

Meccanica quantistica

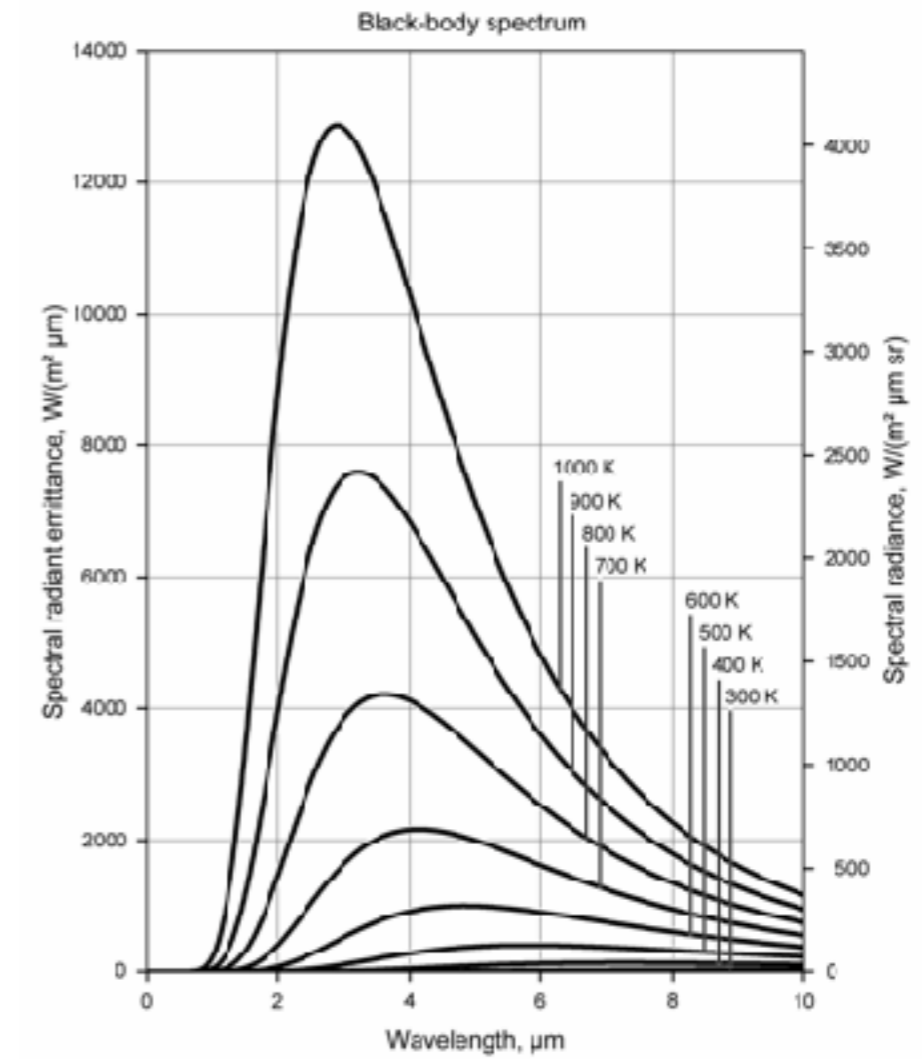
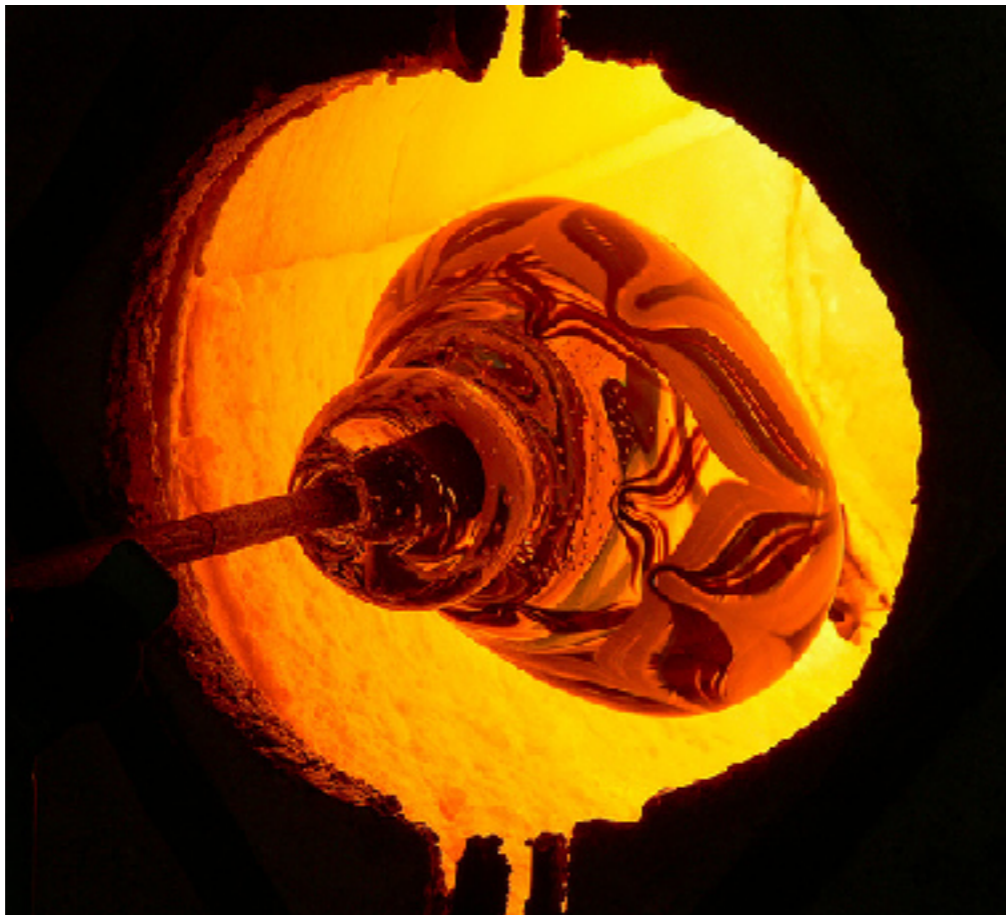
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DIPARTIMENTO DI FISICA



SAPIENZA
UNIVERSITÀ DI ROMA

Il corpo nero



Un corpo caldo...

- Tutti i corpi caldi emettono “luce”
 - non è vero il viceversa
- Perché?

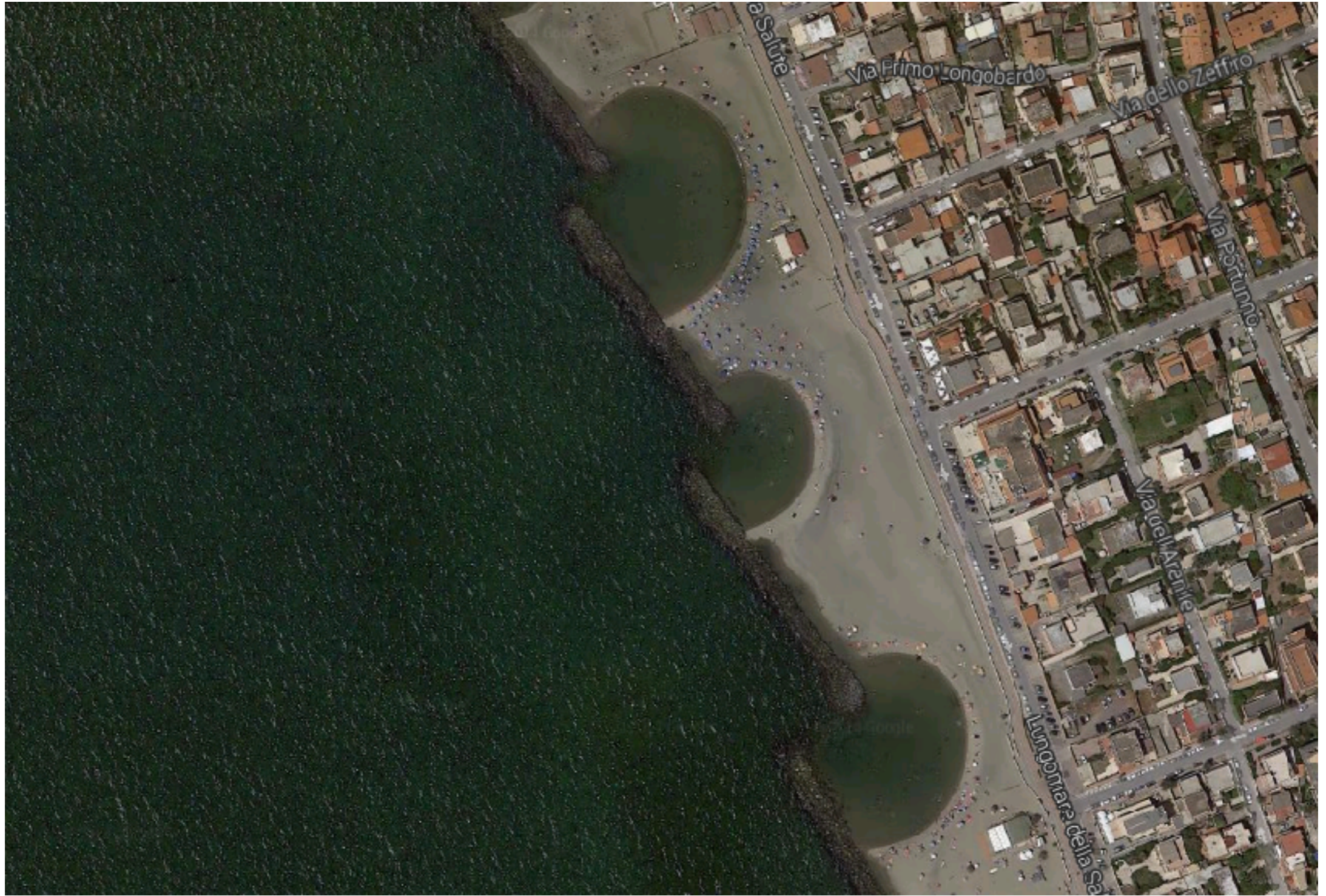
Un corpo nero...

- In equilibrio con la radiazione da lui stesso emessa
- Se l'energia è trasportata da un'onda
 - I suoi costituenti oscillano con frequenza ν
 - Ampiezza qualunque
- Se l'energia è trasportata da quanti di energia $h\nu$
 - I suoi costituenti oscillano con frequenza ν che dipende dall'energia del quanto
 - Posso emettere 0 oppure 1 quanto, non 0.2 quanti

L'effetto fotoelettrico



Natura della luce: onde



Onde ed energia



Effetto fotoelettrico con i quanti



Applicazioni



La misura e il Principio di Heisenberg

■ “Esiste” solo ciò che si misura

■ Misura della posizione di un elettrone in un atomo

$$\Delta x \Delta p \geq \hbar$$

■ Misura dell'energia di un elettrone in un atomo

$$\frac{\Delta x}{\Delta t} \Delta p = v \Delta p = 2\Delta E \geq \frac{\hbar}{\Delta t}$$

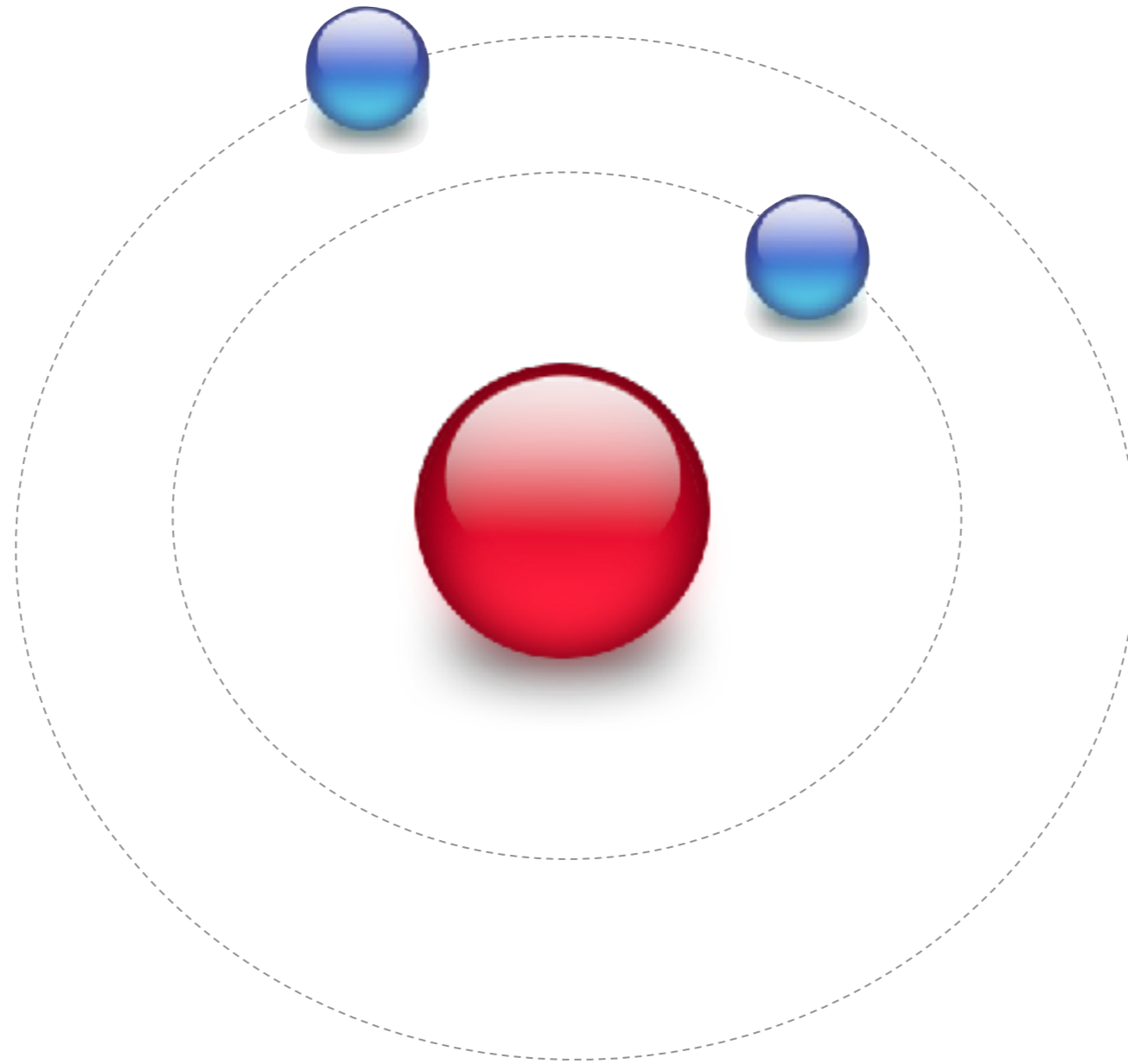
$$\Delta E \Delta t \geq \frac{\hbar}{2}$$

Onde di materia

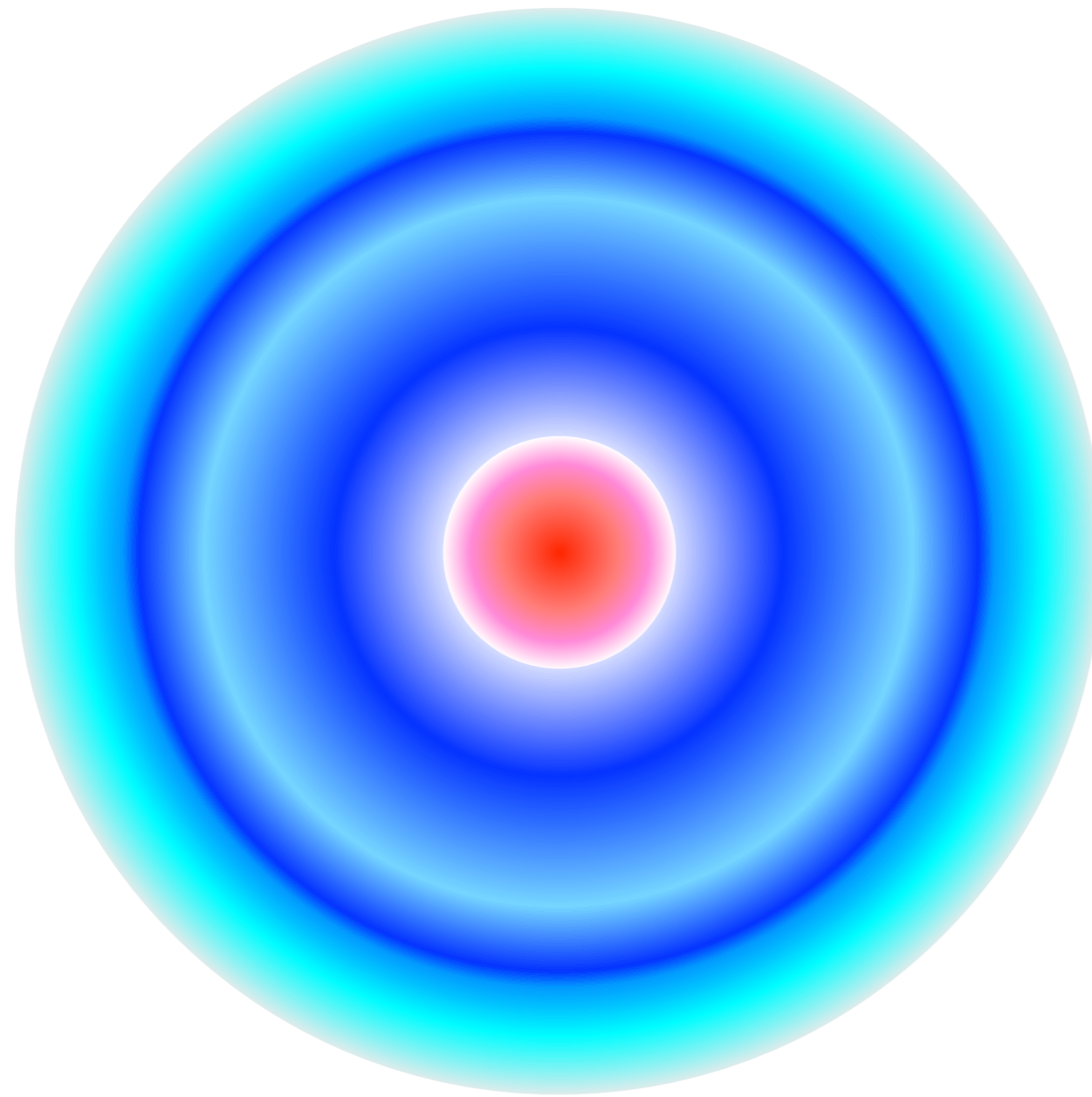
$$\nu = \frac{c}{\lambda} = \frac{p}{h}$$

- Diffrazione di neutroni
- Microscopi elettronici

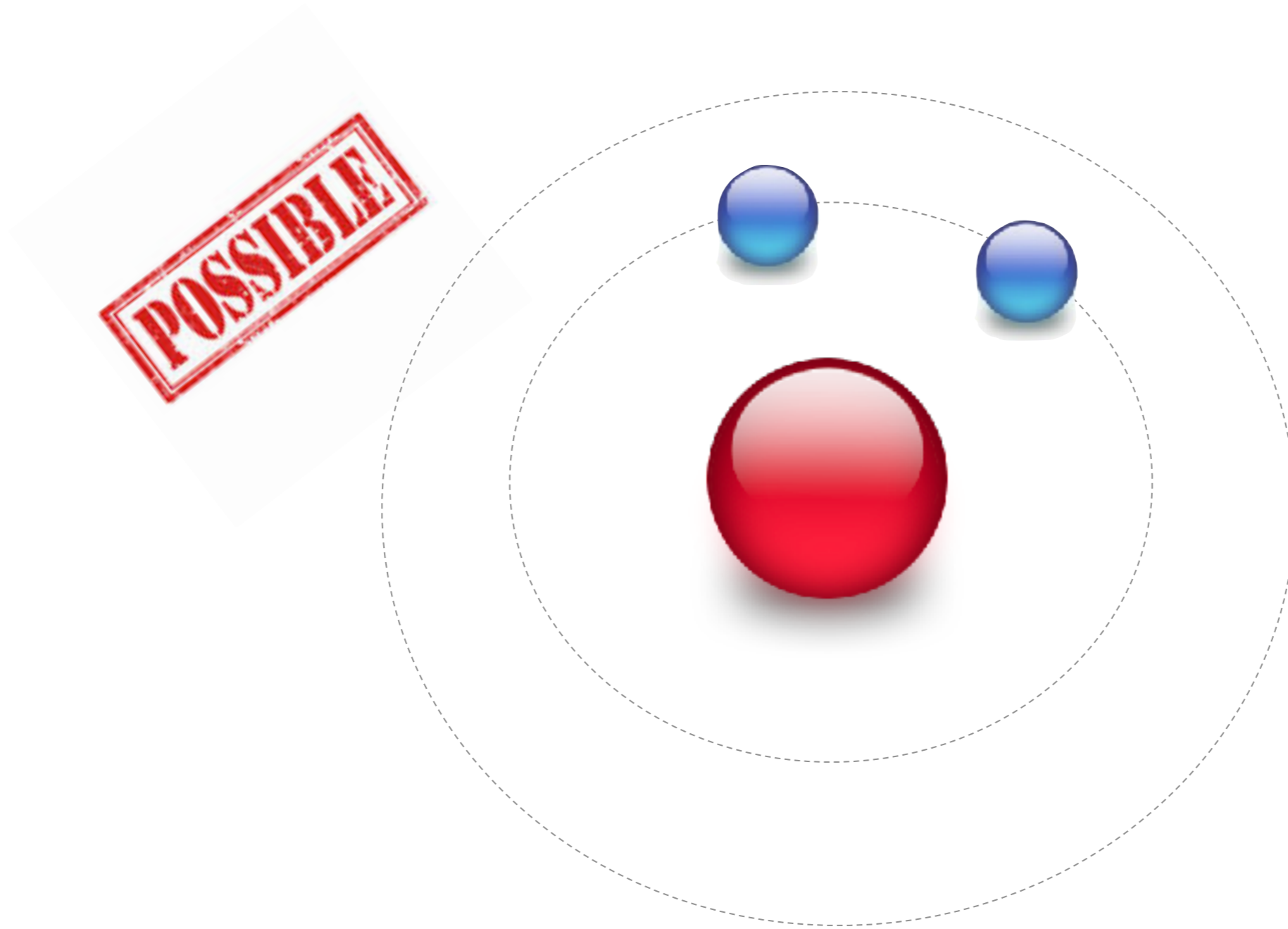
Atomi classici



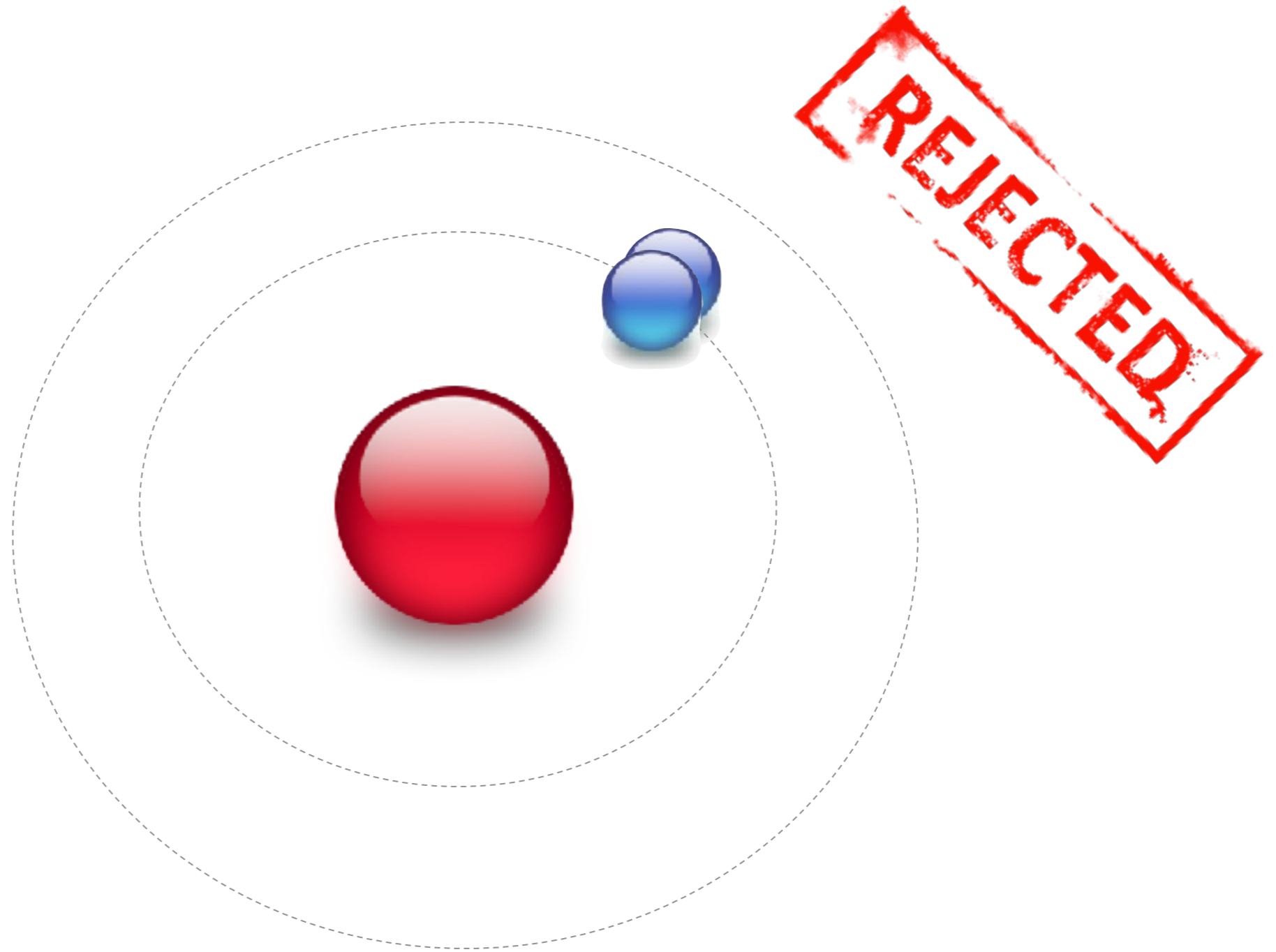
Atomi quantistici



Modelli a confronto

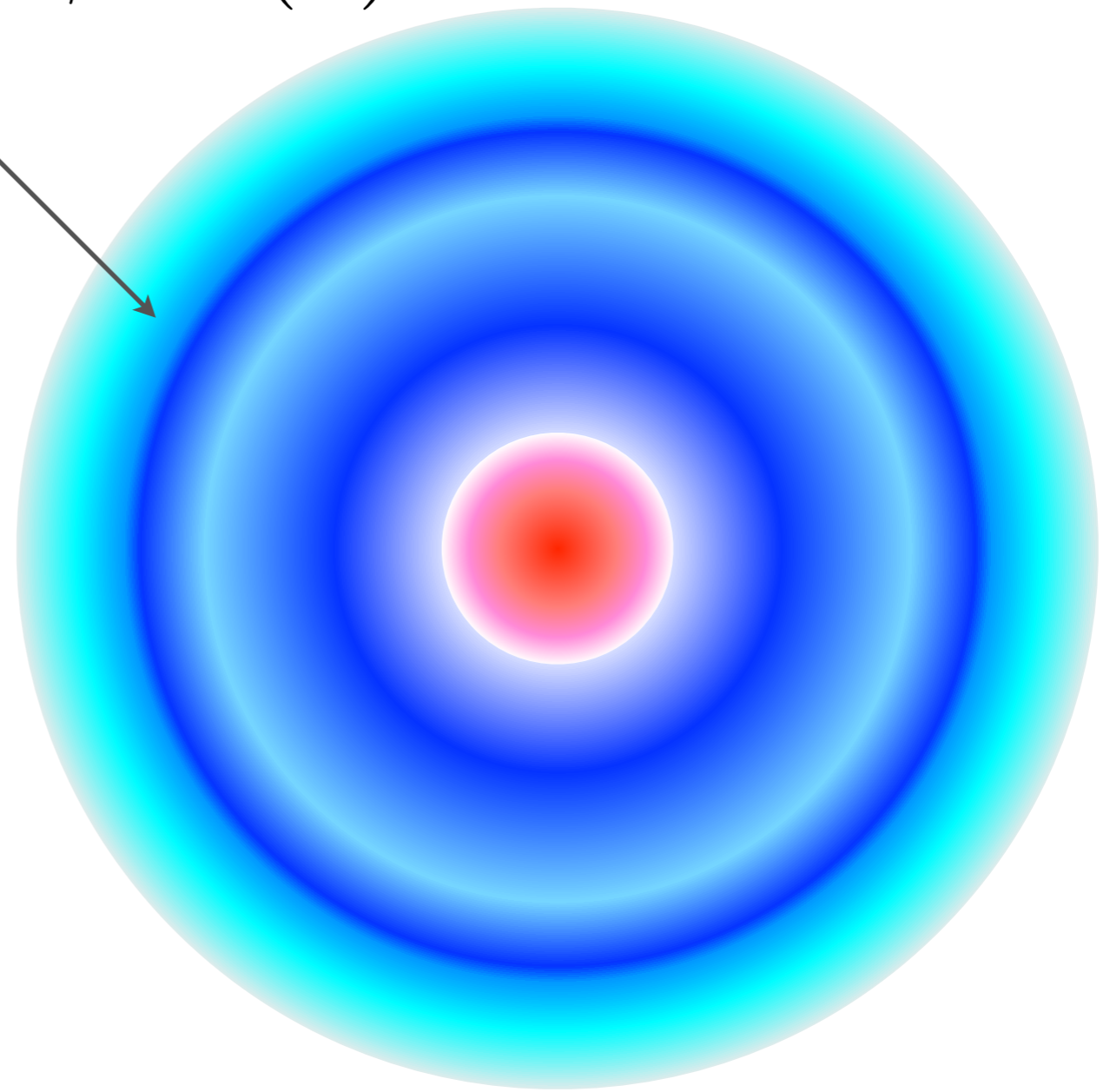


Modelli a confronto



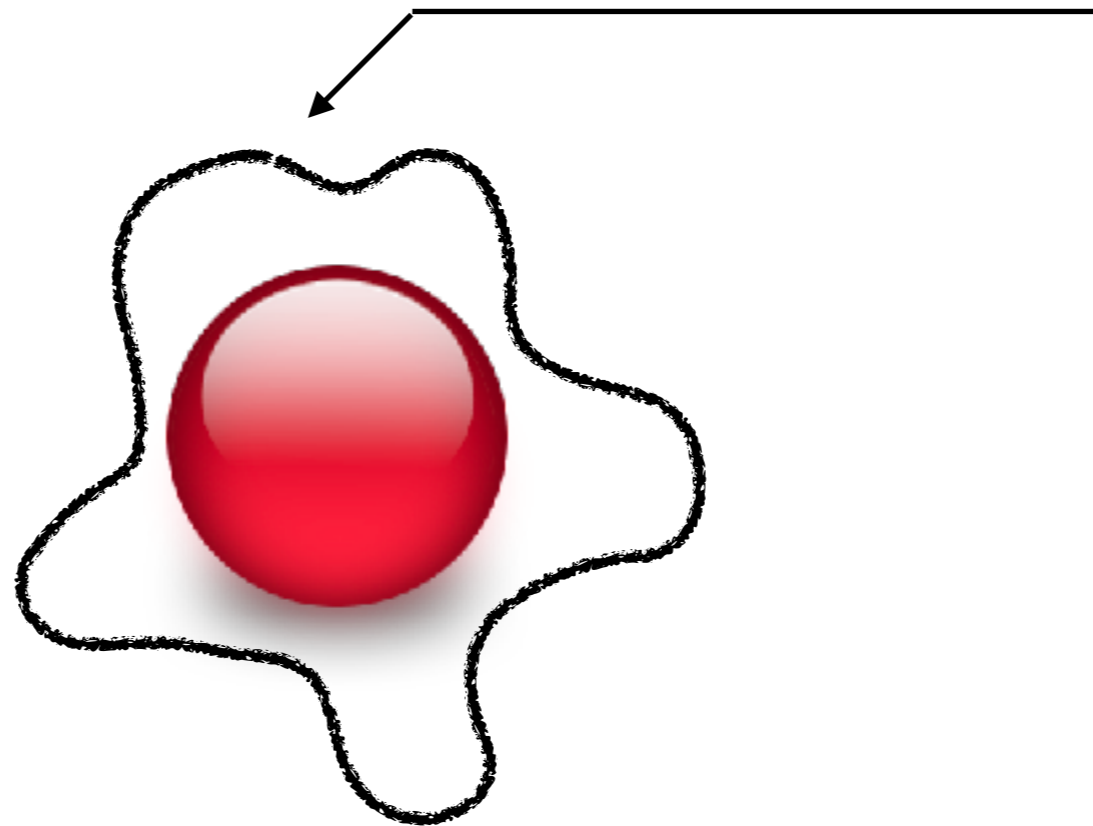
Modelli a confronto

$$\Psi(\vec{x}) = \alpha\Psi_1(\vec{x}) + \beta\Psi_2(\vec{x})$$



Onde elettroniche

Onda stazionaria



$$\psi(x, t) = \sum_n A_n \sin \left(\frac{2\pi n x}{\lambda} + \phi_n \right)$$

Onde stazionarie

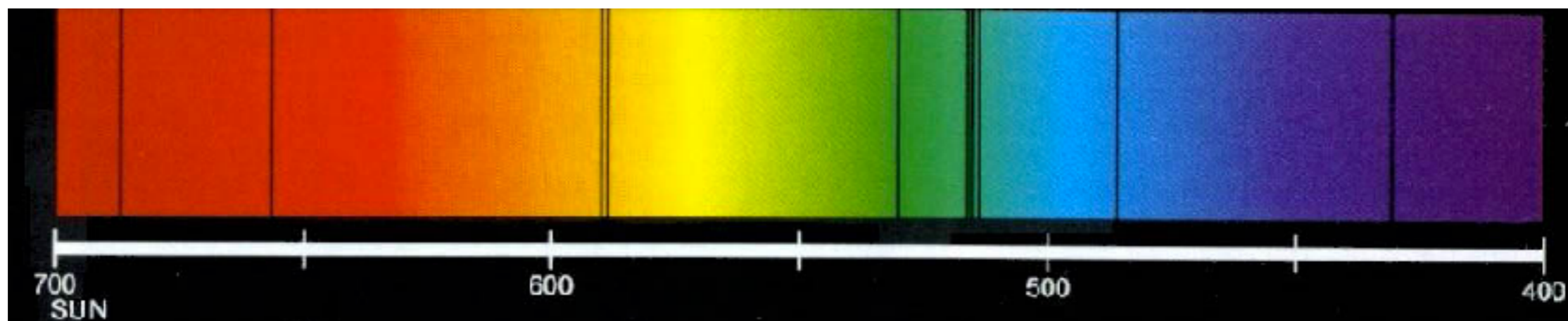
$$2\pi r = n\lambda = n \frac{h}{p}$$

$$pr = mvr = L = n \frac{h}{2\pi} = n\hbar$$

- Momento angolare e quantità di moto quantizzati \Rightarrow energie quantizzate

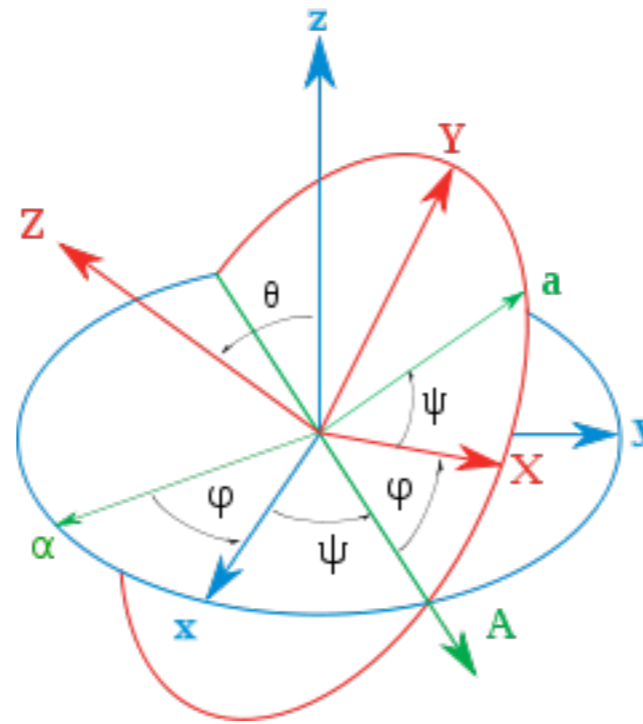
$$E = -k^2 \frac{e^4 m}{2\hbar^2 n^2}$$

Spettri atomici

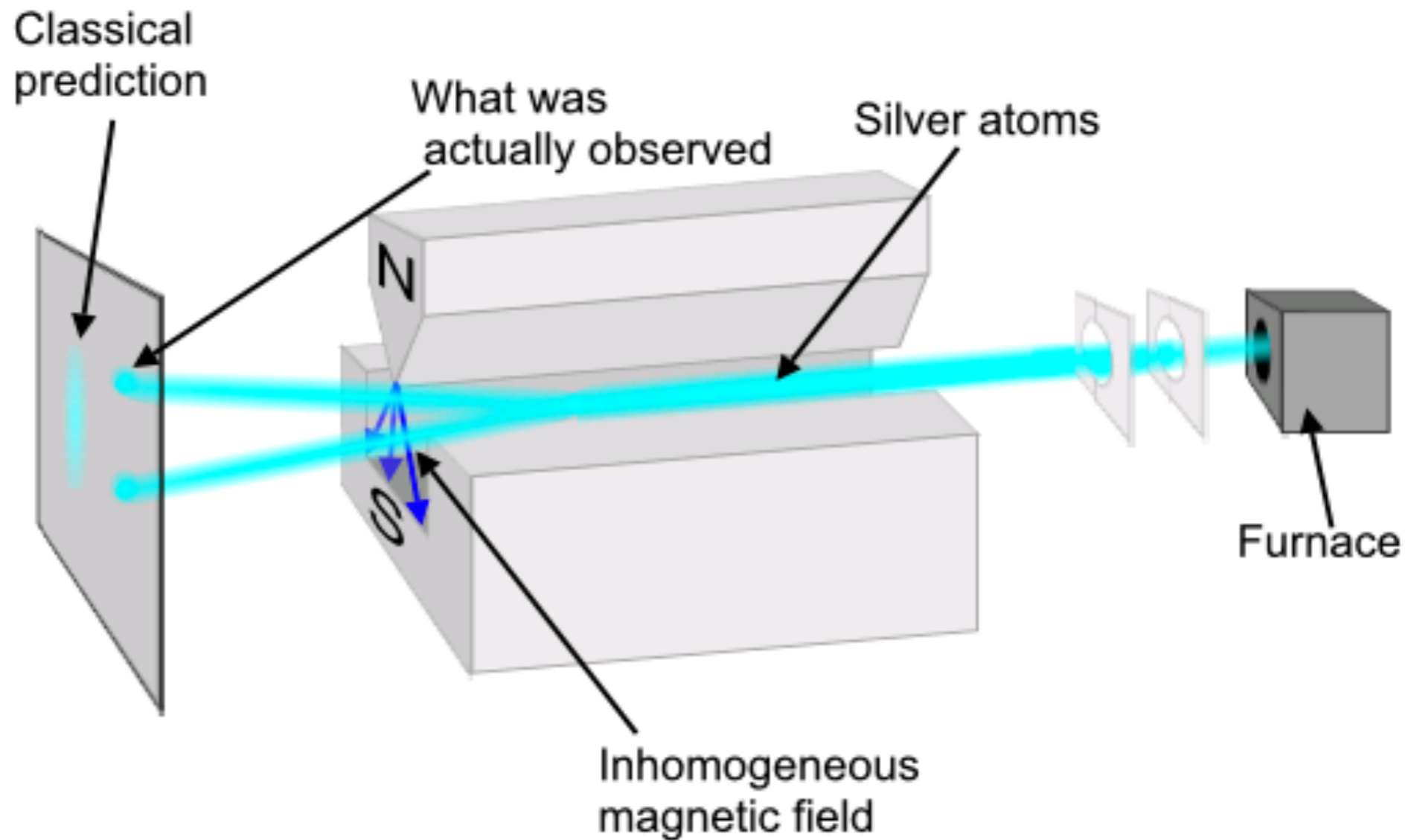


Quantizzazione del momento angolare

$$L = n\hbar$$

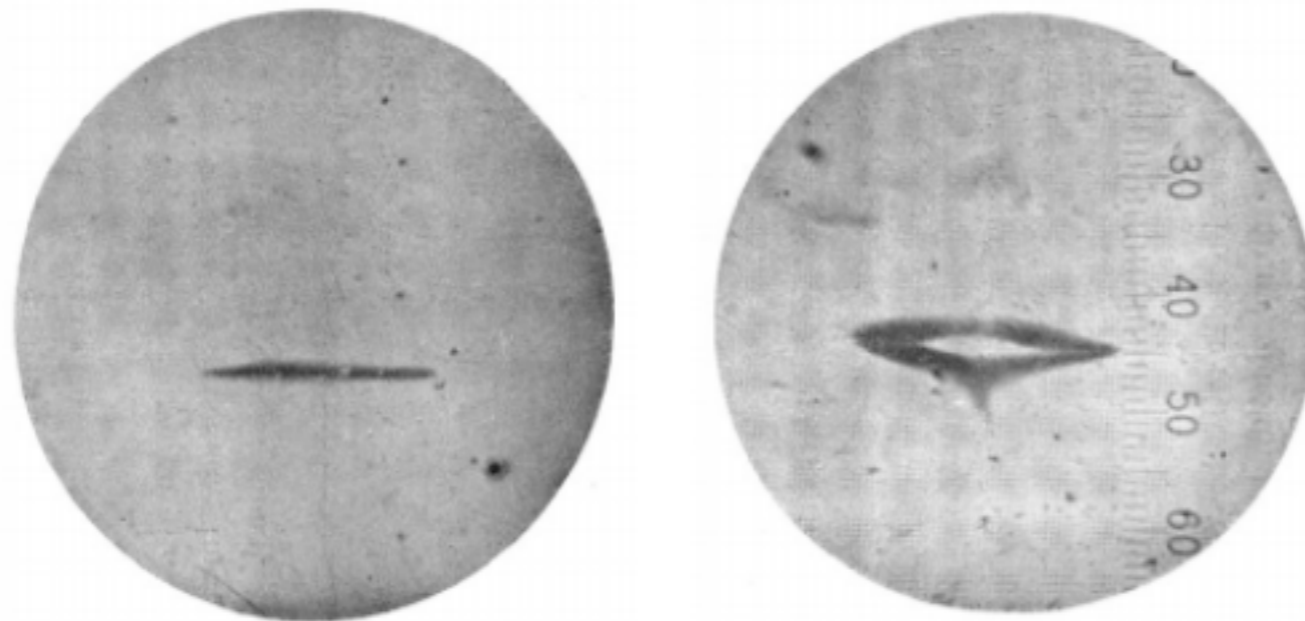


Lo spin: Stern-Gerlach



http://upload.wikimedia.org/wikipedia/commons/9/9e/Quantum_spin_and_the_Stern-Gerlach_experiment.ogg

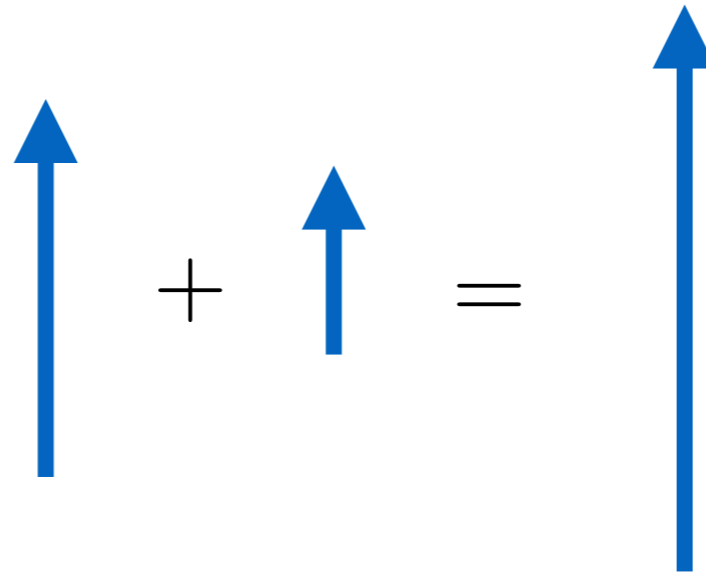
Lo spin: Stern-Gerlach



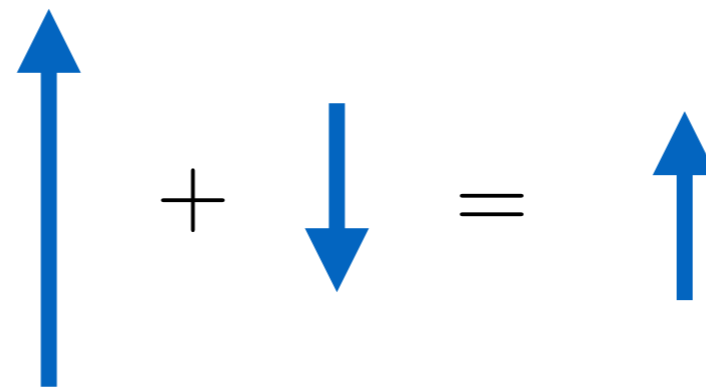
La somma dei momenti angolari

$$J = L + S$$

$$L = 1; S = \frac{1}{2}$$



$$J = L + S = \frac{3}{2}$$



$$J = L - S = \frac{1}{2}$$

Lo stato degli elettroni

■ Il principio di esclusione classico

- due punti materiali non possono stare nello stesso stato nel medesimo istante

■ Il Principio di esclusione di Pauli

- due elettroni non possono stare nello stesso stato nel medesimo istante

■ Stato = $|E, L, L_z\rangle$

- $\left|E, \frac{3}{2}, +\frac{1}{2}\right\rangle \neq \left|E, \frac{3}{2}, -\frac{3}{2}\right\rangle$

La chimica

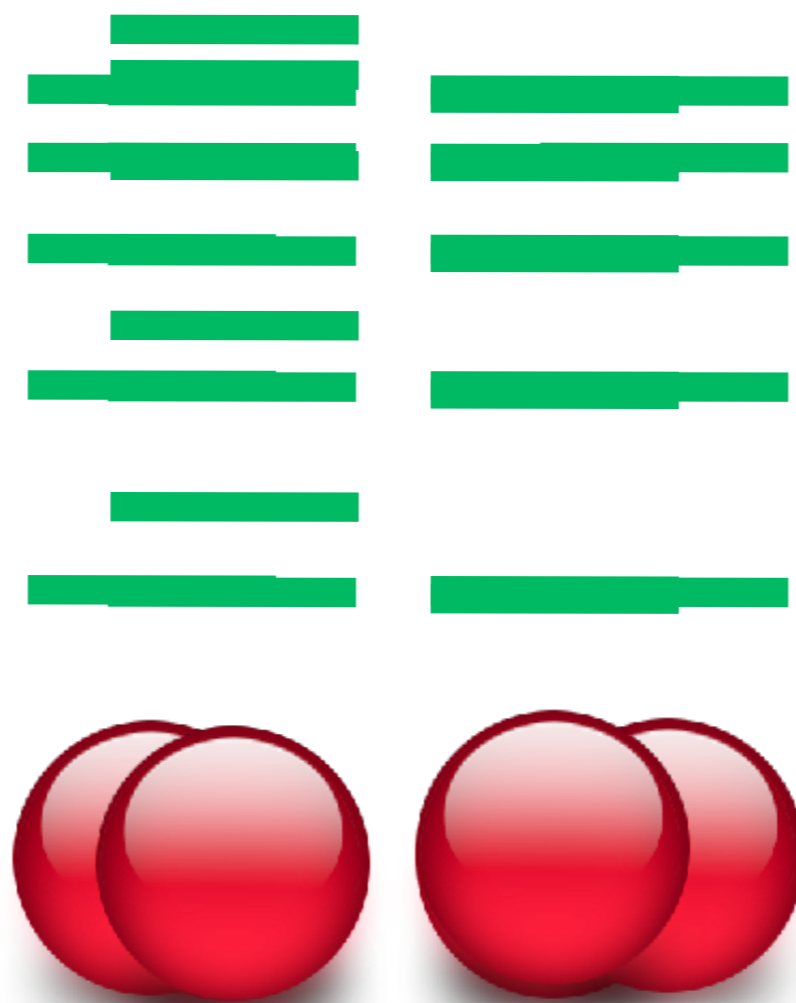
Periodic Table of the Elements

$$L \leq n - 1$$

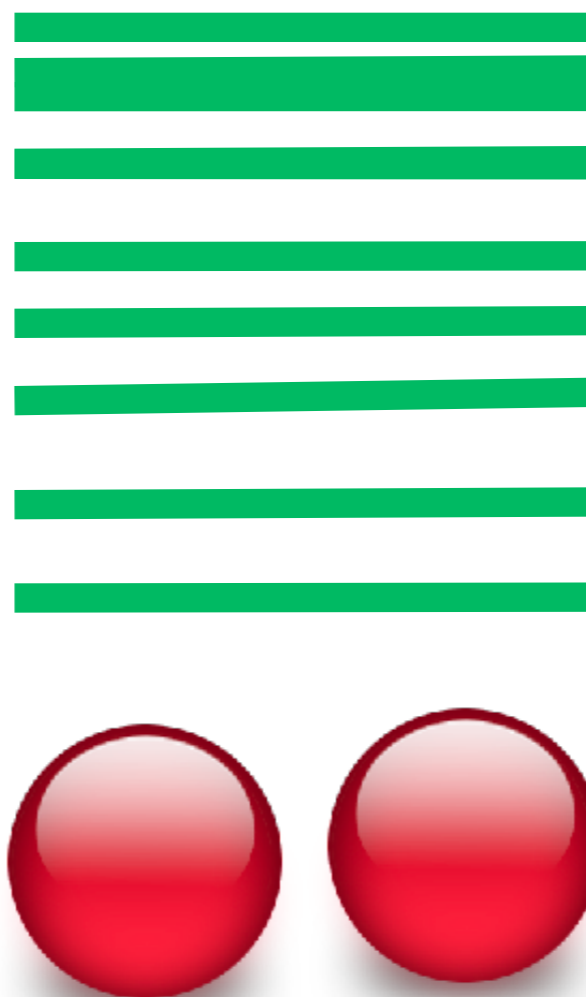
1 1IA 11A	2 IIA 2A											13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A												
1 H Hydrogen 1.0079												5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.00574	8 O Oxygen 15.9994	9 F Fluorine 18.998403	10 Ne Neon 20.1797												
3 Li Lithium 6.941	4 Be Beryllium 9.01218											11 Na Sodium 22.989768	12 Mg Magnesium 24.305	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 Al Aluminum 26.981539	14 Si Silicon 28.3855	15 P Phosphorus 30.973762	16 S Sulfur 32.064	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.95591	22 Ti Titanium 47.88	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938	26 Fe Iron 55.847	27 Co Cobalt 58.9332	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.702	32 Ge Germanium 72.64	33 As Arsenic 74.92159	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80												
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium 98.9062	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.90447	54 Xe Xenon 131.29												
55 Cs Cesium 132.90543	56 Ba Barium 137.327	57-71 Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.9665	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98037	84 Po Polonium [209]	85 At Astatine 209	86 Rn Radon 222.0176												
87 Fr Francium 223	88 Ra Radium 226	89-103 Actinide Series	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Uuq Ununquadium [289]	115 Uup Ununpentium unknown	116 Uuh Ununhexium [296]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown												
		57 La Lanthanum 138.9055	58 Ce Cerium 140.115	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium 144.9127	62 Sm Samarium 150.36	63 Eu Europium 151.9655	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967													
		89 Ac Actinium 227.0278	90 Th Thorium 232.0381	91 Pa Protactinium 231.03688	92 U Uranium 238.0289	93 Np Neptunium 237.0482	94 Pu Plutonium 244.0442	95 Am Americium 243.0614	96 Cm Curium 247.0703	97 Bk Berkelium 247.0703	98 Cf Californium 251.0796	99 Es Einsteinium [254]	100 Fm Fermium 257.0951	101 Md Mendelevium 258.1	102 No Nobelium 259.1009	103 Lr Lawrencium [262]													
		Akali Metal	Alkaline Earth	Transition Metal	Basic Metal	Semimetals	Nonmetals	Halogens	Noble Gas	Lanthanides	Actinides																		



Cristalli



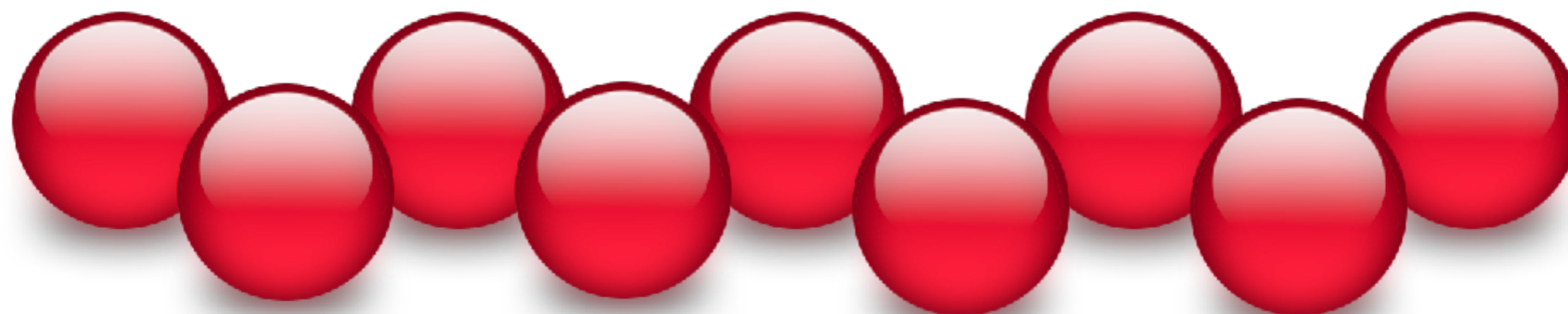
Cristalli



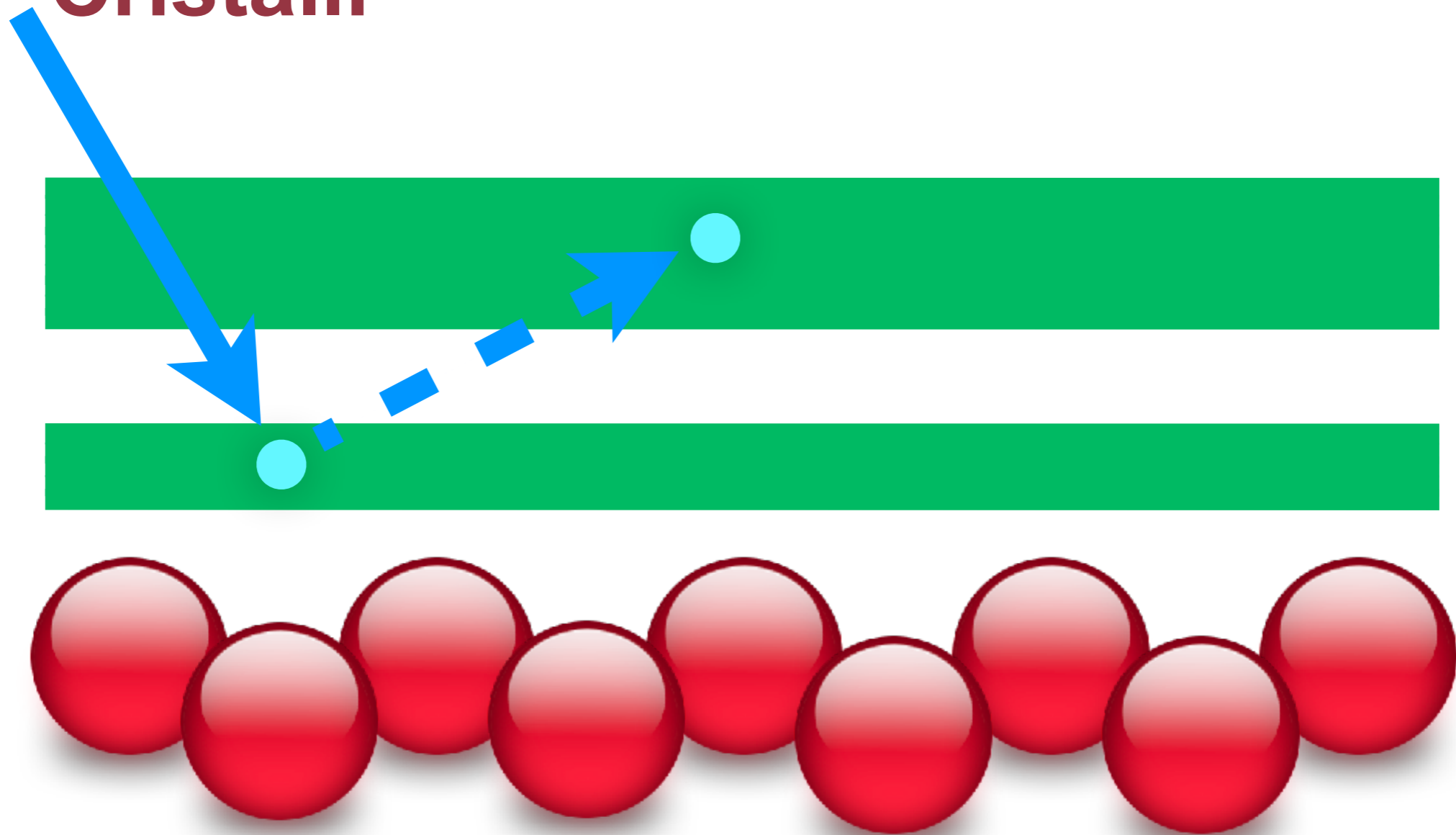
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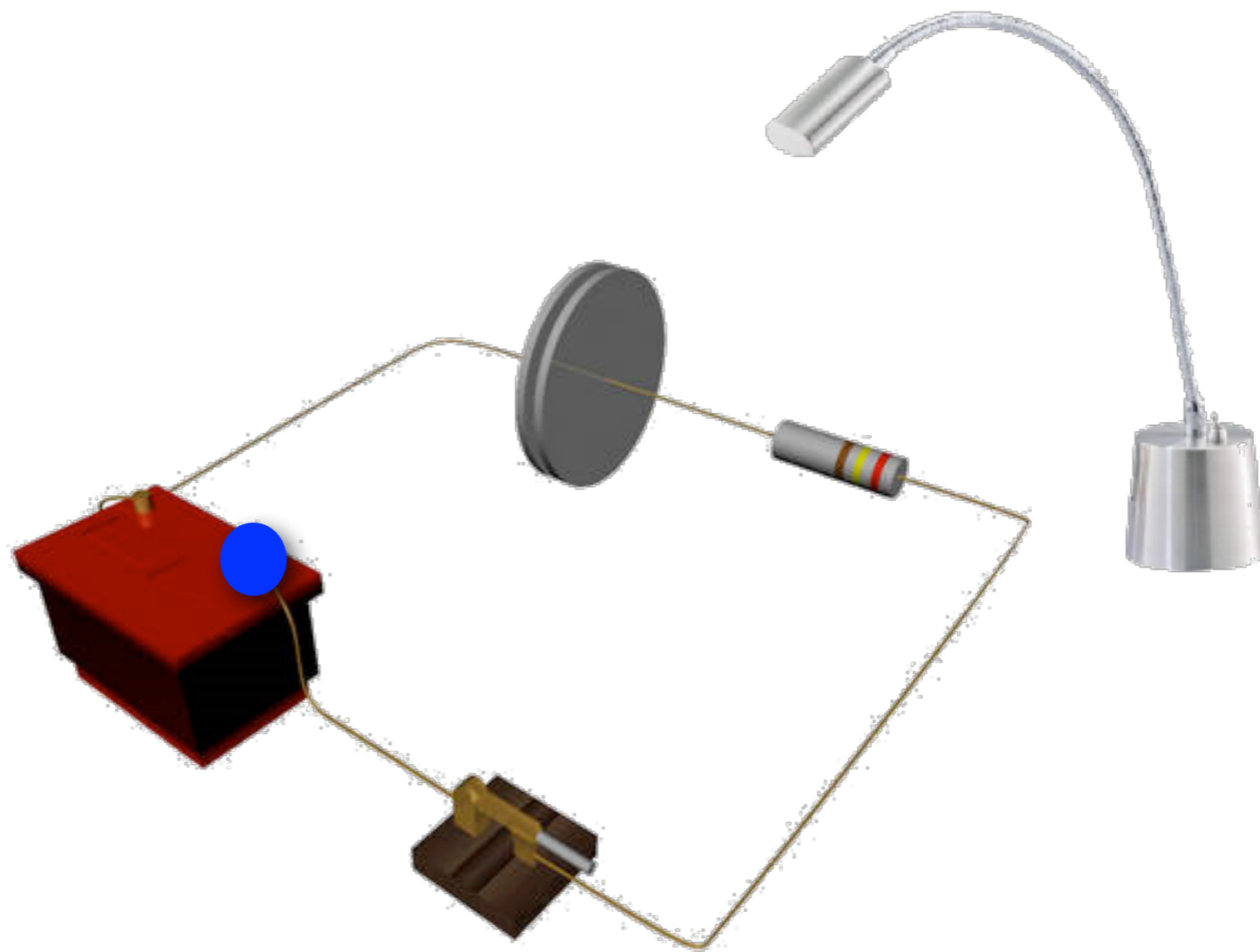
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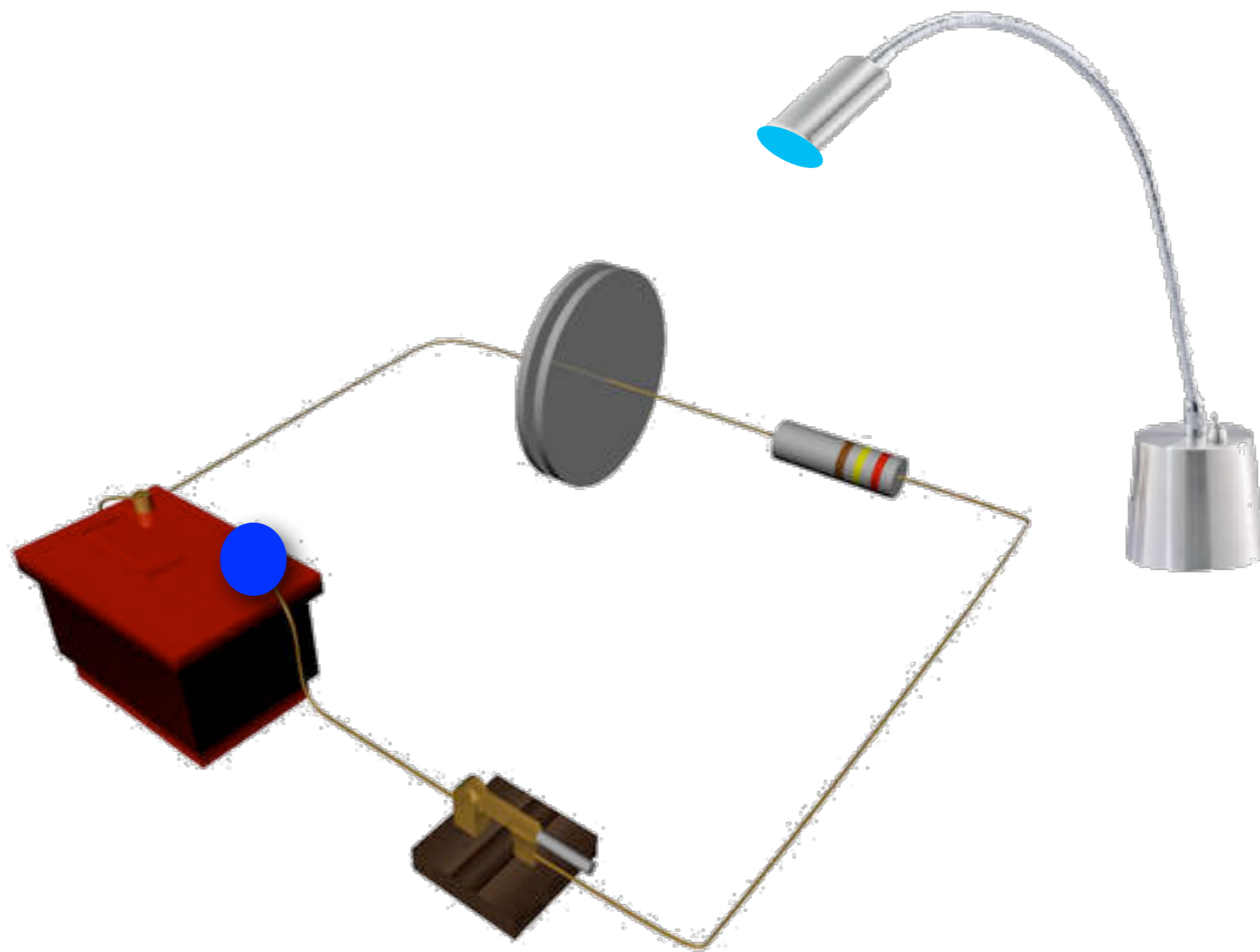
Cristalli



Trasporto e guida degli elettroni



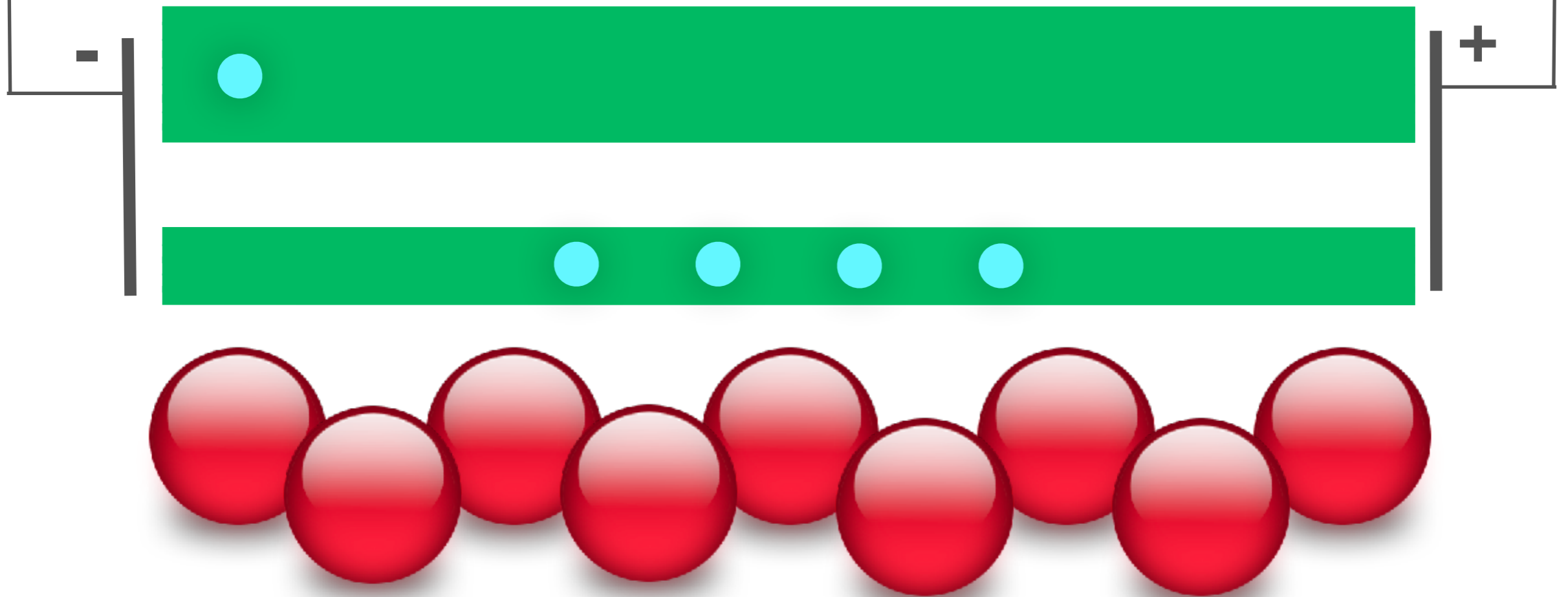
Trasporto e guida degli elettroni



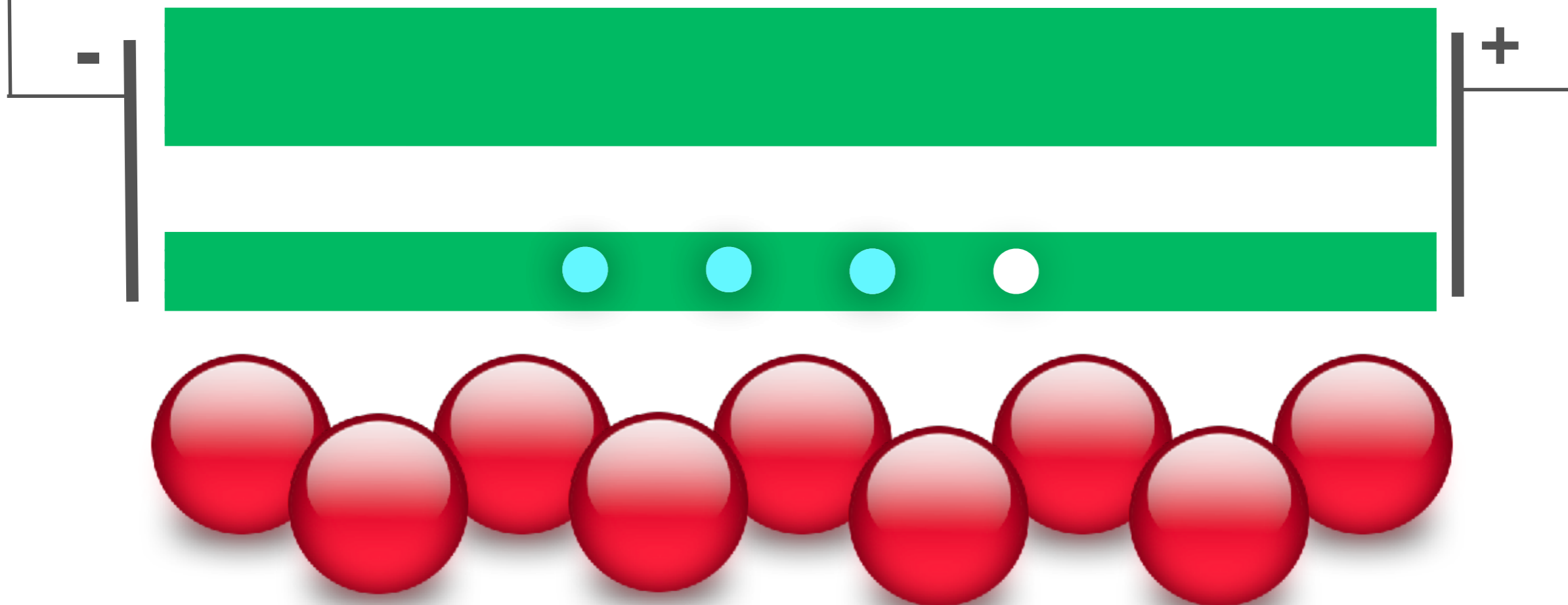
Come distinguere la corrente fotoelettrica?



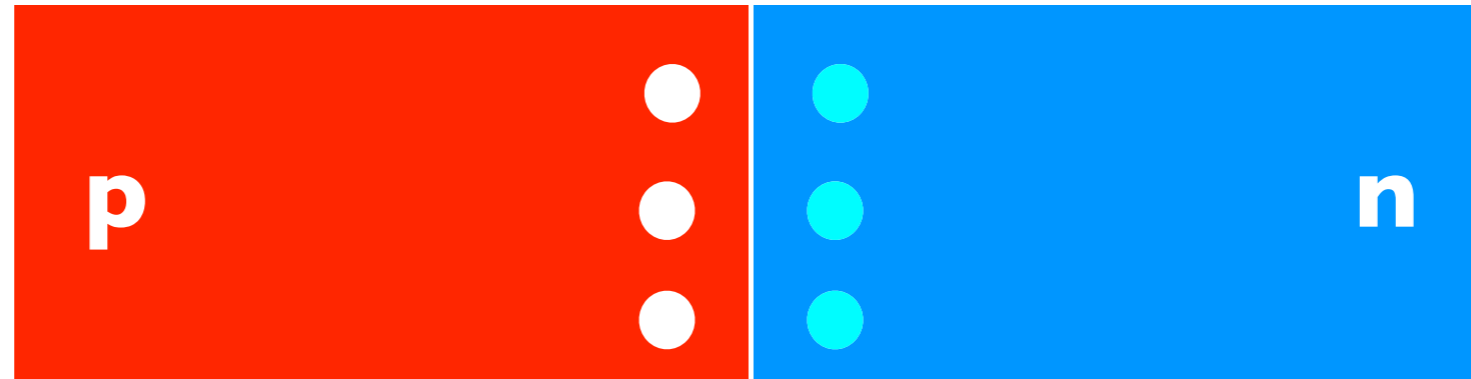
Cristalli N



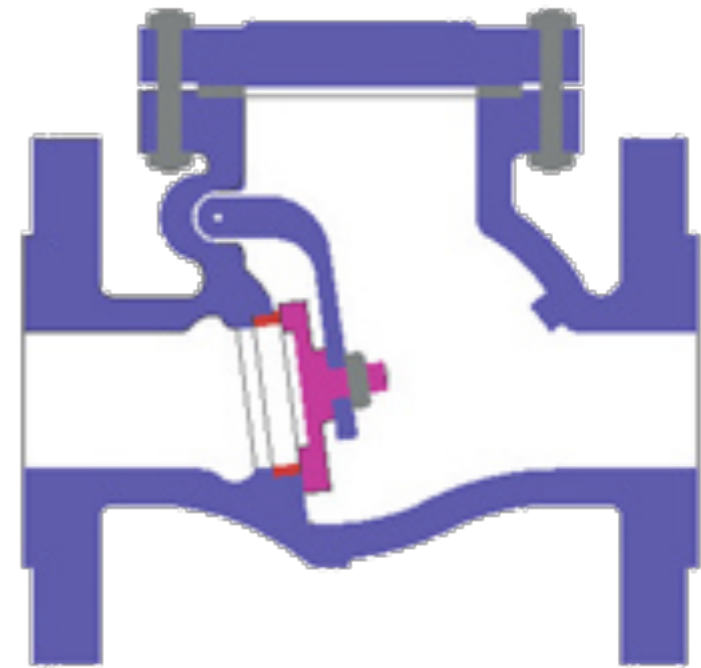
Cristalli P



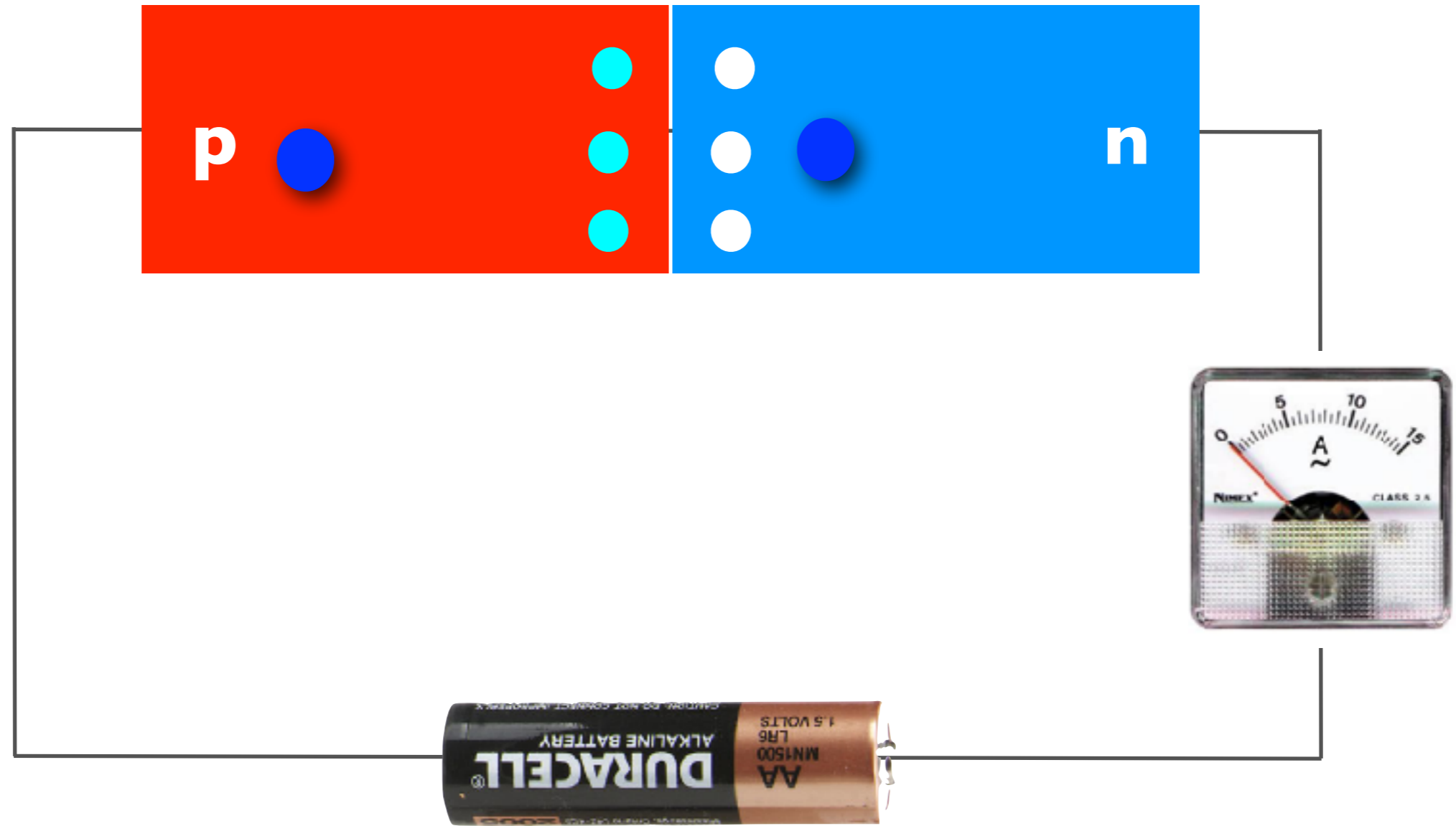
Il diodo



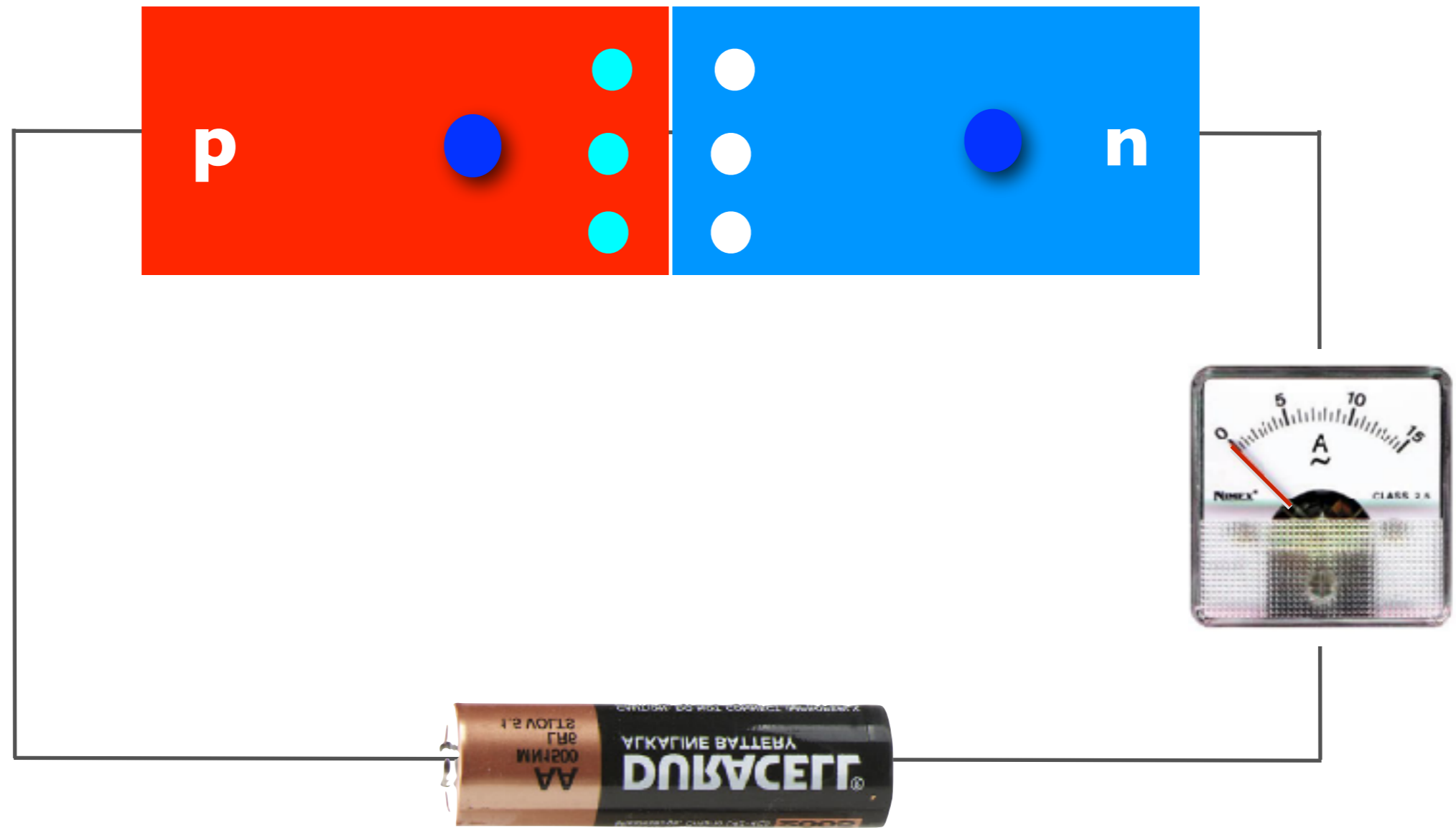
Il diodo come una valvola



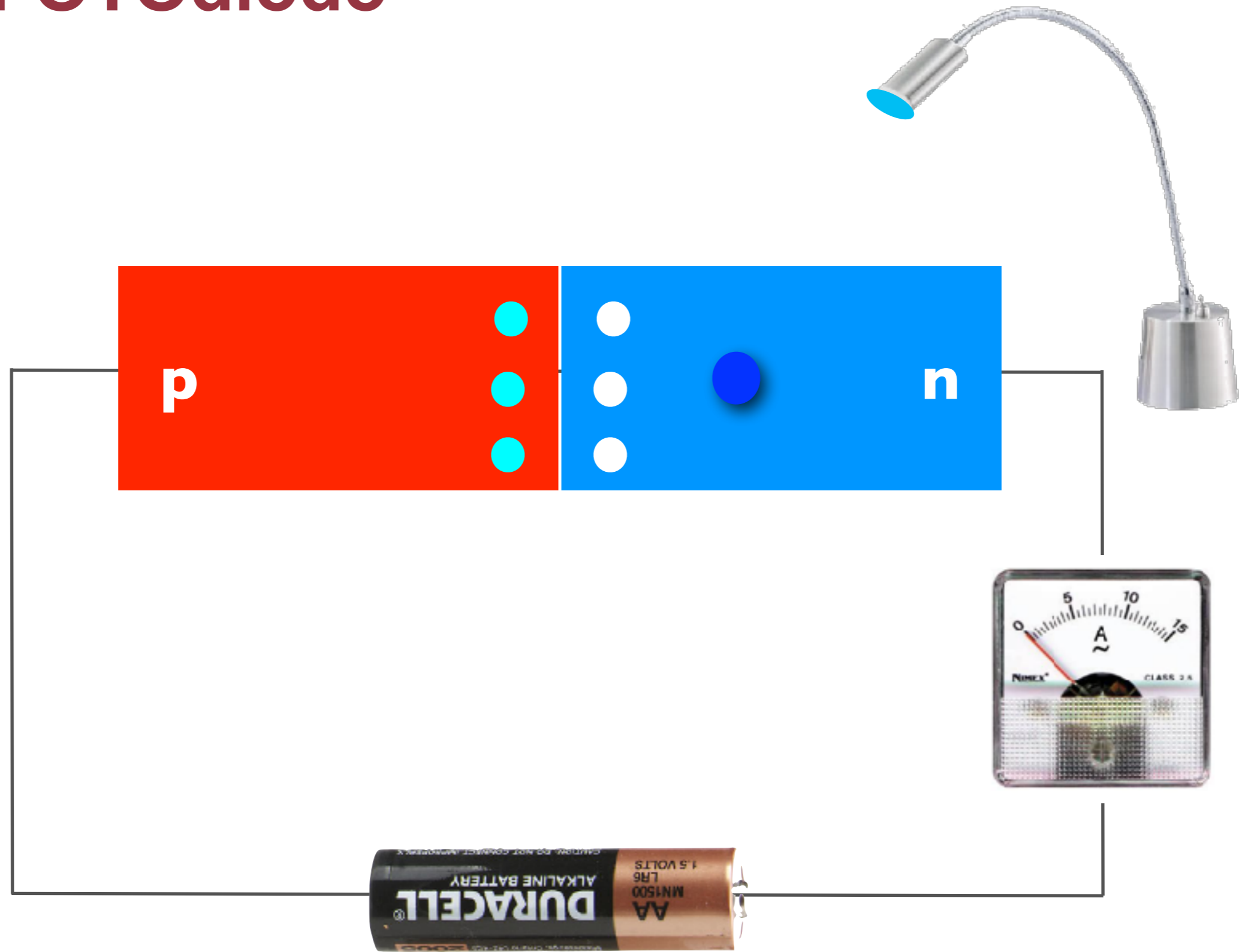
Il diodo



Il diodo

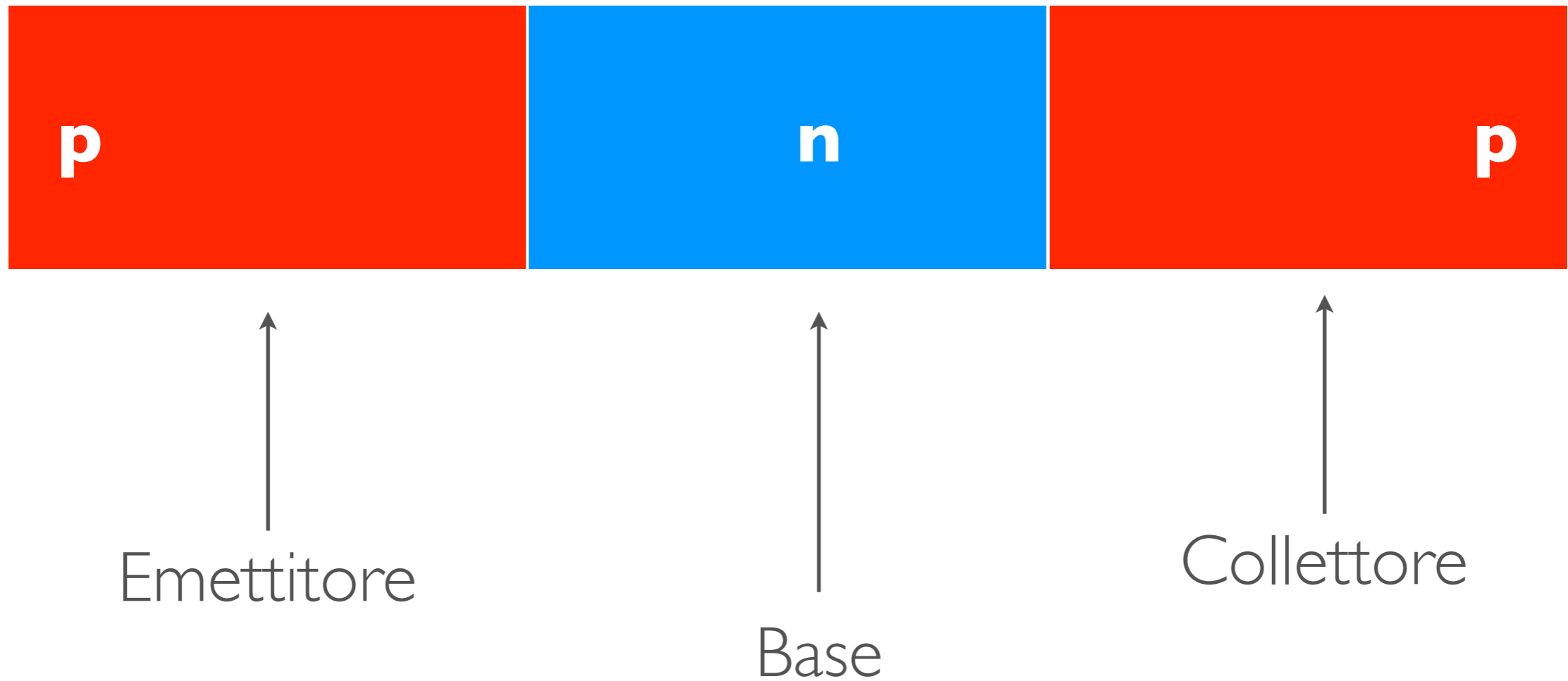


II FOTOdiodo

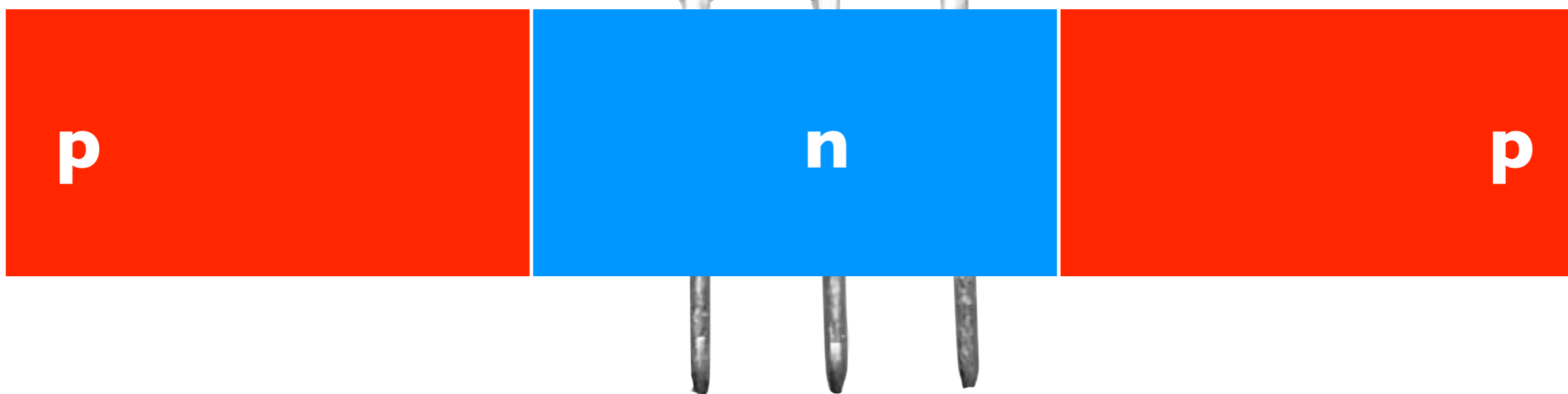
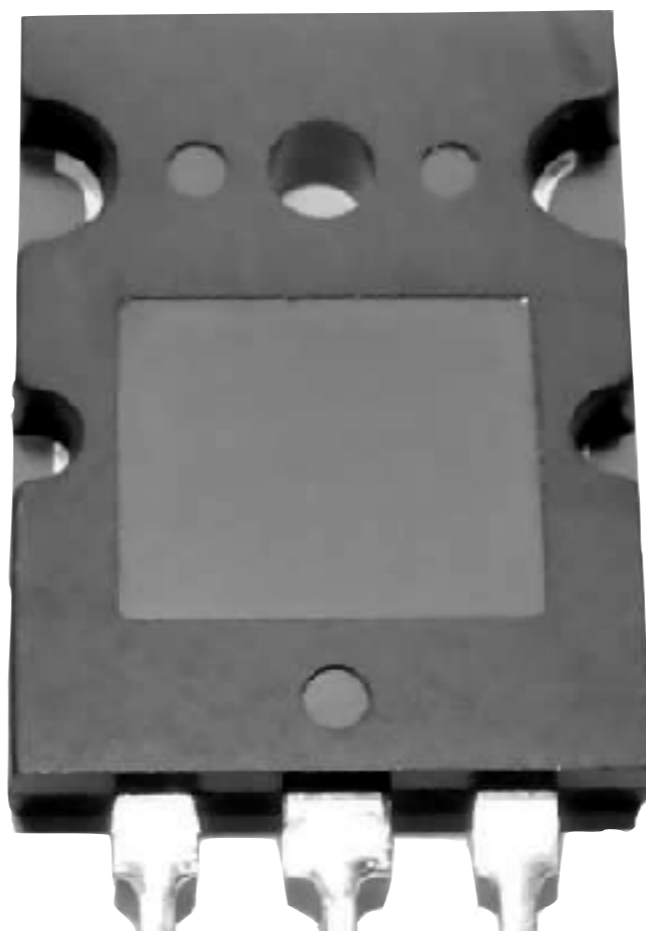




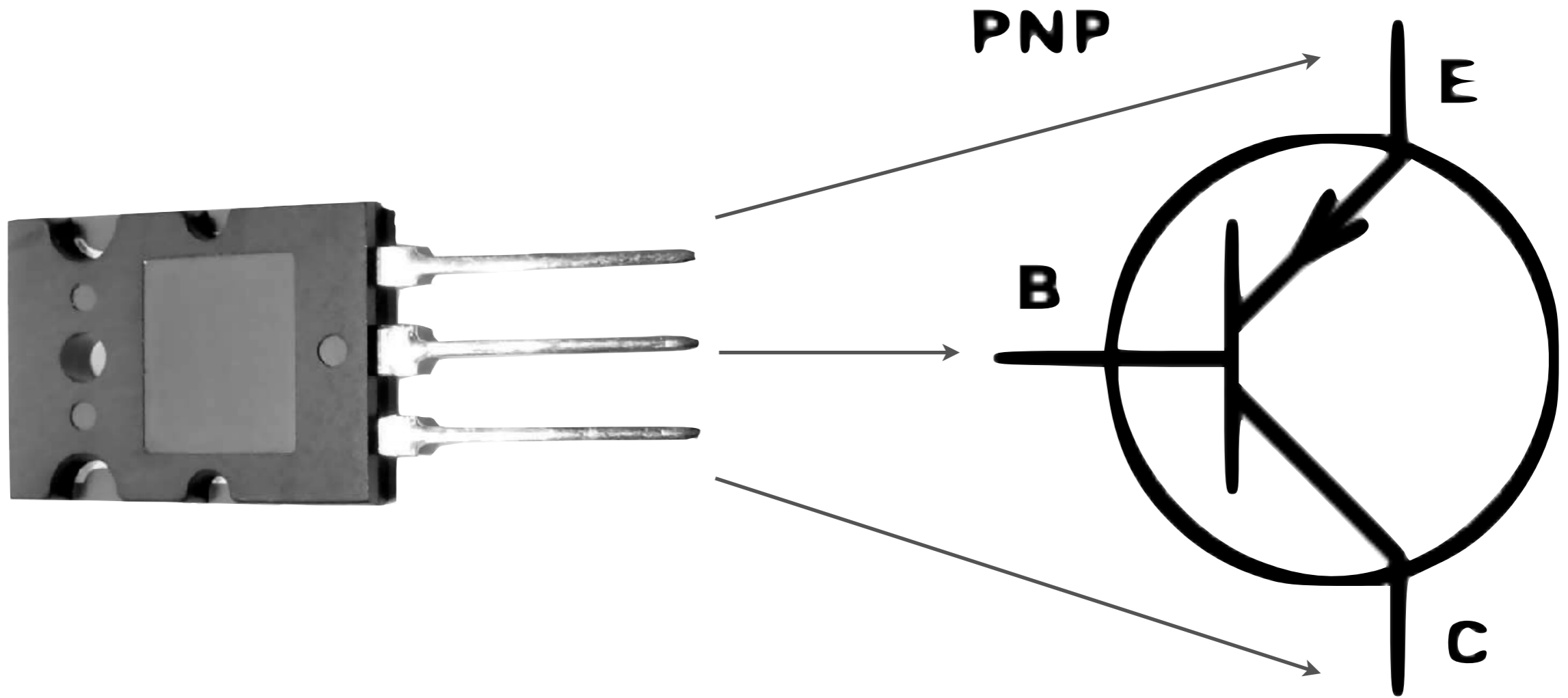
IL TRANSISTOR



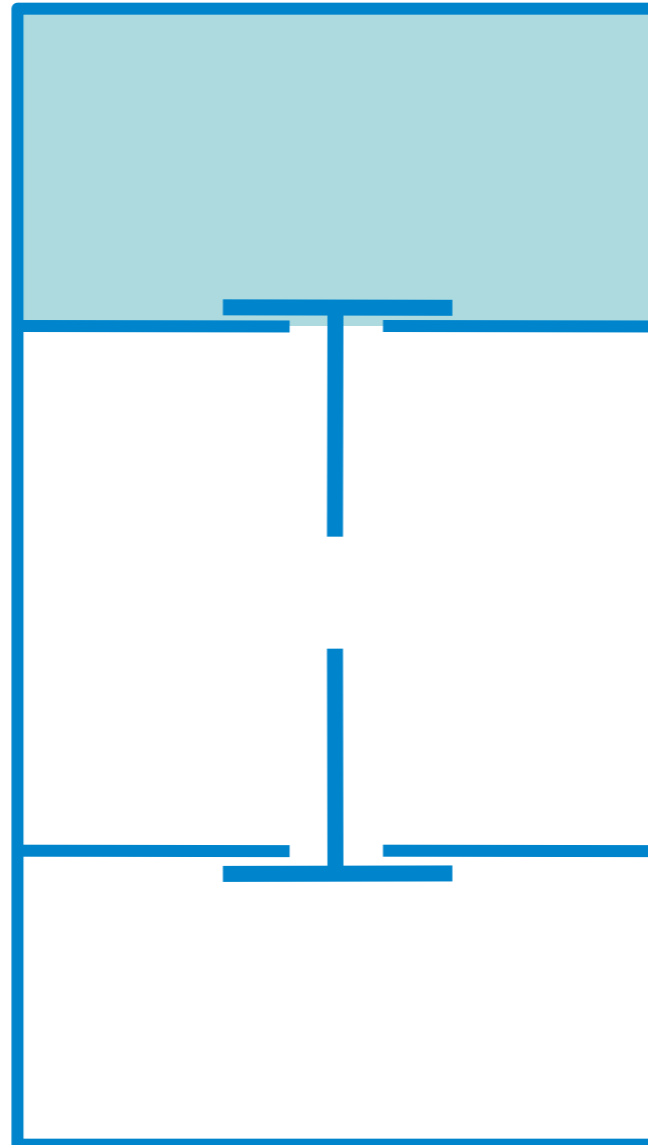
il transistor



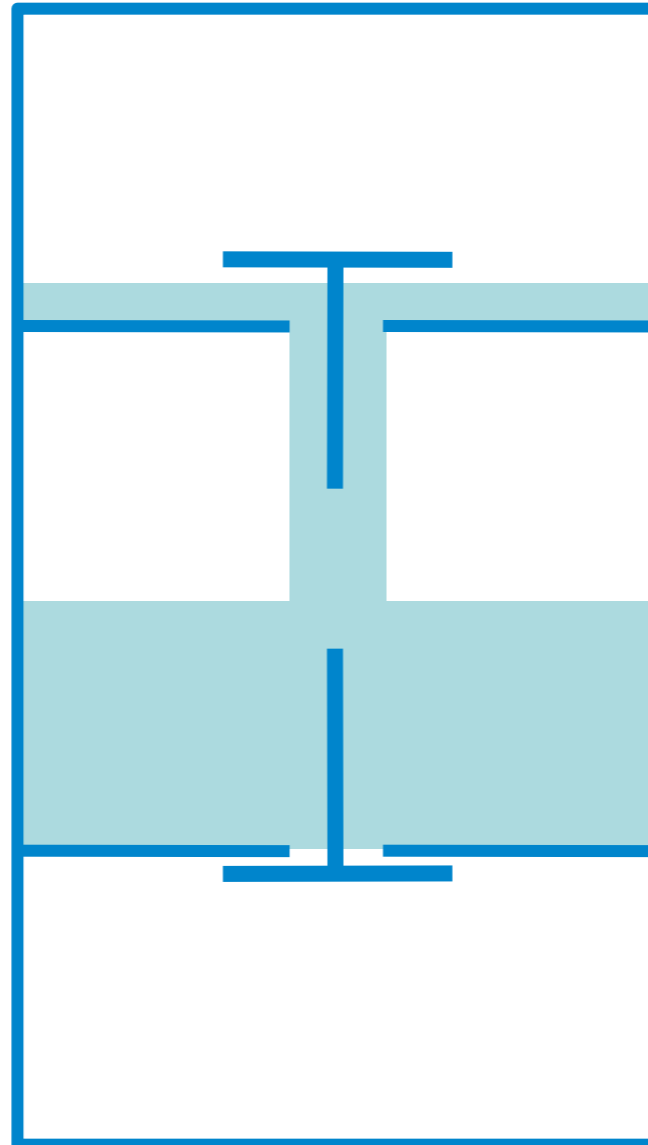
il transistor



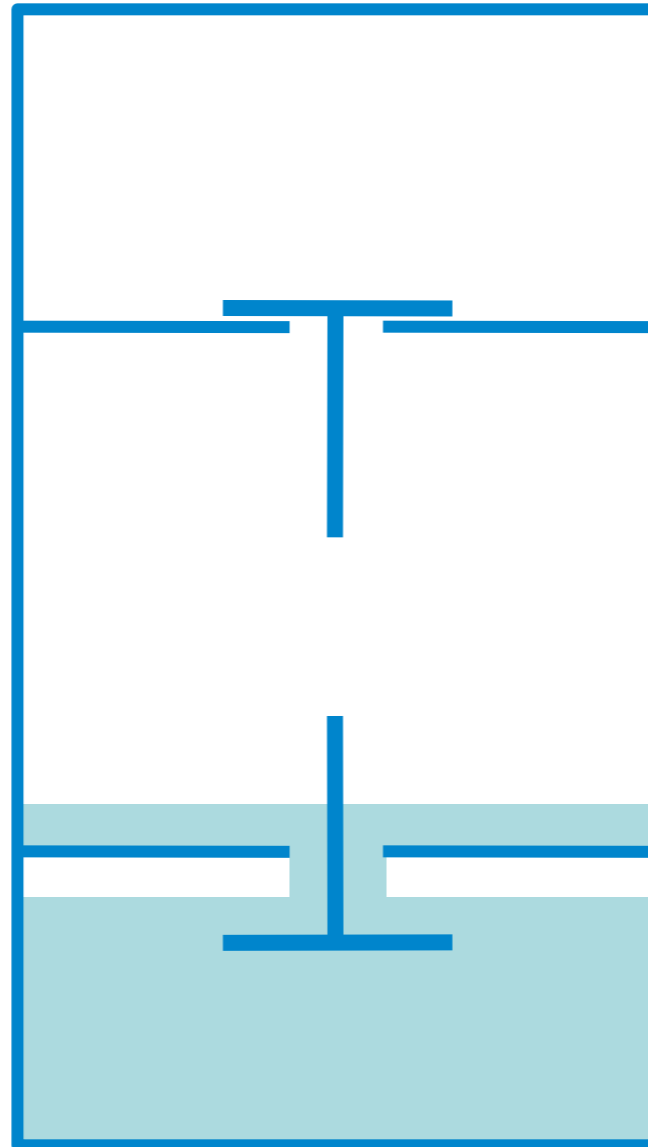
Il transistor come coppia di valvole



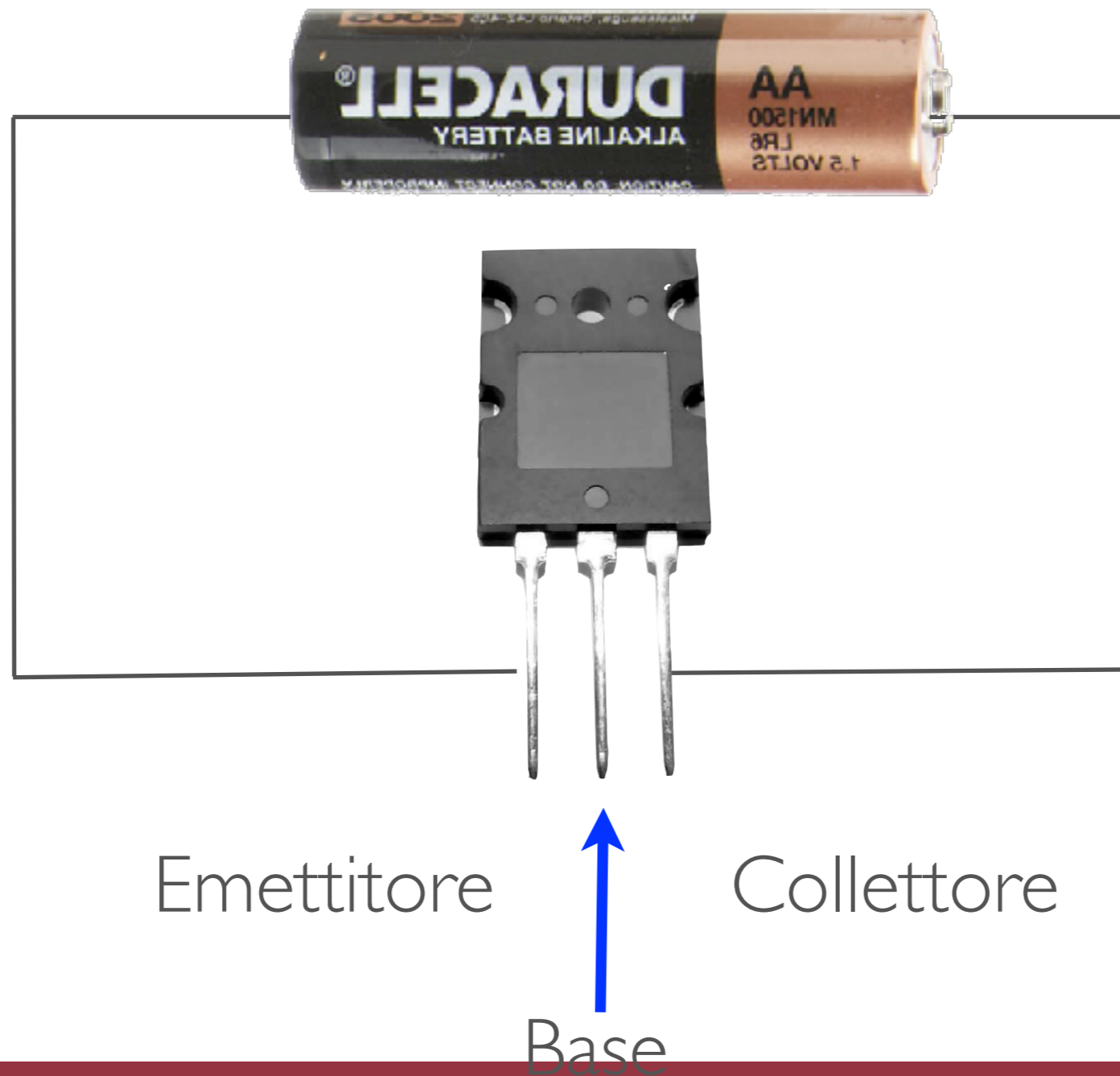
Il transistor come coppia di valvole



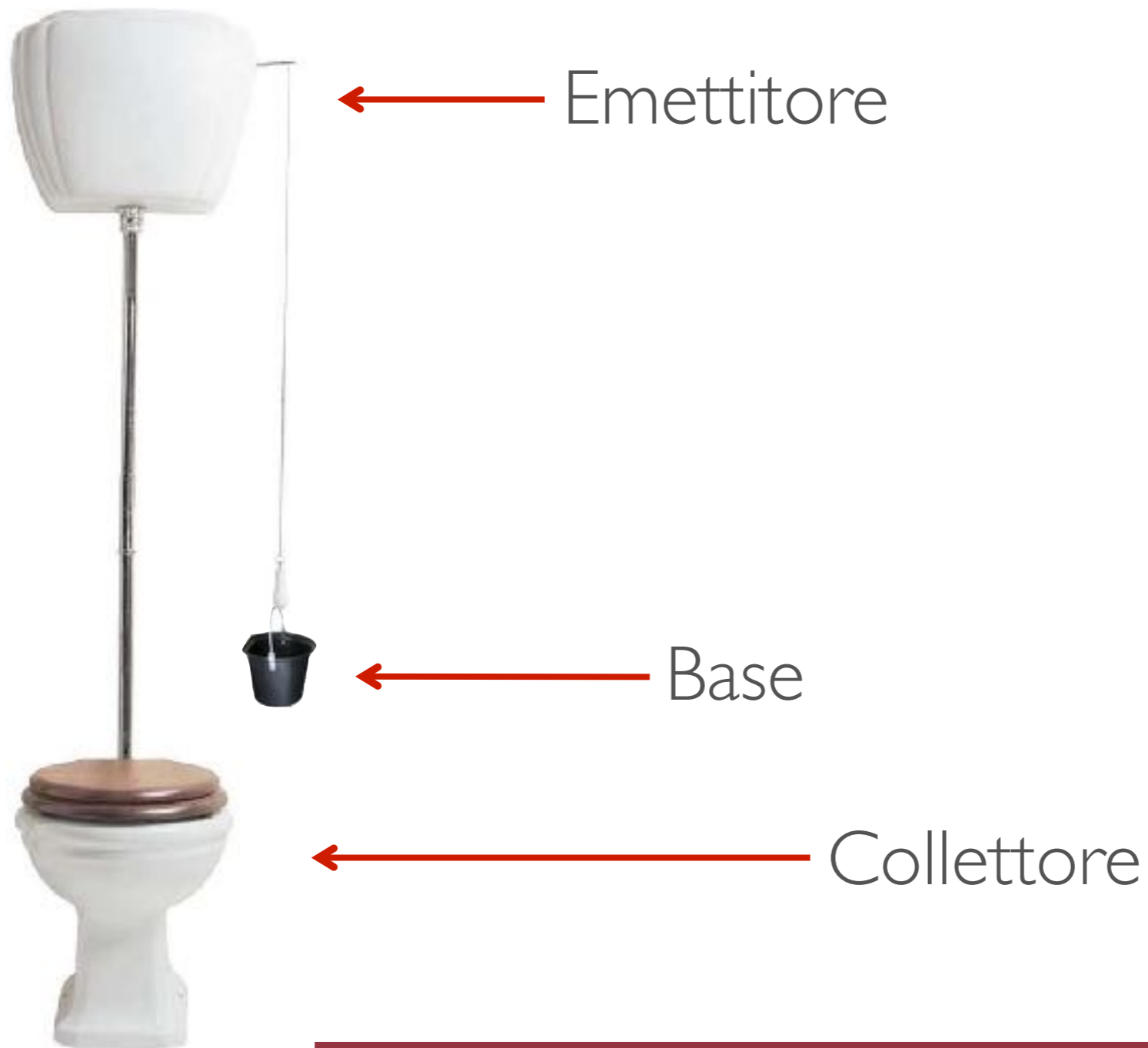
Il transistor come coppia di valvole



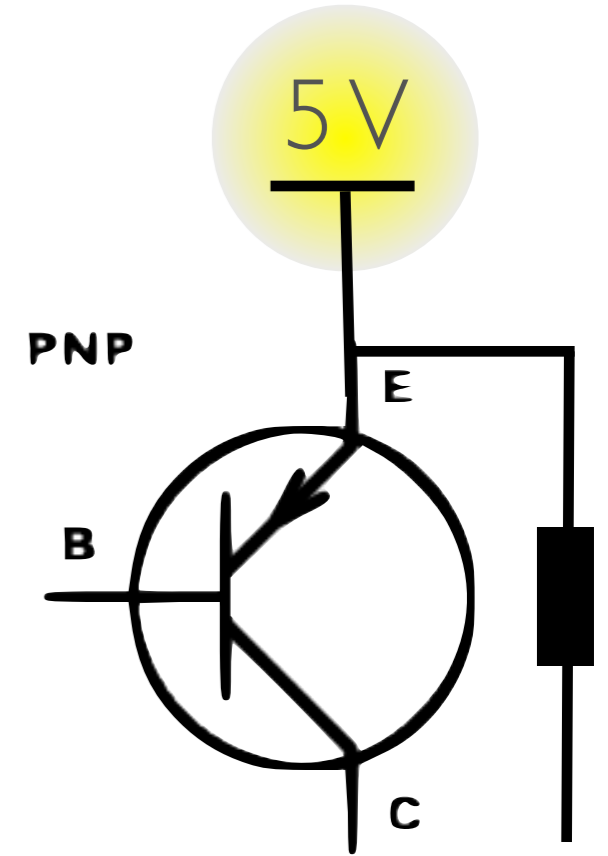
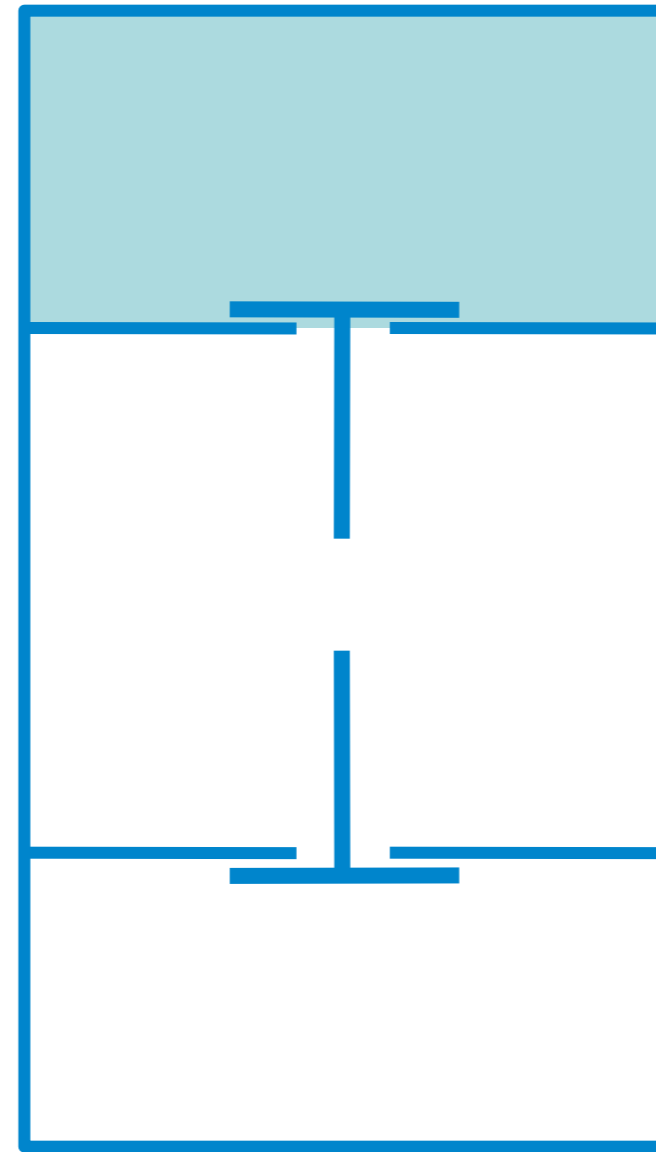
Il transistor come amplificatore



un transistor sui generis



un transistor sui

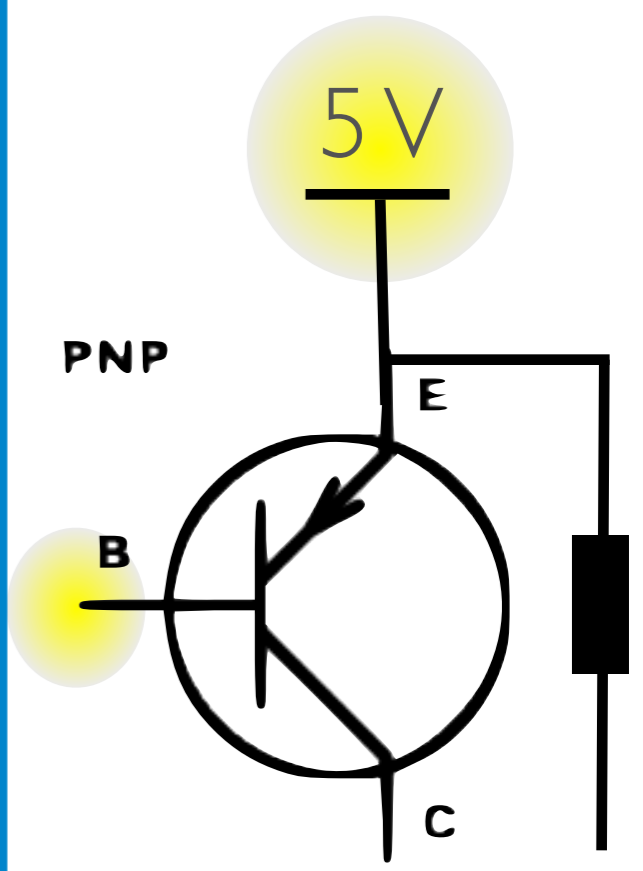
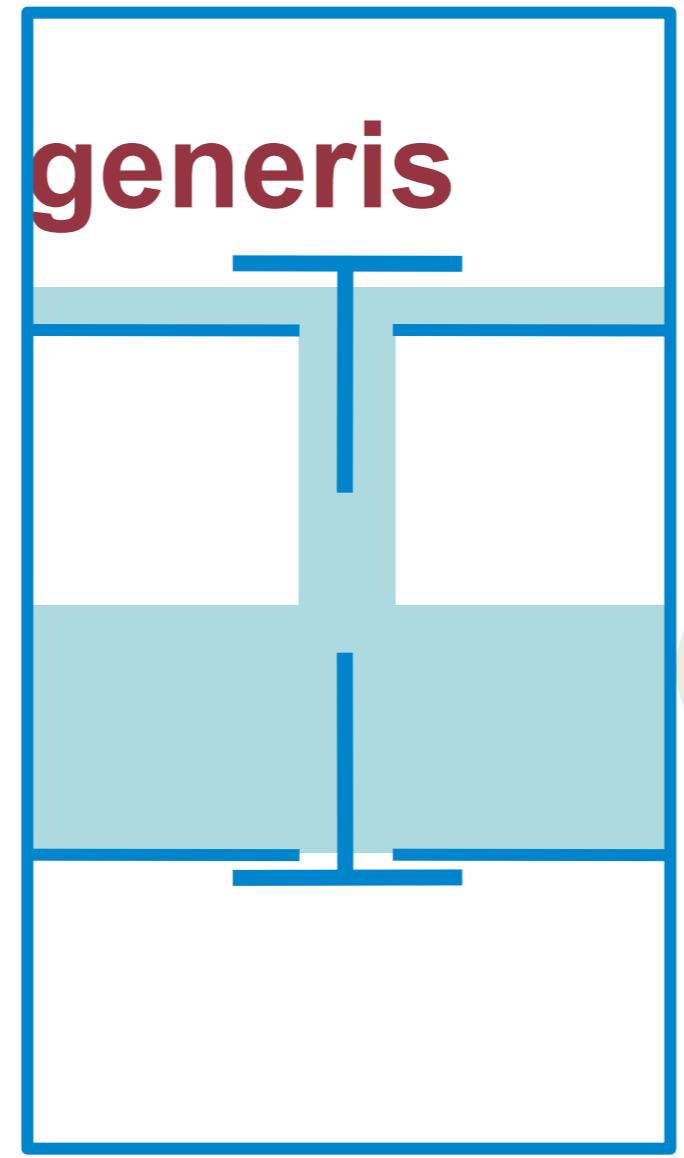


ii generis



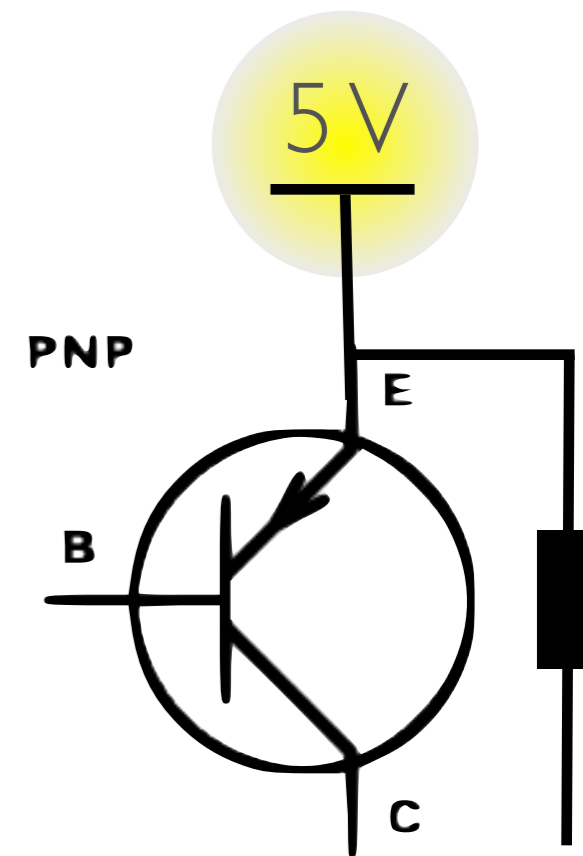
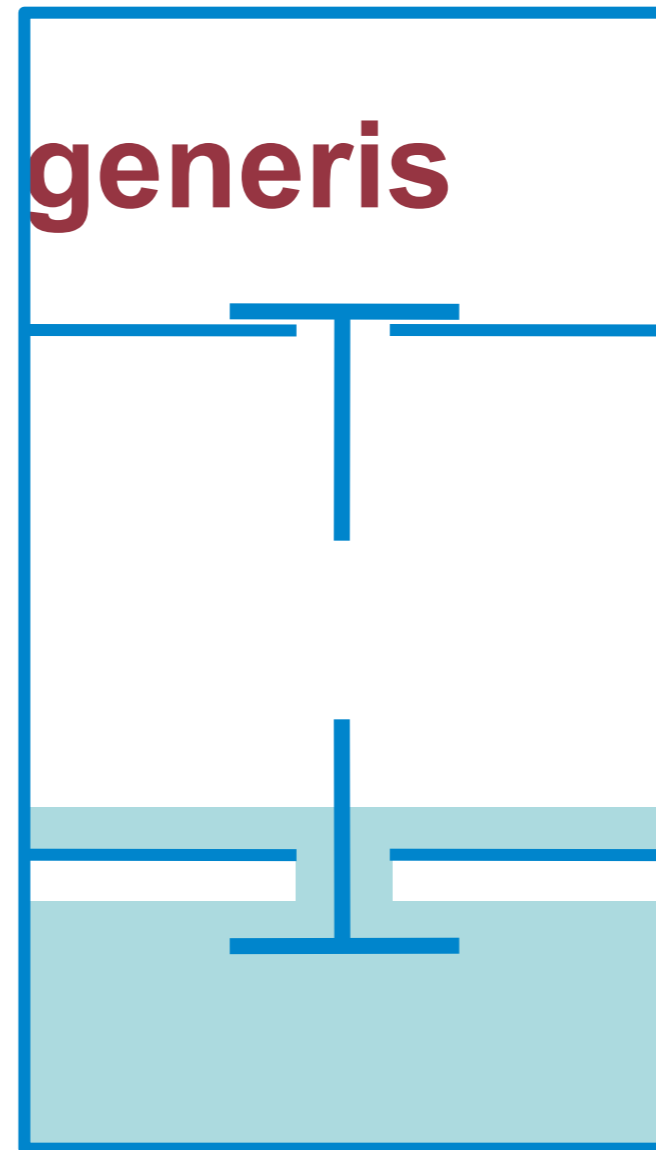


ii generis





ii generis



Risorse

■ Fisicast: www.fisicast.it

■ Animazioni: <http://QuantumMadeSimple.com>

■ Fisica Sperimentale: <http://www.roma1.infn.it/people/organtini/publications/>