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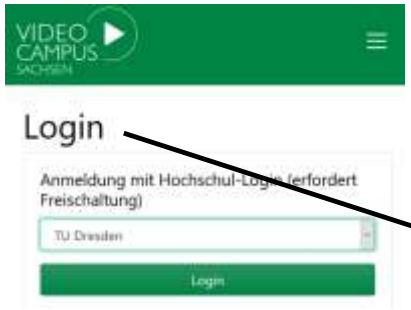

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Vacuum Technology
WS 20/21
Virtually presented
Lecture 14, Feb. 09, 2021

Prof. Dr. Johann W. Bartha

Inst. f. Halbleiter und Mikrosystemtechnik
Technische Universität Dresden

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"VT L01 a 17:02

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Review L13

0. Introduction

Air pressure as a force to the walls of an empty container

1. Gas kinetic

Pressure as momentum transfer, Mol & Molvolume, Pressure units Partial pressure, Boltzmann Velocity&Energy distribution, Impingement rate, monolayer coverage time, mean free path collision rate

2. Pressure Ranges

Viscous, Knudsen, Molecular flow, Rough-, Medium-, High-, Ultrahigh-Vacuum, Heat conduction

3. Vacuum technical terms

Pumping speed, pumping power, gas-flow, residence time, gas flow conduction, impact on tube dimension

4. Vacuum generation

Genealogy of pumps, working principle, assignment to vacuum range

5. Pressure measurement

Direct / Indirect pressure measurement, Different gauges and assignement to vacuum range, Partial pressure measurement, interpretation of QMA spectra

HV and UHV

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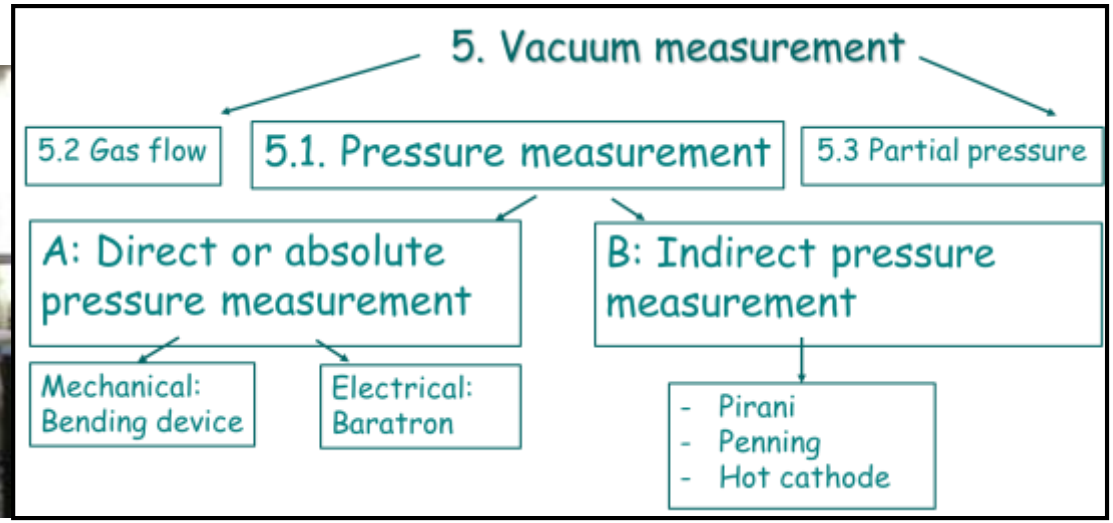

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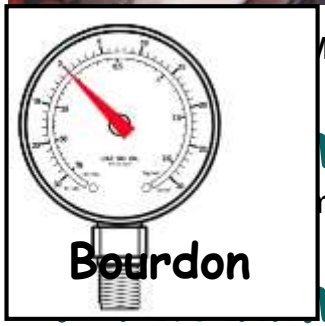

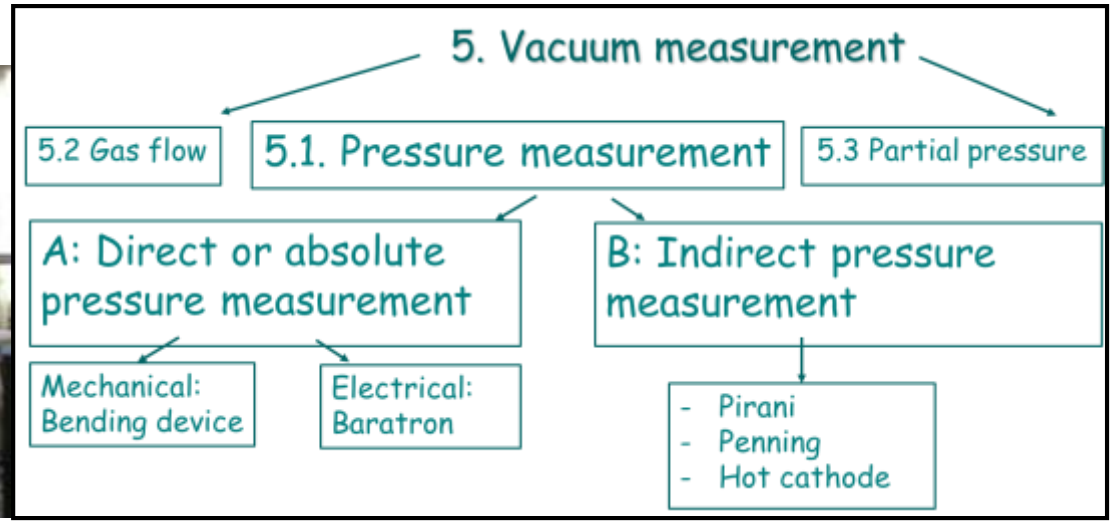

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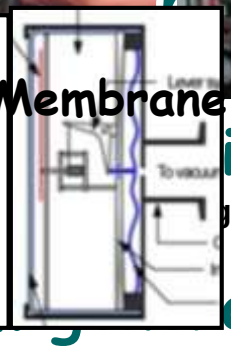

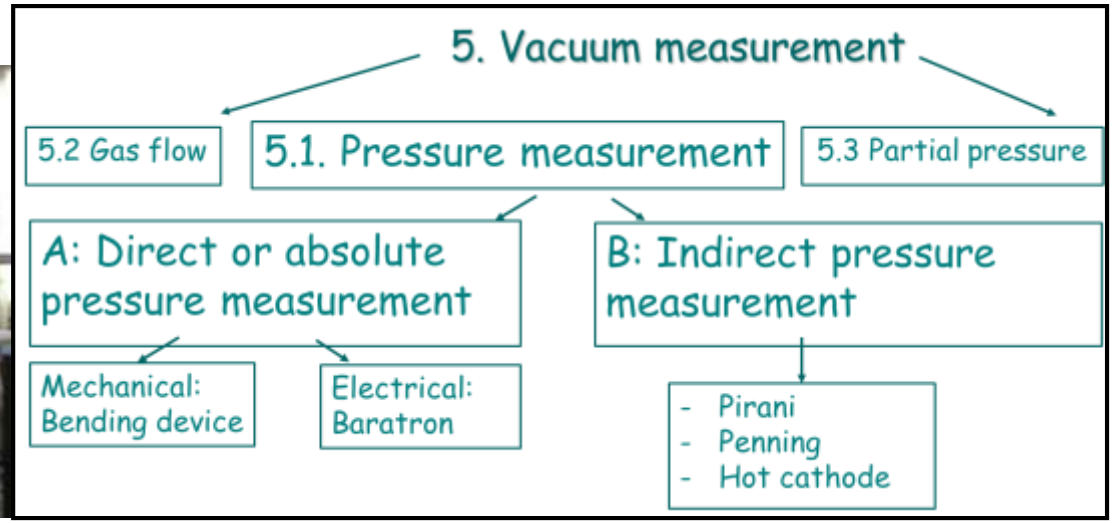

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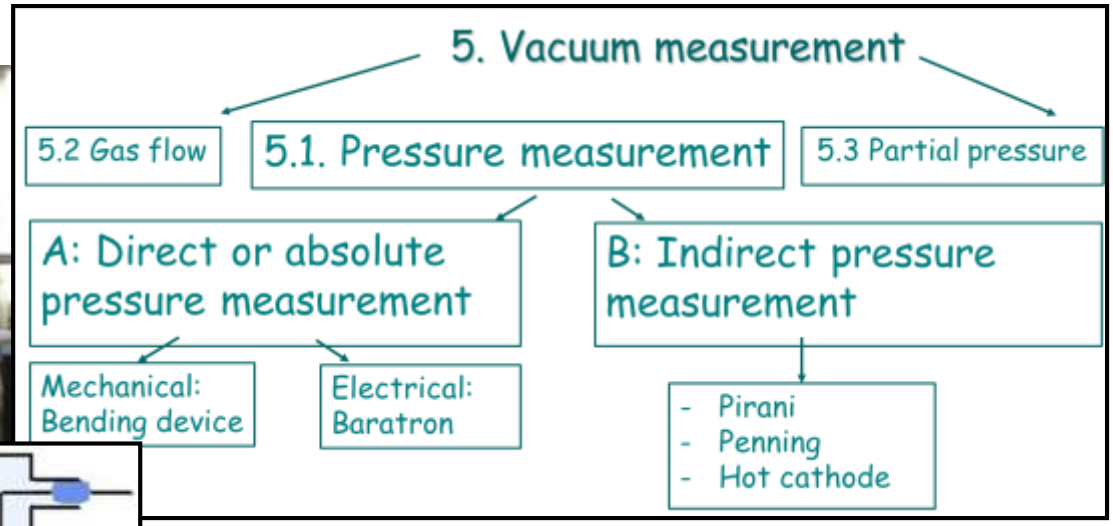

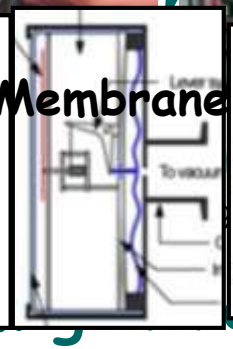

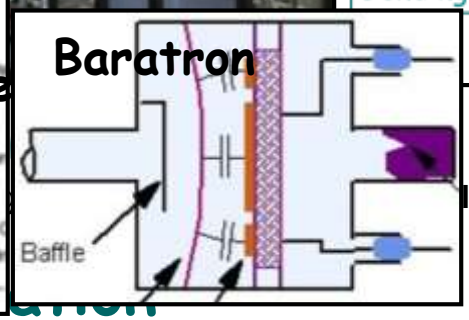

low conduction, impact on tube dimension

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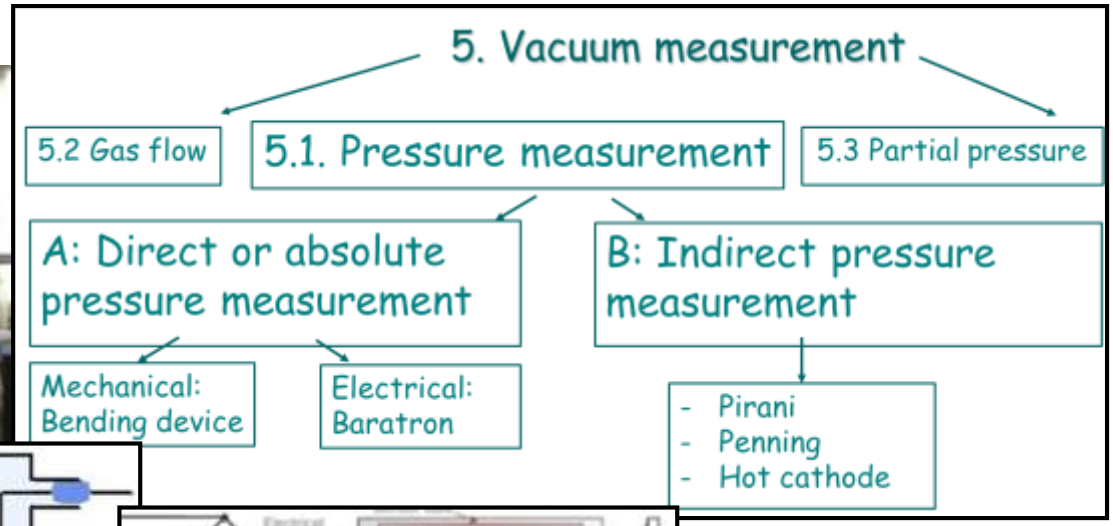

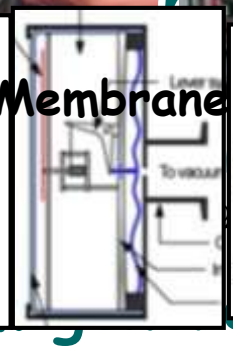

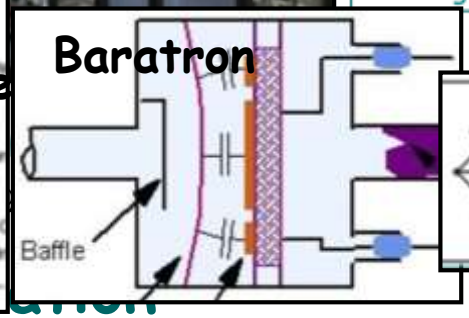

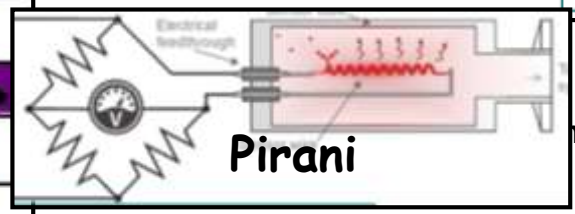

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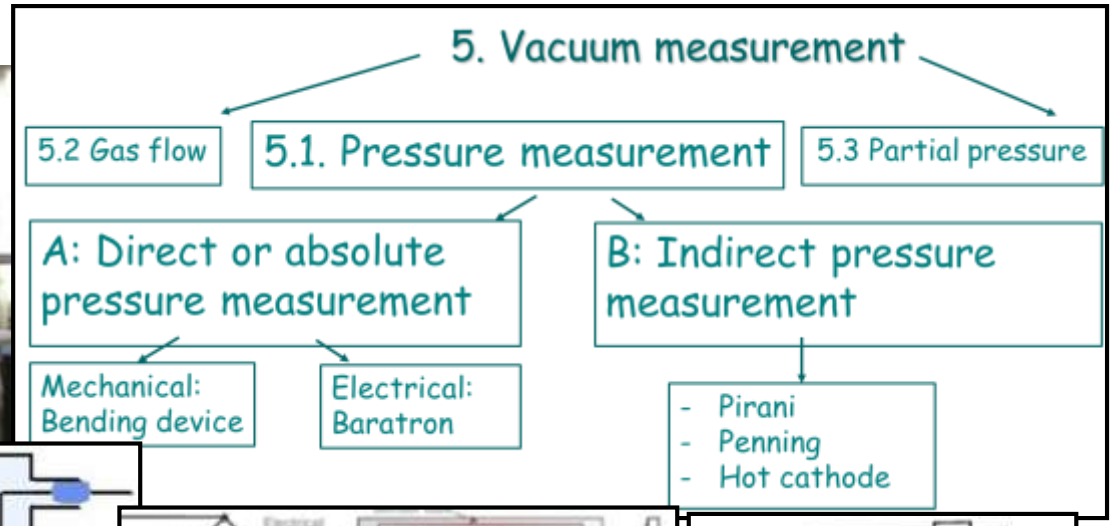

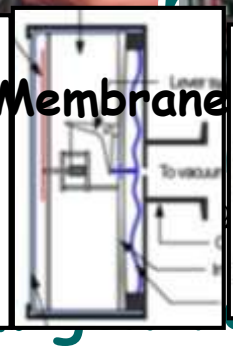

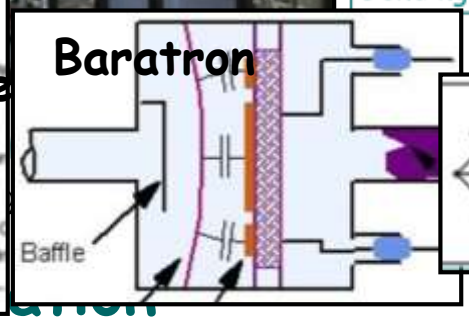

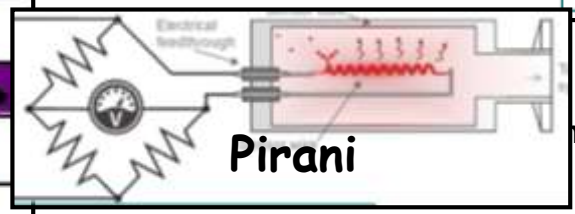

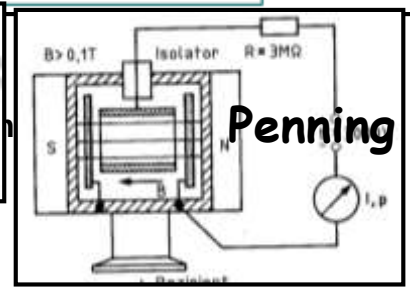

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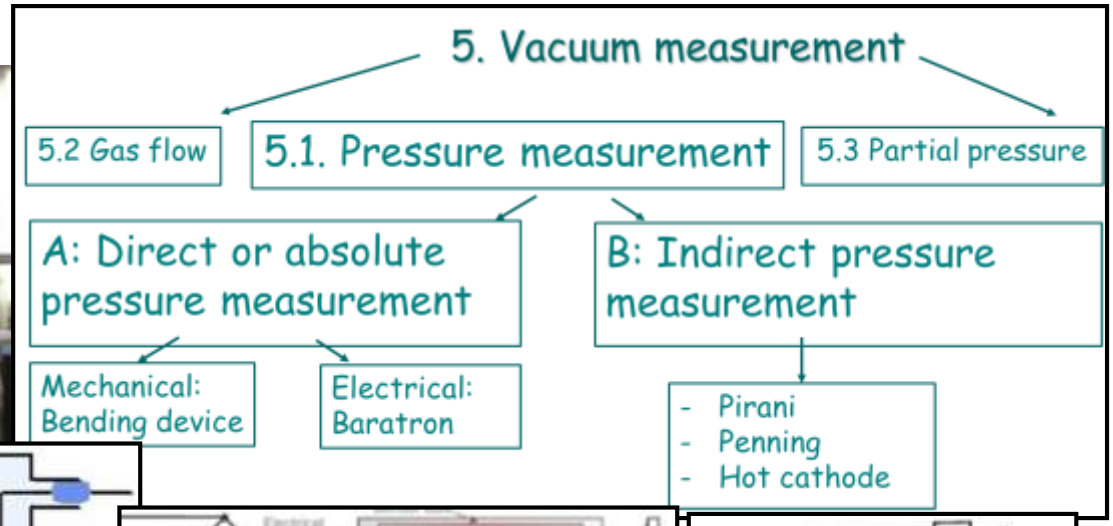

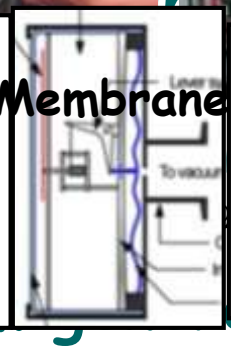

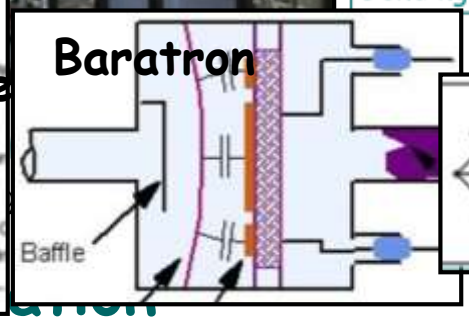

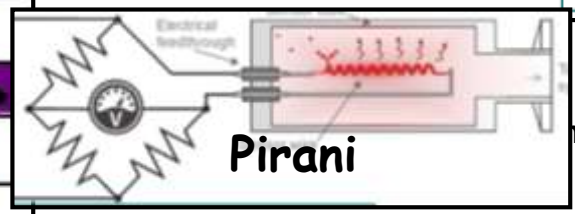

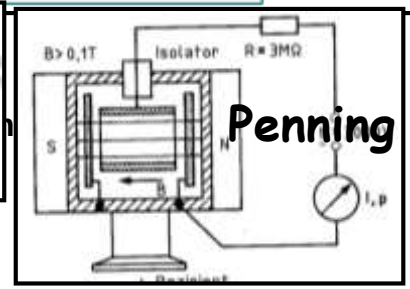

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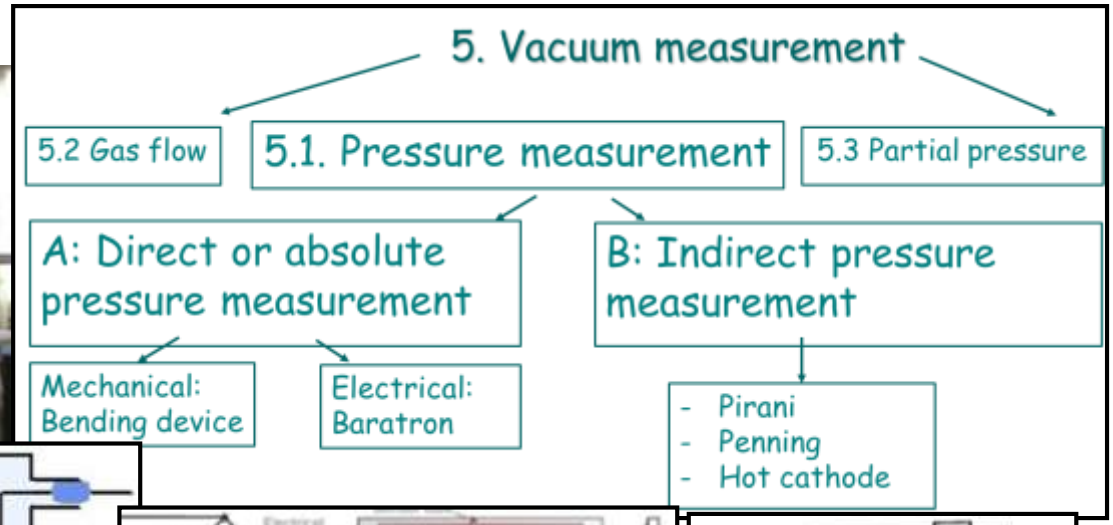

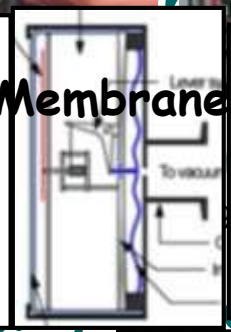

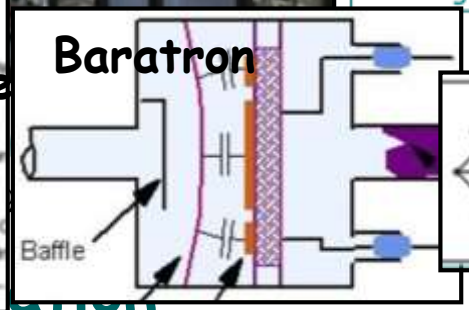

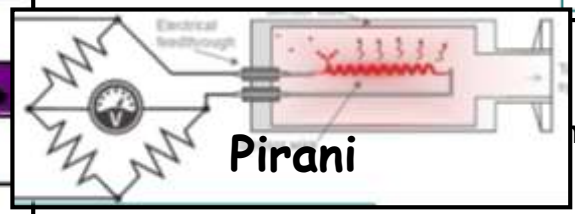

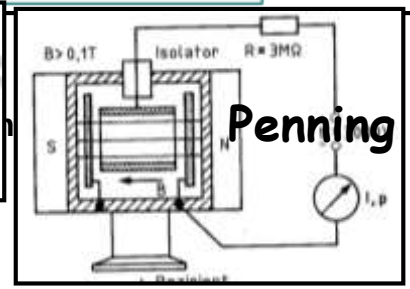

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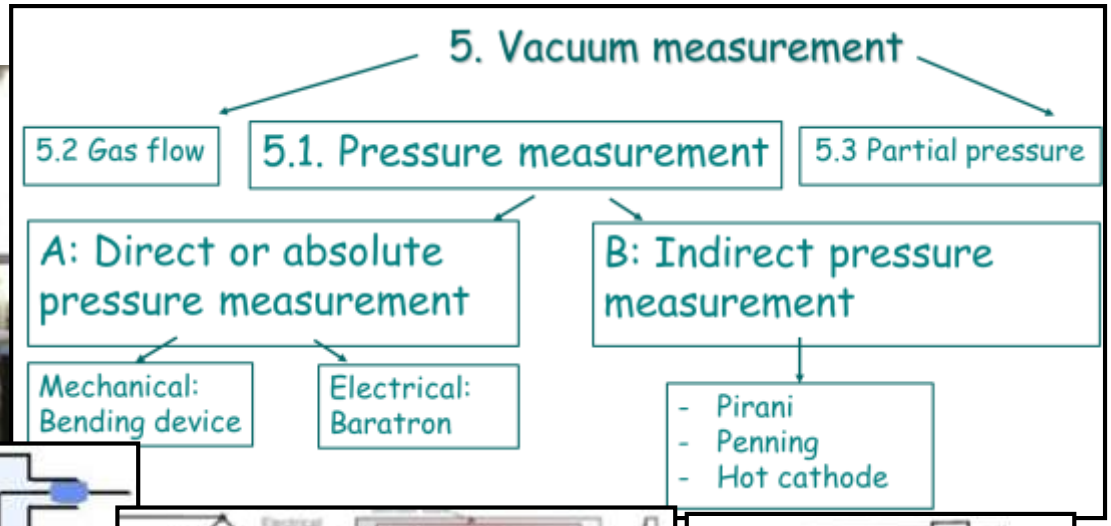

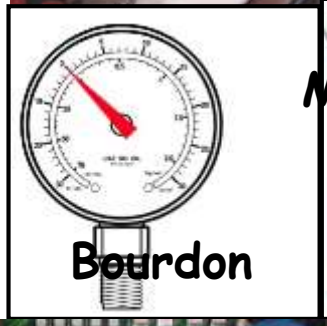

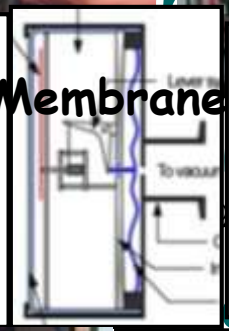

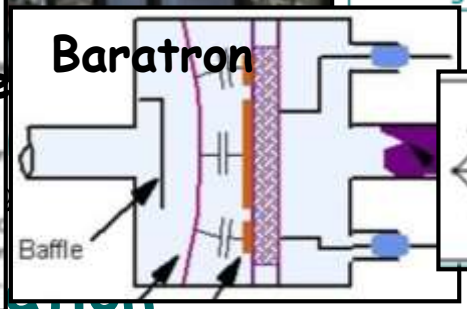

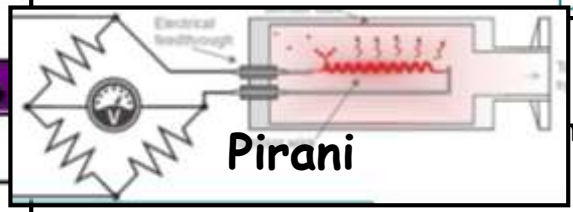

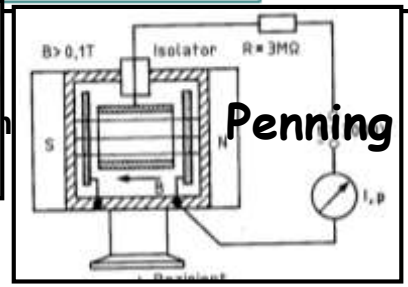

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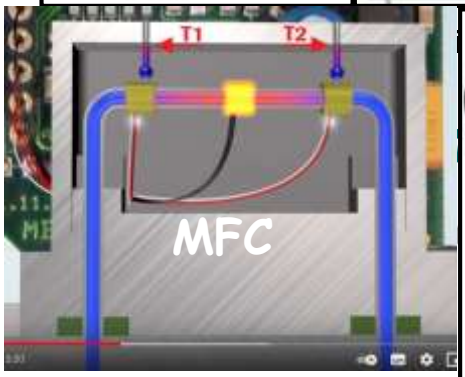

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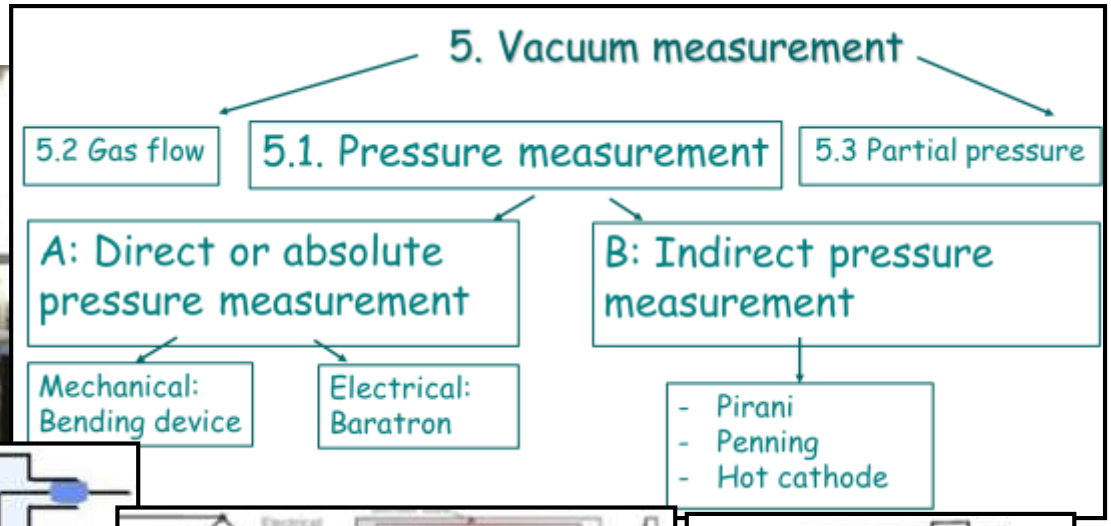

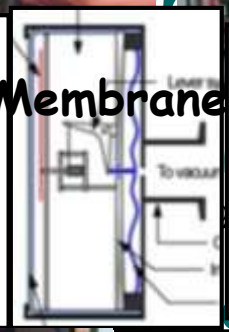

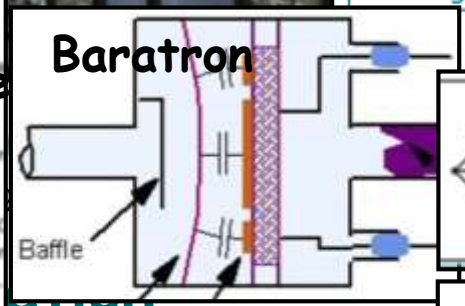

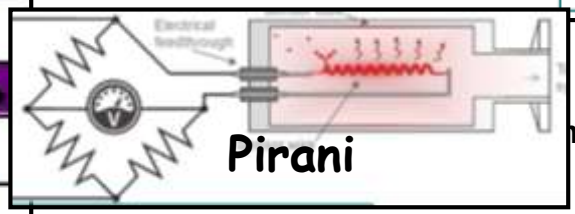

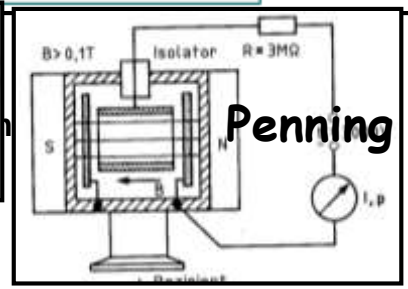

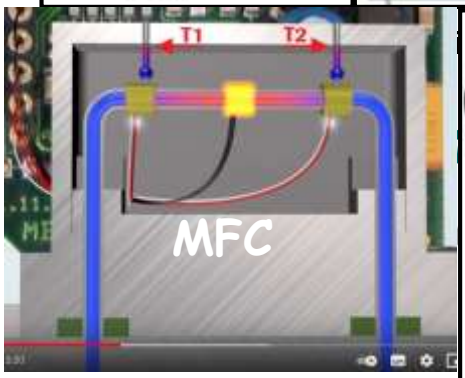

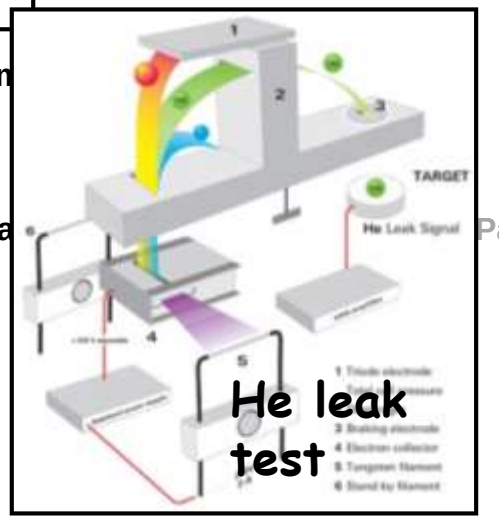

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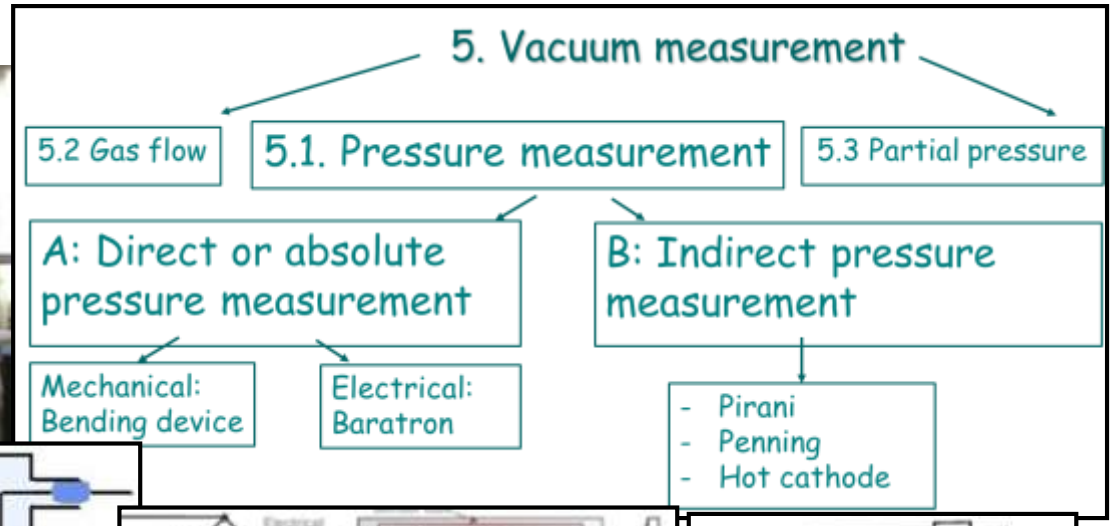

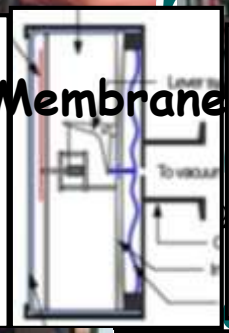

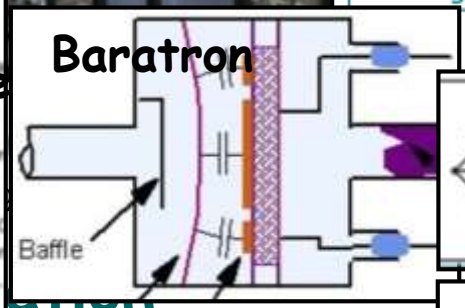

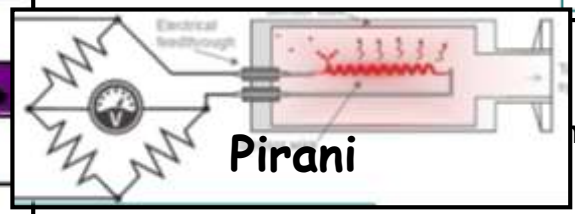

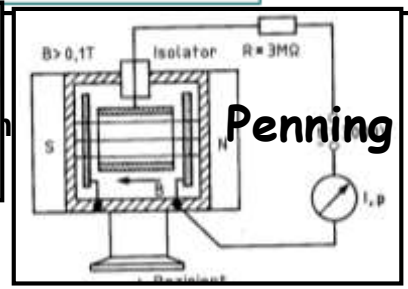

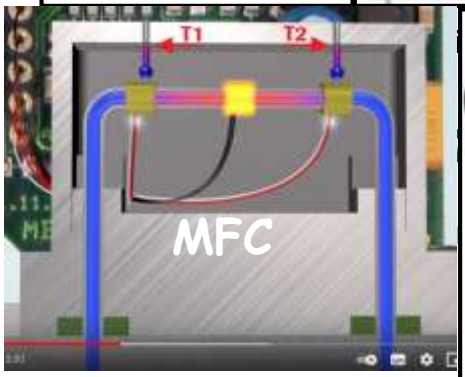

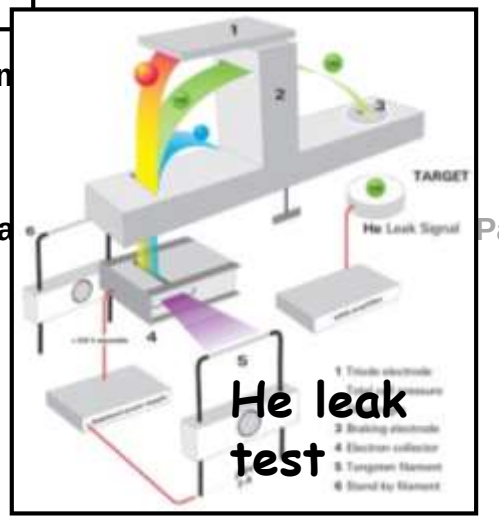

Mass spectrometry

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Partial pressures of an Air leak

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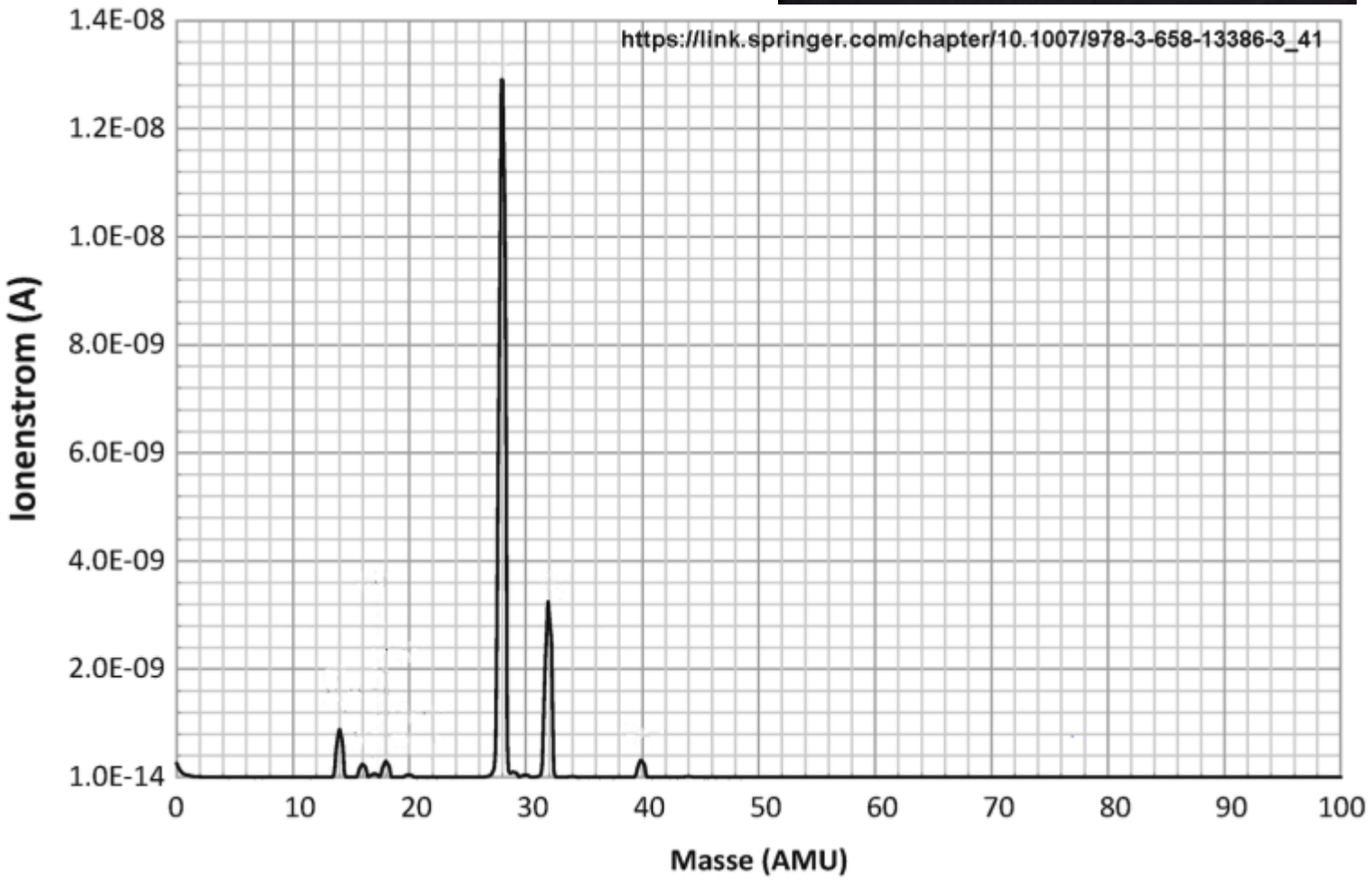

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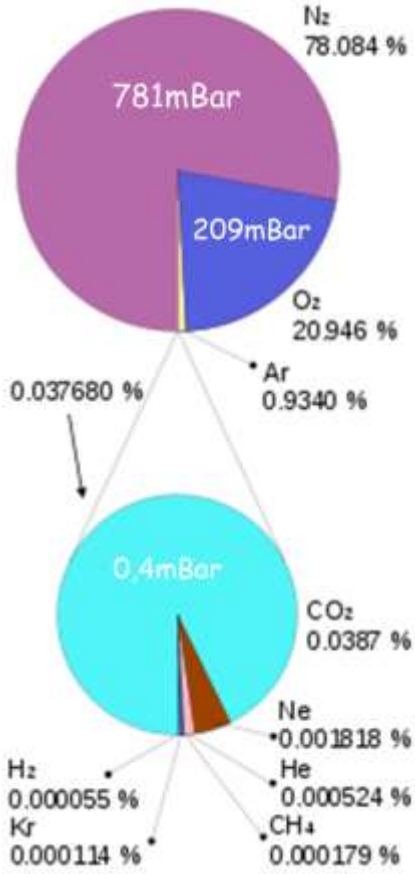

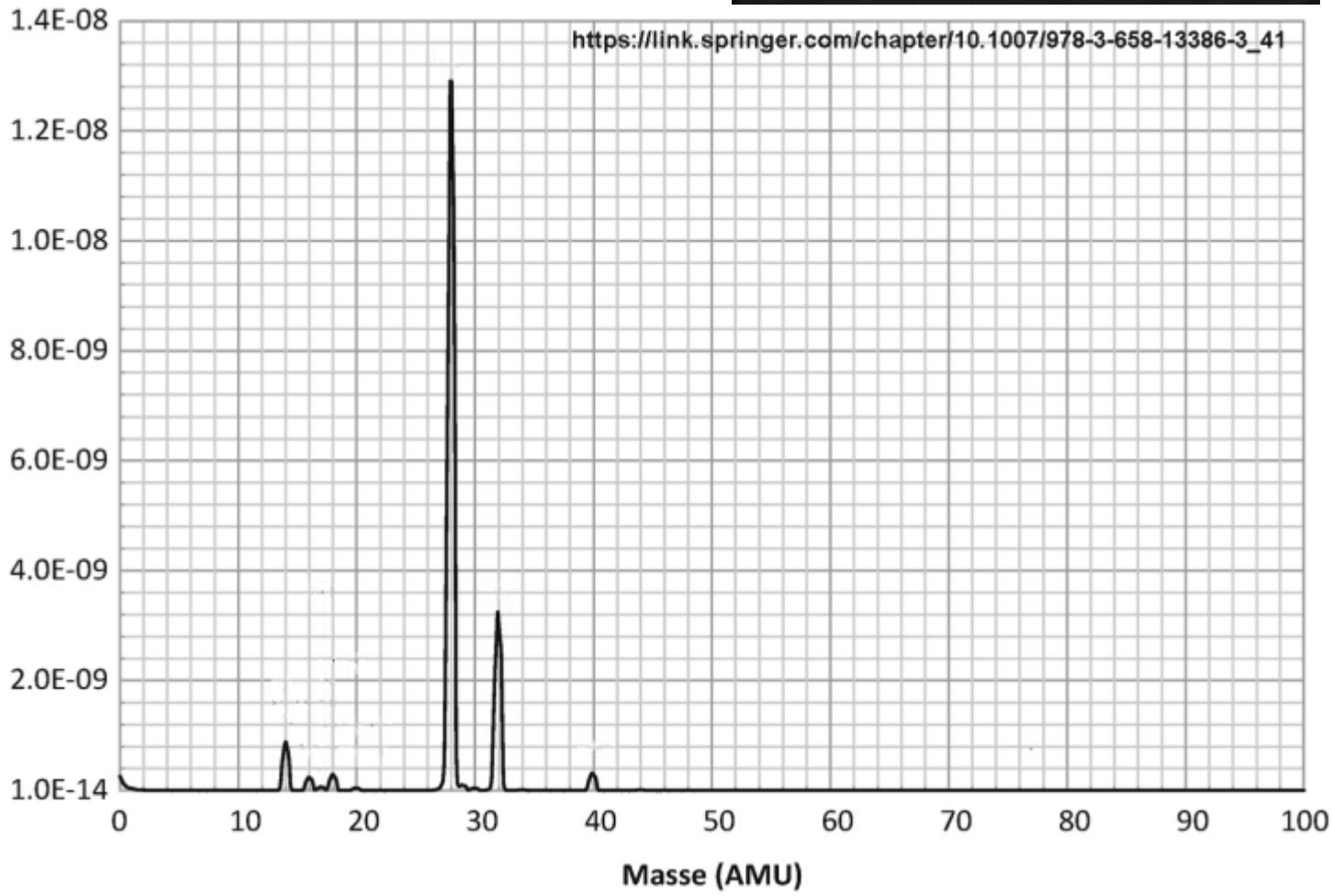

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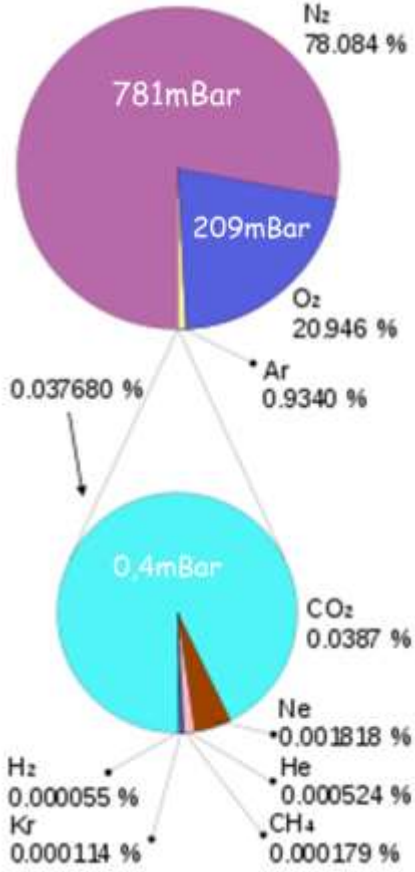

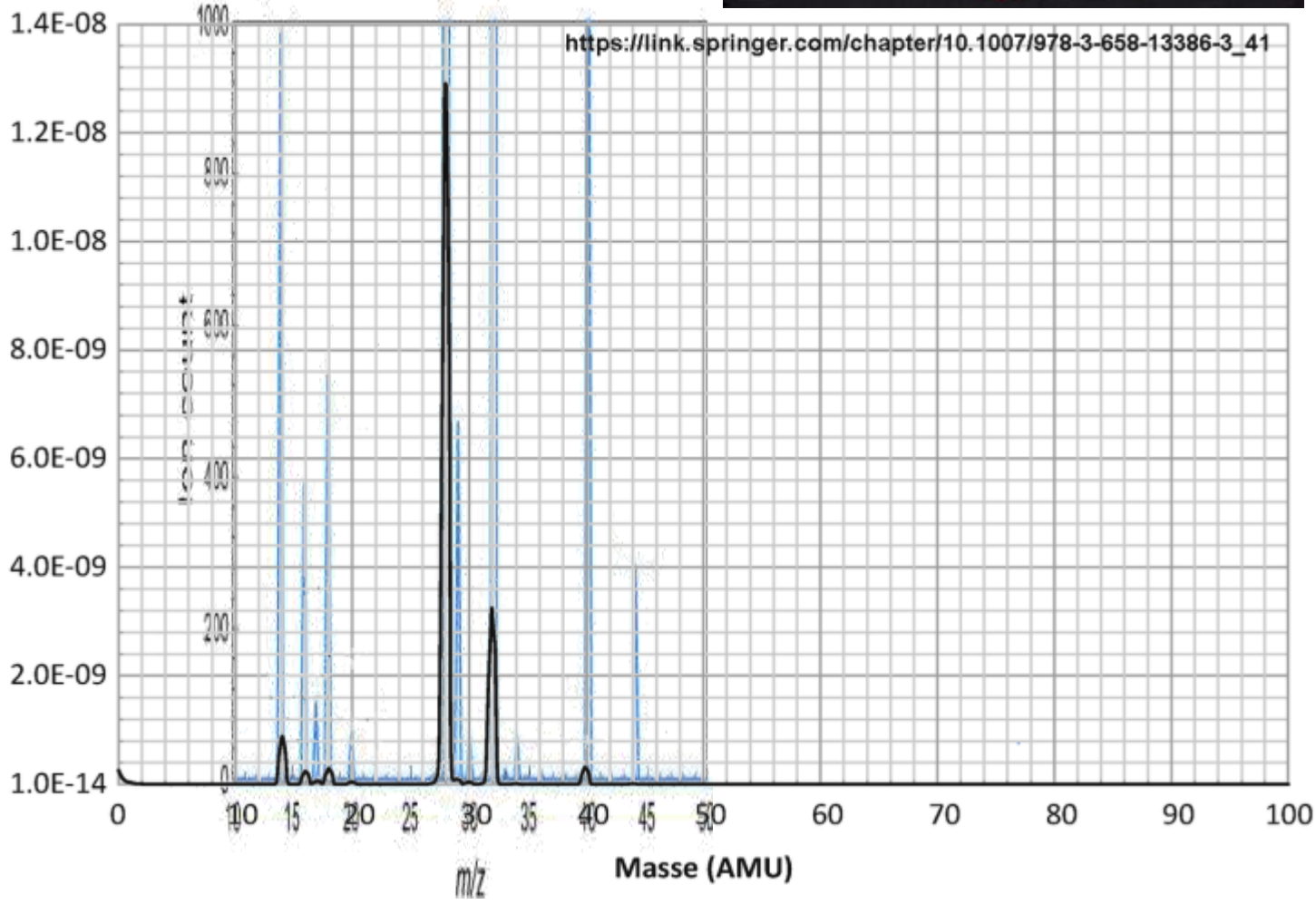

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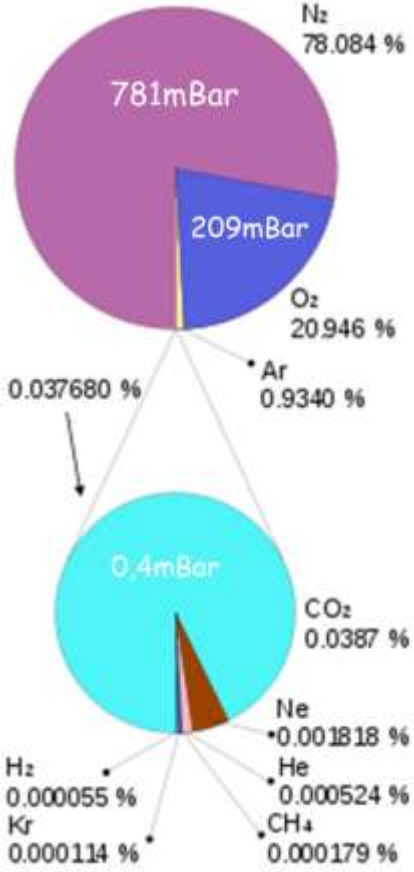
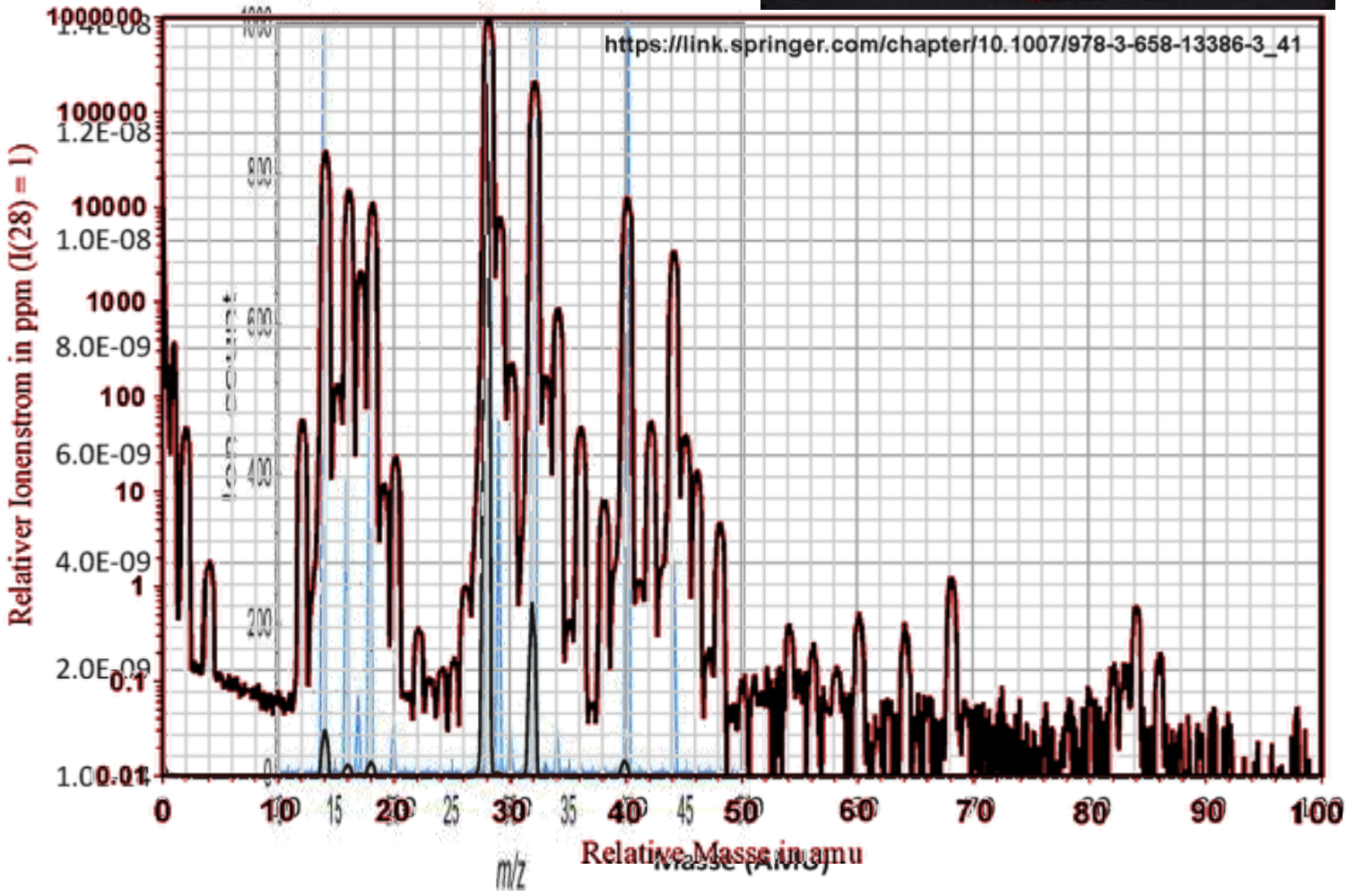
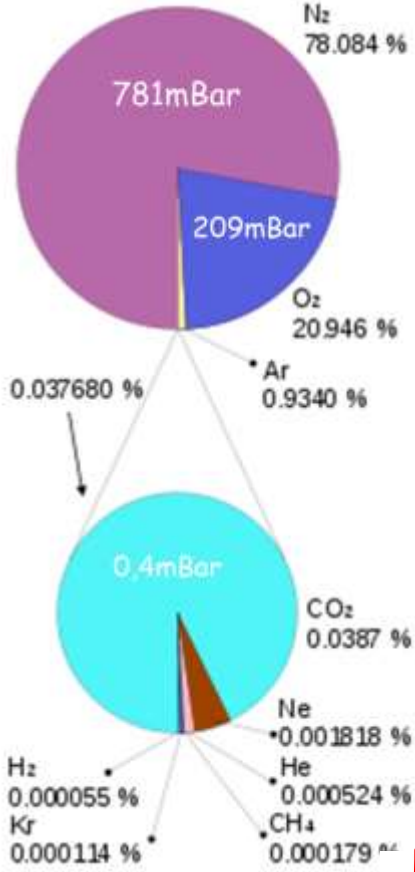
Partial pressures of an Air leak

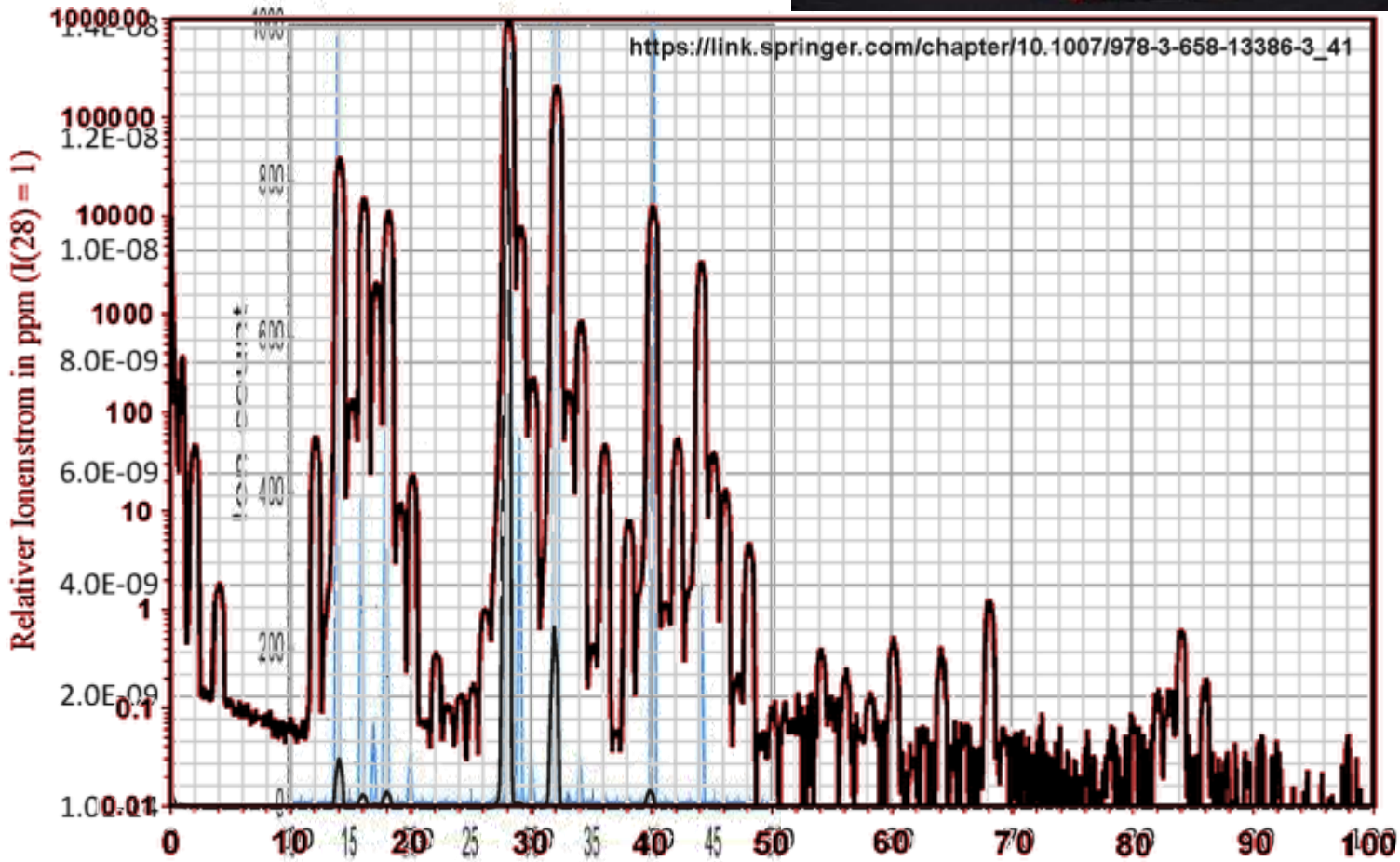




Mass spectrometry

Partial pressures of an Air leak





Log scale very convenient! ppb sensitivity possible!

Application: SIMS for dopant level measurement

Mass spectrometer

https://www.youtube.com/watch?v=NuIH9-6Fm6U

Ion source

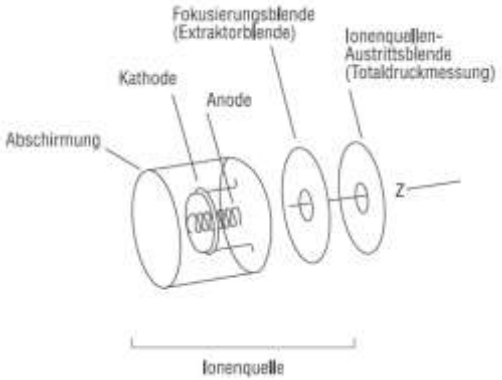
Mass separation

Ion detection

Mass spectrometer

https://www.youtube.com/watch?v=NuIH9-6Fm6U

Ion source



Mass separation

Ion detection

Mass spectrometer

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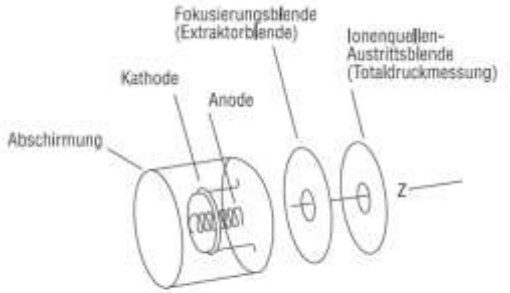

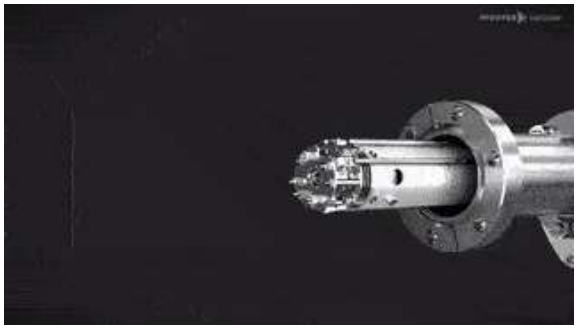

Mass separation

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Mass spectrometer

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Ion source

Mass separation

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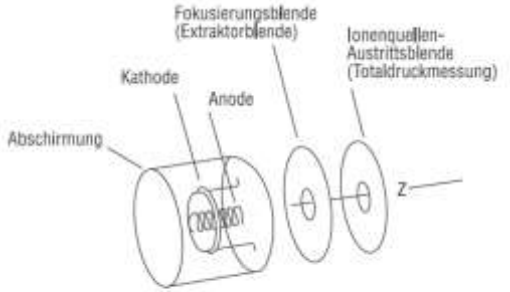
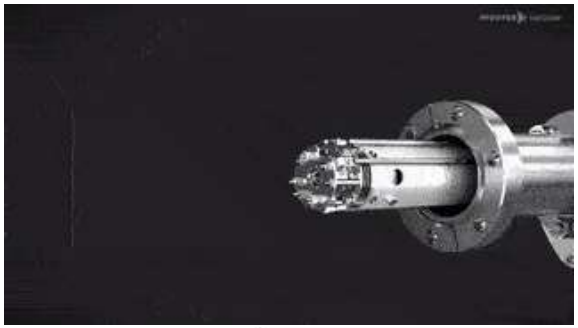
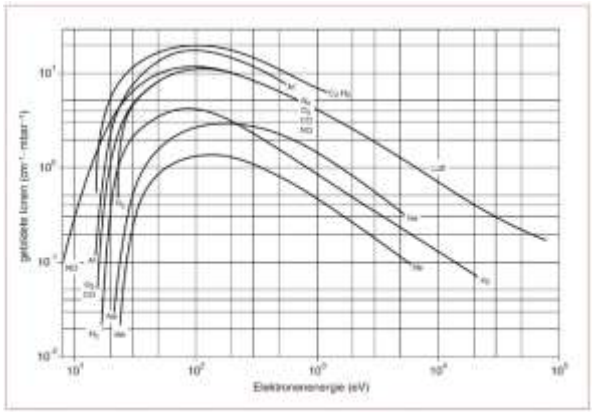




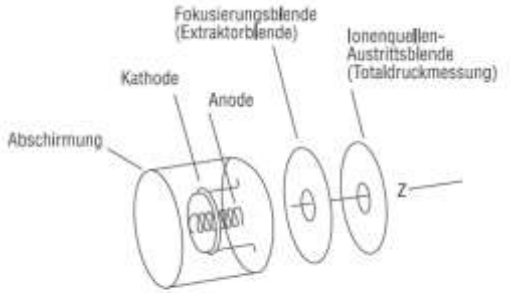


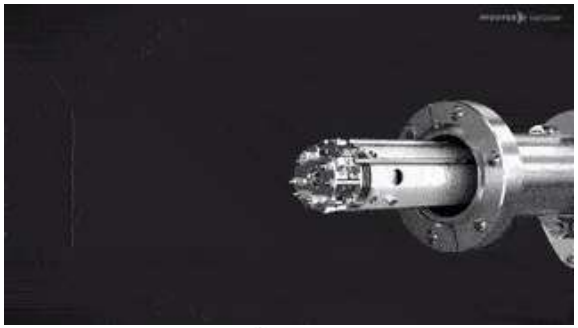
Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

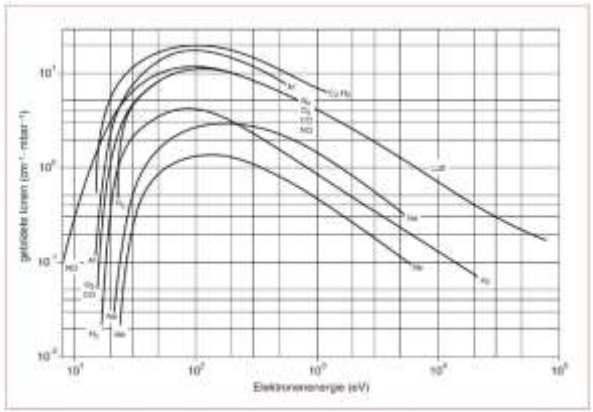
Mass spectrometer

https://www.youtube.com/watch?v=NuIH9-6Fm6U

Ion source







Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

Mass separation

↓

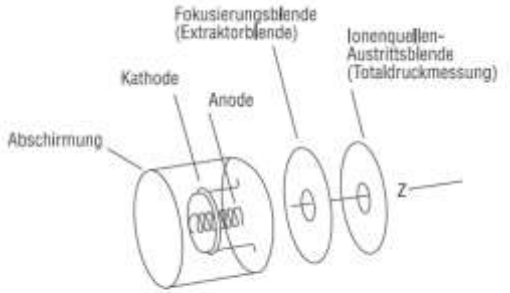
Magnetic field

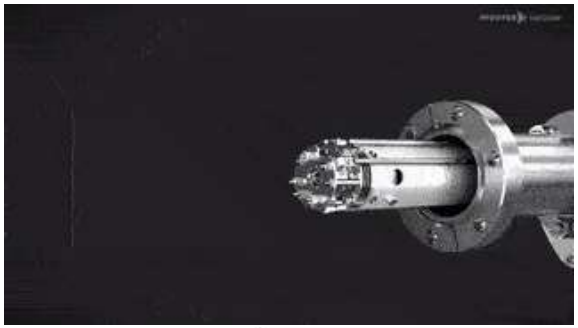
Ion detection

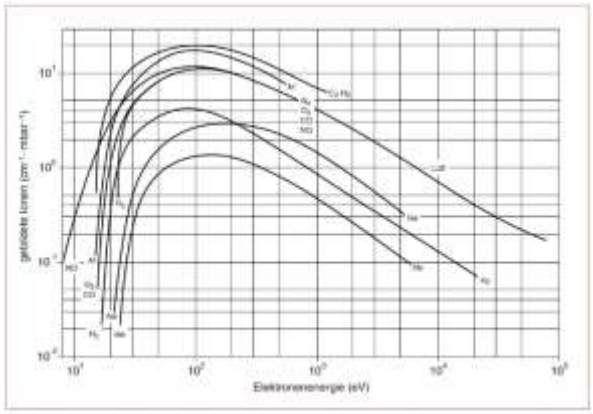
Mass spectrometer

https://www.youtube.com/watch?v=NuIH9-6Fm6U

Ion source







Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

Mass separation

↓

Magnetic field

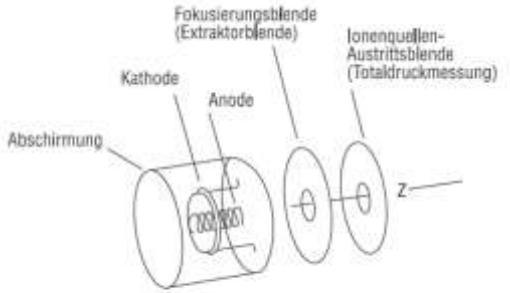
Time of flight

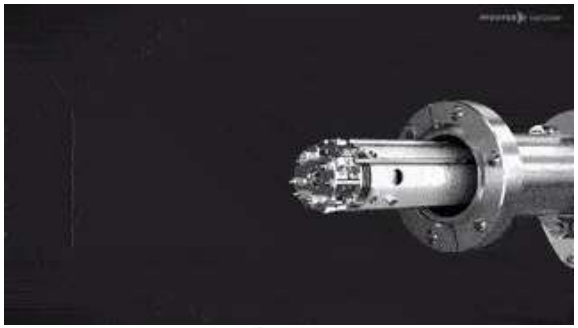
Ion detection

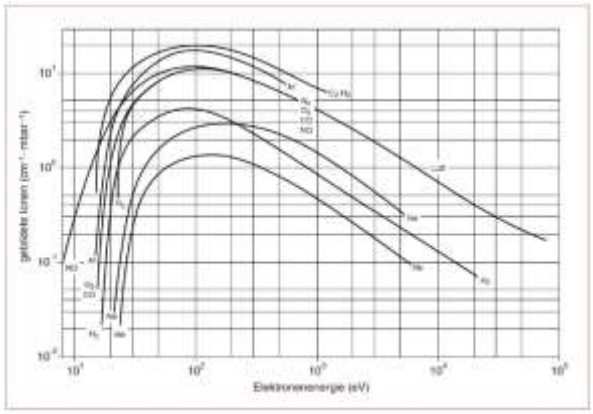
Mass spectrometer

https://www.youtube.com/watch?v=NuIH9-6Fm6U

Ion source







Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

Mass separation

↓

Magnetic field

Time of flight

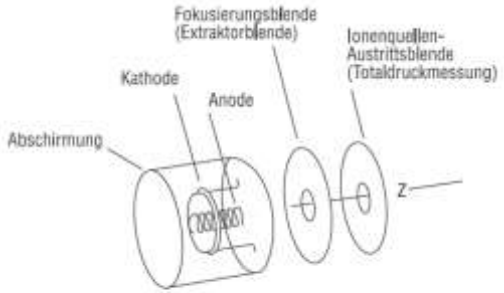
Quadrupol

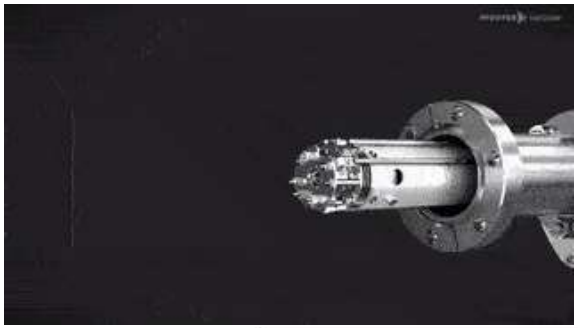
Ion detection

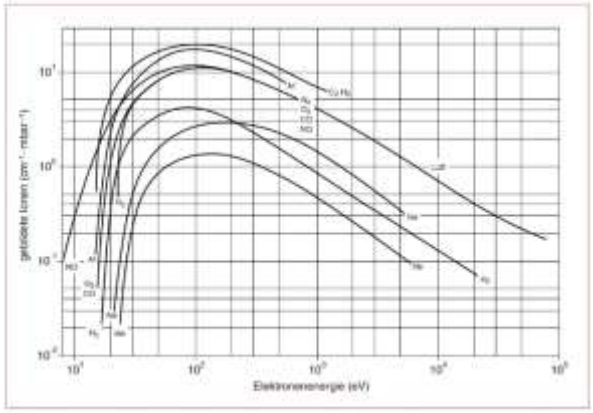
Mass spectrometer

https://www.youtube.com/watch?v=NuIH9-6Fm6U

Ion source







Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

Mass separation

↓

Magnetic field

Time of flight

Quadrupol

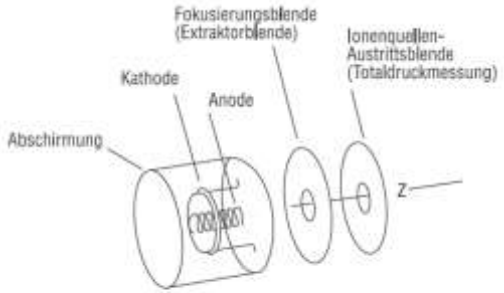
Ion detection

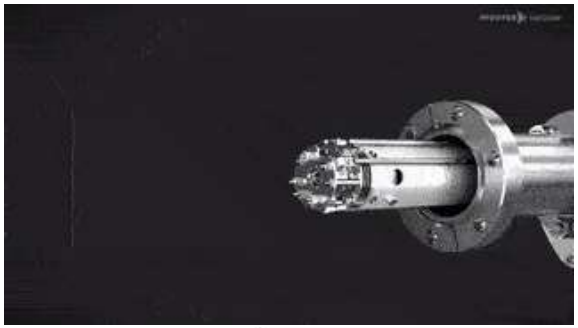
Faraday Cup

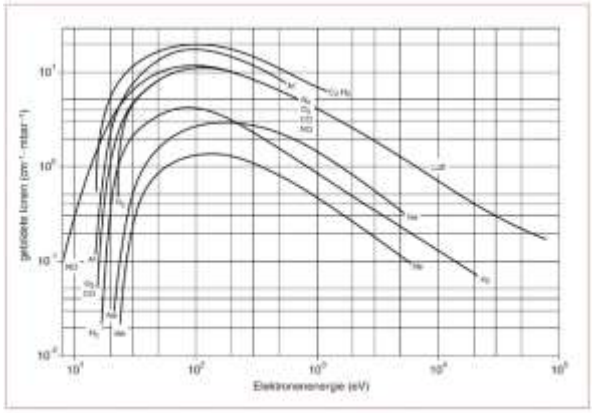
Mass spectrometer

https://www.youtube.com/watch?v=NuIH9-6Fm6U

Ion source







Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

Mass separation

↓

Magnetic field

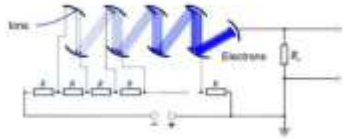
Time of flight

Quadrupol

Ion detection

Faraday Cup

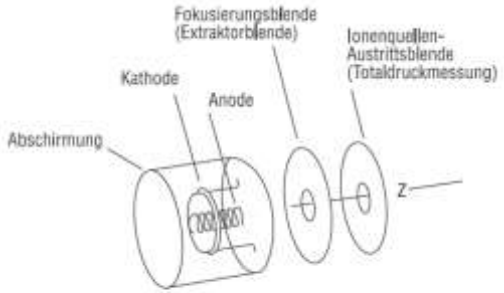
Multiplier

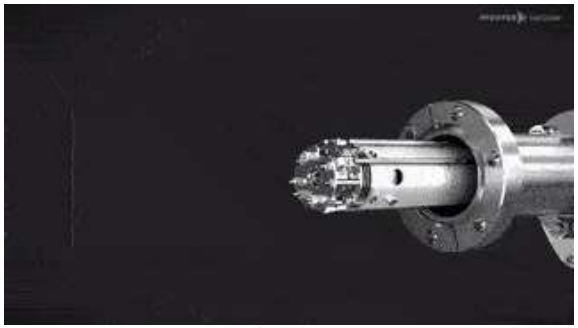


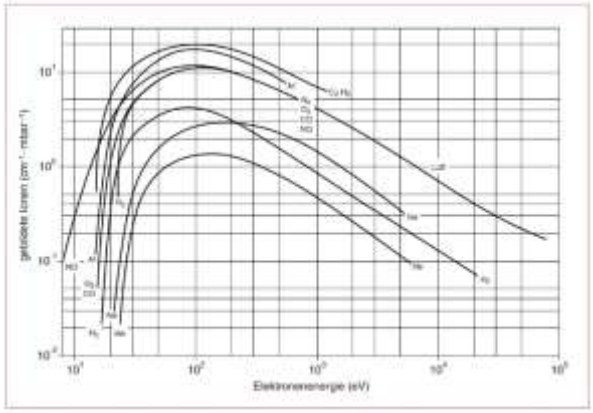
Mass spectrometer

https://www.youtube.com/watch?v=NuIH9-6Fm6U

Ion source







Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

Mass separation

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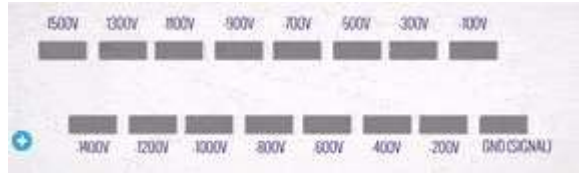

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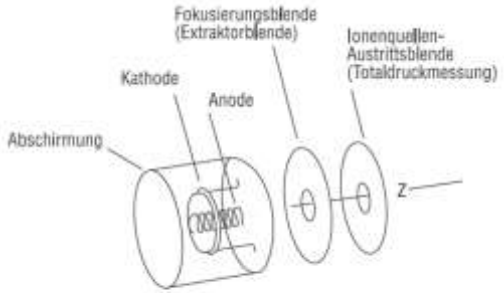

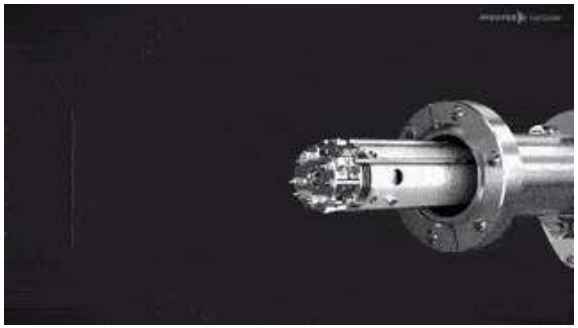

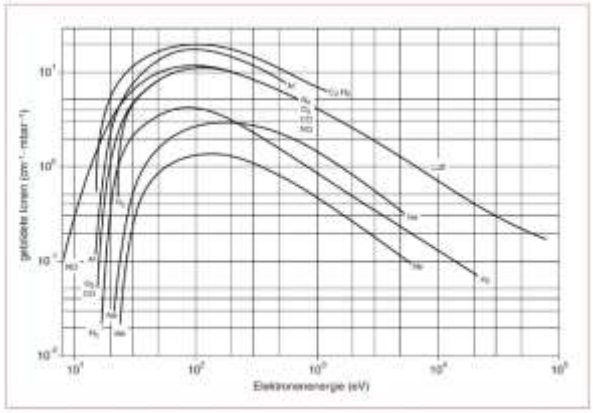

Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

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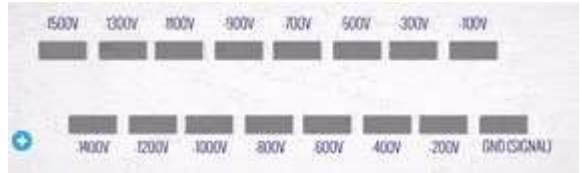
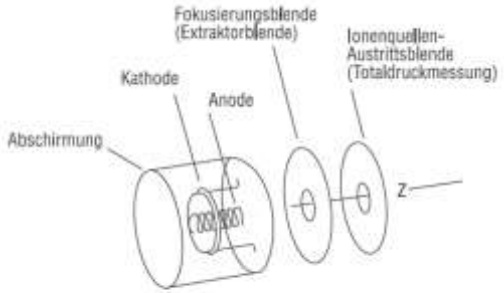


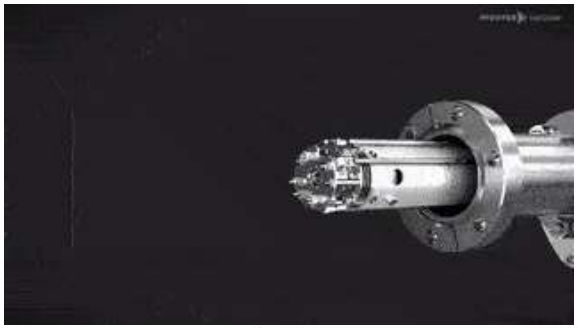
Channeltron

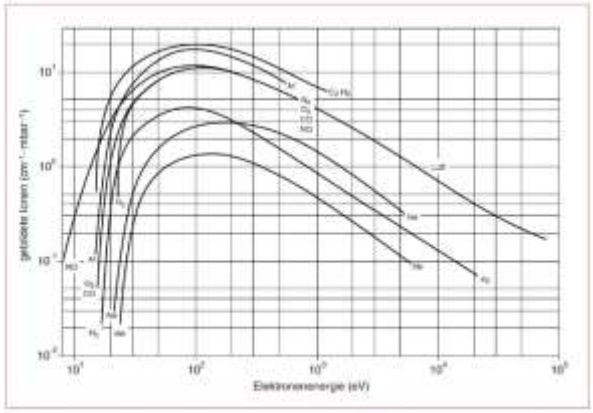
Mass spectrometer

https://www.youtube.com/watch?v=NuIH9-6Fm6U

Ion source







Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

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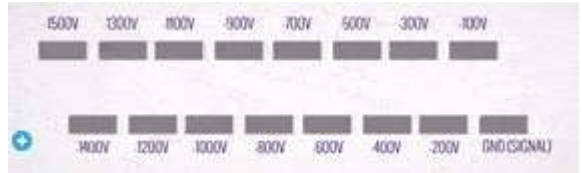

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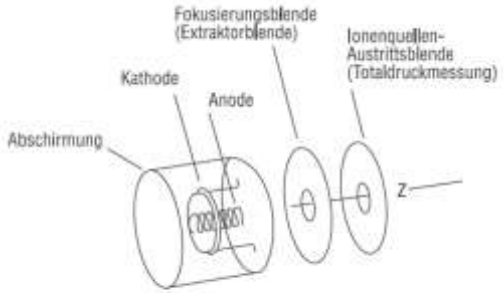

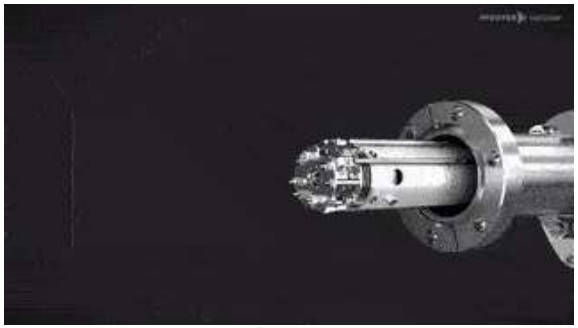

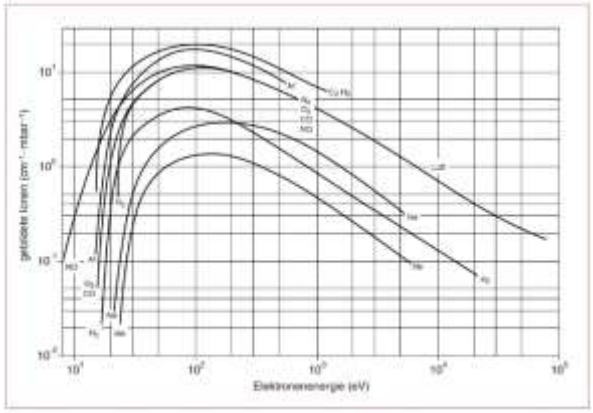

Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

Mass separation

↓

Magnetic field

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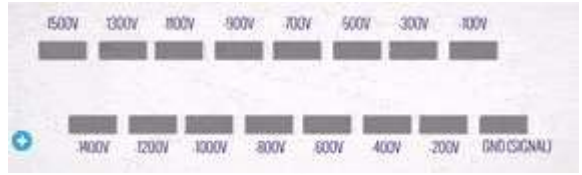
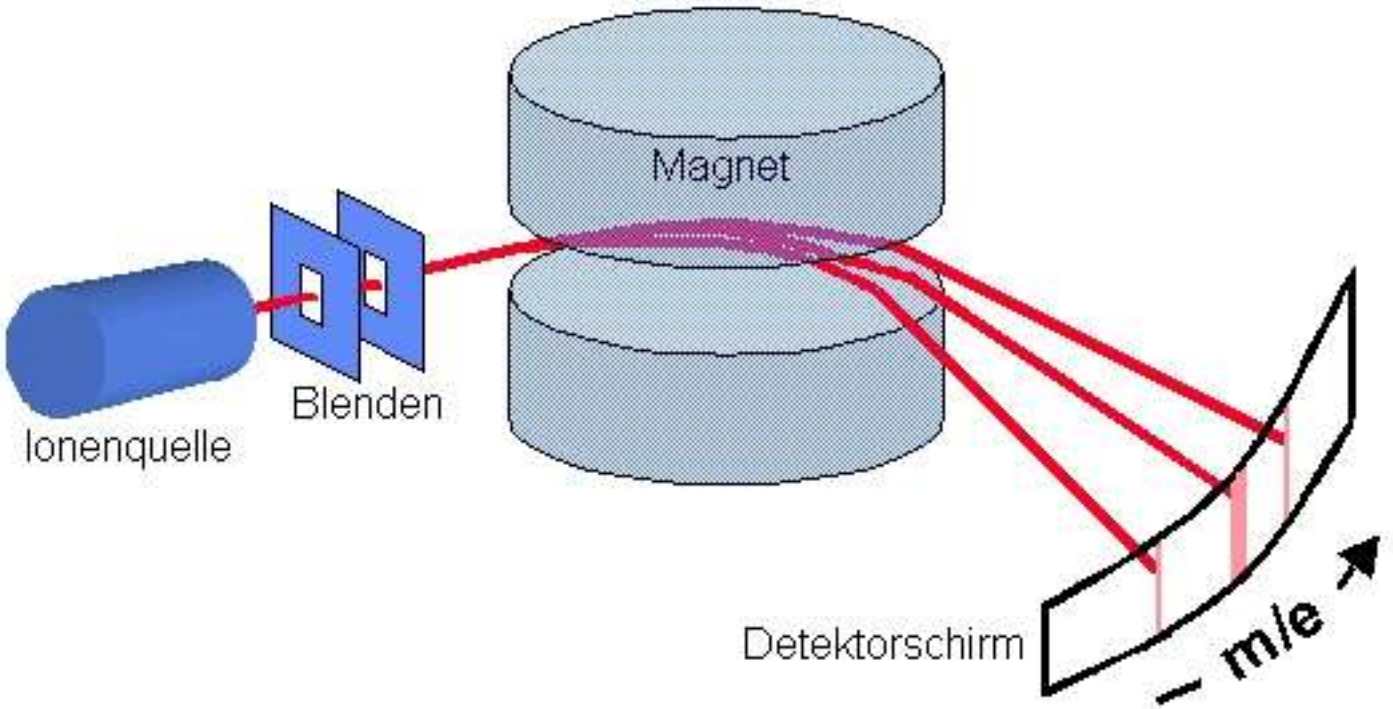
Faraday Cup

Multiplier

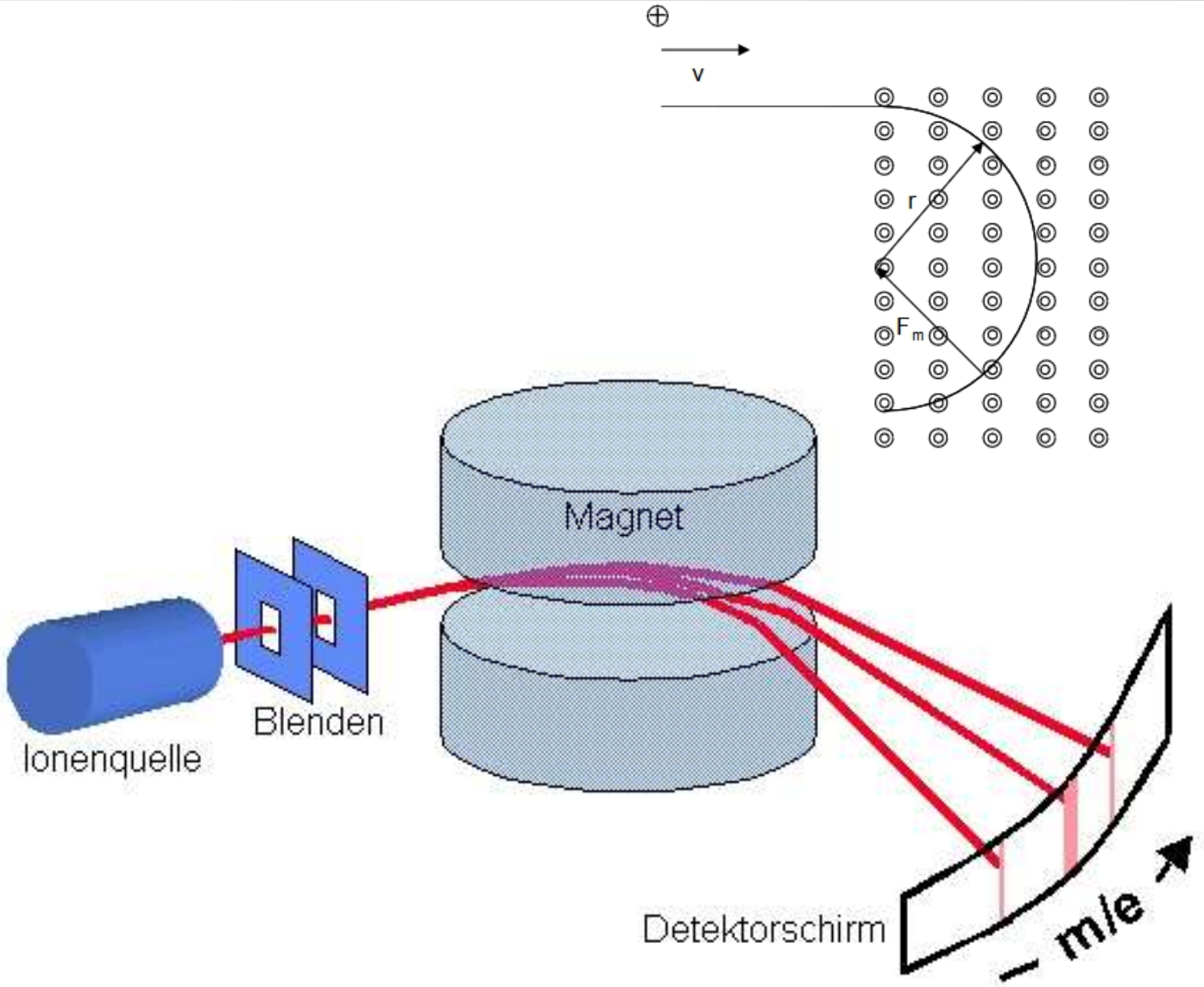


Channeltron

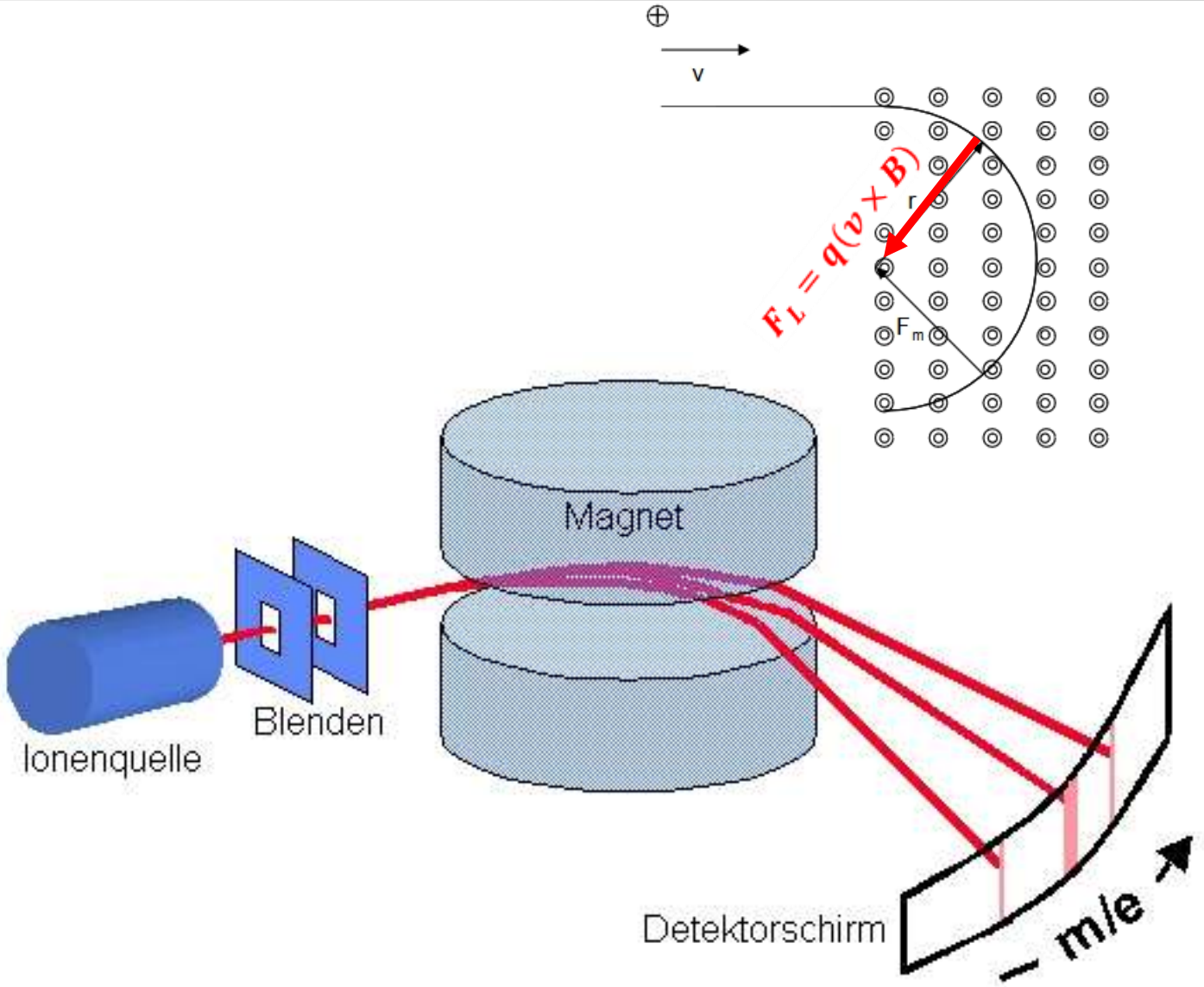
Magnetic filter



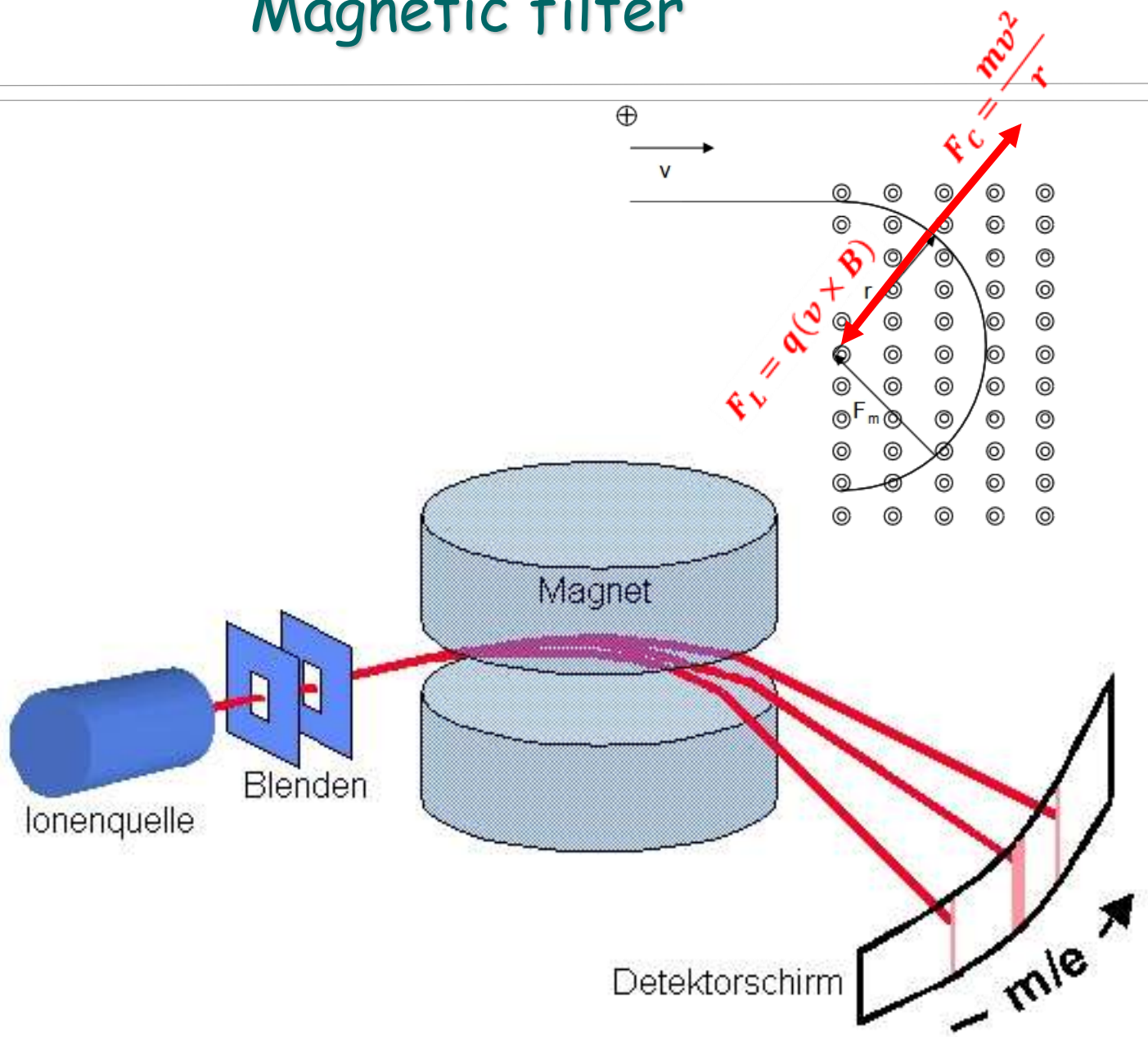
Magnetic filter



Magnetic filter



Magnetic filter



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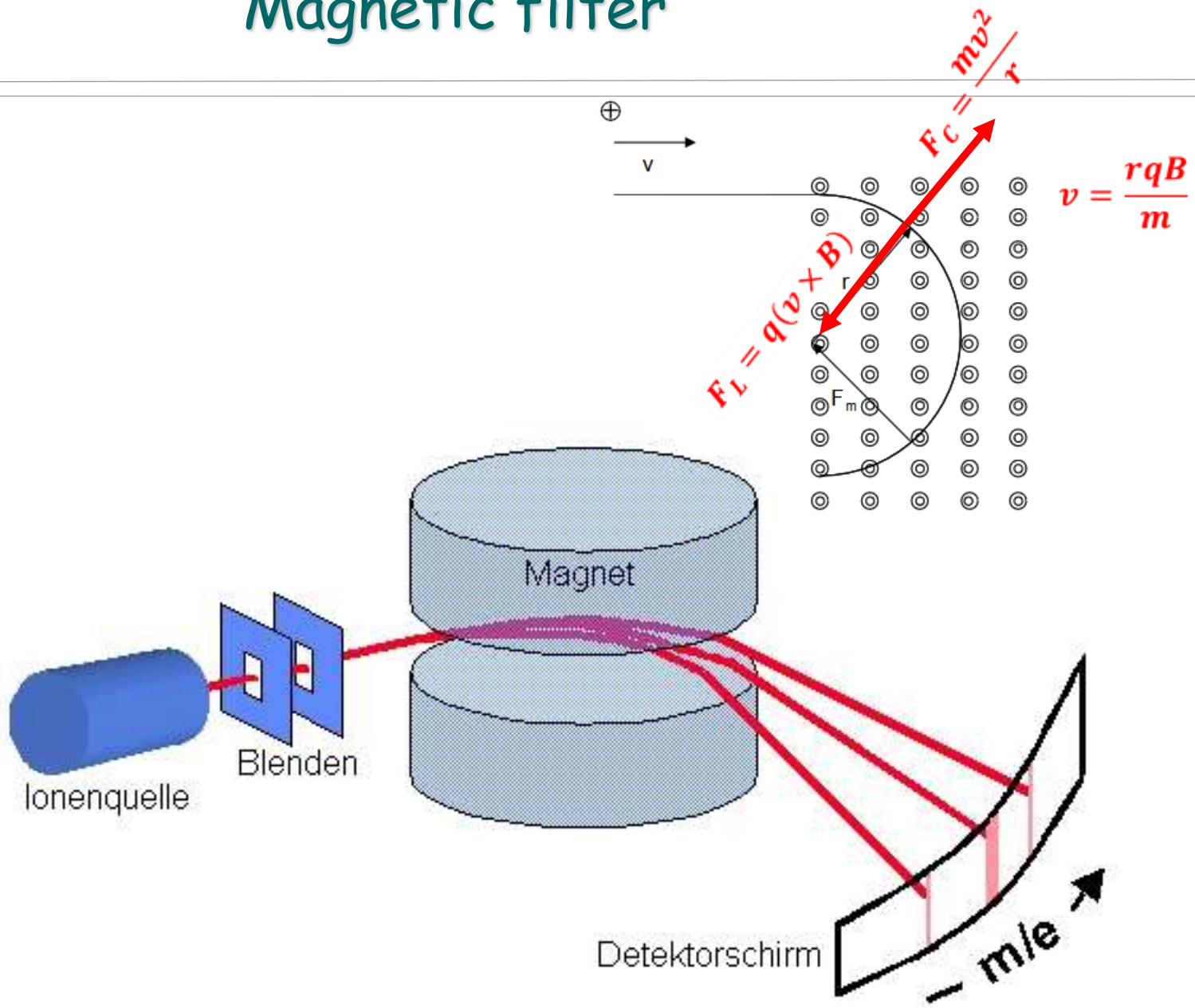
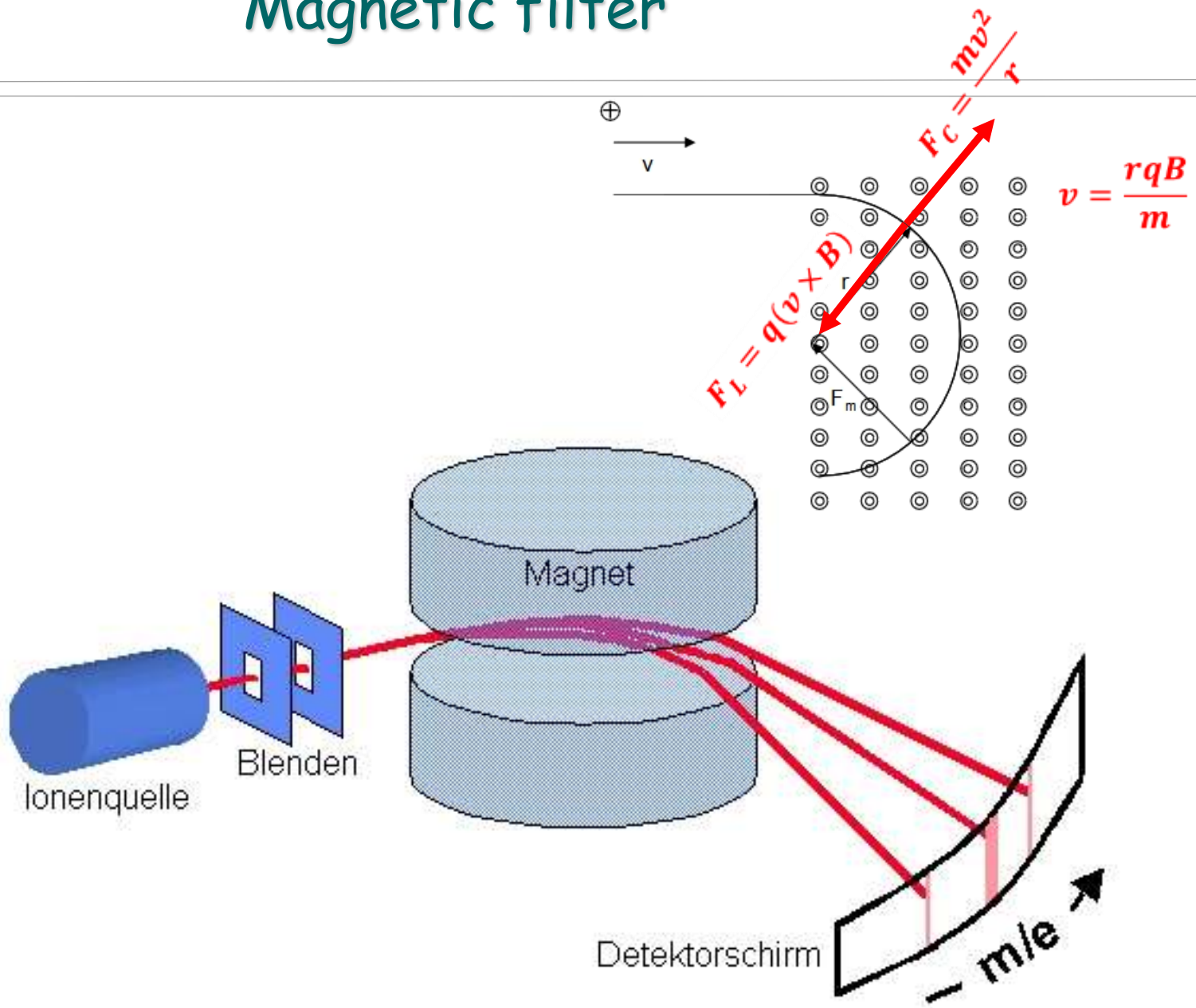


Magnetic filter



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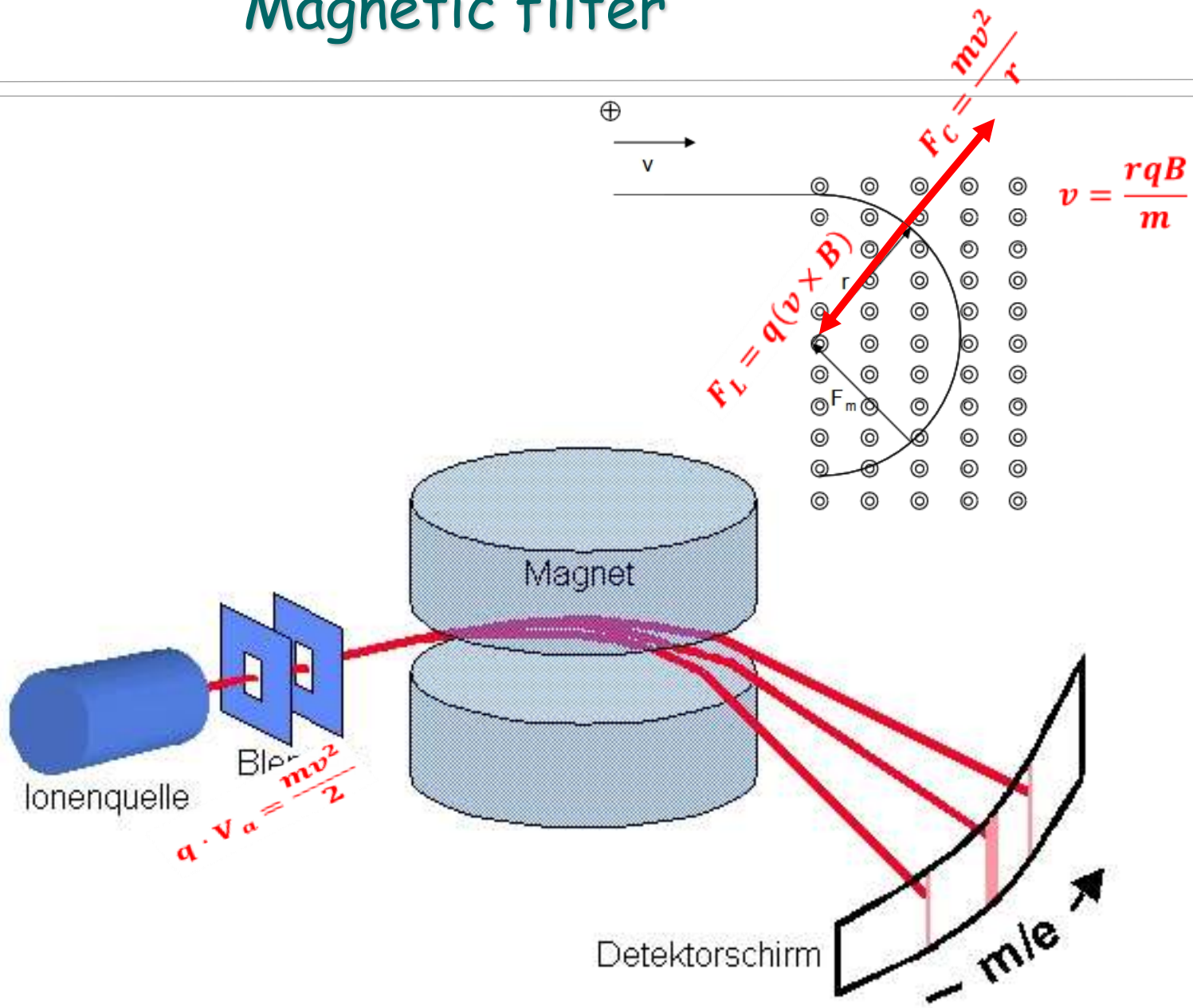
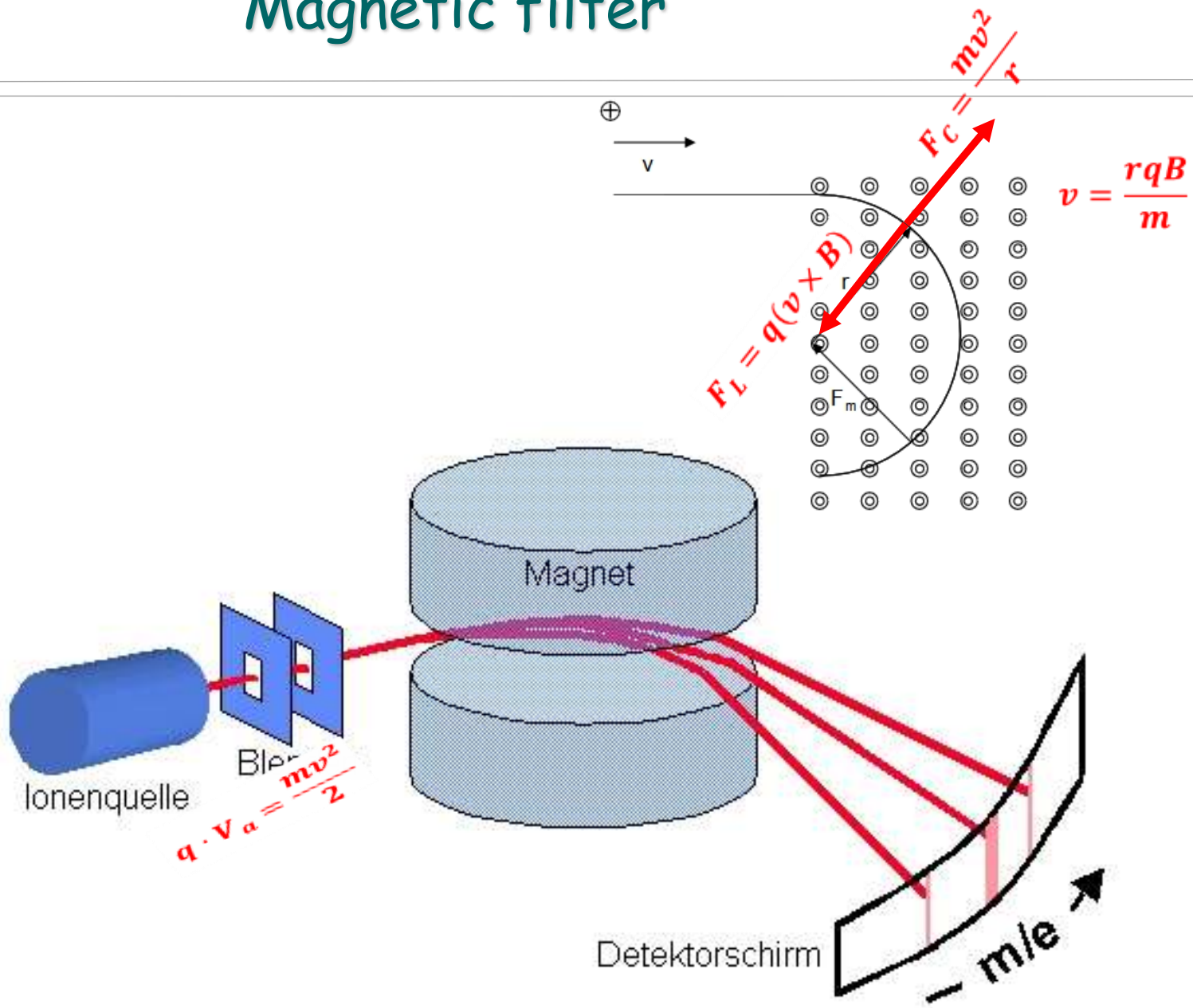


Magnetic filter



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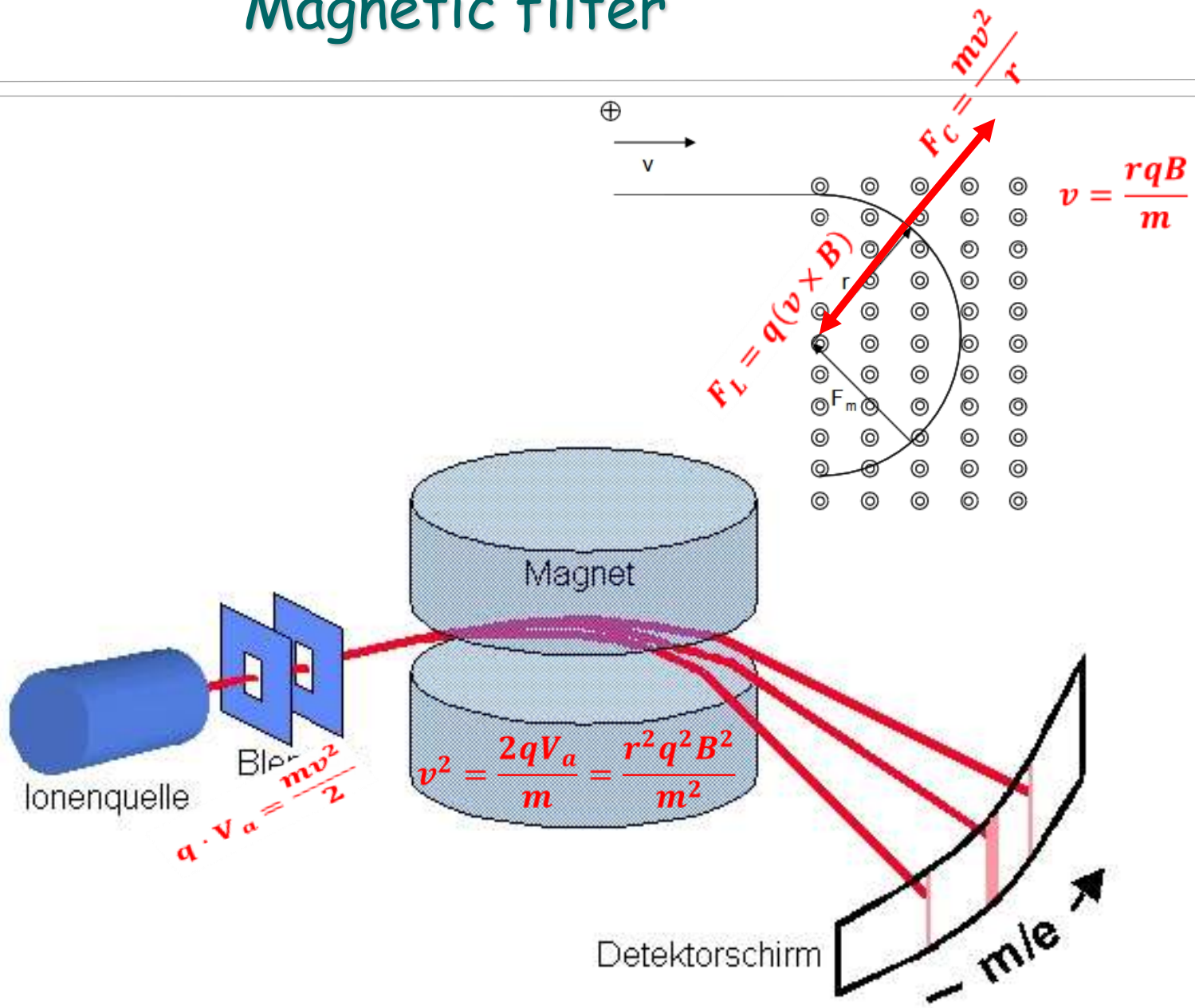

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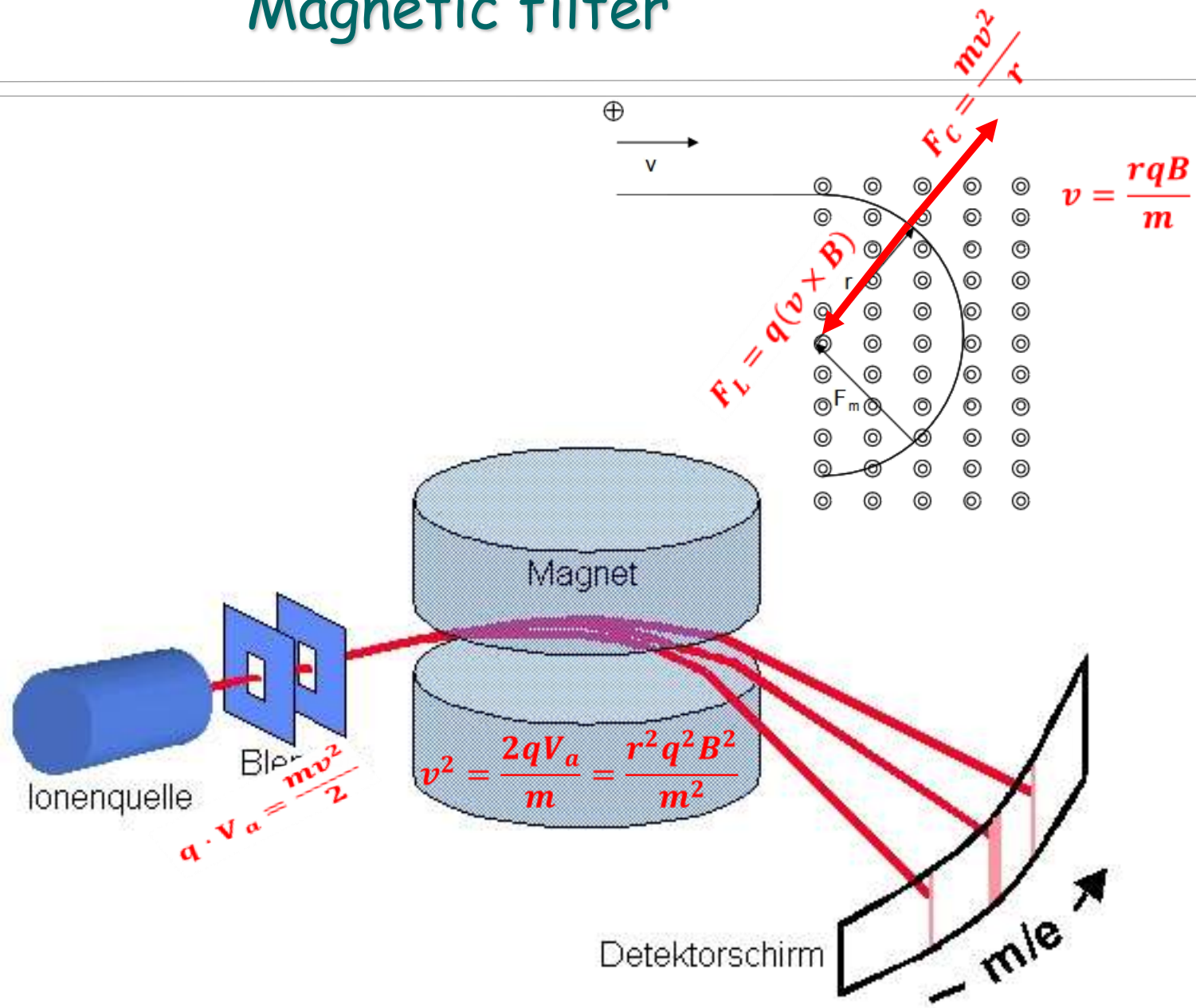
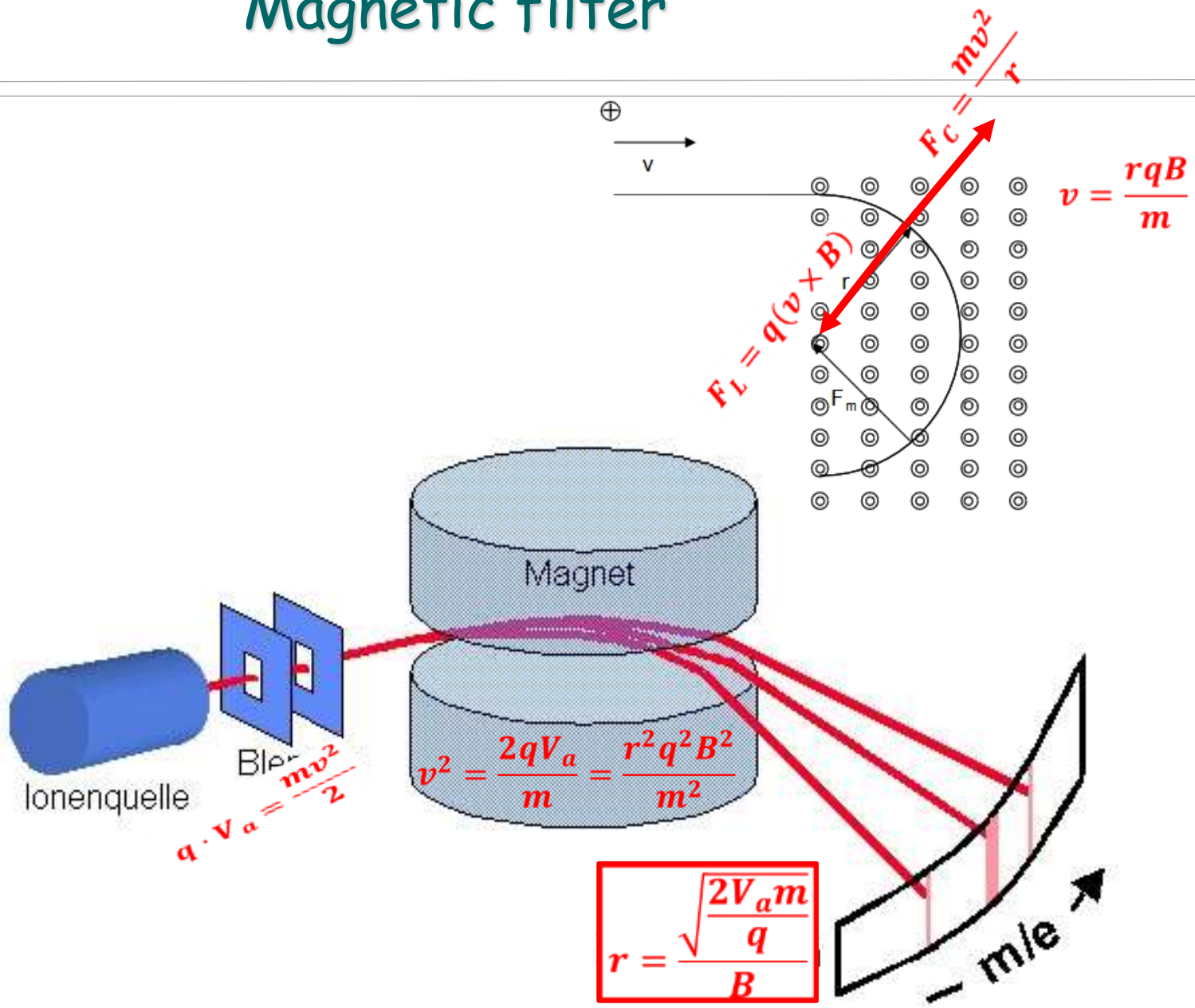
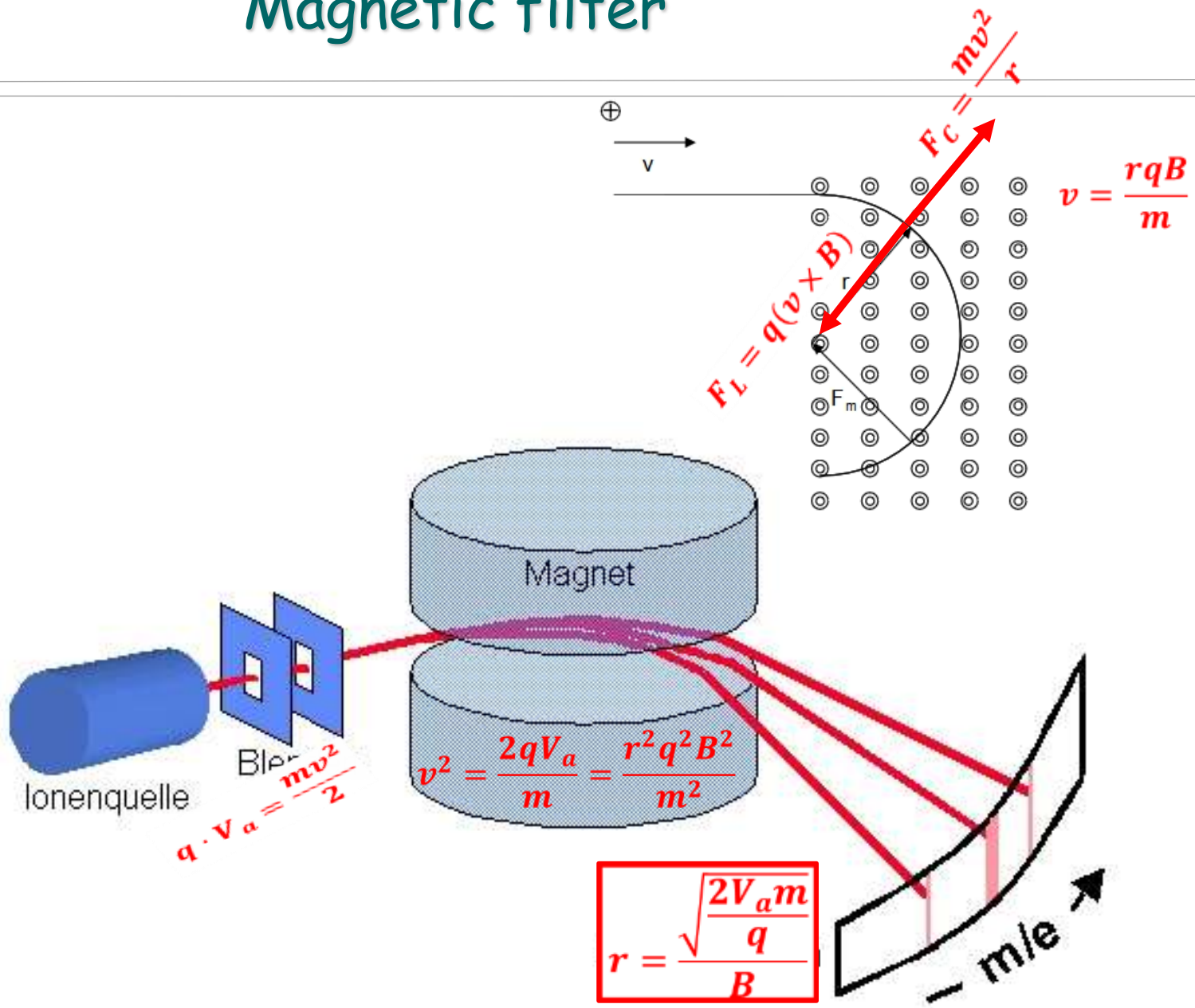


Magnetic filter



Magnetic filter



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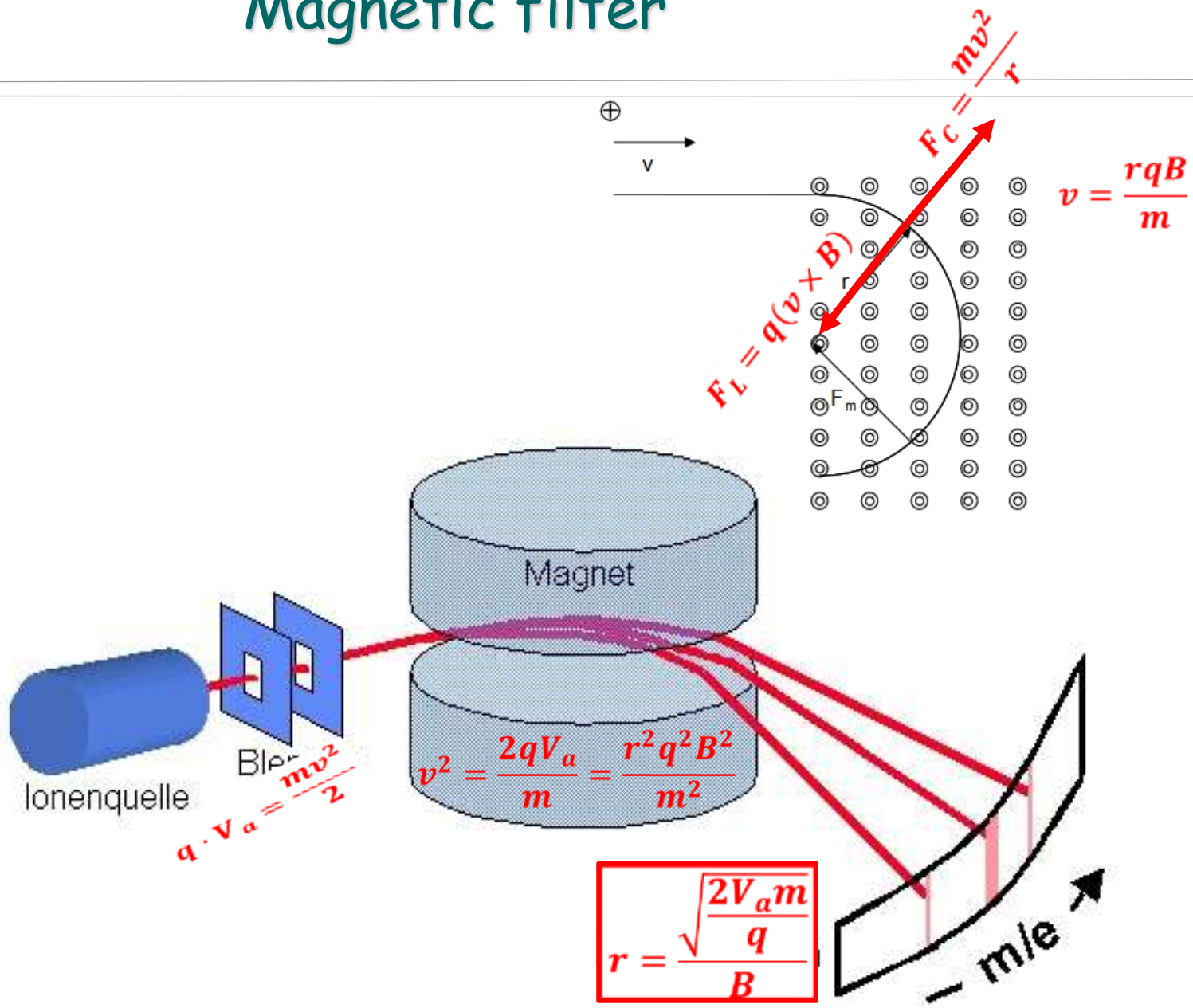
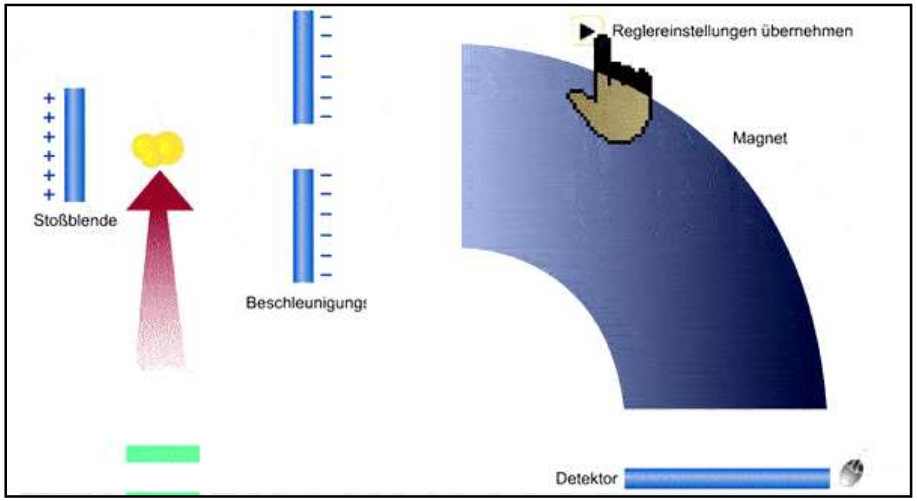
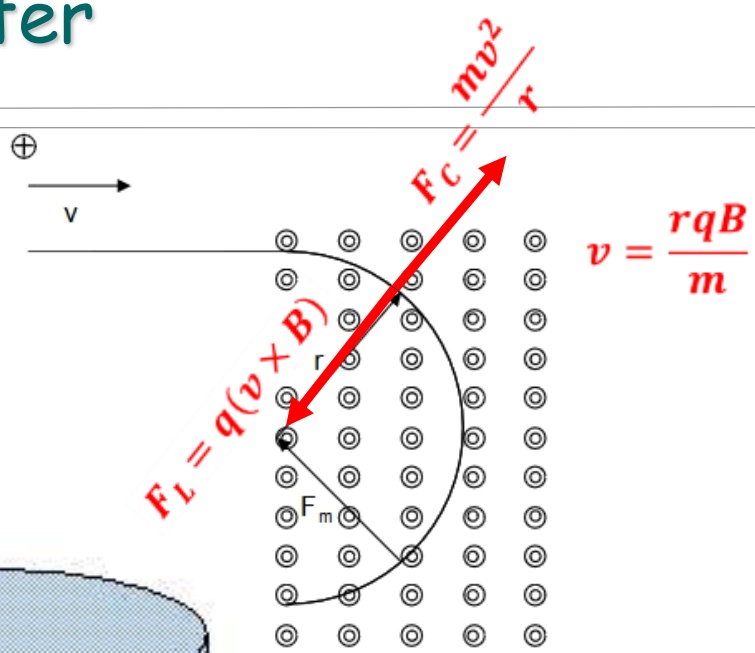


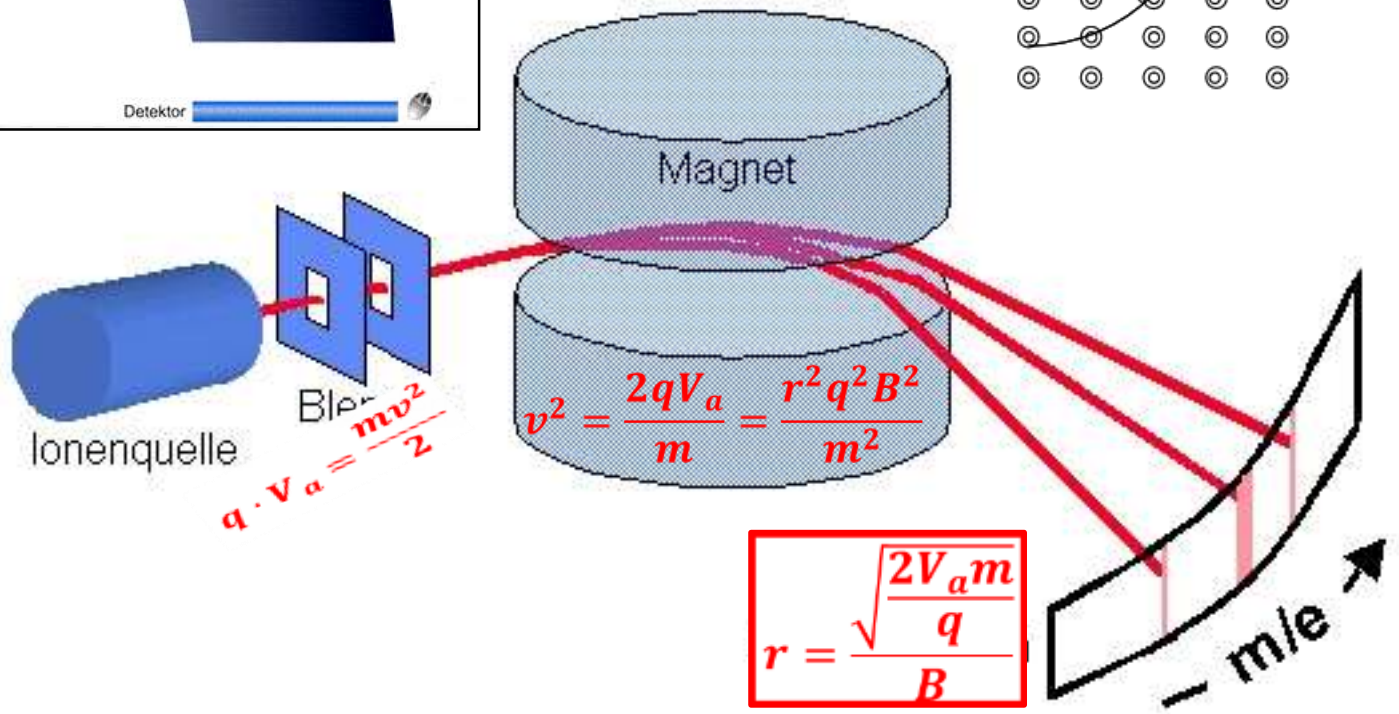
http://www.abi-physik.de/buch/das-magnetfeld/massenspektrometer/

Magnetic filter



http://www.chemgapedia.de/vsengine/vlu/vsc/de/ch/3/anc/masse/ms_massenanalysator_magnet.vlu/Page/vsc/de/ch/3/anc/masse/2_massenspektrometer/2_4_massenanalysator/2_4_1_magnetfeld/2_4_1_2_mess_magnetf/anschaul/magnet_an_m30ht1102.vscml.html

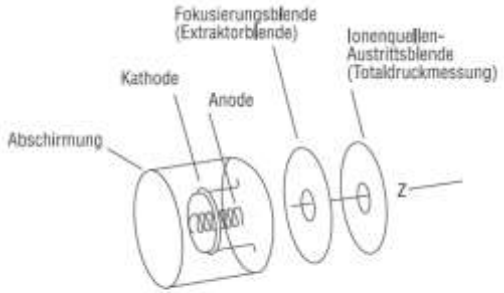


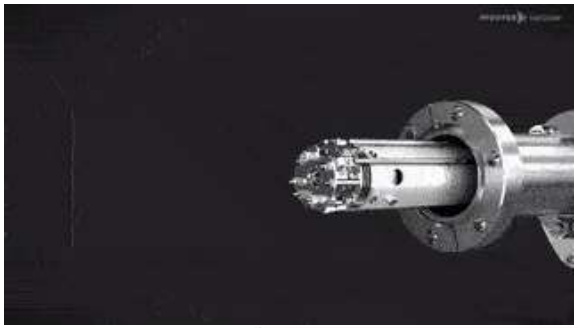


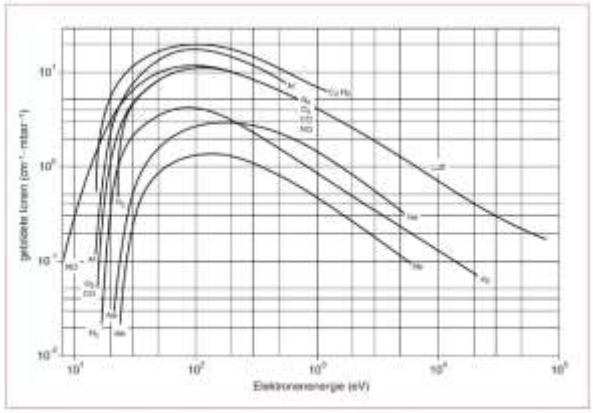
http://www.abi-physik.de/buch/das-magnetfeld/massenspektrometer/

Mass spectrometer

Ion source







Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

Mass separation

↓

Magnetic field

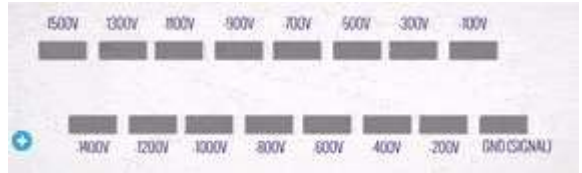
Time of flight

Quadrupol

Ion detection

Faraday Cup

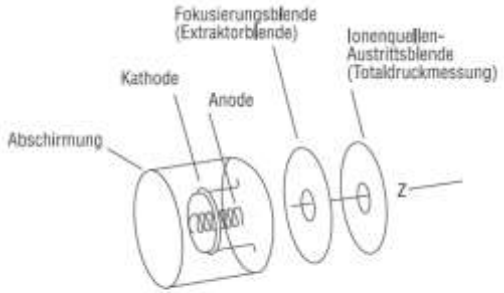
Multiplier

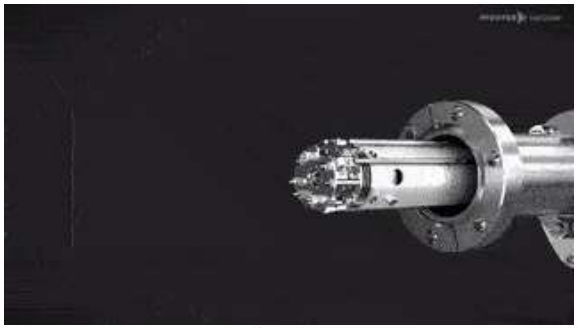


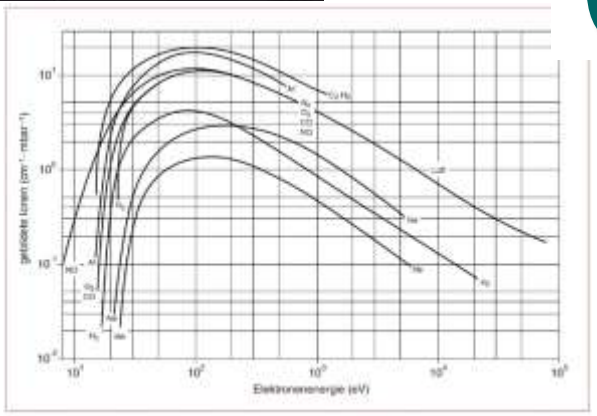
Channeltron

Mass spectrometer

Ion source







Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

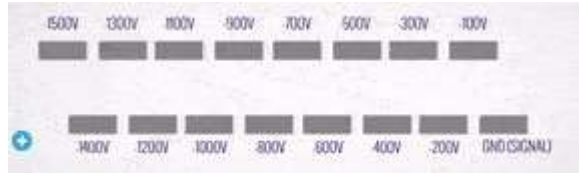
Mass separation

Time of flight (TOF)

Ion detection

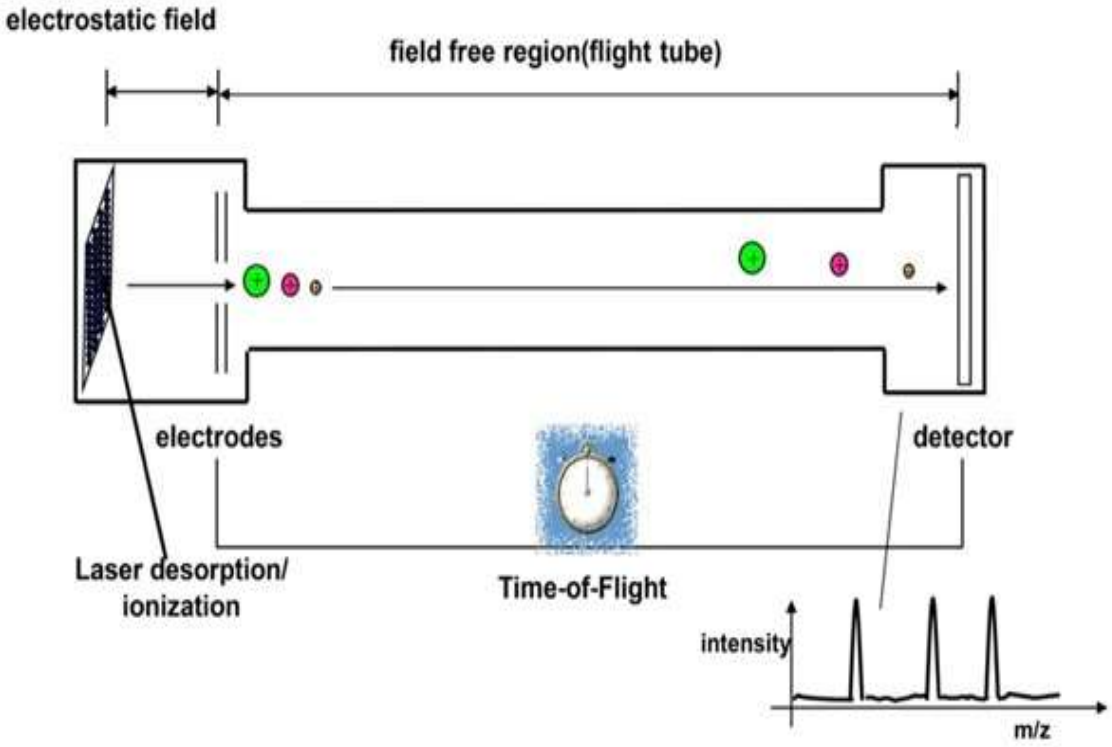
Faraday Cup

Multiplier

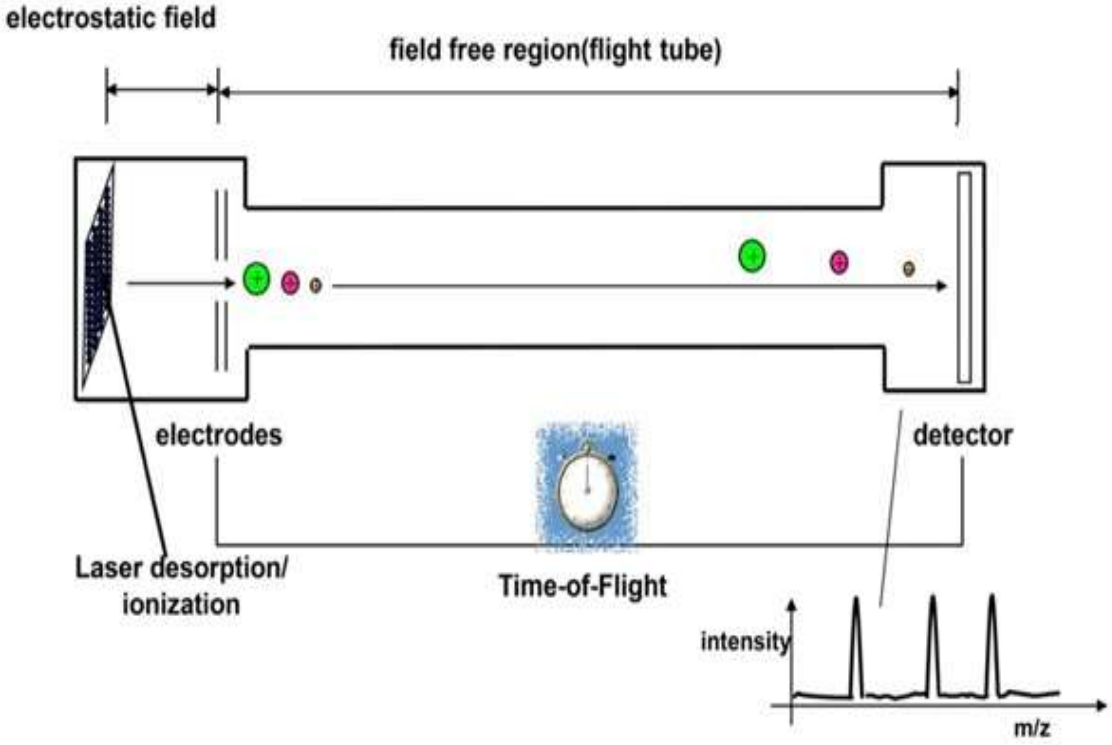


Channeltron

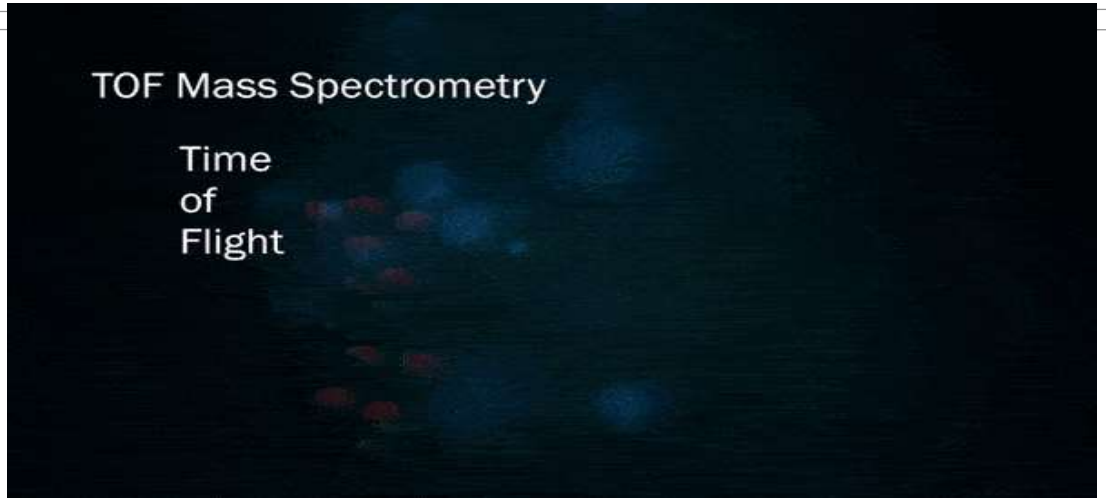
Time of flight filter



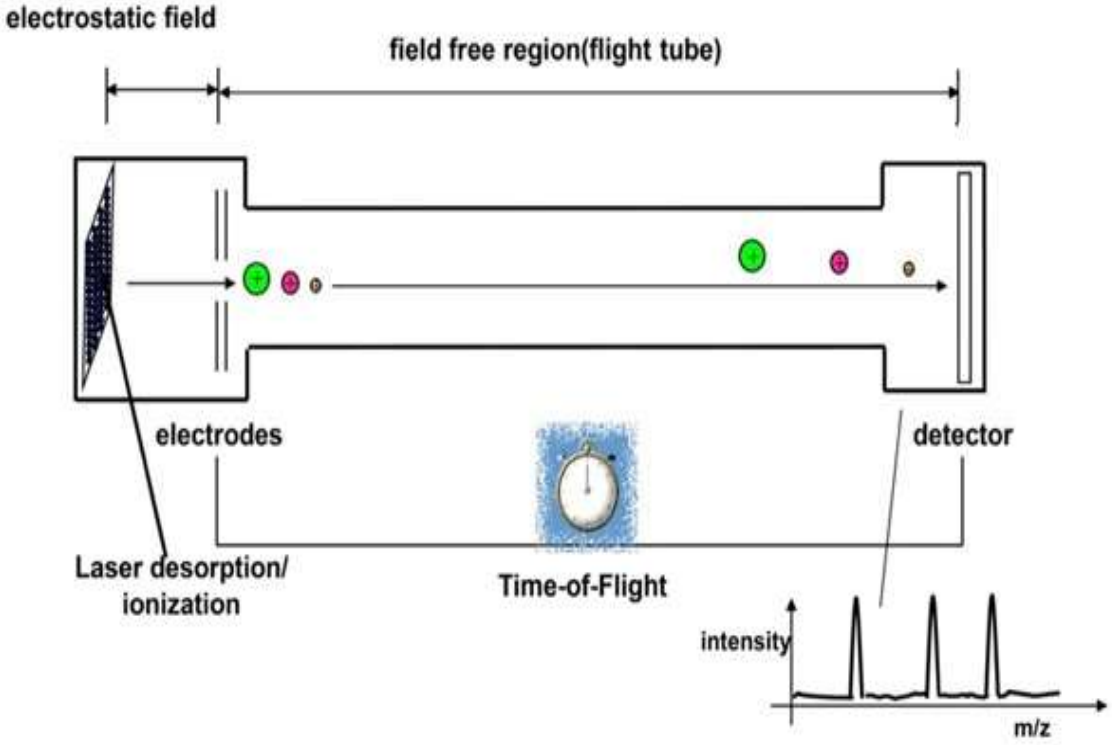
Time of flight filter



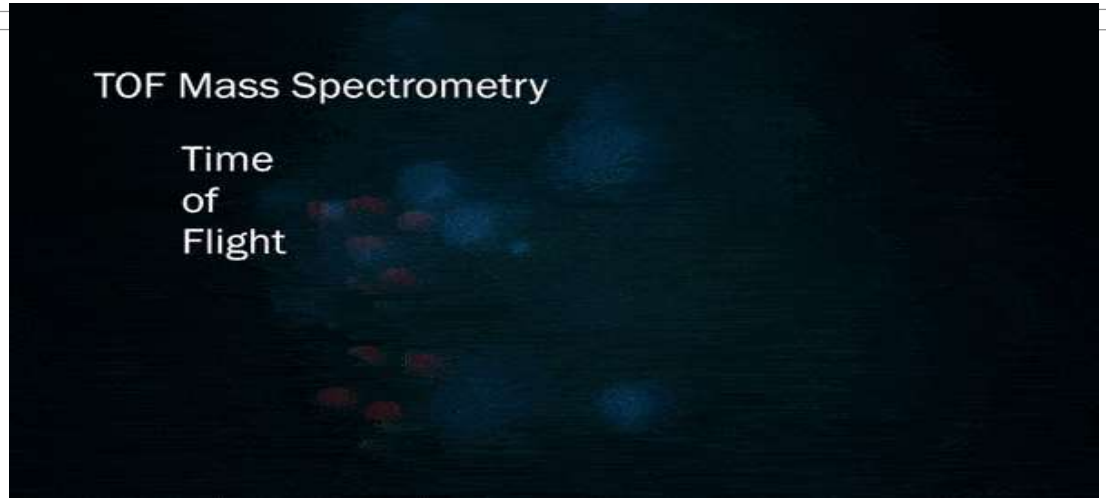
Time of flight filter



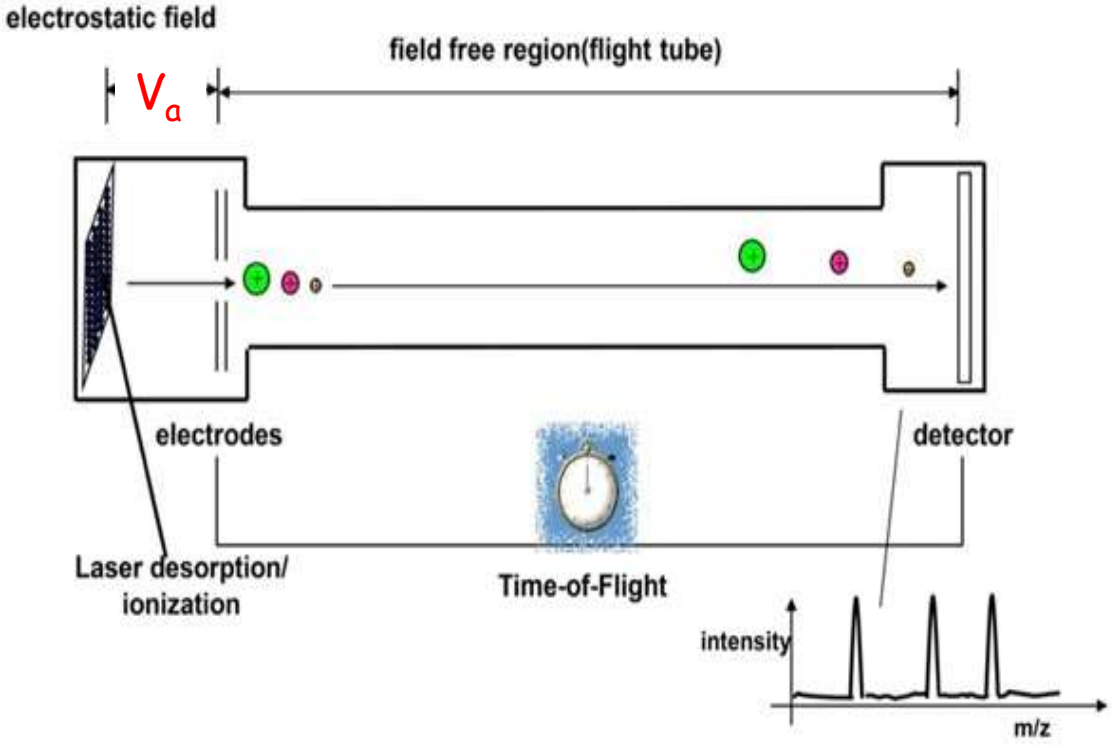
$$qV_a = \frac{1}{2}mv^2$$



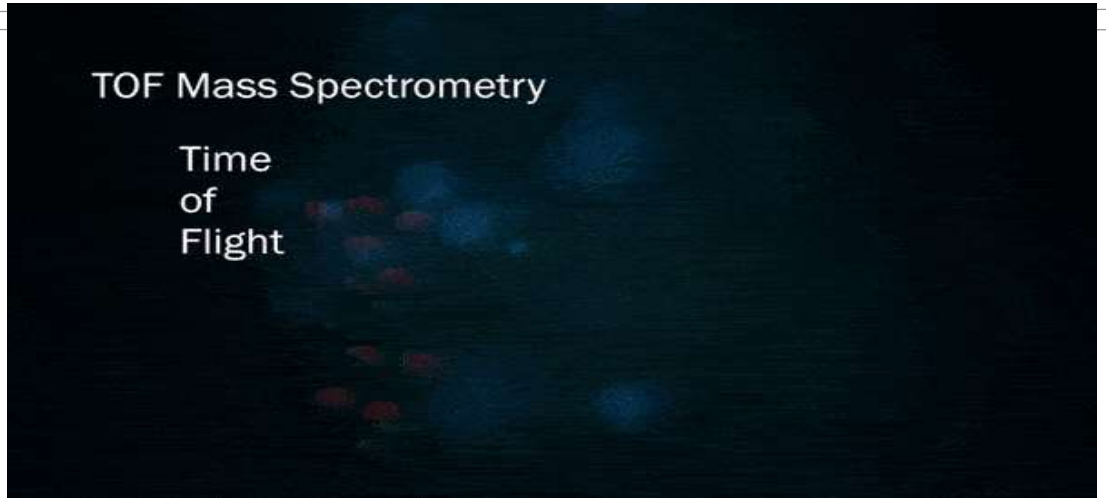
Time of flight filter



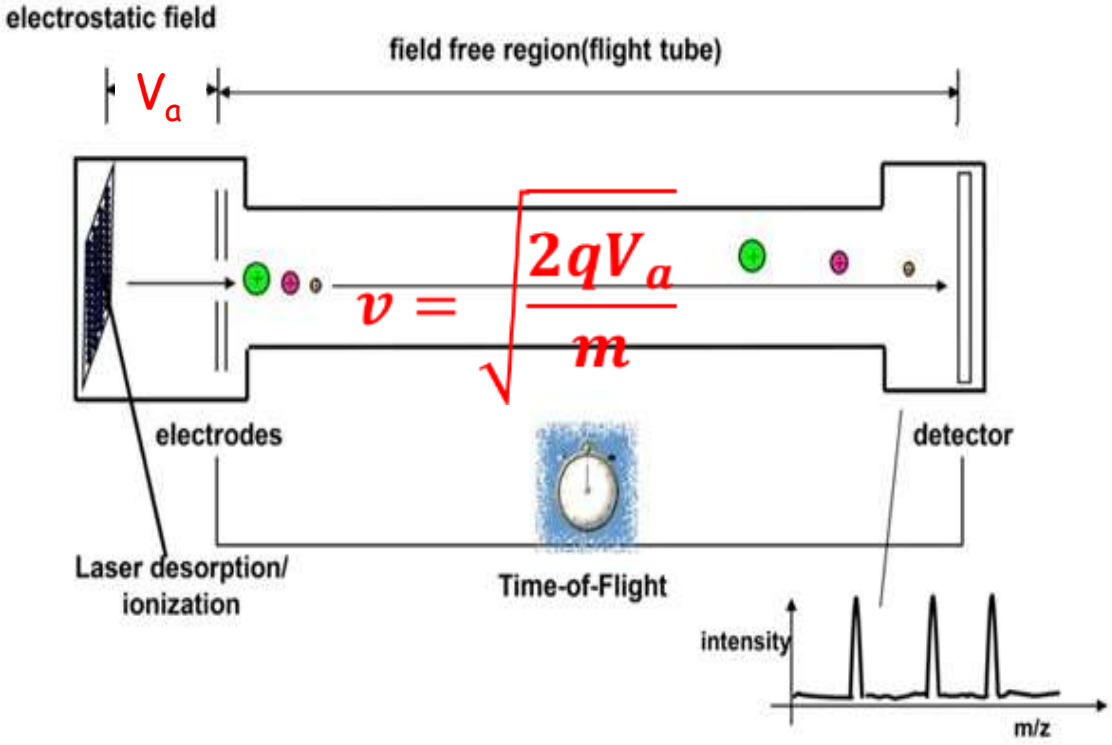
$$qV_a = \frac{1}{2}mv^2$$



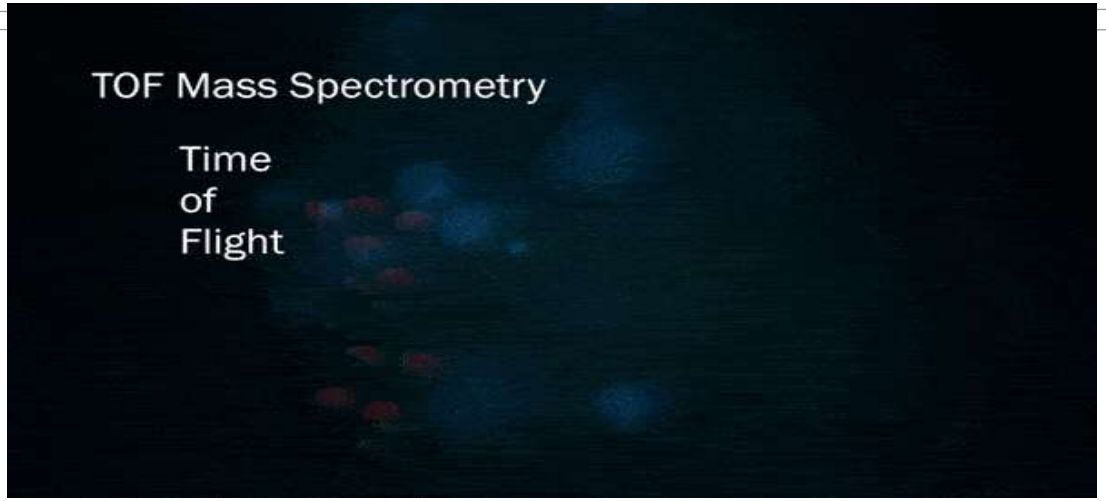
Time of flight filter



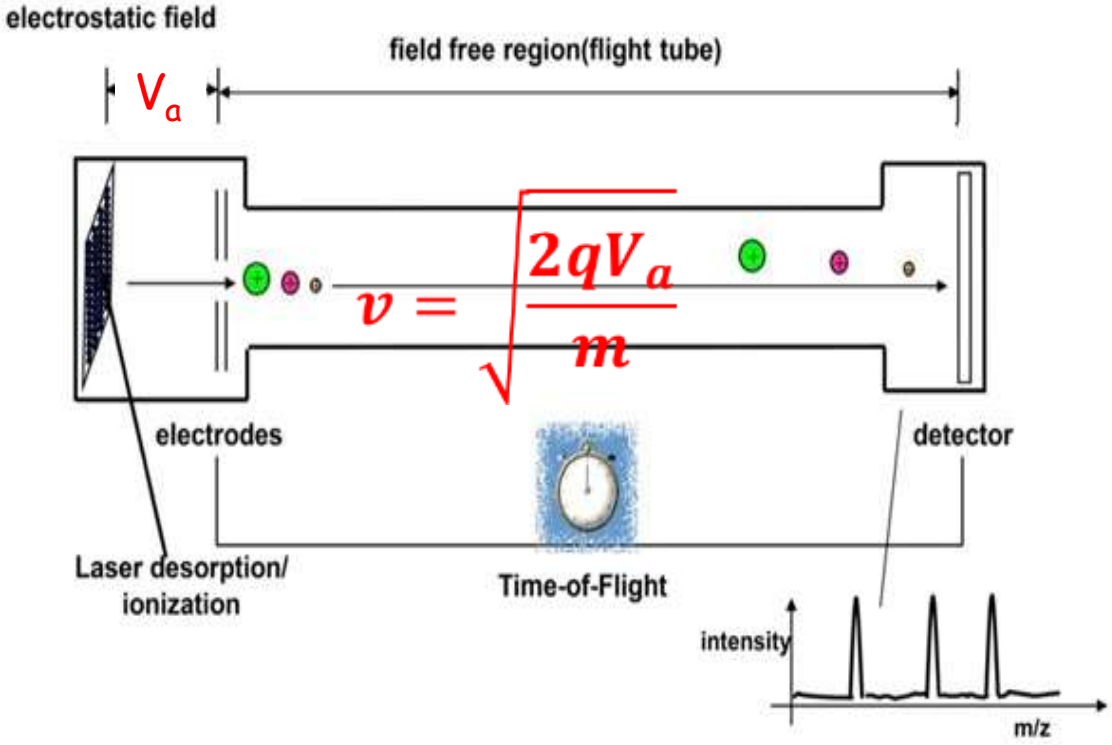
$$qV_a = \frac{1}{2}mv^2$$



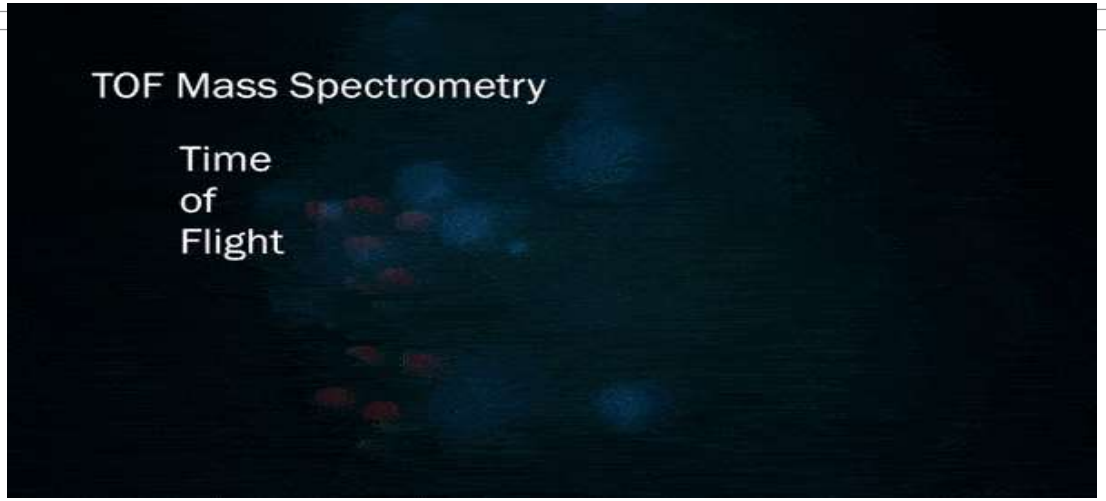
Time of flight filter



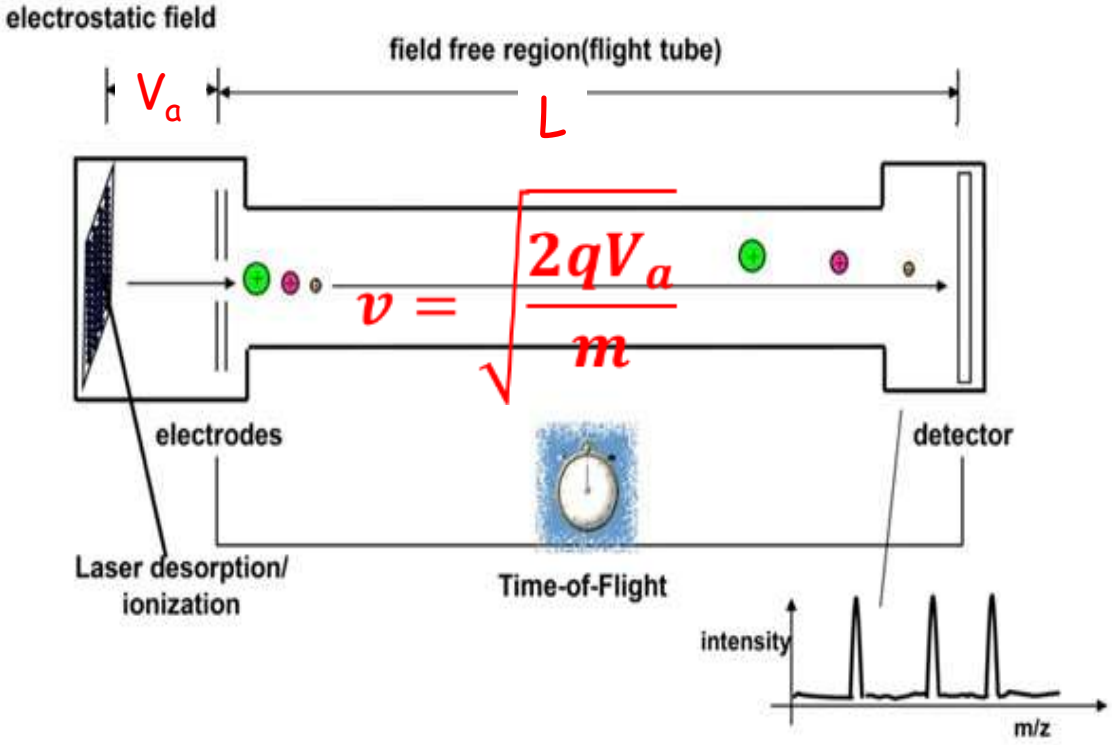
$$qV_a = \frac{1}{2}mv^2$$



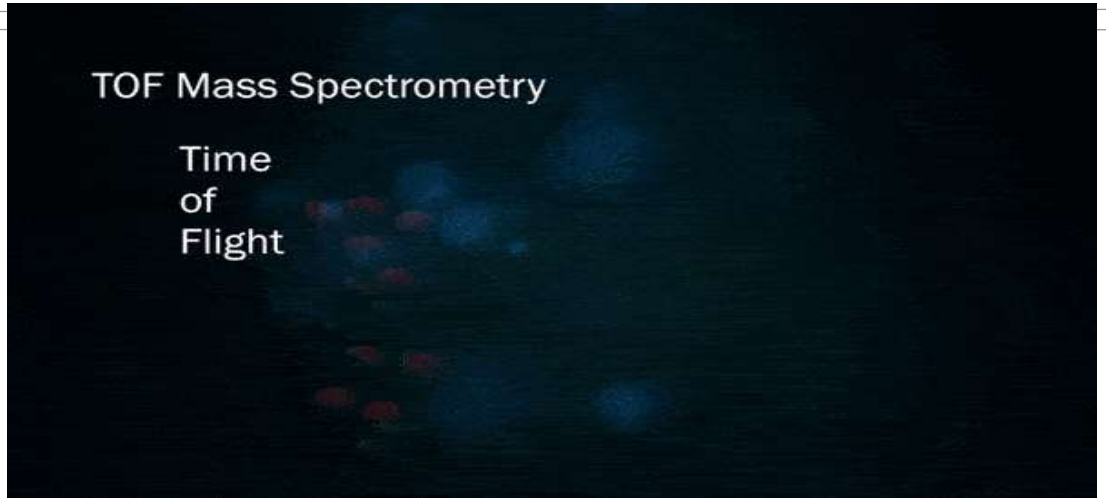
Time of flight filter



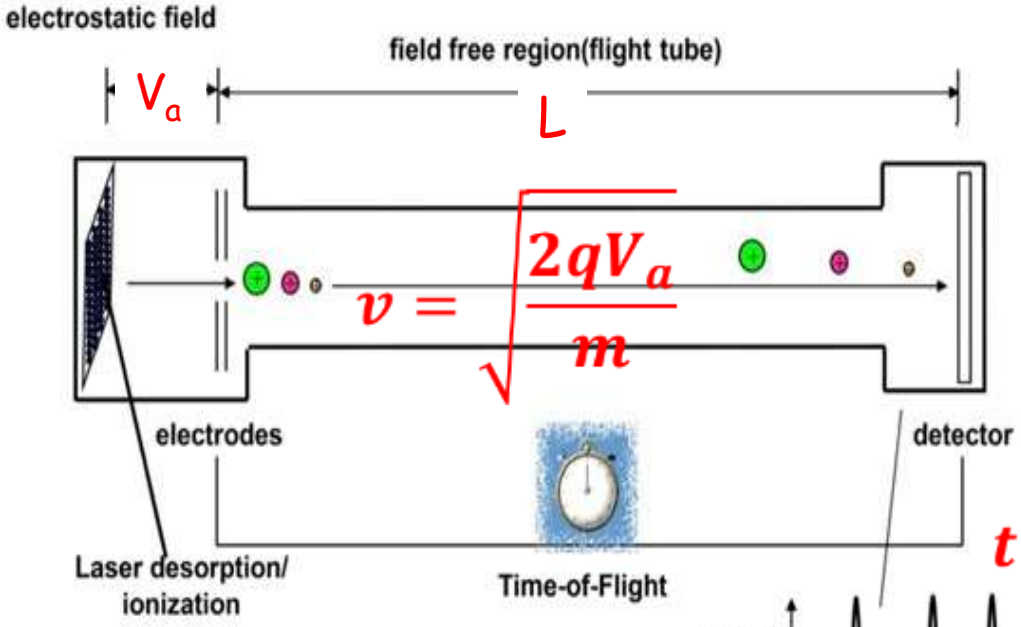
$$qV_a = \frac{1}{2}mv^2$$



Time of flight filter

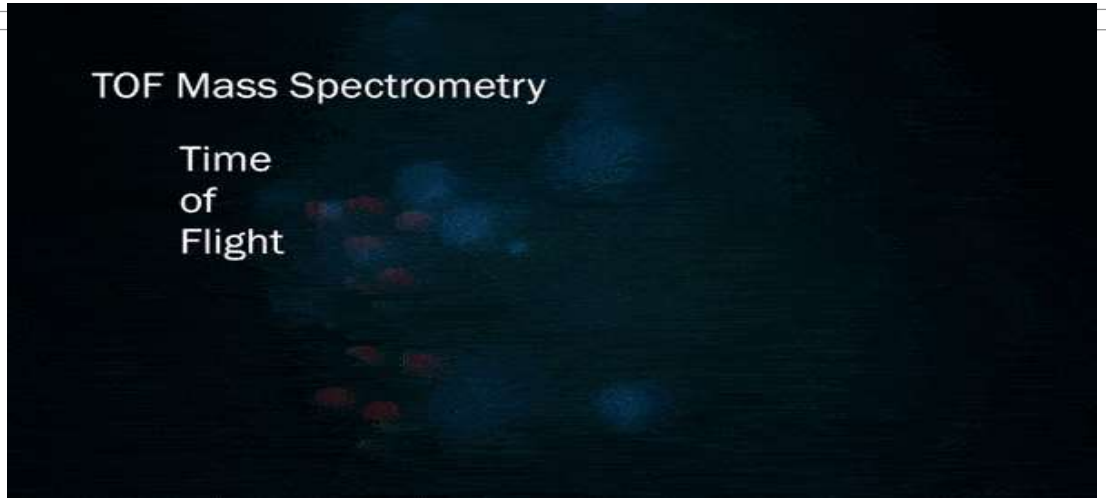


$$qV_a = \frac{1}{2}mv^2$$

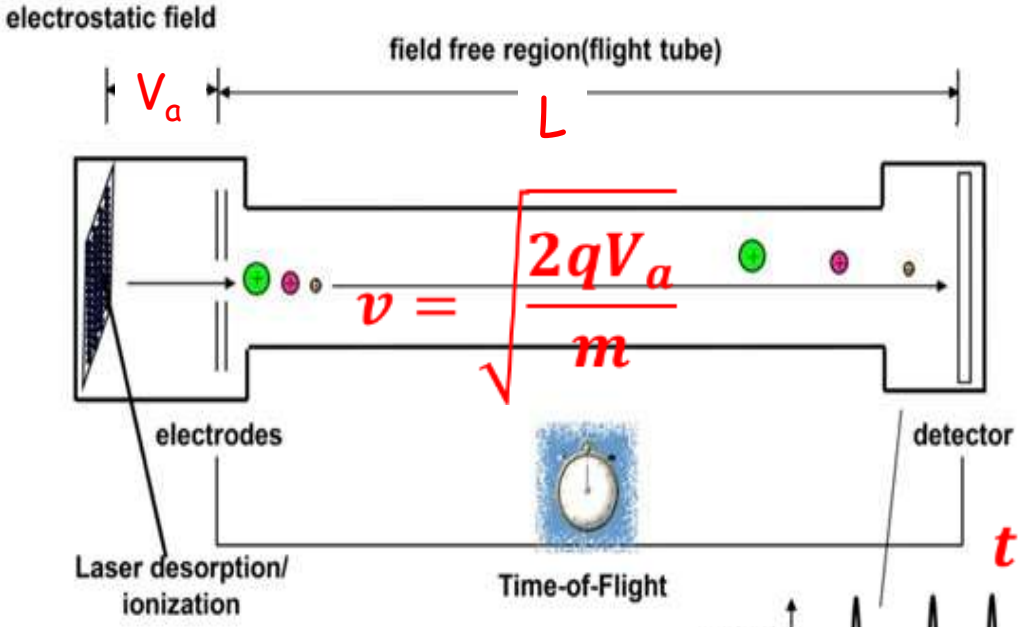


$$t = \frac{L}{v} = \frac{L}{\sqrt{\frac{2qV_a}{m}}}$$

Time of flight filter



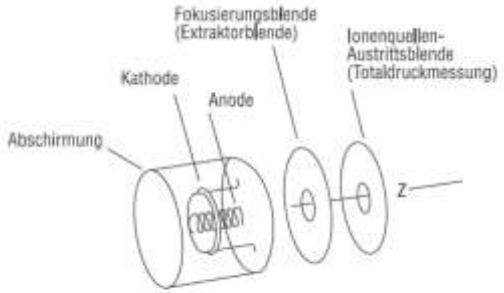
$$qV_a = \frac{1}{2}mv^2$$

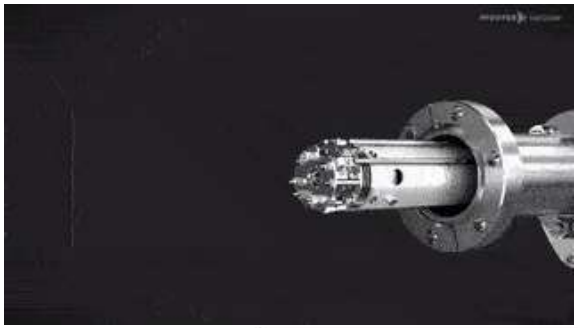


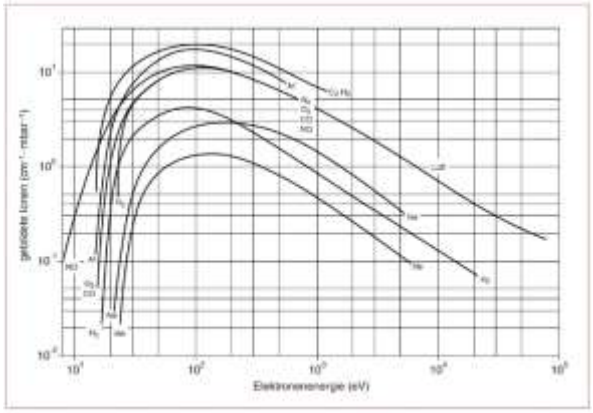
$$t = \frac{L}{v} = \frac{L}{\sqrt{\frac{2qV_a}{m}}}$$

Mass spectrometer

Ion source







Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

Mass separation

Magnetic field

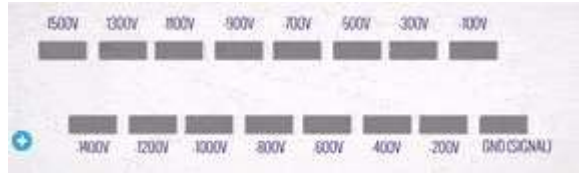
Time of flight

Quadrupol

Ion detection

Faraday Cup

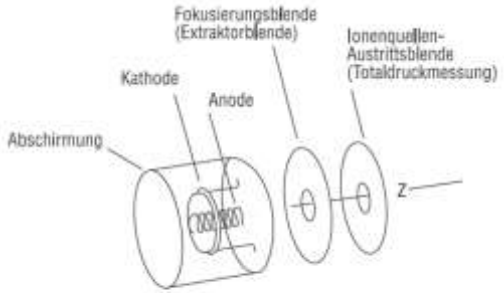
Multiplier

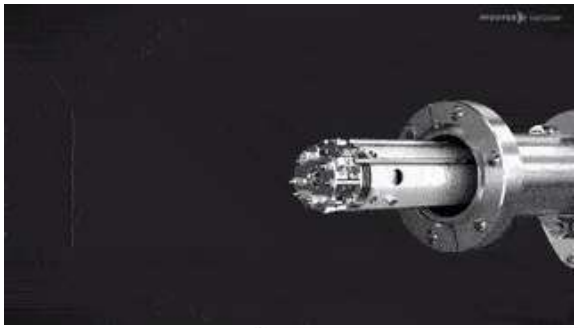


Channeltron

Mass spectrometer

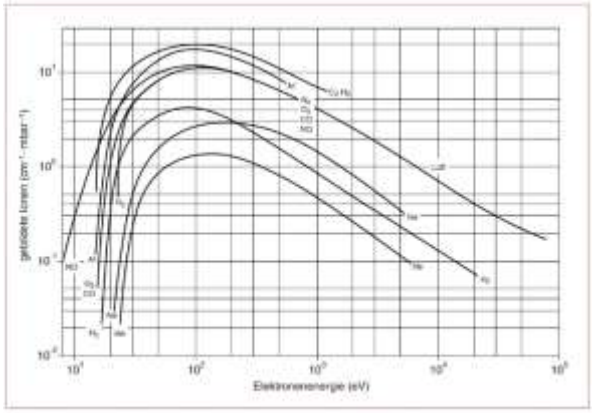
Ion source





Mass separation

Quadrupole

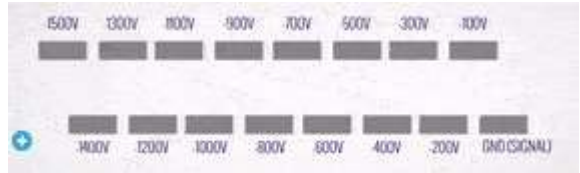


Spezifische Ionisierung S durch Elektronen der Energie E für verschiedene Gase

Ion detection

Faraday Cup

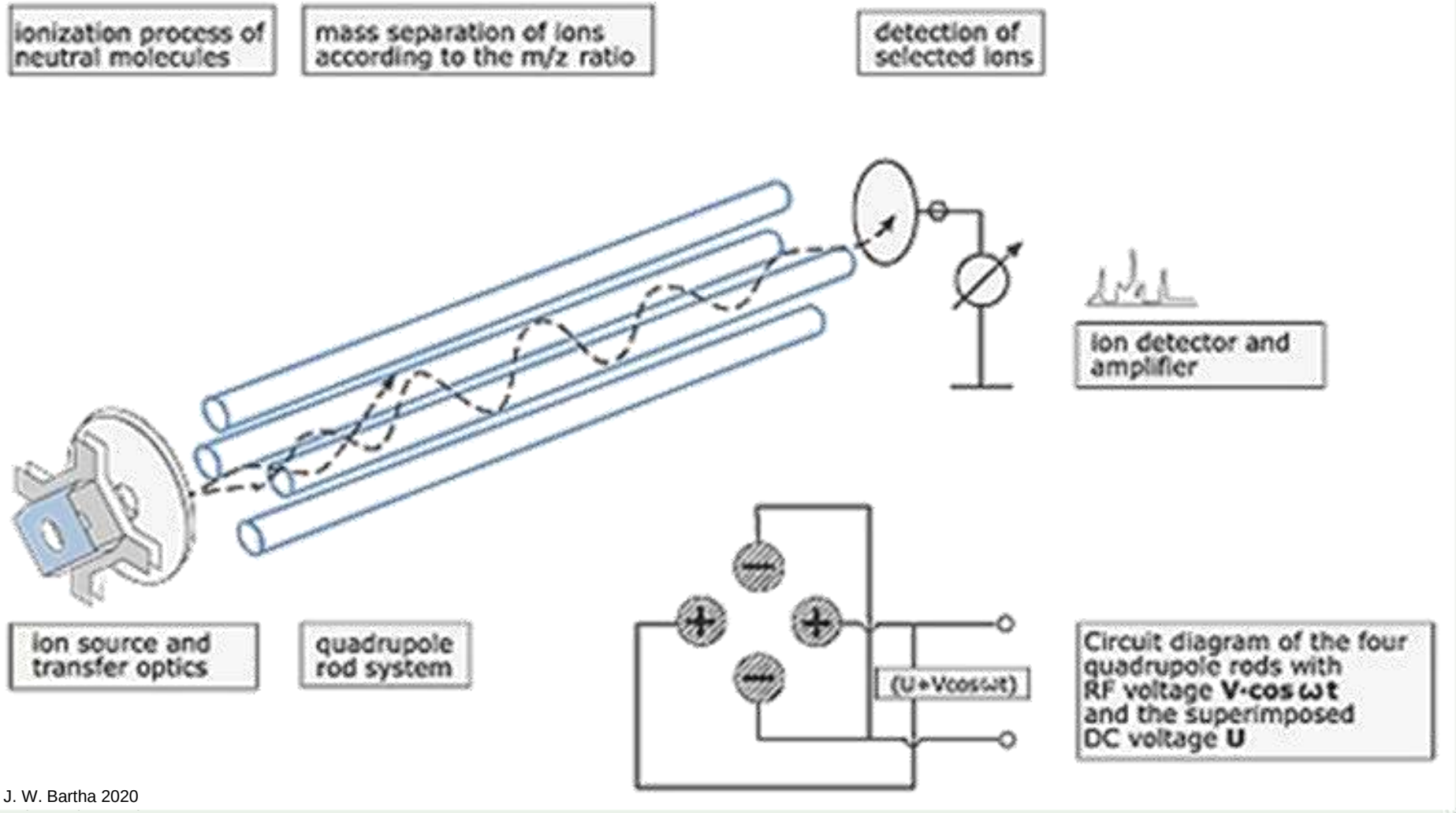
Multiplier



Channeltron

Quadrupole filter

https://www.youtube.com/watch?v=6_mavZ_WKoU
https://www.youtube.com/watch?v=vuLrmgmJ54E



https://www.youtube.com/watch?v=aYOCb6GnXio

Quadrupole filter

https://www.youtube.com/watch?v=6_mavZ_WKoU
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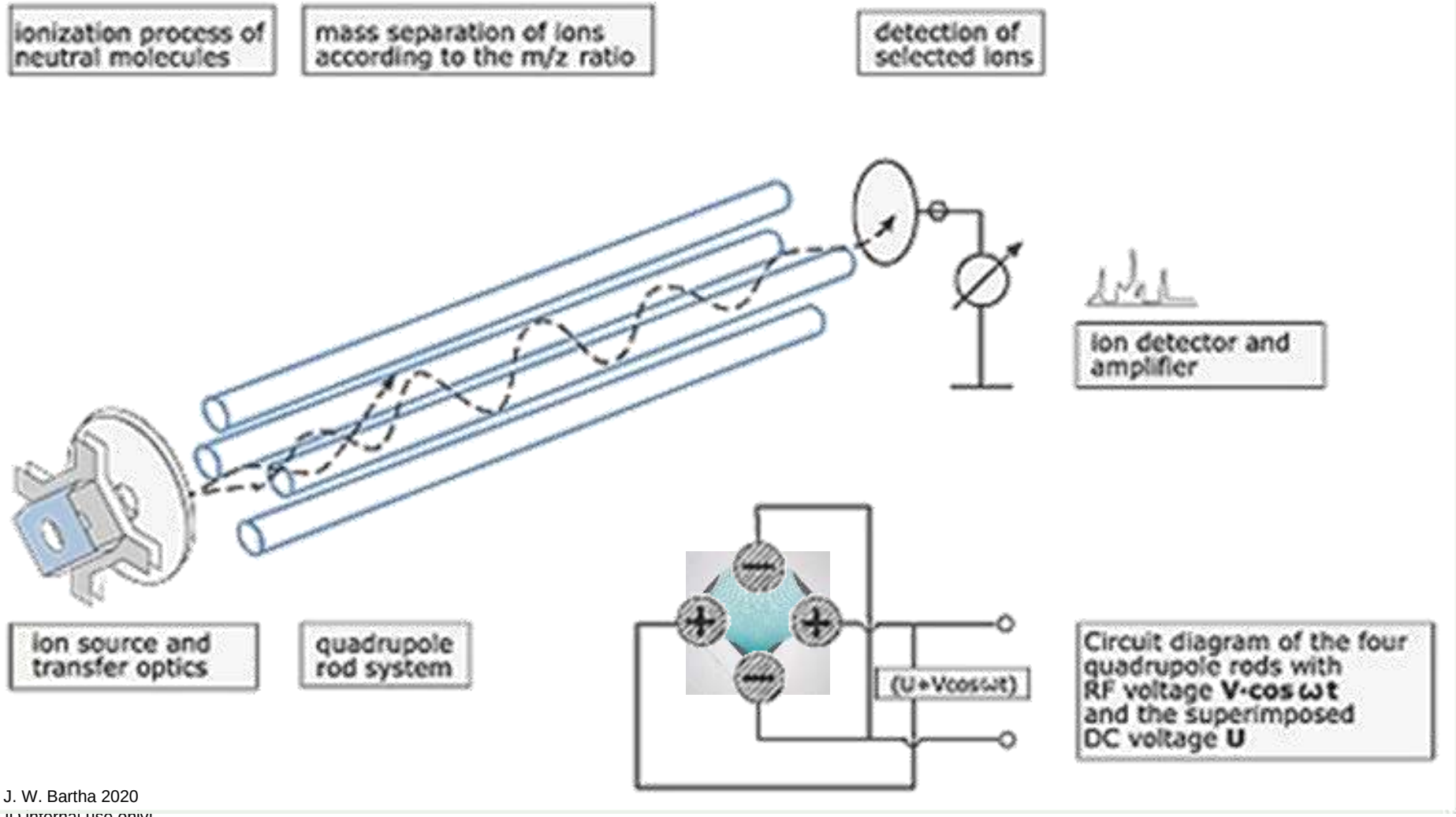

https://www.youtube.com/watch?v=aYOCb6GnXio

Quadrupole filter

https://www.youtube.com/watch?v=6_mavZ_WKoU
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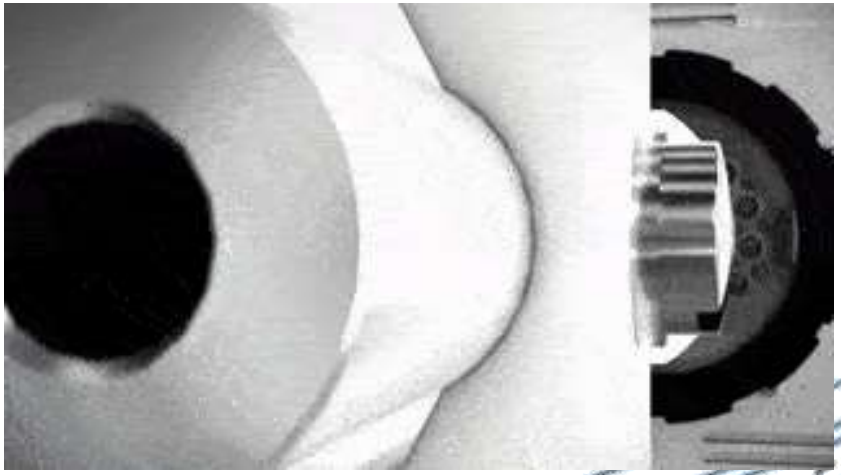

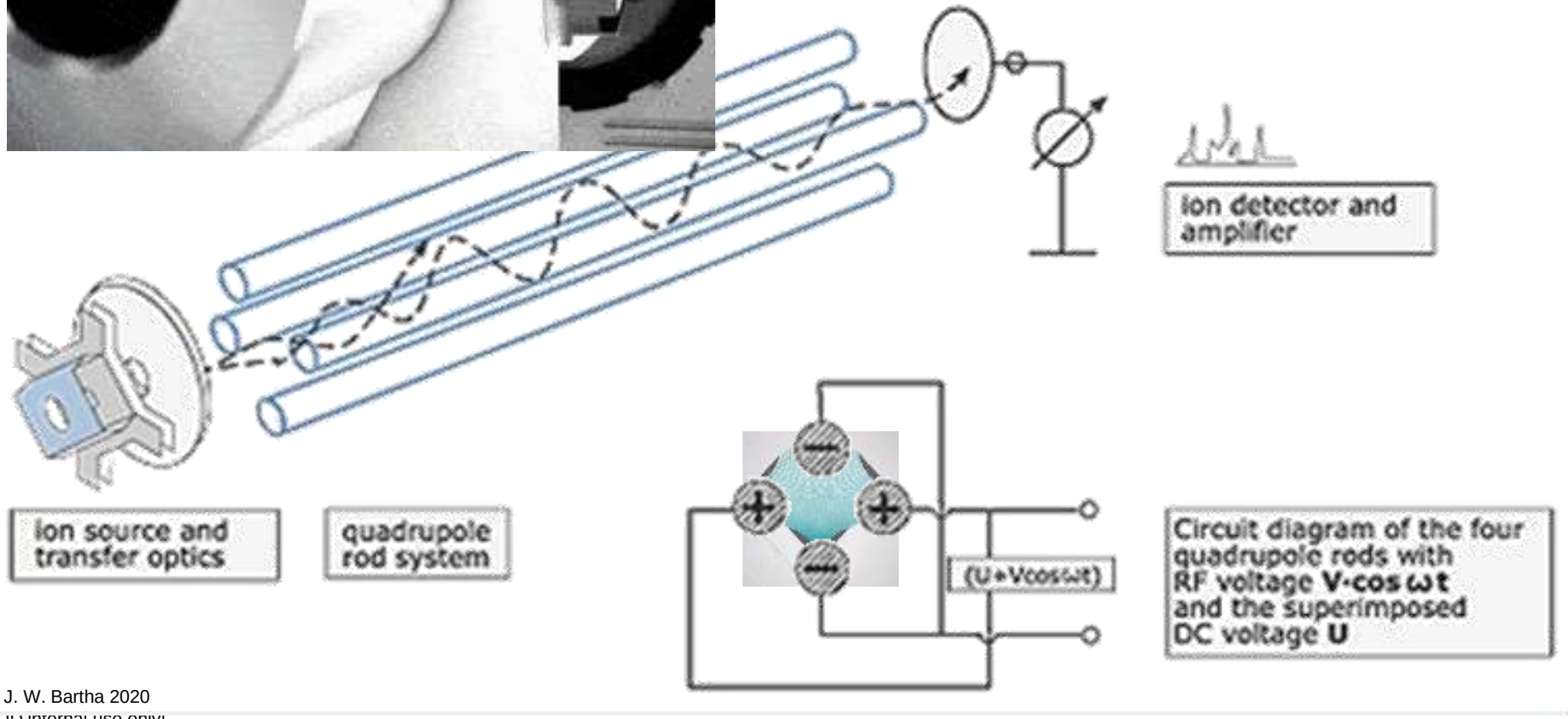

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Quadrupole filter

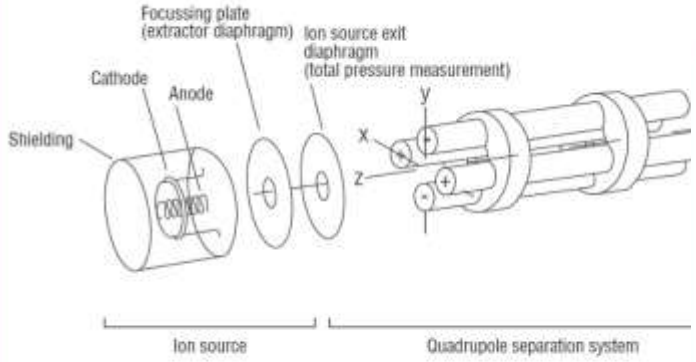


Fig. 4.2 Schematic for quadrupole mass spectrometer

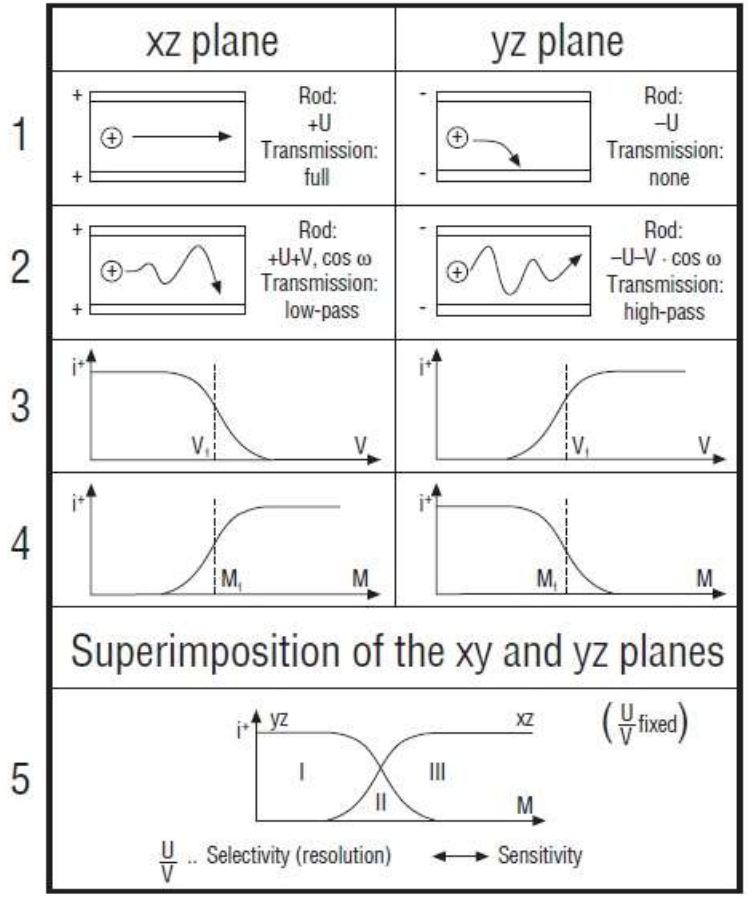


Fig. 4.5 Phenomenological explanation of the separation system

Quadrupole filter

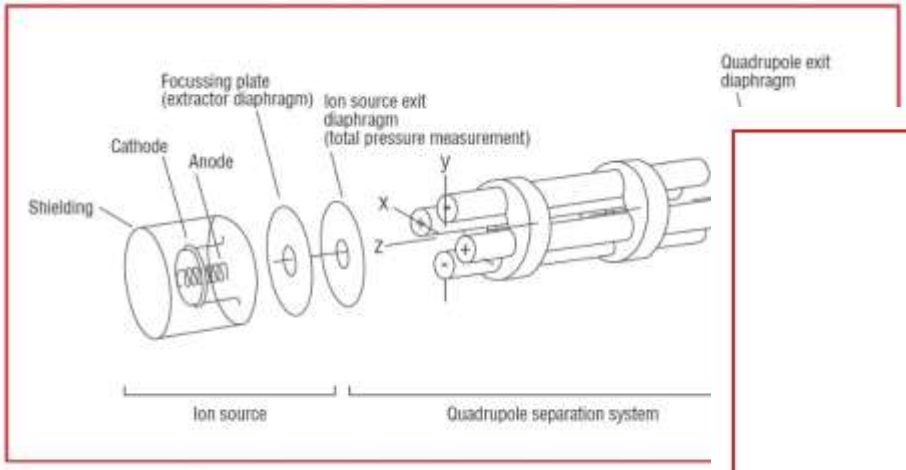
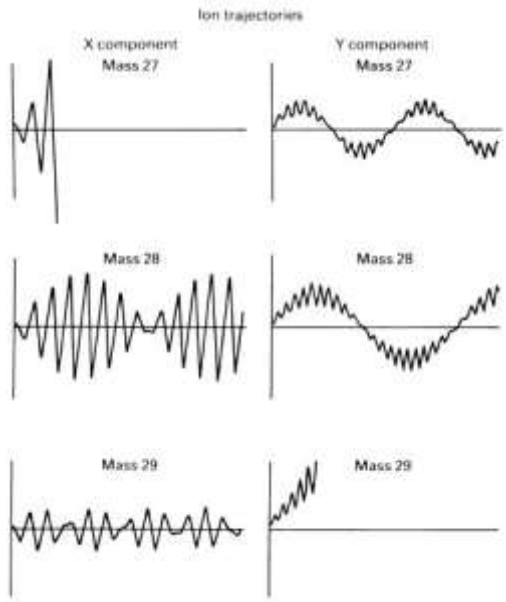


Fig. 4.2 Schematic for quadrupole mass spectrometer



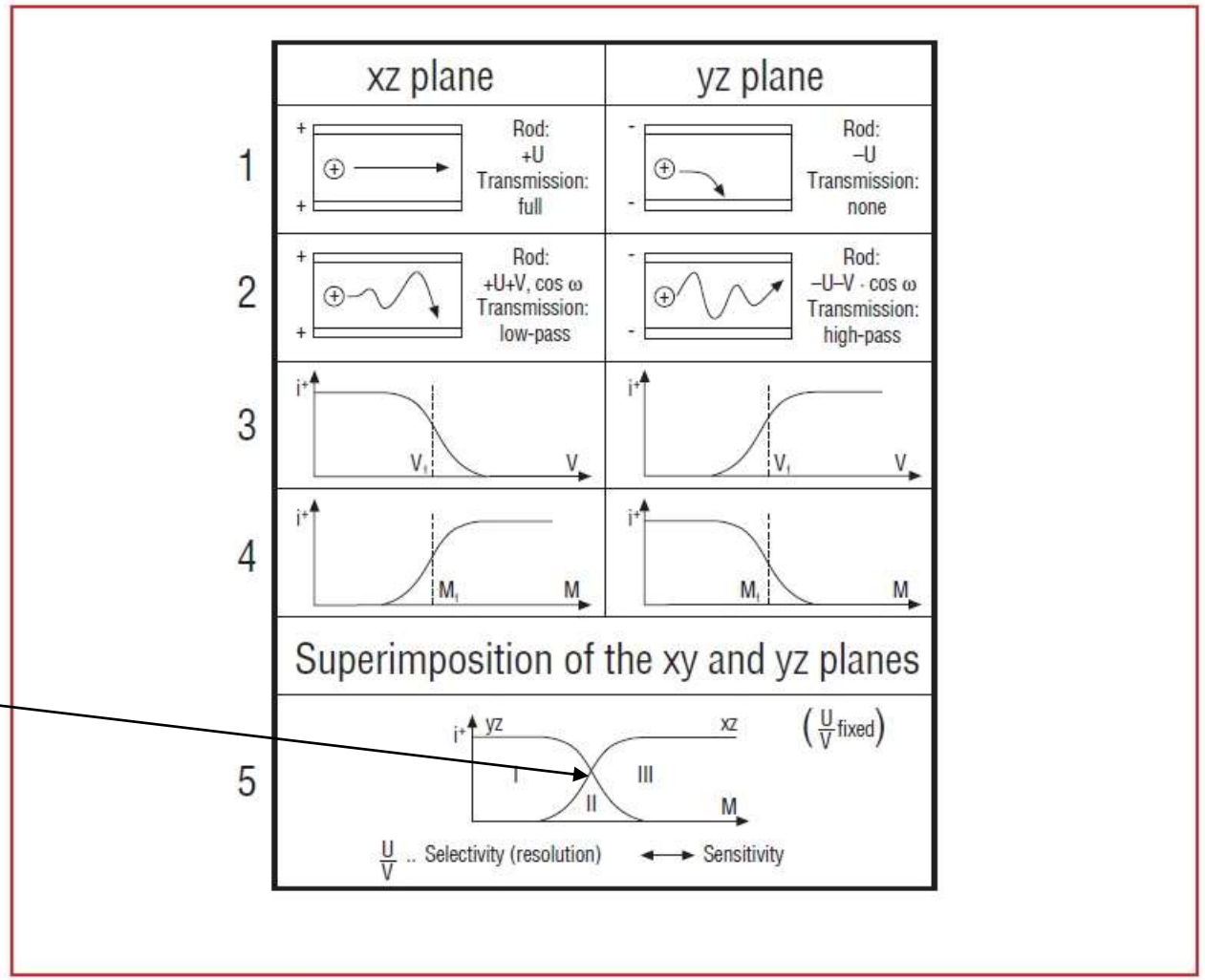
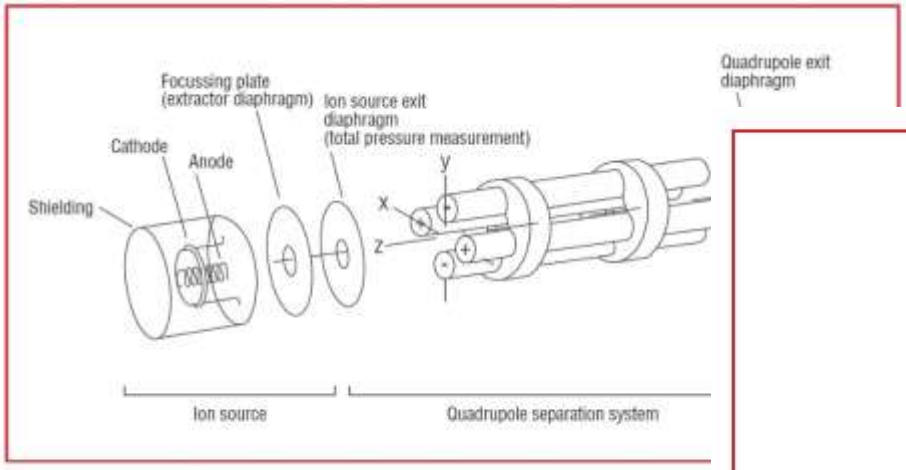


Fig. 4.5 Phenomenological explanation of the separation system

Quadrupole filter



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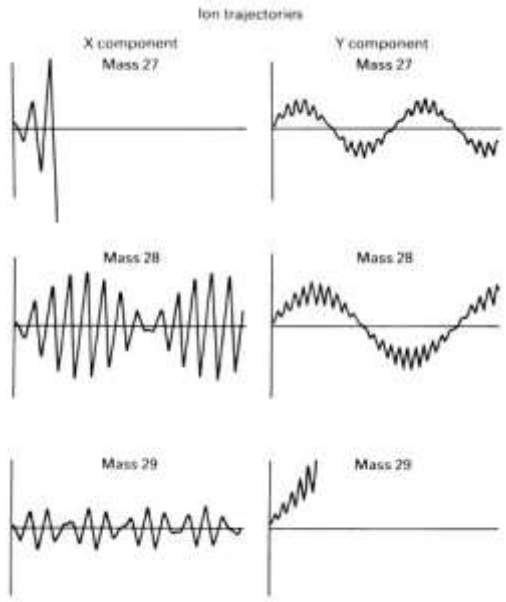


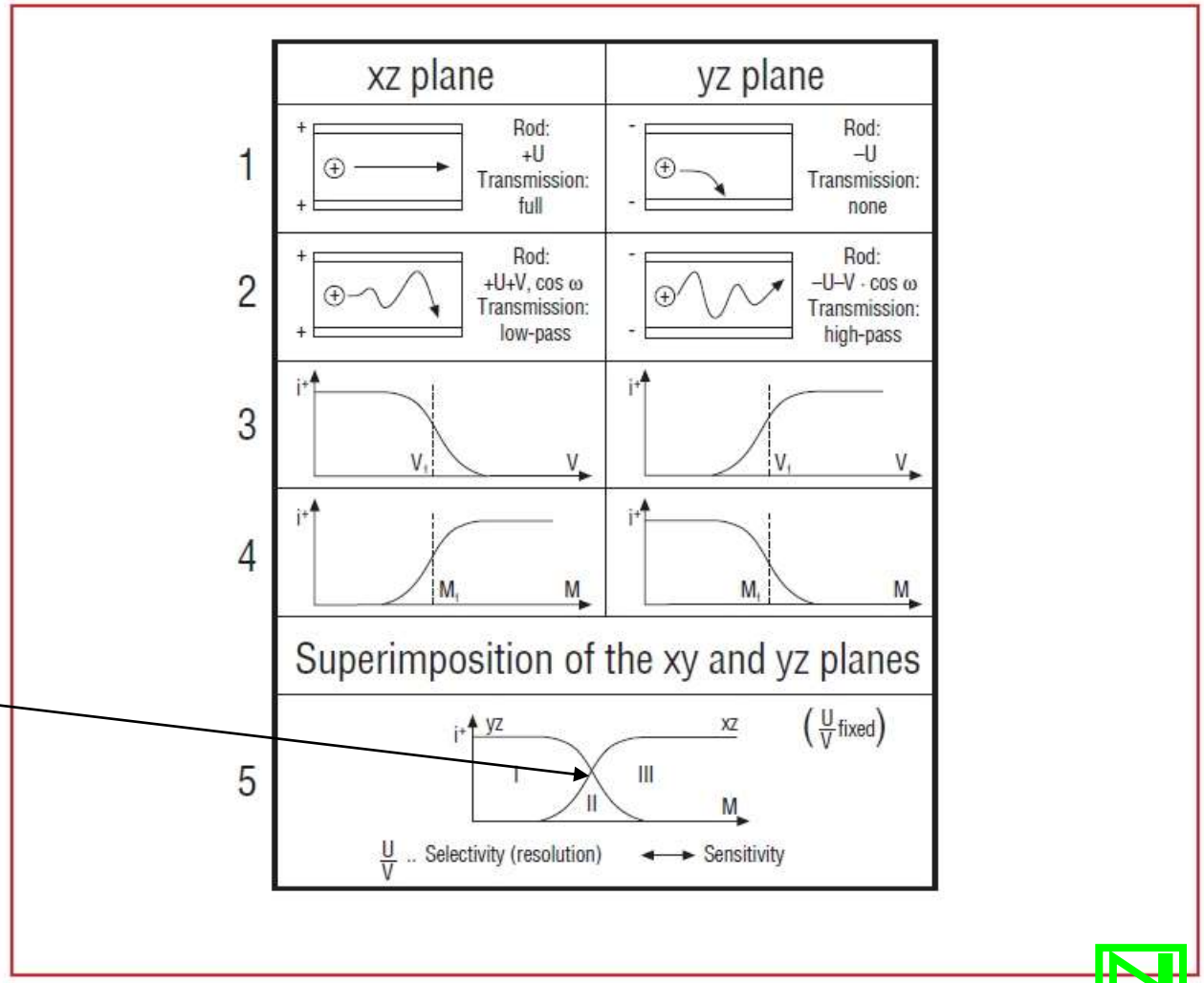
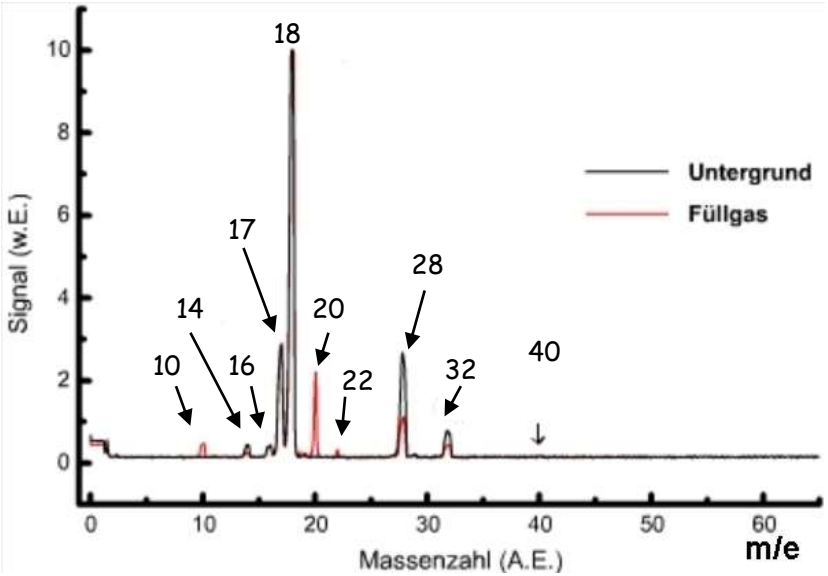
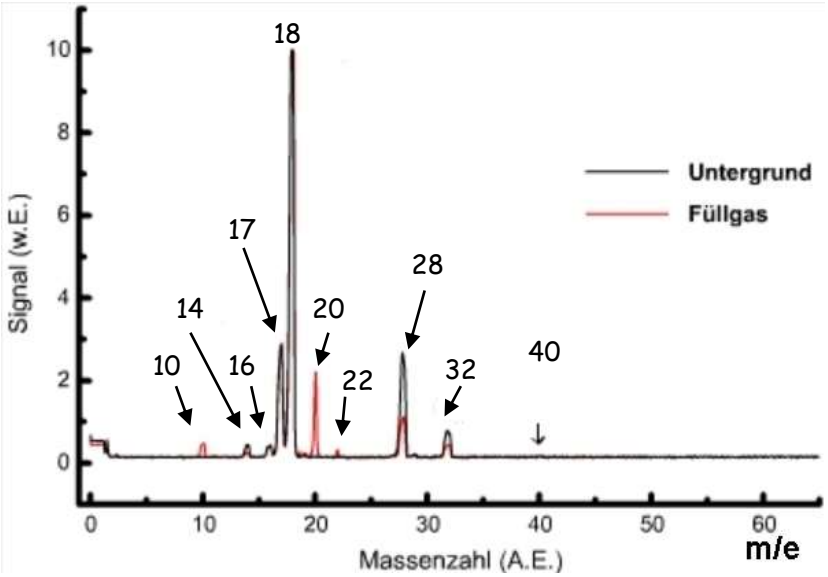


Fig. 4.5 Phenomenological explanation of the separation system

Interpretation of mass spectra



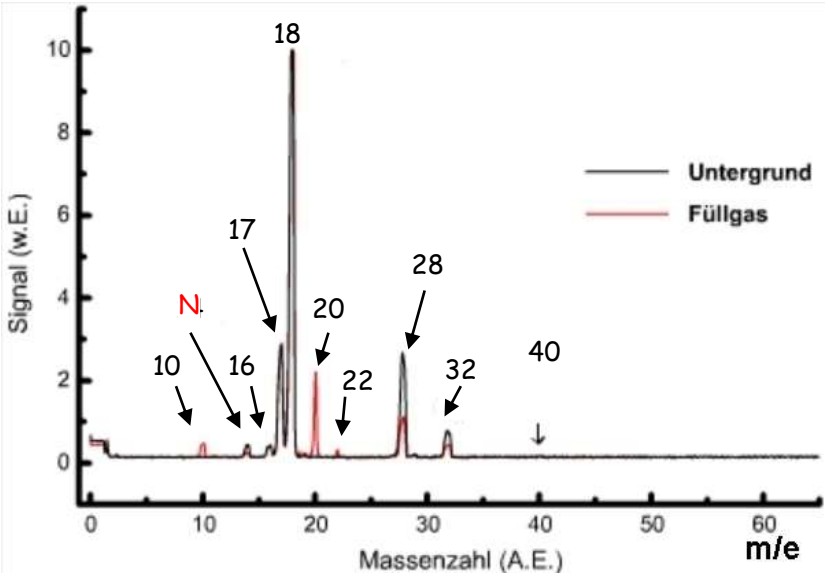
Interpretation of mass spectra



Periodic Table of the Elements

1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.066	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.93	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.82	50 Sn 118.72	51 Sb 121.75	52 Te 127.60	53 I 126.906	54 Xe 131.29
55 Cs 132.905	56 Ba 137.327	71 Lu 174.967	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 209.980	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.025	103 Lr (262)	104 (261)	105 (262)	106 (263)	107 (262)	108 (265)	109 (268)	110 (269)	111 (272)	112 (277)						

Interpretation of mass spectra



Periodic Table of the Elements

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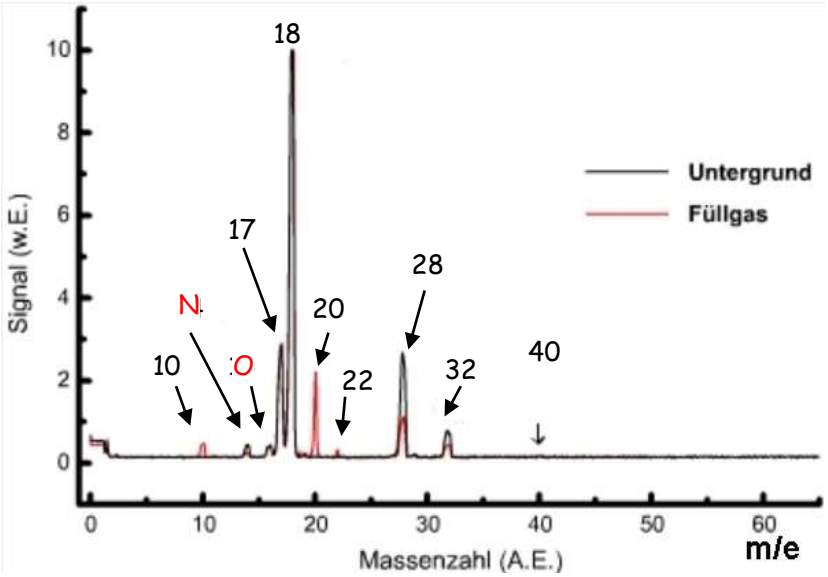
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.066	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.93	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.82	50 Sn 118.72	51 Sb 121.75	52 Te 127.60	53 I 126.906	54 Xe 131.29
55 Cs 132.905	56 Ba 137.327	71 Lu 174.967	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 209.980	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.025	103 Lr (262)	104 (261)	105 (262)	106 (263)	107 (262)	108 (265)	109 (268)	110 (269)	111 (272)	112 (277)						

Interpretation of mass spectra



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11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.066	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.93	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
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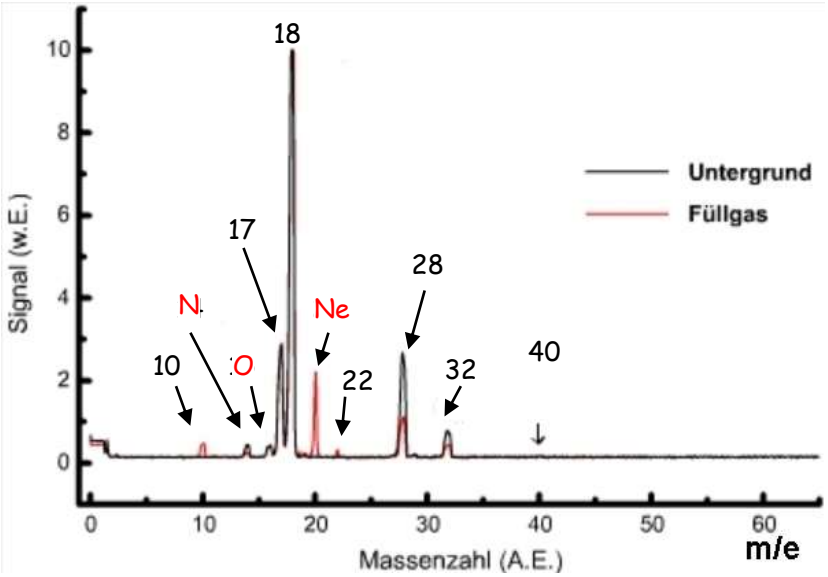

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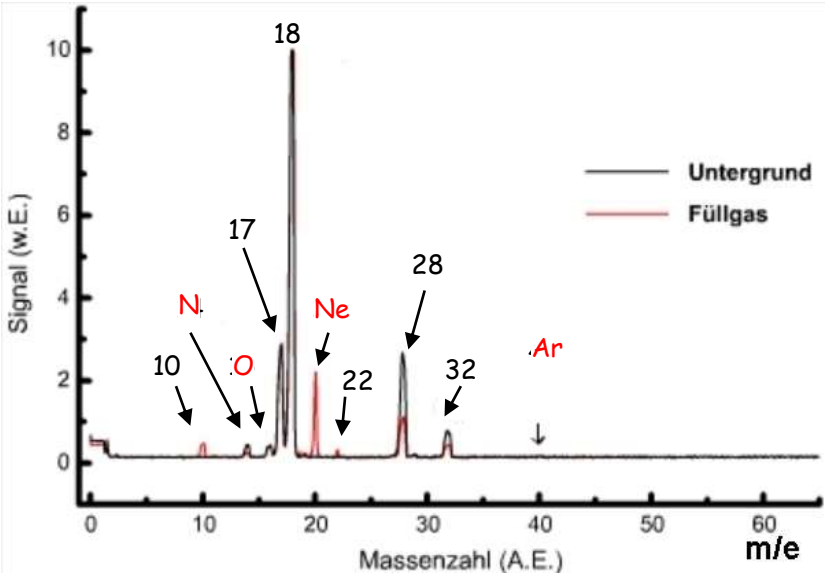

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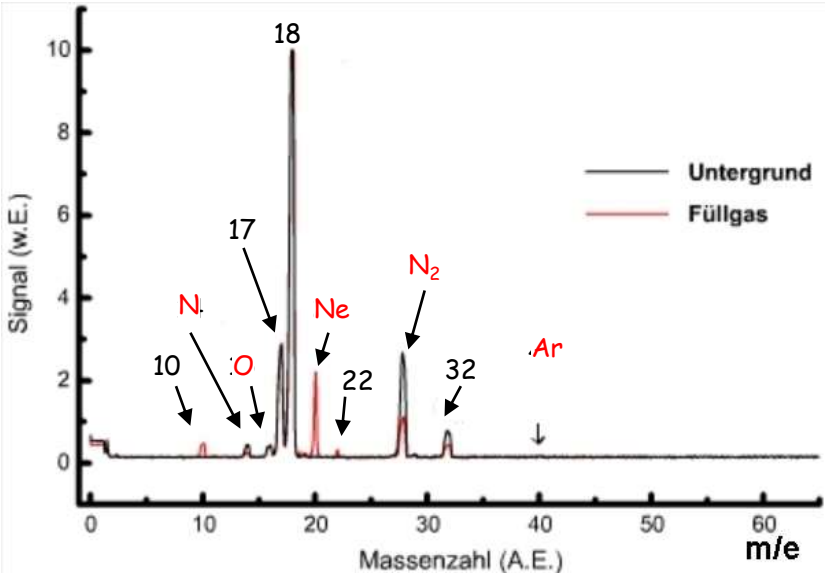

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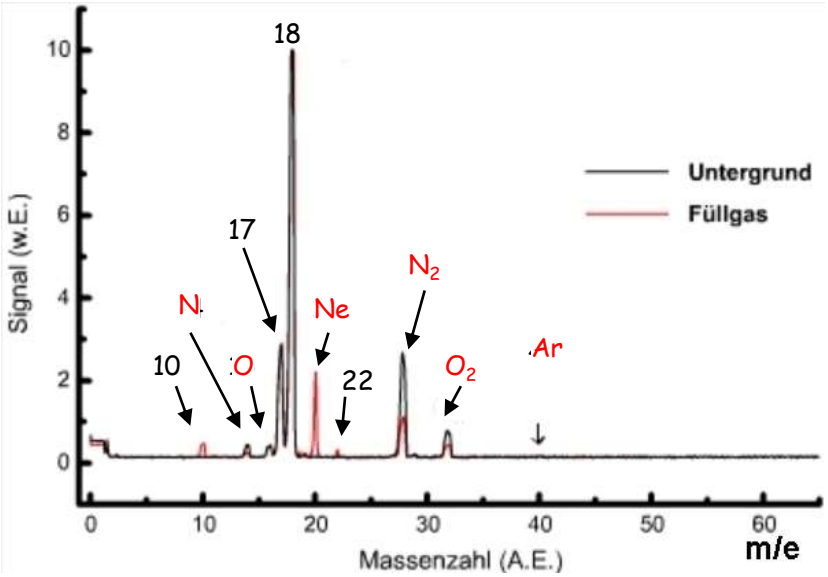

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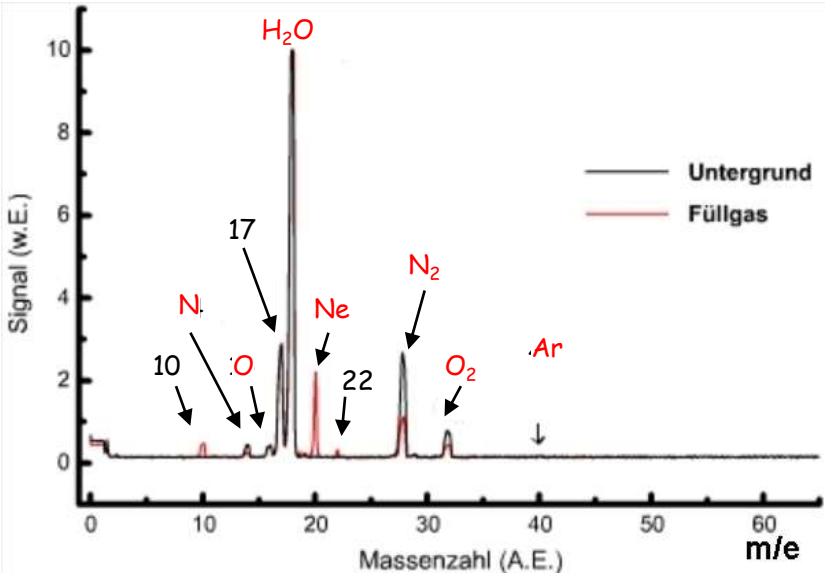

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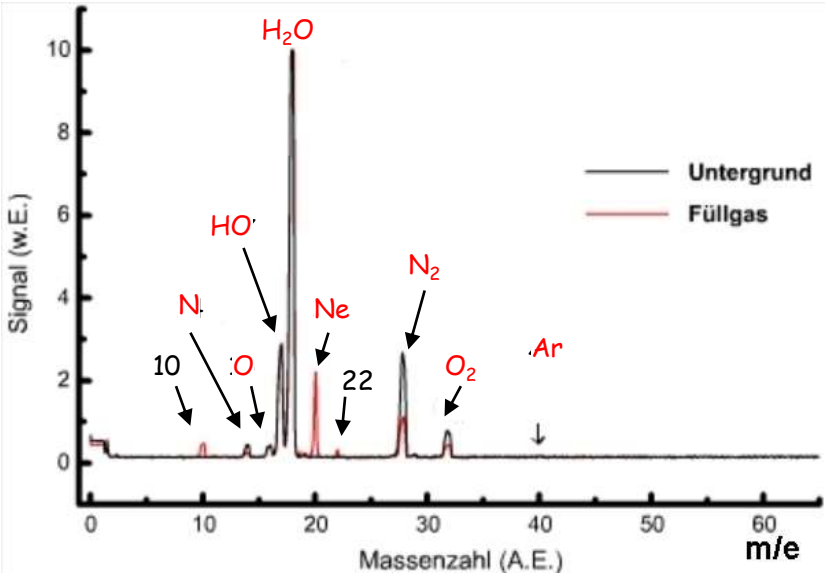
Interpretation of mass spectra



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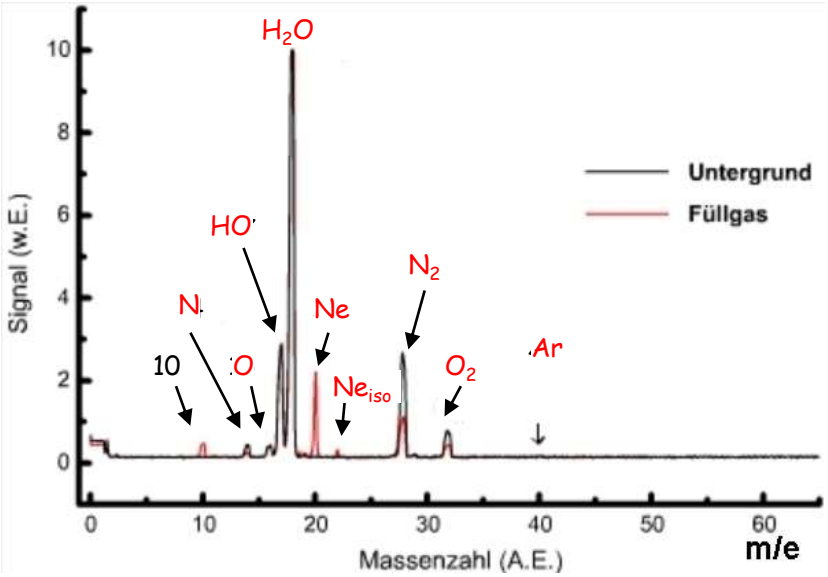

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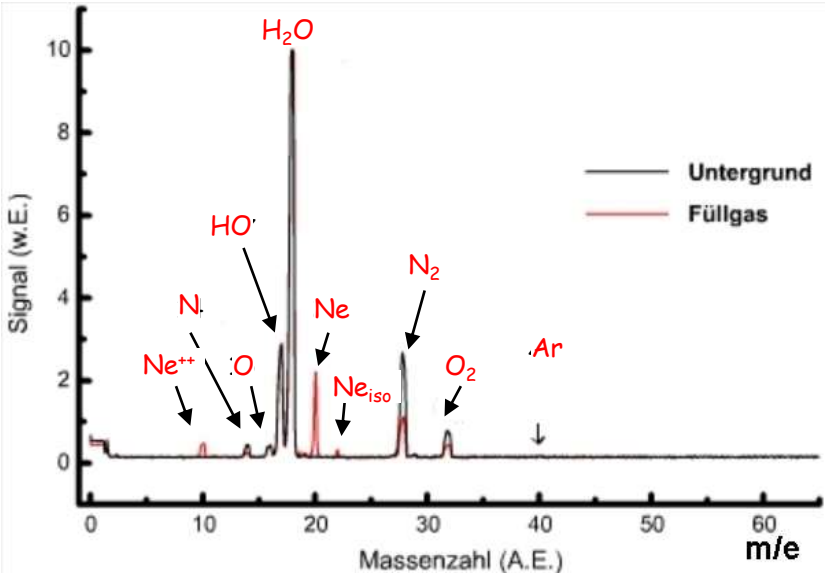

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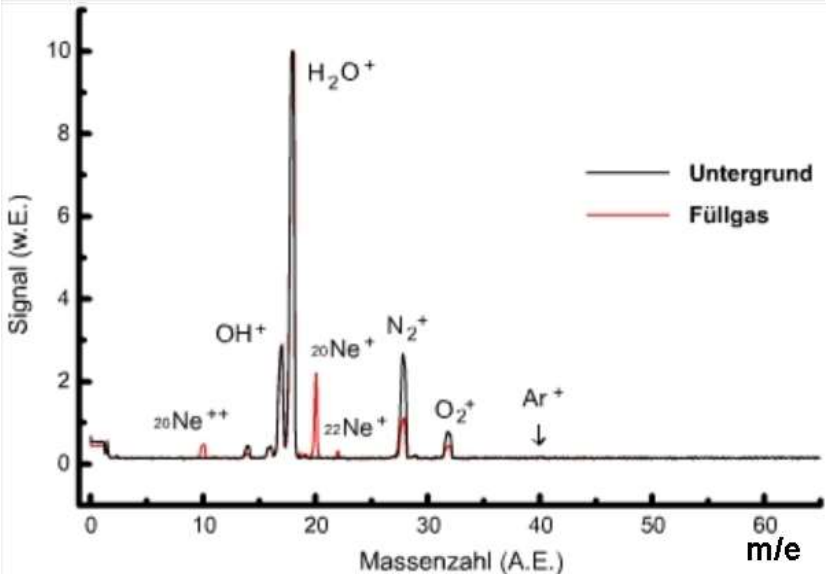

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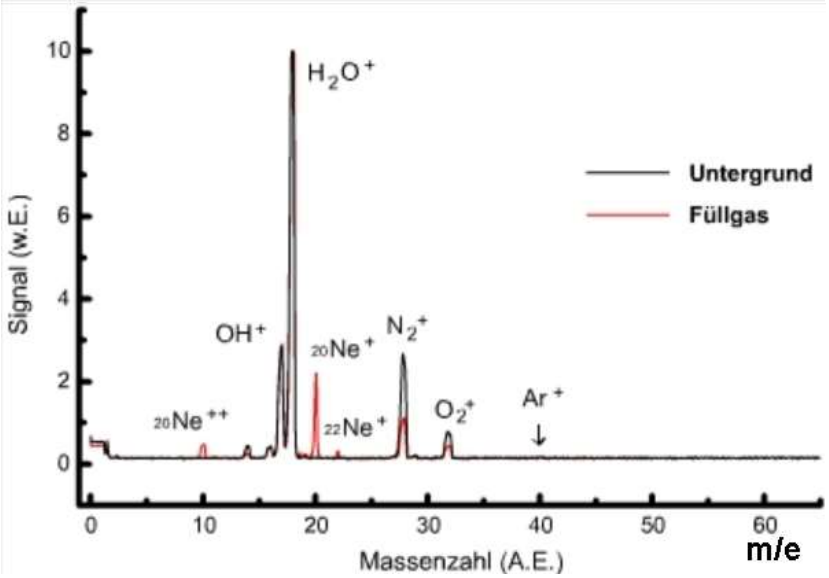

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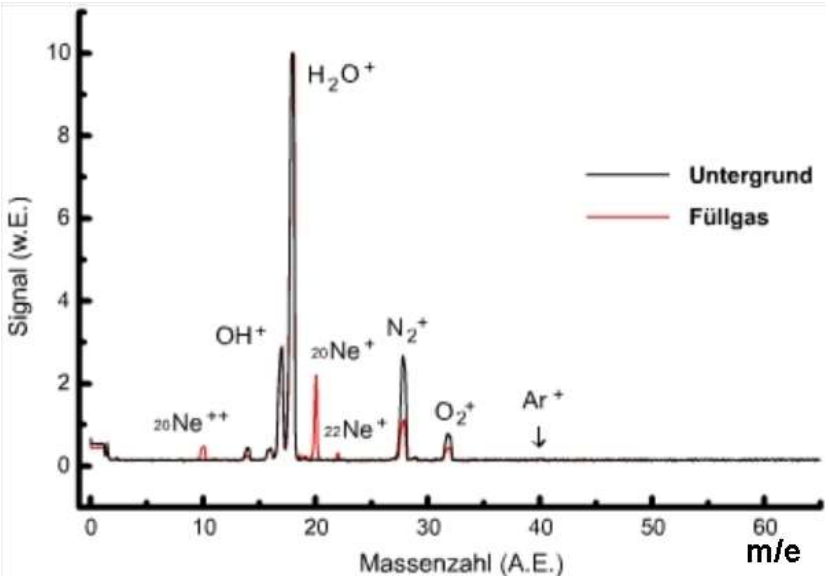
Effects:

- Fragmentation
- Isotopes
- Multiple charged ions (m/e)
- Mass interference example: N_2^+=28=CO^+

Interpretation of mass spectra



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3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.066	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.93	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.82	50 Sn 118.72	51 Sb 121.75	52 Te 127.60	53 I 126.906	54 Xe 131.29
55 Cs 132.905	56 Ba 137.327	71 Lu 174.967	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 209.980	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.025	103 Lr (262)	104 (261)	105 (262)	106 (263)	107 (262)	108 (265)	109 (268)	110 (269)	111 (272)	112 (277)						

Effects:

- Fragmentation
- Isotopes
- Multiple charged ions (m/e)
- Mass interference example: N_2^+=28=CO^+

m/z	Element*	Interferences
56	Fe(91.66)	^{40}ArO, ^{40}CaO
57	Fe(2.19)	^{40}ArOH, ^{40}CaOH
58	Ni(67.77), Fe(0.33)	^{42}CaO, NaCl
59	Co(100)	^{43}CaO, ^{42}CaOH
60	Ni(26.16)	^{43}CaOH, ^{44}CaO
61	Ni(1.25)	^{44}CaOH
62	Ni(3.66)	^{46}CaO, Na_2O, NaK
63	Cu(69.1)	^{46}CaOH, ^{40}ArNa
64	Ni(1.16), Zn(48.89)	$^{32}SO_2$, $^{32}S_2$, ^{48}CaO
65	Cu(30.9)	$^{33}S^{32}S$, $^{33}SO_2$, ^{48}CaOH

Fragmentation

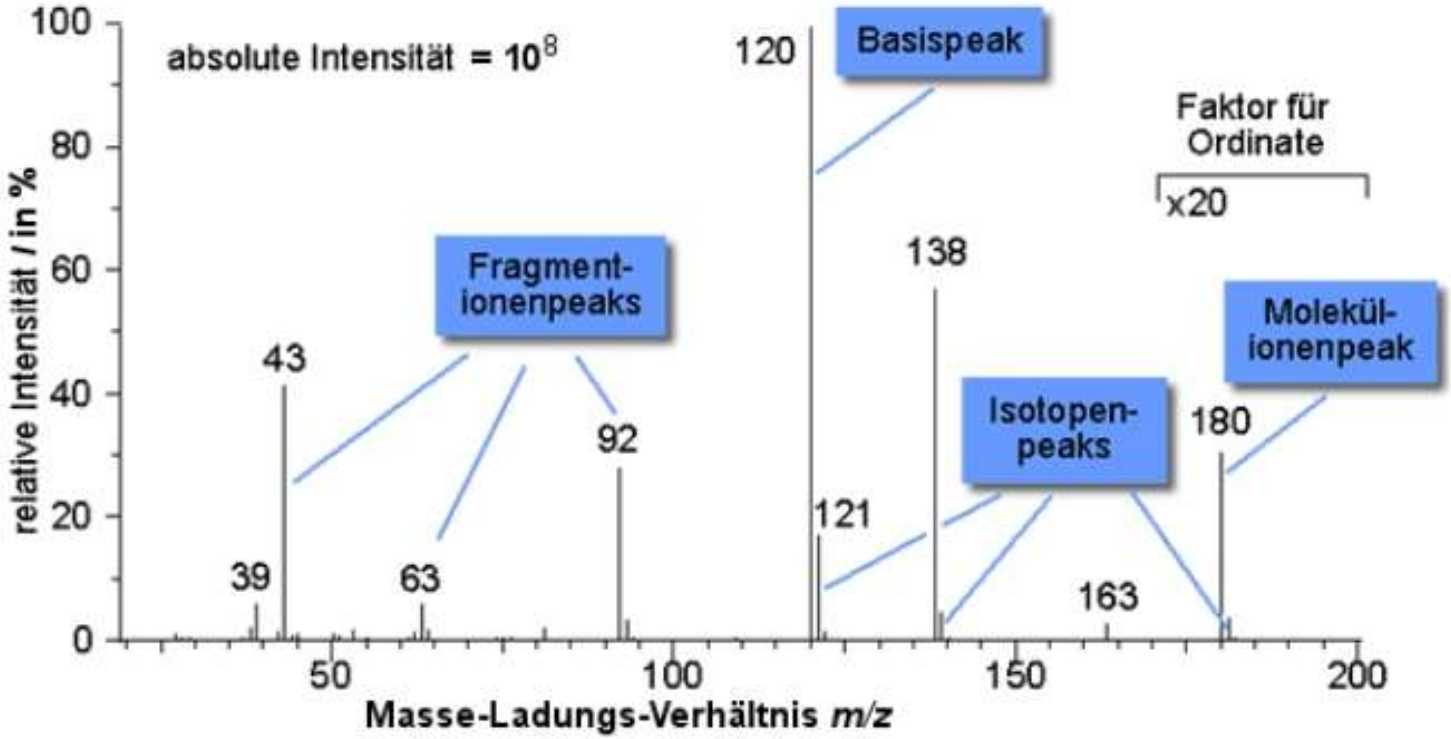


Abb.1 | **Massenspektrum von Acetylsalicylsäure (EI 70 eV)**

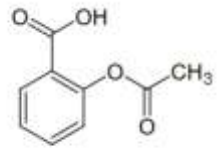


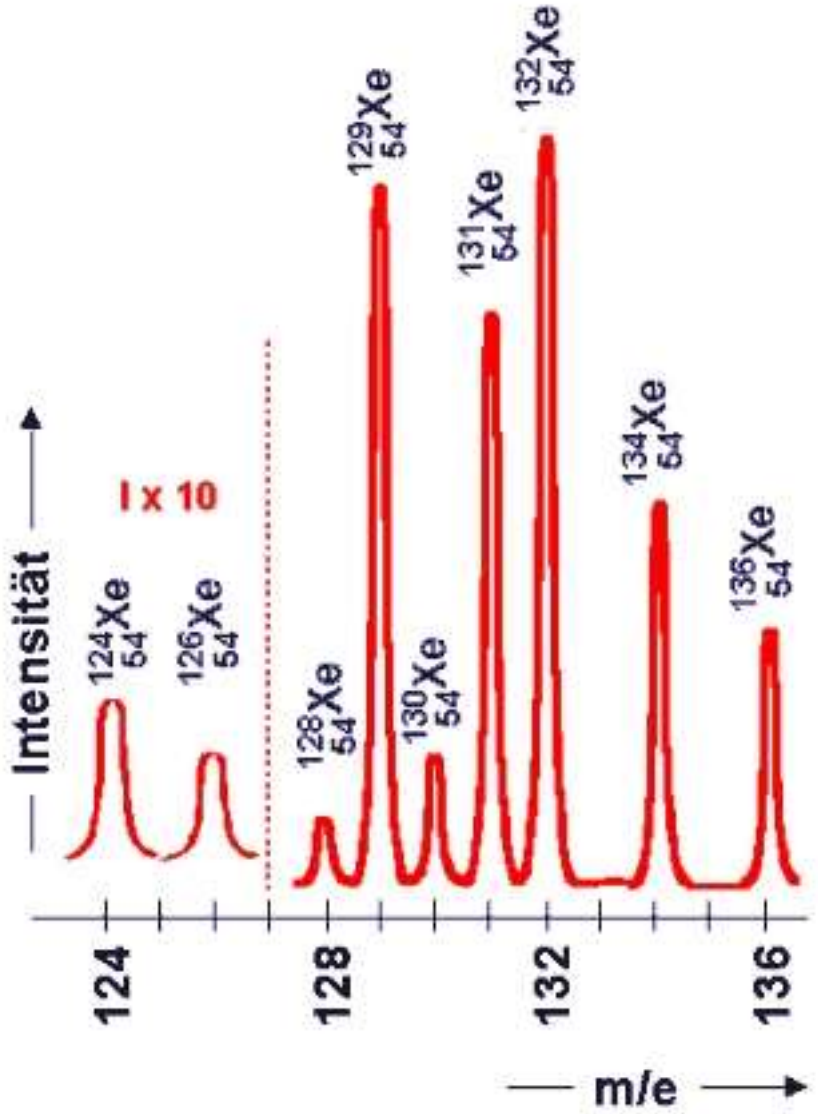
Abb.2 | **2D-Struktur**
Acetylsalicylsäure, $C_9H_8O_4$, M=180 g mol^{-1}

Abb.3 | **3D-Struktur**

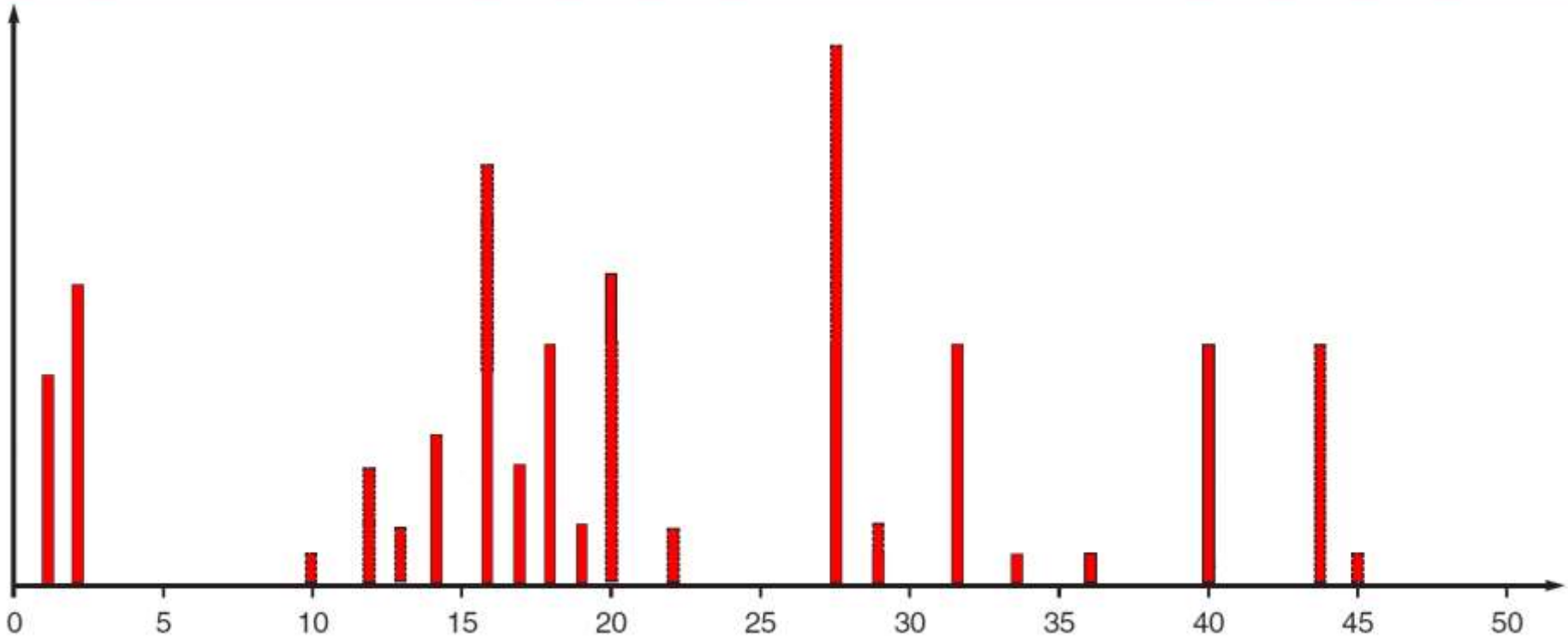
Isotopes

Element	Ordinal-number	Atomic number	Relative frequency
Al	13	27	100.0
Si	14	28	92.27
		29	4.68
		30	3.05
P	15	31	100.0
S	16	32	95.06
		33	0.74
		34	4.18
		36	0.016
Cl	17	35	75.4
		37	24.6
Ar	18	36	0.337
		38	0.063
		40	99.60
Kr	36	78	0.354
		80	2.27
		82	11.56
		83	11.55
		84	56.90
		86	17.37
Xe	54	124	0.096
		126	0.090
		128	1.919
		129	26.44
		130	4.08
		131	21.18
		132	26.89
		134	10.44
		136	8.87

Table 4.2 Relative frequency of isotopes



Unknown MS - How to assign the peaks?



Evaluation problems: The peak at atomic number 16 may, for example, be due to oxygen fragments resulting from O_2, H_2O, CO_2 and CO; the peak at atomic number 28 from contributions by N_2 as well as by CO and CO as a fragment of CO_2; the peak at atomic number 20 could result from singly ionized Ne and double-ionized Ar.

"Synthesis" of a MS as linear combination of known fragmentation pattern

No	Gas	Symbol	1 = 100	2	3	4	5	6
1	Acetone	$(CH_3)_2CO$	43/100	15/42	58/20	14/10	27/19	42/8
2	Air		28/100	32/27	14/6	16/3	40/1	-
3	Ammonia	NH_3	17/100	16/80	15/8	14/2	-	-
4	Argon	Ar	40/100	20/10	-	-	-	-
5	Benzene	C_6H_6	78/100	77/22	51/18	50/17	52/15	39/10
6	Carbon dioxide	CO_2	44/100	28/11	16/9	12/6	45/1	22/1
7	Carbon monoxide	CO	28/100	12/5	16/2	29/1	-	-
8	Carbon tetrachloride	CCl_4	117/100	119/91	47/51	82/42	35/39	121/29
9	Carbon tetrafluoride	CF_4	69/100	50/12	31/5	19/4	-	-
10	Diff. pump oil, DC 705		78/100	76/83	39/73	43/59	91/32	-
11	Diff. pump oil, Fomblin		69/100	20/28	16/16	31/9	97/8	47/8
12	Diff. pump oil, PPE		50/100	77/89	63/29	62/27	64/21	38/7
13	Ethanol	CH_3CH_2OH	31/100	45/34	27/24	29/23	46/17	26/8
14	Halocarbon 11	CCl_3F	101/100	103/60	35/16	66/15	47/12	31/10
15	Halocarbon 12	CCl_2F_2	85/100	87/32	50/16	35/12	-	-
16	Halocarbon 13	$CClF_3$	69/100	85/15	50/14	31/9	35/7	87/5
17	Halocarbon 14	CF_4	69/100	12/7	19/6	31/5	50/8	-
18	Halocarbon 23	CHF_3	51/100	31/58	69/40	50/19	52/1	21/1
19	Halocarbon 113	$C_2C_{13}F_3$	101/100	103/62	85/55	31/50	151/41	153/25
20	Helium	He	4/100	-	-	-	-	-
21	Heptane	C_7H_{16}	43/100	41/62	29/49	27/40	57/34	71/28
22	Hexane	C_6H_{14}	41/100	43/92	57/85	29/84	27/65	56/50
23	Hydrogen	H_2	2/100	1/5	-	-	-	-
24	Hydrogen sulfide	H_2S	34/100	32/44	33/42	36/4	35/2	-
25	Isopropyl alcohol	C_3H_8O	45/100	43/16	27/16	29/10	41/7	39/6
26	Krypton	Kr	84/100	86/31	83/20	82/20	80/4	-
27	Methane	CH_4	16/100	15/85	14/16	13/8	1/4	12/2
28	Mehtyl alcohol	CH_3OH	31/100	29/74	32/67	15/50	28/16	2/16
29	Methyl ethyl ketone	C_4H_8O	43/100	29/25	72/16	27/16	57/6	42/5
30	Mechanical pump oil		43/100	41/91	57/73	55/64	71/20	39/19
31	Neon	Ne	20/100	22/10	10/1	-	-	-
32	Nitrogen	N_2	28/100	14/7	29/1	-	-	-
33	Oxygen	O_2	32/100	16/11	-	-	-	-
34	Perfluorokerosene		69/100	119/17	51/12	131/11	100/5	31/4
35	Perfluor-tributylamine	$C_{12}F_{27}N$	69/100	131/18	31/6	51/5	50/3	114/2
36	Silane	SiH_4	30/100	31/80	29/31	28/28	32/8	33/2
37	Silicon tetrafluoride	SiF_4	85/100	87/12	28/12	33/10	86/5	47/5
38	Toluene	$C_6H_5CH_3$	91/100	92/62	39/12	65/6	45.5/4	51/4
39	Trichloroethane	$C_2H_3Cl_3$	97/100	61/87	99/61	26/43	27/31	63/27
40	Trichloroethylene	C_2HCl_3	95/100	130/90	132/85	97/64	60/57	35/31
41	Trifluoromethane	CHF_3	69/100	51/91	31/49	50/42	12/4	-
42	Turbomolecular pump oil		43/100	57/88	41/76	55/73	71/52	69/49
43	Water vapor	H_2O	18/100	17/25	1/6	16/2	2/2	-
44	Xenon	Xe	132/100	129/98	131/79	134/39	136/33	130/15

Table 4.5 Spectrum library of the 6 highest peaks for the TRANSPECTOR

"Synthesis" of a MS as linear combination of known fragmentation pattern

No	Gas	Symbol	1 = 100	2	3	4	5	6
1	Acetone	$(CH_3)_2CO$	43/100	15/42	58/20	14/10	27/19	42/8
2	Air		28/100	32/27	14/6	16/3	40/1	-
3	Ammonia	NH_3	17/100	16/80	15/8	14/2	-	-
4	Argon	Ar	40/100	20/10	-	-	-	-
6	Carbon dioxide	CO_2	44/100	28/11	16/9	12/6	45/1	22/1
7	Carbon monoxide	CO	28/100	12/5	16/2	29/1	-	-
8	Carbon tetrachloride	CCl_4	117/100	119/91	47/51	82/42	35/39	121/29
9	Carbon tetrafluoride	CF_4	69/100	50/12	31/5	19/4	-	-
10	Diff. pump oil, DC 705		78/100	76/83	39/73	43/59	91/32	-
11	Diff. pump oil, Fomblin		69/100	20/28	16/16	31/9	97/8	47/8
12	Diff. pump oil, PPE		50/100	77/89	63/29	62/27	64/21	38/7
13	Ethanol	CH_3CH_2OH	31/100	45/34	27/24	29/23	46/17	26/8
14	Halocarbon 11	CCl_3F	101/100	103/60	35/16	66/15	47/12	31/10
15	Halocarbon 12	CCl_2F_2	85/100	87/32	50/16	35/12	-	-
16	Halocarbon 13	$CClF_3$	69/100	85/15	50/14	31/9	35/7	87/5
17	Halocarbon 14	CF_4	69/100	12/7	19/6	31/5	50/8	-
18	Halocarbon 23	CHF_3	51/100	31/58	69/40	50/19	52/1	21/1
19	Halocarbon 113	$C_2C_{13}F_3$	101/100	103/62	85/55	31/50	151/41	153/25
20	Helium	He	4/100	-	-	-	-	-
21	Heptane	C_7H_{16}	43/100	41/62	29/49	27/40	57/34	71/28
22	Hexane	C_6H_{14}	41/100	43/92	57/85	29/84	27/65	56/50
23	Hydrogen	H_2	2/100	1/5	-	-	-	-
24	Hydrogen sulfide	H_2S	34/100	32/44	33/42	36/4	35/2	-
25	Isopropyl alcohol	C_3H_8O	45/100	43/16	27/16	29/10	41/7	39/6
26	Krypton	Kr	84/100	86/31	83/20	82/20	80/4	-
27	Methane	CH_4	16/100	15/85	14/16	13/8	1/4	12/2
28	Mehtyl alcohol	CH_3OH	31/100	29/74	32/67	15/50	28/16	2/16
29	Methyl ethyl ketone	C_4H_8O	43/100	29/25	72/16	27/16	57/6	42/5
30	Mechanical pump oil		43/100	41/91	57/73	55/64	71/20	39/19
31	Neon	Ne	20/100	22/10	10/1	-	-	-
32	Nitrogen	N_2	28/100	14/7	29/1	-	-	-
33	Oxygen	O_2	32/100	16/11	-	-	-	-
34	Perfluorokerosene		69/100	119/17	51/12	131/11	100/5	31/4
35	Perfluor-tributylamine	$C_{12}F_{27}N$	69/100	131/18	31/6	51/5	50/3	114/2
36	Silane	SiH_4	30/100	31/80	29/31	28/28	32/8	33/2
37	Silicon tetrafluoride	SiF_4	85/100	87/12	28/12	33/10	86/5	47/5
38	Toluene	$C_6H_5CH_3$	91/100	92/62	39/12	65/6	45.5/4	51/4
39	Trichloroethane	$C_2H_3Cl_3$	97/100	61/87	99/61	26/43	27/31	63/27
40	Trichloroethylene	C_2HCl_3	95/100	130/90	132/85	97/64	60/57	35/31
41	Trifluoromethane	CHF_3	69/100	51/91	31/49	50/42	12/4	-
42	Turbomolecular pump oil		43/100	57/88	41/76	55/73	71/52	69/49
43	Water vapor	H_2O	18/100	17/25	1/6	16/2	2/2	-
44	Xenon	Xe	132/100	129/98	131/79	134/39	136/33	130/15

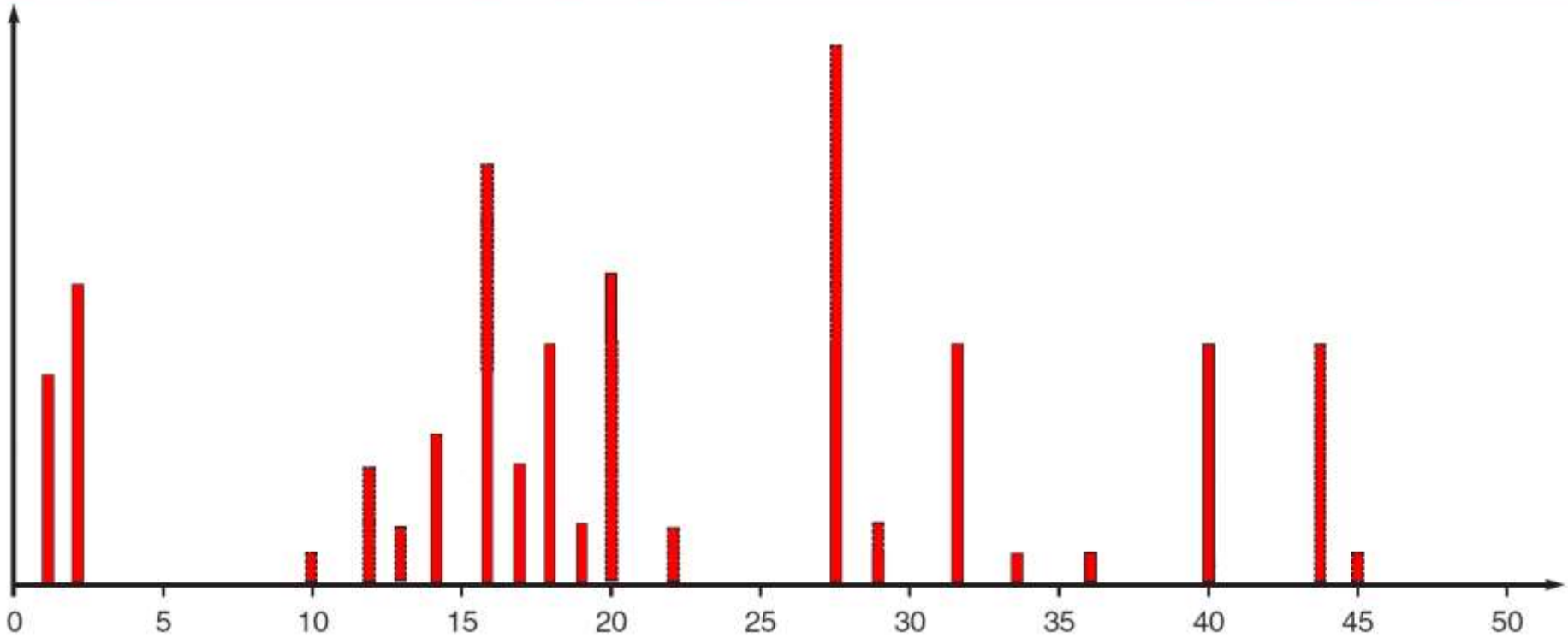
Table 4.5 Spectrum library of the 6 highest peaks for the TRANSPECTOR

"Synthesis" of a MS as linear combination of known fragmentation pattern

No	Gas	Symbol	1 = 100	2	3	4	5	6
1	Acetone	$(CH_3)_2CO$	43/100	15/42	58/20	14/10	27/19	42/8
2	Air		28/100	32/27	14/6	16/3	40/1	-
3	Ammonia	NH_3	17/100	16/80	15/8	14/2	-	-
4	Argon	Ar	40/100	20/10	-	-	-	-
6	Carbon dioxide	CO_2	44/100	28/11	16/9	12/6	45/1	22/1
7	Carbon monoxide	CO	28/100	12/5	16/2	29/1	-	-
11	Diff. pump oil, Fomblin		69/100	20/28	16/16	31/9	97/8	47/8
12	Diff. pump oil, PPE		50/100	77/89	63/29	62/27	64/21	38/7
13	Ethanol	CH_3CH_2OH	31/100	45/34	27/24	29/23	46/17	26/8
14	Halocarbon 11	CCl_3F	101/100	103/60	35/16	66/15	47/12	31/10
15	Halocarbon 12	CCl_2F_2	85/100	87/32	50/16	35/12	-	-
16	Halocarbon 13	$CClF_3$	69/100	85/15	50/14	31/9	35/7	87/5
17	Halocarbon 14	CF_4	69/100	12/7	19/6	31/5	50/8	-
18	Halocarbon 23	CHF_3	51/100	31/58	69/40	50/19	52/1	21/1
19	Halocarbon 113	$C_2C_{13}F_3$	101/100	103/62	85/55	31/50	151/41	153/25
20	Helium	He	4/100	-	-	-	-	-
21	Heptane	C_7H_{16}	43/100	41/62	29/49	27/40	57/34	71/28
22	Hexane	C_6H_{14}	41/100	43/92	57/85	29/84	27/65	56/50
23	Hydrogen	H_2	2/100	1/5	-	-	-	-
24	Hydrogen sulfide	H_2S	34/100	32/44	33/42	36/4	35/2	-
25	Isopropyl alcohol	C_3H_8O	45/100	43/16	27/16	29/10	41/7	39/6
26	Krypton	Kr	84/100	86/31	83/20	82/20	80/4	-
27	Methane	CH_4	16/100	15/85	14/16	13/8	1/4	12/2
28	Mehtyl alcohol	CH_3OH	31/100	29/74	32/67	15/50	28/16	2/16
29	Methyl ethyl ketone	C_4H_8O	43/100	29/25	72/16	27/16	57/6	42/5
30	Mechanical pump oil		43/100	41/91	57/73	55/64	71/20	39/19
31	Neon	Ne	20/100	22/10	10/1	-	-	-
32	Nitrogen	N_2	28/100	14/7	29/1	-	-	-
33	Oxygen	O_2	32/100	16/11	-	-	-	-
34	Perfluorokerosene		69/100	119/17	51/12	131/11	100/5	31/4
35	Perfluor-tributylamine	$C_{12}F_{27}N$	69/100	131/18	31/6	51/5	50/3	114/2
36	Silane	SiH_4	30/100	31/80	29/31	28/28	32/8	33/2
37	Silicon tetrafluoride	SiF_4	85/100	87/12	28/12	33/10	86/5	47/5
38	Toluene	$C_6H_5CH_3$	91/100	92/62	39/12	65/6	45.5/4	51/4
39	Trichloroethane	$C_2H_3Cl_3$	97/100	61/87	99/61	26/43	27/31	63/27
40	Trichloroethylene	C_2HCl_3	95/100	130/90	132/85	97/64	60/57	35/31
41	Trifluoromethane	CHF_3	69/100	51/91	31/49	50/42	12/4	-
42	Turbomolecular pump oil		43/100	57/88	41/76	55/73	71/52	69/49
43	Water vapor	H_2O	18/100	17/25	1/6	16/2	2/2	-
44	Xenon	Xe	132/100	129/98	131/79	134/39	136/33	130/15

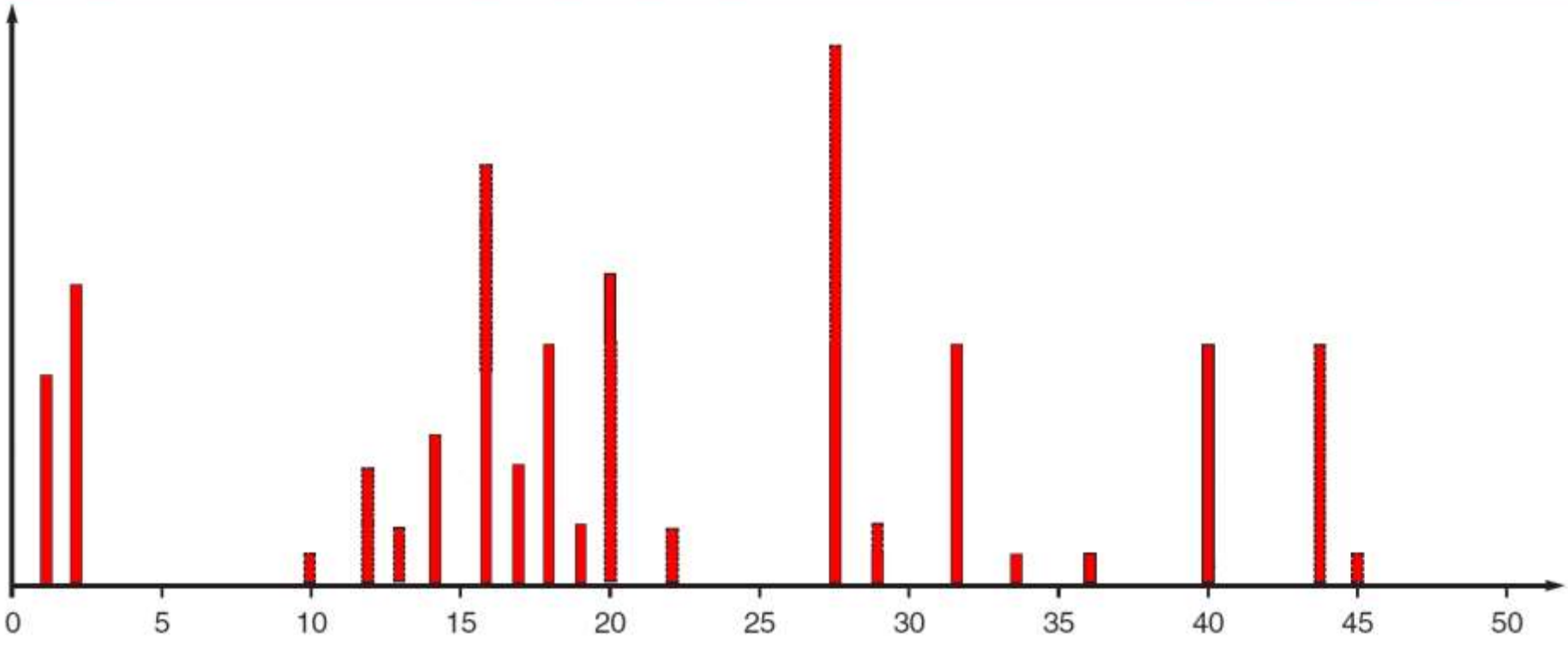
Table 4.5 Spectrum library of the 6 highest peaks for the TRANSPECTOR

Unknown MS - How to assign the peaks?



Evaluation problems: The peak at atomic number 16 may, for example, be due to oxygen fragments resulting from O_2, H_2O, CO_2 and CO; the peak at atomic number 28 from contributions by N_2 as well as by CO and CO as a fragment of CO_2; the peak at atomic number 20 could result from singly ionized Ne and double-ionized Ar.

Unknown MS - How to assign the peaks?



4	Argon	Ar	40/100	20/10	-	-	-	-

Evaluation problems: The peak at atomic number 16 may, for example, be due to oxygen fragments resulting from O_2, H_2O, CO_2 and CO; the peak at atomic number 28 from contributions by N_2 as well as by CO and CO as a fragment of CO_2; the peak at atomic number 20 could result from singly ionized Ne and double-ionized Ar.

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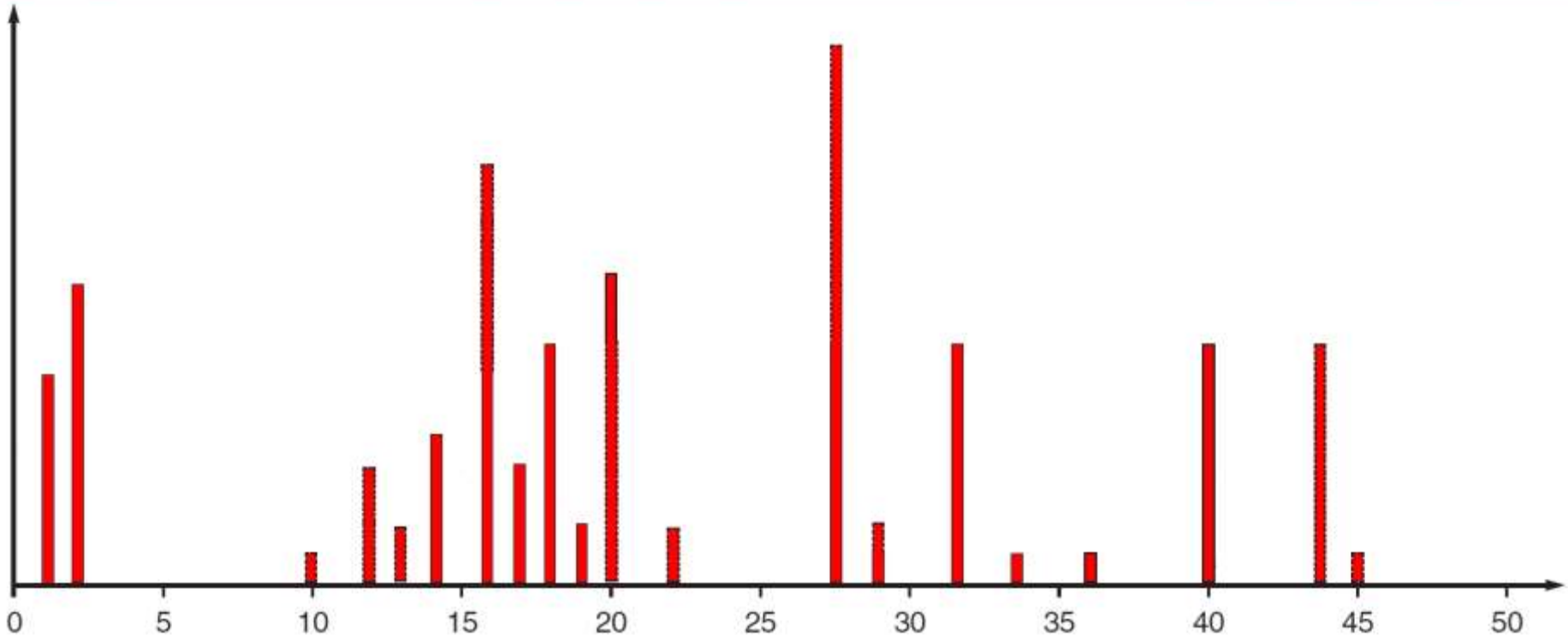
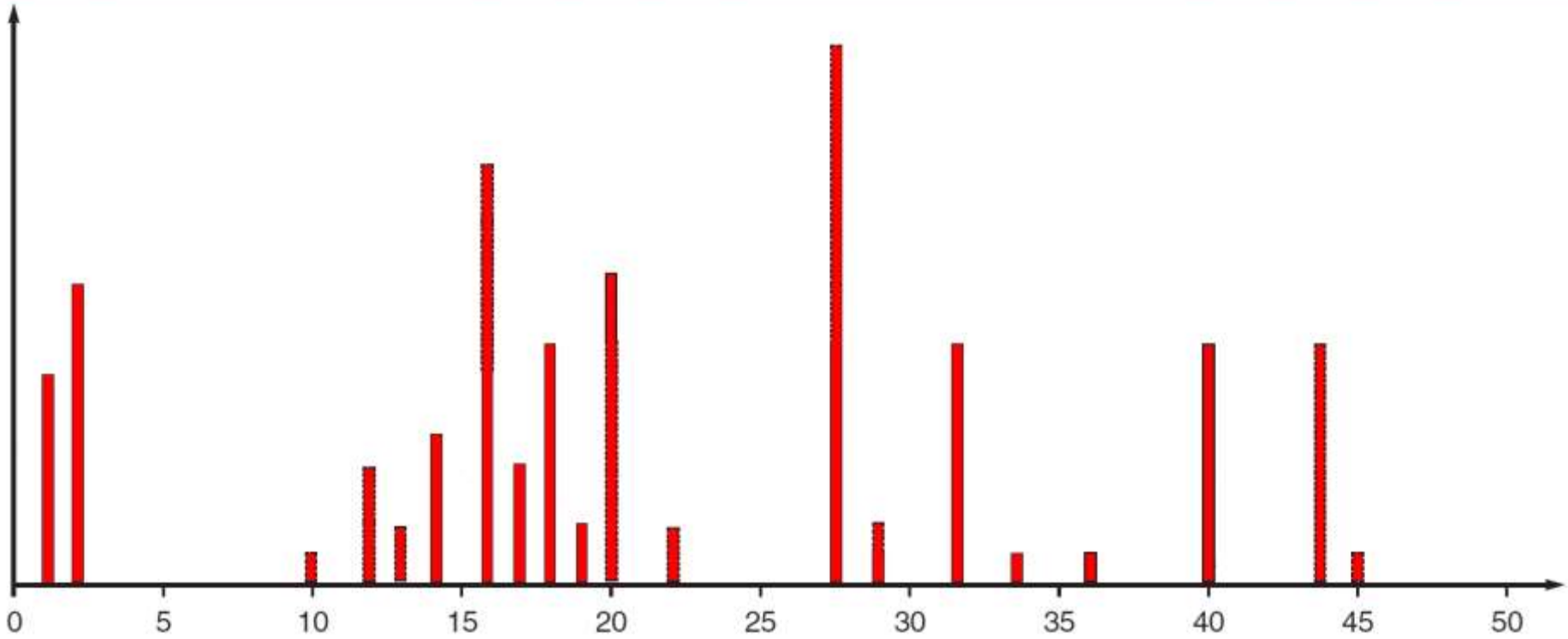


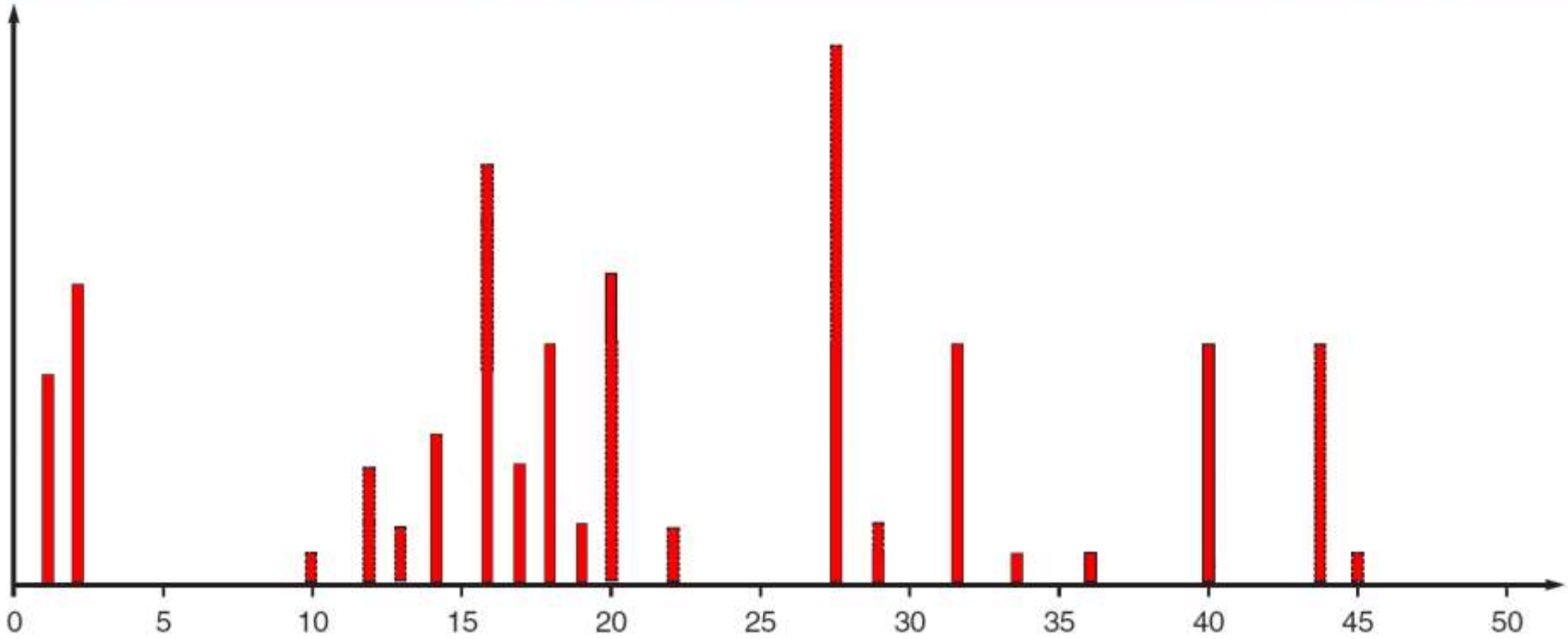
4	Argon	Ar	40/100	20/10	-	-	-	-
31	Neon	Ne	20/100	22/10	10/1	-	-	-
32	Nitrogen	N_2	28/100	14/7	29/1	-	-	-
33	Oxygen	O_2	32/100	16/11	-	-	-	-

Unknown MS - How to assign the peaks?



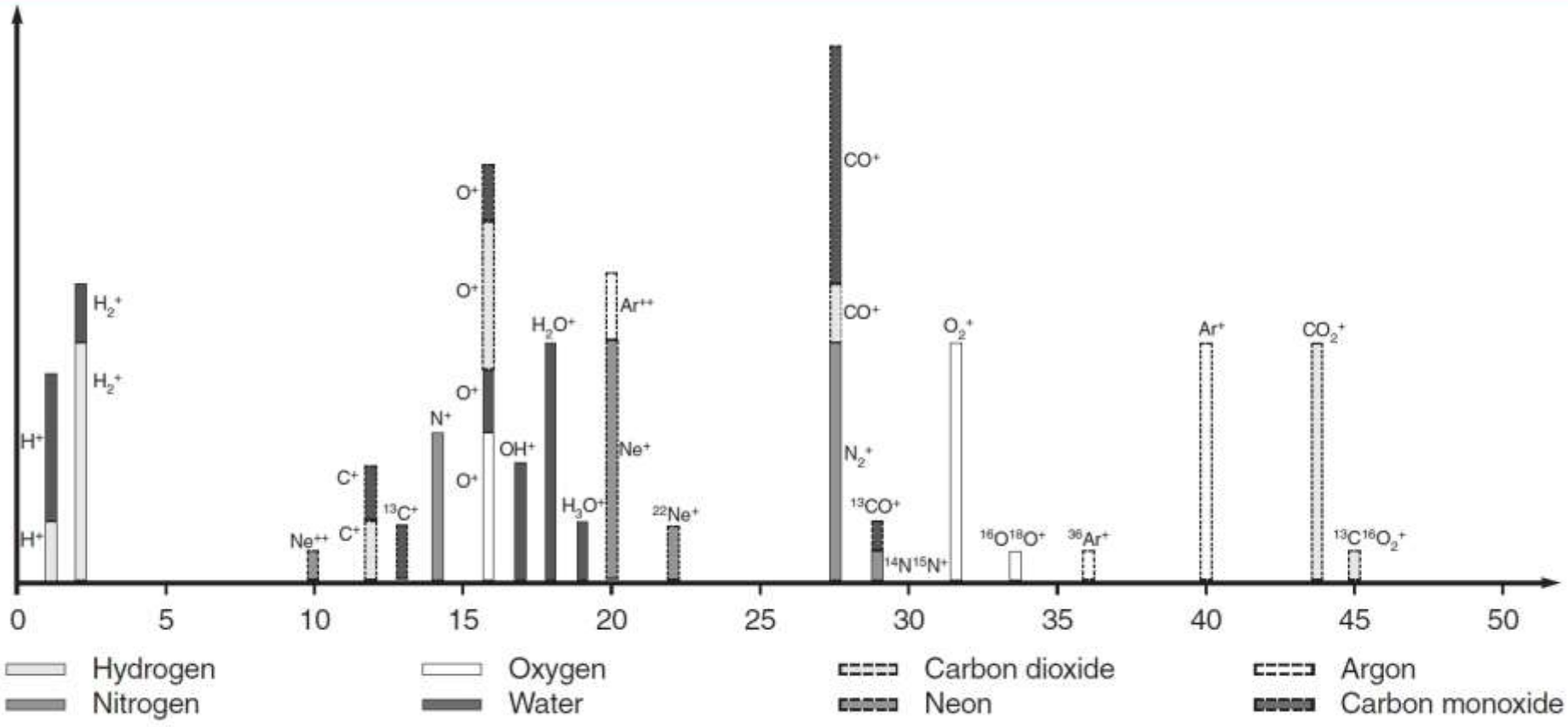
4	Argon	Ar	40/100	20/10	-	-	-	-
31	Neon	Ne	20/100	22/10	10/1	-	-	-
32	Nitrogen	N_2	28/100	14/7	29/1	-	-	-
33	Oxygen	O_2	32/100	16/11	-	-	-	-
6	Carbon dioxide	CO_2	44/100	28/11	16/9	12/6	45/1	22/1
7	Carbon monoxide	CO	28/100	12/5	16/2	29/1	-	-

Unknown MS - How to assign the peaks?



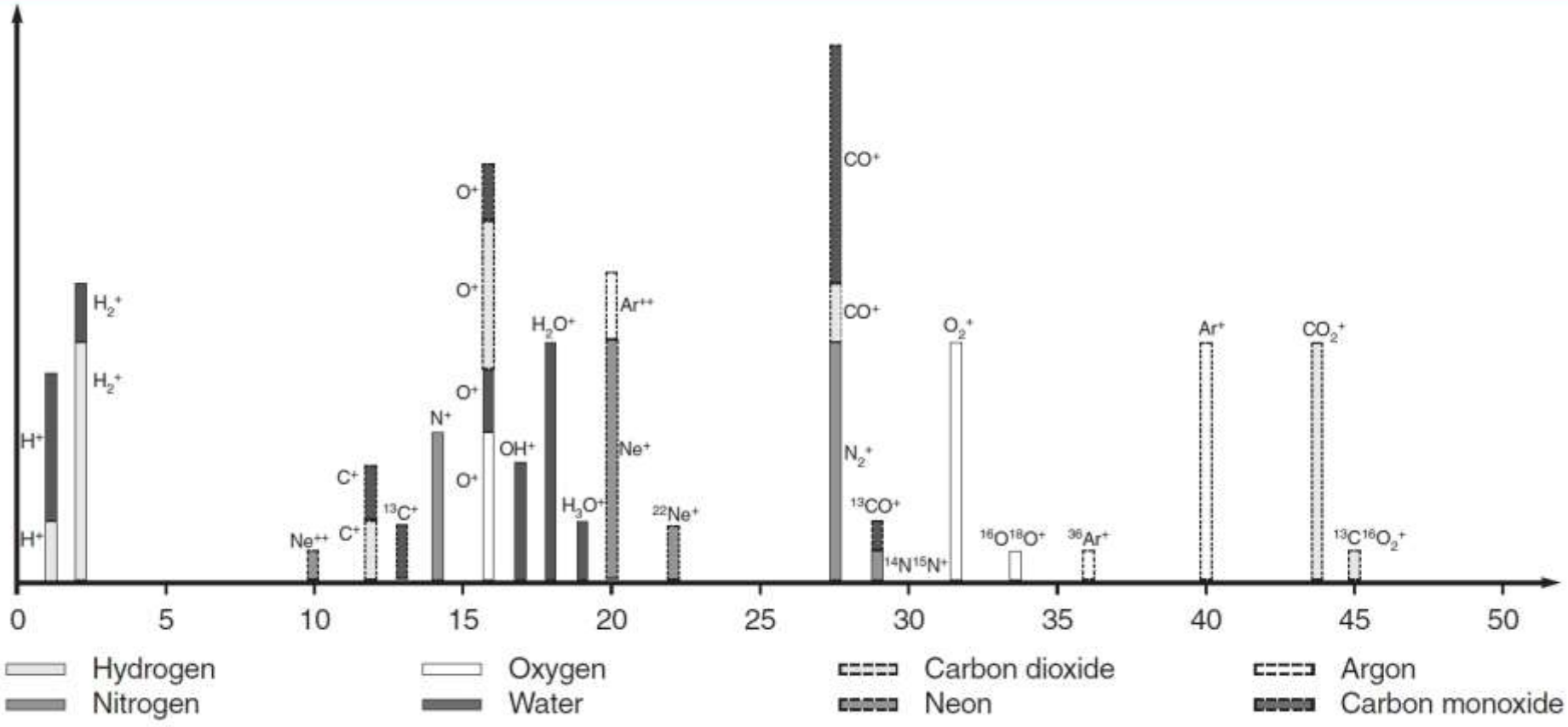
4	Argon	Ar	40/100	20/10	-	-	-	-
31	Neon	Ne	20/100	22/10	10/1	-	-	-
32	Nitrogen	N_2	28/100	14/7	29/1	-	-	-
33	Oxygen	O_2	32/100	16/11	-	-	-	-
6	Carbon dioxide	CO_2	44/100	28/11	16/9	12/6	45/1	22/1
7	Carbon monoxide	CO	28/100	12/5	16/2	29/1	-	-
43	Water vapor	H_2O	18/100	17/25	1/6	16/2	2/2	-

"Synthesis" of a MS as linear combination of a known fragmentation pattern



Evaluation problems: The peak at atomic number 16 may, for example, be due to oxygen fragments resulting from O_2, H_2O, CO_2 and CO; the peak at atomic number 28 from contributions by N_2 as well as by CO and CO as a fragment of CO_2; the peak at atomic number 20 could result from singly ionized Ne and double-ionized Ar.

"Synthesis" of a MS as linear combination of a known fragmentation pattern



Evaluation problems: The peak at atomic number 16 may, for example, be due to oxygen fragments resulting from O_2, H_2O, CO_2 and CO; the peak at atomic number 28 from contributions by N_2 as well as by CO and CO as a fragment of CO_2; the peak at atomic number 20 could result from singly ionized Ne and double-ionized Ar.

Example for illustration: Investigation of plasma induced Si etching using SF_6

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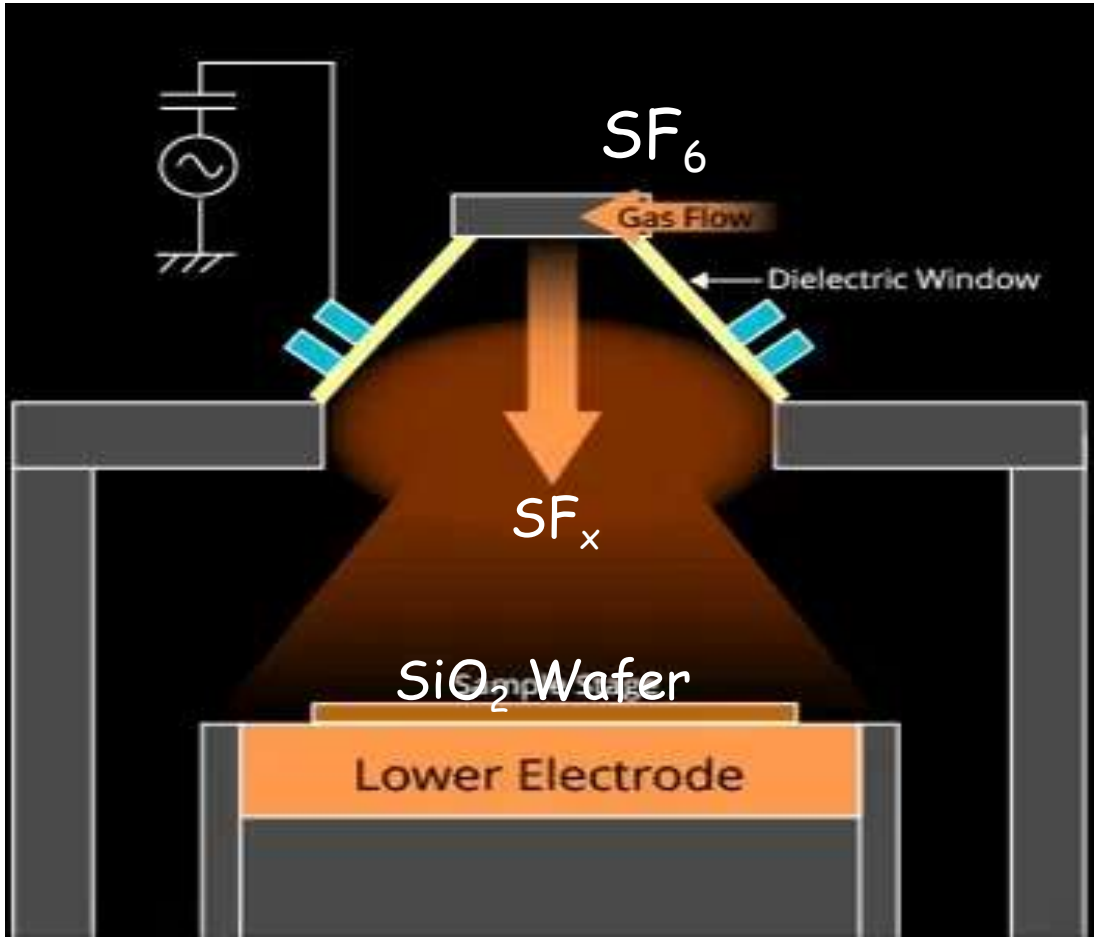

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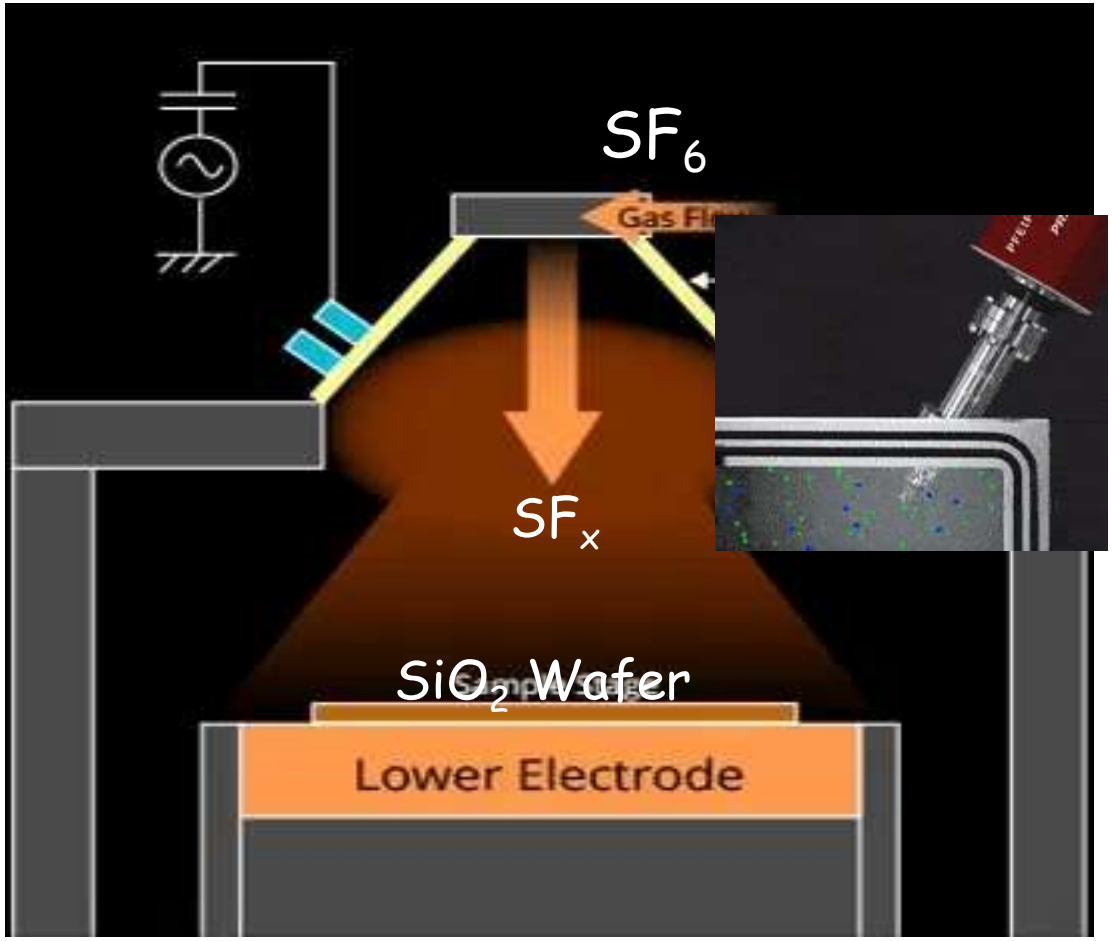

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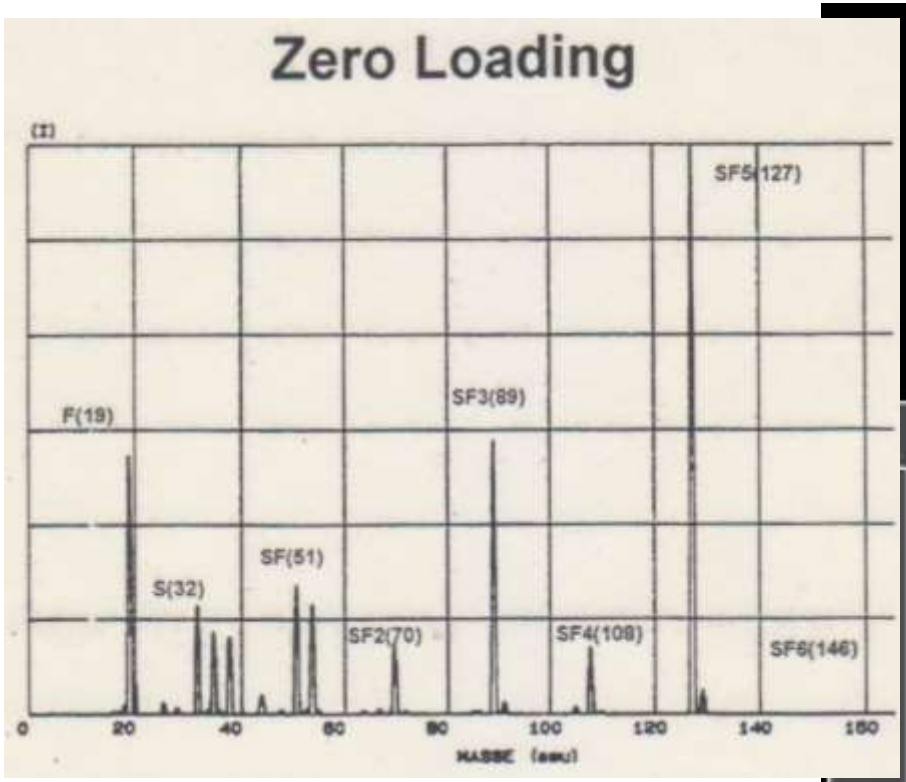

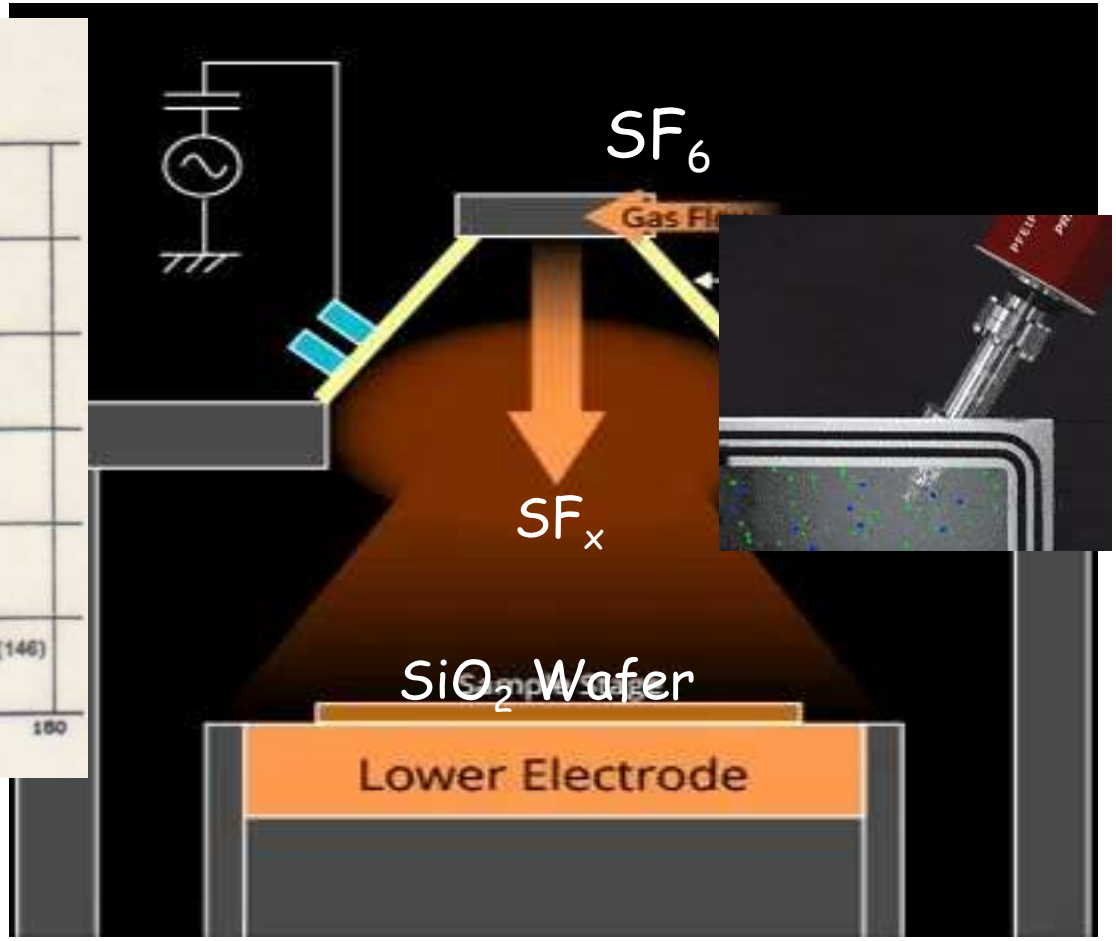

SF_6 Plasma with a fully masked wafer (SiO_2 no Si etching)

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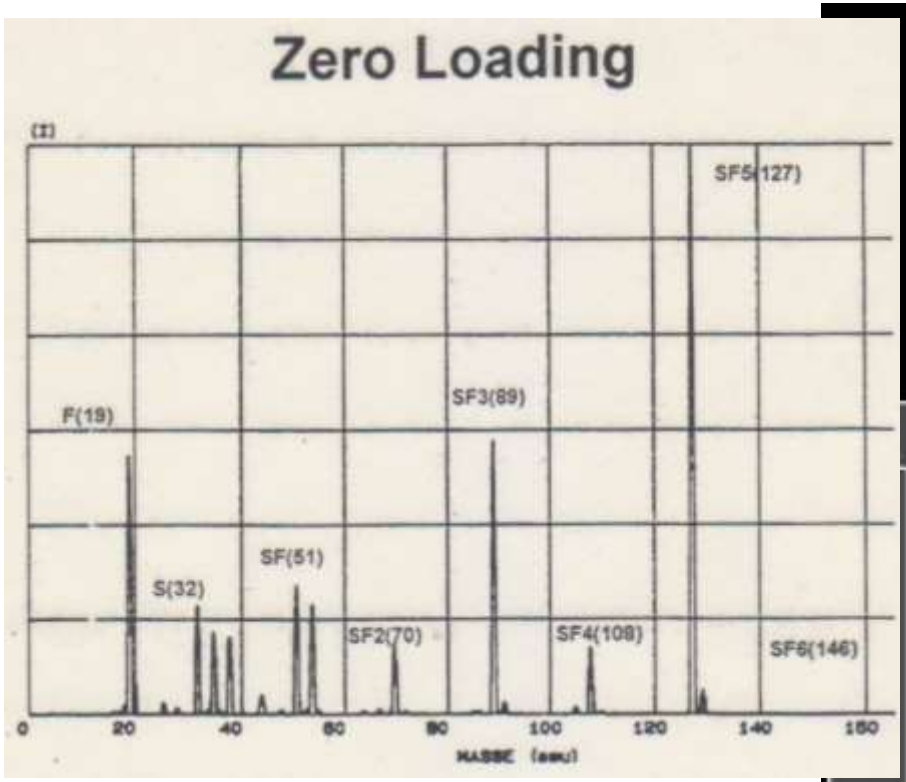
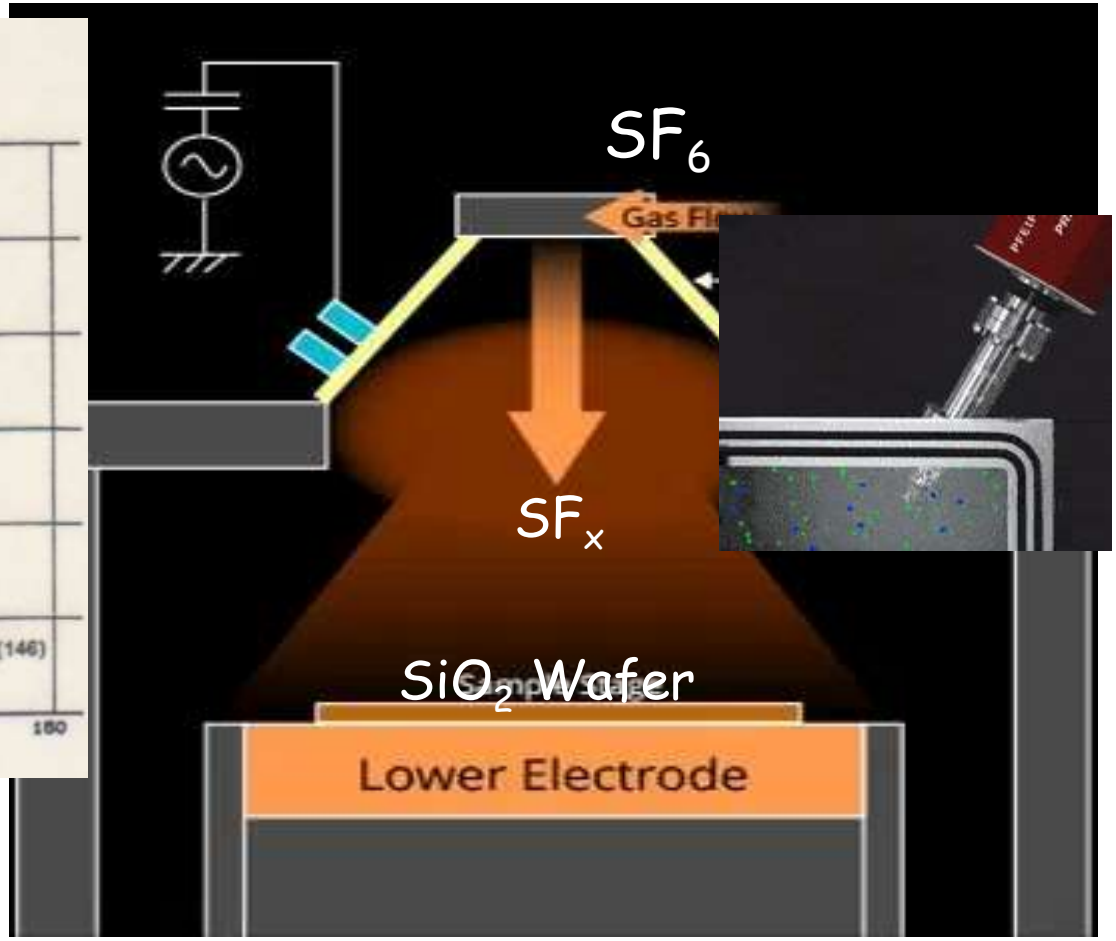
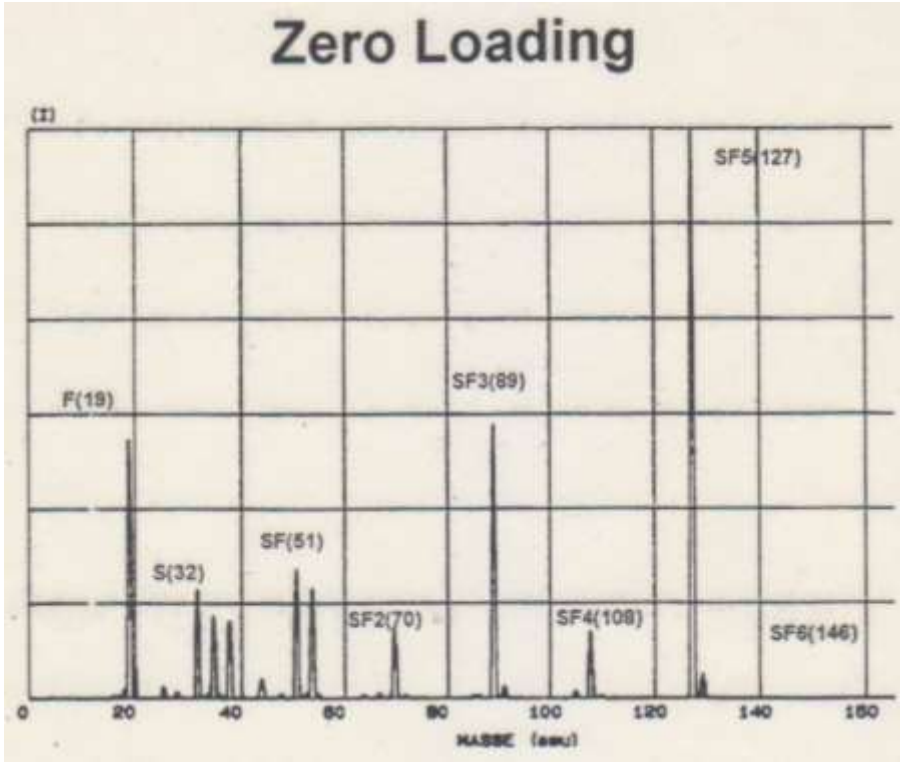


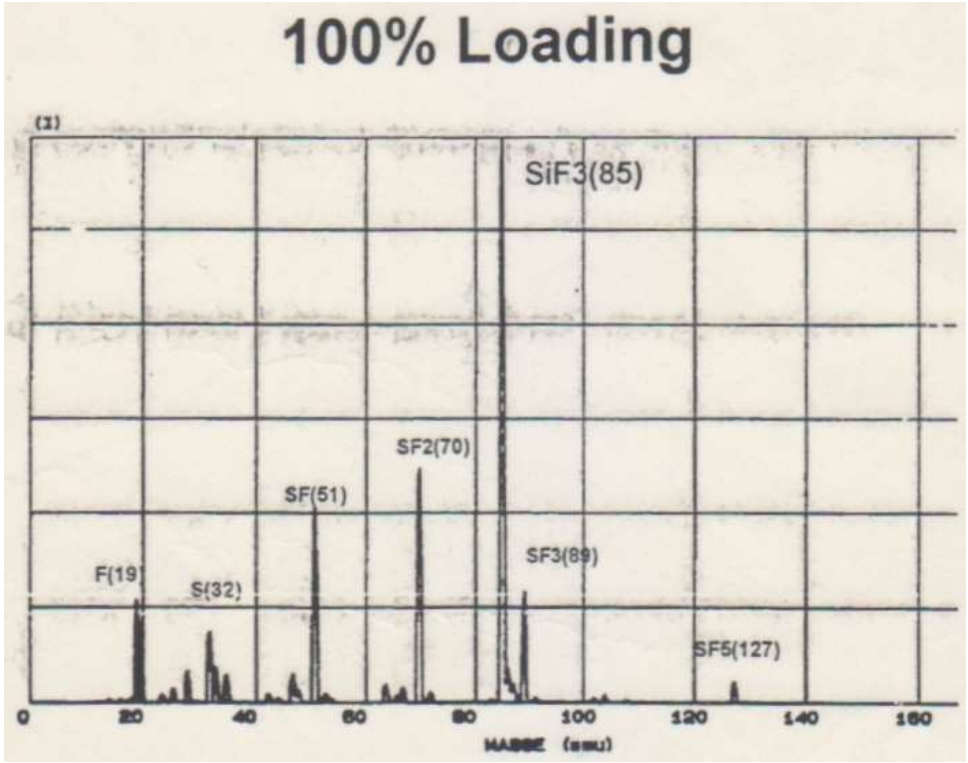


SF_6 Plasma with a fully masked wafer (SiO_2 no Si etching)

Now a "bare" Si wafer instead of SiO_2 as substrate:

Example for illustration: Investigation of plasma induced Si etching using SF_6

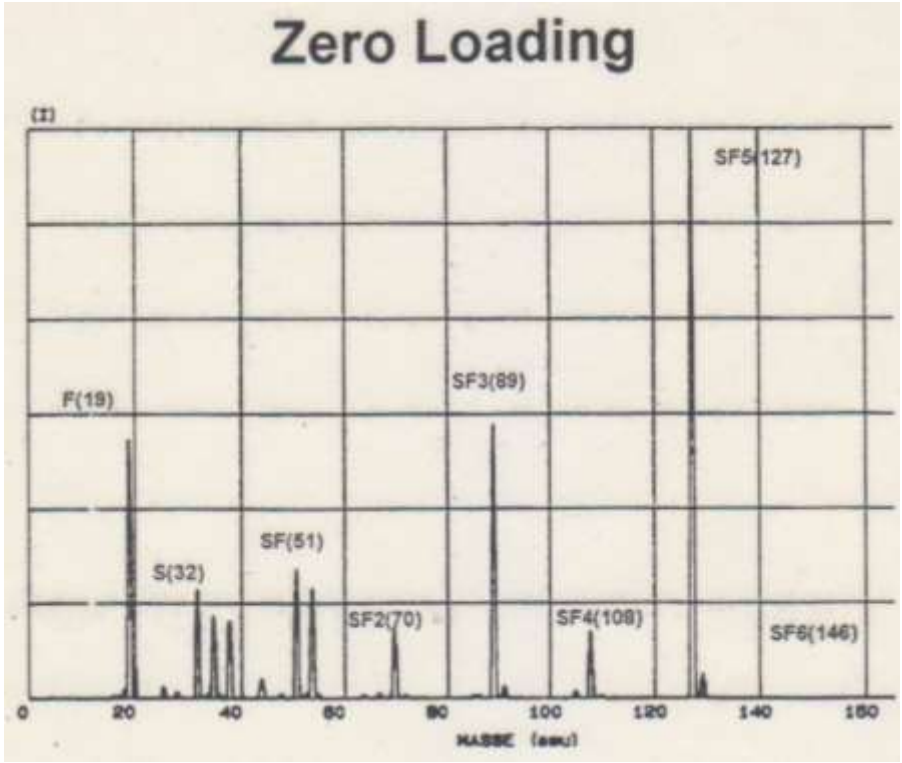


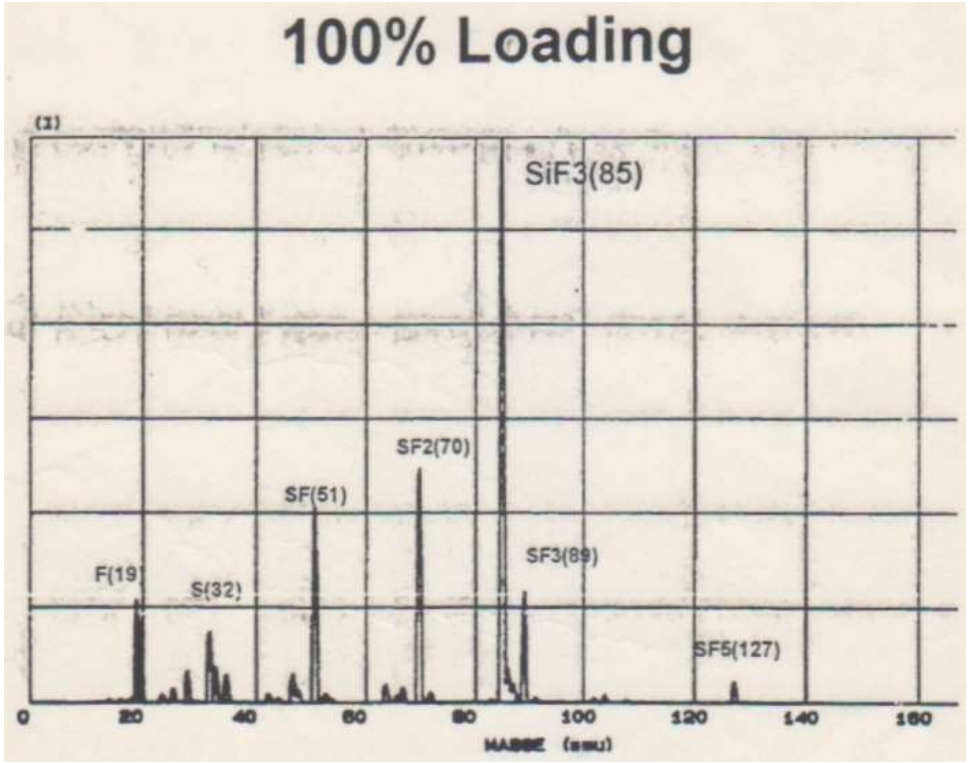


SF_6 Plasma with a fully masked wafer (no Si etching)

SF_6 Plasma with a blanket Si Wafer (full "100%" loading)

Example for illustration: Investigation of plasma induced Si etching using SF_6





SF_6 Plasma with a fully masked wafer (no Si etching)

SF_6 Plasma with a blanket Si Wafer (full "100%" loading)

Etch rate = f(power, gas flow, temperature, …) ~ [85/19]

Chapters

0. Introduction

Air pressure as a force to the walls of an empty container

1. Gas kinetic

Pressure as momentum transfer, Mol & Molvolume, Pressure units Partial pressure, Boltzmann Velocity&Energy distribution, Impingement rate, monolayer coverage time, mean free path collision rate

2. Pressure Ranges

Viscous, Knudsen, Molecular flow, Rough-, Medium-, High-, Ultrahigh-Vacuum, Heat conduction

3. Vacuum technical terms

Pumping speed, pumping power, gas-flow, residence time, gas flow conduction, impact on tube dimension

4. Vacuum generation

Genealogy of pumps, working principle, assignment to vacuum range

5. Pressure measurement

Direct / Indirect pressure measurement, Different gauges and assignement to vacuum range, Partial pressure measurement, interpretation of QMA spectra

Thank you very much for your attention!

All the very best for the upcoming examinations!

Relaxing vacations and stay healthy!

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»Wissen schafft Brücken.«