

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

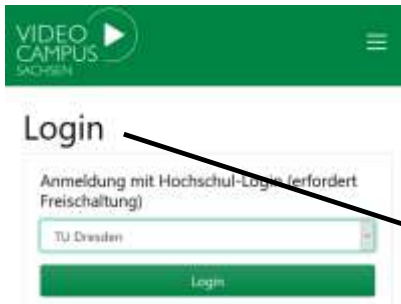
Prof. Dr. Johann W. Bartha

Inst. f. Halbleiter und Mikrosystemtechnik  
Technische Universität Dresden

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## 0. Introduction

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

### 1. Gas kinetic

Pressure as momentum transfer, Mol, Avogadros number

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

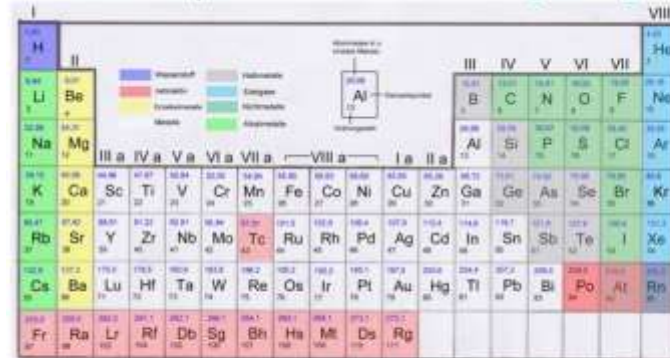
2. Pressure Ranges

3. Vacuum technical terms

4. Vacuum generation

5. Pressure measurement

1 Mol corresponds to the Atomic weight in g




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



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# Change of gas condition

(Phenomenological finding!)

Boyle-Mariotte 1861

$$T = \text{const.}$$

$$P \sim 1/V$$

$$P \cdot V = \text{const.}$$

Gay-Lussac 1808

$$P = \text{const.}$$

$$V \sim T$$

$$V/T = \text{const.}$$

Amontons late 1600

$$V = \text{const.}$$

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VT L02 b 14:05

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Going from  $V_1; P_1; T_1 \xrightarrow[1.]{V_2=V_1} V_2; P_2; T_2 \xrightarrow[2.]{P_3=P_2} V_3; P_3; T_3$

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

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

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

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
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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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# Back to the kinematic approach:

VT L02 d 27:09

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VT L02 d 27:09



Back to the Kinematic approach:

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

or

mean value of the  
kinetic energy

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

Considering 1 Mol:  $N \rightarrow N_A$

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

Comparison  
with  
phenomenological  
observation

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

$$\overline{E_{kin}} = \frac{3}{2} \left( \frac{R}{N_A} \right) T = \frac{m}{2} \overline{u^2}$$

$$\overline{E_{kin}} = \frac{3}{2} kT$$

$k$ : Boltzmann Constant!

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

Different writing of the general gas equation:

$$P = \frac{1}{3} n m \overline{u^2}; \quad m \overline{u^2} = 2 \overline{E_{kin}}; \quad P = n \frac{2}{3} \overline{E_{kin}} = n \frac{2}{3} \frac{3}{2} kT$$

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

$$P = n \cdot k \cdot T$$

Back to the Kinematic approach:

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Question:  
Unit of  
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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!**

Back to the Kinematic approach:

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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 <sup>-3</sup>	101,32 10 <sup>3</sup>	760	14,7
1 Bar =	0,987	1	10 <sup>3</sup>	10 <sup>5</sup>	750	14,5
1 mBar =	0,987 10 <sup>-3</sup>	10 <sup>-3</sup>	1	0,1	0,75	0,0145
1 Pa =	9,87 10 <sup>-6</sup>	10 <sup>-5</sup>	10 <sup>-2</sup>	1	7,5 10 <sup>-3</sup>	145 10 <sup>-6</sup>
1 Torr =	1,31 10 <sup>-3</sup>	1,33 10 <sup>-3</sup>	1,33	133	1	19,3 10 <sup>-3</sup>
1 psi =	68 10 <sup>-3</sup>	69 10 <sup>-3</sup>	69	6,9 10 <sup>3</sup>	51,7	1

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



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## Some exercises:

VT L02 e 27:00

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<sub>2</sub>      c) 1g SF<sub>6</sub>

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I																	VIII
1,01 H 1																	4,00 He 2
6,94 Li 3	9,01 Be 4											10,81 B 5	12,01 C 6	14,01 N 7	16,00 O 8	19,00 F 9	20,18 Ne 10
22,99 Na 11	24,31 Mg 12											26,98 Al 13	28,09 Si 14	30,97 P 15	32,06 S 16	35,45 Cl 17	39,95 Ar 18
		III a	IV a	V a	VI a	VII a	VIII a		I a	II a							
39,10 K 19	40,08 Ca 20	44,96 Sc 21	47,87 Ti 22	50,94 V 23	52,00 Cr 24	54,94 Mn 25	55,85 Fe 26	58,93 Co 27	58,69 Ni 28	63,55 Cu 29	65,39 Zn 30	69,72 Ga 31	72,61 Ge 32	74,92 As 33	78,96 Se 34	79,90 Br 35	83,8 Kr 36
85,47 Rb 37	87,62 Sr 38	88,91 Y 39	91,22 Zr 40	92,91 Nb 41	95,94 Mo 42	97,91 Tc 43	101,0 Ru 44	102,9 Rh 45	106,4 Pd 46	107,9 Ag 47	112,4 Cd 48	114,8 In 49	118,7 Sn 50	121,8 Sb 51	127,6 Te 52	126,9 I 53	131,3 Xe 54
132,9 Cs 55	137,3 Ba 56	175,0 Lu 71	178,5 Hf 72	180,9 Ta 73	183,8 W 74	186,2 Re 75	190,2 Os 76	192,2 Ir 77	195,1 Pt 78	197,0 Au 79	200,6 Hg 80	204,4 Tl 81	207,2 Pb 82	209,0 Bi 83	209,0 Po 84	210,0 At 85	222,0 Rn 86
223,0 Fr 87	226,0 Ra 88	262,0 Lr 103	261,1 Rf 104	262,1 Db 105	266,1 Sg 106	264,1 Bh 107	269,1 Hs 108	268,1 Mt 109	273,1 Ds 110	272,1 Rg 111							

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1,01 H 1																	4,00 He 2
6,94 Li 3	9,01 Be 4											10,81 B 5	12,01 C 6	14,01 N 7	16,00 O 8	19,00 F 9	20,18 Ne 10
22,99 Na 11	24,31 Mg 12											26,98 Al 13	28,09 Si 14	30,97 P 15	32,06 S 16	35,45 Cl 17	39,95 Ar 18
		III a	IV a	V a	VI a	VII a	VIII a	I a	II a								
39,10 K 19	40,08 Ca 20	44,96 Sc 21	47,87 Ti 22	50,94 V 23	52,00 Cr 24	54,94 Mn 25	55,85 Fe 26	58,93 Co 27	58,69 Ni 28	63,55 Cu 29	65,39 Zn 30	69,72 Ga 31	72,61 Ge 32	74,92 As 33	78,96 Se 34	79,90 Br 35	83,8 Kr 36
85,47 Rb 37	87,62 Sr 38	88,91 Y 39	91,22 Zr 40	92,91 Nb 41	95,94 Mo 42	97,91 Tc 43	101,0 Ru 44	102,9 Rh 45	106,4 Pd 46	107,9 Ag 47	112,4 Cd 48	114,8 In 49	118,7 Sn 50	121,8 Sb 51	127,6 Te 52	126,9 I 53	131,3 Xe 54
132,9 Cs 55	137,3 Ba 56	175,0 Lu 71	178,5 Hf 72	180,9 Ta 73	183,8 W 74	186,2 Re 75	190,2 Os 76	192,2 Ir 77	195,1 Pt 78	197,0 Au 79	200,6 Hg 80	204,4 Tl 81	207,2 Pb 82	209,0 Bi 83	209,0 Po 84	210,0 At 85	222,0 Rn 86
223,0 Fr 87	226,0 Ra 88	262,0 Lr 103	261,1 Rf 104	262,1 Db 105	266,1 Sg 106	264,1 Bh 107	269,1 Hs 108	268,1 Mt 109	273,1 Ds 110	272,1 Rg 111							

Back to the kinematic approach:

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

$$P \cdot V = \frac{2}{3} N \frac{m \overline{v^2}}{2} = \frac{2}{3} N \overline{E_{kin}}$$

or mean value of the kinetic energy

Considering 1 Mol:  $N \rightarrow N_A$

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

Comparison with phenomenological observation

$$P \cdot V \stackrel{(1)}{=} RT = \frac{2}{3} N_A \overline{E_{kin}}$$

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

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

Boltzmann const.

$k_B$  = Boltzmann Constant

$$k_B = \frac{R}{N_A} = 1.3804 \cdot 10^{-23} \left[ \frac{J}{K} \right]$$

Different writing of the general gas equation:

$$P = \frac{1}{3} n m \overline{v^2}; \quad m \overline{v^2} = 2 \overline{E_{kin}}$$

$$P = n \frac{2}{3} \overline{E_{kin}} = n \frac{2}{3} \left( \frac{3}{2} k_B T \right)$$

$$\Rightarrow \boxed{P = n \cdot k_B T}$$

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<sub>2</sub>    c) 1g SF<sub>6</sub>

$$P = n k T \leftarrow 20^{\circ}\text{C} \cong 293 \text{ K}$$

$$\begin{array}{l} \uparrow \\ \frac{N}{V} \leftarrow 0,01 \text{ m}^3 \end{array} \quad \begin{array}{l} \uparrow \\ 1,38 \cdot 10^{-23} \frac{\text{Nm}}{\text{K}} \end{array}$$

Atomic weights (amu)

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

$$N_{\text{He}}: 1 \text{ Mol He} = 4 \text{ g} \rightarrow 1 \text{ g He} \cong \frac{1}{4} N_A$$

$$N_{\text{N}_2}: 1 \text{ Mol N}_2 = 28 \text{ g} \rightarrow 1 \text{ g N}_2 \cong \frac{1}{28} N_A$$

$$N_{\text{SF}_6}: 1 \text{ Mol SF}_6 = 146 \text{ g} \rightarrow 1 \text{ g SF}_6 \cong \frac{1}{146} N_A$$

$N_A = 6,02 \cdot 10^{23}$

$$P_{\text{He}} = 60 \overset{853}{\cancel{651}} \text{ Pa} \cong \underline{\underline{608 \text{ mBar}}}$$

$$P_{\text{N}_2} = 8697 \text{ Pa} \cong \underline{\underline{87 \text{ mBar}}}$$

$$P_{\text{SF}_6} = 1668 \text{ Pa} \cong \underline{\underline{17 \text{ mBar}}}$$

**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<sub>2</sub>    c) 1g SF<sub>6</sub>

Question: How many g SF<sub>6</sub> are inside a volume, when the pressure corresponds to that of 1g O<sub>2</sub> ?



## Some exercises:

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$$P_{O_2} = n_{O_2} K T = T K n_{SF_6} = P_{SF_6}$$

membrane: No bending!  
(O<sub>2</sub> ≅ 32 amu)

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

$$xg_{SF_6} = \frac{Mol_{SF_6} \cdot 1g}{Mol_{O_2}} = \frac{14.6 \cdot 1g}{32} = \underline{\underline{4.56g}}$$

$$P = n K T$$

# / V

Question: How many g SF<sub>6</sub> are inside a volume, when the pressure corresponds to that of 1g O<sub>2</sub> ?

$$P_{O_2} = n_{O_2} K T = T K n_{SF_6} = P_{SF_6}$$

( O<sub>2</sub> ≅ 32 amu )

$$\frac{N_A \cdot 1g_{O_2}}{\text{Mol}_{O_2} \cdot V} = \frac{N_A X_{g_{SF_6}}}{\text{Mol}_{SF_6} V}$$

$$X_{g_{SF_6}} = \frac{\text{Mol}_{SF_6} \cdot 1g}{\text{Mol}_{O_2}} = \frac{146 \cdot 1g}{32} = \underline{\underline{4.56 g}}$$



**»Wissen schafft Brücken.«**