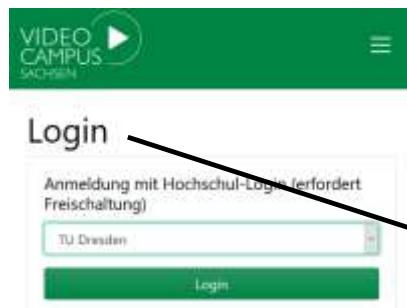


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# Vacuum Technology WS 20/21

## Virtually presented Lecture 3, Nov. 10, 2020

Prof. Dr. Johann W. Bartha

Inst. f. Halbleiter und Mikrosystemtechnik  
Technische Universität Dresden

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## 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

		VIII																			
		III								IV				V			VI		VII		
		I		II		III a		IV a		V a		VI a		VII a		VIII a		I a		II a	
H																					
He																					
Li																					
Be																					
Na																					
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Cu																					
Zn																					
Ga																					
Ge																					
As																					
Se																					
Br																					
Kr																					
I																					
Xe																					
Rn																					

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L02



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



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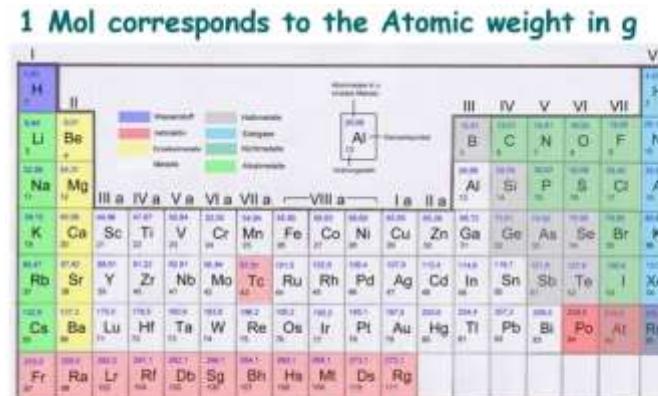
$$P = \frac{1}{3} n m \overline{\omega^2}$$

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



# Change of gas condition

(Phenomenological finding!)

<u>Boyle-Mariotte</u>	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. "Amontons"  $\frac{P_1}{T_1} = \frac{P_2}{T_2}$  and  $V_2 = V_1 = V_{2/1} \rightsquigarrow T_2 = \frac{P_2 T_1}{P_1}$

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

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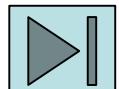
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$$P = \frac{1}{3} n m \bar{v}^2 = \frac{1}{3} \frac{N}{V} m \bar{v}^2 \quad \text{or}$$

$$P \cdot V = \frac{2:1}{3} N \frac{m}{2} \bar{v}^2 = \frac{2}{3} N \frac{m}{2} \bar{v}^2 = \frac{2}{3} N \bar{E}_{\text{kin}}$$

mean value of the  
kinetic energy

Considering 1 Mol :  $N \rightarrow N_A$

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

comparison  
with  
phenomenological  
observation

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

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

$$\bar{E}_{\text{kin}} = \frac{3}{2} K T$$

$k$ : Boltzmann Constant!

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

Different writing of the general gas equation :

$$P = \frac{1}{3} n m \bar{v}^2 ; m \bar{v}^2 = 2 \bar{E}_{\text{kin}} ; P = n \frac{2}{3} \bar{E}_{\text{kin}} = n \frac{2}{3} \frac{3}{2} K T$$

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

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## Question: Unit of PV ?

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

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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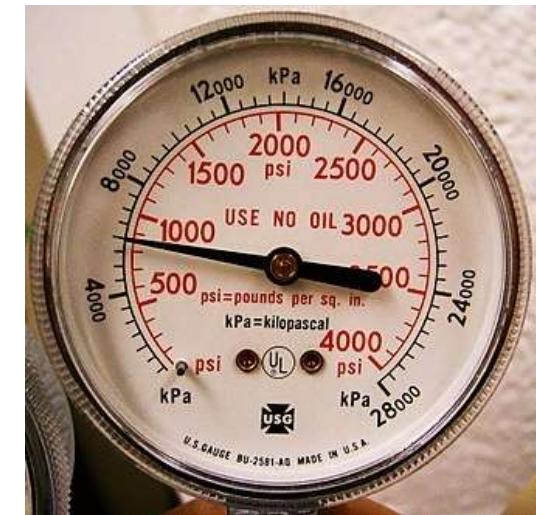
The pressure depends only on particle density and temperature

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

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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<sub>2</sub>    c) 1g SF<sub>6</sub>

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The image shows a detailed periodic table with the following information for aluminum (Al, atomic number 13, atomic mass 26.98):

- Atommasse in u (molare Masse): 26.98
- Elementsymbol: Al
- Ordnungszahl: 13

Legend for element categories:

- Wasserstoff (H)
- radioaktiv (pink)
- Erdalkalimetalle (yellow)
- Metalle (green)
- Halbmetalle (grey)
- Edelgase (light blue)
- Nichtmetalle (light green)
- Alkalimetalle (purple)

Periodic Table grid:

Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII												
H (1.01)							He (4.00)												
Li (6.94)	Be (9.01)						Ne (20.18)												
Na (22.99)	Mg (24.31)						Ar (39.95)												
K (39.10)	Ca (40.08)	Sc (44.96)	Ti (47.87)	V (50.94)	Cr (52.00)	Mn (54.94)	Fe (55.85)	Co (58.93)	Ni (58.69)	Cu (63.55)	Zn (65.39)	Ga (69.72)	Ge (72.61)	B (10.81)	C (12.01)	N (14.01)	O (16.00)	F (19.00)	Ne (20.18)
Rb (85.47)	Sr (87.62)	Y (88.91)	Zr (91.22)	Nb (92.91)	Mo (95.94)	Tc (97.91)	Ru (101.0)	Rh (102.9)	Pd (106.4)	Ag (107.9)	Cd (112.4)	In (114.8)	Sn (118.7)	As (121.8)	Se (127.6)	Br (126.9)	I (131.3)	Xe (131.3)	
Cs (132.9)	Ba (137.3)	Lu (175.0)	Hf (178.5)	Ta (180.9)	W (183.8)	Re (186.2)	Os (190.2)	Ir (192.2)	Pt (195.1)	Au (197.0)	Hg (200.6)	Tl (204.4)	Pb (207.2)	Bi (209.0)	Po (209.0)	At (210.0)	Rn (222.0)		
Fr (223.0)	Ra (226.0)	Lr (262.0)	Rf (261.1)	Db (262.1)	Sg (266.1)	Bh (264.1)	Hs (269.1)	Mt (268.1)	Ds (273.1)	Rg (272.1)									
Fr (223.0)	Ra (226.0)	Lr (262.0)	Rf (261.1)	Db (262.1)	Sg (266.1)	Bh (264.1)	Hs (269.1)	Mt (268.1)	Ds (273.1)	Rg (272.1)									

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The image shows a detailed periodic table of elements. A callout box highlights the element Aluminum (Al) with its atomic mass (26.98), symbol (Al), and order number (13). The table includes group numbers I through VIII and period numbers 1 through 7. Various elements are color-coded according to their properties: purple for hydrogen (Wasserstoff), red for radioactive elements, yellow for Erdalkalimetalle, blue for Halbmetalle, light blue for Edelgase, green for Nichtmetalle, and light green for Alkalimetalle.

I																			VIII
1.01 H 1		II																4,00 He 2	
6,94 Li 3	9,01 Be 4																	20,18 Ne 10	
22,99 Na 11	24,31 Mg 12																	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:

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

$$P \cdot V = \cancel{\frac{2}{3}} N \cancel{\frac{m}{2}} \bar{v}^2 = \frac{2}{3} N \frac{m}{2} \bar{v}^2 = \frac{2}{3} N \bar{E}_{kin}$$

mean value of  
the kinetic energy

Considering 1 Mol -  $N \rightarrow N_A$

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

Comparison  
with  
phenomenological  
observation

K · Boltzmann Constant

$$k = \frac{R}{N_A} = .380 L \cdot 10^{-23} \left[ \frac{W \cdot s}{K} \right]$$

Different writing of the general gas equation:

$$\bar{v} = \frac{1}{3} n m \bar{v}^2; m \bar{v}^2 = 2 \bar{E}_{kin}$$

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

$$(V) = (1) \\ P \cdot V = RT = \frac{2}{3} N_A \bar{E}_{kin}$$

$$\bar{E}_{kin} = \frac{3}{2} \cancel{\left( \frac{R}{N_A} \right)} T = \frac{15}{2} \bar{v}^2$$

$$\bar{E}_{kin} = \frac{3}{2} \cancel{k_B} T$$

$k$   Boltzmann const.

$$P = n \frac{2}{3} \bar{E}_{kin} = n \frac{2}{3} \sum \bar{E}_{kin}$$

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>

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

$\uparrow$        $\uparrow$   
 $\frac{N}{V} \cdot 1,38 \cdot 10^{-23} \frac{\text{Nm}}{\text{K}}$   
 $0,01 \text{ m}^3$

Atomic weights / amu)

$$\begin{aligned} \text{He} &= 4 \\ \text{N} &= 14 \\ \text{S} &= 32 \\ \text{F} &= 19 \end{aligned}$$

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

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

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

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

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

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

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

**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> ?

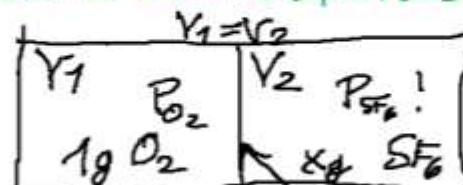
## Some exercises:

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$$P_{O_2} = n_{O_2} kT = T k n_{SF_6} = P_{SF_6}$$

↑

membrane Noberding!

(O<sub>2</sub> ≈ 32 amu)

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

$$x_g_{SF_6} = \frac{Mol_{SF_6} \cdot 1g}{Mol_{O_2}} \cdot \frac{146.18}{32} = \underline{\underline{4.56 \text{ g}}}$$

$P = n k T$

$\frac{\#}{V}$

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

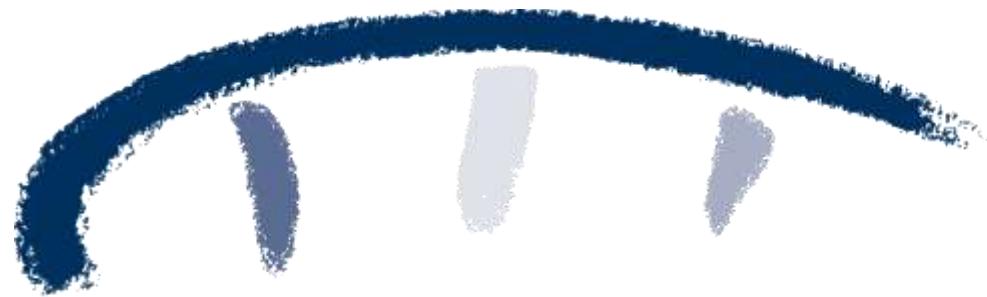
$$P_{O_2} = n_{O_2} kT = T k n_{SF_6} = P_{SF_6}$$

↑    ↑

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



**»Wissen schafft Brücken.«**