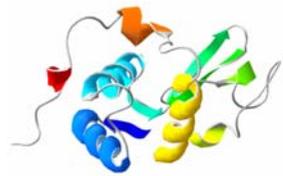


# The microscopic world

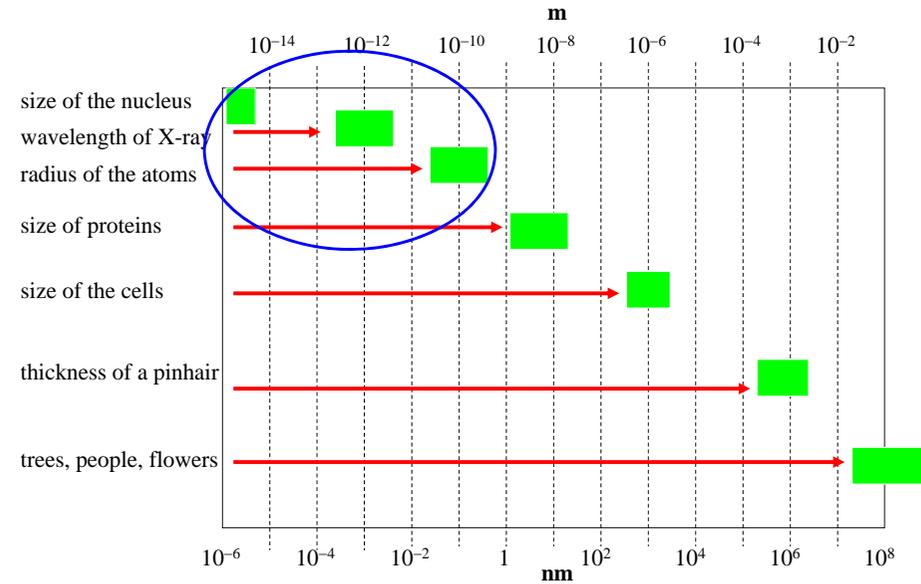
atom, atomic nucleus, electron, photon



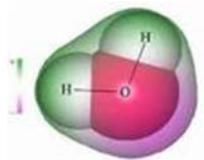
Irén Bárdos-Nagy



## Length scale of the nature



macroscopic world ↔ microscopic world



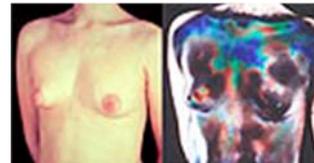
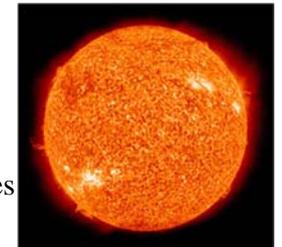
What is common, what is different?  
Are the rules the same?  
Is there any difference?

## Thermal radiation

electromagnetic radiation

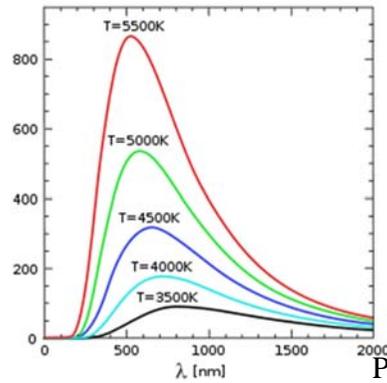
every material emits it, if  $T > 0$  K

the origin of it is the thermal motion of particles



## Characteristics of thermal radiation

$$\Delta M_{black} / \Delta \lambda$$



Stefan – Boltzmann law:

$$M_{black}(T) = \sigma T^4$$

$$\sigma = 5,7 \cdot 10^{-8} [J / m^2 K^4 s]$$

Stefan – Boltzmann constant

$$E = At \sigma T^4$$

Wien's displacement law:

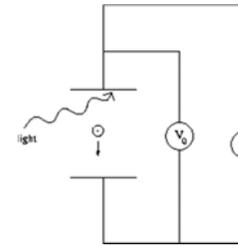
$$\lambda_{max} T = const$$

Planck's law of black body radiation:

the energy is emitted in discrete units

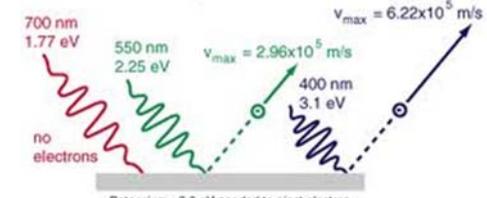
the **photon** is the **energy** (light) **quanta**

## The photoelectric effect and the explanation of it



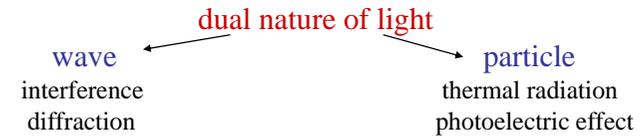
$$E_{photon} = hf = h\nu = hc/\lambda \quad h: \text{Planck constant}$$

$$E_{photon} = h\nu \quad h = 6,6 \cdot 10^{-34} [Js]$$

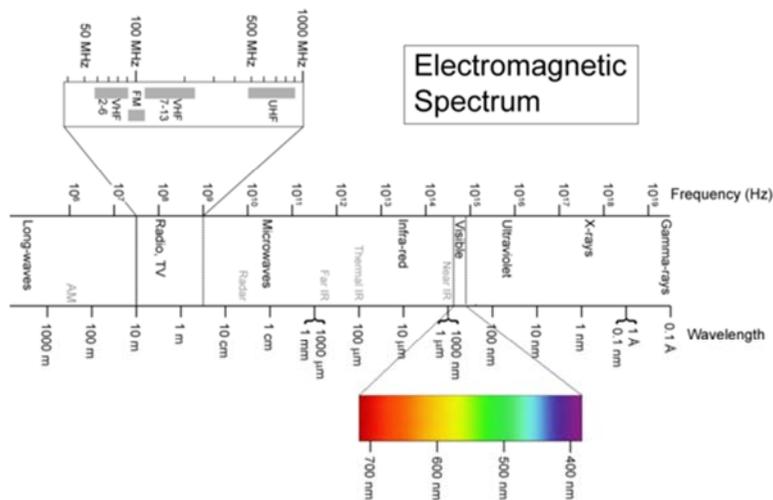


Photoelectric effect

The photons behave as particles:  $E_{kin} = hf - W_{em}$



The dual nature is characteristic not only for the light, but the complete electromagnetic spectrum



## History of the atom



Democritus (BC 406)  
idea of "atoma"



John Dalton (1808)  
all matter is built up from tiny spheres



Joseph J. Thomson (1904)  
the plum pudding model



Ernest Rutherford (1910)  
central nucleus with positive charge

Niels Bohr (1913)  
definite electron orbitals

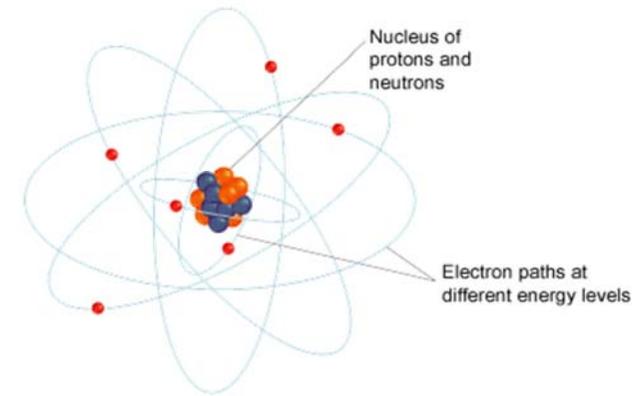


### Building elements of atomic structure:

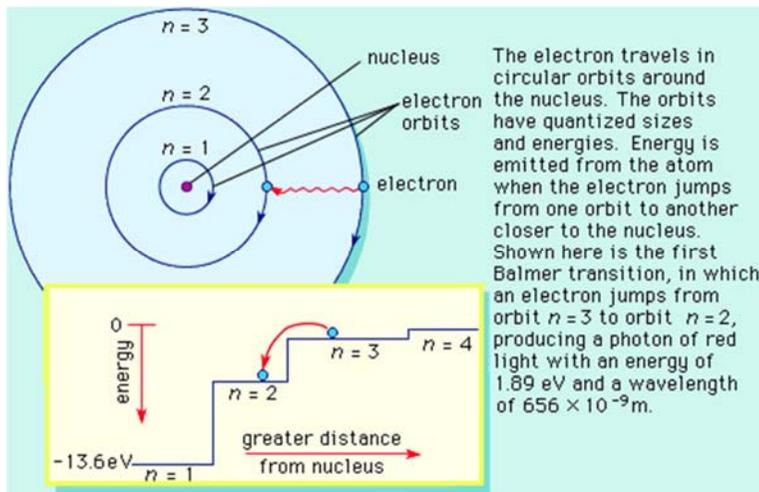
name/where	Charge (elementary)	mass (kg)	atomic mass unit
electron/outside the nucleus	-1	$9,1 \cdot 10^{-31}$	1/1800
proton/inside the nucleus	+1	$1,66 \cdot 10^{-27}$	1,0076
neutron/inside the nucleus	0	$1,67 \cdot 10^{-27}$	1.0086

the charge of the electron:  $1,6 \cdot 10^{-19}$  C

### Structure of atoms based on Bohr model



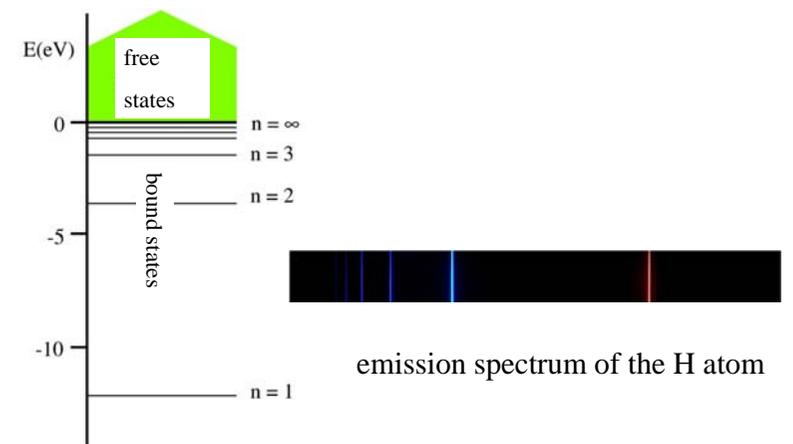
### Structure of atoms based on Bohr model



the radii of the orbitals and the energy levels are determined by the orbital numbers:

$$r \sim n^2 \quad E \sim 1/n^2$$

### possible energy levels of the electron in the H atom



emission spectrum of the H atom

## The periodic system based on the Bohr model

1												18																							
1	H 1.008											2	He 4.003																						
2												10																							
3	Li 6.941	4	Be 9.012											13	B 10.81	14	C 12.01	15	N 14.01	16	O 16.00	17	F 19.00	18	Ne 20.18										
3												16		18																					
11	Na 22.99	12	Mg 24.31											13	Al 26.98	14	Si 28.09	15	P 30.97	16	S 32.07	17	Cl 35.45	18	Ar 39.95										
4												14		18																					
19	K 39.10	20	Ca 40.08	21	Sc 44.96	22	Ti 47.88	23	V 50.94	24	Cr 52.00	25	Mn 54.94	26	Fe 55.85	27	Co 58.93	28	Ni 58.69	29	Cu 63.55	30	Zn 65.39	31	Ga 69.72	32	Ge 72.61	33	As 74.92	34	Se 78.96	35	Br 79.90	36	Kr 83.80
5												18		18																					
37	Rb 85.47	38	Sr 87.62	39	Y 88.91	40	Zr 91.22	41	Nb 92.91	42	Mo 95.94	43	Tc 98.91	44	Ru 101.1	45	Rh 102.9	46	Pd 106.4	47	Ag 107.9	48	Cd 112.4	49	In 114.8	50	Sn 118.7	51	Sb 121.8	52	Te 127.6	53	I 126.9	54	Xe 131.3
6												18		18																					
55	Cs 132.9	56	Ba 137.3	57	La 138.9	58	Ce 140.1	59	Pr 140.9	60	Nd 144.2	61	Pm 144.9	62	Sm 150.4	63	Eu 152.0	64	Gd 157.3	65	Tb 158.9	66	Dy 162.5	67	Ho 164.9	68	Er 167.3	69	Tm 168.9	70	Yb 173.0				
7												18		18																					
87	Fr 223.0	88	Ra 226.0	89	Ac 227.0	90	Th 232.0	91	Pa 231.0	92	U 238.0	93	Np 237.0	94	Pu 244.1	95	Am 243.1	96	Cm 247.1	97	Bk 247.1	98	Cf 251.1	99	Es 252.0	100	Fm 257.1	101	Md 258.1	102	No 259.1				

Legend:   
■ Metal   
■ Semimetal   
■ Nonmetal

Labels:   
 - Atomic number (top left of element)   
 - Symbol (center of element)   
 - Atomic weight (bottom of element)

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## Further improvement: Quantum mechanics



V.de Broglie (1923)



J. Davisson and L. H. Germer (1927)



G. P. Thomson (1928)

The wave nature and a certain wavelength have to be associated to every material mass

$$\lambda = \frac{h}{m \cdot v} = \frac{h}{I}$$

← Planck constant (6.63x10<sup>-34</sup> Js)  
 ← momentum of the particle



E. Schrödinger (1926)  
Schrödinger (wave) equation



W. Heisenberg (1930)  
the Heisenberg uncertainty relation

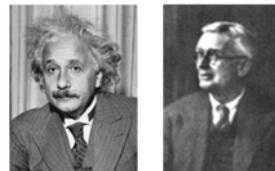
## Further properties of quantized atomic electron states:

azimuthal (l) and magnetic (m<sub>l</sub>) quantum numbers



O. Haas and W. Gerlach (1922)

the spin (s) quantum number



A. Einstein and J. W. de Haas



W. Pauli (1925)

Pauli exclusion principle



H. Hund (1925)

Hund principle

## The Bohr model and the quantum mechanical atomic structure

Bohr model

- circular orbitals
- one energy level (n) to characterise the orbital energy quanta
- the orbitals have no overlapping
- photon absorption/emission

quantum mechanical aspects

- there is no orbital, only probability (electron cloud)
- four quantum numbers n, l, m<sub>l</sub>, s to characterise the energy levels energy quanta
- the orbitals have overlapping (chance for change energy levels)
- photon absorption/emission

Electron clouds based on the quantum mechanical calculations

