HOCHSCHULE RHEINMAIN

PHYSICS LAB 3

Experiment P3-1
GEIGER-MUELLER-Tube

Authors

CIHAN ÜNLÜ

DENNIS HUNTER

SEBASTIAN KRESS

DEPARTMENT OF ENGINEERING

APPLIED PHYSICS & MEDICAL TECHNOLOGY

Date of experiment:	November 17, 2020; November 24, 2020
Date of submission:	December 1, 2020

Contents

1 Introduction

Aim of this experiment is to examin the statistical characteristics of radioactive decay as well as comparing the expected with the actual behavior of the core component - the GEIGER-MÜLLER-Tube (GMT).
A GMT is a device to detect and quantify radiation by counting induced ionization events inside its volume. The nature of the GMT does not allow to distinguish between types of sources of ionization directly (i.e. α-, β- or γ-radiation).

1.1 Half-life time

Radioactive decay is a statistical process. According to quantum physics it is impossible to predict the life span of a single atom. Given a significantly large number of atoms one can state the overall time until half of the nuclei present at t_0 did disintegrate. Thus, for each radioactive nuclide one can describe a characteristical mean lifespan τ[1][2].
Mathmatically speaking, the amount of decayed radio-nuclides after a time t can be described as eq. (1.1).

$$\dot{N}(t) = -\tau N(t) \quad \Leftrightarrow \quad N(t) = N_0 e^{-t/\tau} \tag{1.1}$$

If $\frac{1}{2}N_0 = N(t)$ is inserted in above equation and solved in terms of the time t one gets the half-life $T_{1/2}$ with

$$T_{1/2} = \frac{\ln 2}{\tau} \tag{1.2}$$

1.2 GMT-characteristics

The GMT's principle of operation is based around the phenomenon called TOWNSEND-discharge. If the seperated particles after an ionising event are left with enough kinetic energy, they become ionising themself striking surrounding atoms. This releases a cascade of free electrons and positive nuclei according to fig. 1.1. To prevent the e^- to recombine before they reach the anode the accelerating voltage needs to be high

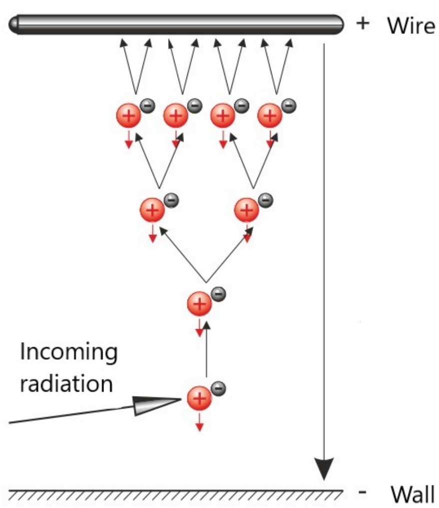


Figure 1.1: A single ionising event releases an avalanche of free electrons. These - fast enough accelerated toward the anode - form a pulse that can be further processed [1].

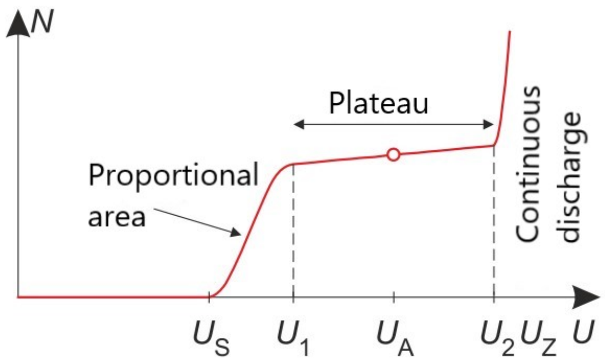


Figure 1.2: The characteristical curve of a GM-Tube. At a onset-voltage U_S the count rate is rapidly rising (plateau area). A certain voltage-range is considered the working area (plateau). Further increase of the acceleration voltage leads to a second steep rise of counts (continuous discharge) [1].

enough. On the other hand a voltage too high leads to spontanious self discharge of the inert gas. A rapid rise of counts can be observed covering the actual ionisation events. While the preceding avalanche is not yet expired a new event will produce no pulses, hence, no counts can be measured. This dead time is usually within the range of 10^{-4} s. Still, the sensitivity of the GMT does not instantaniously recover to full potential. Instead, for another period of time ongoing pules will gradually rise in magnitude until reaching there original (maximum) level. In consequence some pulses may be too small for the downstream amplifying electronics to trigger ultimately leading to undesired false-negatives i.e. too low count rate in a highly radiating environment.

1.3 Stochastic principles

Since radioactive decay is a stochastic process, some usefull mathmatic principles need to be discussed.

1.3.1 Binomial distribution

A random experiment with only *two mutually exclusive* results is called *Bernoulli-experiment*[3]

Given an event has only two possible outcomes - A or $\bar{A}$ - with the individual propabilities $p(A) = 1 - p(\bar{A})$ one can express the propability P for k successive events A within n repetitions as follows:

$$P(k) = \binom{n}{k} \cdot p(A)^k \cdot p(\bar{A})^{n-k} \tag{1.3}$$

Accordingly, the propability for $k \leq x$ outcomes is expressed as

$$P(k \leq x) = \sum_{k \leq x} \binom{n}{k} p(A)^k \cdot (1 - p(A))^{n-k} \tag{1.4}$$

In other words: summing up all possibilities $k \in 1, ..., x$

2 Set-up of experiment

3 Execution

3.1 GMT Characteristics

In this experiment the characteristics of the Geiger-Müller tube are investigated. For this purpose, the protective cap is first removed from the mica window. The radioactive sample is then removed from its protective enclosure and clamped in the holder provided on the mounting plate. The distance between the front edge of the radioactive sample and the front edge of the Geiger-Müller tube is set to $d = 5\,\mathrm{cm}$. For this purpose, a steel ruler is used as displayed in the lab. If not already done, connect the probe to the test point and ground and switch on the oscilloscope. It is adjusted so that it triggers correctly. The rotary wheel of the potentiometer is turned to center position. The vertical scaling on the oscilloscope is changed so that an observed peak maxes out the height of the screen to allow a more accurate reading. The oscillogram is photographed for documentation purposes.
The potentiometer is now turned to the counter-clockwise stop. This corresponds to $U_{GMT} = 200\,\mathrm{V}$. The LCD does not yet show any counts at this voltage. The potentiometer is turned up in appropiate increments and the registered counts are recorded as shown on the LCD. The step size is adjusted accordingly. A small step size is selected for the range in which the number of pulses increases sharply. A large step size is selected on the plateau. The size of the steps used can be taken from the tab / graph **??**. U_{Start} is the voltage at which the first pulse can be detected on the oscilloscope.

3.2 Angular Dependency of the Count Rate

To investigate the influence of the alignment of the GMT, it is set to a distance of $d = 5\,\mathrm{cm}$ from the radioactive source. Locking points are already provided on the mounting plate in the range $-45°$ to $+45°$ with increments of $15°$ each. The radioactive sample remains untouched throughout the entire experiment. The GMT is inserted into the various locking points one after the other while keeping aligned to the marks on the mounting plate hence facing the mica window toward the radioactive sample. In each position 12 samples are taken with a fixed capture time of $10\,\mathrm{s}$ each.

3.3 Absorption Characteristics of Materials

In this experiment the shielding effect of different samples is investigated. For this purpose the GMT is aligned in $10°$ position. There is a slot on the mounting plate into which the test materials can be inserted. The materials are:

1. Aluminium
2. Lead
3. Tin
4. Acylic glass
5. Cardboard

The thickness of the materials is $2\,\mathrm{mm}$ each. For every material 12 measurements are taken.

3.4 Counting Statistics

For this experiment it is useful to achieve a high count rate. The GMT is placed back in $0°$ position. This time the distance is reduced to $d = 1\,\mathrm{cm}$. To increase the counting rate of the GMT the voltage is increased. A voltage of $U_{GMT} = 500\,\mathrm{V}$ is used as this voltage should lie within the working area of the GMT. 90 measurements are taken.

3.5 Background Radiation

To measure the background radiation, the experiment described in section 3.4 is repeated. Unlike before, this time the radioactive source is removed and brought back into the protective vessel.

3.6 Natural Radioactivity

The radioactivity of Brazil nuts is investigated. For this purpose a beaker is filled with Brazil nuts and the GMT is carefully inserted into the glass with the mica window facing the nuts. 90 measurements are recorded with the voltage remaining $U_{GMT} = 500\,\mathrm{V}$

4 Evaluation

4.1 GMT characteristics

4.1.1 Characteristic values of the oscilloscope

The signal of the GMT can be seen on the oscilloscope screen (s. fig.1-5). fig.1 shows us the zero level U_0 and the amplitude $\hat{U}$:

$$U_0 = 24\,\mathrm{mV} \pm 40\,\mathrm{mV} \tag{4.1}$$
$$\hat{U} = 1,56\,\mathrm{V} \pm 0,04\,\mathrm{V} \tag{4.2}$$

Further there can be read off the fall time t_f (fig.2), rise time t_r (fig.3), the pulse width t_p (fig.4) and recovery time t_r (fig.5):

$$t_f = 56\,\mu\mathrm{s} \pm 20\,\mu\mathrm{s} \tag{4.3}$$
$$t_r = 228\,\mu\mathrm{s} \pm 20\,\mu\mathrm{s} \tag{4.4}$$
$$t_p = 108\,\mu\mathrm{s} \pm 20\,\mu\mathrm{s} \tag{4.5}$$
$$t_{re} = 288\,\mu\mathrm{s} \pm 20\,\mu\mathrm{s} \tag{4.6}$$

4.1.2 Characteristic curve of the GMT

After determining the starting voltage U_{start} to $U_{start} = 328\,\mathrm{V}$, the characteristic curve has been recorded by measuring the count rate over 100 seconds for each step-by-step-increased voltage. The calculated mean value of the count rate has been plotted versus the mean voltage by SciDAVis:

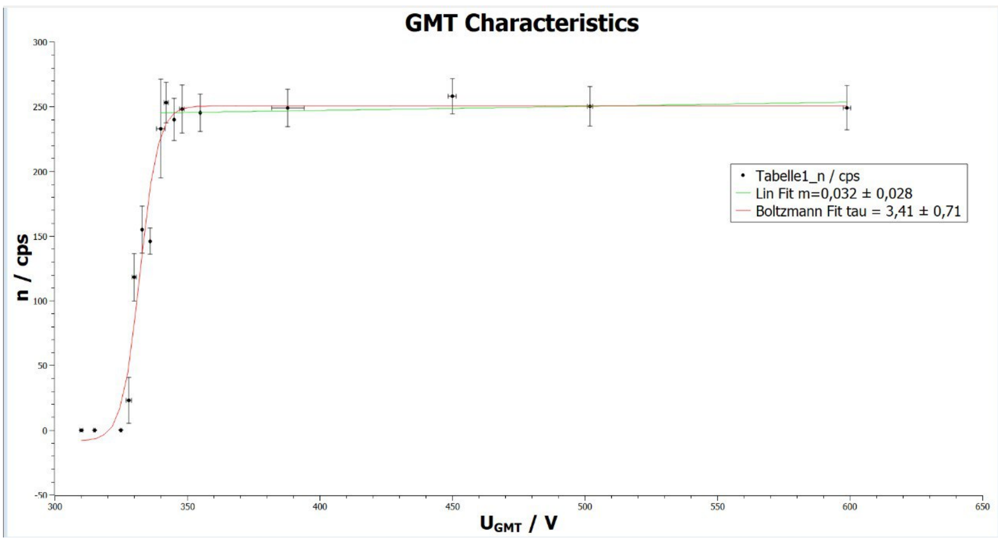


Figure 4.1: Plot characterising the operating GMT.

The relative slope in the plateau area is determined to $m = (3,2 \pm 2,8)\frac{\%}{100\,\mathrm{V}}$ by SciDAVis.
The optimum working voltage U_{opt} is determined to $U_{opt} = 500\,\mathrm{V}$, since the maximum possible adjustable voltage of $U_{GMT} = 600\,\mathrm{V}$ is still in the plateau area, which starts at $U_{GMT} = 340\,\mathrm{V}$.

4.2 Angular dependency of the count rate

To examine the angular dependency of the count rate the angle of the tube has been varied from $-45°$ to $+45°$ in $15°$ steps. After measuring the count rate at the optimum working voltage of $U_{opt} = 500\,\mathrm{V}$ and calculating the mean value of the 12 count rates of each angle, the count rate was output versus angle by SciDAVis:

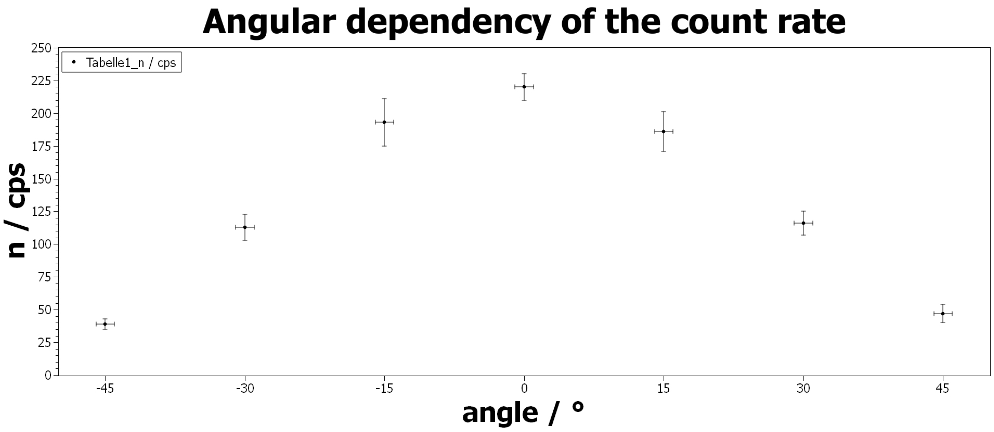


Figure 4.2: Angular dependency of the measured count rate.

4.3 Absorption characteristics of materials

For investigating the absorption characteristics of materials the count rate has been measured 12 times at $U_{opt} = 500\,\mathrm{V}$ for different materials (thickness $= 2\,\mathrm{mm}$) in front of the tube:

no absorbing material:	$n = 221\,\mathrm{cps} \pm 11\,\mathrm{cps}$	(4.7)
Aluminum (Al):	$n = 10\,\mathrm{cps} \pm 4\,\mathrm{cps}$	(4.8)
Lead (Pb):	$n = 7\,\mathrm{cps} \pm 2\,\mathrm{cps}$	(4.9)
Tin (Sn):	$n = 6\,\mathrm{cps} \pm 2\,\mathrm{cps}$	(4.10)
Acrylic glass:	$n = 26\,\mathrm{cps} \pm 5\,\mathrm{cps}$	(4.11)
Cardboard:	$n = 104\,\mathrm{cps} \pm 8\,\mathrm{cps}$	(4.12)

The explanation for the different absorption of the different materials is the mass attenuation coefficient of the different materials. The mass attenuation coefficient is dependent on the material density ρ and the attenuation coefficient μ. Since the attenuation coefficient depends on the atomic number, the size of the atom does matter. The reason why there is happening an attenuation is because of the α-, β- and γ-rays are interacting with the material atoms. While the α- and β-rays have a strong interaction with the material, γ-rays have better penetration due to less likeliness to interact. The smaller the half-value layer of a material the weaker the penetration. With lead ($^{82}\mathrm{Pb}$) and Tin ($^{50}\mathrm{Sn}$) and presumably Aluminum ($^{13}\mathrm{Al}$) as well almost all rays are absorbed (dependent on the ray energy). Acrylic glass can probably be traversed by the γ-rays. Due to there size already a thin sheet of cardboard is sufficient to absorbed α-ray particles almost entirely.

4.4 Counting statistics

For examining the statistics, 90 measurements were taken at a distance of $1\,\mathrm{cm}$ and a voltage of $U_{opt} = 500\,\mathrm{V}$. The following values for mean $\bar{n}$, variance σ^2 and standard deviation σ were obtained:

$$\bar{n} = 4327\,\mathrm{cps} \tag{4.13}$$
$$\sigma^2 = 4168\,(\mathrm{cps})^2 \tag{4.14}$$
$$\sigma = 65\,\mathrm{cps} \tag{4.15}$$

The measurement series results a scatter plot in SciDAVis: A histogram made with SciDAVis shows the

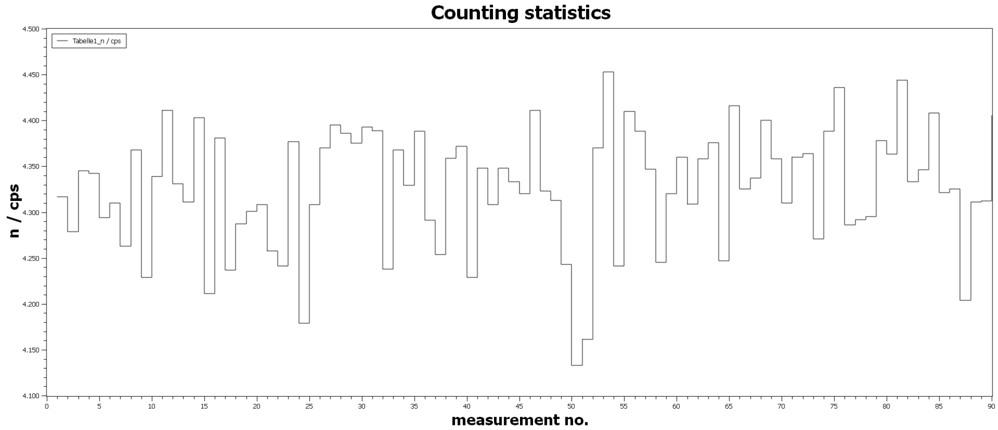


Figure 4.3: Counting statistics.

distribution of the measures: With radioactive decay it cannot be said which atom will decay when. Since it

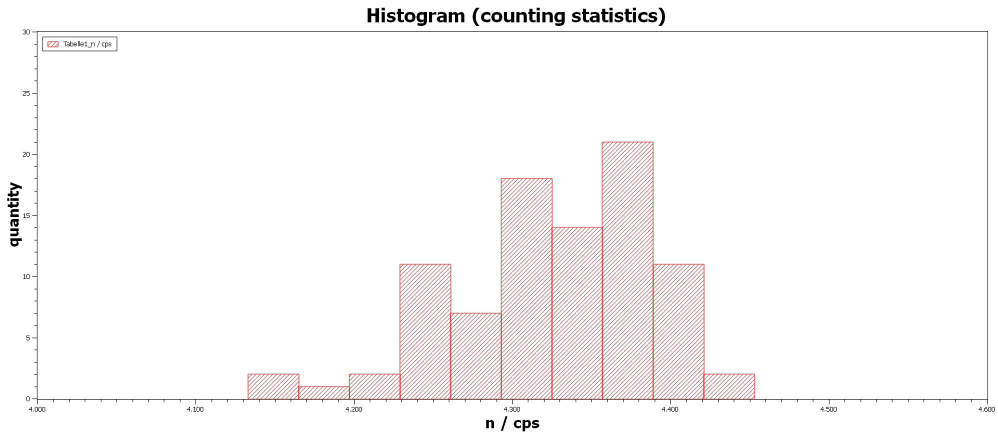


Figure 4.4: Count. Stats histogram.

is a statistical process, the histogram can be described with a Poisson-distribution.

4.5 Background radiation

To investigate the background radiation the count rate was measured 90 times with no radiation source at a voltage of $U_{opt} = 500\,\mathrm{V}$. The measurement stats are:

$$\bar{n} = 3\,\mathrm{cps} \tag{4.16}$$
$$\sigma^2 = 20\,(\mathrm{cps})^2 \tag{4.17}$$
$$\sigma = 4\,\mathrm{cps} \tag{4.18}$$

The measurement number was plotted versus the count rate by SciDAVis: The associated distribution his-

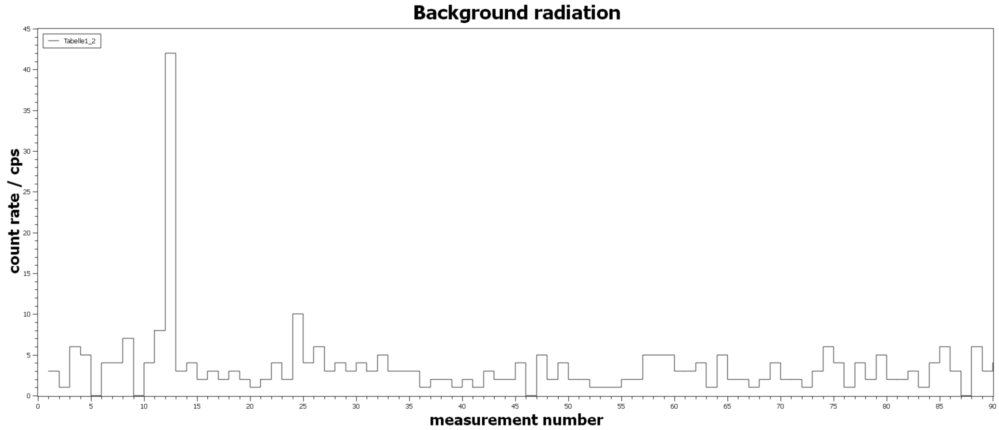


Figure 4.5: Measured counts caused by natural background radiation.

togram was drawn by SciDAVis: This histogram can also be described by a Poisson-distribution for the

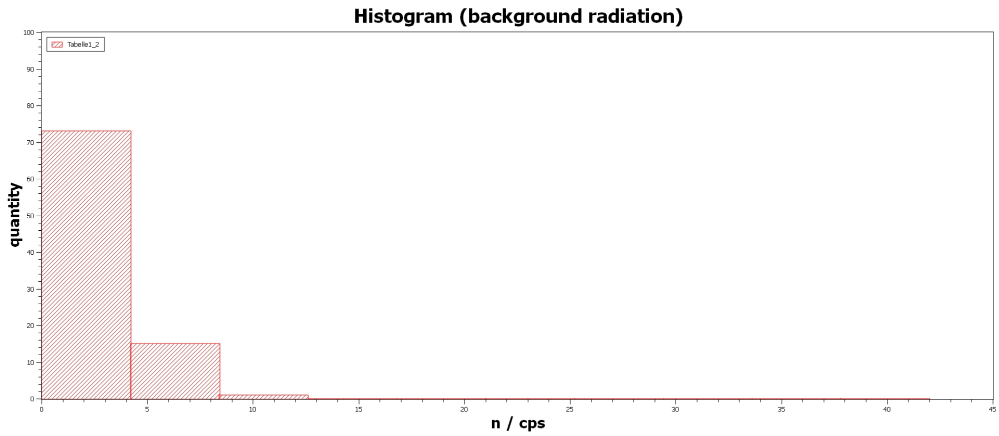


Figure 4.6: Background Radiation Histogram.

same reason as histogram of the counting statistics.

4.6 Natural radioactivity

The radioactivity of a package Brazil nuts should have been determined by measuring the count rate. For that the GMT was put in a beaker filled with Brazil nuts for 900 seconds at $U_{opt} = 500\,\mathrm{V}$.
The mean value of $\bar{n} = 3\,\mathrm{cps}$ indicates that the radioactivity of the Brazil nuts is very weak because it has the same mean value as the background radiation. However, this does not have to mean that the Brazil nuts do not emit any radiation. Because the tube was very close to the nuts, the background radiation could not pass directly through the nuts, which implies that the rest of the radiation must have come from the Brazil nuts.

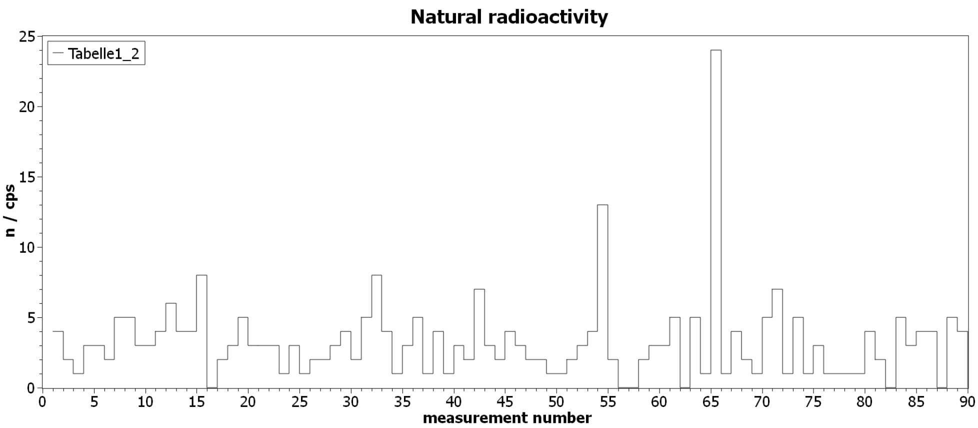


Figure 4.7: Lots of Brazil Nuts.

5 Conclusion

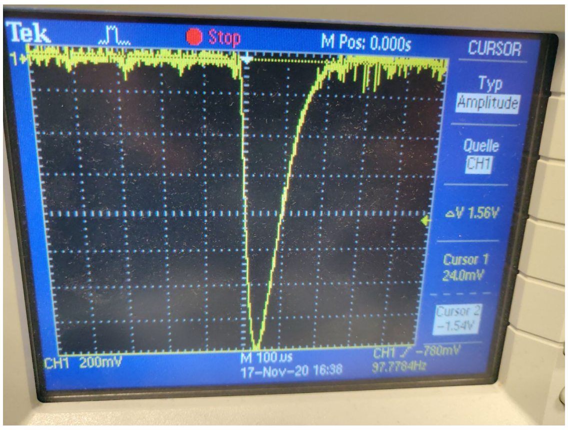
List of Figures

List of Tables

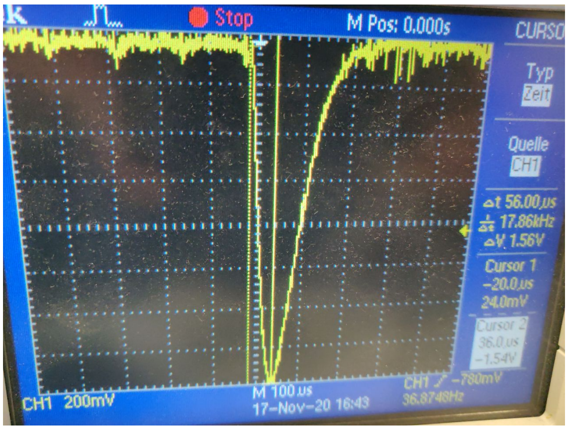
Glossary

s Strahlweg

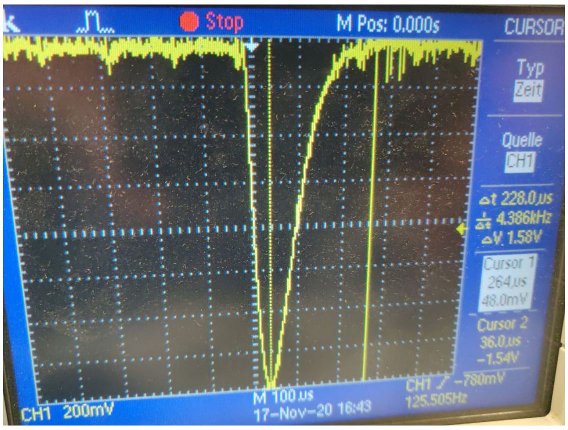
A Appendix



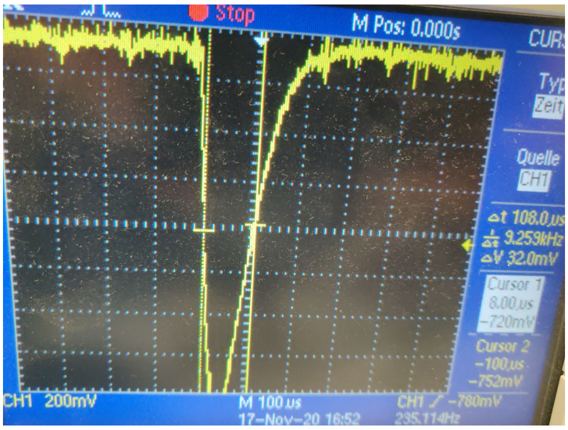
(a) *Amplitude* $\hat{U}$



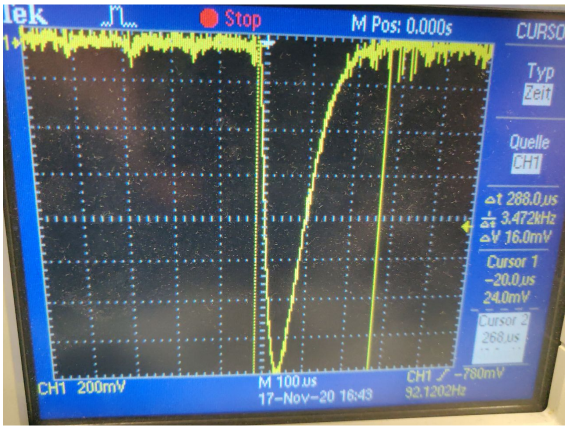
(b) *Fall Time* t_f



(c) *Rise Time* t_r



(d) *Pulse Width* t_p



(e) *Recovery Time* t_r

Figure A.1: During the course of the experiment captured oscillograms.

Bibliography

[1] H.-J. Eichler, H.-D. Kronfeldt, and J. Sahm, *Das neue Physikalische Grundpraktikum*, ger, 3., ergänzte und aktualisierte Auflage 2016, Springer-Lehrbuch, Eichler, Hans-Joachim (VerfasserIn) Kronfeldt, Heinz-Detlef (VerfasserIn) Sahm, Jürgen (VerfasserIn) (Springer Spektrum, Berlin and Heidelberg, 2016), 470 pp.

[2] L. Papula, *Mathematik für Ingenieure und Naturwissenschaftler Band 1* (Springer Fachmedien Wiesbaden, Wiesbaden, 2018).

[3] L. Papula, *Mathematische Formelsammlung* (Springer Fachmedien Wiesbaden, Wiesbaden, 2017).