Vacuum Technology
WS 20/21
Virtually presented
Lecture 2, Nov. 3’rd 2020

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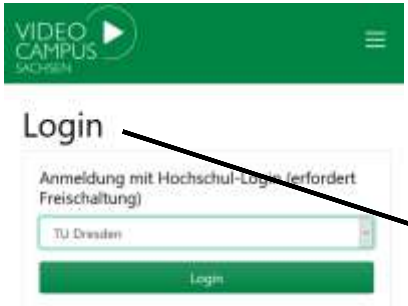

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Prof. Dr. Johann W. Bartha

Inst. f. Halbleiter und Mikrosystemtechnik
Technische Universität Dresden

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VT L02 a 34:23

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Chapters

0. Introduction

Air pressure as a force to the walls of an empty container -> Pressure = Force/Area

1. Gas kinetic

Air pressure as momentum transfer per time and area

2. Pressure Ranges

3. Vacuum technical terms

4. Vacuum generation

5. Pressure measurement

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1. Gas kinetics

Remember - Aproximations

- Gas particles are spheres of atomic dimension
- no forces except when collide
- movement independent from each other
- isotropy (no special direction)
- law of conservation of energy and momentum holds
- velocity of individual particles changes frequently due to collisions

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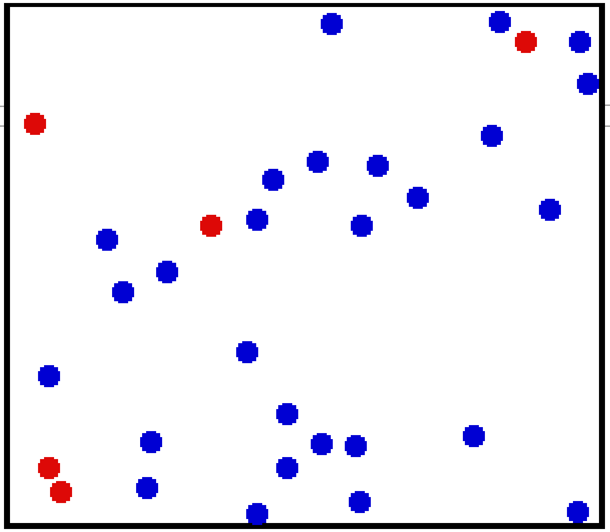

What is Pressure?
Unit is Pa (=N/m²)

↓

Pressure = Force / Area

= mass · accelleration / Area

= mass · (velocity change per time unit) / Area

= (mass · times velocity change) / time unit · Area

= change in momentum / time unit · Area

$P = F / \Delta A = m \cdot a / \Delta A = (m \cdot \Delta v/\Delta t) / \Delta A = \Delta p / \Delta A \cdot \Delta t$

Pressure is
the "transfer" of momentum to a wall per time- and area unit

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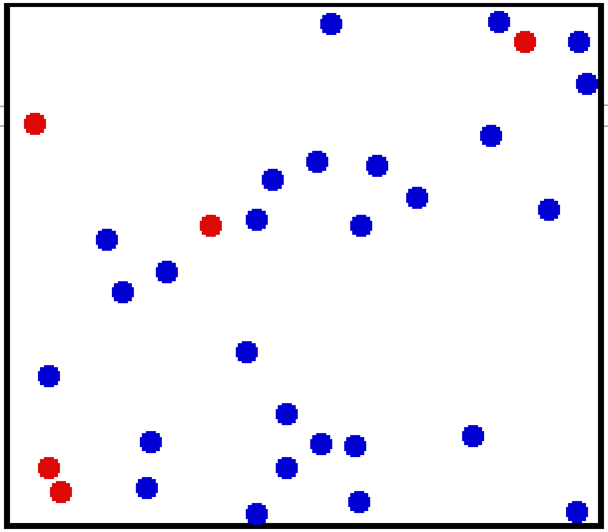

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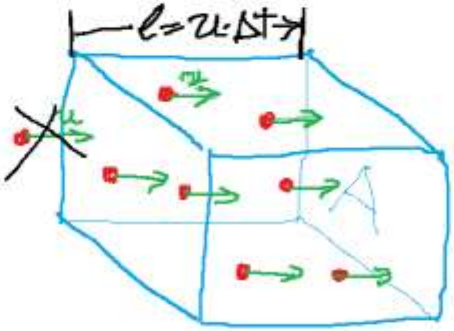
Prsr

B02a x

Pressure: Simple Derivation



Box contains N particles with velocity u

1/6 of the N moves towards A with velocity u

? How many particles hit A per time unit? →

$$Z = \frac{N}{6}\,\frac{1}{\Delta t}\,\frac{1}{A}$$

Particle density $n = \frac{N}{V} = \frac{N}{A\cdot u\cdot\Delta t}$

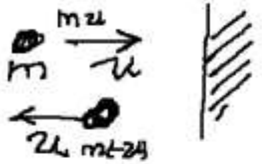
$N = n\cdot A\cdot u\cdot\Delta t$

$$\boxed{Z = \frac{1}{6}\,n\,u}$$

B02b x

Pressure → momentum transfer per timeunit & Area unit

Momentum transfer of single particle



momentum

$$\Delta p = m(u-(-u)) = \underline{\underline{2mu}}$$

$$P = 2mu\,Z = 2mu\cdot\frac{1}{6}nu$$

$P = \frac{1}{3}nmu^2$ ⚠ since not all velocities are equal $u^2 \rightarrow \overline{u^2}$

$$\boxed{P = \frac{1}{3}nm\overline{u^2}}$$

mean value of u^2

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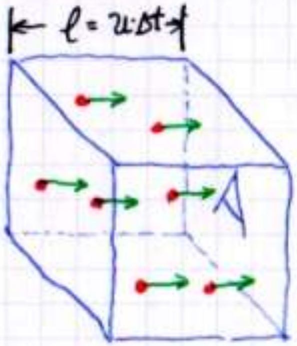
Pressure: Simple Derivation



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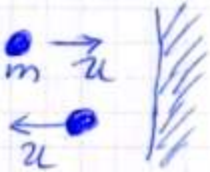
Particle density $n = \frac{N}{V} = \frac{N}{A\cdot u\cdot\Delta t}$

$N = n\cdot A\cdot u\cdot\Delta t$

$Z = \frac{1}{6} n u$

Pressure is momentum transfer per timeunit and Area

Momentum transfer of a particle to a wall



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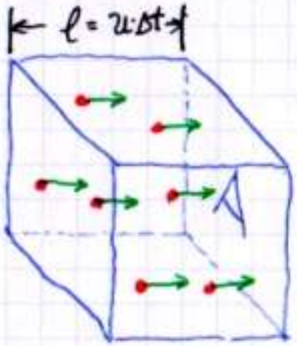
$$P = 2muZ = 2mu\cdot\frac{1}{6}nu$$

$P = \frac{1}{3}nmu^2$ ⚠ since not all velocities are equal $u^2 \to \overline{u^2}$

⇒ $\boxed{P = \frac{1}{3}nm\overline{u^2}}$

Pressure: Simple Derivation



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Pressure is momentum transfer per timeunit and Area

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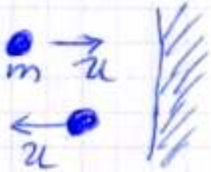

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⇒ $\boxed{P = \frac{1}{3}nm\overline{u^2}}$

Some critics on this derivation

- Gas particles are spheres of atomic dimension
- no forces except when collide
- movement independent from each other
- isotropy (no special direction)
- law of conservation of energy and momentum holds
- velocity of individual particles changes frequently due to collisions

Yellow marked properties do not apply to the model!

We can do better!!

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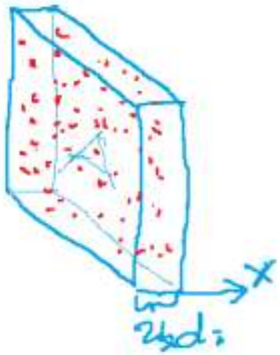
B02c x

Pressure: Exact derivation



(Isotropic System!)

We consider only the x-component of the particle velocity

Fraction of particles having v_x between v_x and $v_x + dv_x$ is

$$\frac{dN}{N} = \boxed{f(v_x)\,dv_x} \quad \text{per definition} \quad \int_{-\infty}^{+\infty} f(v_x)\,dv_x = 1$$

↑ distribution function

Maks it easi to get a mean value: Example $\overline{v_x^2}$

$$\overline{v_x^2} = \int_{-\infty}^{+\infty} v_x^2 f(v_x)\,dv_x = 2\int_{0}^{+\infty} v_x^2 f(v_x)\,dv_x$$

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B02d x

- # of particles having v_x per volume unit $n\,f(v_x)\,dv_x$
- Particle that reach A within dt come from the volume $A \cdot v_x\,dt$
- # o- ollisions with A within dt is $n\,f(v_x)\,dv_x\;A\,v_x\,dt$
- Momentum tranfer per particle & collision is $2m\,v_x$

Momentum transferred by all particles with v_x (between v_x & $v_x + dv_x$)

$$d\acute{p} = 2m\,v_x\;n\,f(v_x)\,dv_x\;A\,v_x\,dt = 2mn\,v_x^2\,f(v_x)\,dv_x \cdot A \cdot dt$$

$$\text{Pressure} = \frac{\text{momentum transf.}}{A \cdot dt} \Rightarrow d\underset{\nwarrow\,\text{Pressure}}{P} = 2mn\,v_x\,f(v_x)\,dv_x$$

B02e x

Total pressure is the sum of all particles with all velocities

$$P = \int_0^{+\infty} dp - 2mn\int_0^{+\infty} v_x^2 f(v_x)\,dv_x = mn\,\underbrace{2\int_0^{-\infty} v_x^2 f(v_x)\,dv_x}_{\text{see blackboard before} \rightarrow \overline{v_x^2}}$$

$$P = nm\,\overline{v_x^2}$$

Because of isotropy follows

$$\left.\begin{array}{l}\overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2} = \overline{v^2} \\ \text{and } \overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2}\end{array}\right\} \Rightarrow \overline{v_x^2} = \frac{1}{3}\overline{v}$$

$$\boxed{P = \frac{1}{3} nm\,\overline{v^2}}$$

shown in the simple derivation !!

⚠ the distribution function was considered but not explicidly known!

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Pressure: Exact derivation

We consider only the x-component of the particle velocity

Fraction of particles having v_x between v_x and v_x+dv_x is

$$\frac{dN}{N} = f(v_x)\,dv_x \qquad \text{Per definition} \int_{-\infty}^{+\infty} f(v_x)\,dv_x = 1$$

↑ distribution function

Makes it easy to get a mean value. Example $\overline{v_x^2}$:

$$\overline{v_x^2} = \int_{-\infty}^{+\infty} v_x^2 \cdot f(v_x)\,dv_x = 2\int_{0}^{+\infty} v_x^2 f(v_x)\,dv_x$$

- # of particles having v_x per volume unit : $n\,f(v_x)\,dv_x$
- Particles that reach A within dt come from the volume $A \cdot v_x\,dt$
- # of collision with A within dt is $n\,f(v_x)\,dv_x\,A\,v_x\,dt$
- Momentum transfer per particle & collision is $2m\,v_x$

Momentum transferred by all particles with v_x (between v_x & v_x+dv_x)

$$dp = 2m\,v_x\,n\,f(v_x)\,dv_x\,A\,v_x\,dt = 2mn\,v_x^2 f(v_x)\,dv_x \cdot A \cdot dt$$

$$\text{Pressure} = \frac{\text{momentum transferred}}{A \cdot dt} \Rightarrow dP = 2mn\,v_x^2 f(v_x)\,dv_x$$

Total pressure is the sum of all particles with all velocities

$$P = \int_{0}^{+\infty} dP = 2mn \int_{0}^{+\infty} v_x^2 f(v_x)\, dv_x = mn \underbrace{2\int_{0}^{+\infty} v_x^2 f(v_x)\, dv_x}_{\overline{v_x^2}}$$

look at definition above! ⟶ $\overline{v_x^2}$

$$P = nm\overline{v_x^2}$$

Because of isotropy follows:

$$\left.\begin{array}{l} \overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2} = \overline{v^2} \\ \text{and } \overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2} \end{array}\right\} \Rightarrow \overline{v_x^2} = \frac{1}{3}\overline{v}$$

therefore: $\boxed{P = \frac{1}{3} nm\overline{v^2}}$ as shown in the simple derivation!

⚠ The distribution function was considered but not needed explicitly !!

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Total pressure is the sum of all particles with all velocities

$$P = \int_0^{+\infty} dP = 2mn \int_0^{+\infty} v_x^2 f(v_x)\, dv_x = mn\, \underbrace{2\int_0^{+\infty} v_x^2 f(v_x)\, dv_x}$$

look at definition above! $\longrightarrow \overline{u_x^2}$

$$P = nm\overline{v_x^2}$$

Because of isotropy follows:

$$\left.\begin{array}{l} \overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2} = \overline{v^2} \\ \text{and } \overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2} \end{array}\right\} \Rightarrow \overline{v_x^2} = \frac{1}{3}\overline{v}$$

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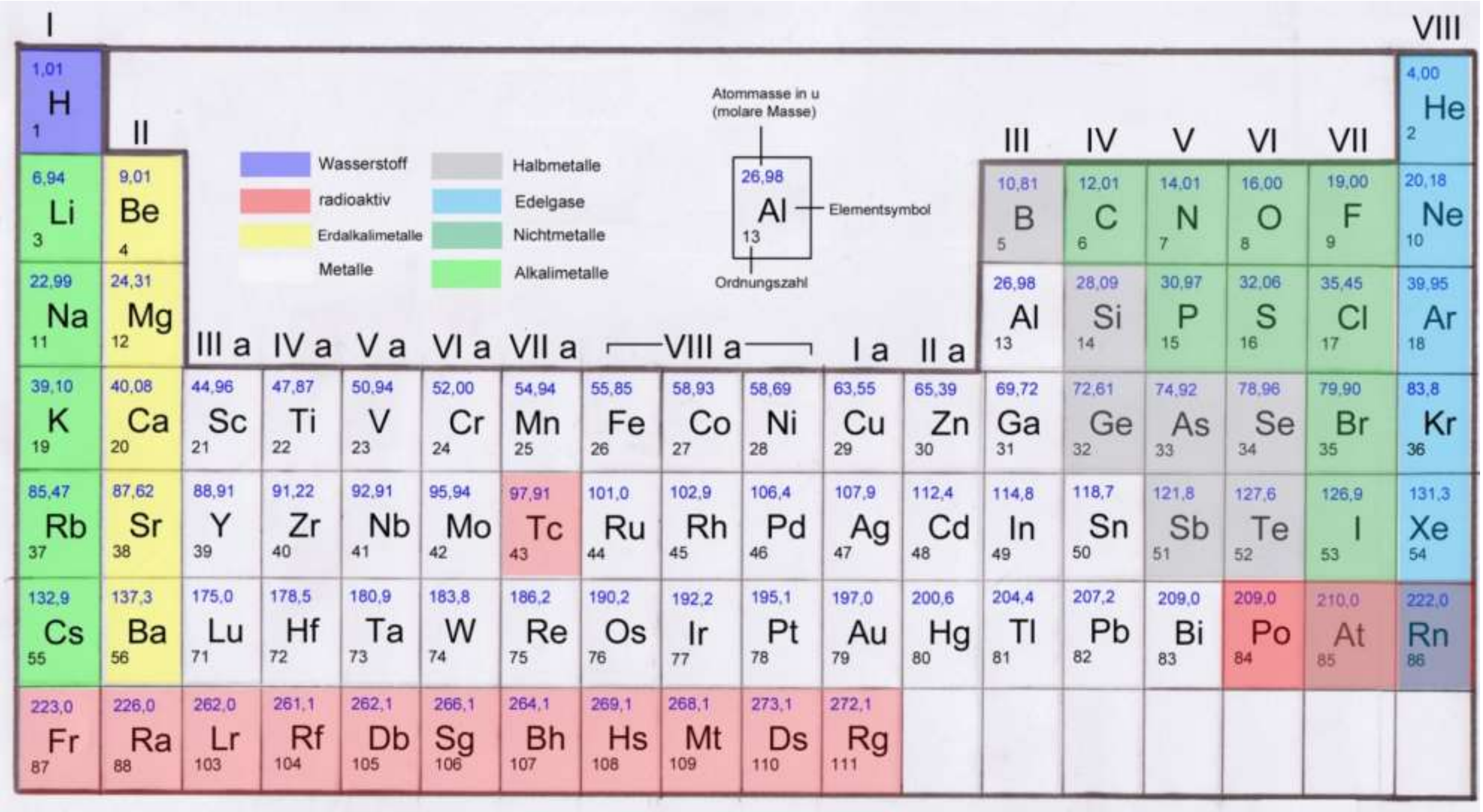
New topic:

VT L02 c 23:26



Wasserstoff
radioaktiv
Erdalkalimetalle
Metalle
Halbmetalle
Edelgase
Nichtmetalle
Alkalimetalle

Atommasse in u (molare Masse)
26,98 Al 13
Elementsymbol
Ordnungszahl

I	II	III a	IV a	V a	VI a	VII a	VIII a			I a	II a	III	IV	V	VI	VII	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
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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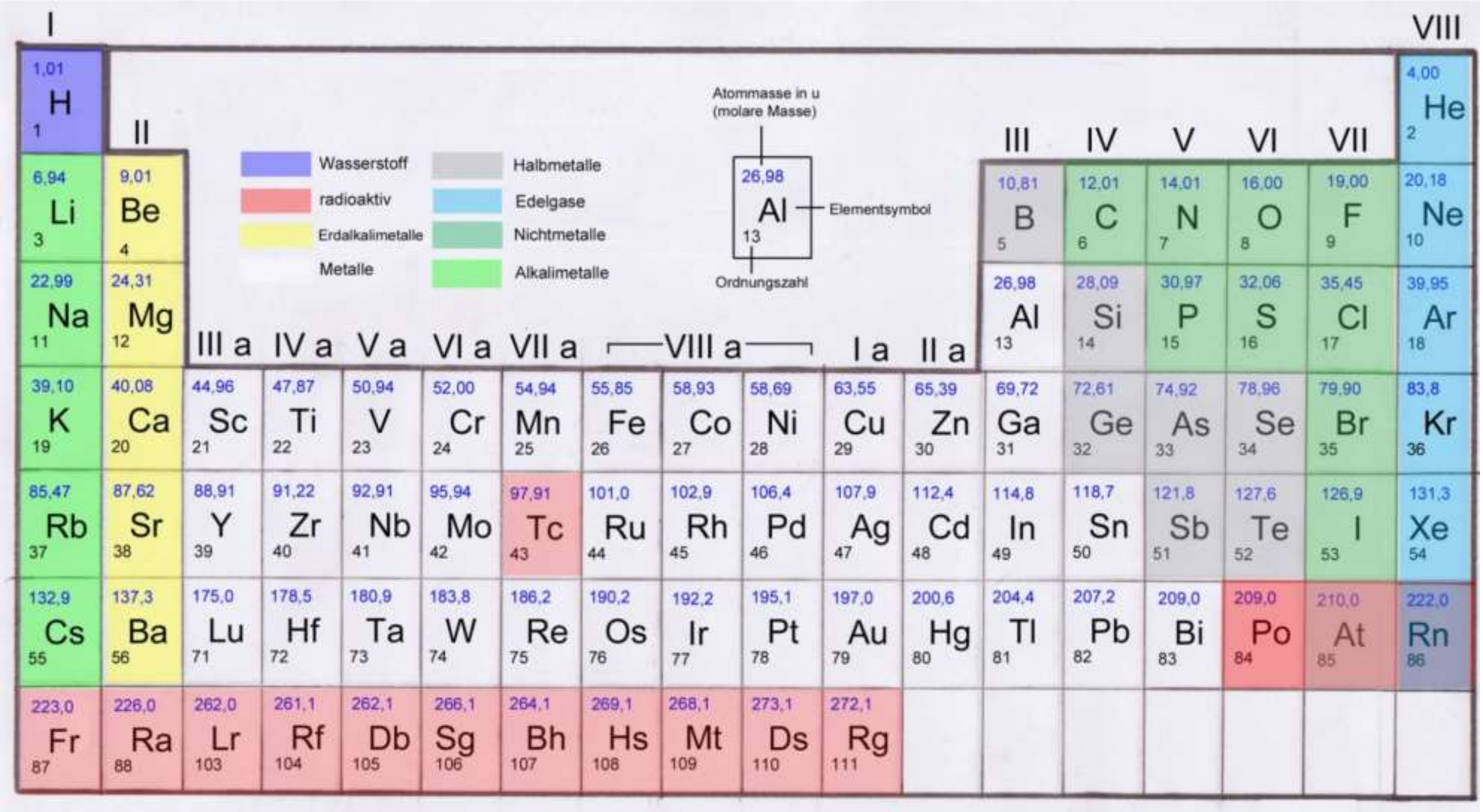
New topic:



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B02f x

↙ 1Mol Ca = 40g Ca

Weigt Ca 40 amu

Weigt F 19 amu

↑

1Mol F = 19g F

$$\underset{40}{\text{Ca}}\ \underset{19}{\text{F}} \quad 1g \qquad \Sigma = 1g$$

$$1g\,\frac{40}{59} \qquad 1g\,\frac{19}{59}$$

$$0.678g + 0.322g = 1g$$

$$1g\ \underset{2\times1}{H_2}O \leftarrow 18$$

Mol ≙ atomic weight in g

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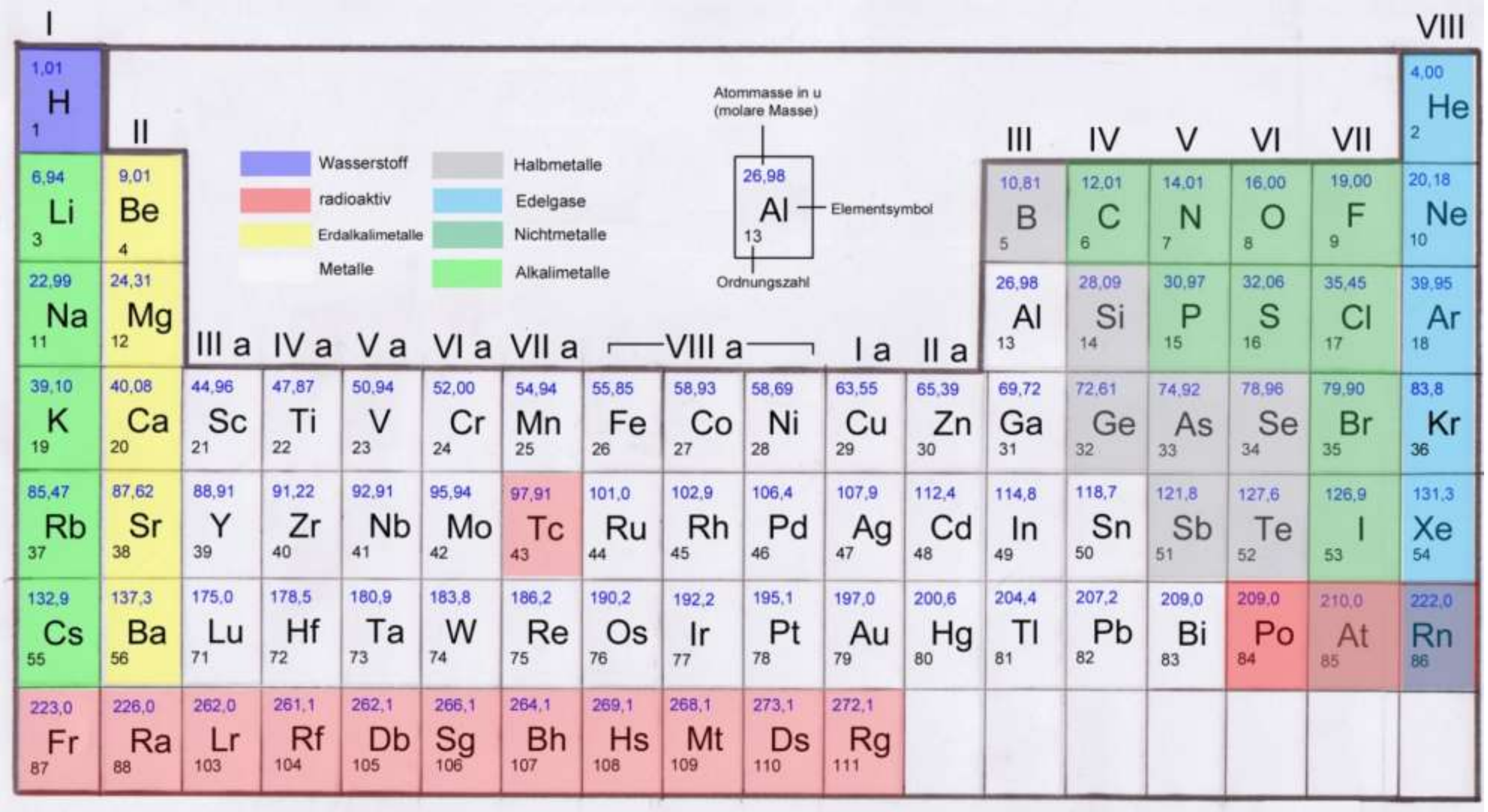
New topic: Mol- & Molvolume

1 Mol corresponds to the Atomic weight in g



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radioaktiv	Edelgase
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Atommasse in u (molare Masse)

26,98
Al — Elementsymbol
13

Ordnungszahl

New topic: Mol- & Molvolume

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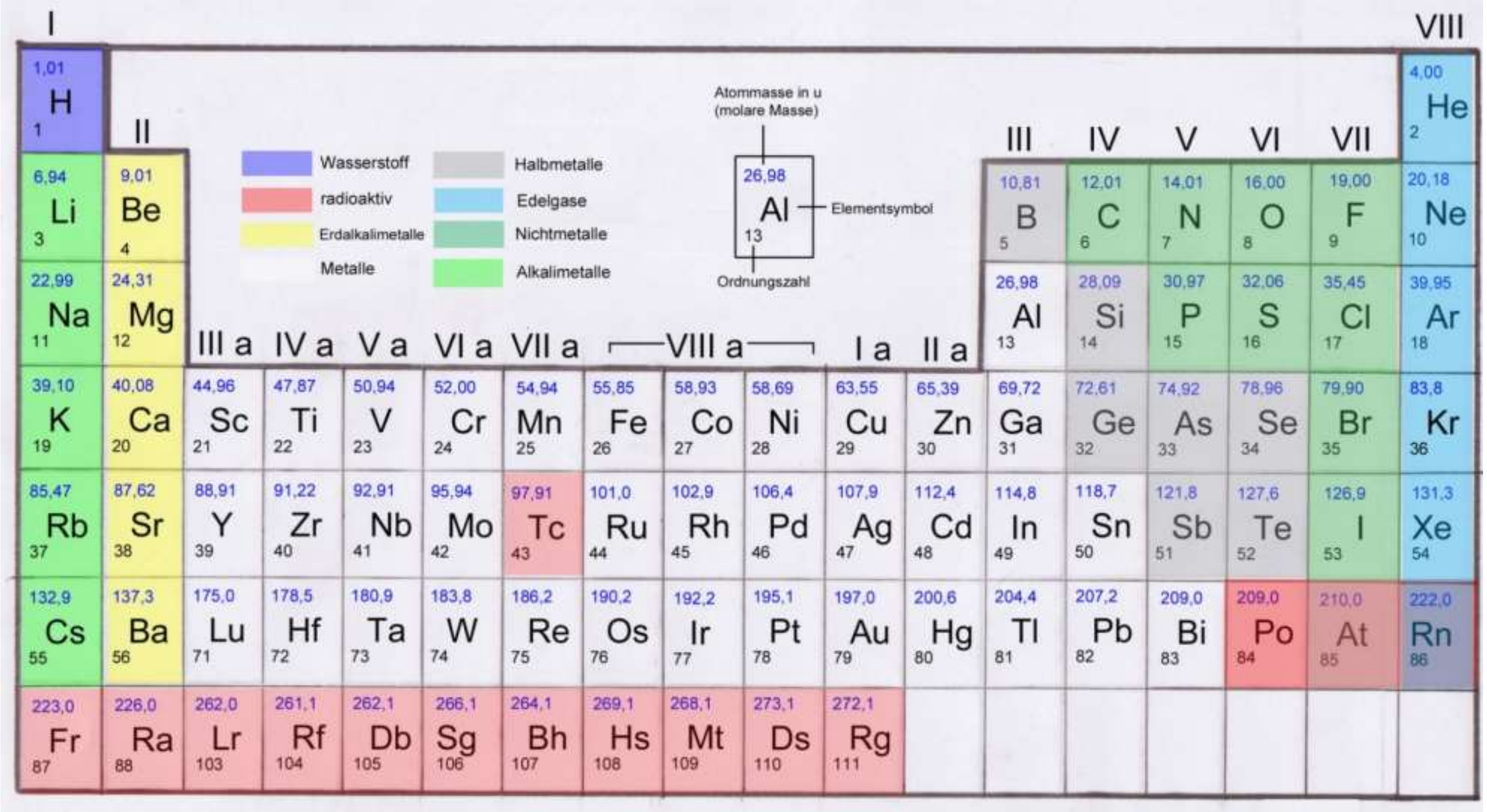

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Atommasse in u (molare Masse)
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of particles within 1 Mol is a universal constant = Avogadro Number

$$N_A = 6.022 \cdot 10^{23} \;!$$

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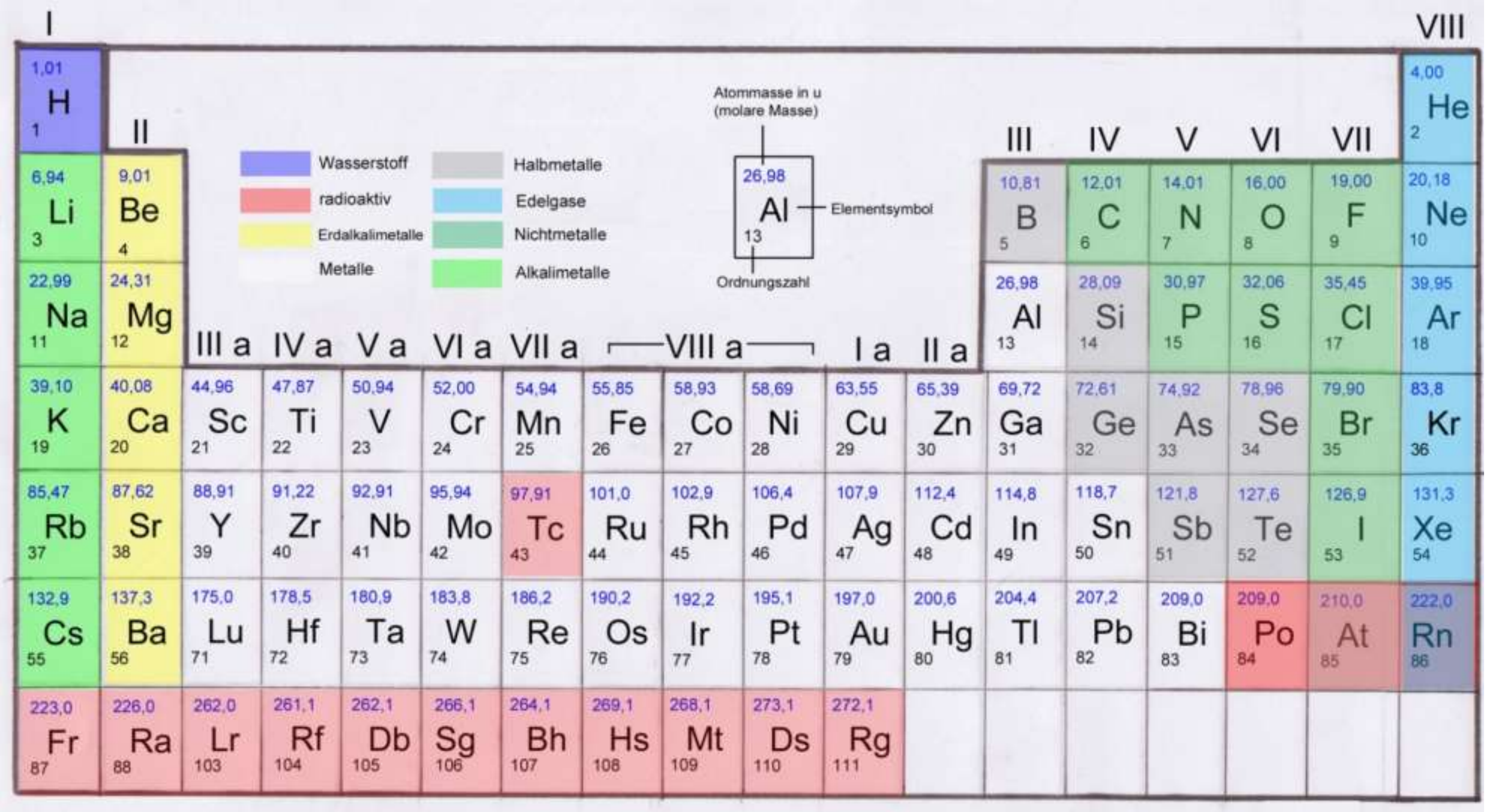

I	II	III a	IV a	V a	VI a	VII a	VIII a			I a	II a	III	IV	V	VI	VII	VIII
1,01 H 1																	4,00 He 2
6,94 Li 3	9,01 Be 4											10,81 B 5	12,01 C 6	14,01 N 7	16,00 O 8	19,00 F 9	20,18 Ne 10
22,99 Na 11	24,31 Mg 12											26,98 Al 13	28,09 Si 14	30,97 P 15	32,06 S 16	35,45 Cl 17	39,95 Ar 18
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							

🟦	Wasserstoff	▨	Halbmetalle
🟥	radioaktiv	🟦	Edelgase
🟨	Erdalkalimetalle	🟩	Nichtmetalle
☐	Metalle	🟩	Alkalimetalle

Atommasse in u (molare Masse)

26,98
Al — Elementsymbol
13

Ordnungszahl

of particles within 1 Mol is a universal constant = Avogadro Number

$$N_A = 6.022 \cdot 10^{23} \; !$$

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»Wissen schafft Brücken.«

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