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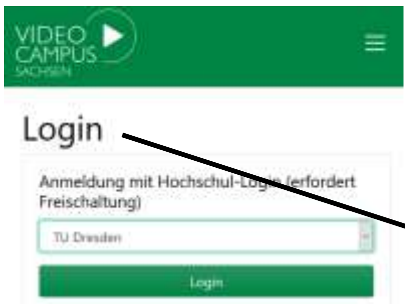

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Vacuum Technology
WS 20/21
Virtually presented
Lecture 9, Jan. 05, 2021

Prof. Dr. Johann W. Bartha

Inst. f. Halbleiter und Mikrosystemtechnik
Technische Universität Dresden

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“VT L09 a 14:24

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This document including the contained video streams is only available to students of the lecture „Vacuum Technology"
at TU-Dresden.
It must not be copied and published outside of TUD!
It is intended for
TUD internal use only!

Please participate in the review of the teacher for this class!

Dear Students of the class Vacuum Technology in the WS 20/21,
First of all, I want to wish you a very happy, healthy and successful new Year! I was convinced, that I have sent you the following message below in mid-December and wanted to send a reminder now. Since I could not find it in my records, I am not so sure any more if I really have sent it. Therefore, I want to ask you urgently, to participate in this review and please do this as quick as possible since I do not know how long the questionnaire will be open.
Teaching in this web-based format is a general challenge for the students as well as for the teachers. In our department of ET+IT we ask every semester our students for an evaluation of the teacher's performance in the specific classes. This evaluation is handled by a TUD central department for quality analysis. I will later receive a summary of the results. Below, you find a link, that gets you to a questionnaire (English version), concerning Vacuum Technology. I urge all of you very much to participate.
Since we do not meet personally, it is even more important for me to learn, how the lecture is received.
This is the link: http://befragung.zqa.tu-dresden.de/uz/sl/3tTb5m9h8xdd
I appreciate any comment and thank you very much for your participation.
Many regards, take care and stay healthy
Johann W. Bartha

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, Heat conduction

2. Pressure Ranges

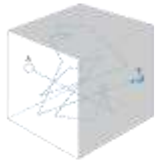
Viscous, Knudsen, Molecular flow, Rough-, Medium-, High-, Ultrahigh-Vacuum, adsorbed gas

3. Vacuum technical terms

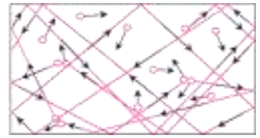
4. Vacuum generation

5. Pressure measurement

$$Z_p = \frac{\bar{u}}{\lambda}$$



$$Z_V = \frac{n}{2} Z_p = \frac{p}{2kT} Z_p$$



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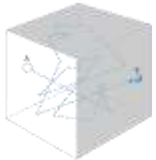

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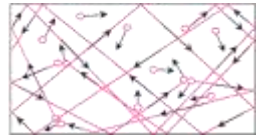

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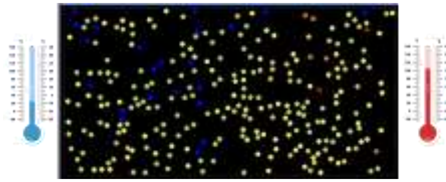

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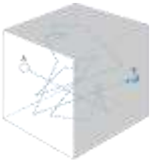

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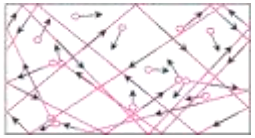

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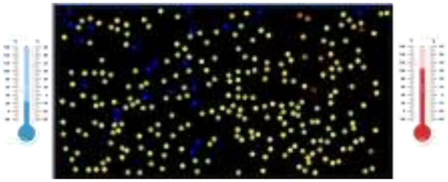

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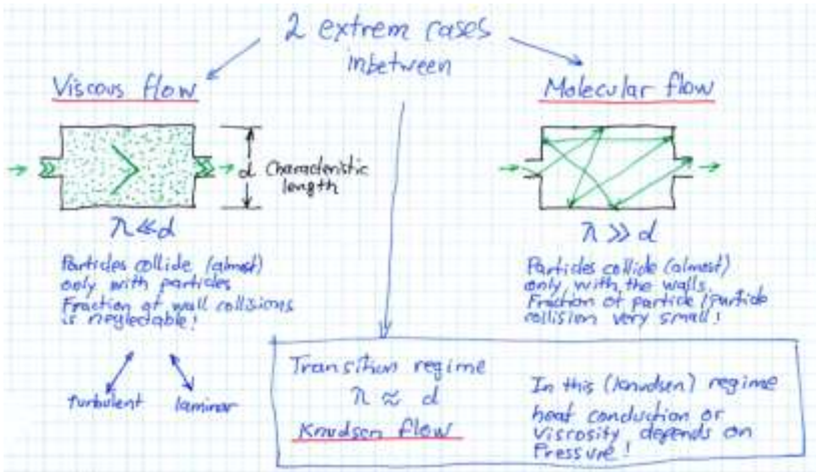

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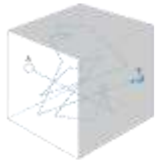

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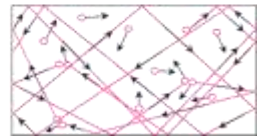

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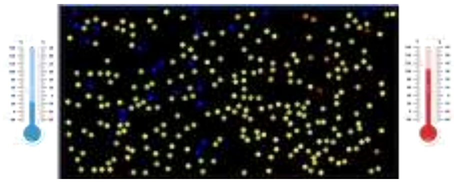

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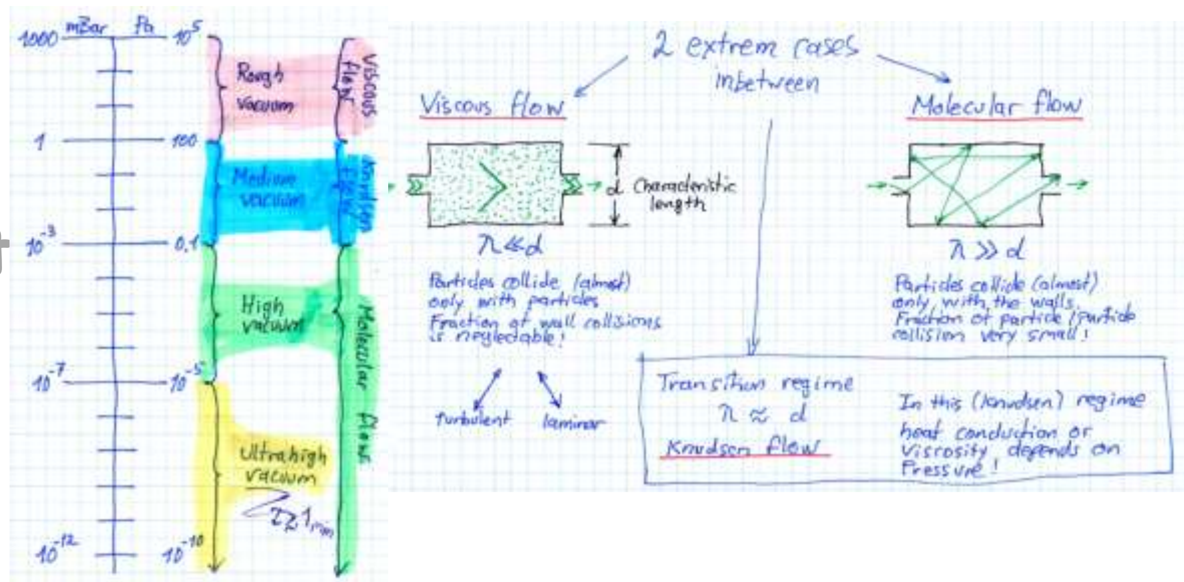

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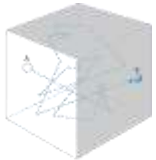

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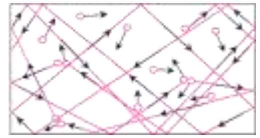

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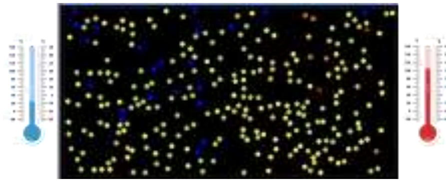

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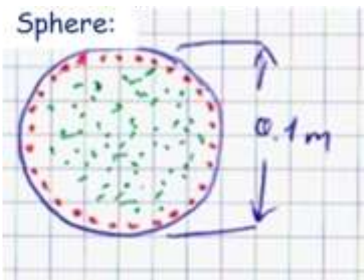

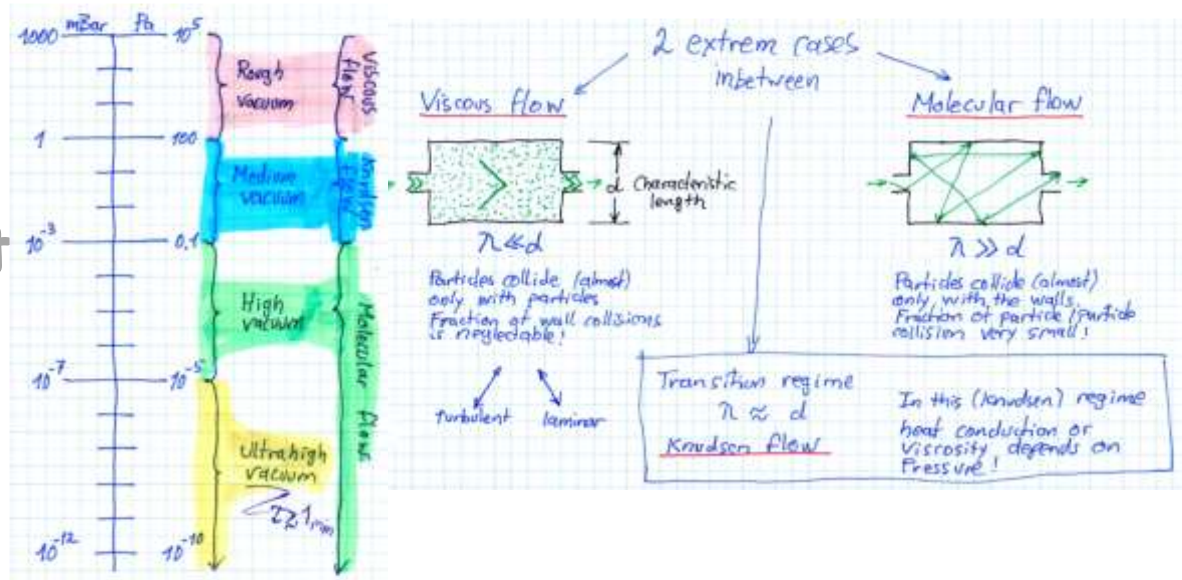

Review L8

0. Introduction

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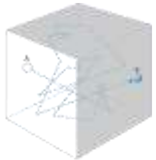

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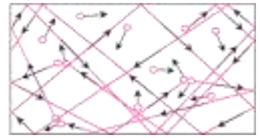

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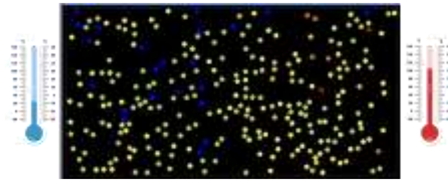

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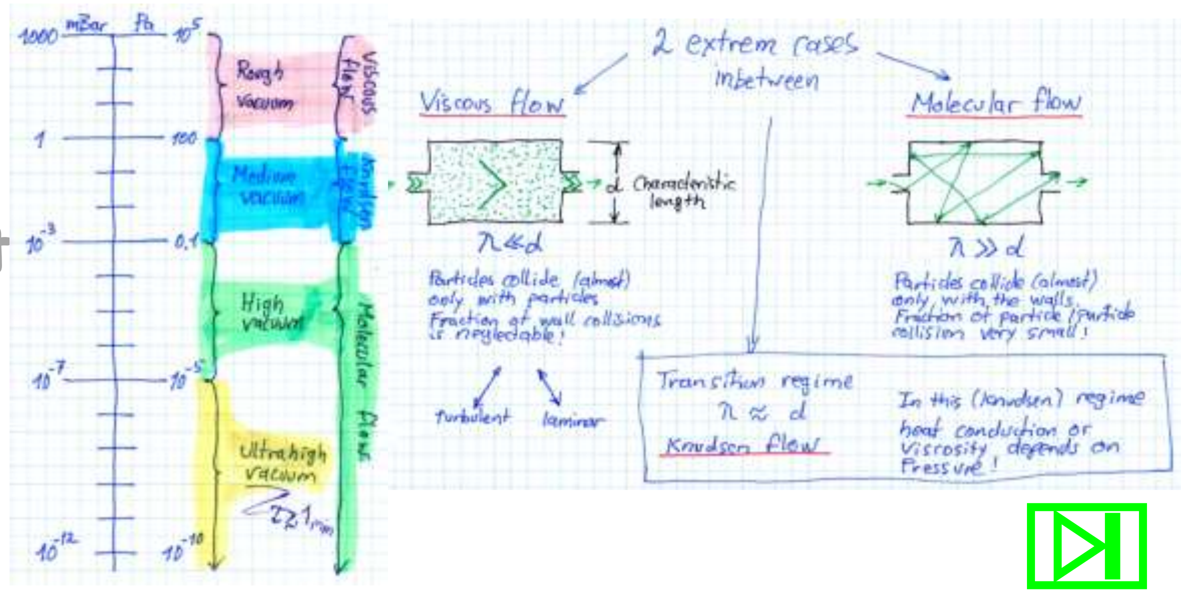

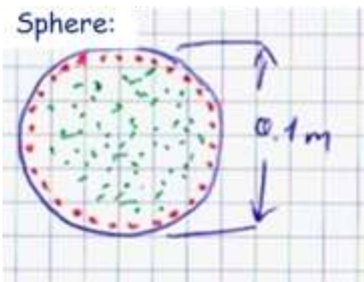

3. Vacuum technology terms

"VT L09 b 25:03

TRIVAC D 40 B

Pumping speed (50 Hz):	40 m³/h
Pumping speed (60 Hz):	48 m³/h
Ultimate pressure:	2×10^{-3} mbar

Please login to see prices.

Motor:

Please select

1 Add to shopping cart

Compare Add to wishlist
Product questions?

3. Vacuum technology terms

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Please login to see prices.

Motor:

Please select

Pumping speed,
Pumping power,
Gas flow,
Residence Time,
Gas flow conductance L

Pumps from the late 17'th century

https://skd-online-collection.skd.museum/Details/Index/328901

3. Vacuum technology terms

A pump is capable to convey a certain volume per time unit, which is called:

Pumping speed **$S = \Delta V/\Delta t$** for example in l/s or in m^3/h

(does not say anything about the amount of gas being transported)

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Quantification of amount of gas via **$P \cdot V$** for example as [mBar·l]

The transported amount of gas per time unit is the **Pumping- throughput or power**

$Q = \Delta(P \cdot V)/\Delta t = P \cdot S$ for example in [mBar·l/s]

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Q corresponds to a ***Gas flow***. The common unit for Gas flow is [sccm] which stands for **S**tandard **C**ubic **C**entimeter per **M**inute. For larger flow another common unit is [slm] which stands for **S**tandard **L**iter per **M**inute.

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Standard (STP) means: 0°C and 1 Bar. or 760 Torr or 101300 Pa
In that case we have within the mole volume of 22414 cm^3 $6{,}023 \cdot 10^{23}$ particles.

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Therefore (uncorrected for RT):
1sccm = 101300 Pa $\cdot 10^{-3}$ l / 60 sec = 1,7 Pa·l/s or 17 $\cdot 10^{-3}$ [mBar·l/s] also
1sccm = $6{,}023 \cdot 10^{23}$ particles / 22414 $cm^3 \cdot$min = $2{,}69 \cdot 10^{19}$ Molecules or Atoms/min

STP : 0 °C ← ⚠

1 atm ≙ 760 Torr ≙ 101300 Pa

1 Mol ≙ 22414 cm^3 ≙ $6{,}022 \cdot 10^{23}$ Particles

$$1\ sccm = \frac{6{,}022 \cdot 10^{23}}{22414} \frac{Molecules}{min}$$

$$1\ sccm = 2{,}69 \cdot 10^{19} \frac{Molecules}{min}$$

1 sccm!

or

$$1\ sccm = \frac{101300\ Pa \cdot 10^{-3}\ \ell}{60\ sec} = 1{,}7 \frac{Pa \cdot \ell}{s}$$

or

$$1\ sccm = 17 \cdot 10^{-3} \frac{mBar\ \ell}{s}$$

(room temp)

Gas flow corrected for RT:

→ 20°C

Unit "standard ccm / minute" sccm

correction factor

$$1\,\text{sccm} = \frac{1013{,}25\,\text{mBar} \cdot 0{,}001\,l}{60\,s} \left(\frac{293{,}15\,K}{273{,}15\,K}\right) = 0{,}018124\,\frac{\text{mBar}\ l}{s}$$

Unit "standard liter per minute" slm

$$1\,\text{slm}\ \ \frac{1013{,}25\,\text{mbar} \cdot 1\,l}{60\,s}\ \frac{293{,}..K}{273{,}.\,K} = 18{,}124\,\frac{\text{mbar}\ l}{s}$$

$1\ \text{sccm} = 1{,}8\ \text{Pa}\ l/s = 18\,10^{-3}\ \text{m Bar}\ l/s = 2{,}89 \cdot 10^{19}$ Particles / min !

STP: 0°C

1 atm ≙ 760 Torr ≙ 101300 Pa

1 Mole ≙ 22414 cm^3 ≙ $6{,}023 \cdot 10^{23}$ Part.

$$1\ \text{sccm} = \frac{6.023 \cdot 10^{23}}{22414} \frac{\text{Molecules}}{\text{min}}$$

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Gas flow corrected for RT:

$$Q = p \cdot \frac{\mathrm{d}V}{\mathrm{d}t}$$

Q Gasflow
P Pressure
V Volume
t time

Unit "standard ccm per minute" sccm

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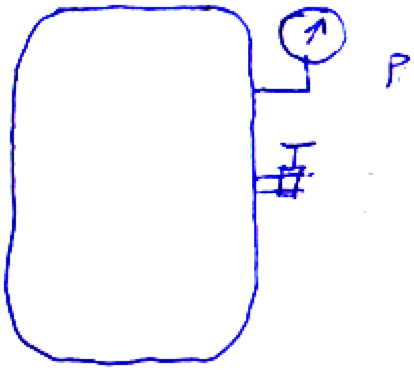
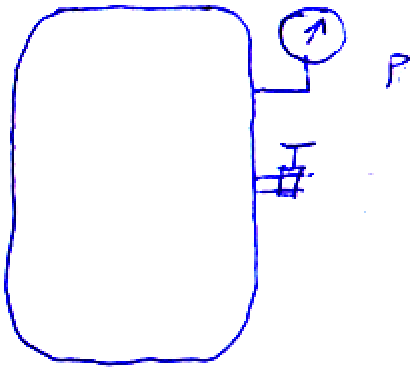
Assessment of the chamber volume:



Assessment of the chamber volume:

Vol ?



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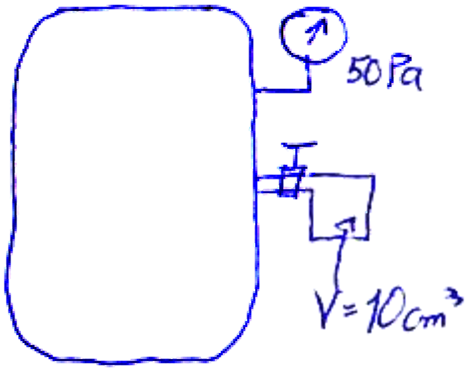


An evacuated and sealed vacuum chamber is connected via a valve with a reference container of 10 ccm volume at 1 Bar. After opening the valve the chamber pressure is 50 Pa

$$P \cdot V = const \Rightarrow P_{chamber} \cdot V_{chamber+RefVol} = P_{RefVol} \cdot V_{RefVol}$$

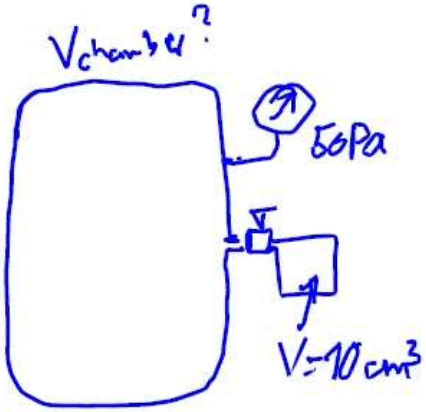
$$V_X = V_{chamber} + \cancel{V_{RefVol}} = \frac{P_{RefVol} \cdot V_{RefVol}}{P_{chamber}} = \frac{1 \cdot 10^5 \, Pa \cdot 10 \, cm^3}{50 \, Pa}$$

↑ neglectable

$$V_{chamber} = 20\,000 \, cm^3$$

$$= 20 \, l$$

Assessment of the chamber volume:



An evacuated and sealed vacuum chamber is connected via a valve with a reference container of 10 ccm volume at 1 Bar. After opening the valve the chamber pressure is 50 Pa.

$$P \cdot V = const \Rightarrow \underbrace{P_{chamber} \cdot V_{chamber+RefVol}}_{\text{after opening}} = \underbrace{P_{Ref} \cdot V_{RefVol}}_{\text{before opening}}$$

$$V_x = V_{chamber} + \cancel{V_{Ref}} = \frac{P_{Ref\,Vol} \cdot V_{RefVol}}{P_{chamber}} , \quad \frac{1 \cdot 10^5\,Pa \cdot 10\,cm^3}{50\,Pa}$$

(V_{Ref} neglectable)

$$V_{chamber} \approx 20000\,cm^3$$

$$\approx 20\,l$$

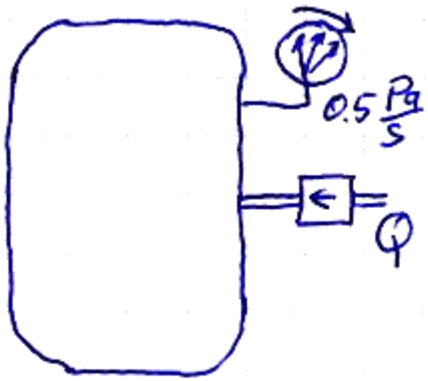
Flowmeter

Very "tricky" device!

Important for many processes –

But requires frequent calibration

Assessment of the gas flow:



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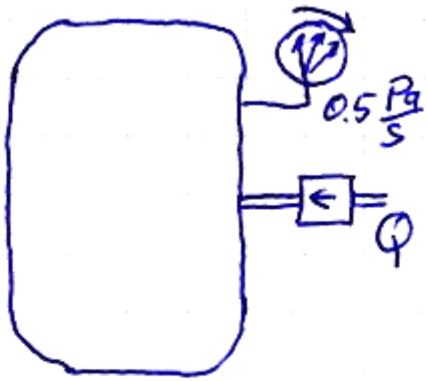

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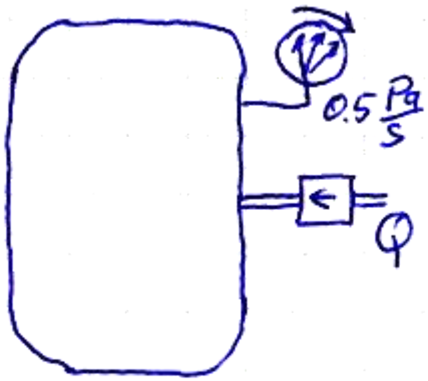

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$$Q = \frac{\Delta (P \cdot V)}{\Delta t} \Big/ (V = const) \Rightarrow Q = \frac{V \, \Delta P}{\Delta t}$$

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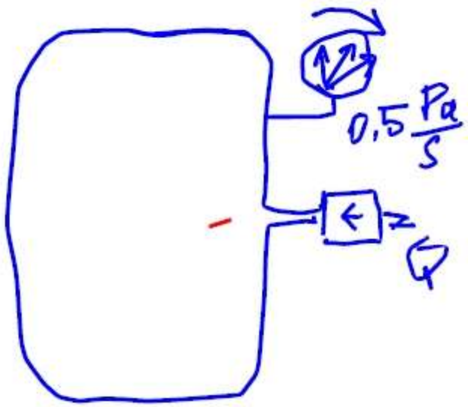

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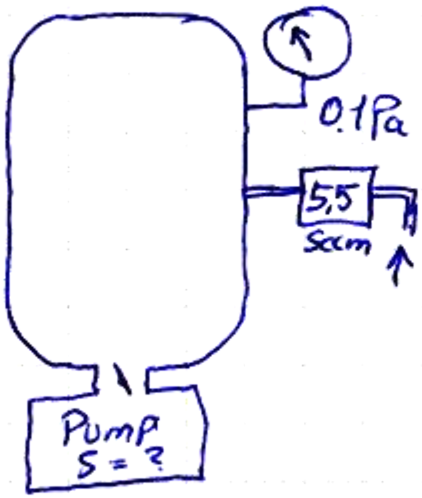

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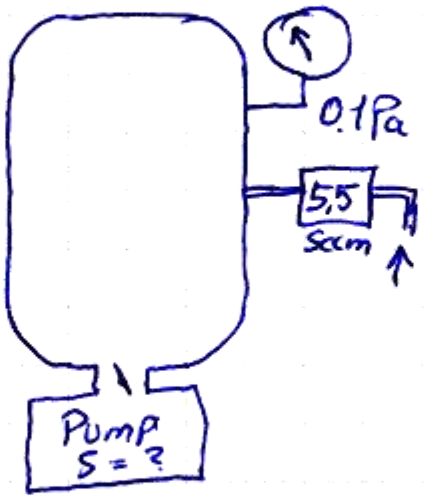

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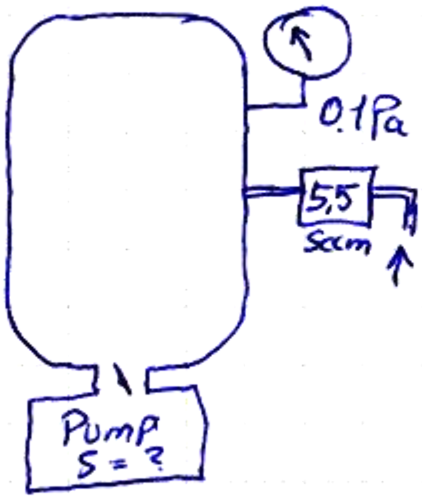

Which pumping speed is required to obtain a chamber pressure of 0,1 Pa with the previously determined gas flow (5,5 sccm)?

$$S = \frac{Q}{P} \qquad (Q = P \cdot S)$$

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$$\underline{\underline{S = 100\ \frac{\ell}{s}}}$$

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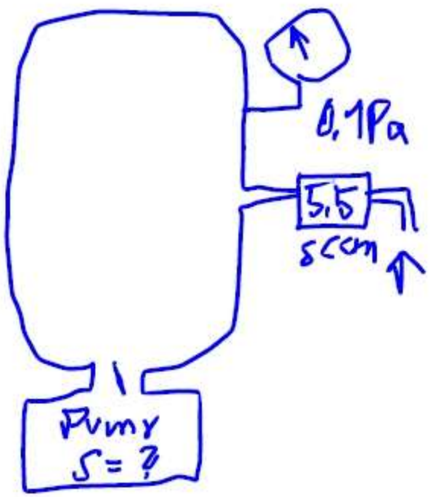

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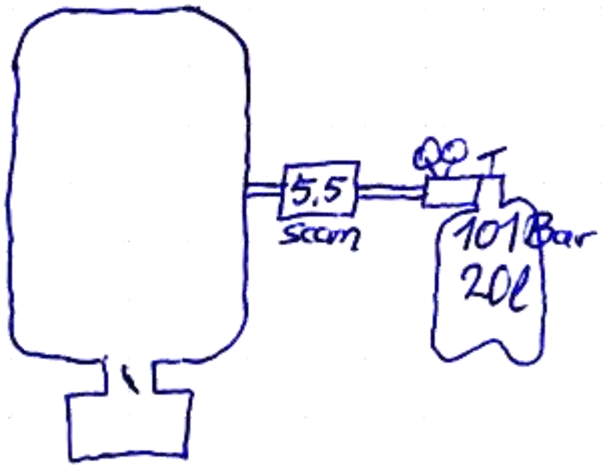
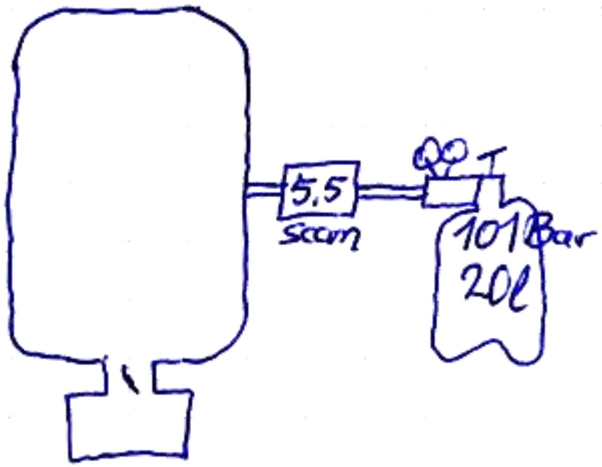


Assessment of the process time:

Time?



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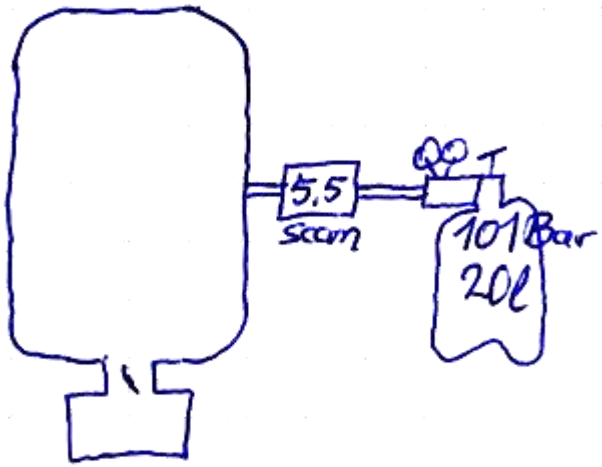

The gas bottle has a size of 20 l and an initial pressure of 101 Bar. Which is the maximum process time before the replacement of the bottle becomes necessary?

Usable gas volume in the bottle:

$20\,l \cdot 100\,\text{Bar} = 2000\,\text{Bar}\cdot l$

$\hat{=}\; 2 \cdot 10^6\,\text{cm}^3$ gas

At 5,5 sccm this lasts

$$t_{max} = \frac{2 \cdot 10^6\,\text{cm}^3}{5{,}5\,\text{cm}^3/\text{min}} = 363 \cdot 10^3\,\text{min}$$

$$= 252\ \text{days}$$

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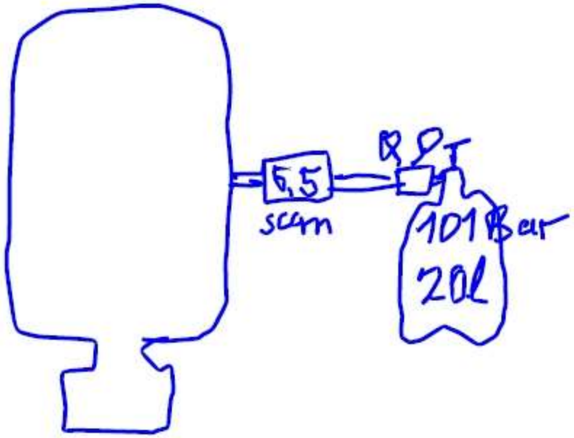

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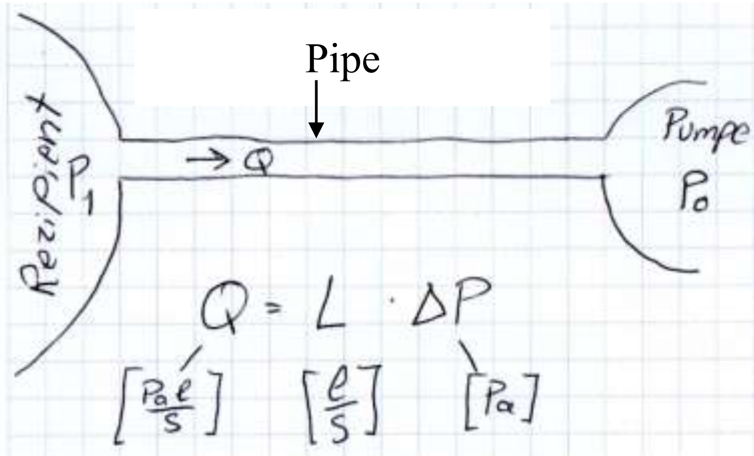
Gas flow conductance L

Proportionality constant between gas flow and pressure difference.



Analogy to Ohm's law:

$$I = \frac{1}{R} \cdot U$$

Correspondingly this applies to a serious circuit:

$$R_{Ges} = \sum_i R_i \;\hat{=}\; \frac{1}{L_{Ges}} = \sum_i \frac{1}{L_i}$$

and for a parallel circuit:

$$\frac{1}{R_{Ges}} = \sum \frac{1}{R_i} \;\hat{=}\; L_{Ges} = \sum_i L_i$$

However the conductance of pipes and openings outside of the molecular flow regime depends on the pressure!

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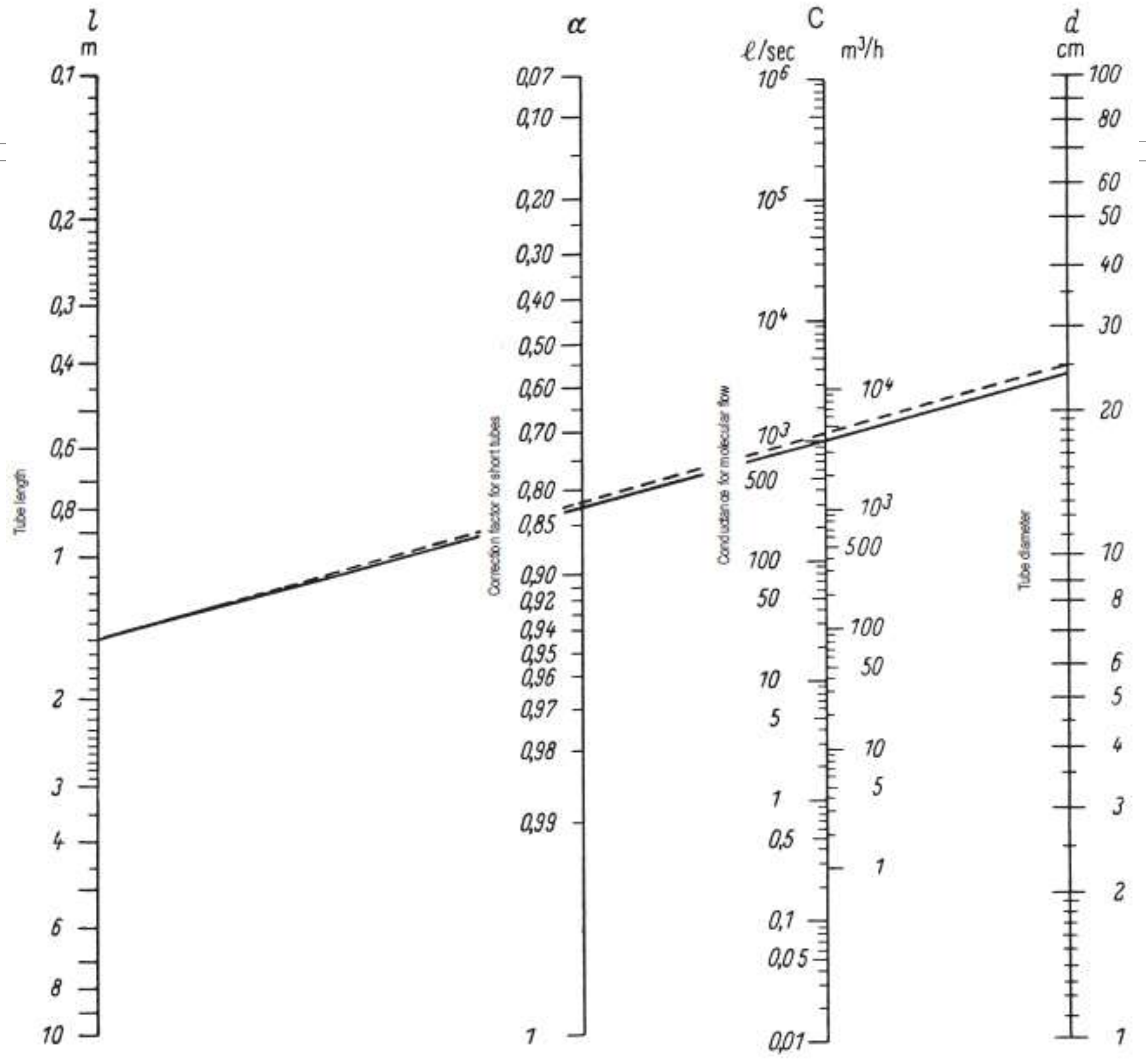
Determination of gas flow conduction using a nomogram

->

Valid in the molecular flow regime only:



Example: What diameter d must a 1.5-m-long pipe have so that it has a conductance of about C = 1000 l / sec in the region of molecular flow? The points l = 1.5 m and C = 1000 l/sec are joined by a straight line which is extended to intersect the scale for the diameter d. The value d = 24 cm is obtained. The input conductance of the tube, which depends on the ratio d / l and must not be neglected in the case of short tubes, is taken into account by means of a correction factor α. For d / l < 0.1, α can be set equal to 1. In our example d/l = 0.16 and α = 0.83 (intersection point of the straight line with the a scale). Hence, the effective conductance of the pipeline is reduced to
C · α = 1000 · 0.83 = 830 l/sec. If d is increased to 25 cm, one obtains a conductance of 1200 · 0.82 = 985 l / sec (dashed straight line).

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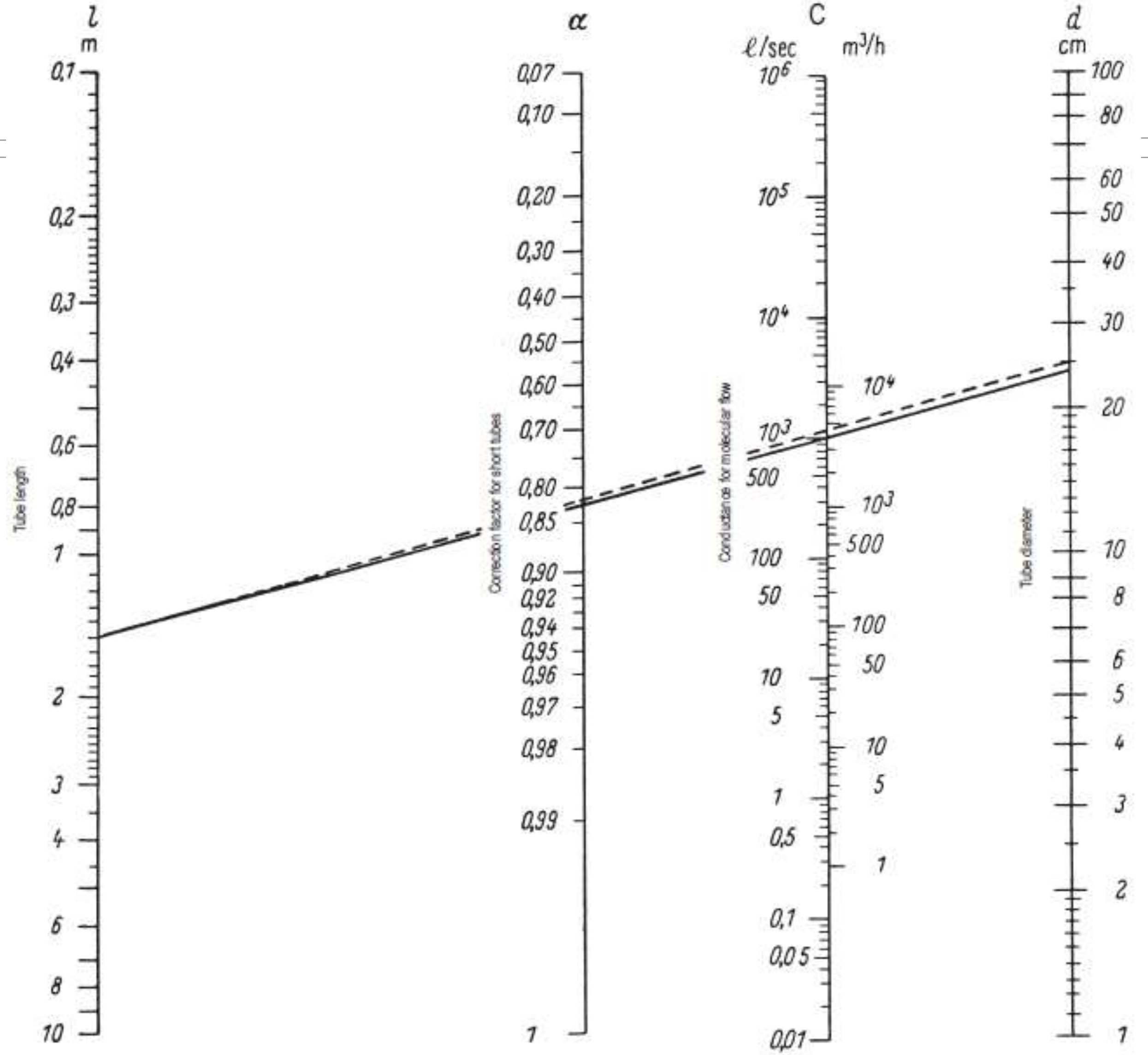

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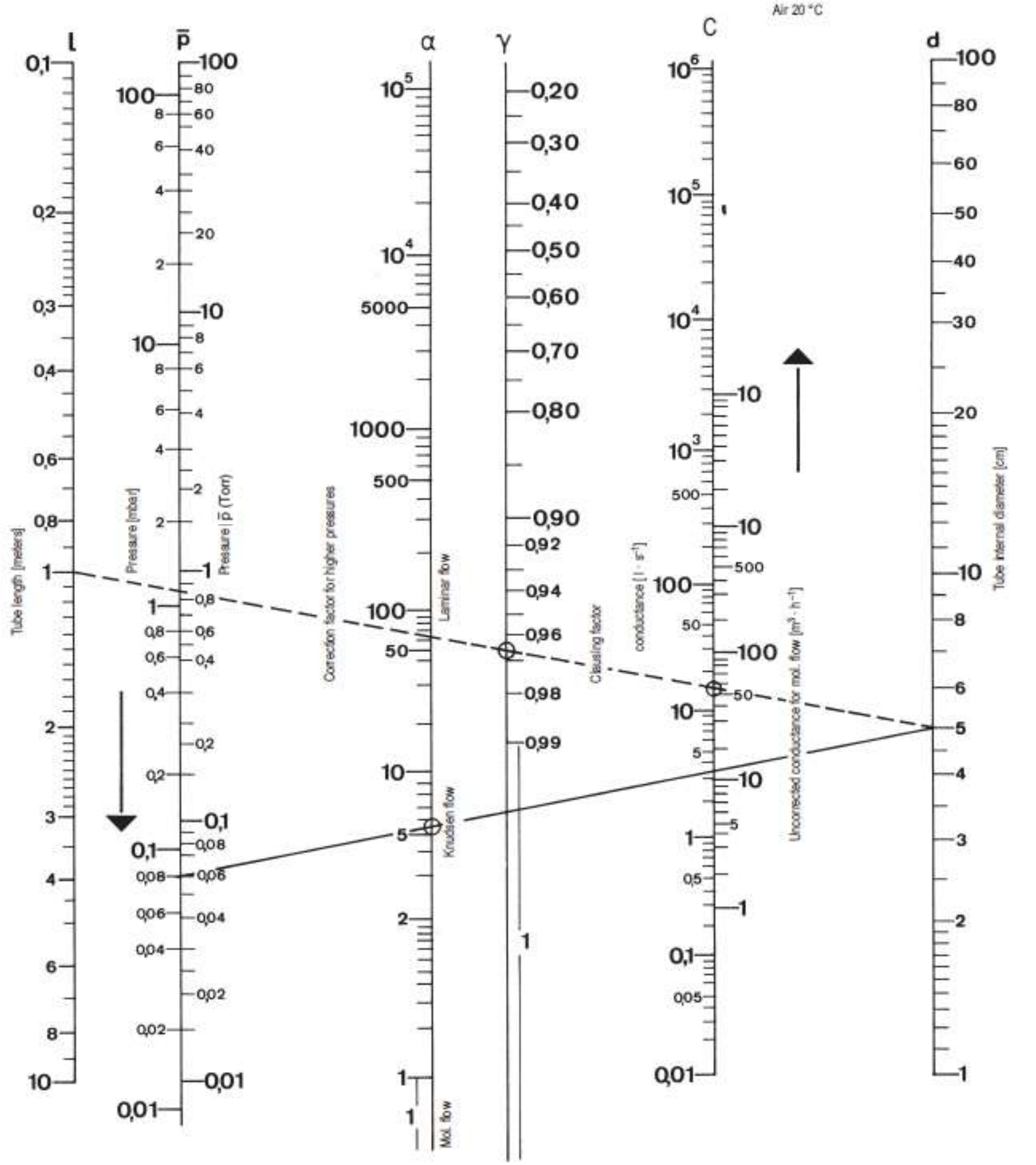
For different pressure regimes:



Procedure: For a given length (l) and internal diameter (d), the conductance C_m, which is independent of pressure, must be determined in the molecular flow region. To find the conductance C* in the laminar flow or Knudsen flow region with a given mean pressure of p in the tube, the conductance value previously calculated for Cm has to be multiplied by the correction factor a determined in the nomogram: $C^* = C_m \cdot \alpha$.

Example: A tube with a length of 1 m and an internal diameter of 5 cm has an (unconnected) conductance C of around 17 l/s in the molecular flow region, as determined using the appropriate connecting lines between the "l" scale and the "d" scale. The conductance C found in this manner must be multiplied by the clausing factor $\gamma = 0.963$ (intersection of connecting line with the γ scale) to obtain the true conductance C_m in the molecular flow region:
$C_m \cdot \gamma = 17 \cdot 0.963 = 16.37$ l/s.

In a tube with a length of 1 m and an internal diameter of 5 cm a molecular flow prevails if the mean pressure p in the tube is $< 2.7 \cdot 10^{-3}$ mbar.
To determine the conductance C* at higher pressures than $2.7 \cdot 10^{-3}$ mbar, at $8 \cdot 10^{-2}$ mbar ($= 6 \cdot 10^{-2}$ torr), for example, the corresponding point on the p scale is connected with the point d = 5 cm on the "d" scale. This connecting line intersects the "α" scale at the point $\alpha = 5.5$. The conductance C* at $p = 8 \cdot 10^{-2}$ mbar is: $C^* = C_m \cdot \alpha = 16.37 \cdot 5.5 = 90$ l/s.

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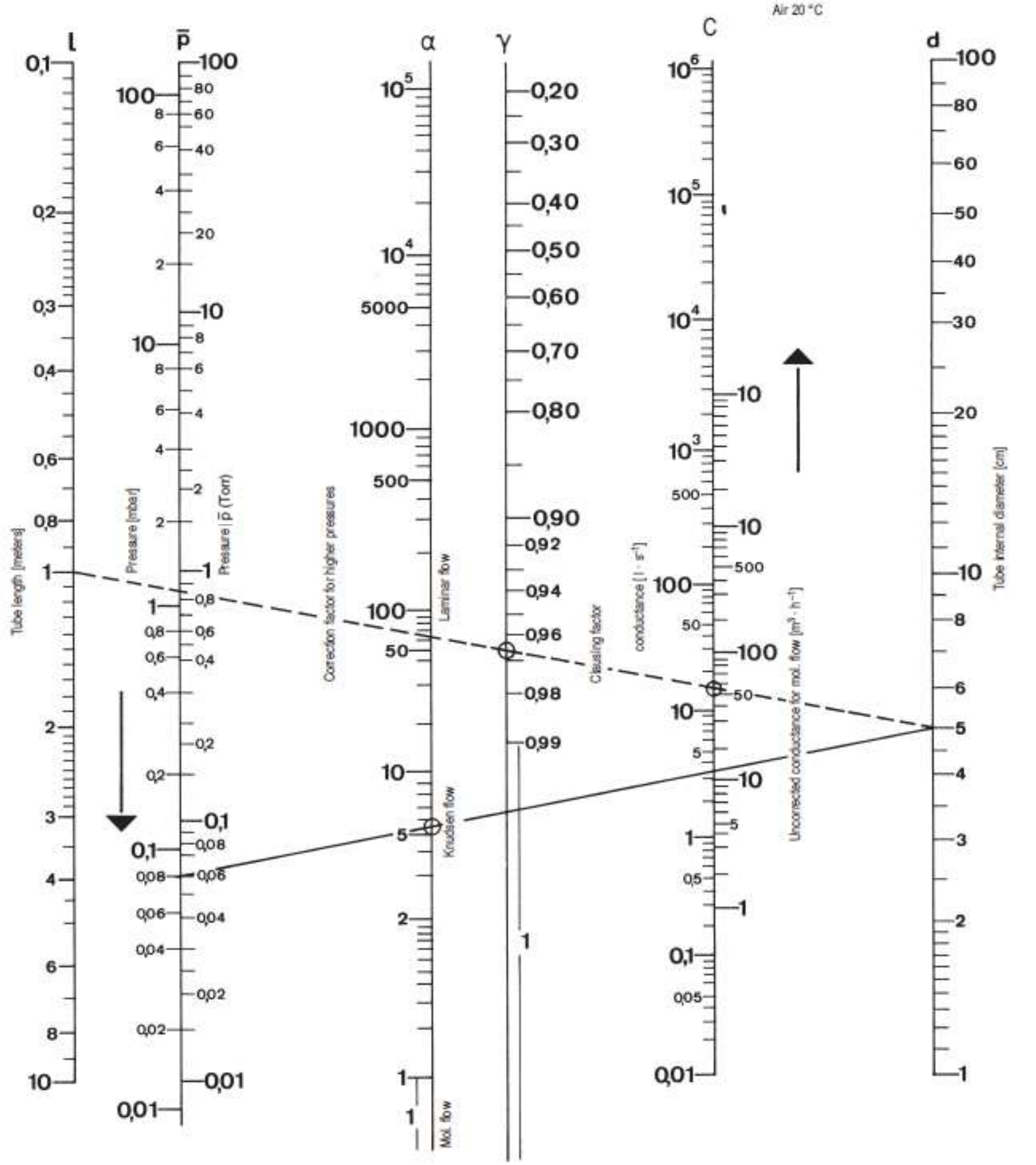

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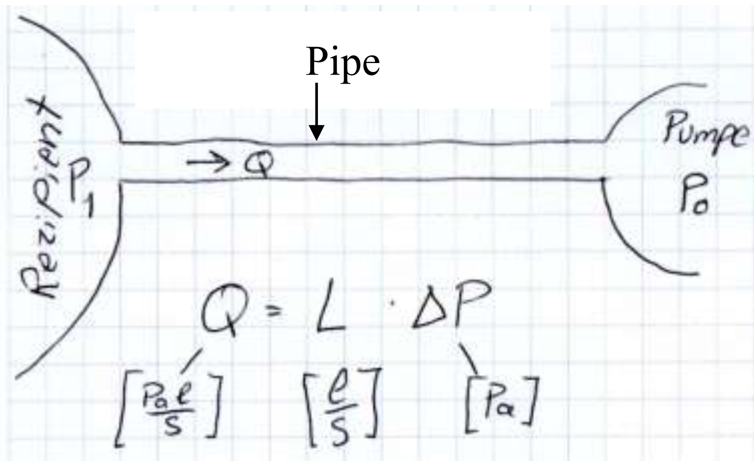

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Here we have pump and pipe as a serious circuit:

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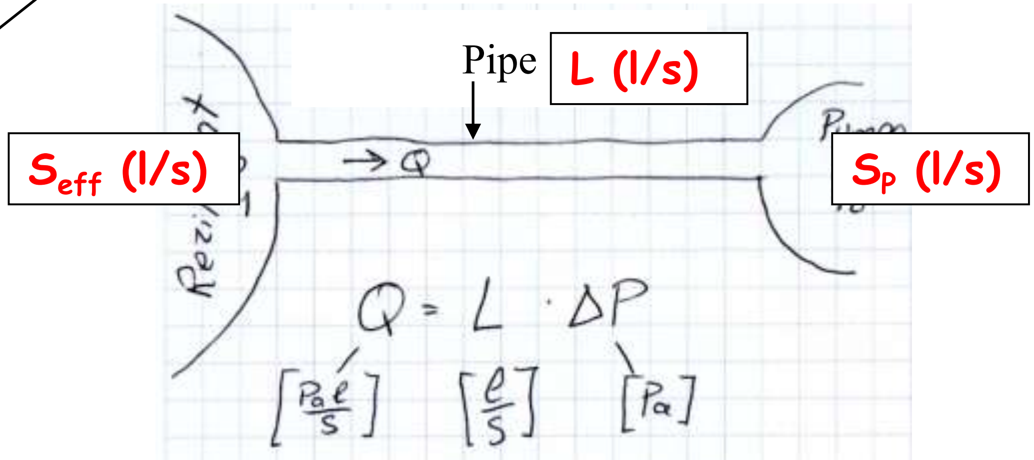

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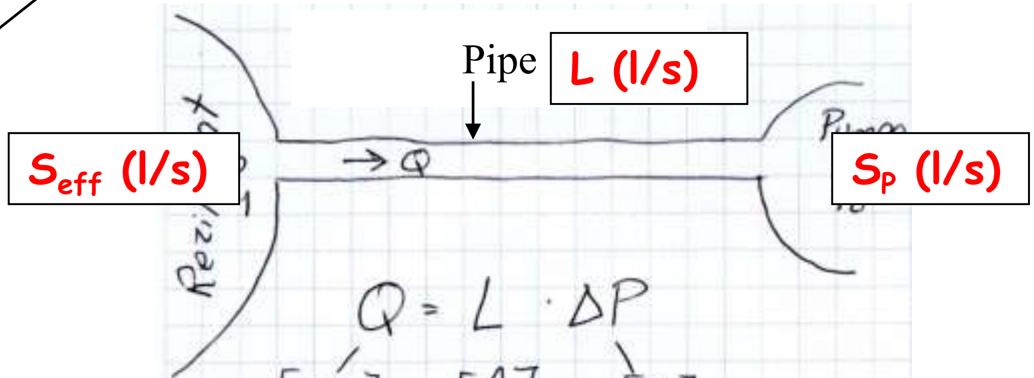

$$Q = L \cdot \Delta P$$

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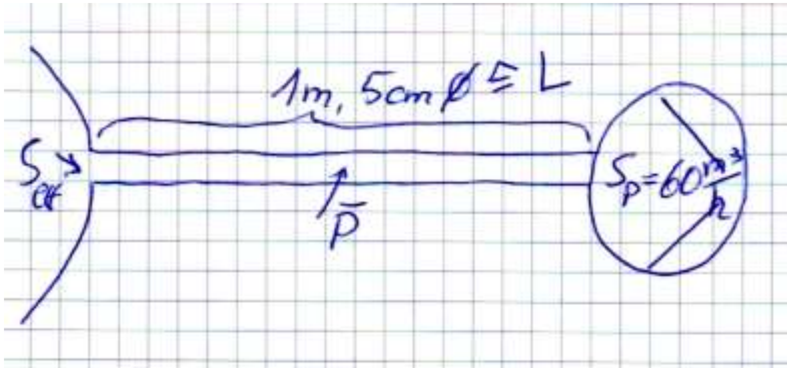
Example: Tubing between chamber and pump

Determine the pressure dependent flow conductance (in l/s) for the tube sketched below ranging from 100 mBar – 10^{-3} mBar (mean pressure!):



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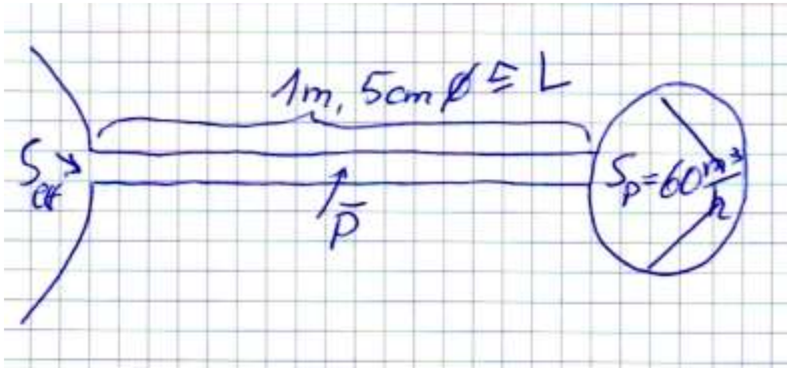

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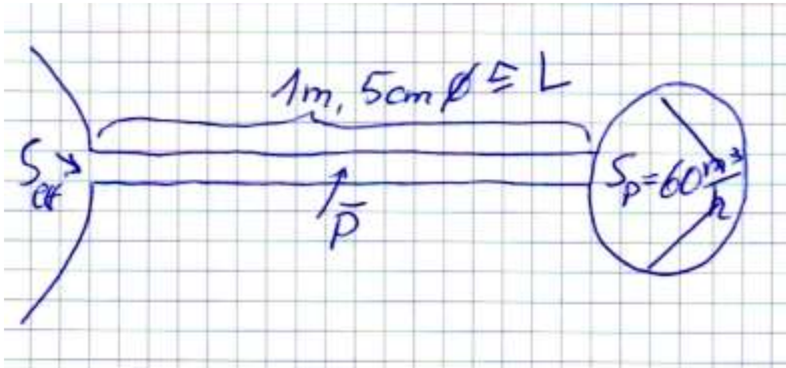

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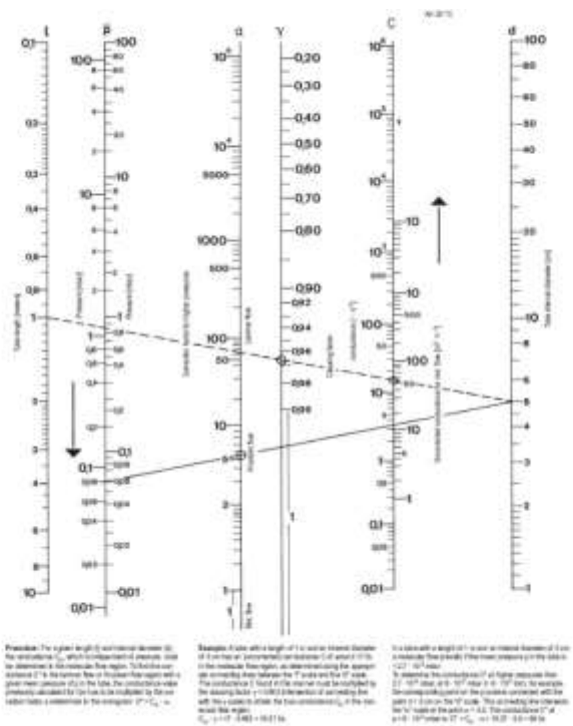

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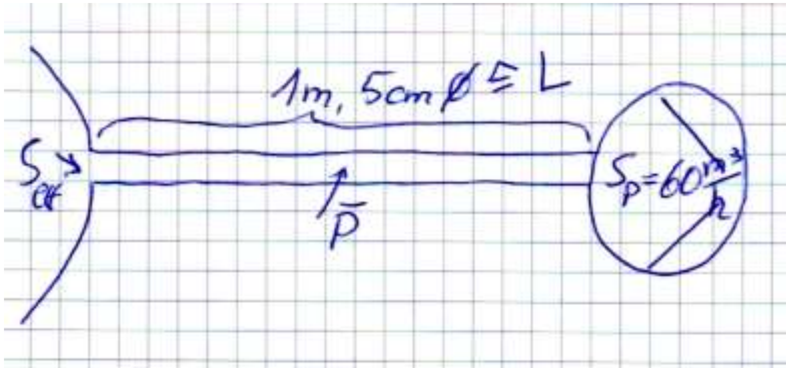

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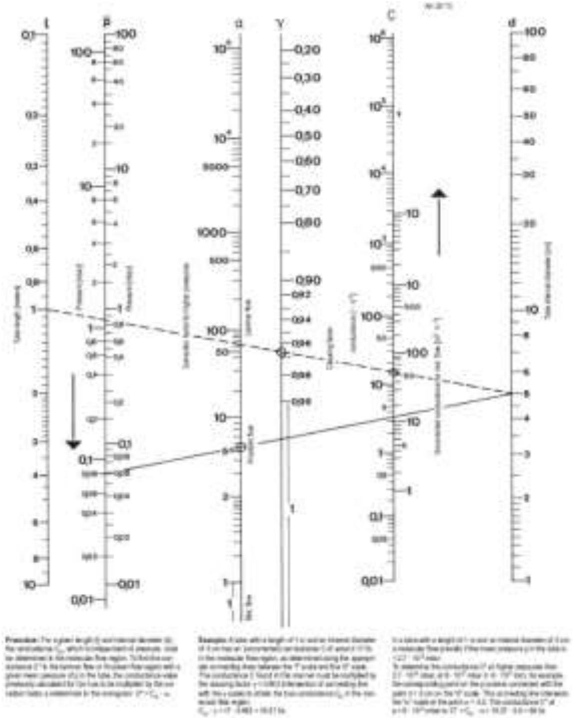

Ø = 5cm

mBar $\bar{p}$	Korrektur α	$L\left[\frac{l}{s}\right]$ $\alpha \cdot L_0$	$S_p\left[\frac{l}{s}\right]$	$\frac{1}{L}\left[\frac{s}{l}\right]$	$\frac{1}{S_p}\left[\frac{s}{l}\right]$	S_{eff}
100						
10						
1						
0,1						
0,01						
0,001						

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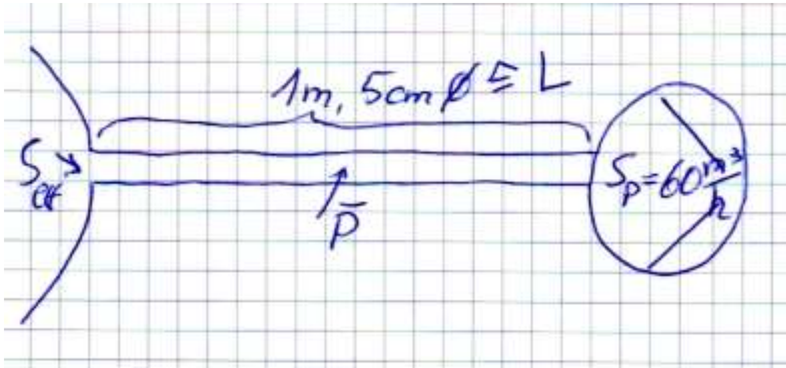

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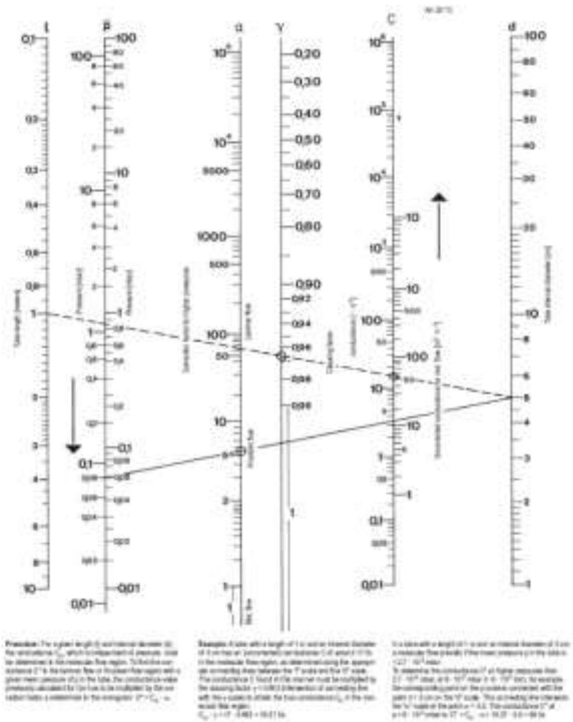

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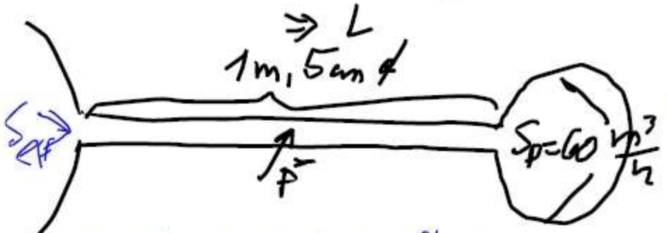
mBar $\bar{p}$	Korrektur α	$L\left[\frac{l}{s}\right]$ $\alpha \cdot L_0$	$S_p\left[\frac{l}{s}\right]$	$\frac{1}{L}\left[\frac{s}{l}\right]$	$\frac{1}{S_p}\left[\frac{s}{l}\right]$	S_{eff}
100						
10						
1						
0,1						
0,01						
0,001						

B09h

Determining the effective pumping speed in l/s for the setup sketched below in dependence to the mean pressures.



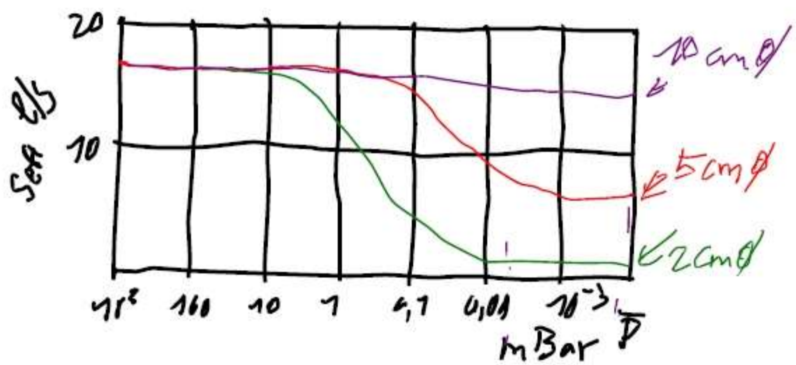
$S_p = 60\ \frac{m^3}{h} = \frac{60 \cdot 1000\, l}{60 \cdot 60\, s} = 16{,}6\ \frac{l}{s}$

$\frac{1}{S_{eff}} = \frac{1}{S_p} + \frac{1}{L(\bar{p})}$

conduction L molecular flow

$L_0 = \gamma \cdot 17\frac{l}{s} = 0.965 \cdot 17\frac{l}{s} = 16{,}4\ \frac{l}{s}$

$L_0 \cdot \alpha$



mBar $\bar{p}$	Correct. α	$L\,[\frac{l}{s}]$	$S_p\,[\frac{l}{s}]$	$\frac{1}{L}\,[\frac{s}{l}]$	$\frac{1}{S_p}\,[\frac{s}{l}]$	S_{eff} l/s
100	5010	82000	16,6	$1{,}2 \cdot 10^{-5}$	0,06	16,6
10	550	9000	16.6	$1 \cdot 10^{-4}$	0,06	16.6
1	50	820	16.6	0,0012	0.06	16.3
0,1	7	115	16.6	0,0087	0.06	14.5
0,01	1,3	21	16.6	0,05	0.06	9.1
0,001	1	16,4	16.6	0.06	0.06	8.3
	1	16.4	16.6	0.06	0.06	8.3

Example: Tubing between chamber and pump

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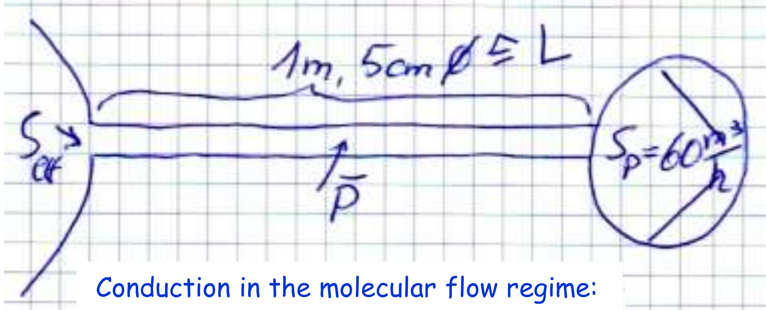

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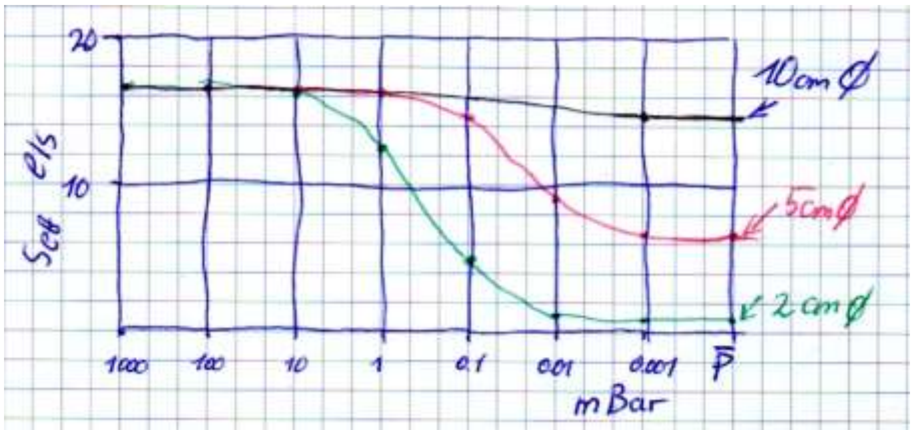
Conduction in the molecular flow regime:

$$L_0 = \gamma \cdot 17\frac{l}{s} = 0.965 \cdot 17\frac{l}{s} = 16{,}4\frac{l}{s}$$

$$\frac{1}{S_{eff}} = \frac{1}{S_p} + \frac{1}{L}$$



Ø = 5cm

$\bar{p}$ mBar	Korrektur α	$L [\frac{l}{s}]$ $\alpha \cdot L_0$	$S_p [\frac{l}{s}]$	$\frac{1}{L} [\frac{s}{l}]$	$\frac{1}{S_p} [\frac{s}{l}]$	S_{eff}
100	5000	82000	16.6	$1{,}2 \cdot 10^{-5}$	0.06	16.6
10	550	9000	16.6	$1 \cdot 10^{-4}$	0.06	16.6
1	50	820	16.6	0,0012	0.06	16.3
0,1	7	115	16.6	0.0087	0.06	14.5
0,01	1,3	21	16.6	0.05	0.06	9.1
0,001	1	16,4	16.6	0.06	0.06	8.3
-	1	16,4	16.6	0.06	0.06	8.3

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»Wissen schafft Brücken.«