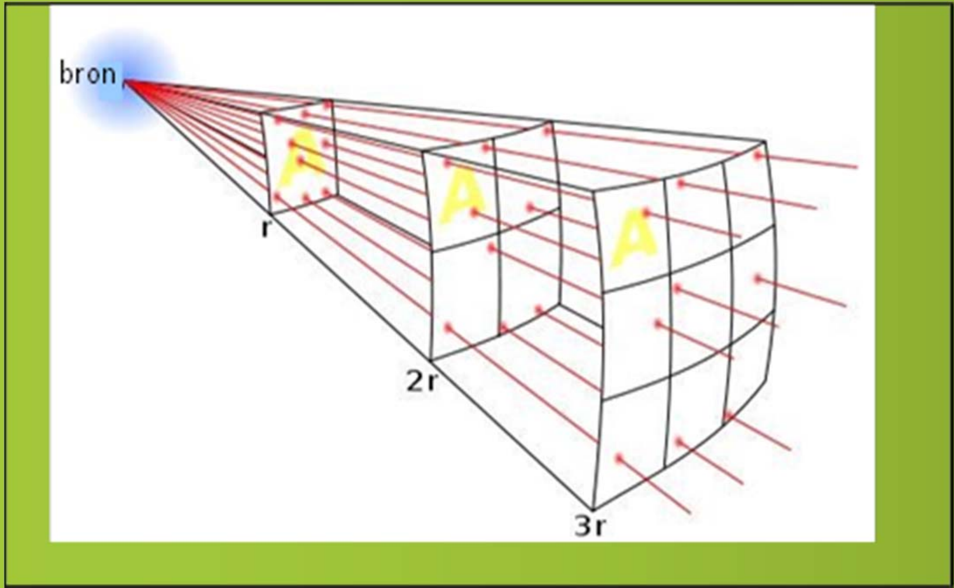
gamma-radiation = EM waves = photons



a few
cm
lead

up to
meters
concrete

Half-value thickness depending on the energy



Protection from radiation:

influence of distance *r*

reversed square law $I \sim \frac{1}{r^2}$

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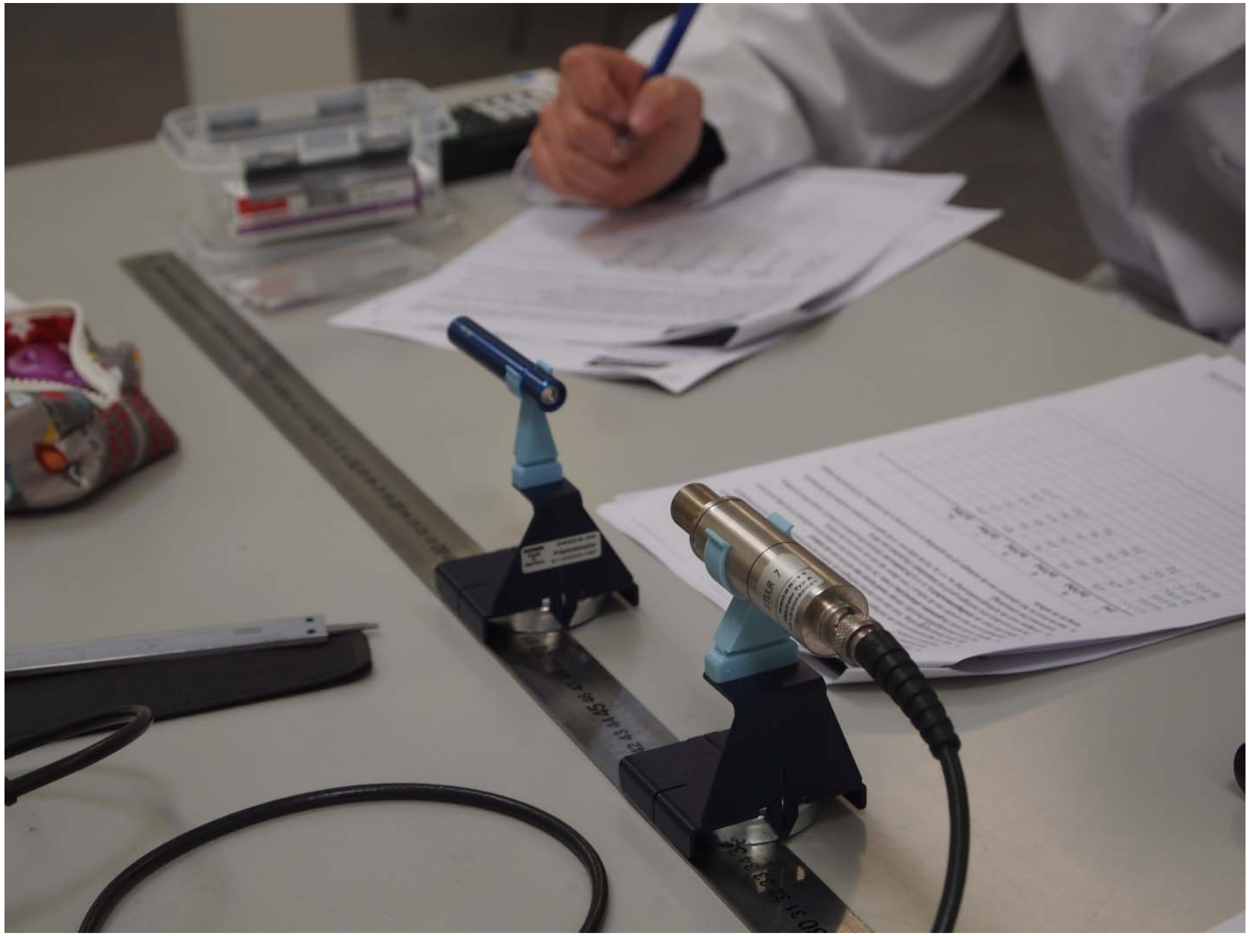
reversed square law $I \sim \frac{1}{r^2}$



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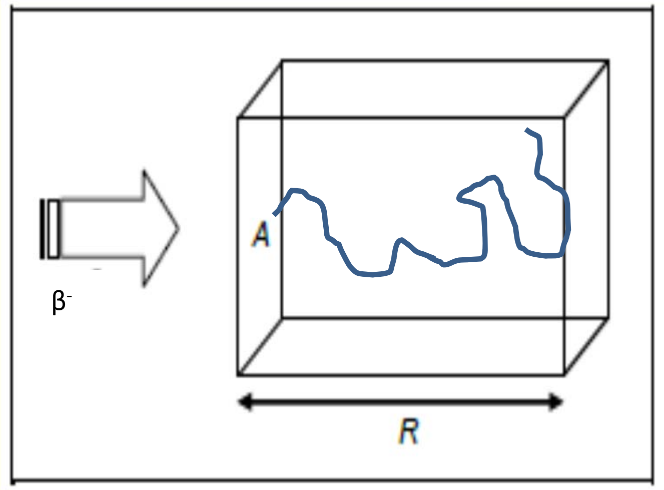
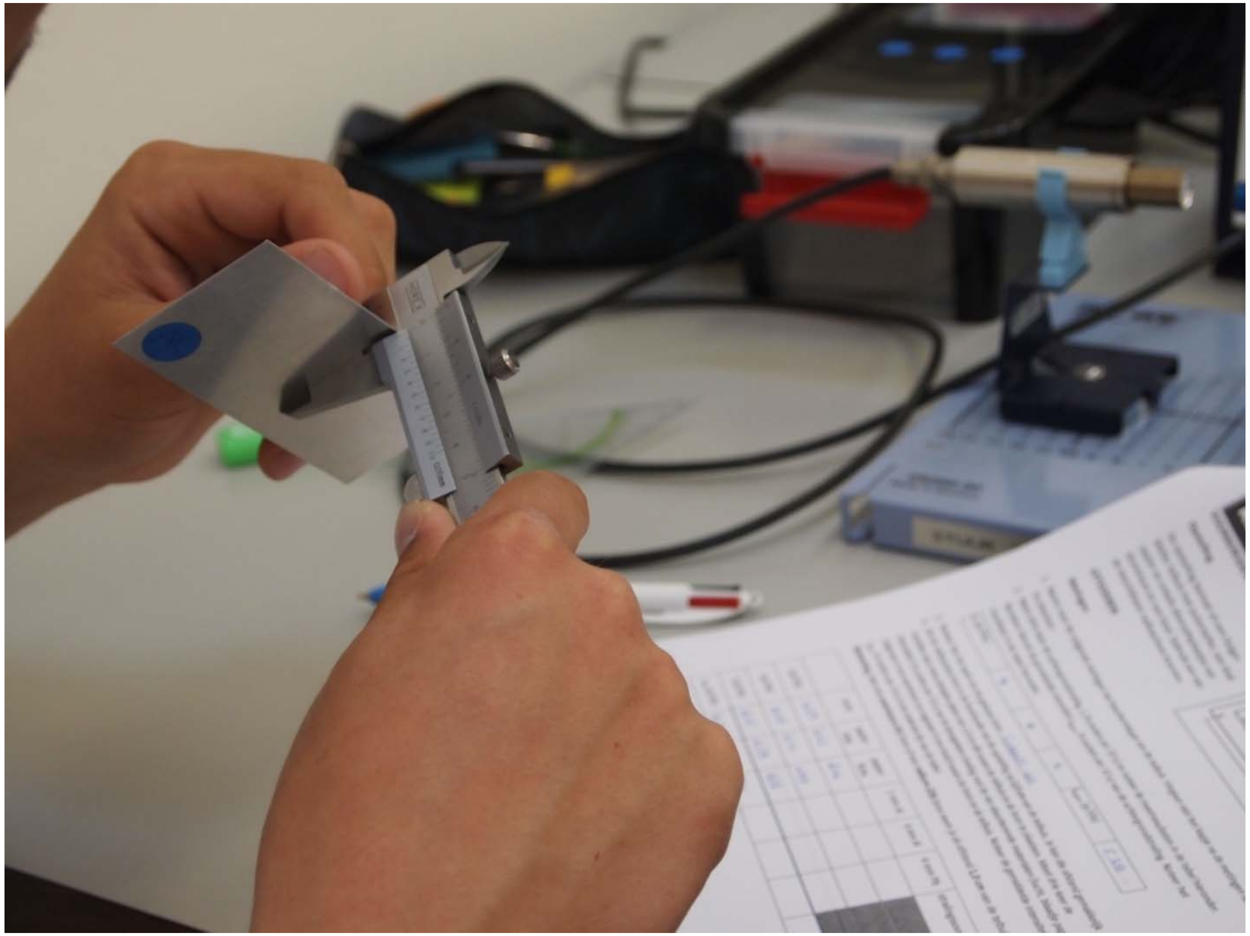
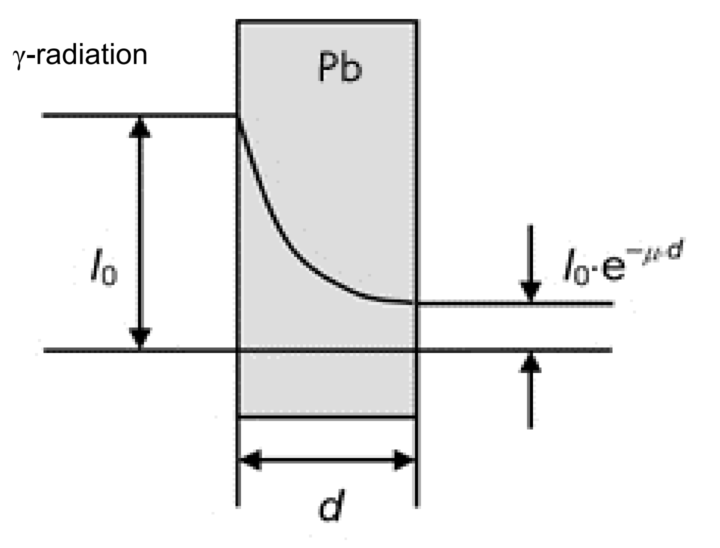


Protection by shielding: absorption of β^{-} radiation

limited penetration depth in materials
definition of range *R* of β-particles
and universal range

absorption: the range *R* of β-particles



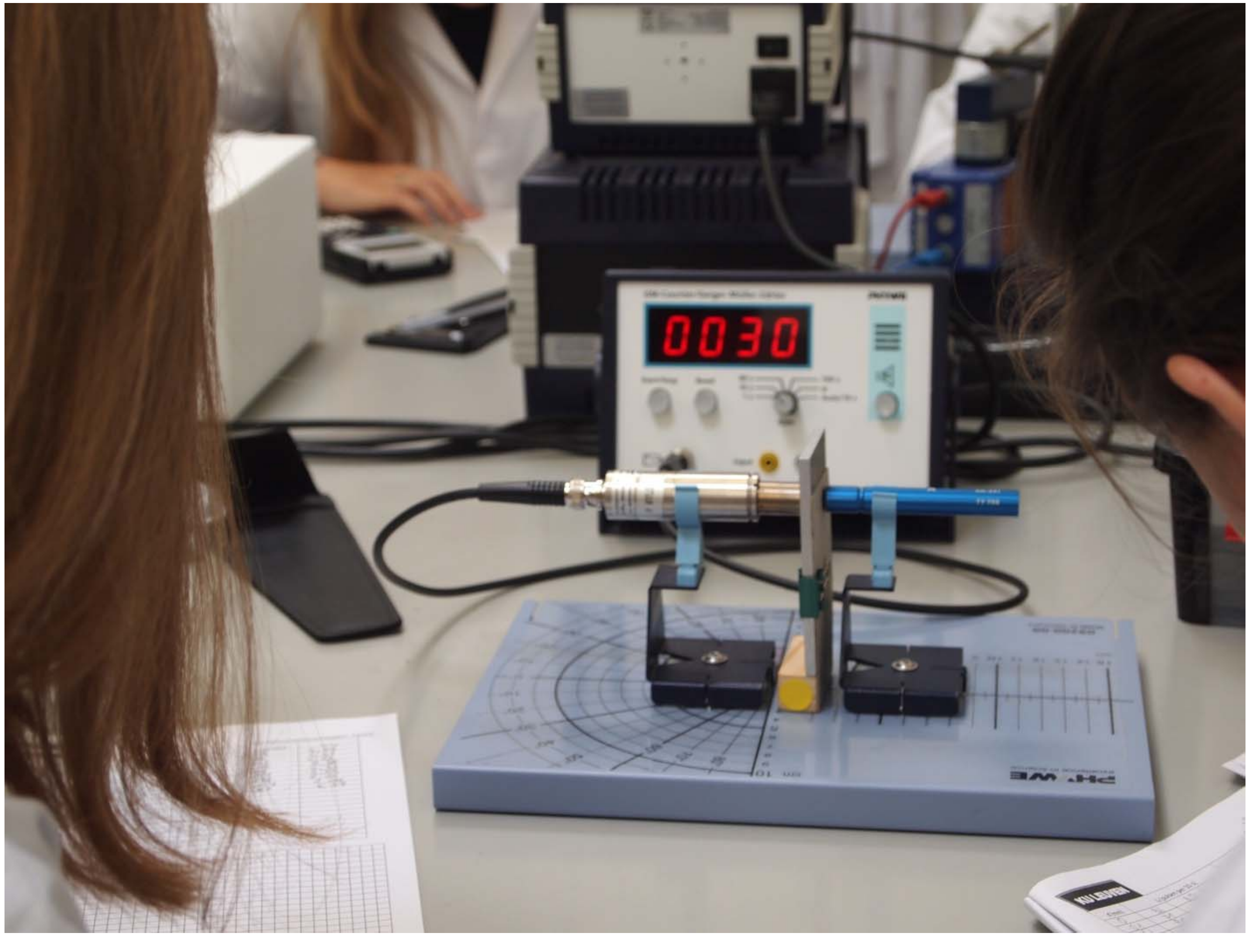


Protection by shielding: absorption of γ-radiation

absorption coefficient μ

half-value thickness $d_{1/2} = \frac{\ln 2}{\mu}$

absorption:
attenuation of γ-rays in lead or in aluminium.



β-energy:

bending of a beam of charged particles in a magnetic field

different behavior of β^+ and β^-

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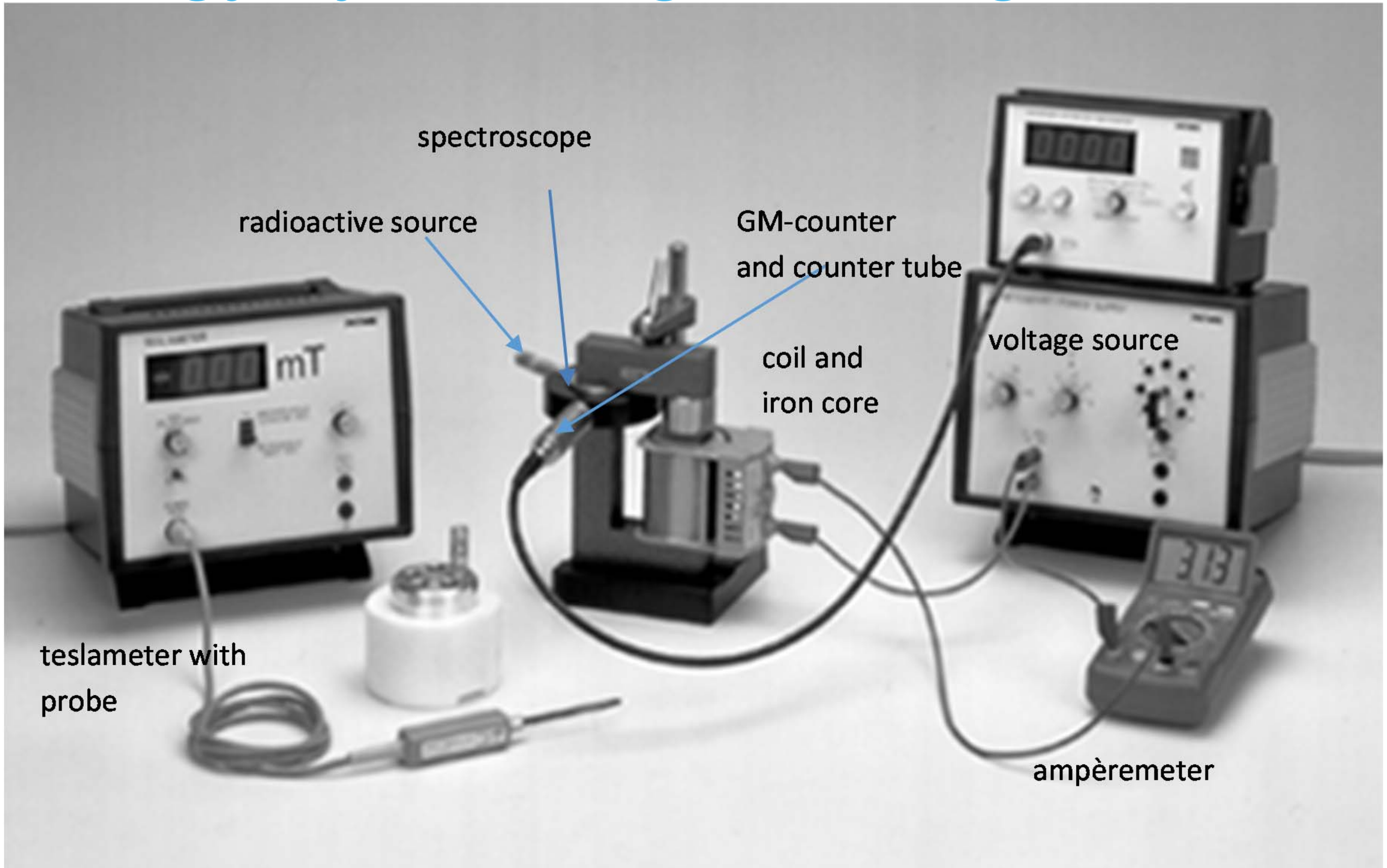
β-energy by bending in a magnetic field



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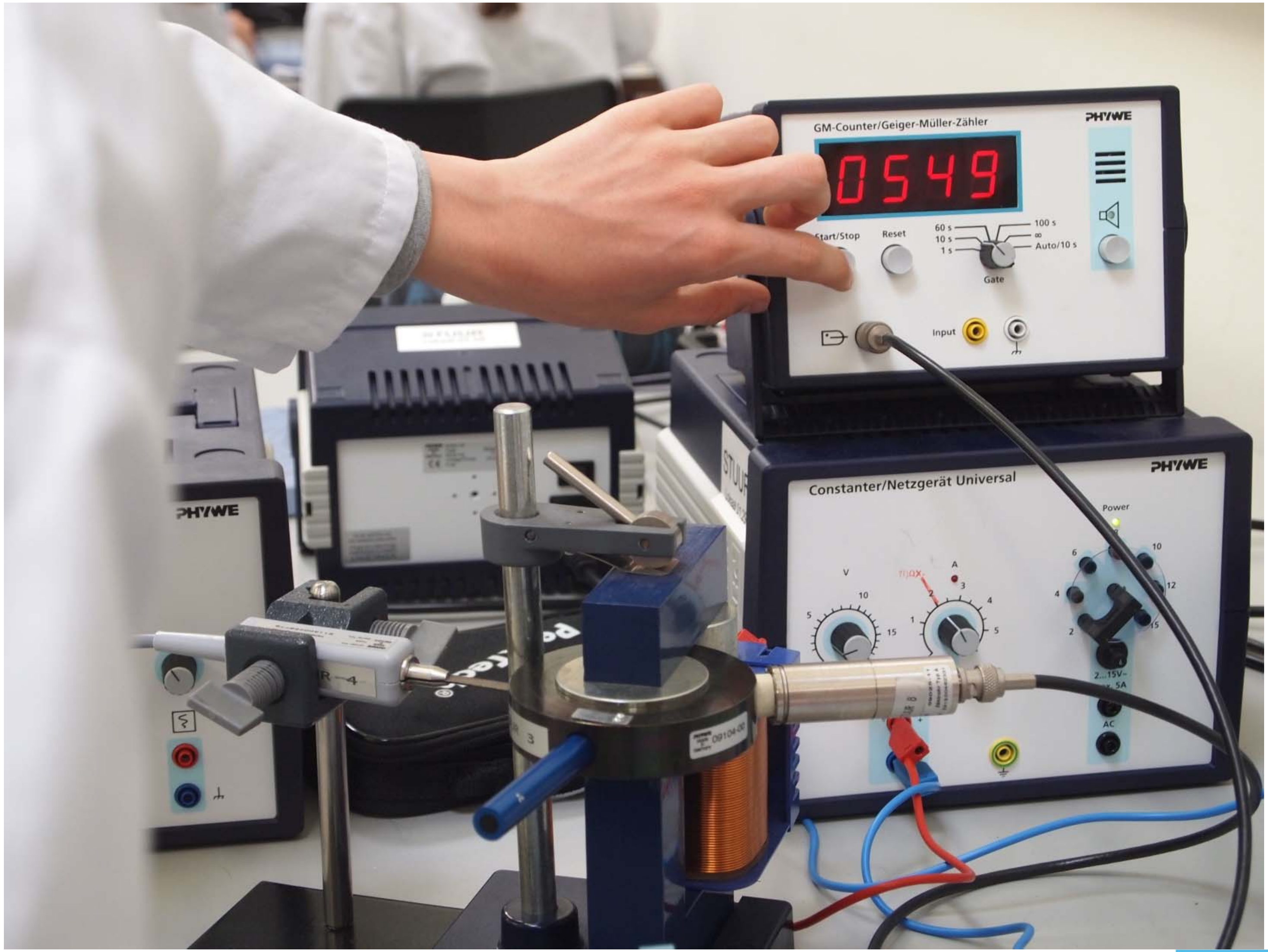
β-energy determined in a magnetic field



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Background radiation values

I_b (p/10s)	8	2	4	$I_{b,average}$	5

Intensities behind chosen absorption sheets

Sr-90	air	thin paper foil	paper sheet	1 mm Al	4 mm Al	4 mm Pb	radiation type(s)
I (p/10s)	4819	4822	4585	1342	11	5	
I (p/10s)	4769	4799	4488	1312	8	9	
I (p/10s)	4779	4808	4418	1295	15	5	
I_{av} (p/10s)	4789	4810	4497	1316	11	6	β^-

Background radiation values

I_b (p/10s)	8	2	4	$I_{b,average}$ (p/10s)	5

Intensities behind chosen absorption sheets

Na-22	air	thin paper foil	paper sheet	1 mm Al	4 mm Al	4 mm Pb	radiation type(s)
I (p/10s)	3418	3303	2121	223	200	174	
I (p/10s)	3459	3295	2157	216	196	189	
I (p/10s)	3422	3336	2147	210	203	184	
I_{av} (p/10s)	3433	3311	2142	216	200	182	β^+, γ

Background radiation values

I_b (p/10s)	8	2	4	$I_{b,average}$ (p/10s)	5

Intensities behind chosen absorption sheets

Am-241	air	thin paper foil	paper sheet	1 mm Al	4 mm Al	4 mm Pb	radiation type(s)
I (p/10s)	3924	111	80	56	33	5	
I (p/10s)	4528	107	109	54	30	1	
I (p/10s)	4370	108	87	54	28	4	
I_{av} (p/10s)	4274	109	92	55	30	3	α, γ

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By performing experiments students realize different goals

- recognition of key features in ionizing radiation:
  - stochastic behavior of ionizing radiation
  - multiple radiation of one source
  - protection by distance
  - protection by absorbers
  - attenuation of γ-rays depending on half-value thickness of materials

By performing experiments students realize different goals

- they learn about ionizing radiation
  - by means of quantitative comparison of radiation intensities
  - produced by closed sources
  - without contamination risks
  - in support of the curriculum
- their understanding is reinforced by practice

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By performing experiments students train different skills

- the use of new devices
- accuracy of measurements
- correction for background radiation
- the need to repeat experiments
- average of repeated measurement results
- relations between measured quantities
- the use of a logarithmic scale

goals we hope to achieve in this project:

- recognition of key features on ionizing radiation
- a better understanding by practice
- dealing on concepts of ionizing radiation
- a better understanding of communication in media
  - to participate in debate
  - to reflect on dangers of radiation
  - to estimate its usefulness in applications

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Results (extra)

Distance

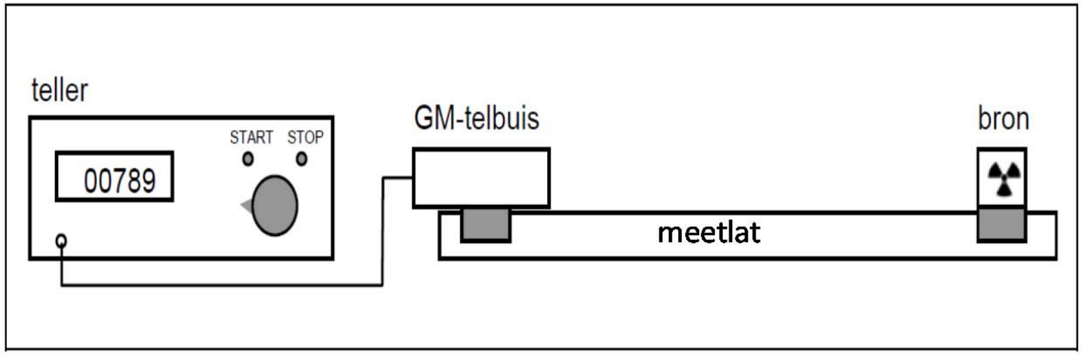
- in Sr-90
- in Co-60
- in Na-22

Absorption

- Gamma radiation of Co-60 in lead
- Beta-minus particles of Sr-90 in different materials:
  - Aluminium
  - Plexiglas
  - Paper sheet

Experiment 8 Radiation intensity and distance

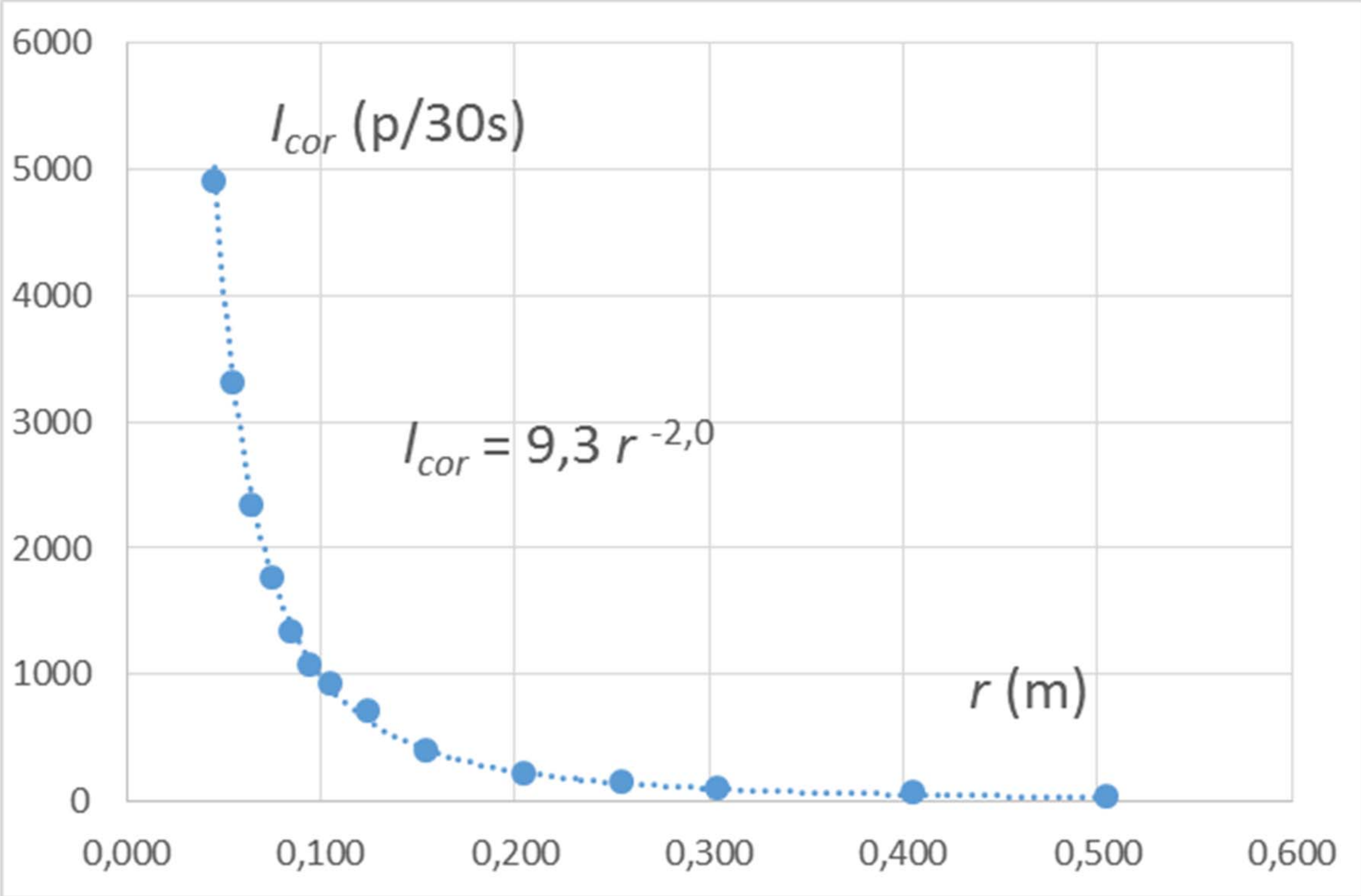
Choose the place to start the distance measurements where the radiation intensity of the source is about 3 times larger than the background radiation. Enter a dozen measurements, each time at a shorter distance from the source in order to cover the whole area between the counter and the source, but not shorter than **4,0 cm!**



Record **the measured distance plus 5 mm** in the table. That's because the radioactive material is placed 4 mm deep in the source and the window of the counter tube is situated 1 mm deeper than the edge of the tube.

Record three times the radiation intensity I_1, I_2 en I_3 **(in pulses per 10 s)** at each chosen distance r between the source and the counter tube. The sum of these three measurements gives the intensity I **(in pulses per 30 s)**.

Results for Sr-90



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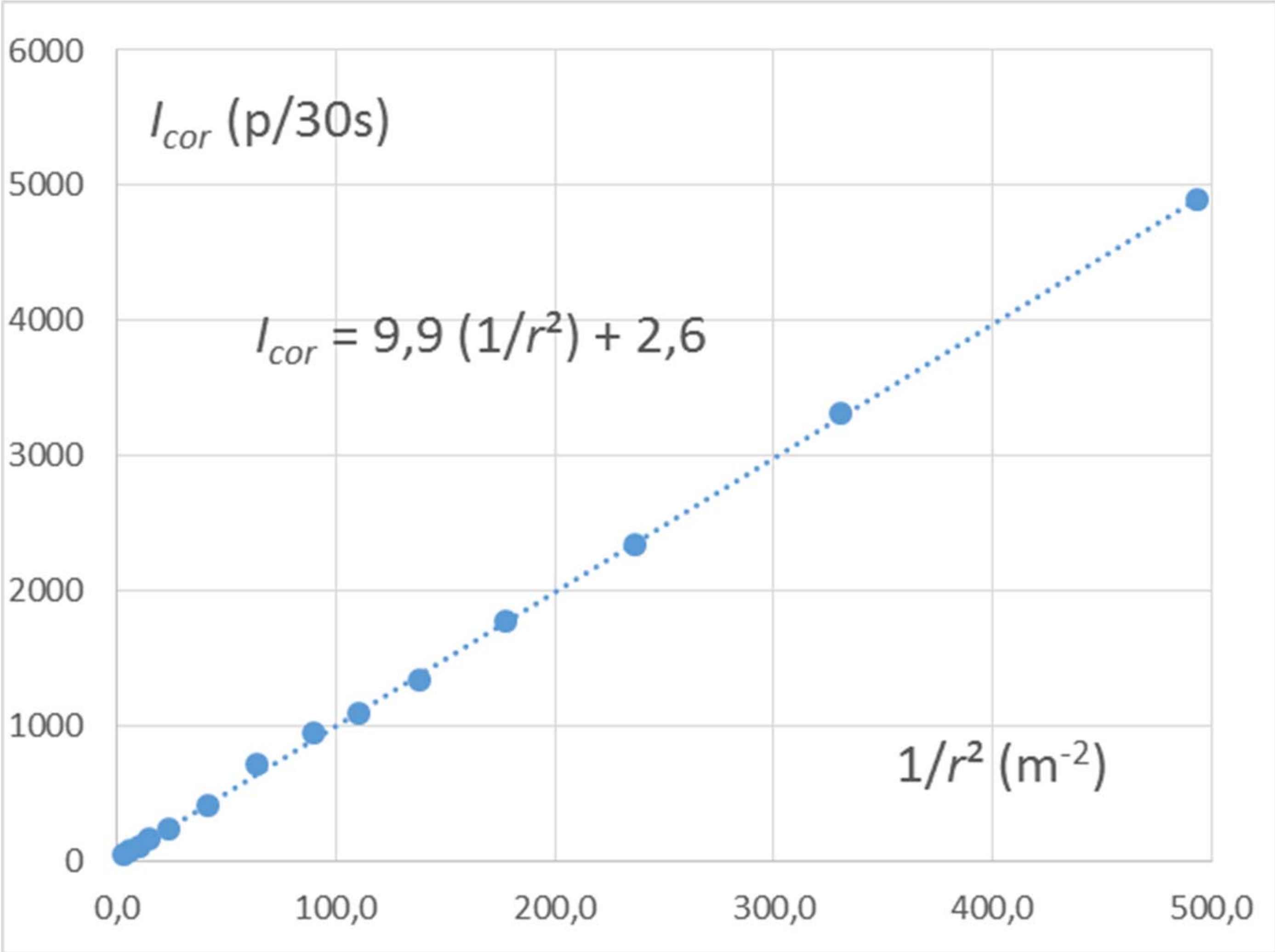
Results for Sr-90



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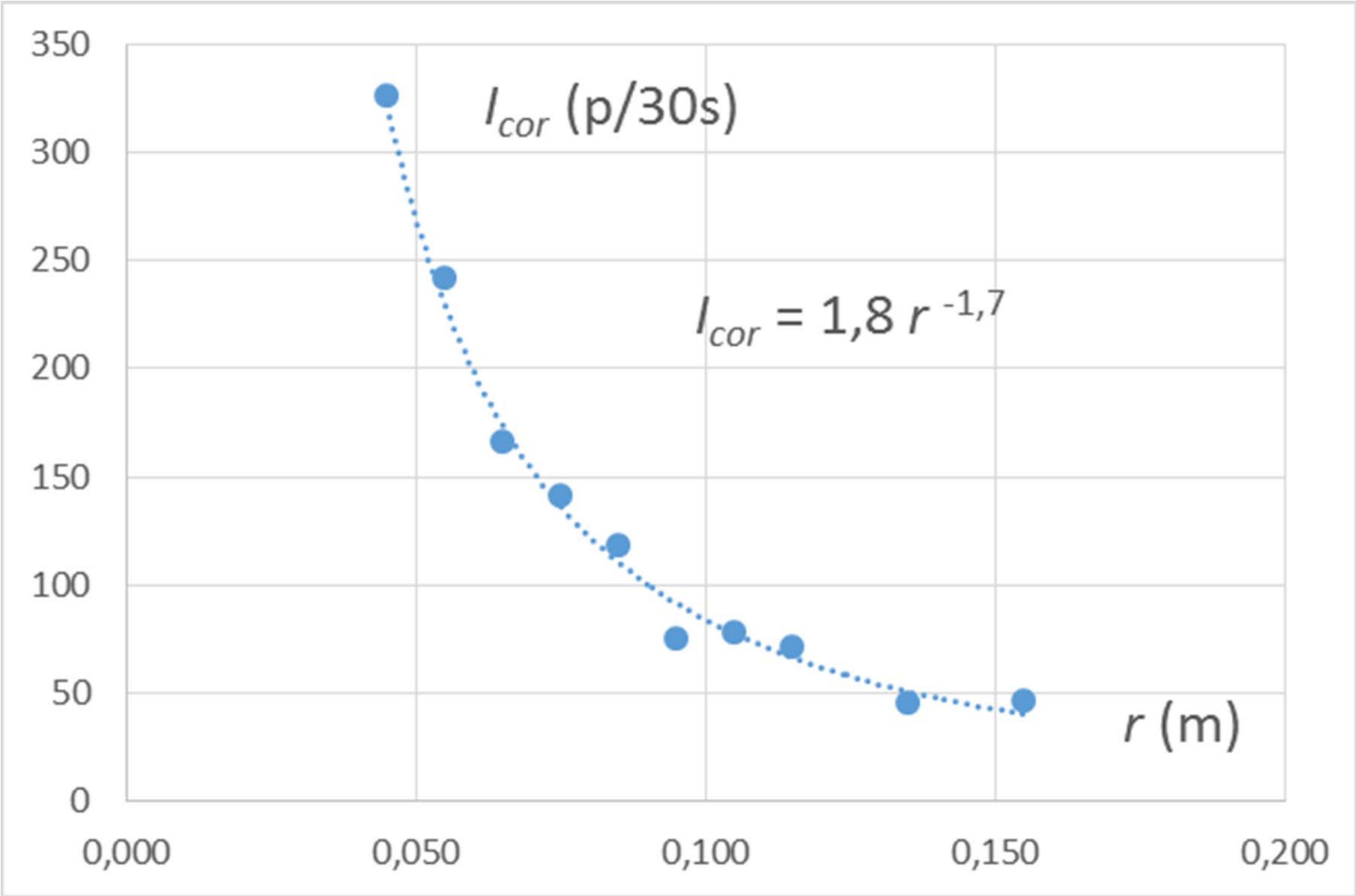
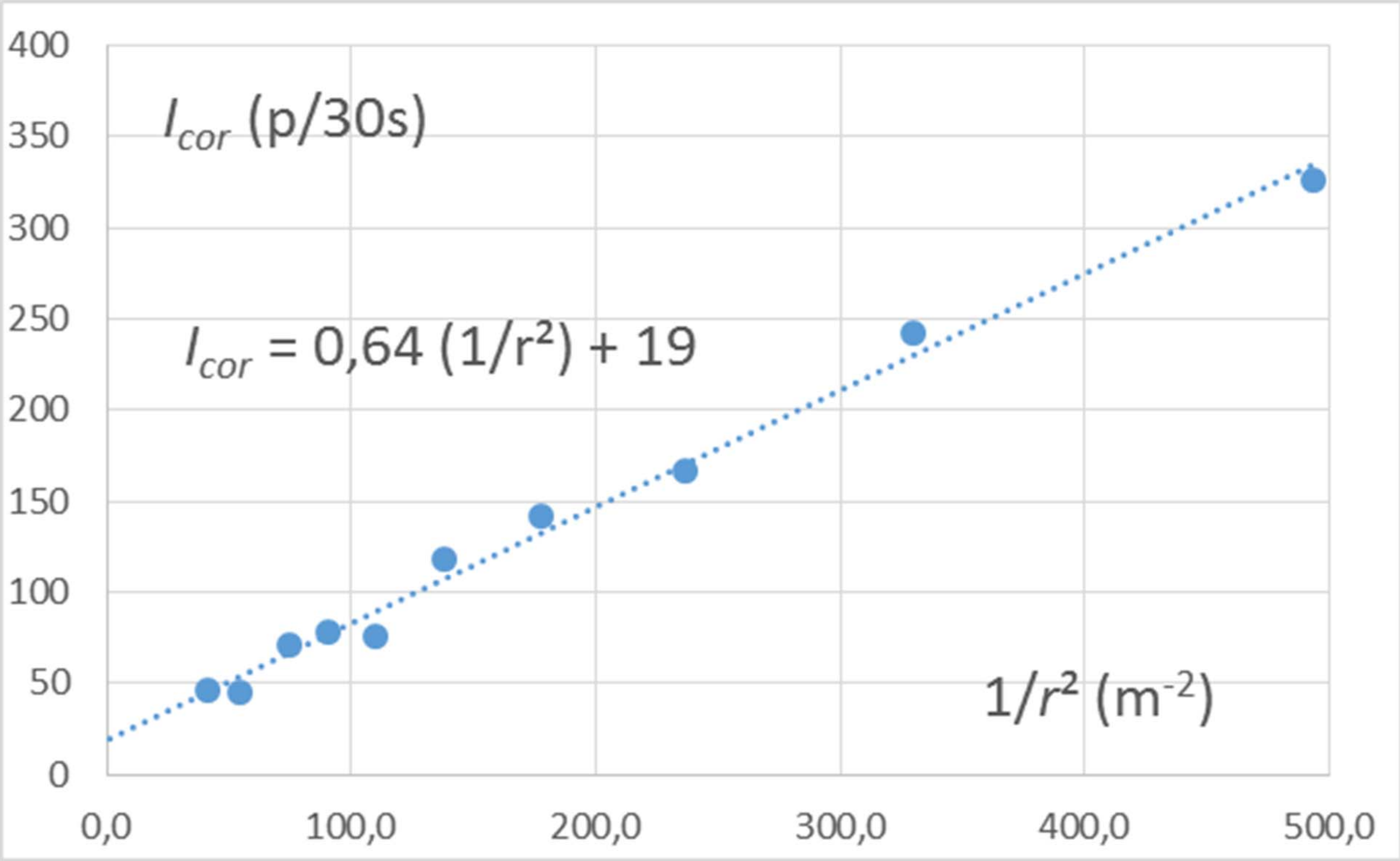
Results for Co-60



Results for Co-60



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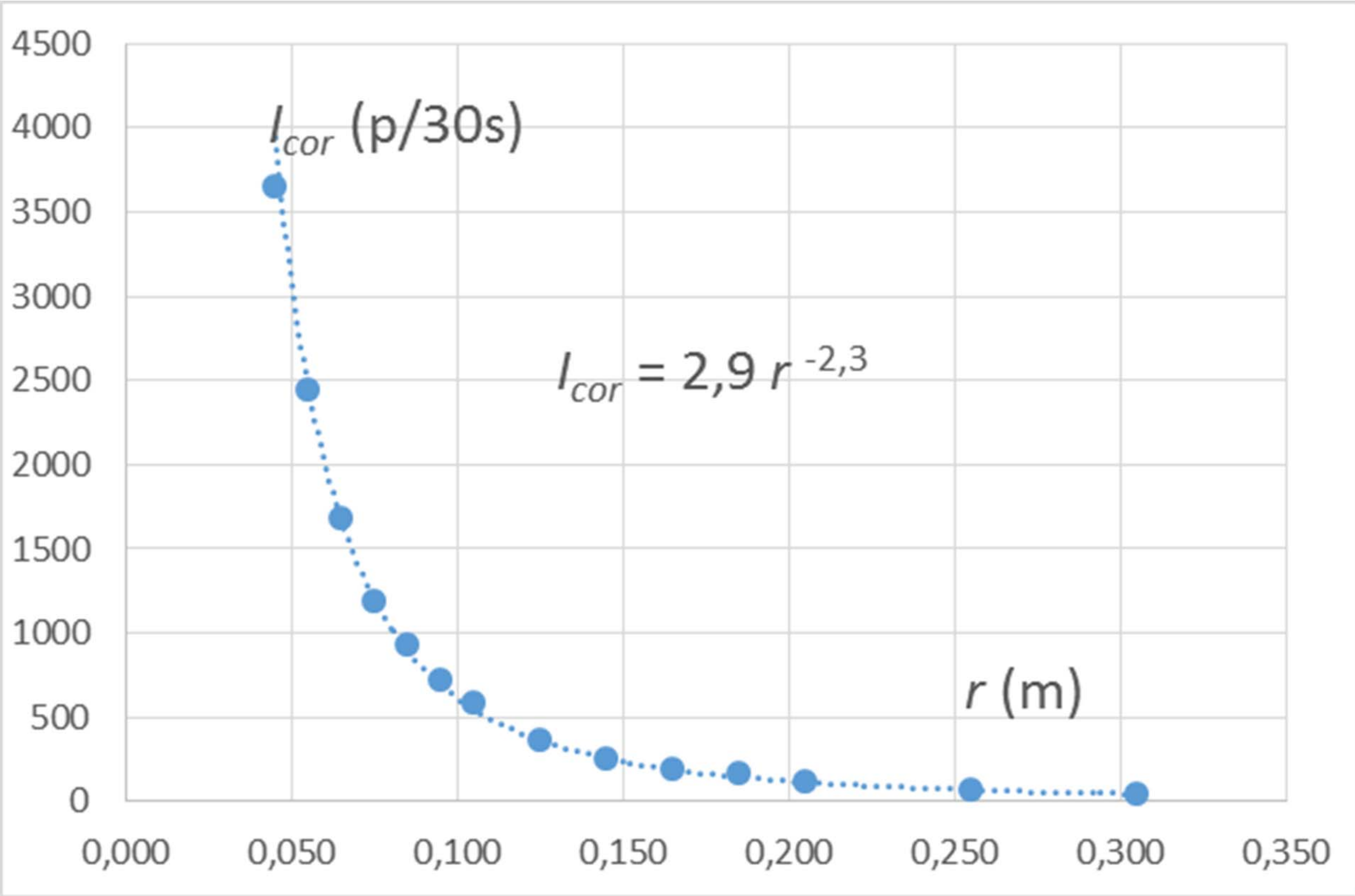
Results for Na-22



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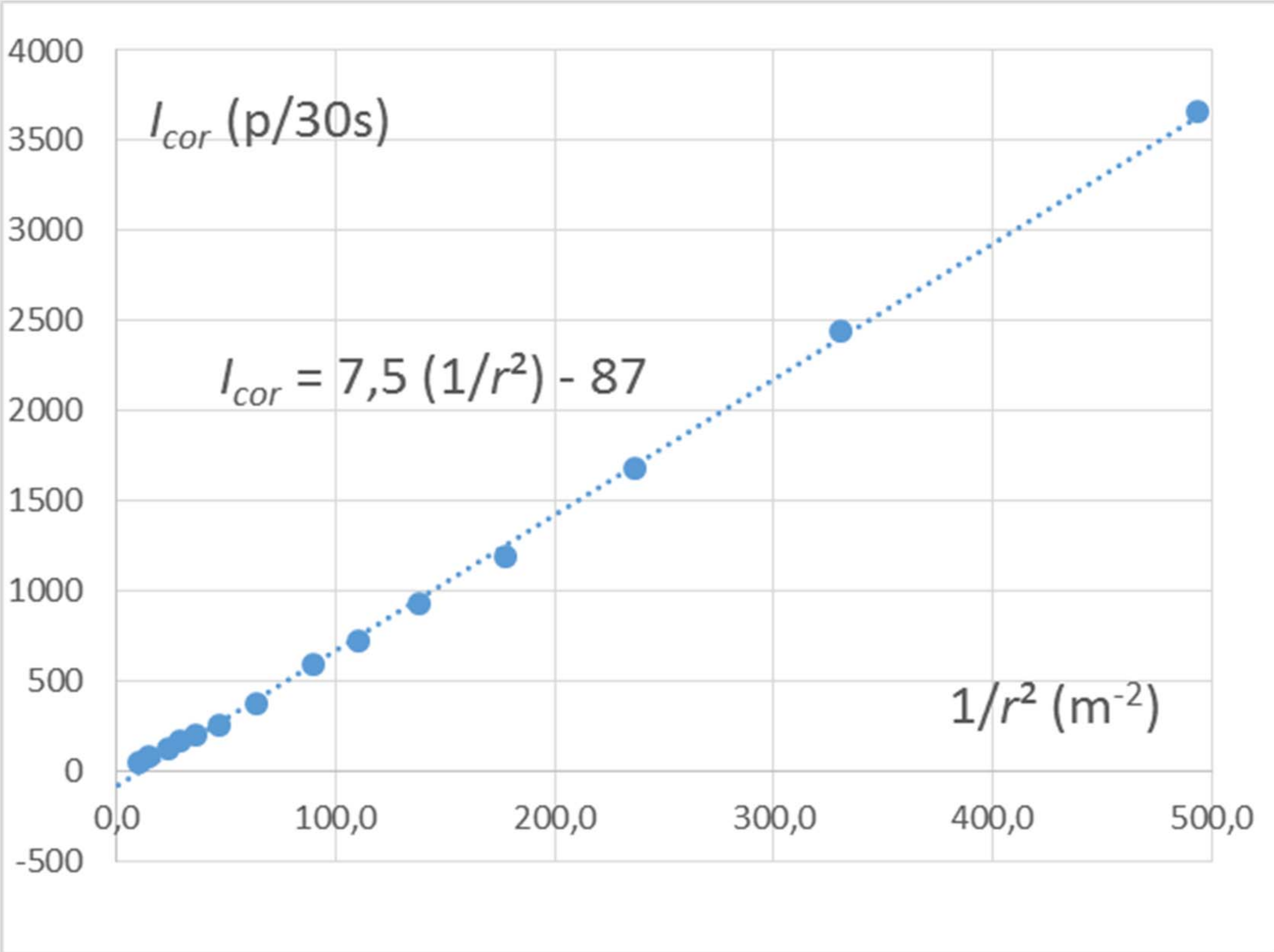
Results for Na-22



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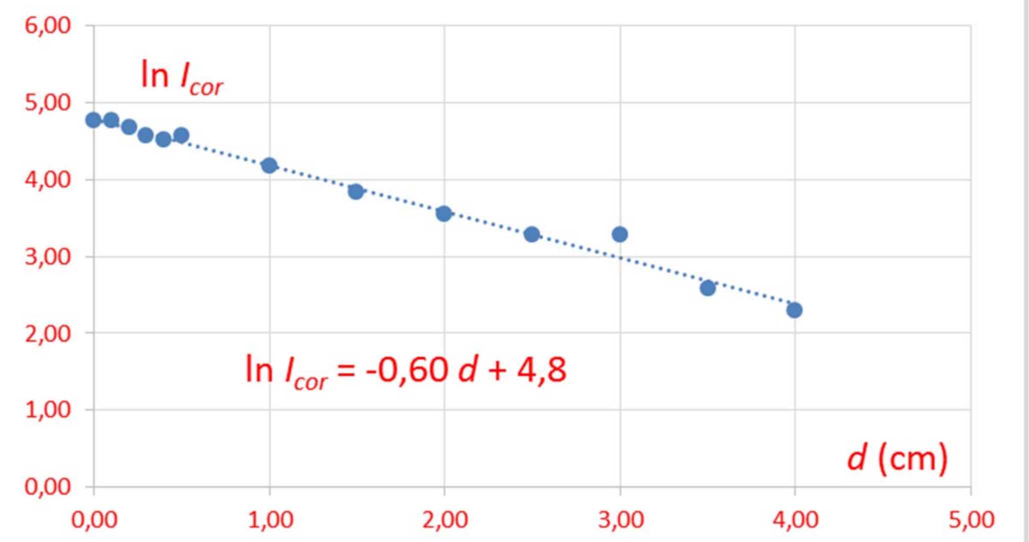
Experiment 12 Absorption of γ-radiation produced by Co-60 in lead

Measure the **thickness** *d* of lead sheets of increasing thickness. Measure three times the **intensity** I_d of the pass through radiation (in p/10 s) and calculate the **average intensity** I_{av}. Correct for the **background radiation**. Make a graph of the natural logarithm of the I_{cor} intensity as a function of the thickness *d* of the absorption sheets. Draw a line through the measuring points average and determine the slope of that line. This is the **absorption coefficient** µ of γ-radiation of lead for Co-60. Calculate the **half-value thickness** $d_{1/2}$ of lead for Co-60. The half-thickness and absorption coefficient are inversely proportional.

Results

The absorption coefficient of lead is µ= 0,60 cm^{-1} and the half-value thickness is $d_{1/2} = \frac{ln\,2}{\mu}$ = 1,2 cm for the γ-radiation of cobalt-60



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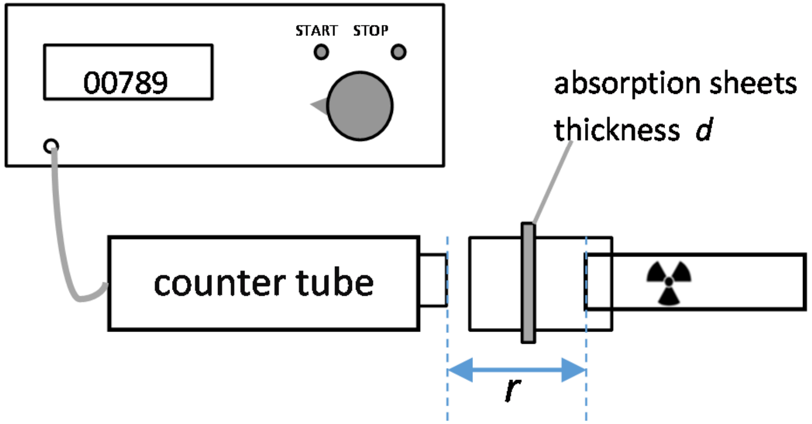
Experiment 5 Absorption of β⁻-particles in materials

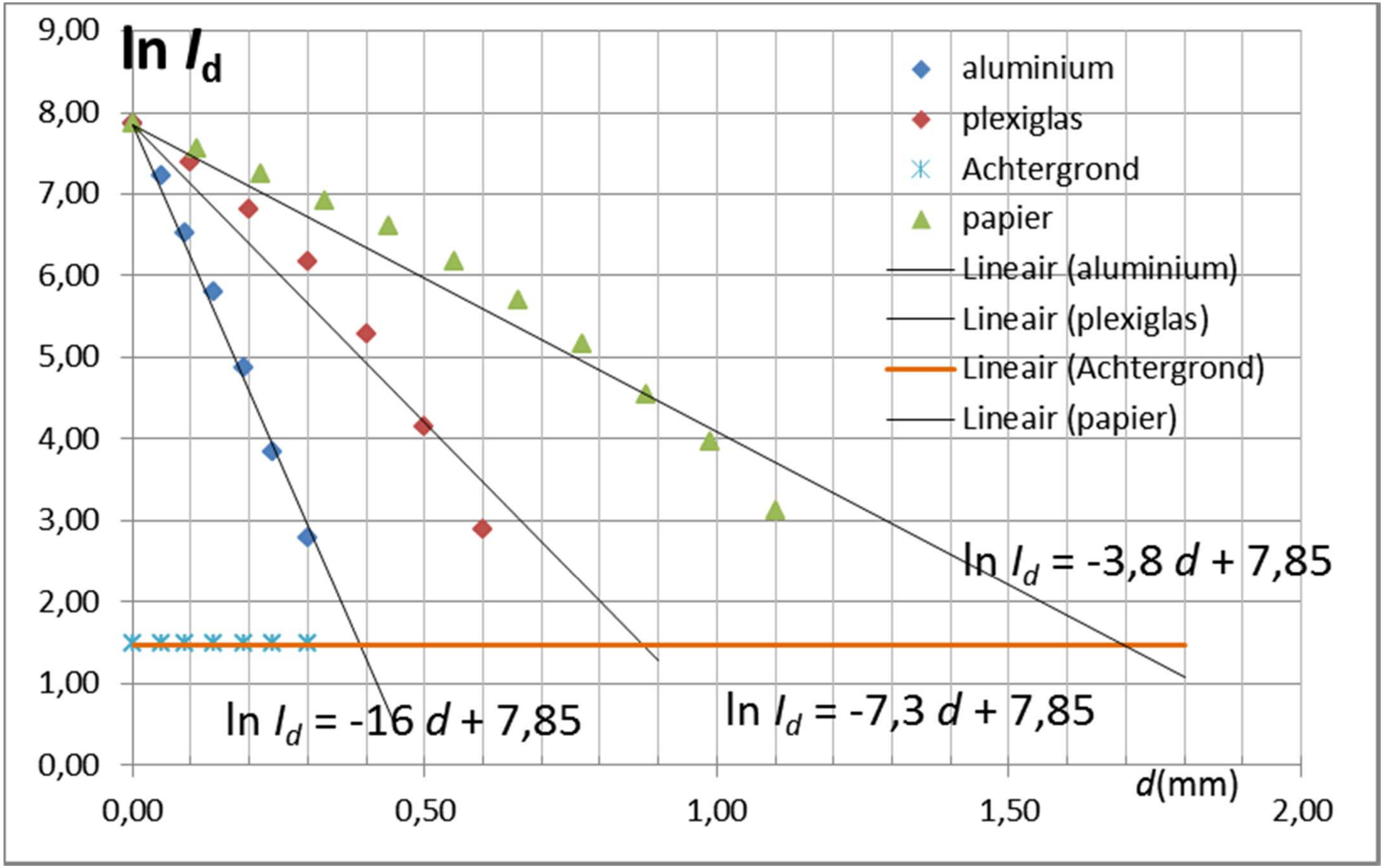
The setup consists of a Geiger-Müller counter-tube with pulse counter. The counter-tube is on a straight line towards the **strontium-90** source, on a fixed distance *r*. Absorption sheets of different thicknesses *d* are clamped in a holder between the source and the tube.



Make a graph of the natural logarithm of the intensity I_d as a function of the thickness *d* of the absorption sheets for three different materials (aluminium, Plexiglas and paper).

Does the linear course of the graphs be confirmed? Draw a line through the measuring points average and determine the slope of each line. Determine the values of the corresponding absorption coefficients.

Calculate for the three materials a value for the **range *R***. The product of R and the density ρ is the **universal range R_u** for the β-rays produced in a strontium-90 source.


ln I_d
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
0,00
0,50
1,00
1,50
2,00
d(mm)
aluminium
plexiglas
Achtergrond
papier
Lineair (aluminium)
Lineair (plexiglas)
Lineair (Achtergrond)
Lineair (papier)
ln I_d = -3,8 d + 7,85
ln I_d = -16 d + 7,85
ln I_d = -7,3 d + 7,85

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Results for a strontium-90 source
4 mm aluminium stops beta$^-$ radiation in Sr-90

Range *R* depends on density ρ	aluminium	plexiglas	paper	average
R (cm)	0,38	0,86	1,7	/
$R_u = R \cdot \rho$ (g/cm²)	1,0	1,0	1,1	1,0

Deduction for other materials enquiry learning element or class-discussion

	human tissue or water	glass	MDF-wood	hardboard
Density (g/cm^3)	1,00	2,55 g/cm^3	0,78 g/cm^3	1,34 g/cm^3
$R = \frac{R_u}{\rho}$ (cm)	1,0	0,41	1,3	0,72