

# Mass spectrometry and trace analysis

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Experimental setup: room 24 in the lecture hall building (HBR 14)  
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Duration of the test: 4 to 5 hours

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## 1. Introduction

Mass spectrometry is an important and widely used analytical method that allows the mass-to-charge ratio of ions to be measured, unknown substances to be identified, quantified and their structure to be investigated. Even extremely small amounts of substances (approx.  $10^{-14}$  mol) are sufficient for analysis; the analysis can often be carried out *online* and *in situ*. Areas of application range from physics (determination of nuclear masses), chemistry (determination of the structure of molecules, investigation of reaction processes, determination of enthalpies and binding energies) and biology (peptide sequencing) to astronomy, geology (age determination) and medicine (blood analysis) to industrial applications (monitoring of chemical and biological processes).

The experiment aims to familiarise students with the basics of mass spectrometry. For this purpose, a time-of-flight mass spectrometer developed at the II. Physics Institute is used. It is to be put into operation, calibrated, and used to determine the composition of air, the relative isotope abundance of krypton, and traces of organic compounds. In addition to theoretical and practical knowledge of (time-of-flight) mass spectrometry, knowledge of fast detector systems is also imparted.

## 2. Task

1. Put a time-of-flight mass spectrometer into operation to observe ions.
2. Find  $\text{N}_2^+$  peak, zoom into it, optimize the operating parameters, save the spectrum, and estimate the resolving power of the setup.
3. Record the mass spectrum of air, determine the relative composition of air ( $\text{N}_2$ ,  $\text{O}_2$ , Ar) and determine the mass resolution and mass accuracy of the mass spectrometer for the mass line of  $\text{N}_2$ .
4. Determine the relative isotopic abundance of krypton using the mass spectrum of krypton. Identify all mass lines in the recorded spectrum.
5. Identify three samples containing a small amount (~5 ppm) of the organic substances *trichloromethane*, *ethylbenzene*, *dibromochloromethane* or *hexane dissolved in methanol and water*. For sample spectra, see the source 9.5.

## 3. Experimental preparation

When preparing the experiment, the following theoretical and practical principles should be worked out in writing. Knowledge of these principles is a prerequisite for successfully conducting the experiment. Questions about these basic principles should be answered in the colloquium preceding the experiment.

In addition, the experiment procedure should be thoroughly known and the questions in Chapter 8 should be answered.

### 3.1 Theoretical foundations

- a) Atomic mass unit, mass definition
- b) Isotopes of an element, isotope ratios
- c) Movement of charged particles in electric and magnetic fields.
- d) Basic concepts of mass spectrometry, mass resolution, mass accuracy, sensitivity, dynamic range.

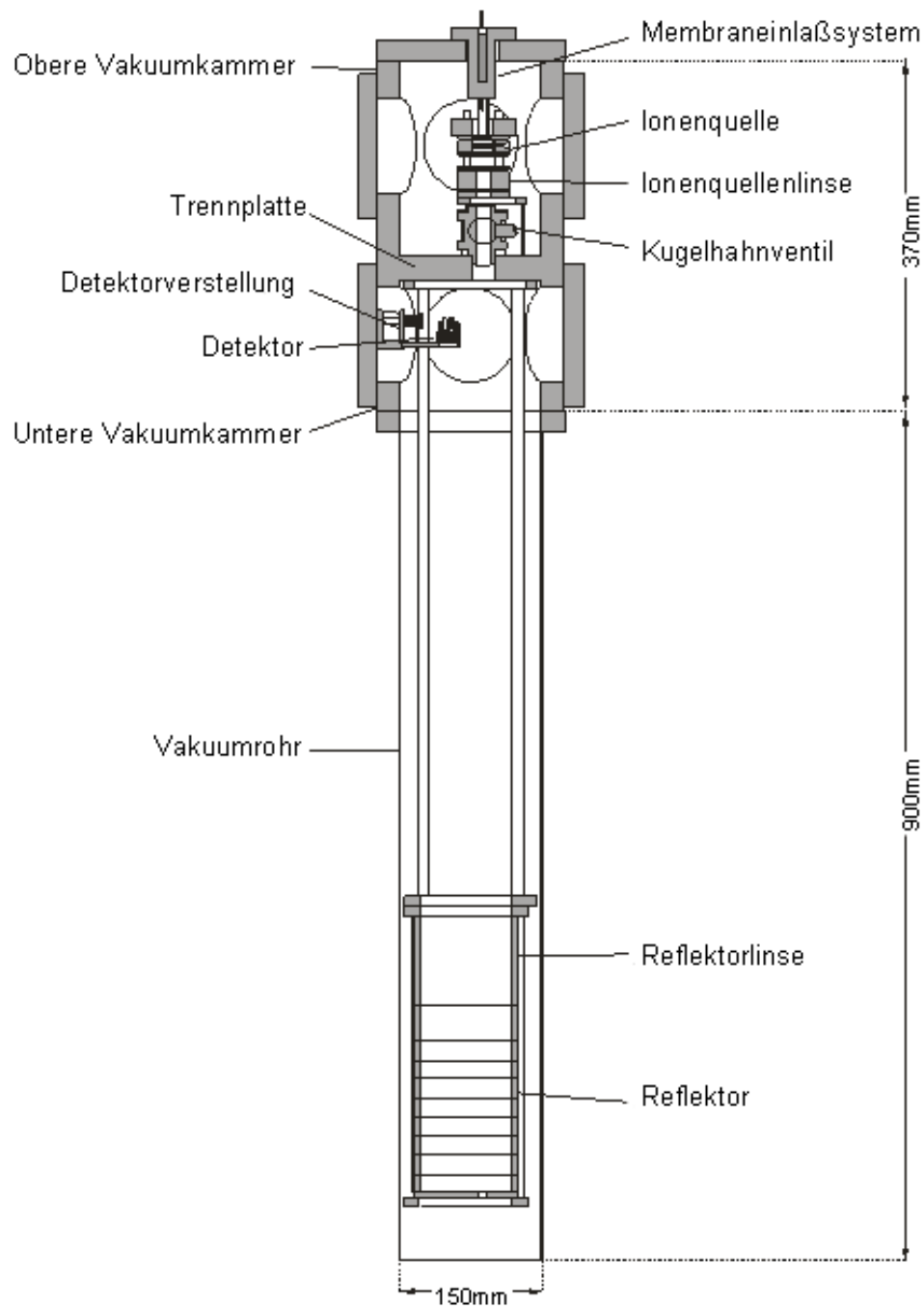
### 3.2 Practical basics

- a) Electron impact ionization
- b) Types of mass spectrometers and their operation (principle): sector field mass spectrometer, RF mass filter (RF quadrupole), RF ion trap (Paul trap), Penning trap (FT-ICR), time-of-flight mass spectrometer (TOF-MS).
- c) Time-of-flight mass spectrometry: mass-time-of-flight relationship, reversal time, time/energy focusing in linear TOF-MS (two-stage extraction) and reflector TOF-MS (two-stage reflector)
- d) Detection of ions in ion detectors: multi-channel plate detectors (MCP).

### 3.3 Experimental setup

This part describes the time-of-flight mass spectrometer used in the experiment. It consists of 5 functional units (see also Figure 1):

- (a) Sample inlet system
- (b) Ion source
- (c) Time-of-flight mass analyzer
- (d) Ion detector (detection system)
- (e) Data acquisition system (digital oscilloscope)

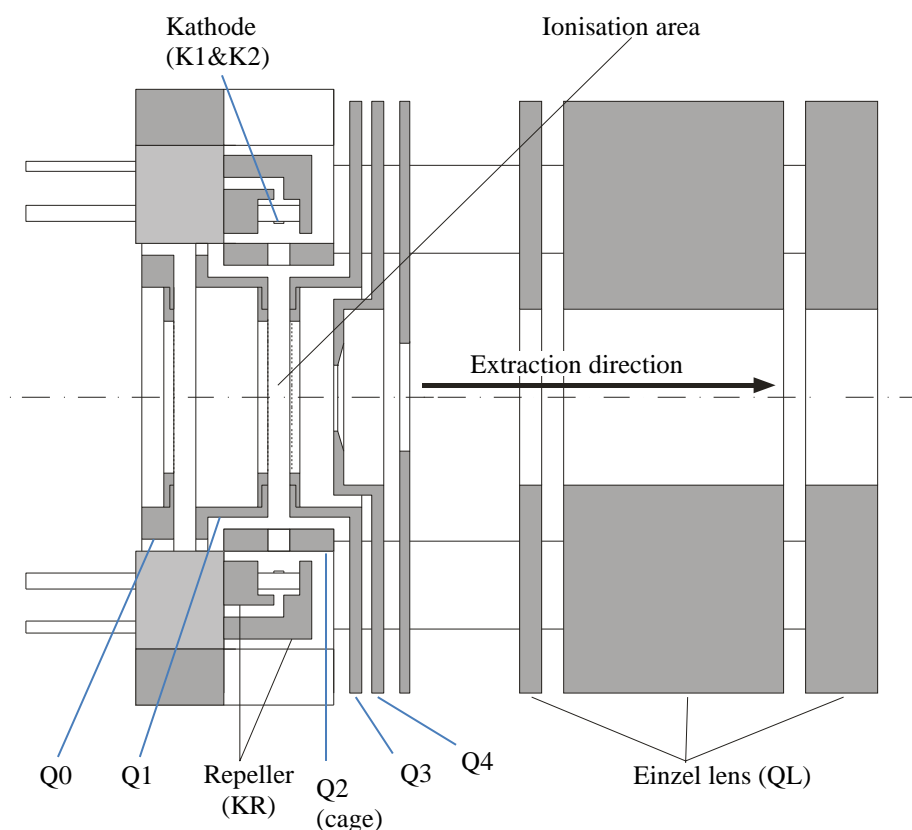


**Figure 1: Schematic representation of the time-of-flight mass spectrometer.**

In this experiment, two different sample inlet systems will be used:

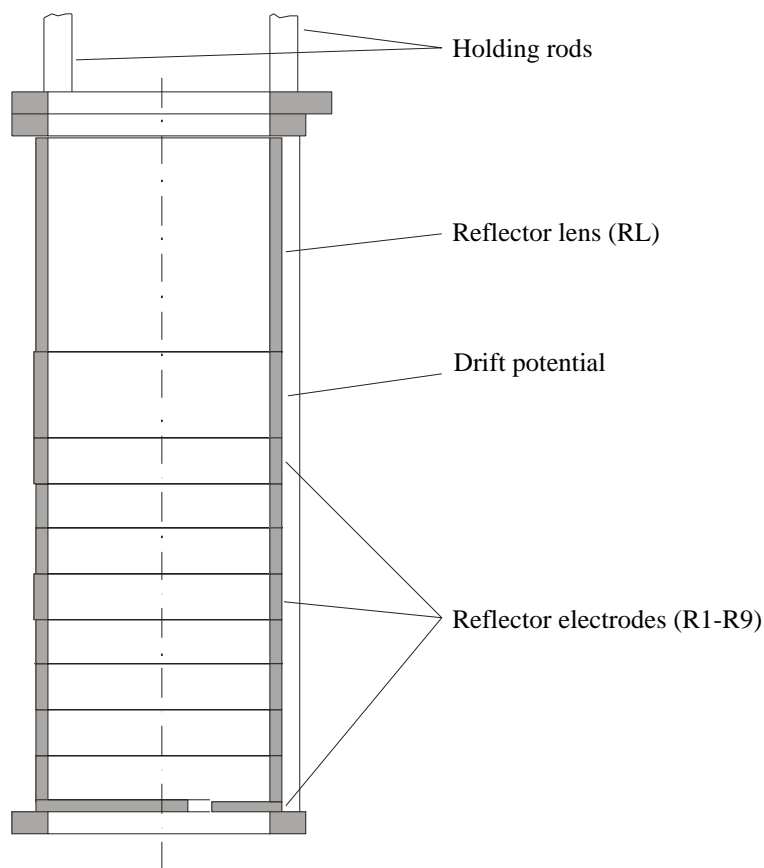
- (i) direct gas inlet through a metering valve for the inlet of gases and
- (ii) membrane inlet system (Membrane Introduction Dimensions Spectrometry (MIMS) for the inlet of non-polar gaseous or liquid substances.

An electron impact ionization source is used as the ion source. A current-carrying tantalum wires are used, from which electrons are emitted and accelerated into the ionization region. Ions are formed there by collision with atoms or molecules.



**Figure 2: Schematic representation of the ion source.**

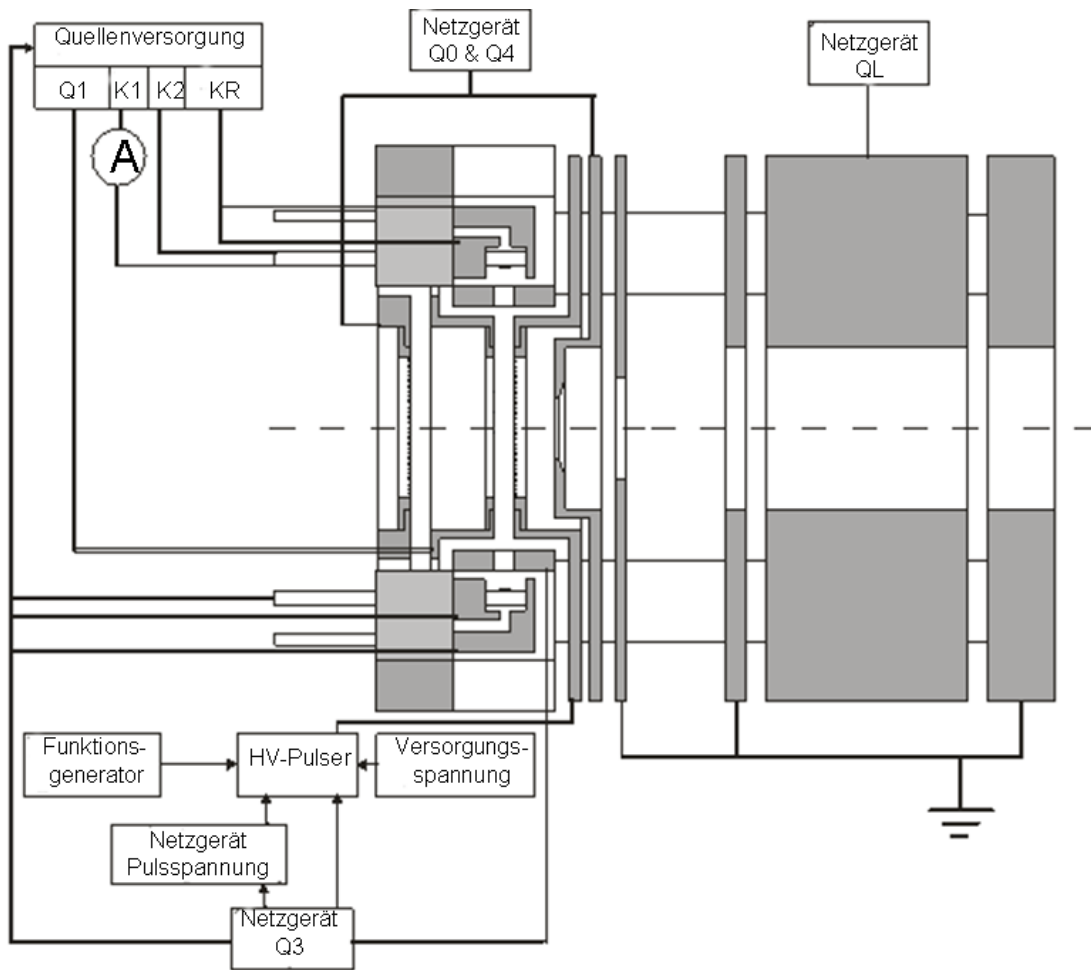
The mass is determined by measuring the time of flight between extraction from the ion source and the time the ions hit the detector. To make the time of flight almost independent of the initial location and energy distribution of the ions, an electrostatic reflector (Figure 3) is used (time/energy focusing). The ions are detected in a microchannel plate detector (chevron arrangement).



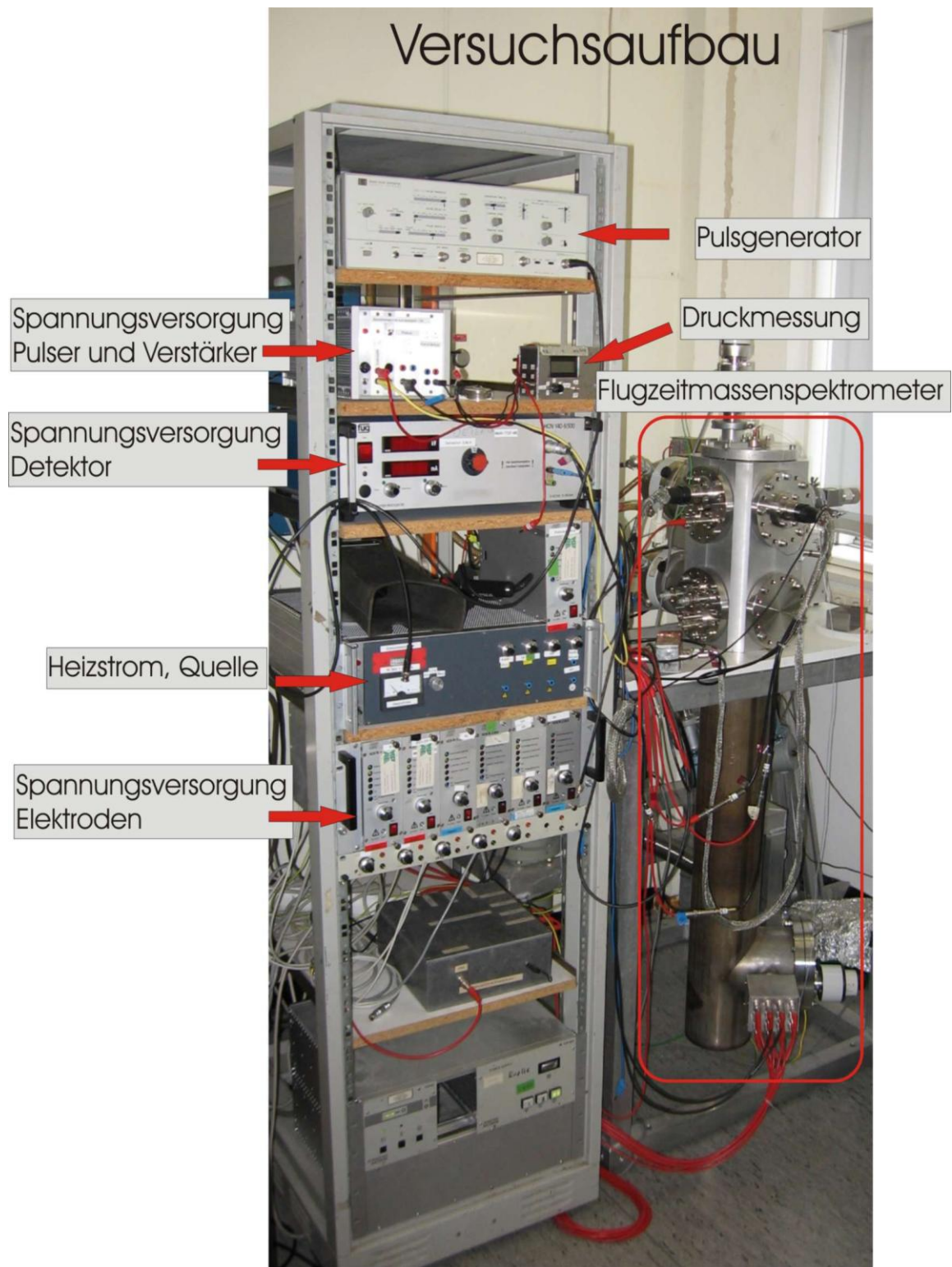
**Figure 3: Schematic representation of the reflector.**

The electrodes in the ion source, reflector and detector are supplied with voltage by high-voltage power supplies. Voltage dividers are used for the reflector and detector. The cathode heating current is supplied by a low-voltage power supply that is isolated by an isolating transformer. The extraction pulse (at the electrode Q3) is generated by a high-voltage pulser that receives its trigger signal from a pulse generator. Details can be found in Figure 4.

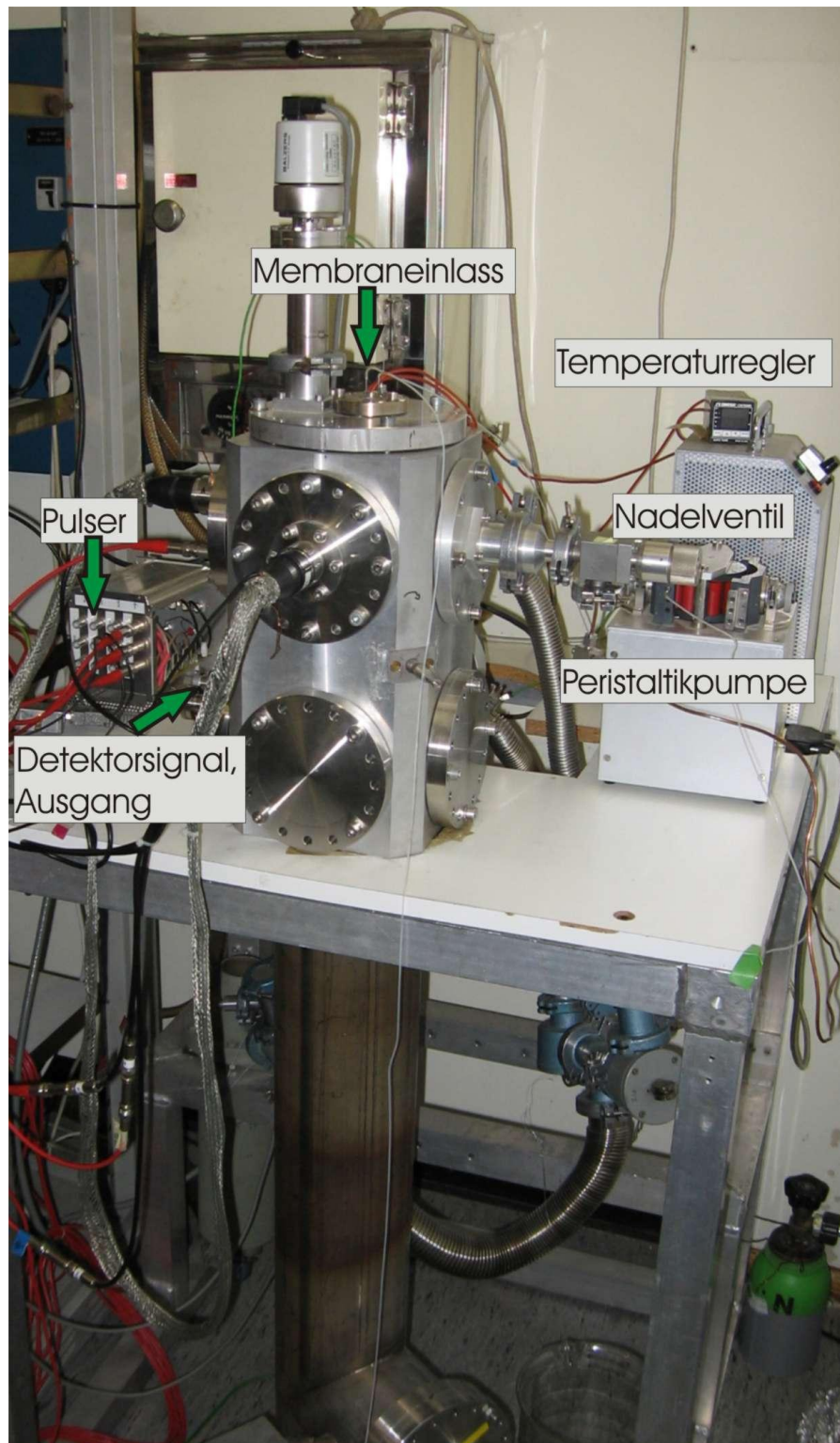
The detector signal is amplified by a preamplifier and viewed and optimized using a digital oscilloscope. The data is also recorded using the oscilloscope used, from which the data is saved directly to a USB stick (please bring your own).



**Figure 4: Schematic of the voltage and power supply of the ion source.**



**Figure 5: Photo of the electrical supply of the experimental setup.**



**Figure 6: Photo of the mass spectrometer.**

## 4. Experimental procedure

### 4.1 Safety instructions

Caution: High voltage! In this experiment you will be working with high voltages of up to 3 kV. Be aware of this at all times and exercise caution accordingly. The experiment was set up with great care, but like most equipment set up for experimental purposes, it does not comply with VDE guidelines or similar safety regulations. It can always happen that a cable becomes damaged and open contacts arise. If in doubt, always ask your supervisor!

### 4.2 General information on use

Be careful when setting the cathode heating current (risk of damaging the heating wire), the emission current must always be checked and adjusted. The setting of the dosing valve may only be changed after the cathode heating current and the detector voltage have been switched off. Make sure that the dosing valve for the gas inlet is not closed beyond the specified mark. The signal cable may only be reconnected to the oscilloscope after the detector voltage has been switched off. The vacuum pumps may only be operated by the supervisor.

### 4.3 Test protocol

Prepare a test protocol while carrying out the experiment, which contains all the steps and settings (voltages, pressures, pulse shapes). The measurement protocol must be signed by the supervisor immediately after the experiment is completed and attached to the report. Make a note of the name and time of the saved files, add a short comment to the protocol, e.g. purpose of the measurement.

### 4.4 Commissioning and optimization of the time-of-flight mass spectrometer

1. **Before commissioning** the time-of-flight mass spectrometer, the pressure in the two vacuum chambers of the device and the pre-pressure of the pumps must be checked and recorded. The pressure of the vacuum chambers is indicated on a display, a unit is mbar.  
It must be ensured that the pressure in the source chamber does not exceed  $10^{-5}$  mbar and in the lower chamber does not exceed  $10^{-6}$  mbar.
2. **Air** must be let into the source chamber of the mass spectrometer. To do this, a dosing valve on the chamber is opened. A pressure of  $4.4 \cdot 10^{-6}$  mbar must be set in the source chamber and recorded. **If the pressure needs to be adjusted later, the cathode heating current and the detector voltage must first be switched off!**

3. **Supplies and electrodes.** The source supply is switched on while the heating current is set to zero. The pulse generator is set to a frequency of 5 kHz and a pulse width of 3  $\mu$ s. The setting is checked on the digital oscilloscope. The preamplifier is switched on. The electrode voltages can then be switched on.
4. Finally, the **detector** voltage should be **slowly** (min. 1 minute) adjusted in several steps to -2300 V, and the cathode heating current should be switched on. The cathode emission current should be approximately 40  $\mu$ A and must be checked and adjusted regularly.

First, the signal of individual ions must be observed. To do this, the oscilloscope is triggered with the ion signal itself. The trigger threshold, signal width and signal height must be recorded in the protocol and specified in the evaluation. The ion signal is then triggered with the extraction pulse. It should now be possible to observe a mass spectrum on the digital oscilloscope. To examine the quality of the spectrum, the  $N_2$  peak should be zoomed in. The spectrum (in particular the  $N_2^+$  peak) is optimized by varying the voltages at the electrodes Q1, Q0/Q4, QL, reflector, R7 and RL. A maximum peak area with a minimum peak width must be used as the optimization criterion. After optimization, all voltages as well as the width and height of the  $N_2^+$  peak must be measured and recorded. If the peak shape is not symmetric, vary the detector voltage in the range -2300 .. - 2000 V and stay with the optimal value.

For an optimal signal, the oscilloscope should be set in the vertical zoom so that no signal is cut off at the top in the "Real-time" trigger mode. Then the "Average" trigger mode should be set, which should average 32 - 128 spectra. This mode can already be used to optimize the voltages. To remove noise, the "Math" function, "F1" should also be set to "eres", which can smooth the signal. Here "Bin" must be adjusted to the spectrum so that 50 - 200 MHz are displayed. Otherwise, the signal might be simplified/smoothed too much. To improve the spectrum further, another math channel F2 with "Average" should be selected. 100 - 1000 sweeps can be added up here. This new channel can now be enlarged and panned vertically without cutting off signals.

To save the signal, use the "File" "Save Waveform" menu, which should save the "F2" channel.

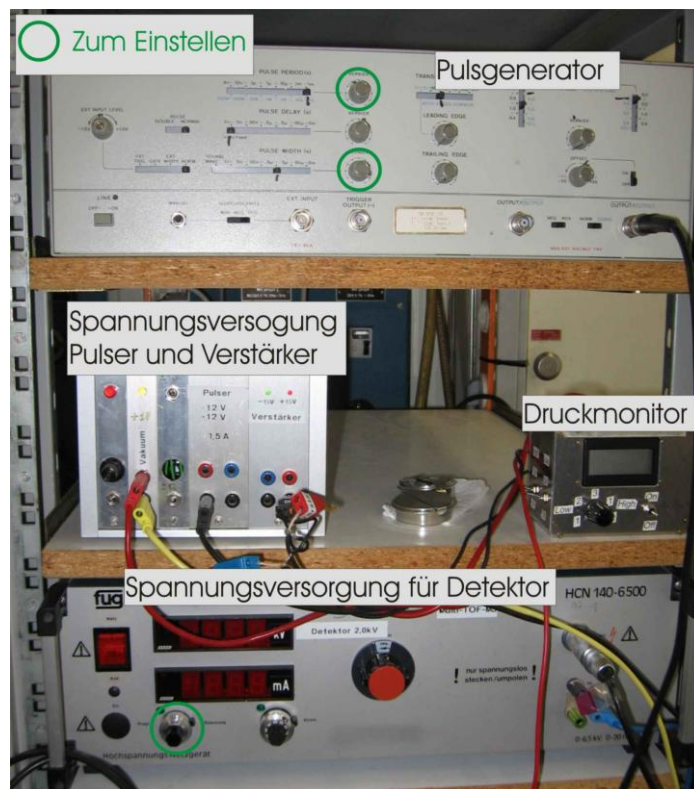


Figure 7: Photo of the electrical supply of the experimental setup (top)

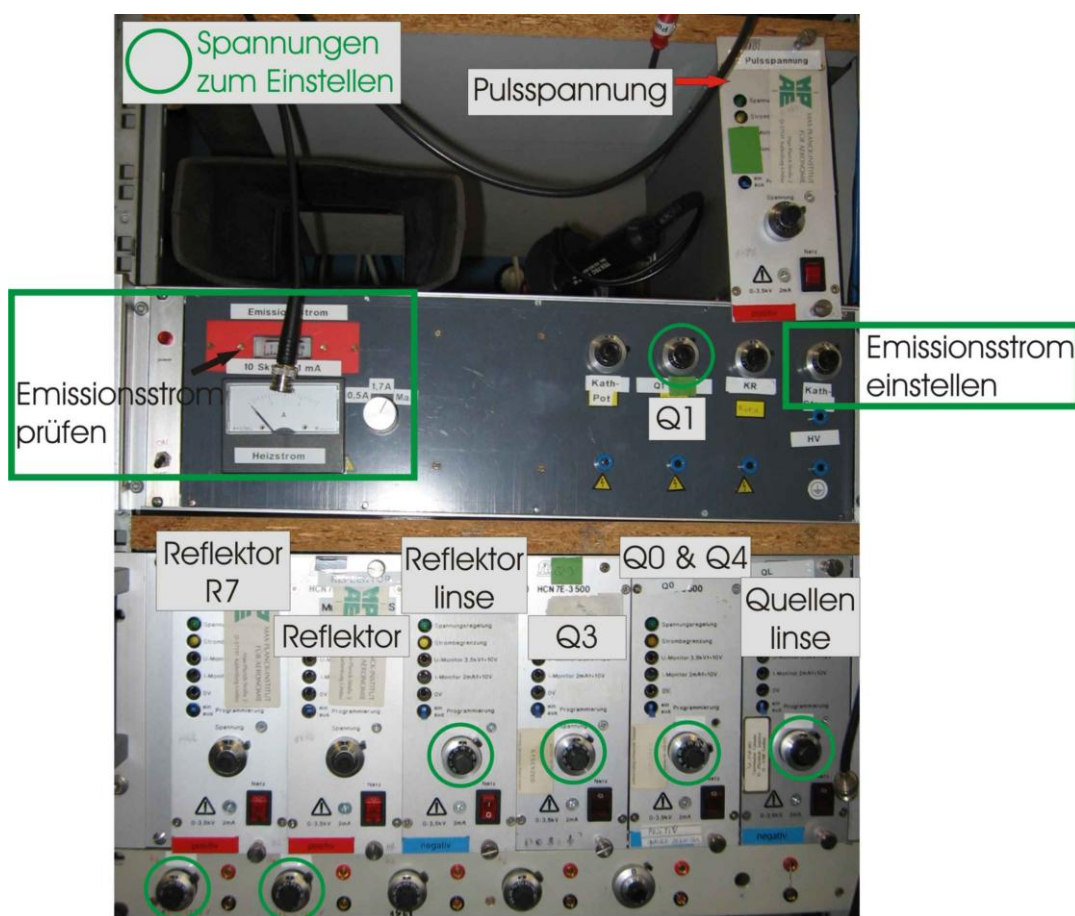


Figure 8: Photo of the electrical supply of the experimental setup (bottom)

#### **4.5 Measurement of the relative composition of air, determination of mass resolution and mass accuracy**

Once a suitable setting of the mass spectrometer has been found, the mass spectrum of air can be recorded using the information from the averaged channel.

- (i) First, the oscilloscope must be adjusted so that the complete spectrum is visible on the oscilloscope and fills the screen. The spectrum must be shown to the supervisor and saved.
- (ii) Then the vertical setting on the oscilloscope must be selected so that the Ar peak is displayed optimally. This spectrum must also be saved.

#### **4.6 Determination of the relative isotopic abundance of krypton**

To record the mass spectrum of krypton, krypton gas must be introduced into the source chamber of the mass spectrometer ( $4.4 \cdot 10^{-6}$  mbar). The same settings as in 4.5 must be used.

Relying on the result of the air spectrum measurement, estimate the position of krypton lines.

#### **4.7 Trace analysis of volatile organic compounds**

To record mass spectra with the membrane inlet, first close the needle valve and switch on the peristaltic pump to pump water or samples through the inlet system. Plug in the temperature control of the inlet system and the system automatically regulates to a temperature of 70 °C. You must wait until the desired temperature is reached. **Make sure that water or samples are pumped through the inlet system while the heater is switched on.**

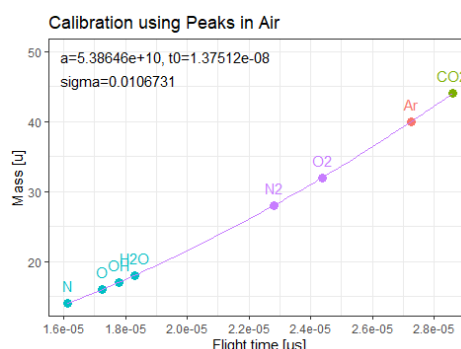
Before each measurement with a sample, a water spectrum must be recorded first and saved. Pumping should be continued for 5 minutes between measurements until the concentration of the sample substance in the source chamber has stabilized. One or more additional mass lines should appear during the measurement of the samples compared to the water spectrum. Note: the analytes are dissolved in methanol and water.

**If this is not the case, the supervisor must be contacted.**

## 5. Evaluation

### 5.1 Calibration of mass spectra, determination of mass resolution and mass accuracy

To calibrate the mass spectrometer, sufficiently intense mass lines ("peaks") from the recorded air spectrum must be used ( $O^+$ ,  $N^+$ ,  $OH^+$ ,  $H_2O^+$ ,  $O_2^+$ ,  $N_2^+$ , possibly  $Ar^+$ ,  $CO_2^+$ ). Make sure that they are identified correctly! Normally, all of the masses mentioned are visually located in the plot on the fit function. If peaks are missing or not clearly visible, they must be excluded from the calibration.



The mass values of these ions can be found in the literature. Note the missing electron mass and the difference between the average molecular mass and the exact isotope mass (for example,  $m(\text{carbon}) = 12.011 \text{ u}$  vs  $m(^{12}\text{C}) = 12.000 \text{ u}$ ). The binding energy of the electrons can be neglected here. The relationship between flight time  $T$  and mass  $m$  is given by the equation

$$m(T) = a(T - t_0)^2 \quad (1)$$

Here,  $a$  and  $t_0$  are constants to be determined.

The flight time of an ion type is determined from the center of gravity of the mass line (Gaussian fit). The mass resolving power is determined from the half-width of the peak  $\Delta T$  as

$$R = m / \Delta m = T / 2 \Delta T \quad (2)$$

The mass accuracy is estimated from the deviations of the measured values from the literature values.

### 5.2 Determination of the relative composition of air or the relative isotope abundance of krypton

To determine the relative composition of air and the isotopic abundance of krypton, the area of the respective Gaussian fits is considered in relation. For air, the fragment ions are included proportionally. For example, half of the area of  $N^+$  is added to  $N_2^+$ . An error calculation must be carried out.

### 5.3 Trace analysis of volatile organic compounds

The identity of the organic compounds is determined by comparing the recorded mass spectra with electron impact spectra from the literature. In order to exclude the influence of impurities contained in the mass spectrometer, the background spectrum must be compared with the sample spectrum.

## 6. Notes on data evaluation



Any software can be used to evaluate the data. We recommend Origin from OriginLabs (free for students via <https://www.uni-giessen.de/de/fbz/svc/hrz/svc/services/softwarelizenzen/origin/download>), SciDavis (freeware) or R (script language) with RStudio (GUI). Excel currently does not offer an easy way to create fits for calibration and Gaussian curves and is therefore not well suited.

The data is stored in ASCII format and consists of a header, which can be ignored, and two columns for the measurement data. The first column describes the time values of the data in seconds, the second describes the amplitude in volts.

Further information and videos can be found at <http://uni-giessen.de/ionas/fprak>

### 6.1 Evaluation in Origin

Files can be dragged and dropped into the window to **import them into a “workbook”**. You can change the name of the workbook by clicking it in the list on the left and pressing F2.

To **plot** the data, you can click on Draw and 2D line in the menu. You then have to select the X and Y axes and a new "graph" will open. You can use the "Zoom-Pan" tool in the left-hand toolbar to  change the display area by clicking, dragging, using the mouse wheel and the Shift key. Double-click the numbers on an axis and change the value for "Major ticks" in the "Scaling" tab to select the ticks that make sense. Each axis must show several numbers and only different numbers. You can achieve nice formatting for the time axis in the "Tick labels" tab with a "division factor" of 1e-6. This will make the values appear in  $\mu\text{s}$ . Finally, you have to give the axis a meaningful name (amplitude [V], time [ $\mu\text{s}$ ] or time [s]) by double-clicking on the name. You can read off or mark data points using the annotation tool . Here you have to triple-click on a signal to insert (X,Y). You can move and change the text (double-click) using the normal mouse pointer (press ESC).

In the next step, you will have to create **Gaussian fits**. To do this, select “Analysis – Adjustment – Nonlinear Fit” in the menu and, if necessary, “Open Dialog”. Here, select “Gauss” in the function. In the lower area, the formula tab now appears containing the following equation:

$$f(x) = y_0 + \frac{A}{\omega\sqrt{\pi/2}} e^{-2\left(\frac{x-\mu}{\omega}\right)^2} \quad (3)$$

with the center  $x_c$ , the area  $A$  and the width  $\omega$ . Resolving power R and full width at half maximum FWHM are estimated as following:

$$R = \frac{t}{2\Delta t} = \frac{x_c}{2 FWHM}, \quad FWHM = \omega \cdot \sqrt{\ln 4}$$

A red line appears in the plot showing the fit with start parameters. If the position and amplitude are roughly correct, you can click on "Fit". Otherwise, switch to the "Parameters" tab and change  $x_c$  (position) and  $A$  (area) by double-clicking in the "Value" column. Clicking on the  $\chi^2$  button redraws the preview. The buttons to the right can be used to perform iteration steps to see whether the fit converges. A table now appears in the graph window, which you should move to the side so that you can see the fit and data. The table shows  $x_c$  (center of gravity) and  $A$  (area), as well as  $\omega$  (width). A yellow symbol appears in the top left of the graph, which can be used to change the fit parameters. Multiple fits can also be inserted into the same graph.

For **calibration**, the centers of gravity for all ions in air must be determined. Note logical distances in the spectrum (e.g. OH in the middle between O and H<sub>2</sub>O). Create a new workbook for these values. Enter the time centers of gravity in the first column and the literature mass in the second. Now select "Analysis-Fit-Open nonlinear fit dialog" again and <New> as the function. In the new dialog, select "Next", set " $t$ " as the independent, " $m$ " as the dependent and " $a, t_0$ " as the parameter and click "Next". You can now type in  $m = "a*(t-t_0)^2"$  as the function field. The "initial values" can be roughly estimated:  $t_0 = 0, a = 20u/(20\mu s)^2 \approx 5e10$ . Now click on "Finish" and adjust the start parameters again if necessary before clicking on "Fit". Two new tabs with the results will now appear at the bottom of the workbook. On the first tab there is an "adjusted curve diagram" that should look something like the one in Chapter 5.

**To convert** the time axes into mass axes, open the workbooks again and right-click in the free area to select "new column". Here, select the function  $F(X) = "a * (Col(A) - t_0)^2"$ , where you take  $a$  and  $t_0$  from the calibration and in this case the time values are in column A. Now create a new plot that uses the new column as the mass axis.

The area of the Gaussian fits is used to determine the ratios.

If the data contains **too much noise**, you can run "Menu-Analysis-Data processing-Reduce by group" e.g. with "N=10" BEFORE calibration. Here you have to select X and Y as "input". After clicking on "OK", two new columns are inserted that can be used/plotted as averaged time/amplitude columns.

## 6.2 Working with R

Alternatively, fits and plots can also be created in R. R was developed specifically for data analysis and can be downloaded free of charge from <https://www.r-project.org/>. It is recommended to use the RStudio Desktop environment:

<https://posit.co/downloads/>.

For easier data analysis and presentation, the *tidyverse* package should be installed (`install.packages("tidyverse")`).

An example script for the required processes is available at

<https://www.uni-giessen.de/de/fbz/fb07/fachgebiete/physik/institute/iipi/arbeitsgruppen/ag-scheidenberger/lehre/auswertung-1.r>

Frequently used functions are

```
# Read files data
<- read_tsv ( " filename ", col_names =c("Time"," Ampl "),skip=5)

# Gaussian fit
gauss <- function (x, a, u, s, yc ){ #define Gaussian Function
  yc + a/(s*sqrt(2*pi)) * exp(-0.5 * ((xu)/s)^2 )
}
fitdata <- peak2 %>% filter(Time > 22.81e-6 & Time < 22.92e-6) # filter data
fitPeak <- nls ( Ampl ~ gauss(x= Time,a,u,s,yc =1e-4), # create fit
start = c(a=1e-10, s=5e-9, u=22.88e-6),data= fitdata ) #start parameter
# " fitPeak " contains information about errors and values

# Plot data
ggplot ( data,aes ( Time,Ampl ))+ # Plot data
  geom_line ()+ # Plot data as lines
  coord_cartesian ( xlim =c(15e-6, 30e-6), ylim =c(NA, 2.5e-3))+ # x/y
Limits
  stat_function (color="red", fun=~gauss(x=., yc =1e-4, # show Gaussian
fit
a= coef ( fitPeak )["a"],u= coef ( fitPeak )["u"],
s= coef ( fitPeak )["s"])+
labs(x= "Time [µs]",y="Amplitude [V]", title=" Air spectrum ") # Axes

# Determined calibration Data
calibData <- tibble (
  time = c( 16.17e-6, 18.273e-6, 18.326e-6, 22.818e-6, 24.388e-6),
  mass = c( 14.0067, 17.007, 18.01528, 28.0134, 31.998)
)

# Calibration fit
calibFit <- nls ( mass ~ a*(time-t0)^2,start=c(a=5e10,t0=0),data= calibData )
calA = coef ( calibFit )["a"]
calT0= coef ( calibFit )["t0"]
# " calibFit " contains information about errors and values

# Mass axis add
data = data %>% mutate( Mass= calA *(Time-t0)^2)

ggplot ( data,aes ( Mass,Ampl )) # + [...]
```

## 7. Important information for the evaluation

- If in doubt, the supervisor can help, even in advance. The email address and address are on the first page.
- All topics from chapters 3.1 and 3.2 should be explained in the theory part.
- For each type of spectrometer, the functionality (how masses are determined) as well as the disadvantages and advantages, especially compared to the TOF-MS used here, should be briefly explained.
- Plots must be labeled on each axis. All axes must have **multiple numbers** and **only different** numbers. Origin sometimes produces axes with only one number, no number, or too few decimal places.
- Plots should be large enough and intercepts chosen to see relevant peaks.
- Peak fits should roughly correspond to the signal shape. If the fit is too flat or narrow, the initial conditions of the fit must be adjusted. For peaks with extremely few statistics, position and area can be replaced by the center of gravity and sum of the signals (with a note in the protocol).
- Uncertainties needs to be properly estimated so that comparisons with literature data and any conclusions drawn from analysing the data are reliable.
- It is important to ensure that the calibration makes sense. The calibration function should roughly hit all points (see example plot in the "Evaluation" chapter). Points that deviate significantly are probably misidentified and should not be included in the calibration, with a note in the protocol.
- The calibration must also be used! The spectra for air, krypton and the organic substances must be included in the protocol with a mass scale.
- The certificate must be attached as a scan at the end or submitted in the original.

## 8. Questions

The questions below are intended to help you prepare for the experiment and should be able to be answered in the colloquium preceding the experiment. It is not necessary to prepare the questions in writing.

1. What are the different types of mass spectrometers? Explain how they operate.
2. How does an electron impact mass spectrum of air look like?
3. How one could detect ions? How does MCP works?
4. Why is the use of a reflector in a time-of-flight mass spectrometer advantageous, even though energy focusing can already be achieved with two-stage extraction from the ion source?
5. How to reduce the turnaround time?
6. Why does the detector voltage have to be set to zero before changing the detector cable on the oscilloscope?
7. What determines the start and stop signals for the time measurement in the time-of-flight mass spectrometer?
8. Derive equations (1) and (3).
9. Does the mass resolution of a time-of-flight mass spectrometer depend on the mass?
10. Why can it be assumed that the area of the mass lines is proportional to the number of ions?
11. Assume, the  $\text{N}_2^+$  peak has been identified with the time  $t_{ref}$ . How could the time of  $^{80}\text{Kr}^+$  be estimated?
12. Assume the device accelerates ions to  $E = 1300 \text{ eV}$  at a flight distance of 2 m. What is the flight time of  $\text{N}_2^+$ ,  $^{84}\text{Kr}^+$  and singly charged ions with the mass of 200 u?
13. What is the ion signal width at 20  $\mu\text{s}$  flight time and a resolution of 1000?
14. Performing data evaluation, you were provided with the value  $x = 3.57894 \cdot 10^{-9}$  and the uncertainty  $\Delta x = 7.8355219 \cdot 10^{-10}$ . How many figures will you keep to write down the meaningful value?

## 9. Sources

The literature listed is available in the electronic journal library of the Justus Liebig University Giessen (<https://www.uni-giessen.de/ub/en>) or from the supervisor.

### 9.1 Mass spectrometry and ion optics

- C. Dass, Fundamentals of Contemporary Mass Spectrometry, Wiley, New Jersey, 2007.
- E. Hoffmann, V. Stroobant, Mass Spectrometry Principles and Applications, Wiley, New Jersey, 2007.
- H. Wollnik, Ion optics in mass spectrometers, *J. Mass Spectrom.*, **34** (1999) 991.

### 9.2 Time-of-flight mass spectrometry

- H. Wollnik, Energy-isochronous time-of-flight mass analyzers, *Int. J. Mass Spectrom. Ion Processes* **131** (1994) 387.
- M. Guilhaus, Principles and Instrumentation in Time-of-flight Mass Spectrometry, *J. Mass Spectrom.* **30** (1995) 1519-1532.
- B.A. Mamyrin, Time-of-flight mass spectrometry (concepts, achievements, and prospects), *Int. J. Mass Spectrom.* **206** (2001) 251.

### 9.3 Membrane inlet mass spectrometry (MIMS)

- S. Bauer, Membrane Introduction Mass Spectrometry (MIMS); An Old Method that is Gaining New Interest Through Recent Technological Advances, *Trends in Anal. Chem.* **14** (1995) 202.

### 9.4 Experimental apparatus

- W.R. Plaß, Construction of a time-of-flight mass spectrometer for the analysis of volatile organic compounds at low partial pressure, diploma thesis, Justus Liebig University Gießen, 1997.

### 9.5 Standard electron impact spectra

- National Institute of Standards and Technology, Chemistry Webbook, <https://webbook.nist.gov/chemistry/> .  
Use the search options 'Name' or 'Formula' to obtain the mass spectrum data.

### 9.6 Uncertainty estimation and data treatment

- Philip R. Bevington, D. Keith Robinson, Data reduction and error analysis for the physical sciences, 3<sup>rd</sup> edition, McGraw Hill, New York, 2003.