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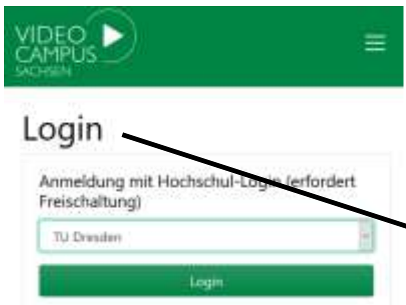

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Vacuum Technology
WS 20/21
Virtually presented
Lecture 3, Nov. 10, 2020

Prof. Dr. Johann W. Bartha

Inst. f. Halbleiter und Mikrosystemtechnik
Technische Universität Dresden

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TECHNISCHE UNIVERSITÄT DRESDEN

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0. Introduction

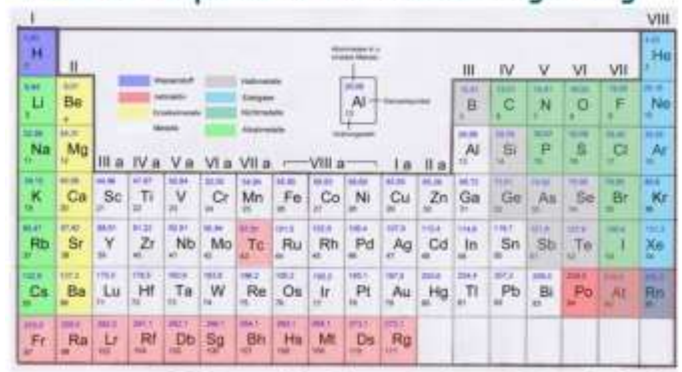
Air pressure as a force to the walls of an empty container

1. Gas kinetic

Pressure as momentum transfer, Mol, Avogadros number

$$P = \frac{1}{3} n m \overline{v^2}$$

1 Mol corresponds to the Atomic weight in g



# of particles within 1 Mol is a universal constant = Avogadro Number $N_A = 6.022 \cdot 10^{23}$!

2. Pressure Ranges

3. Vacuum technical terms

4. Vacuum generation

5. Pressure measurement

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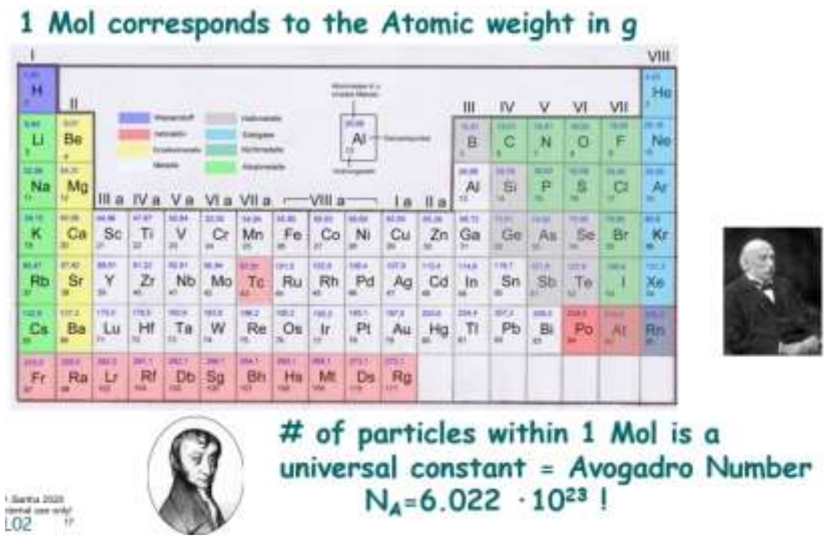

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Change of gas condition
(Phenomenological finding!)

Boyle-Mariotte 1861	T=const.	P~1/V	P·V=const.
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Going from $V_1; P_1; T_1 \xrightarrow[V_2=V_1]{1.} V_2; P_2; T_2 \xrightarrow[P_3=P_2]{2.} V_3; P_3; T_3$

1. "Amontos" $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ and $V_2 = V_1 = V_{2/1}$ ↷ $T_2 = \frac{P_2 T_1}{P_1}$

2. "Gay-Lussac" $\frac{V_{2/1}}{T_2} = \frac{V_3}{T_3}$ and $P_3 = P_2 = P_{3/2}$ ↷ $V_3 = \frac{V_{2/1} T_3}{T_2}$

$$V_3 = \frac{V_{2/1} T_3 P_1}{P_{3/2} T_1} \quad \text{or} \quad \frac{V_3 P_3}{T_3} = \frac{V_1 P_1}{T_1}$$

or in short: $\boxed{\frac{P \cdot V}{T} = \text{const}}$

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Back to the Kinematic approach:

mean value of the kinetic energy

$$P = \frac{1}{3} n m \overline{u^2} = \frac{1}{3} \frac{N}{V} m \overline{u^2} \quad \text{or}$$

$$P \cdot V = 2 \cdot \frac{1}{3} N \frac{m}{2} \overline{u^2} = \frac{2}{3} N \frac{m}{2} \overline{u^2} = \frac{2}{3} N \overline{E}_{kin}$$

Considering 1 Mol: $N \rightarrow N_A$

$$P \cdot V = \frac{2}{3} N_A \overline{E}_{kin}$$

comparison with phenomenological observation

$$P \cdot V = RT = \frac{2}{3} \cdot N_A \overline{E}_{kin}$$

$$\overline{E}_{kin} = \frac{3}{2} \frac{R}{N_A} T = \frac{m}{2} \overline{v^2}$$

$$\overline{E}_{kin} = \frac{3}{2} k T$$

k: Boltzmann Constant!

$$k = \frac{R}{N_A} = 1{,}3804 \cdot 10^{-23} \left[\frac{Ws}{K}\right]$$

Different writing of the general gas equation:

$$P = \frac{1}{3} n m \overline{v^2}; \quad m\overline{v^2} = 2 \overline{E}_{kin}; \quad P = n \frac{2}{3} \overline{E}_{kin} = n \frac{2}{3} \underbrace{\frac{3}{2} kT}_{\overline{E}_{kin}}$$

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$P = n \cdot k \cdot T$

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Question:
Unit of PV ?

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Question:
Unit of PV ?

Answer:
$(N/m^2) \cdot m^3$
Respectively
Nm or
J or
Ws
It is WORK
or ENERGY!

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The pressure depends only on particle density and temperature

$$P = n\,k\,T$$

	(std) atm	Bar	mBar	Pa	Torr	psi
1(std) atm=	1	1,0132	1,01 10^{-3}	101,32 10^{3}	760	14,7
1 Bar =	0.987	1	10^{3}	10^{5}	750	14,5
1 mBar =	0,987 10^{-3}	10^{-3}	1	0,1	0,75	0,0145
1 Pa =	9,87 10^{-6}	10^{-5}	10^{-2}	1	7,5 10^{-3}	145 10^{-6}
1 Torr =	1,31 10^{-3}	1,33 10^{-3}	1,33	133	1	19,3 10^{-3}
1 psi =	68 10^{-3}	69 10^{-3}	69	6,9 10^{3}	51,7	1

http://www.onlineconversion.com/pressure.htm

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Some exercises:

Question: **What is the pressure in a volume of 10 l at 20 C when the amount of gas inside is**
a) 1g He; b) 1g N_2 c) 1g SF_6

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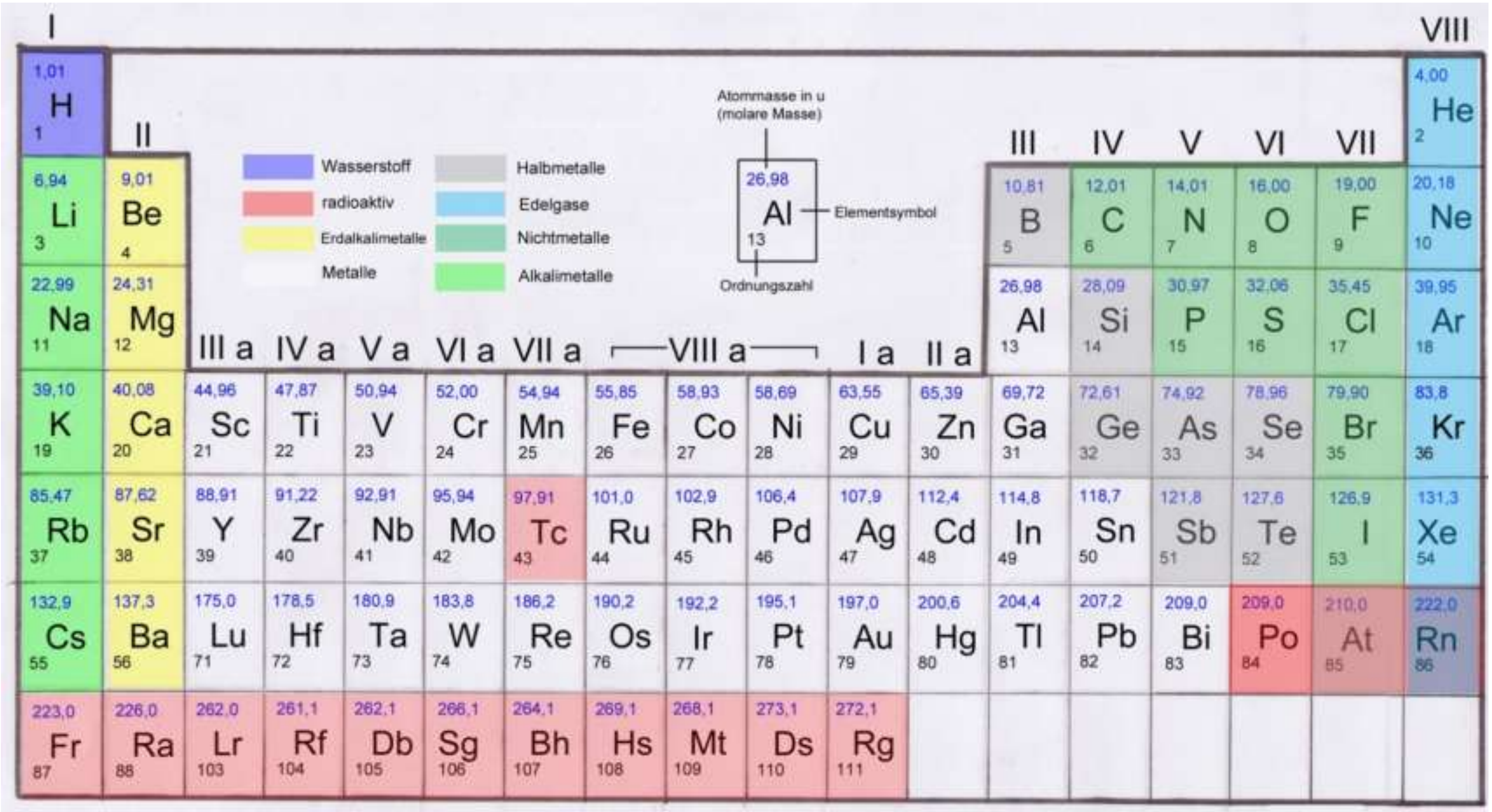

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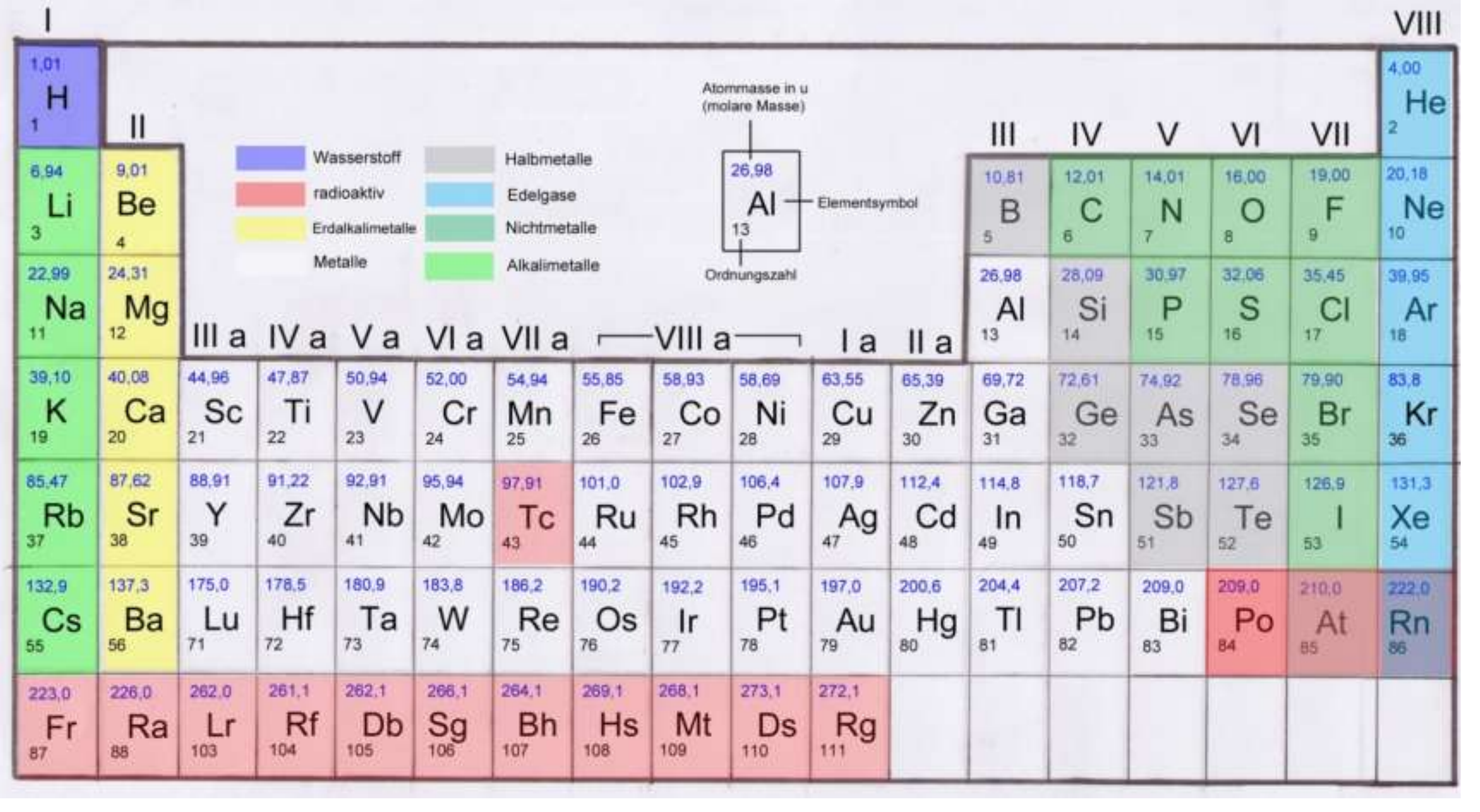

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$\overline{E_{kin}} = \frac{3}{2} \frac{R}{N_A} T = \frac{m}{2} \overline{v^2}$

$\overline{E_{kin}} = \frac{3}{2} k_B T$

Boltzmann Const.

K: Boltzmann Constant

$K = \frac{R}{N_A} = 1.3801 \cdot 10^{-23} \left[\frac{Ws}{K} \right]$

Different writing of the general gas equation:

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$\Rightarrow$ $\boxed{P = n \cdot KT}$

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Question: What is the pressure in a volume of 10 l at 20 C when the amount of gas inside is

a) 1g He; b) 1g N_2 c) 1g SF_6

$$P = n\,k\,T \leftarrow 20°C \mathrel{\hat{=}} 293\,K$$

$k = 1{,}38 \cdot 10^{-23}\ \frac{Nm}{K}$

$n = \frac{N}{V}$, $V \leftarrow 0{,}01\ m^3$

Atomic weights (amu)

He = 4
N = 14
S = 32
F = 19

N_{He}: 1 Mol He = 4 g → 1 g He $\hat{=}$ $\frac{1}{4} N_A$

N_{N_2}: 1 Mol N_2 = 28 g → 1 g N_2 $\hat{=}$ $\frac{1}{28} N_A$

N_{SF_6}: 1 Mol SF_6 = 146 g → 1 g SF_6 $\hat{=}$ $\frac{1}{146} N_A$

$N_A = 6.02 \cdot 10^{23}$

P_{He} = 60 ~~651~~ 853 Pa $\hat{=}$ **608 mBar**

P_{N_2} = 8697 Pa $\hat{=}$ **87 mBar**

P_{SF_6} = 1668 Pa $\hat{=}$ **17 mBar**

Remember: For T=const. the Pressure depends only on the particle density!

Some exercises:

Question: What is the pressure in a volume of 10 l at 20 C when the amount of gas inside is
a) 1g He; b) 1g N_2 c) 1g SF_6

Question: How many g SF_6 are inside a volume, when the pressure corresponds to that of 1g O_2 ?

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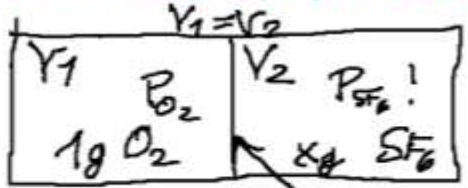

membrane: No bending!

$$P_{O_2} = n_{O_2} KT = TK n_{SF_6} = P_{SF_6}$$

($O_2 \hat{=} 32$ amu)

$$\frac{N_A \, 1g_{O_2}}{Mol_{O_2} \cdot V} = \frac{N_A \, Xg_{SF_6}}{Mol_{SF_6} \, V}$$

$$Xg_{SF_6} = \frac{Mol_{SF_6} \, 1g}{Mol_{O_2}} \quad \frac{146 \cdot 1g}{32} \Rightarrow \underline{\underline{4{,}56 \text{ g}}}$$

$$P = n kT$$

n: #/V

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Question: How many g SF_6 are inside a volume, when the pressure corresponds to that of 1g O_2 ?

$$P_{O_2} = n_{O_2} kT = Tk\, n_{SF_6} = P_{SF_6}$$

$$(O_2 \triangleq 32 \text{ amu})$$

$$\frac{N_A \cdot 1g_{O_2}}{Mol_{O_2} \cdot V} = \frac{N_A\, Xg_{SF_6}}{Mol_{SF_6}\, V}$$

$$Xg_{SF_6} = \frac{Mol_{SF_6} \cdot 1g}{Mol_{O_2}} = \frac{146 \cdot 1g}{32} = \underline{\underline{4.56\ g}}$$

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»Wissen schafft Brücken.«