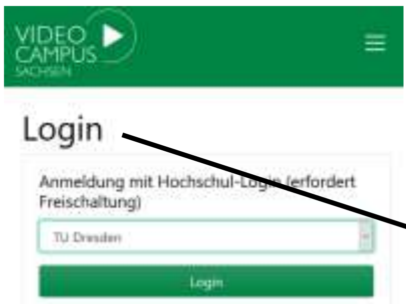
TECHNISCHE UNIVERSITÄT DRESDEN

Vacuum Technology
WS 20/21
Virtually presented
Lecture 8, Dec. 15, 2020

The imbedded video streams of this document are hosted by "video campus Saxony". Before starting the lecture please logon with your ZIH ID and password here:



Just click on the Login above, it brings you to the web-page

Prof. Dr. Johann W. Bartha

Inst. f. Halbleiter und Mikrosystemtechnik
Technische Universität Dresden

After Login at VCS Start watching 1'st stream of the lecture here

"VT L08 a 10:20

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!

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

2. Pressure Ranges

3. Vacuum technical terms

4. Vacuum generation

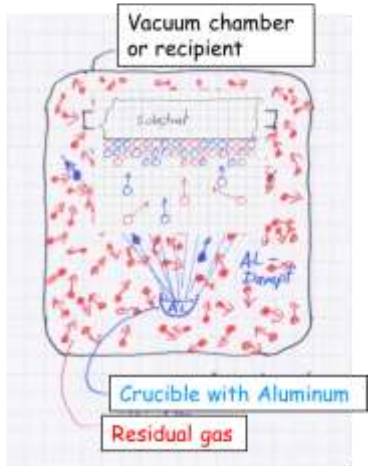
5. Pressure measurement

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



2. Pressure Ranges

3. Vacuum technical terms

4. Vacuum generation

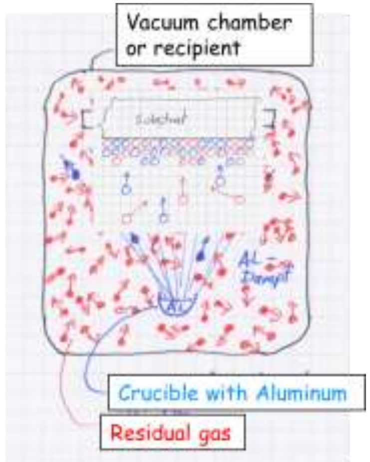
5. Pressure measurement

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

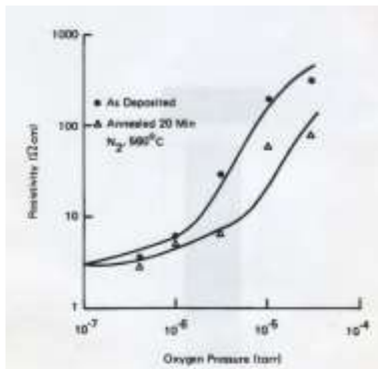


2. Pressure Ranges

3. Vacuum technical terms

4. Vacuum generation

5. Pressure measurement

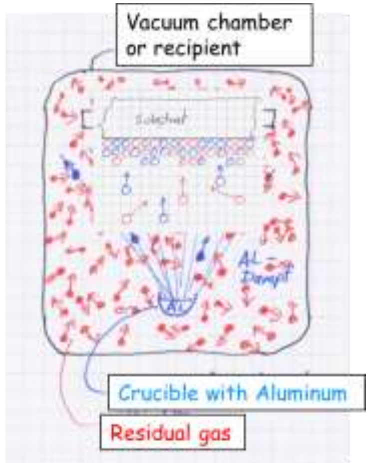


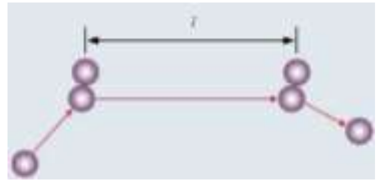
0. Introduction

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



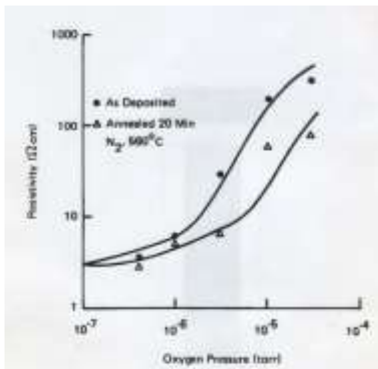


2. Pressure Ranges

3. Vacuum technical terms

4. Vacuum generation

5. Pressure measurement



0. Introduction

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

1. Gas kinetic

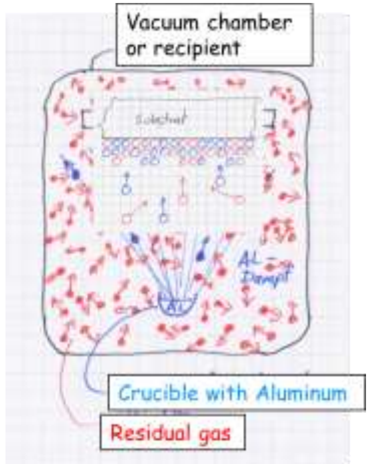
Pressure as momentum transfer, Mol & Molvolume, Pressure units, Partial pressure, Boltzmann Velocity&Energy distribution, Impingement rate, monolayer coverage time, mean free path

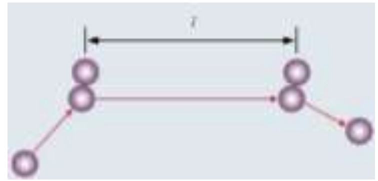
2. Pressure Ranges

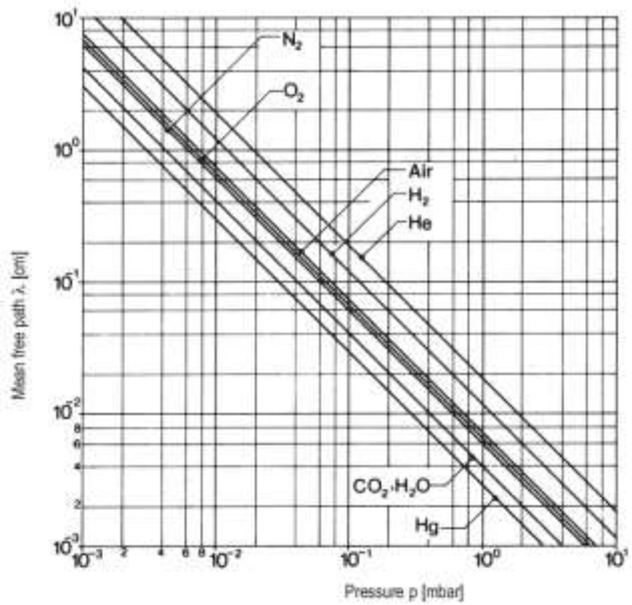
3. Vacuum technical terms

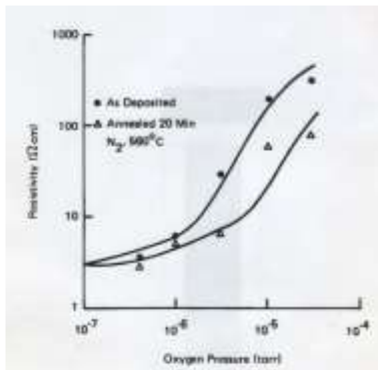
4. Vacuum generation

5. Pressure measurement









0. Introduction

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

1. Gas kinetic

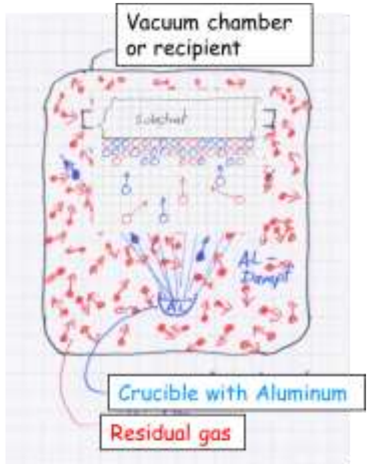
Pressure as momentum transfer, Mol & Molvolume, Pressure units, Partial pressure, Boltzmann Velocity&Energy distribution, Impingement rate, monolayer coverage time, mean free path

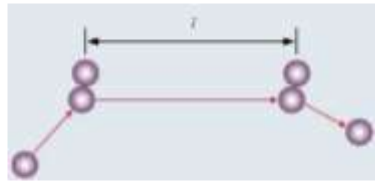
2. Pressure Ranges

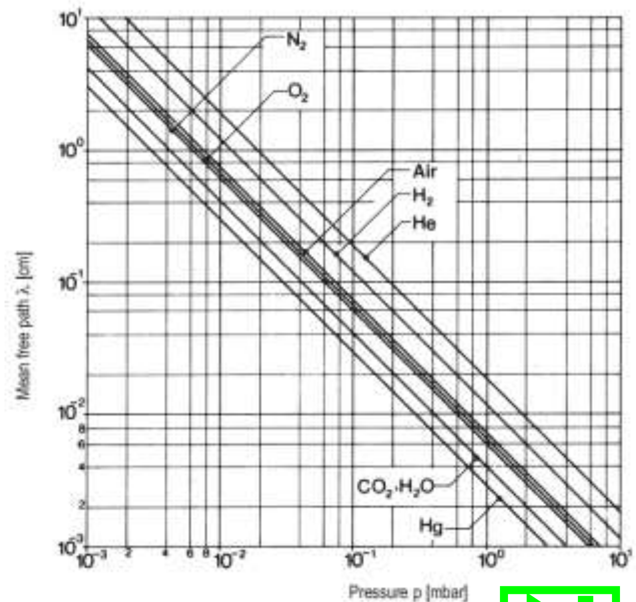
3. Vacuum technical terms

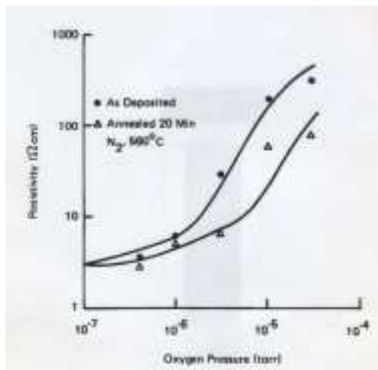
4. Vacuum generation

5. Pressure measurement





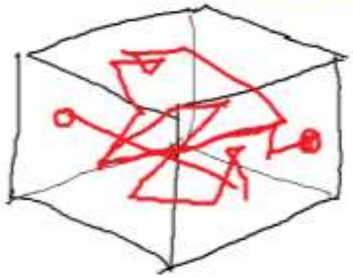




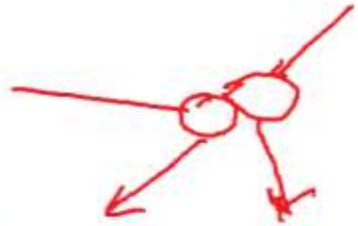
Collision rate:

Collision rate:

Collision rate: Number of collisions of a single particle per time unit

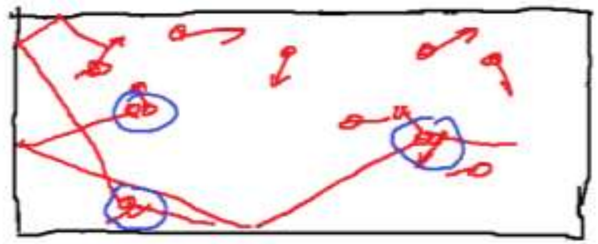


$$Z_p = \frac{\bar{u}}{\lambda}$$



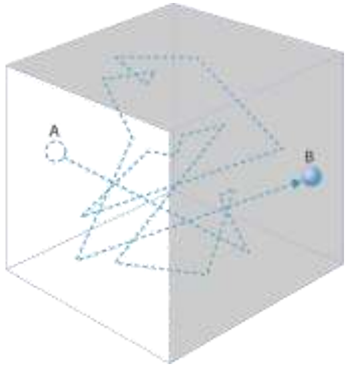
Volume collision rate: Number of collisions of all particles per time and volume unit (collision frequency)

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



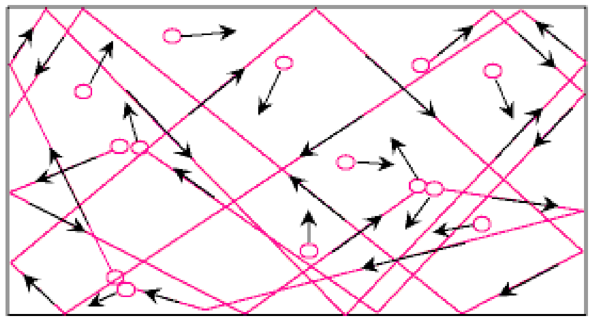
Collision rate: Number of collisions of a **single** particle per time unit

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



Volume collision rate: Number of collisions of **all** particles per time and volume unit (**collision frequency**)

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



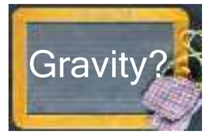
!: n/2 because a collision of 2 particles counts as one collision!

Kinetic gas theory – approximation -> Gravity ?

Question: An Ar atom "travels" within a vacuum chamber at 20°C vertically 1 m upwards. Which fraction of its kinetic energy is transferred to potential energy?

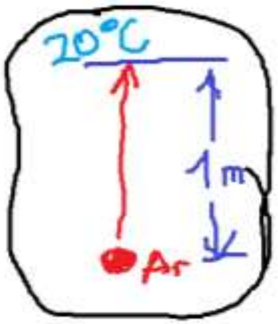
Kinetic gas theory – approximation -> Gravity ?

Question: An Ar atom "travels" within a vacuum chamber at 20°C vertically 1 m upwards. Which fraction of its kinetic energy is transferred to potential energy?



B08b

An Ar atom "travels" within a vacuum chamber at 20°C 1m upwards. Which fraction of its kinetic energy is transferred to potential energy?



$$E_{pot} = m g \Delta x = \frac{40 \, \text{kg} \, 10^{-3}}{N_A} \cdot 9.81 \frac{\text{m}}{\text{s}^2} \cdot 1 \, \text{m} = 6.5 \cdot 10^{-25} \, \text{J}$$

$$E_{kin} = \frac{3}{2} kT = 6.06 \cdot 10^{-21} \, \text{J}$$

$$\underline{\underline{\frac{E_{pot}}{E_{kin}} \approx 1 \cdot 10^{-4}}} \Rightarrow$$

Gravity can be neglected !!

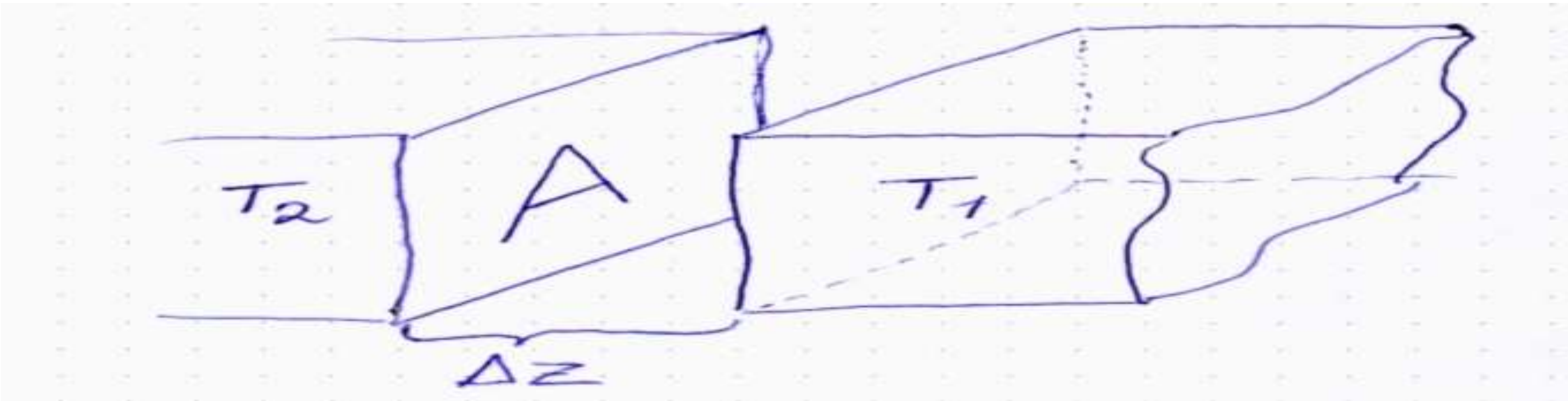
Question: An Ar atom "travels" within a vacuum chamber at 20°C vertically 1m upwards. Which fraction of its kinetic energy is transferred to potential energy?

$$E_{pot} = mg\,\Delta x = \frac{40 \cdot 10^{-3}\,\mathrm{kg} \cdot 9.81\,\frac{\mathrm{m}}{\mathrm{s}^2} \cdot 1\,\mathrm{m}}{N_a} = 6{,}5 \cdot 10^{-25}\,\mathrm{J}$$

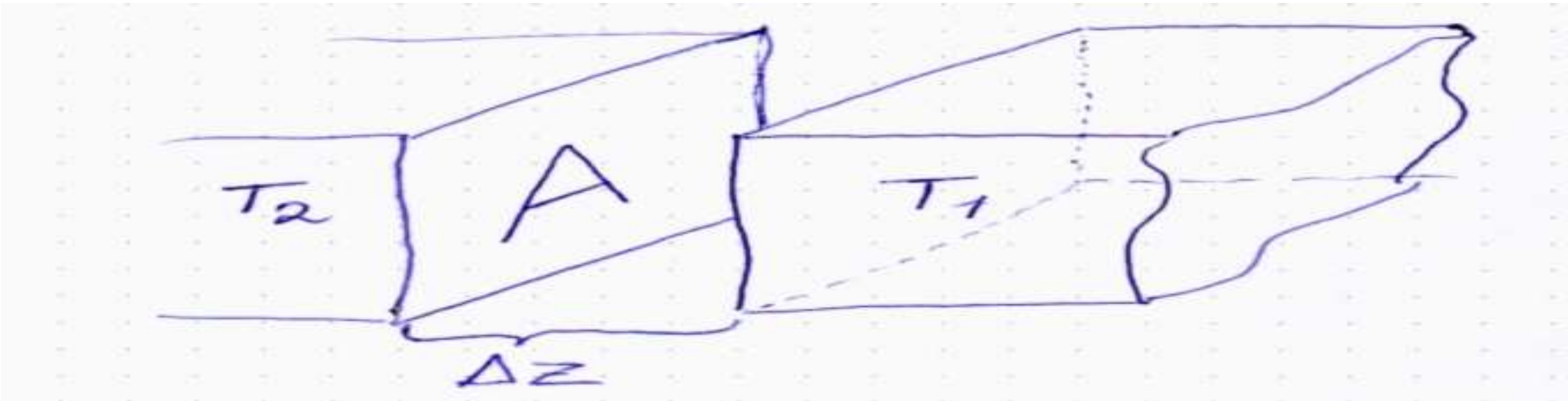
$$E_{kin} = \frac{3}{2} kT = 6{,}06 \cdot 10^{-21}\,\mathrm{J}$$

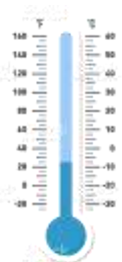
$$\underline{\underline{\frac{E_{pot}}{E_{kin}} \approx 1 \cdot 10^{-4}}}$$

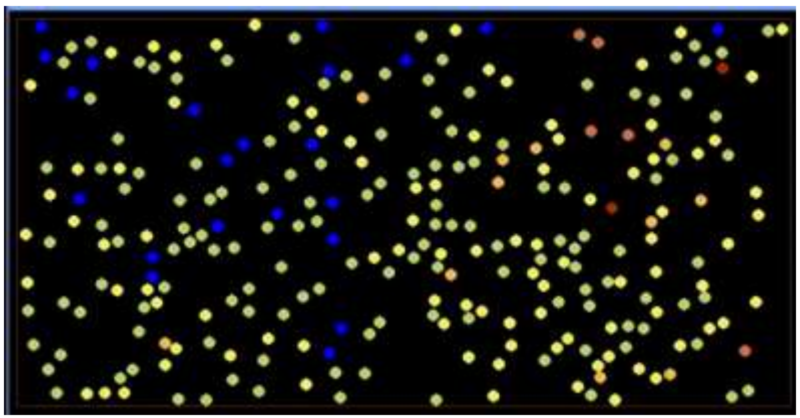
Heat conduction in a gas and pressure?

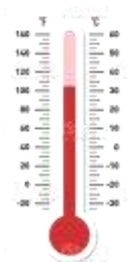


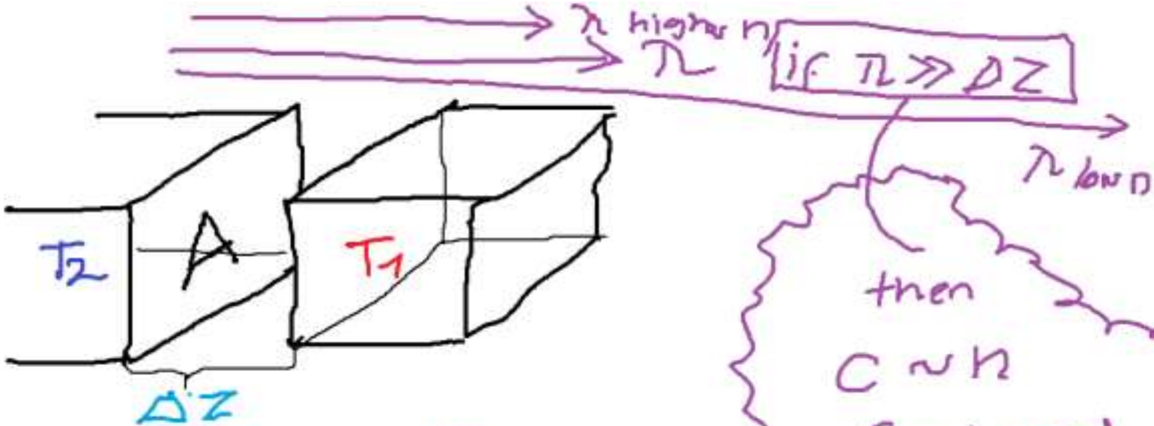
Heat conduction in a gas and pressure?











$\boxed{\text{if } \lambda \gg \Delta Z}$

then

$C \sim n$

Can be used for pressure measurement !!

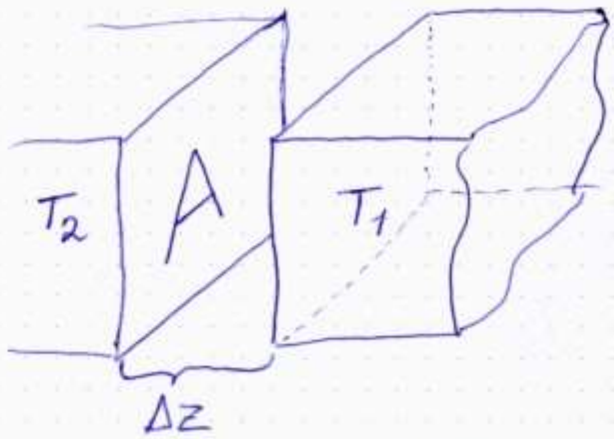
Heat flow: $\frac{\Delta Q}{\Delta t} = C \frac{\Delta T}{\Delta Z} A$

Heat flow conductivity: $C \sim n \, \bar{v} \, \lambda$

$n = \frac{p}{kT}$, $\bar{v} = \sqrt{\frac{8kT}{\pi m}}$, $\lambda = \frac{kT}{p \, 4\pi r^2 \sqrt{2}}$

- $C \sim \sqrt{T}$
- independent on Pressure!!

Heat conduction in a gas:



Heat flow: $\frac{\Delta Q}{\Delta t} = C \frac{\Delta T}{\Delta z} A$

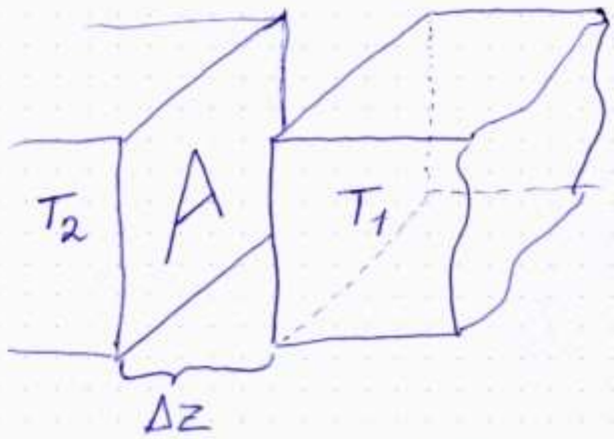
Heat flow conductivity: $C \sim n \cdot \bar{u} \cdot \lambda$

$n = \frac{p}{kT}$, $\bar{u} = \sqrt{\frac{8kT}{\pi m}}$, $\lambda = \frac{kT}{p\,4\pi r^2 \sqrt{2}}$

Heat flow conductivity increases by $\sqrt{T}$ but is independent from Pressure!

However only as long as $\lambda < \Delta z$!!

Heat conduction in a gas:



Heat flow: $\frac{\Delta Q}{\Delta t} = c \frac{\Delta T}{\Delta z} A$

Heat flow conductivity: $c \sim n \cdot \bar{u} \cdot \lambda$

$n = \frac{P}{kT}$, $\bar{u} = \sqrt{\frac{8kT}{\pi m}}$, $\lambda = \frac{kT}{P\, 4\pi r^2 \sqrt{2}}$

Heat flow conductivity increases by $\sqrt{T}$ but is independent from Pressure!

However only as long as $\lambda < \Delta z$!!

In case $\lambda > \Delta z$

we find $c \sim n \sim P$

$\Rightarrow$ Method for pressure determination!

Constants

Designation, alphabetically	Symbol	Value and unit	Remarks
Atomic mass unit	m_u	$1.6605 \cdot 10^{-27}$ kg	
Avogadro constant	N_A	$6.0225 \cdot 10^{23}$ mol^{-1}	Number of particles per mol, formerly: Loschmidt number
Boltzmann constant	k	$1.3805 \cdot 10^{-23}$ J $\cdot$ K^{-1} $13.805 \cdot 10^{-23} \frac{\text{mbar} \cdot \text{l}}{\text{K}}$	
Electron rest mass	m_e	$9.1091 \cdot 10^{-31}$ kg	
Elementary charge	e	$1.6021 \cdot 10^{-19}$ A $\cdot$ s	
Molar gas constant	R	8.314 J $\cdot$ mol^{-1} K^{-1} $= 83.14 \frac{\text{mbar} \cdot \text{l}}{\text{mol} \cdot \text{K}}$	$R = N_A \cdot k$
Molar volume of the ideal gas	V_o	22.414 m^3 kmol^{-1} 22.414 l $\cdot$ mol^{-1}	DIN 1343; formerly: molar volume at 0 °C and 1013 mbar
Standard acceleration of free fall	g_n	9.8066 m $\cdot$ s^{-2}	
Planck constant	h	$6.6256 \cdot 10^{-34}$ J $\cdot$ s	
Stefan-Boltzmann constant	σ	$5.669 \cdot 10^{-8} \frac{\text{W}}{\text{m}^2\,\text{K}^4}$	also: unit conductance, radiation constant
Specific electron charge	$\frac{-e}{m_e}$	$-1.7588 \cdot 10^{11} \frac{\text{A} \cdot \text{s}}{\text{kg}}$	
Speed of light in vacuum	c	$2.9979 \cdot 10^{8}$ m $\cdot$ s^{-1}	
Standard reference density of a gas	ϱ_n	kg $\cdot$ m^{-3}	Density at $\vartheta = 0$ °C and $p_n = 1013$ mbar
Standard reference pressure	p_n	101.325 Pa = 1013 mbar	DIN 1343 (Nov. 75)
Standard reference temperature	T_n	$T_n = 273.15$ K, $\vartheta = 0$ °C	DIN 1343 (Nov. 75)

Gas kinetic formulas

Variable	General formula	For easy calculation	Value for air at 20°C
Most probable speed of particles c_w $\hat{=} \hat{u}$	$c_w = \sqrt{\frac{2 \cdot R \cdot T}{M}} = \sqrt{\frac{3kT}{m}}$	$c_w = 1.29 \cdot 10^4 \sqrt{\frac{T}{M}} \left[\frac{cm}{s}\right]$	$c_w = 410$ [m/s]
Mean velocity of particles $\bar{c}$ $\bar{u}$	$\bar{c} = \sqrt{\frac{8 \cdot R \cdot T}{\pi \cdot M}} = \sqrt{\frac{8kT}{\pi m}}$	$\bar{c} = 1.46 \cdot 10^4 \sqrt{\frac{T}{M}} \left[\frac{cm}{s}\right]$	$\bar{c} = 464$ [m/s]
Mean square of velocity of particles $\overline{c^2}$ u_{ms}	$\overline{c^2} = \frac{3 \cdot R \cdot T}{M} = \frac{3kT}{m}$	$\overline{c^2} = 2.49 \cdot 10^6 \frac{T}{M} \left[\frac{cm^2}{s^2}\right]$	$\overline{c^2} = 25.16 \cdot 10^4 \left[\frac{cm^2}{s^2}\right]$
Gas pressure p of particles	$p = n \cdot k \cdot T$ $p = \frac{1}{3} \cdot n \cdot m_T \cdot \overline{c^2}$ $p = \frac{1}{3} \cdot \varrho \cdot \overline{c^2}$	$p = 13.80 \cdot 10^{-20} \cdot n \cdot T$ [mbar]	$p = 4.04 \cdot 10^{-17} \cdot n$ [mbar] (applies to all gases)
Number density of particles n	$n = p/kT$	$n = 7.25 \cdot 10^{18} \frac{p}{T}$ [cm^{-3}]	$p = 2.5 \cdot 10^{16} \cdot p$ [cm^{-3}] (applies to all gases)
Area-related impingement Z_A	$Z_A = \frac{1}{4} \cdot n \cdot \bar{c}$ $Z_A = \sqrt{\frac{N_A}{2 \cdot \pi \cdot M \cdot k \cdot T}} p$	$Z_A = 2.63 \cdot 10^{22} \frac{p}{\sqrt{M \cdot T}} \cdot p$ [cm^{-2} s^{-1}]	$Z_A = 2.85 \cdot 10^{20} \cdot p$ [cm^{-2} s^{-1}] (see Fig. 78.2)
Volume collision rate Z_V	$Z_V = \frac{1}{2} \frac{n \cdot \bar{c}}{\lambda}$ $Z_A = \frac{1}{c^*} \sqrt{\frac{2 \cdot N_A}{\pi \cdot M \cdot k \cdot T}} p^2$	$Z_V = 5.27 \cdot 10^{22} \frac{p^2}{c^* \cdot \sqrt{M \cdot T}}$ [cm^{-3} s^{-1}]	$Z_V = 8.6 \cdot 10^{22} \cdot p^2$ [cm^{-3} s^{-1}] (see Fig. 78.2)
Equation of state of ideal gas	$p \cdot V = \nu \cdot R \cdot T$	$p \cdot V = 83.14 \cdot \nu \cdot T$ [$mbar \cdot \ell$]	$p \cdot V = 2.44 \cdot 10^4 \nu$ [$mbar \cdot \ell$] (for all gases)
Area-related mass flow rate q_{m}, A	$q_{m,A} = Z_A \cdot m_T = \sqrt{\frac{M}{2 \cdot \pi \cdot k \cdot T \cdot N_A}} p$	$Q_{m,A} = 4.377 \cdot 10^{-2} \sqrt{\frac{M}{T}} \cdot p$ [g cm^{-2} s^{-1}]	$q_{m,A} = 1.38 \cdot 10^{-2} \cdot p$ g [cm^{-2} s^{-1}]

$c^* = \lambda \cdot p$ in cm · mbar (see Tab. III)
k Boltzmann constant in mbar · l · K^{-1}
λ mean free path in cm
M molar mass in g · mol^{-1}
m_T particle mass in g
N_A Avogadro constant in mol^{-1}
n number density of particles in cm^{-3}
ν amount of substance in mol
p gas pressure in mbar
R molar gas constant in mbar · l · mol^{-1} K^{-1}
T thermodynamic temperature in K
V volume in l

TECHNISCHE UNIVERSITÄT DRESDEN

Gas kinetic formulas

Variable	General formula	For easy calculation	Value for air at 20°C
Most probable speed of particles c_w $\hat{=} \hat{u}$	$c_w = \sqrt{\frac{2 \cdot R \cdot T}{M}} = \sqrt{\frac{3kT}{m}}$	$c_w = 1.29 \cdot 10^4 \sqrt{\frac{T}{M}} \left[\frac{cm}{s}\right]$	$c_w = 410$ [m/s]
Mean velocity of particles $\bar{c}$ $\bar{u}$	$\bar{c} = \sqrt{\frac{8 \cdot R \cdot T}{\pi \cdot M}} = \sqrt{\frac{8}{\pi}\frac{kT}{m}}$	$\bar{c} = 1.46 \cdot 10^4 \sqrt{\frac{T}{M}} \left[\frac{cm}{s}\right]$	$\bar{c} = 464$ [m/s]
Mean square of velocity of particles $\bar{c}^2$ u_{ms}	$\bar{c}^2 = \frac{3 \cdot R \cdot T}{M} = \frac{3kT}{m}$	$\bar{c}^2 = 2.49 \cdot 10^6 \frac{T}{M} \left[\frac{cm^2}{s^2}\right]$	$\bar{c}^2 = 25.16 \cdot 10^4 \left[\frac{cm^2}{s^2}\right]$
Gas pressure p of particles	$p = n \cdot k \cdot T$ $p = \frac{1}{3} \cdot n \cdot m_T \cdot \bar{c}^2$ $p = \frac{1}{3} \cdot \varrho \cdot \bar{c}^2$	$p = 13.80 \cdot 10^{-20} \cdot n \cdot T$ [mbar]	$p = 4.04 \cdot 10^{-17} \cdot n$ [mbar] (applies to all gases)
Number density of particles n	$n = p/kT$	$n = 7.25 \cdot 10^{18} \frac{p}{T}$ [cm^{-3}]	$p = 2.5 \cdot 10^{16} \cdot p$ [cm^{-3}] (applies to all gases)
Area-related impingement Z_A	$Z_A = \frac{1}{4} \cdot n \cdot \bar{c}$ $Z_A = \sqrt{\frac{N_A}{2 \cdot \pi \cdot M \cdot k \cdot T}}\, p$	$Z_A = 2.63 \cdot 10^{22} \frac{p}{\sqrt{M \cdot T}} \cdot p$ [$cm^{-2}\ s^{-1}$]	$Z_A = 2.85 \cdot 10^{20} \cdot p$ [$cm^{-2}\ s^{-1}$] (see Fig. 78.2)
Volume collision rate Z_V	$Z_V = \frac{1}{2} \frac{n \cdot \bar{c}}{\lambda}$ $Z_A = \frac{1}{c^*} \sqrt{\frac{2 \cdot N_A}{\pi \cdot M \cdot k \cdot T}}\, p^2$	$Z_V = 5.27 \cdot 10^{22} \frac{p^2}{c^* \cdot \sqrt{M \cdot T}}$ [$cm^{-3}\ s^{-1}$]	$Z_V = 8.6 \cdot 10^{22} \cdot p^2$ [$cm^{-3}\ s^{-1}$] (see Fig. 78.2)
Equation of state of ideal gas	$p \cdot V = \nu \cdot R \cdot T$	$p \cdot V = 83.14 \cdot \nu \cdot T$ [mbar $\cdot \ell$]	$p \cdot V = 2.44 \cdot 10^4 \nu$ [mbar $\cdot \ell$] (for all gases)
Area-related mass flow rate q_m,A	$q_{m,A} = Z_A \cdot m_T = \sqrt{\frac{M}{2 \cdot \pi \cdot k \cdot T \cdot N_A}}\, p$	$Q_{m,A} = 4.377 \cdot 10^{-2} \sqrt{\frac{M}{T}} \cdot p$ [g $cm^{-2}\ s^{-1}$]	$q_{m,A} = 1.38 \cdot 10^{-2} \cdot p$ g [$cm^{-2}\ s^{-1}$]

$c^* = \lambda \cdot p$ in cm · mbar (see Tab. III)
k Boltzmann constant in mbar · l · K^{-1}
λ mean free path in cm
M molar mass in g · mol^{-1}
m_T particle mass in g
N_A Avogadro constant in mol^{-1}
n number density of particles in cm^{-3}
ν amount of substance in mol
p gas pressure in mbar
R molar gas constant in mbar · l · mol^{-1} K^{-1}
T thermodynamic temperature in K
V volume in l

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

3. Vacuum technical terms

4. Vacuum generation

5. Pressure measurement

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

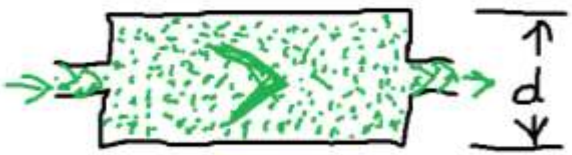
3. Vacuum technical terms

4. Vacuum generation

5. Pressure measurement

2 extreme cases
in between

Viscous flow



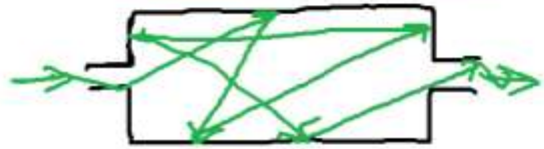
$\lambda \ll d$

Particles collide (almost) only with particles
wall collisions neglectable!

turbulent   laminar

typical vacuum condition

Molecular flow



$\lambda \gg d$

Particles collide (almost) only with the walls
particle/particle collision neglectable !

Transition regime

$\lambda \approx d$

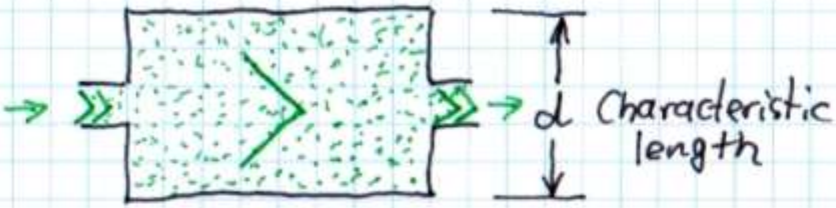
Knudsen flow

In the (Knudsen) regime heat conductivity and viscosity depends on pressure

Chapter. 2: Pressure ranges and their characteristics

2 extrem cases
inbetween

Viscous flow

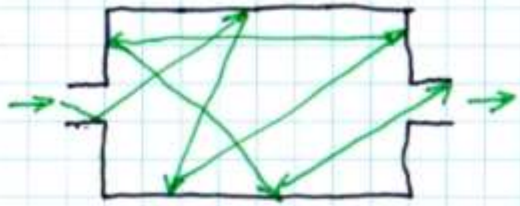


$\lambda \ll d$

Particles collide (almost) only with particles
Fraction of wall collisions is neglectable!

turbulent laminar

Molecular flow



$\lambda \gg d$

Particles collide (almost) only, with the walls.
Fraction of particle / particle collision very small!

Transition regime

$\lambda \approx d$

Knudsen flow

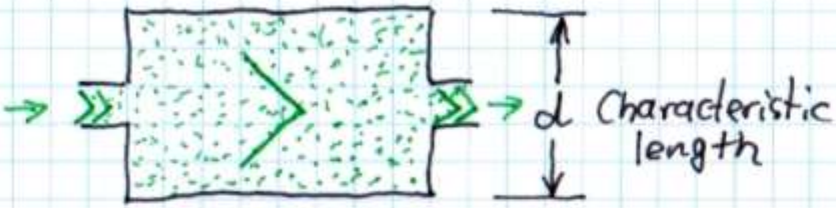
In this (Knudsen) regime heat conduction or viscosity depends on Pressure!

http://www.falstad.com/gas/fullscreen.html

2 extrem cases

inbetween

Viscous flow



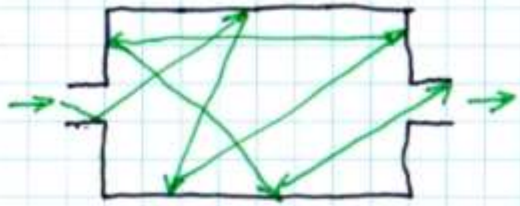
$\lambda \ll d$

Particles collide (almost) only with particles
Fraction of wall collisions is neglectable!

turbulent laminar

The typical condition in vacuum systems

Molecular flow



$\lambda \gg d$

Particles collide (almost) only with the walls.
Fraction of particle / particle collision very small!

Transition regime

$\lambda \approx d$

Knudsen flow

In this (Knudsen) regime heat conduction or viscosity depends on Pressure!

http://www.falstad.com/gas/fullscreen.html

TECHNISCHE UNIVERSITÄT DRESDEN

Reynolds number

From Wikipedia, the free encyclopedia

The plume from this candle flame goes from laminar to turbulent. The Reynolds number can be used to predict where this transition will take place.

For flow in a pipe or tube, the Reynolds number is generally defined as[10]

$$\mathrm{Re} = \frac{\rho u D_\mathrm{H}}{\mu} = \frac{u D_\mathrm{H}}{\nu} = \frac{Q D_\mathrm{H}}{\nu A},$$

where

- D_H is the hydraulic diameter of the pipe (the inside diameter if the pipe is circular) (m),
- Q is the volumetric flow rate (m^3/s),
- A is the pipe's *cross-sectional* area (m^2),
- u is the mean velocity of the fluid (m/s),
- μ is the dynamic viscosity of the fluid (Pa·s = N·s/m^2 = kg/(m·s)),
- ν (nu) is the kinematic viscosity ($\nu = \frac{\mu}{\rho}$) (m^2/s),
- ρ is the density of the fluid (kg/m^3).

For flow in a pipe of diameter D, experimental observations show that for "fully developed" flow, laminar flow occurs when $\mathrm{Re}_D < 2300$ and turbulent flow occurs when $\mathrm{Re}_D > 2600$.

Reynolds number

From Wikipedia, the free encyclopedia

The plume from this candle flame goes from laminar to turbulent. The Reynolds number can be used to predict where this transition will take place.

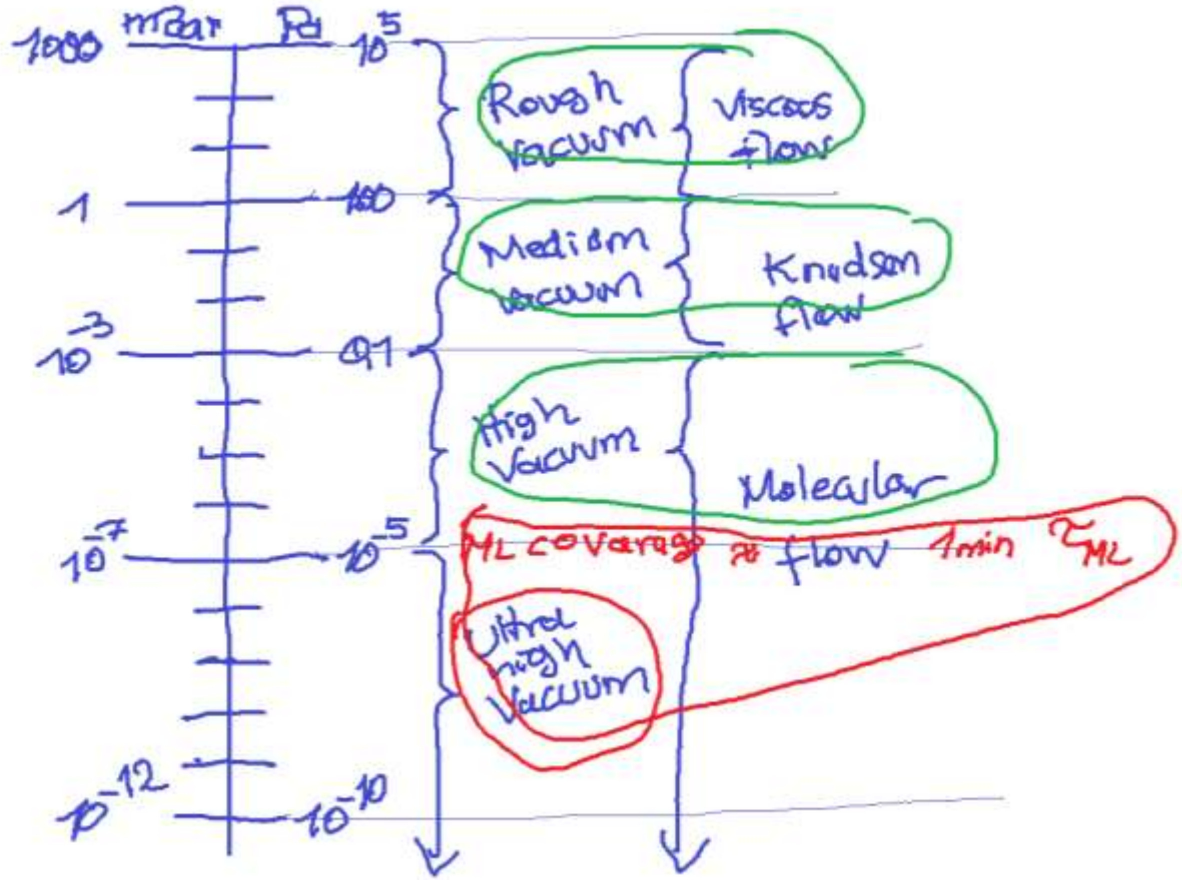
For flow in a pipe or tube, the Reynolds number is generally defined as[10]

$$\mathrm{Re} = \frac{\rho u D_\mathrm{H}}{\mu} = \frac{u D_\mathrm{H}}{\nu} = \frac{Q D_\mathrm{H}}{\nu A},$$

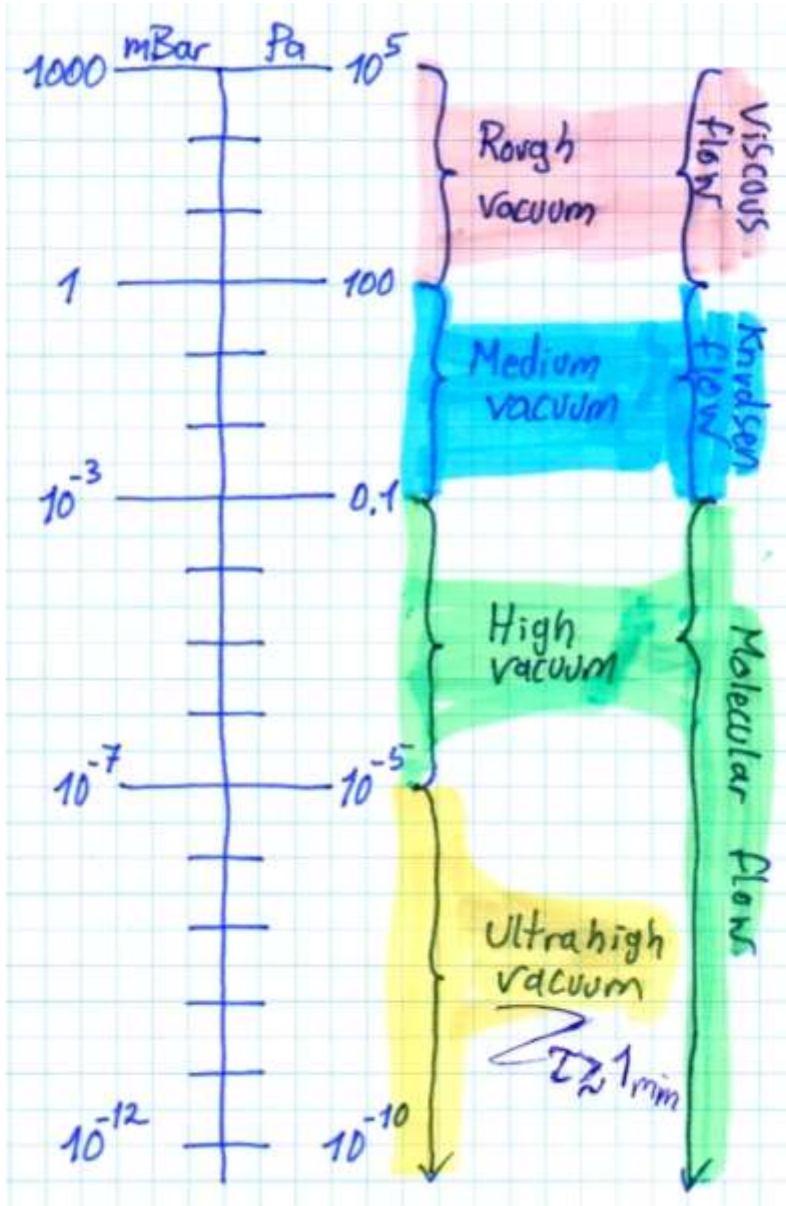
where

- D_H is the hydraulic diameter of the pipe (the inside diameter if the pipe is circular) (m),
- Q is the volumetric flow rate (m^3/s),
- A is the pipe's *cross-sectional* area (m^2),
- u is the mean velocity of the fluid (m/s),
- μ is the dynamic viscosity of the fluid (Pa·s = N·s/m^2 = kg/(m·s)),
- ν (nu) is the kinematic viscosity ($\nu = \frac{\mu}{\rho}$) (m^2/s),
- ρ is the density of the fluid (kg/m^3).

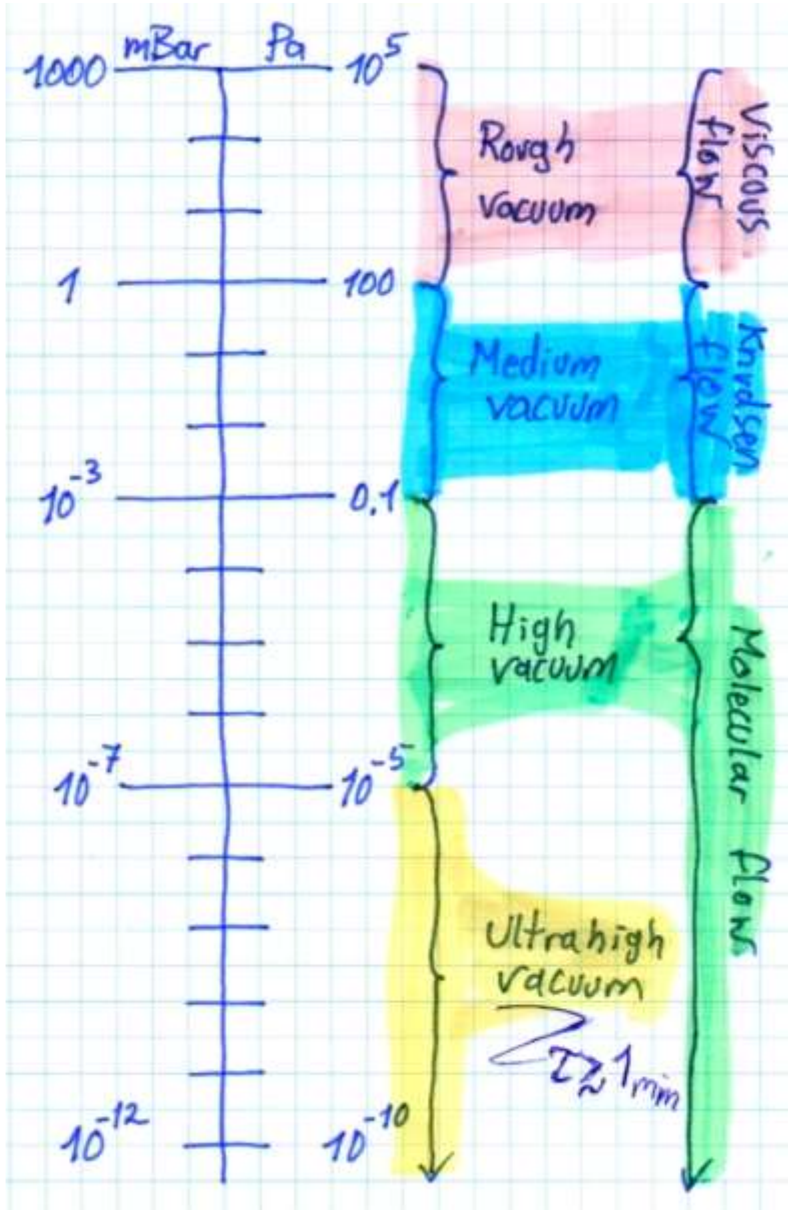
For flow in a pipe of diameter D, experimental observations show that for "fully developed" flow, laminar flow occurs when $\mathrm{Re}_D < 2300$ and turbulent flow occurs when $\mathrm{Re}_D > 2600$.


1000
mBar
Pa
10^5
1
100
10^-3
0.1
10^-7
10^-5
10^-12
10^-10
Rough vacuum
Viscous flow
Medium vacuum
Knudsen flow
High vacuum
Molecular flow
ML coverage ≈ 1min
τ ML
Ultra high vacuum

The definition of UHV is associated with the monolayer coverage time, while the other ranges are associated with the kind of gas flow.



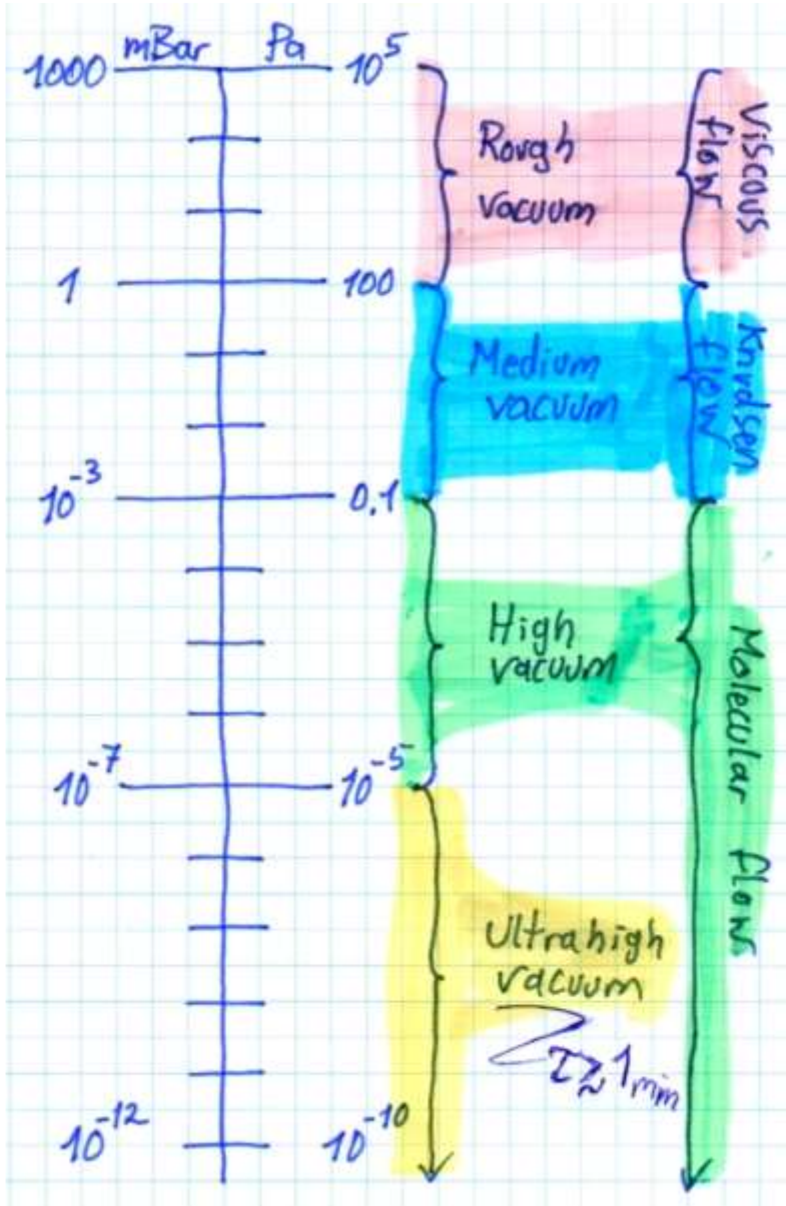
TECHNISCHE UNIVERSITÄT DRESDEN



λ<<d

The definition of UHV is associated with the monolayer coverage time, while the other ranges are associated with the kind of gas flow.

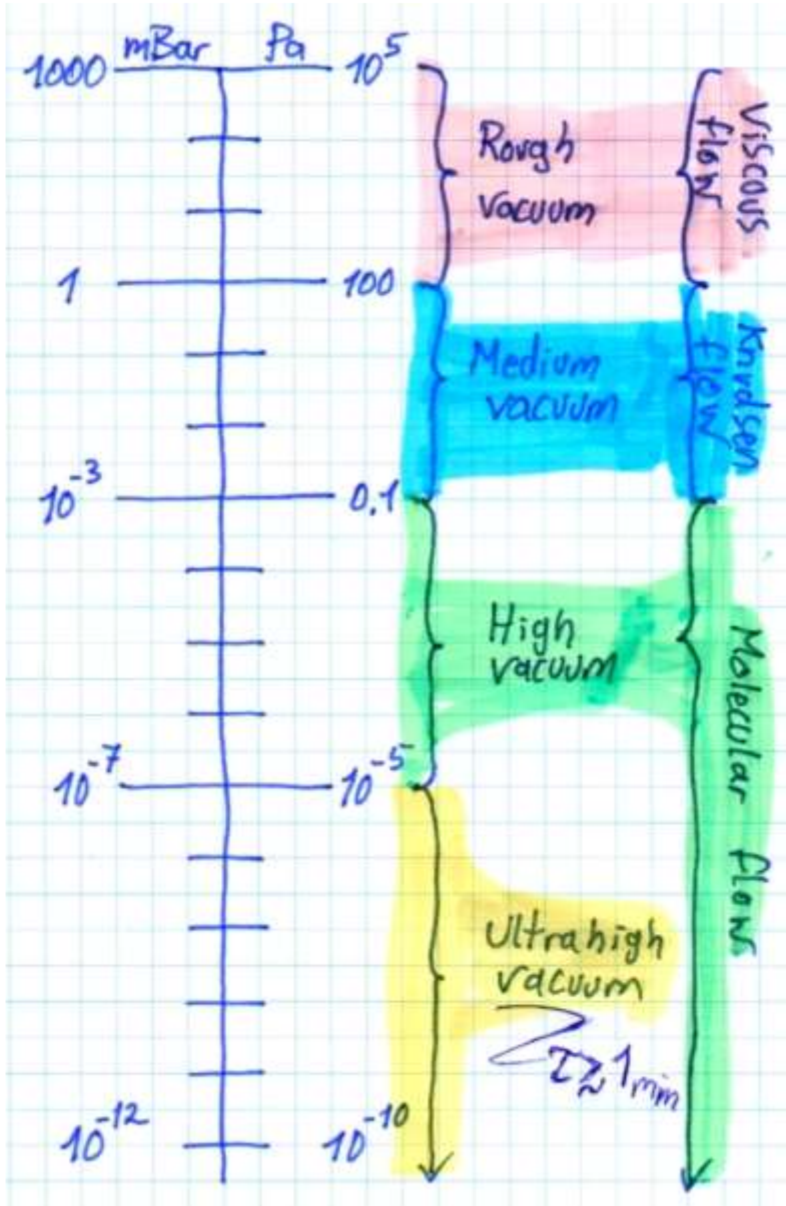
TECHNISCHE UNIVERSITÄT DRESDEN



λ<<d

λ≈d

The definition of UHV is associated with the monolayer coverage time, while the other ranges are associated with the kind of gas flow.



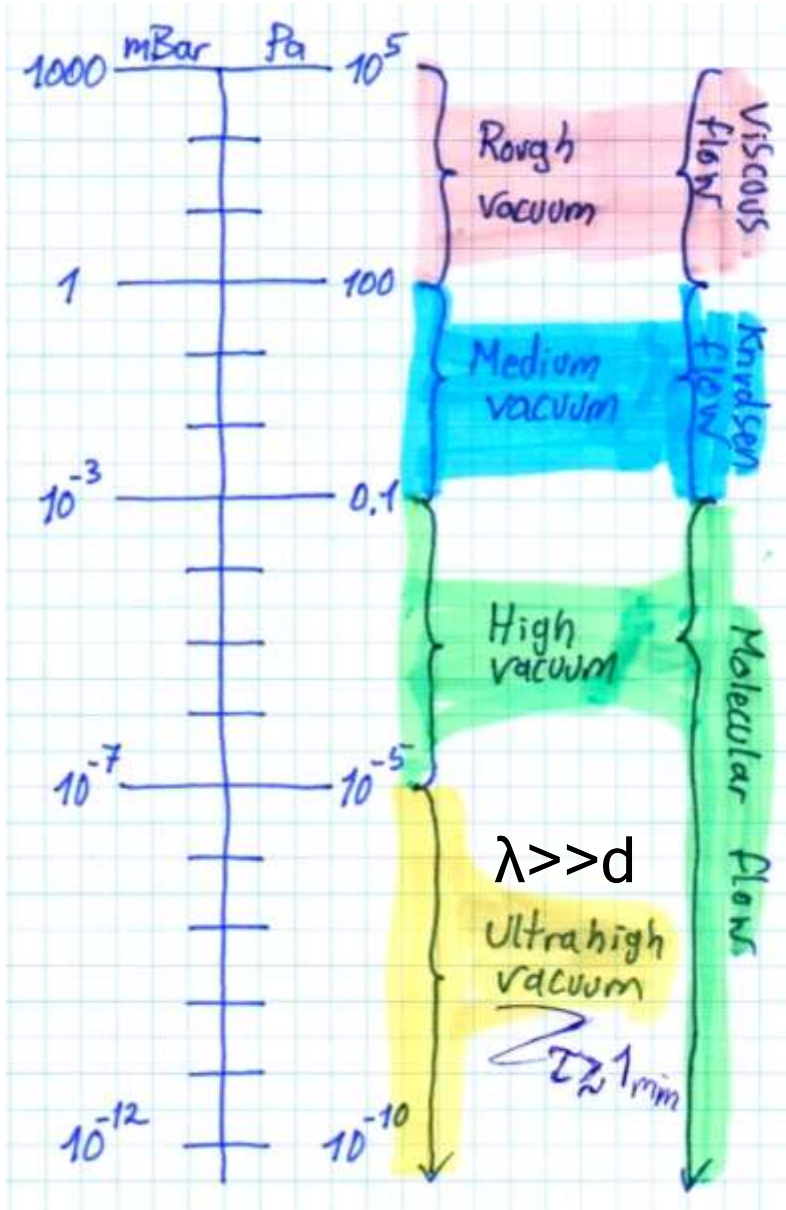
λ<<d

λ≈d

λ>>d

The definition of UHV is associated with the monolayer coverage time, while the other ranges are associated with the kind of gas flow.

TECHNISCHE UNIVERSITÄT DRESDEN



λ<<d

λ≈d

λ>>d

λ>>d

The definition of UHV is associated with the monolayer coverage time, while the other ranges are associated with the kind of gas flow.

Pressure ranges in vacuum technology

		Rough vacuum	Medium vacuum	High vacuum	Ultrahigh vacuum
Pressure	p [mbar]	1013 – 1	1 – 10^{-3}	10^{-3} – 10^{-7}	< 10^{-7}
Particle number density	n [cm^{-3}]	10^{19} – 10^{16}	10^{16} – 10^{13}	10^{13} – 10^{9}	< 10^{9}
Mean free path	λ [cm]	< 10^{-2}	10^{-2} – 10	10 – 10^{5}	> 10^{5}
Impingement rate	Z_a [$cm^{-2} \cdot s^{-1}$]	10^{23} – 10^{20}	10^{20} – 10^{17}	10^{17} – 10^{13}	< 10^{13}
Vol.-related collision rate	Z_V [$cm^{-3} \cdot s^{-1}$]	10^{29} – 10^{23}	10^{23} – 10^{17}	10^{17} – 10^{9}	< 10^{9}
Monolayer time	τ [s]	< 10^{-5}	10^{-5} – 10^{-2}	10^{-2} – 100	> 100
Type of gas flow		Viscous flow	Knudsen flow	Molecular flow	Molecular flow
Other special features		Convection dependent on pressure	Significant change in thermal conductivity of a gas	Significant reduction in volume related collision rate	Particles on the surfaces dominate to a great extend in relation to particles in gaseous space

Viscous flow:
Mean free path << container dimension
(Rough vacuum)

Knudsen flow:
Mean free path ~ container dimension
(Fine vacuum)

Molecular flow:
Mean free path >> container dimension

Monolayer coverage time > 1min

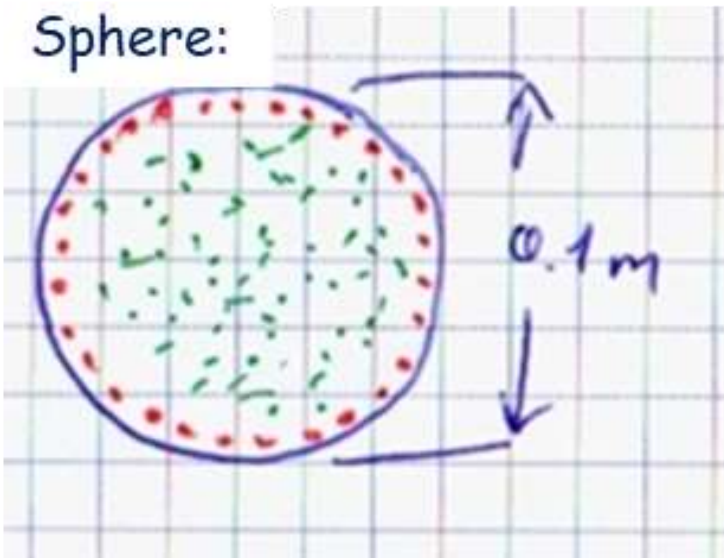
http://www.falstad.com/gas/

Example: We assume that the inner wall of a spherical vacuum chamber is covered by a monoatomic (gas) layer. The pressure inside is $1 \cdot 10^{-3}$ mBar.

Q: How many particles are within the volume and how many of them are attached to the wall?

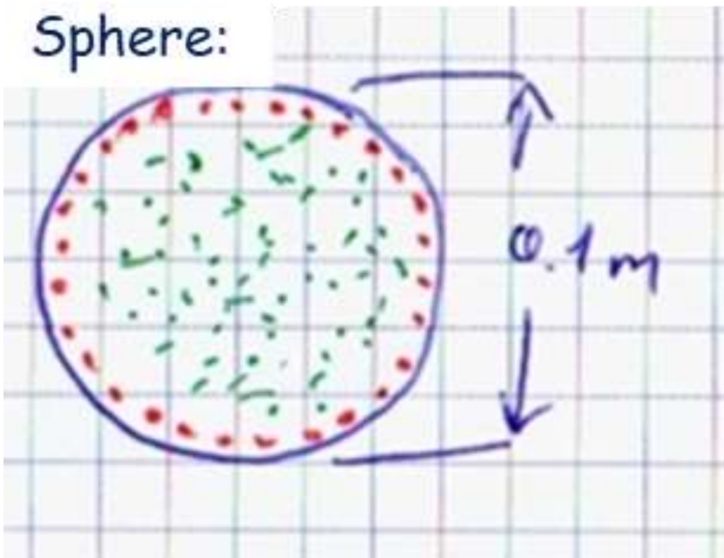
Example: We assume that the inner wall of a spherical vacuum chamber is covered by a monoatomic (gas) layer. The pressure inside is $1{\cdot}10^{-3}$ mBar.

Q: How many particles are within the volume and how many of them are attached to the wall?



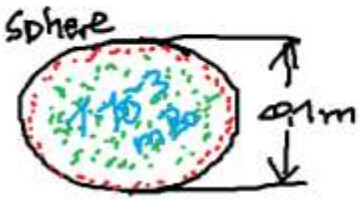
Example: We assume that the inner wall of a spherical vacuum chamber is covered by a monoatomic (gas) layer. The pressure inside is $1 \cdot 10^{-3}$ mBar.

Q: How many particles are within the volume and how many of them are attached to the wall?



We assume that the inner wall of a spherical vacuum chamber is covered by a monoatomic (gas) layer. The pressure inside is $1 \cdot 10^{-3}$ mBar.

Q: How many particles are within the volume and how many are attached to the wall?



$$V = \frac{1}{6} d^3 \pi = 5{,}2 \cdot 10^{-4}\ m^3$$

$$A = \pi d^2 = 0{,}03\ m^2$$

$$\text{Monolayer} \mathrel{\hat=} 1 \cdot 10^{19}\ \frac{1}{m^2}$$

$$N_{surf} = 0{,}03 \cdot 10^{19} = \underline{3 \cdot 10^{17}\ \text{Particles}}$$

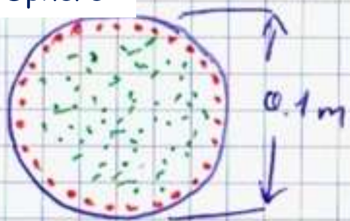
$$N_{vol} = n \cdot V = \frac{p}{kT} \cdot V = \underline{1{,}3 \cdot 10^{16}\ \text{Particles}}$$

20 times more particles at the wall than inside the volume!!

Example: We assume that the inner wall of a spherical vacuum chamber is covered by a monoatomic (gas) layer. The pressure inside is $1 \cdot 10^{-3}$ mBar.

Q: How many particles are within the volume and how many of them are attached to the wall?

Sphere:



$$V = \frac{1}{6} d^3 \pi = 5{,}2 \cdot 10^{-4}\ m^3$$

$$A = \pi d^2 = 0.03\ m^2$$

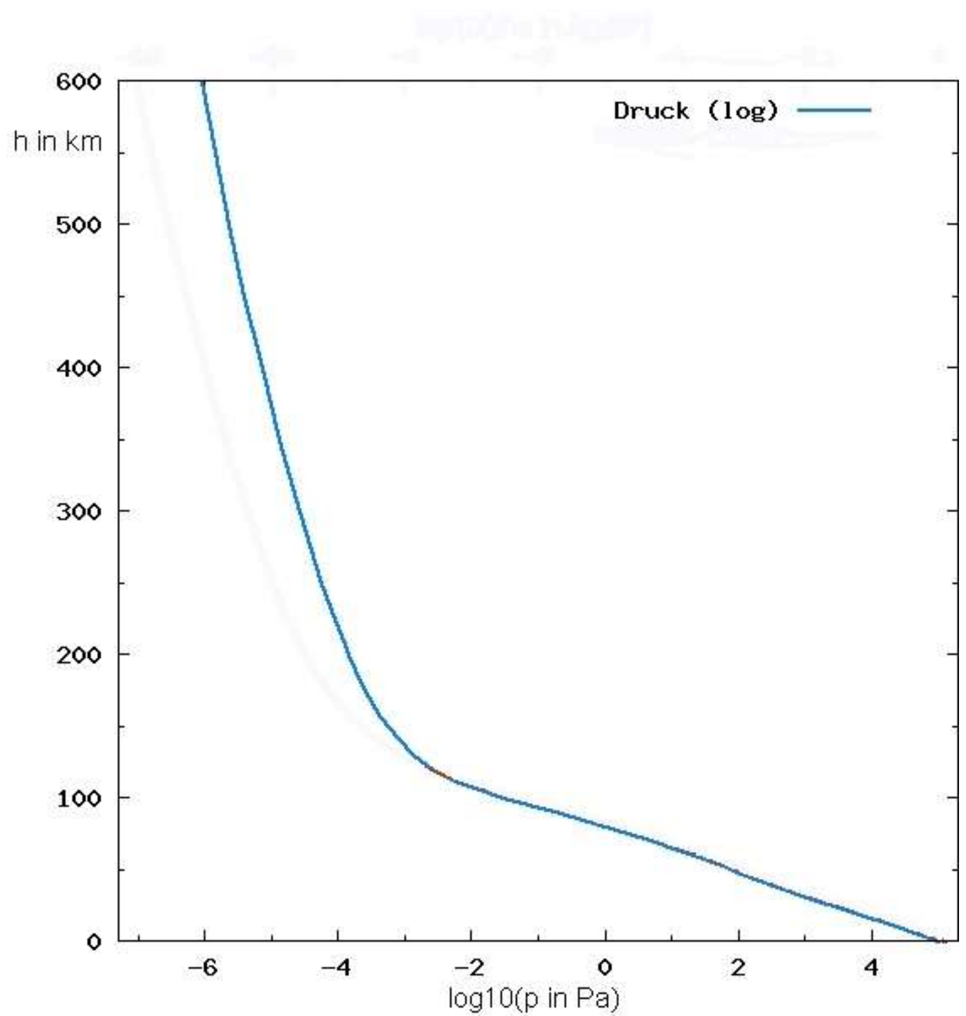
$$\text{Monolage} \;\hat{=}\; 1 \cdot 10^{19} \frac{1}{m^2}$$

$$N_{\text{obefl.}} = 0.03 \cdot 10^{19} = 3 \cdot 10^{17} \text{ Particles}$$

$$N_{\text{Vol}} = n \cdot V = \frac{p}{kT} \cdot V = 1{,}3 \cdot 10^{16} \text{ Particles}$$

At this pressure, there are 20 times more particles at the wall than inside the "vacuum"!

Vacuum in space



Ultrahoch- Hoch- Fein- Grob- Vakuum

https://de.wikipedia.org/wiki/Weltraum

»Wissen schafft Brücken.«