

I raggi X e lo sviluppo della “Fisica moderna”

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Sommario

- La scoperta dei raggi X
- Radiologia
- Cosa sono i raggi X ?
- I raggi X e la Fisica Moderna
 - Breve storia dell'atomo
 - La struttura dei solidi cristallini
 - La struttura elettronica dell'atomo

La scoperta dei raggi X

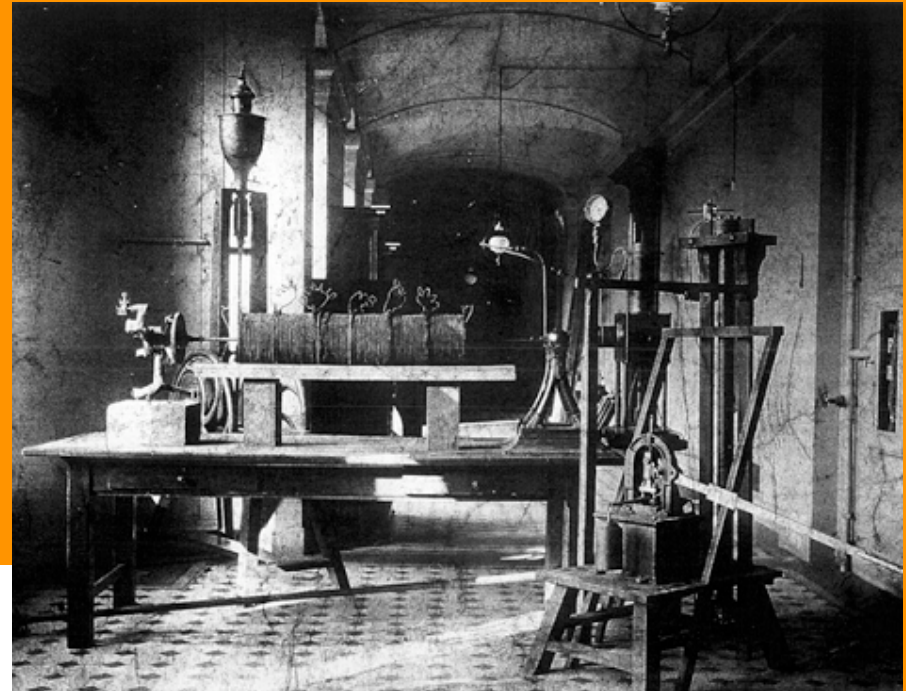


8 Novembre 1895



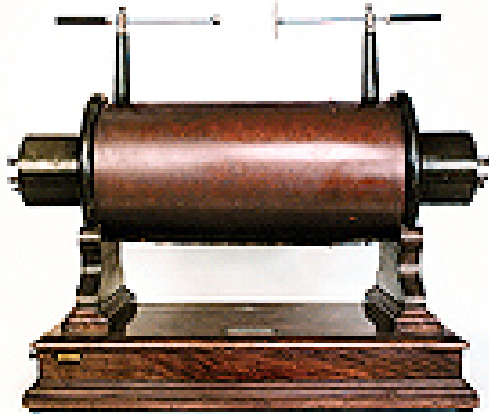
Wilhelm Konrad Röntgen
(1845-1923)

e il suo laboratorio
all'Università di Würzburg

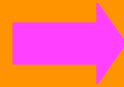


La sera dell'8 Novembre 1895
Röntgen scopre **un nuovo tipo di radiazione**, che chiama “raggi X”.

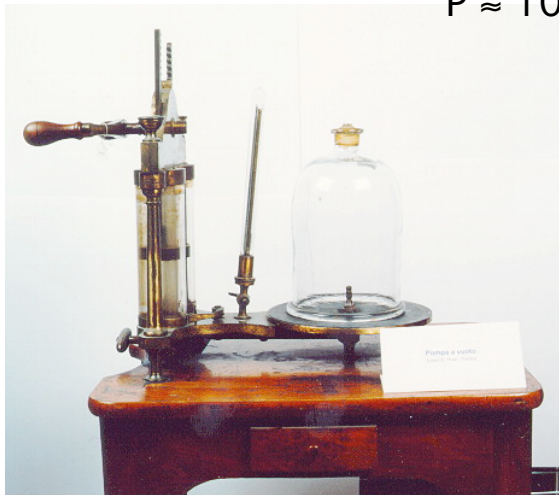
Le scariche nei gas



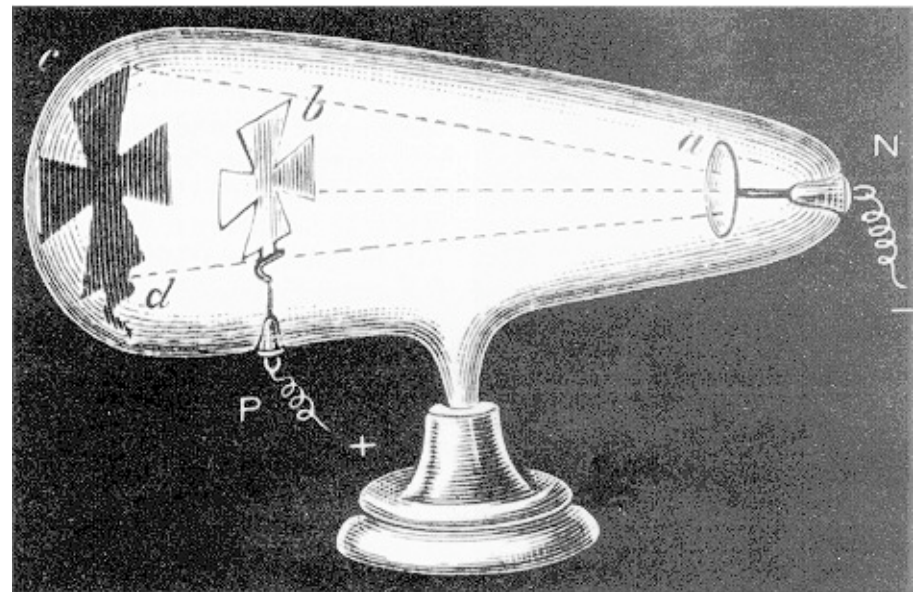
Rocchetto di Ruhmkorff
Alte tensioni impulsate



Pompe da vuoto manuali
 $P \approx 10^{-6}$ bar



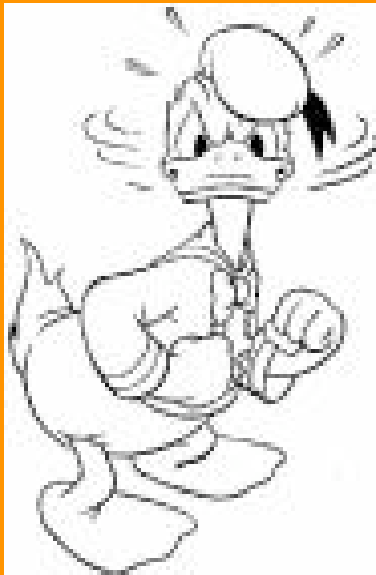
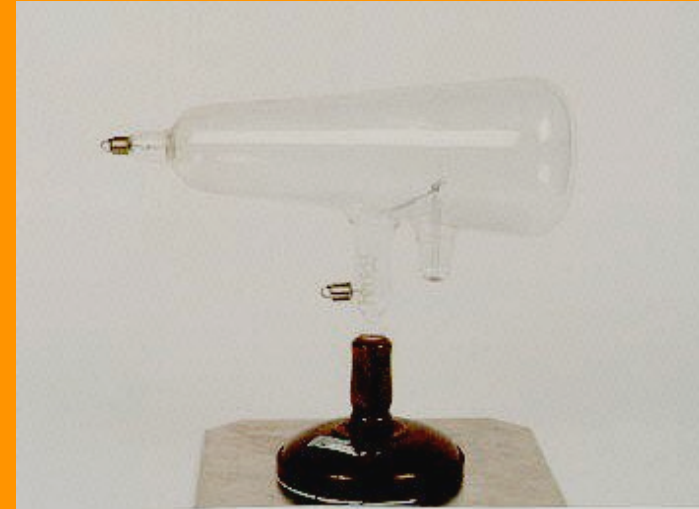
Scariche elettriche nei gas rarefatti



1869 - J.W.Hittorf scopre i "raggi catodici"

Prima di Röntgen

W. Crookes costruisce una grande varietà di tubi catodici (i “tubi di Hittorf-Crookes”).



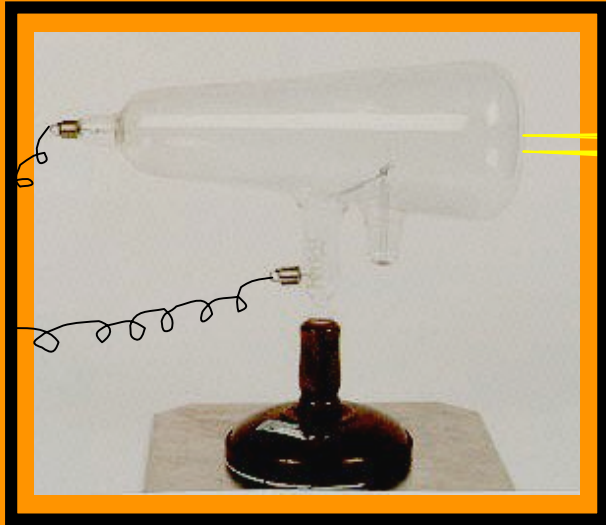
1880 - W. Crookes
appannamenti di pellicole presso tubi catodici -
restituisce le pellicole come difettose.

1890 - A.W.Goodspeed
ombra lasciata da due monete su una lastra fotografica - non
indaga oltre.

1893 - P. Lenard
fluorescenza inattesa al di fuori del tubo catodico
non può svolgere ulteriori indagini.

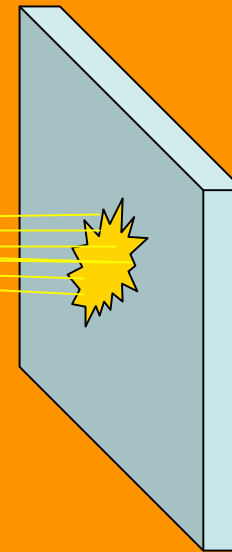
La scoperta di Roentgen

Tubo catodico schermato



Fluorescenza !

Nuovo tipo
di radiazione ?



Lastra
 $\text{BaPt}(\text{CN})_4 \cdot \text{H}_2\text{O}$

Per sette settimane Roentgen non abbandona il laboratorio, eseguendo una serie di esperimenti decisivi per caratterizzare le proprietà dei “raggi X”.

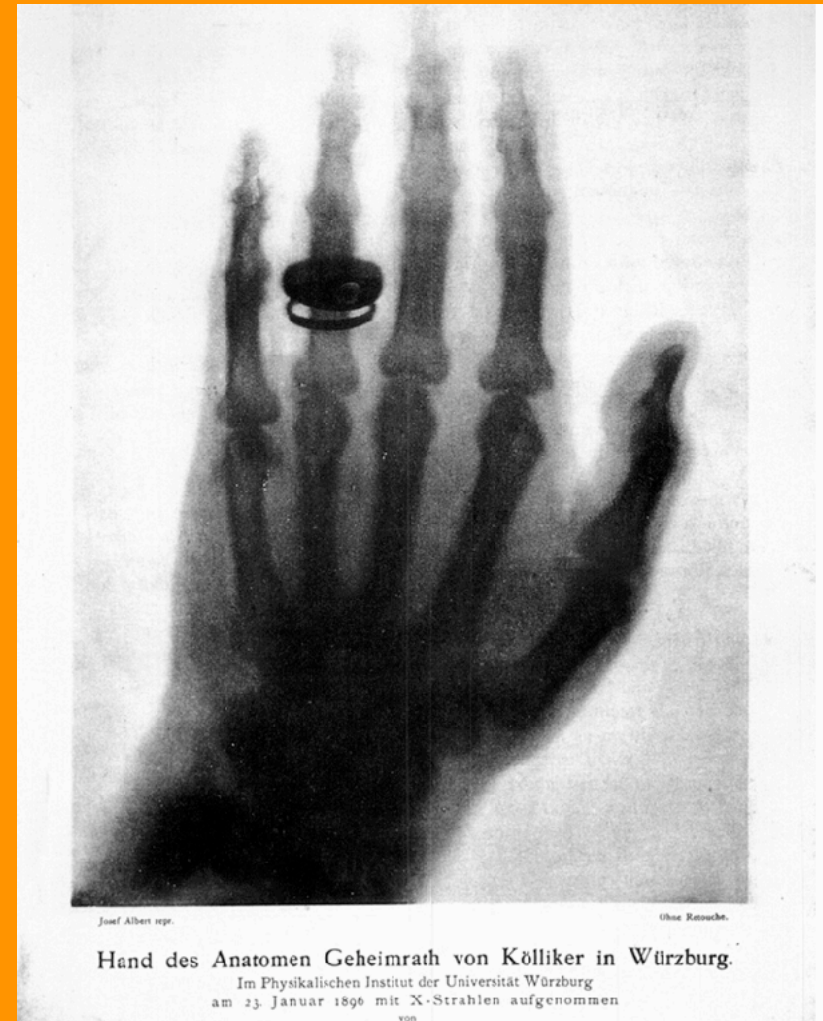
Prime proprietà dei raggi X

➤ Elevato potere di penetrazione,
dipendente da
natura e densità dei materiali.

➤ I raggi X impressionano
le lastre fotografiche



Radiografia



Europa e Germania nel 1895



1861-1888
Guglielmo I

1862-1890
Bismark

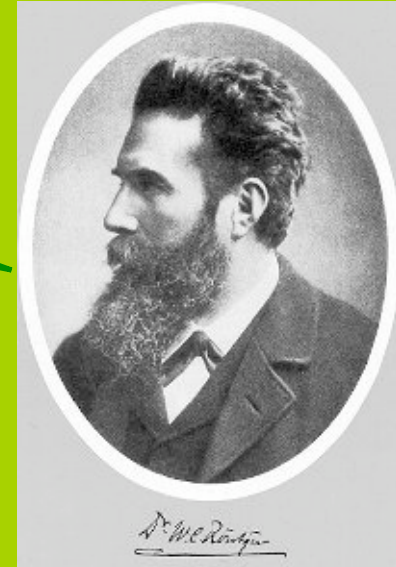
1888-1918
Guglielmo II

1870	Guerra franco-prussiana
1871	Unificazione tedesca
1914	Inizio Grande Guerra

Il valore della scoperta scientifica

La mia scoperta
appartiene al mondo intero.

Roentgen rifiuta di brevettare la sua scoperta,
favorendo così il rapido sviluppo delle applicazioni.



- Röntgen comunica subito ai colleghi di tutto il mondo la sua scoperta, illustra gli esperimenti condotti e le sue ipotesi.
- Fisici, medici e molti altri iniziano subito a studiare e utilizzare la nuova radiazione.

La scoperta si diffonde

28-12-1895 Röntgen invia all'Associazione Fisico-Medica di Würzburg e a colleghi sparsi in tutto il mondo la comunicazione della scoperta.

5-1-1896 *Neue Freie Presse* (Vienna)

6-1-1896 *Frankfurter Zeitung*

7-1-1896 *London Standard*

8-1-1896 New York

12-1-1896 *Corriere della Sera*

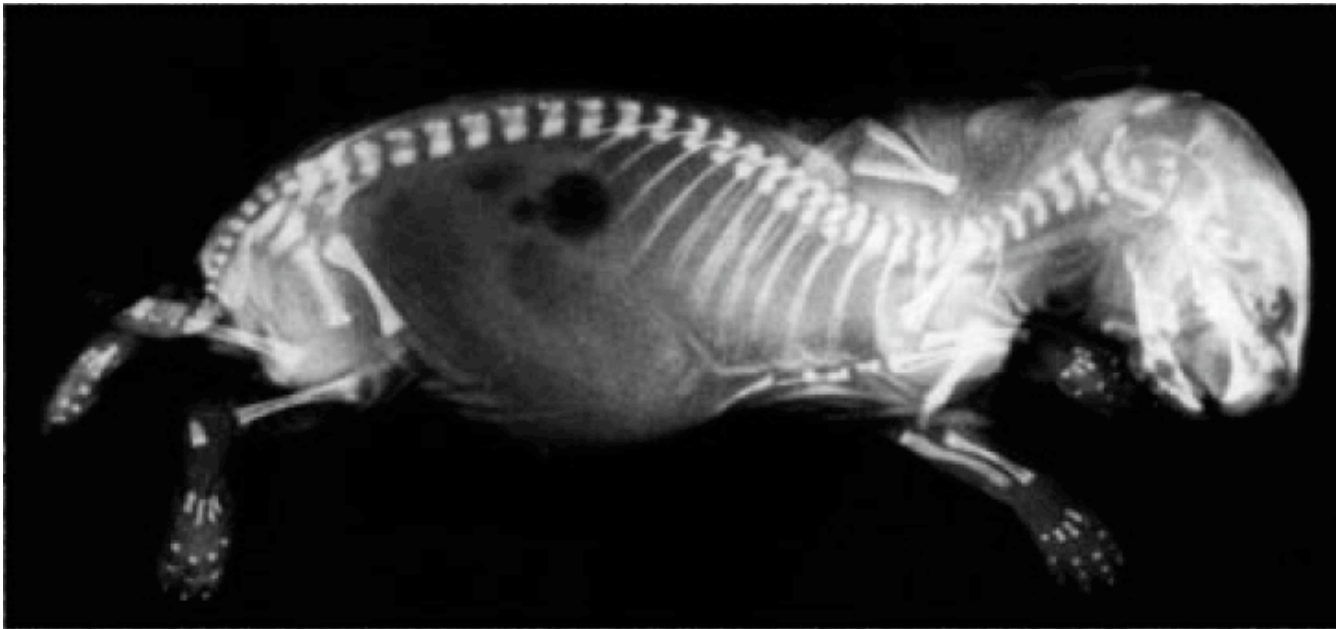
21-1-1896 *Alto Adige* (Trento)



Iniziano subito in Europa e in America le prime applicazioni mediche:

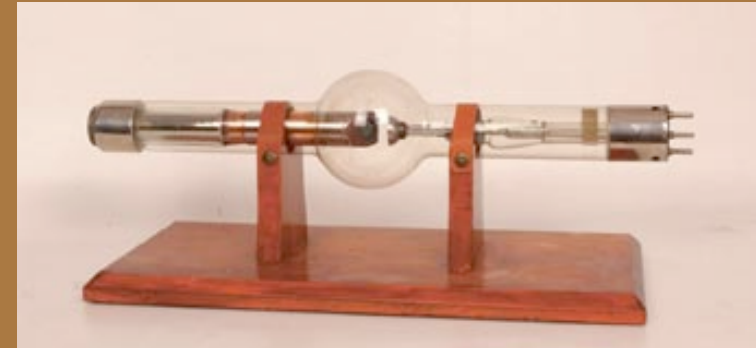
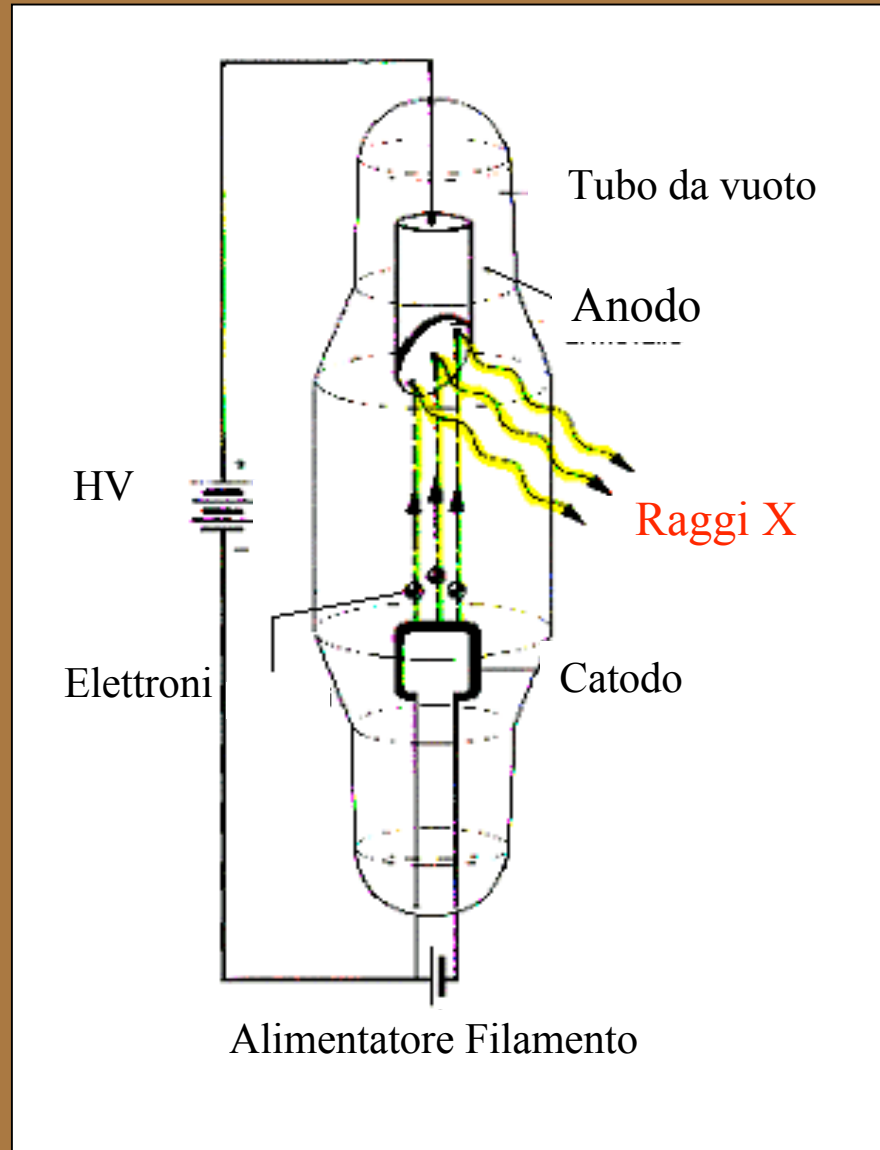
Febbraio 1896: primo trattamento contro il cancro a base di raggi X

Maggio 1896: prime radiografie in guerra (guerra italo-etioptica).



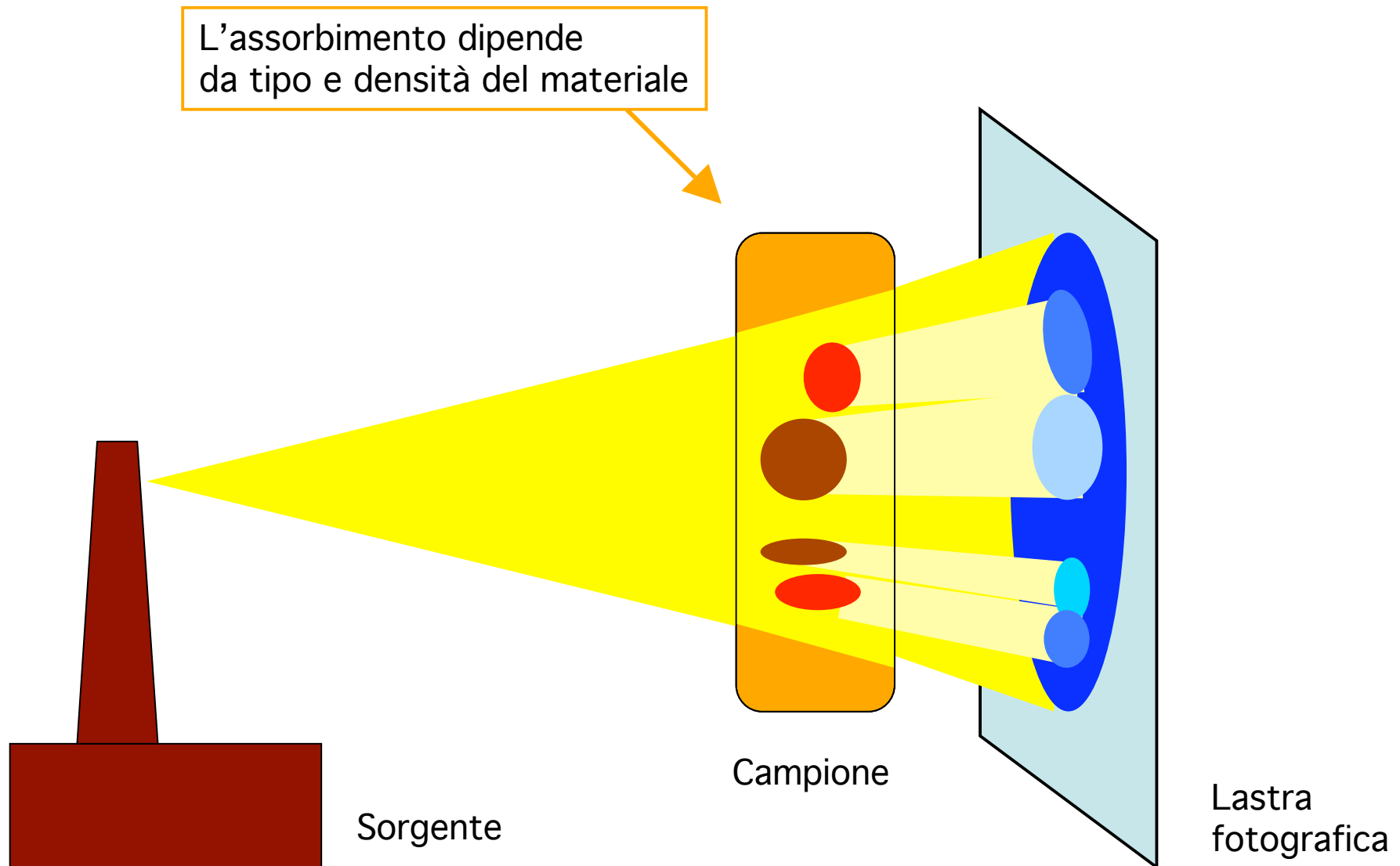
Radiografia

I tubi a raggi X



Tubo di Coolidge, 1913

Il meccanismo della radiografia



Gli inizi della radiologia



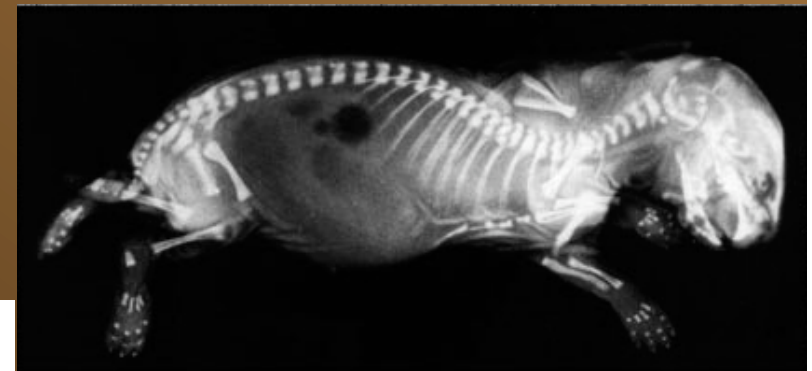
1903

WONDERFUL NEW RAY
SEES THROUGH HAND!



X-Ray Studio . . .
110 East Twenty-Sixty Street,
....New York City.

1896



L'evoluzione della radiologia

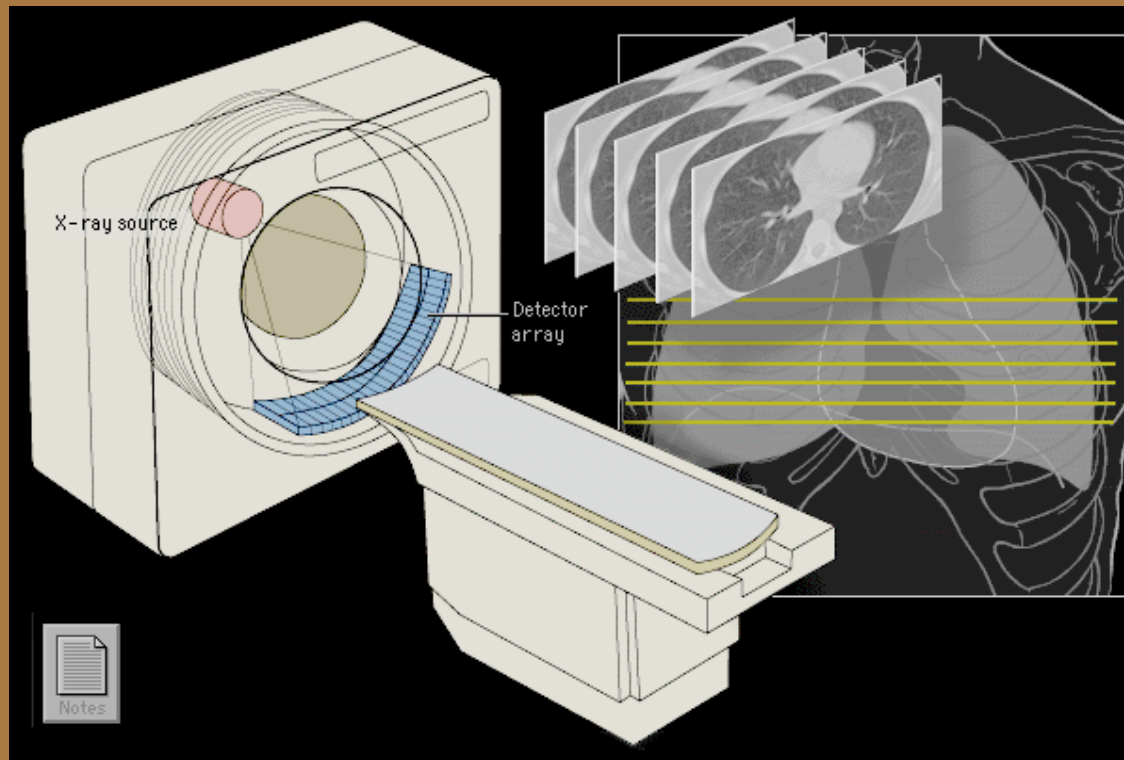


Dalle prime radiografie...



... alla TAC

Radiologia oggi



Tomografia
Assiale
Computerizzata



Il primo Nobel per la Fisica



1901 - W.K. Roentgen
Nobel per la Fisica

Altri Nobel per ricerche con raggi X

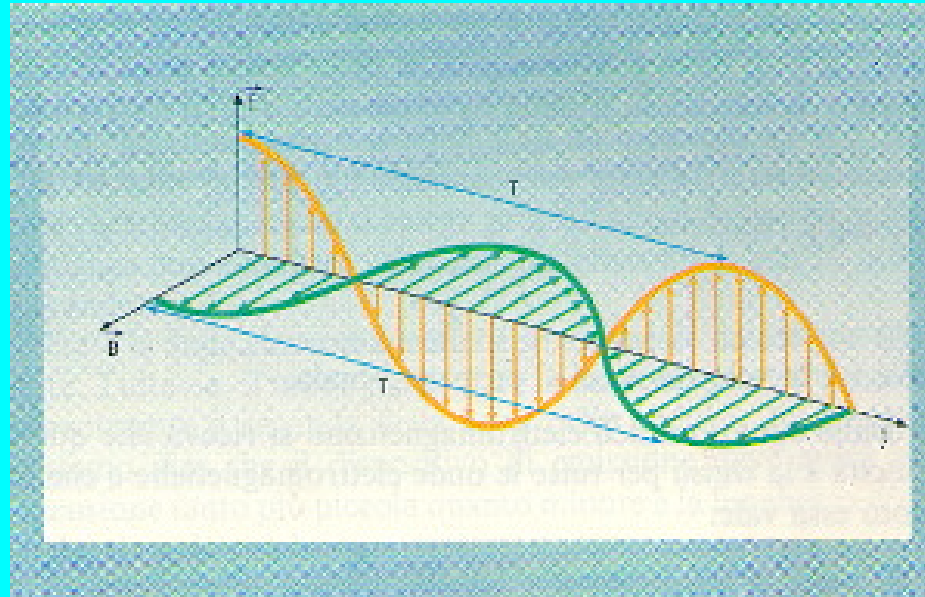
- 6 per la Fisica
- 4 per la Chimica
- 2 per la Medicina



Cosa sono i raggi X ?

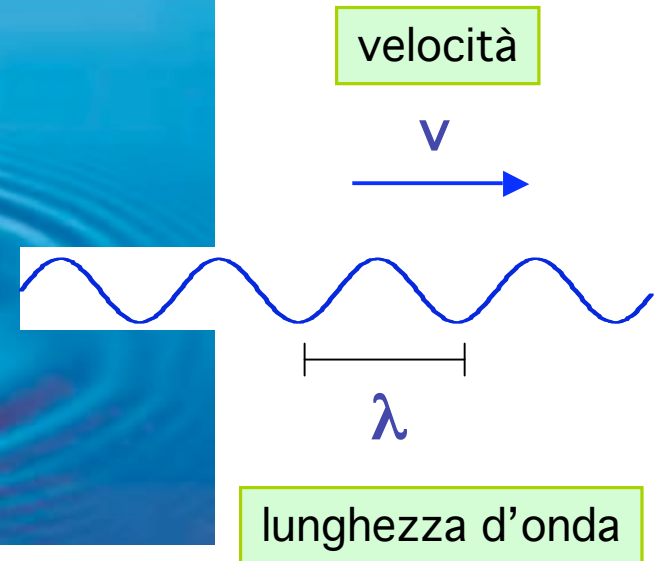
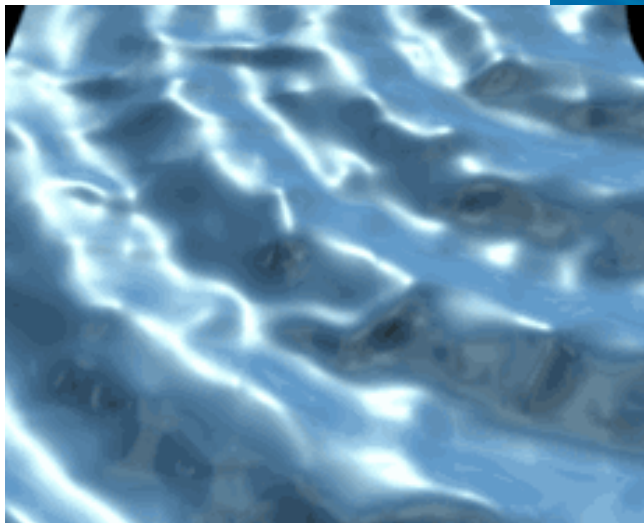
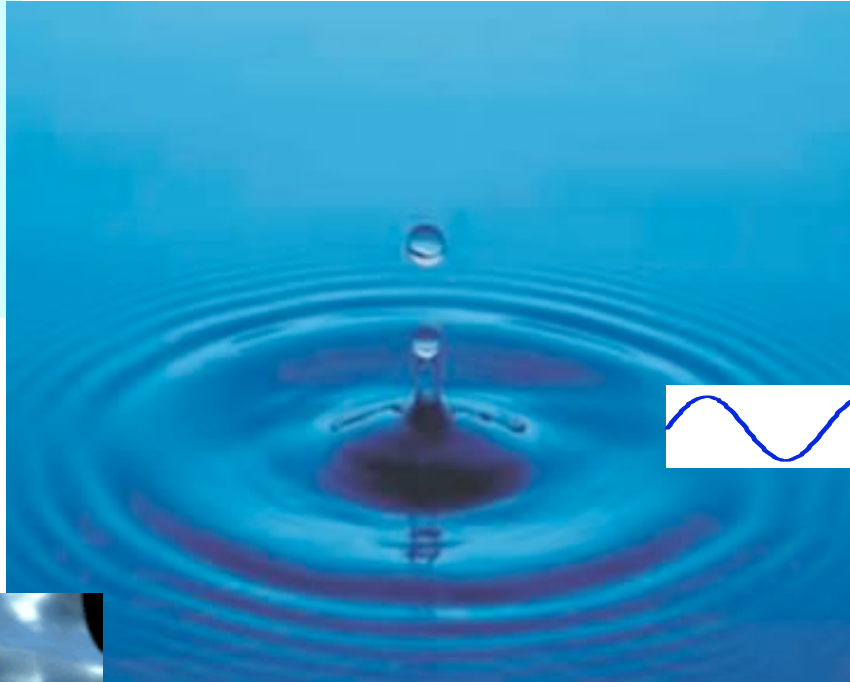


Cosa sono i raggi X



I raggi X sono
onde elettromagnetiche

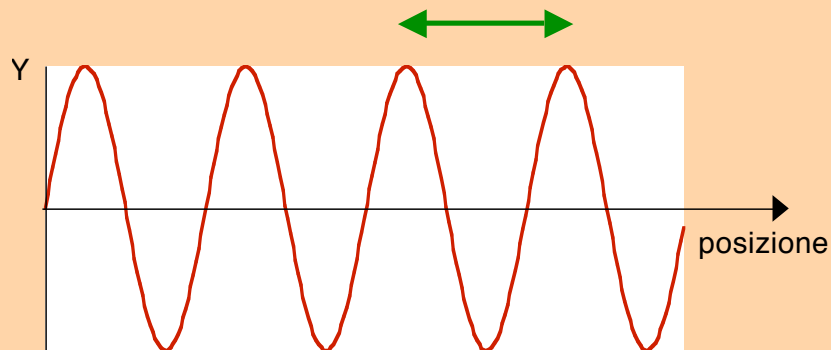
Onde nell'acqua



La fisica delle onde

Istante fisso

Lunghezza d'onda λ

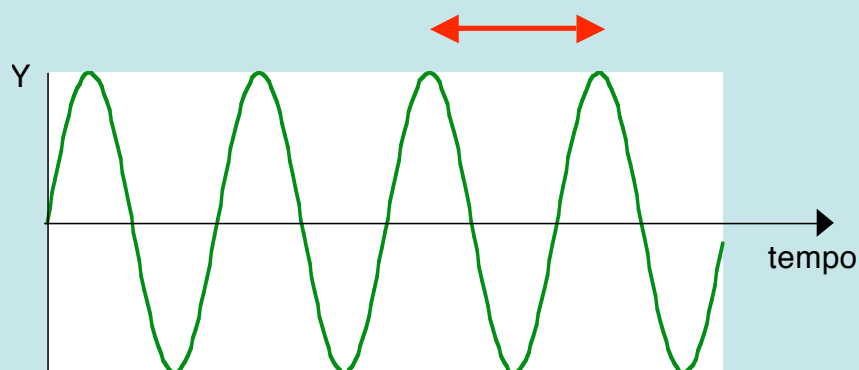


Frequenza

$$\nu = \frac{1}{T}$$

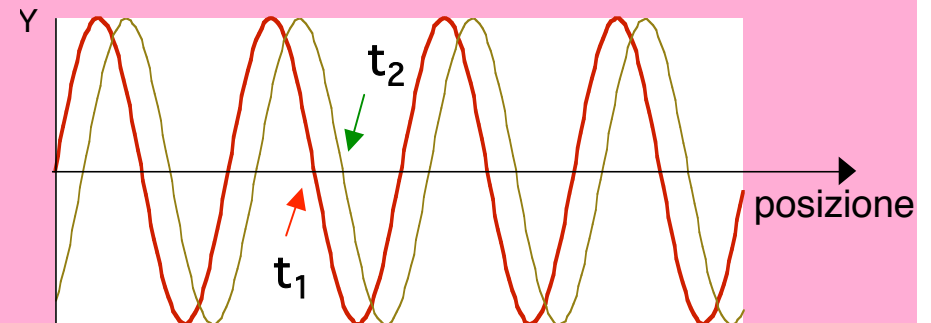
Posiz. fissa

Periodo T

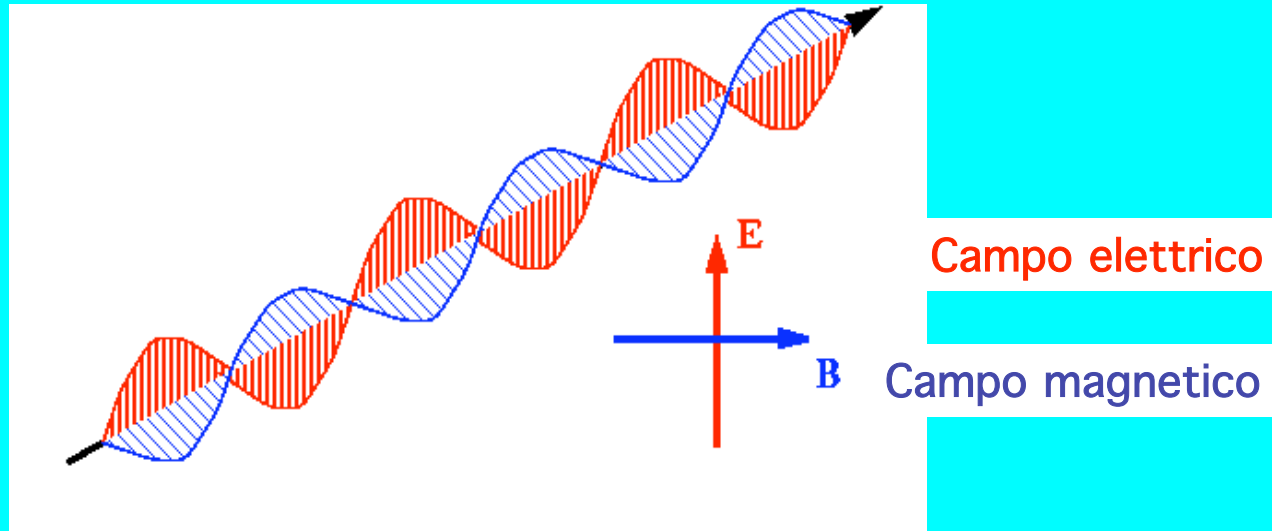


Velocità di propagazione

$$v = \frac{\lambda}{T} = \lambda \nu$$



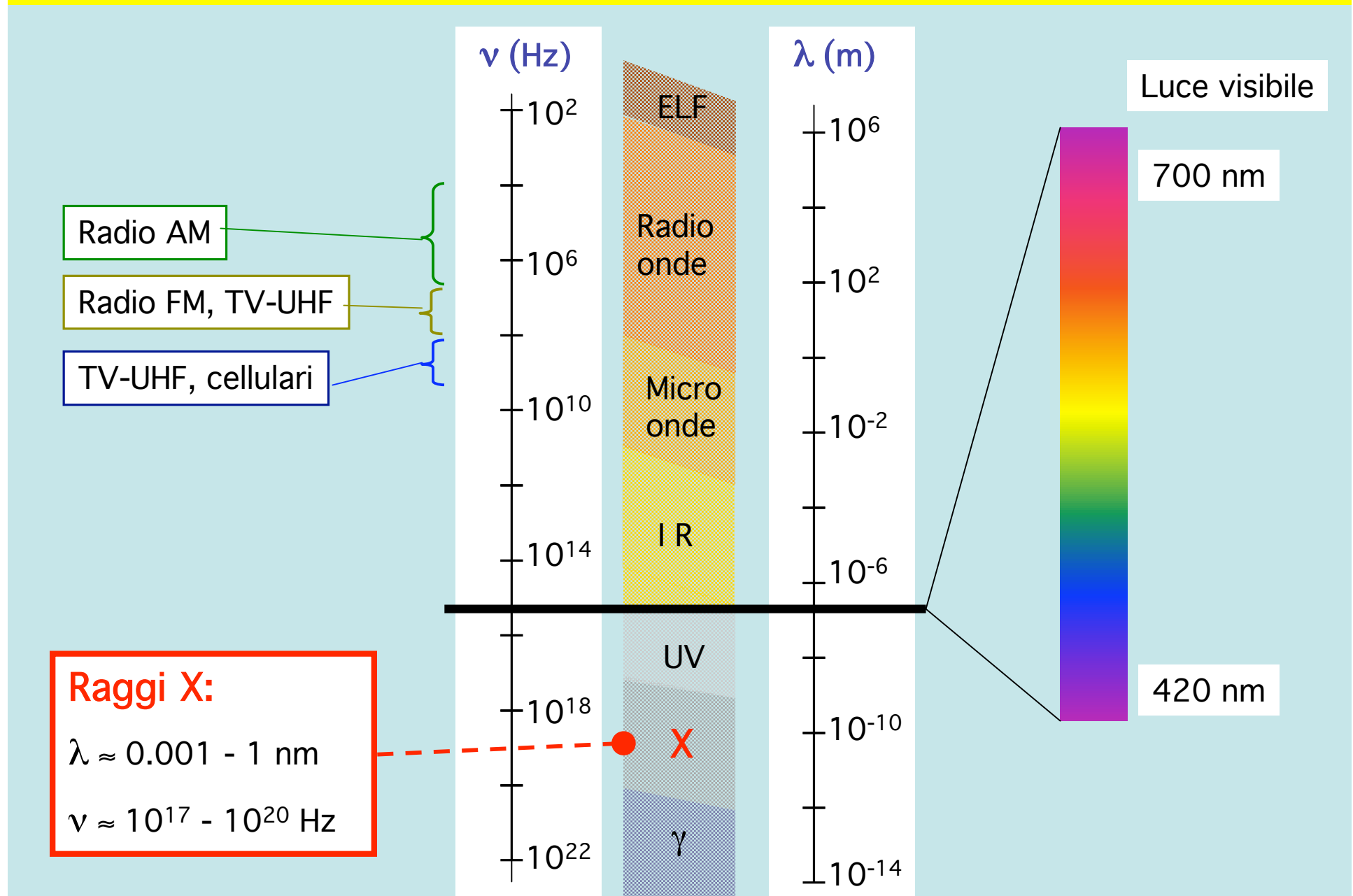
Onde elettromagnetiche



Velocità di propagazione nel vuoto:

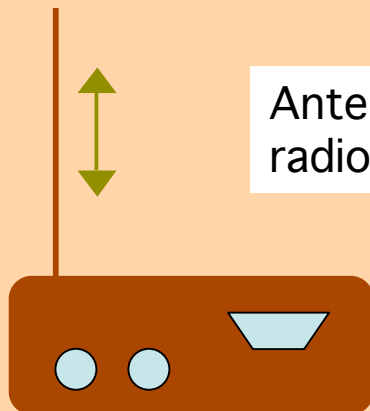
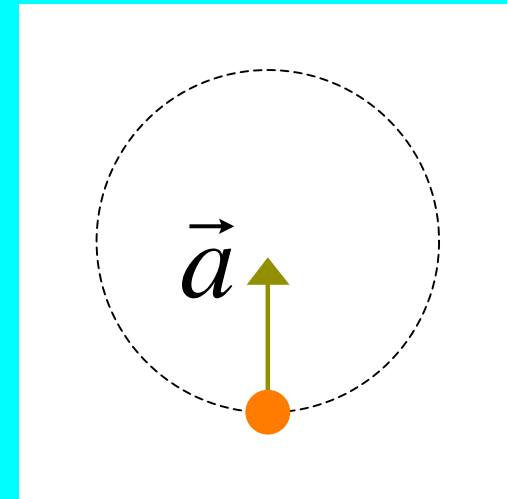
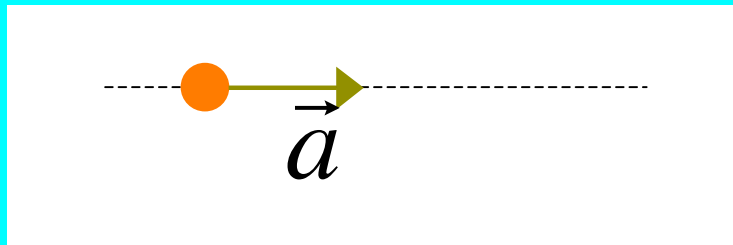
$$c = 299792458 \text{ m/s}$$
$$\approx 3 \times 10^8 \text{ m/s}$$

Lo spettro elettromagnetico



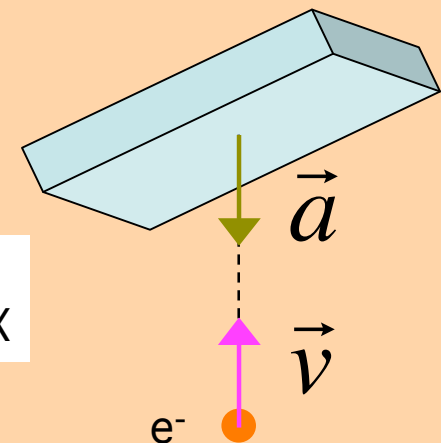
Generazione di onde elettromagnetiche

Una carica elettrica accelerata emette onde elettromagnetiche



Antenna
radio/trasmittente

Anodo di
tubo a raggi X



Raggi X e Fisica Moderna

- Storia dell'atomo
- Struttura dei cristalli
- Spettroscopia atomica



Fisica “Classica” e Fisica “Moderna”

1700

1800

1900

2000

Meccanica classica

Termodinamica

Elettromagn.

Atomi
Particelle sub-atomiche
Relatività
Meccanica quantistica

1700

1800

1900

2000

Breve storia dell'atomo

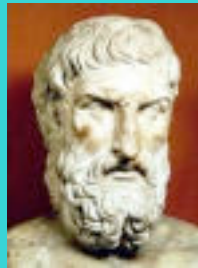
ELEMENTS					
	Hydrogen.	1		Strontian	46
	Azote	5		Barytes	68
	Carbon	5		Iron	50
	Oxygen	7		Zinc	56
	Phosphorus	9		Copper	56
	Sulphur	13		Lead	90
	Magnesia	20		Silver	190
	Lime	24		Gold	190
	Soda	28		Platina	190
	Potash	42		Mercury	167

Atomi: le origini

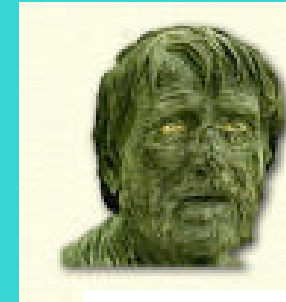
- Atomi
- discontinuità



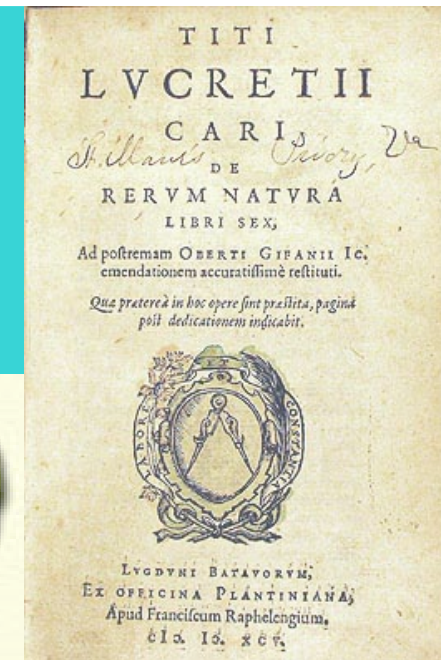
Democrito



Epicuro



T. Lucrezio Caro



500

400

300

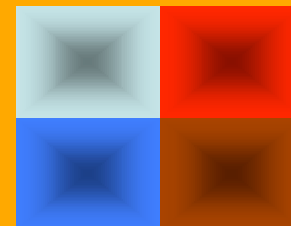
200

100

AC

Empedocle

Aristotele



- 4 elementi
- continuità

L' "ipotesi atomica" in chimica

J.L. Proust

- proporzioni costanti

J. Dalton

- proporz. multiple
- atomi

Gay-Lussac

- gas: rapporti di volume

Berzelius

- simboli chimici

Group	I	II	III	IV	V	VI	VII	VIII
Period 1	H=1							
2	Li=7	Be=9.4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5	
4	K=39	Ca=40	?=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59 Ni=59
5	Cu=63	Zn=65	?=68	?=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	?=100	Ru=104, Rh=104 Pd=106
7	Ag=108	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140				
9								
10			?Er=178	?La=180	Ta=182	W=184		Os=195, Ir=197 Pt=198
11	Au=199	Hg=200	Tl=204	Pb=207	Bi=208			
12				Th=231		U=240		

He

1700

1800

1900

A.L. Lavoisier

- elementi chimici
- qualità delle particelle

1860

S. Cannizzaro

1811 - A. Avogadro

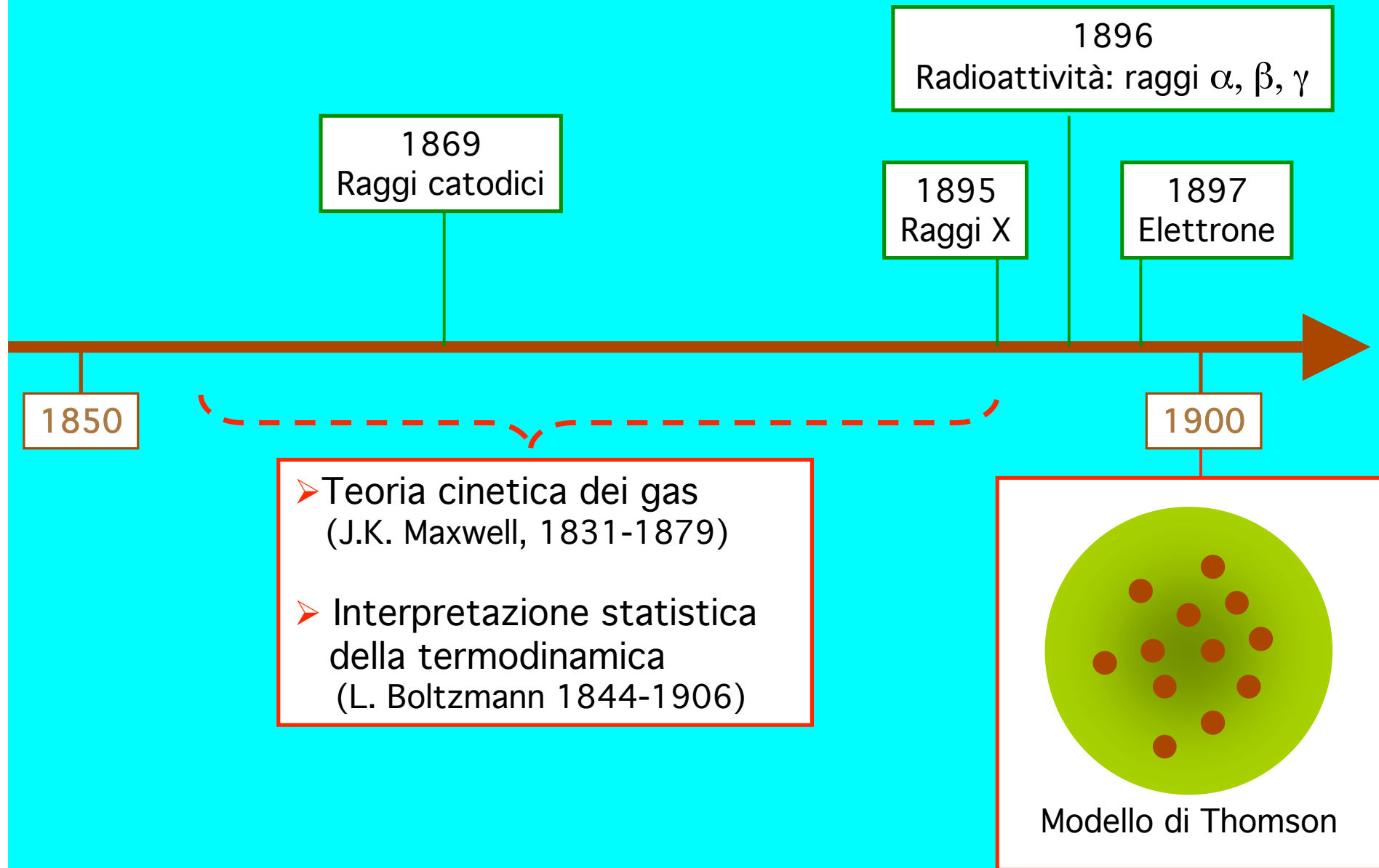
- atomi e molecole
- legge del volume di gas diversi

R. Boyle

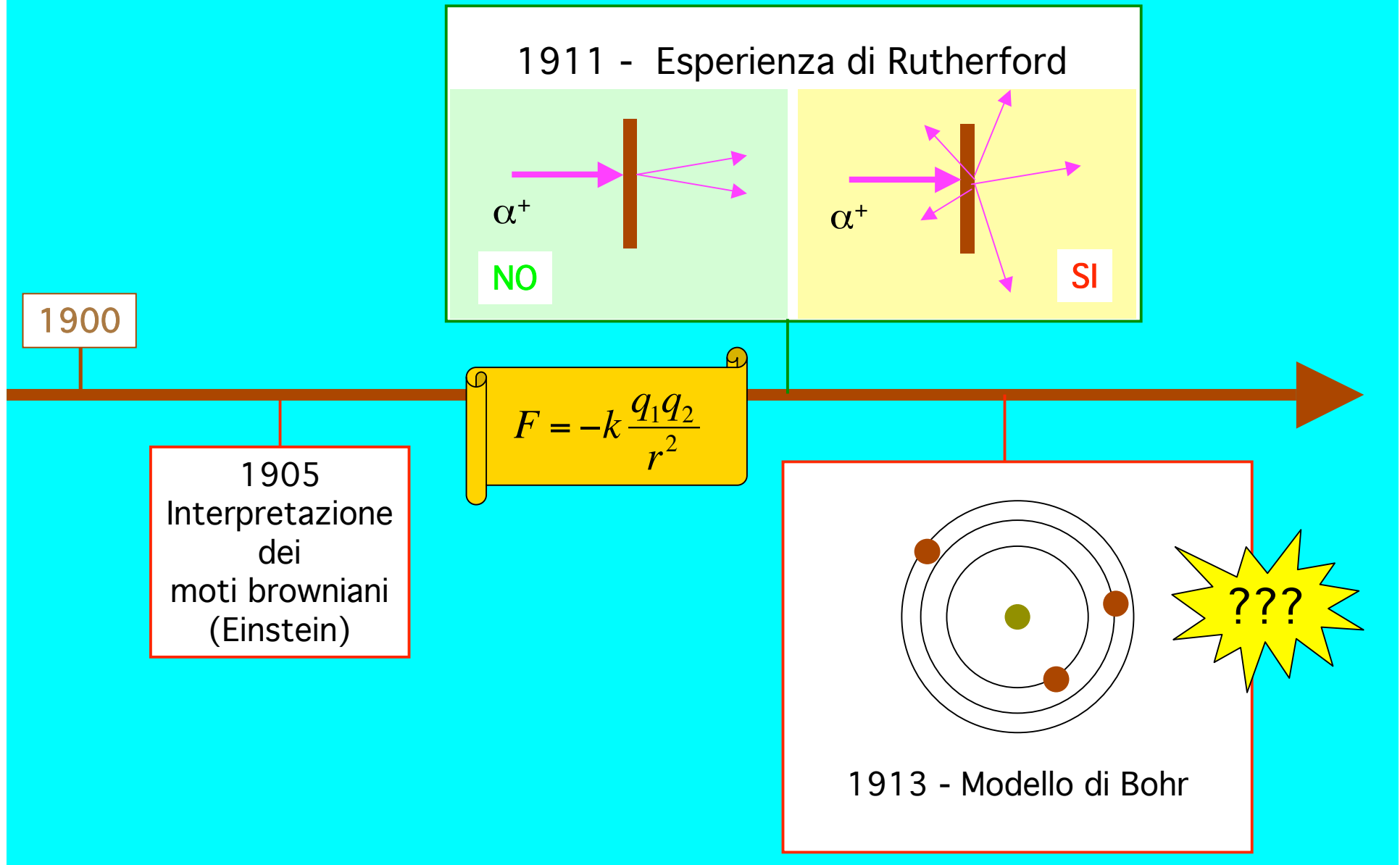
Materia = particelle in movimento

S. Arrhenius
dissociazione elettrolitica

L' "ipotesi atomica" in fisica (1)



L' "ipotesi atomica" in fisica (2)



La struttura dei cristalli

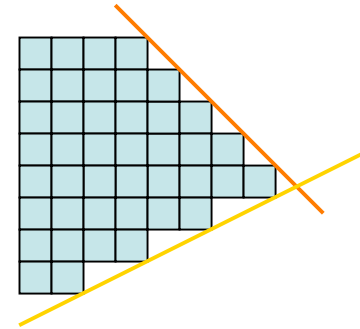


Cristalli



Cristallo di quarzo (SiO_2)

Legge della costanza degli angoli
R. de l'Isle (1736-1790)



Impaccamento regolare
di unità strutturali microscopiche
R.J. Haüy (1743-1822)

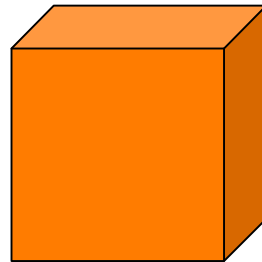
Classificazione dei cristalli

Atomi e cristalli

IPOTESI:

Unità strutturali = atomi

Esempio: NaCl

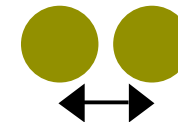


Masse atomiche: Na $38,12 \times 10^{-24}$ g
Cl $58,85 \times 10^{-24}$ g

Struttura cubica

1 cm^3 $m = 2,165 \text{ g}$

$N = 44,6 \times 10^{21}$ atomi



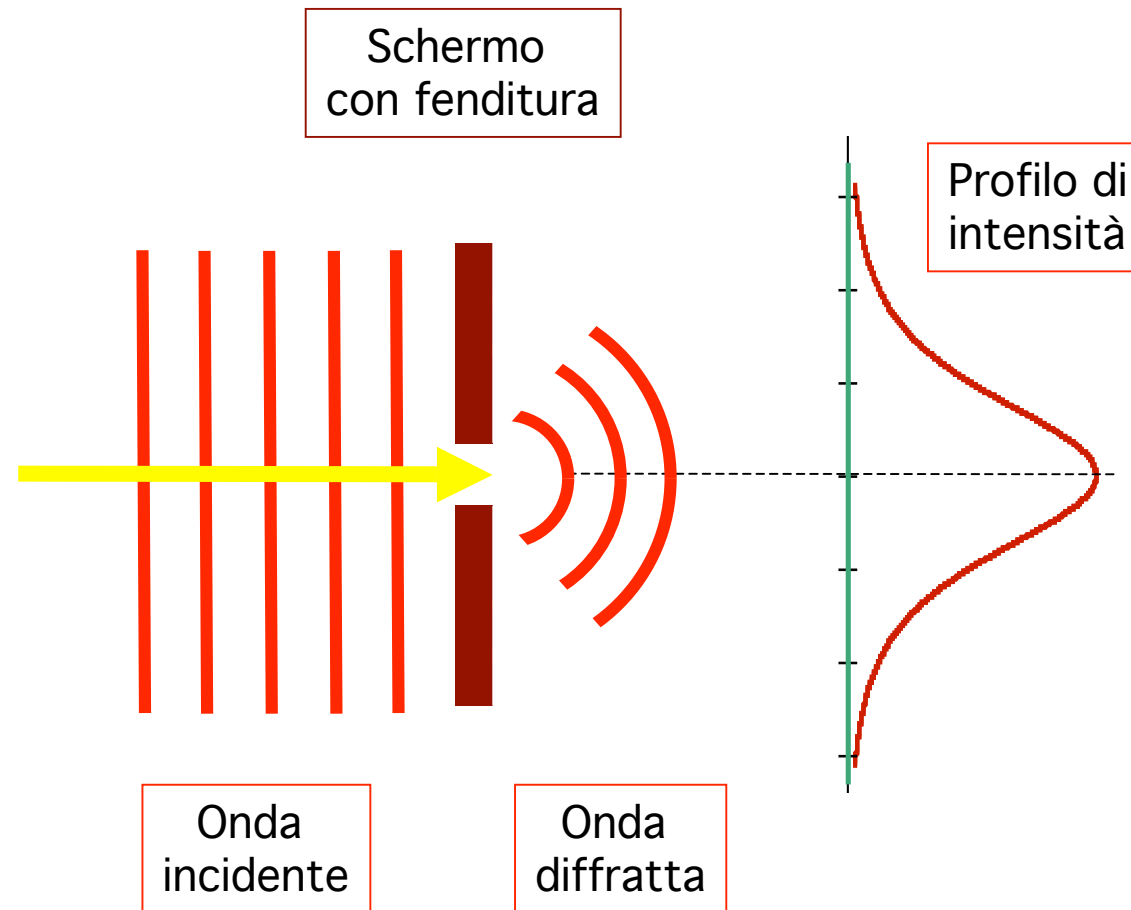
0,28 nm

CONCLUSIONE:

Distanze interatomiche
Dimensioni atomiche

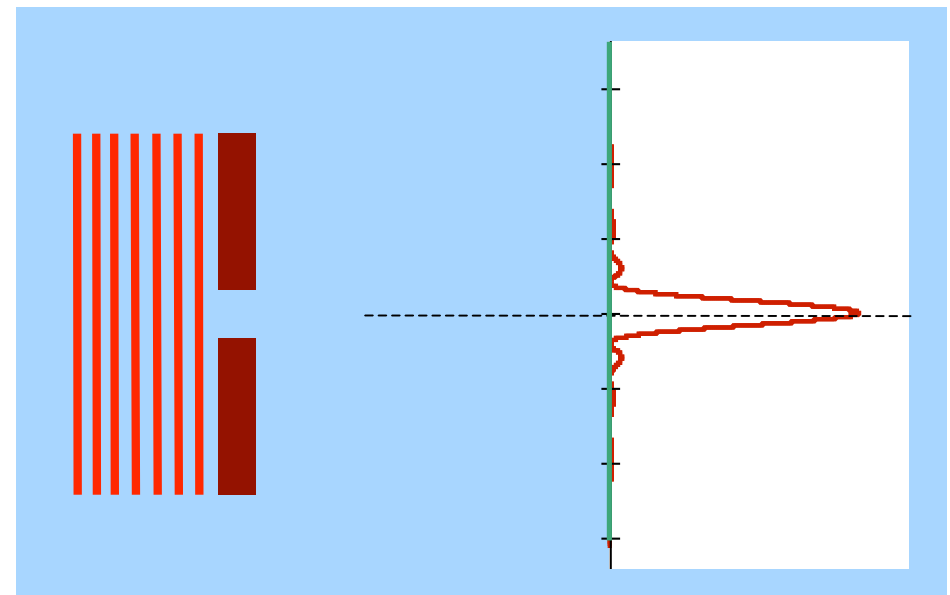
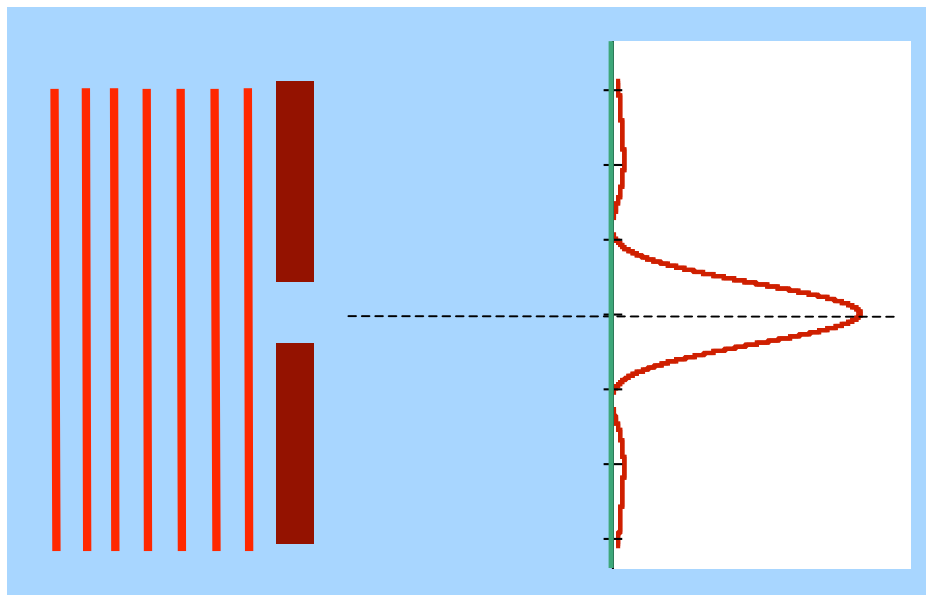
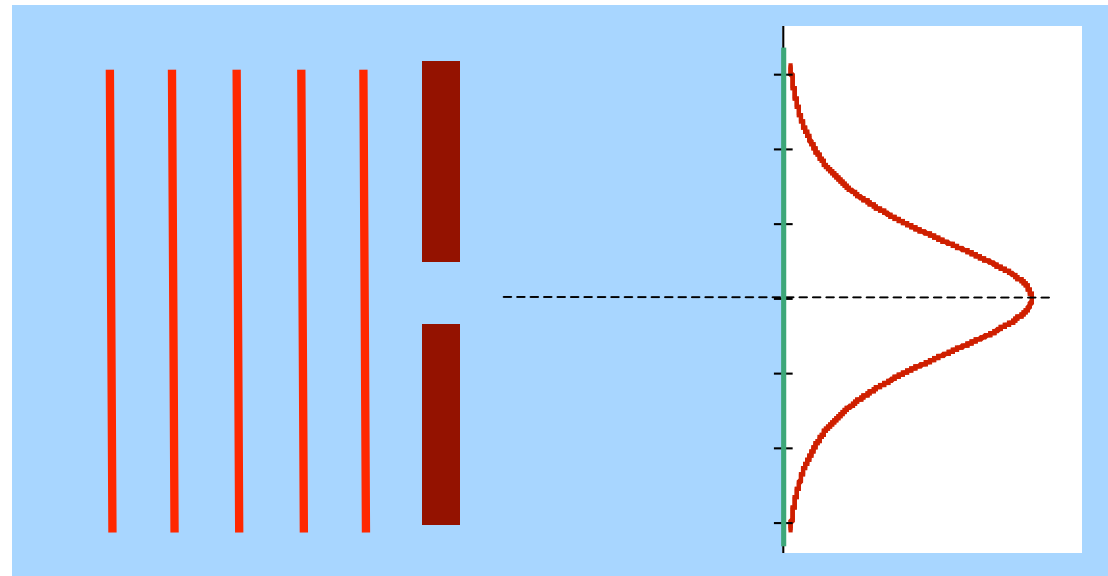
\approx lunghezze d'onda raggi X

Diffrazione (1)



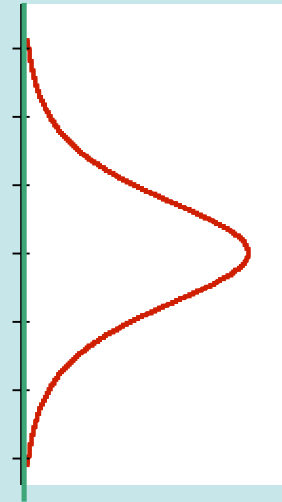
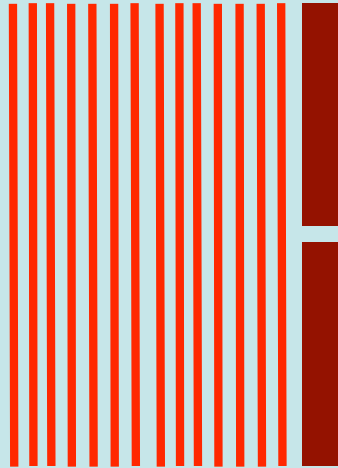
Luce visibile, $\lambda \approx 400 - 700 \text{ nm}$

Diffrazione (2)



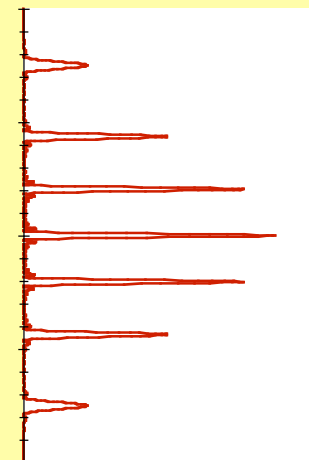
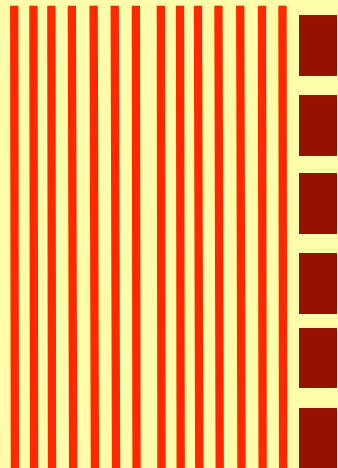
Reticoli di diffrazione (1)

1 fenditura



Diffrazione

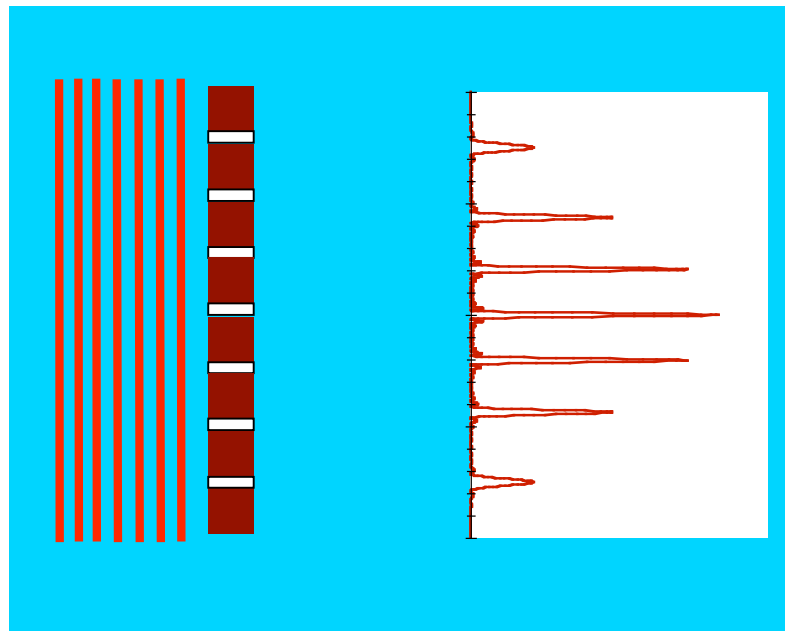
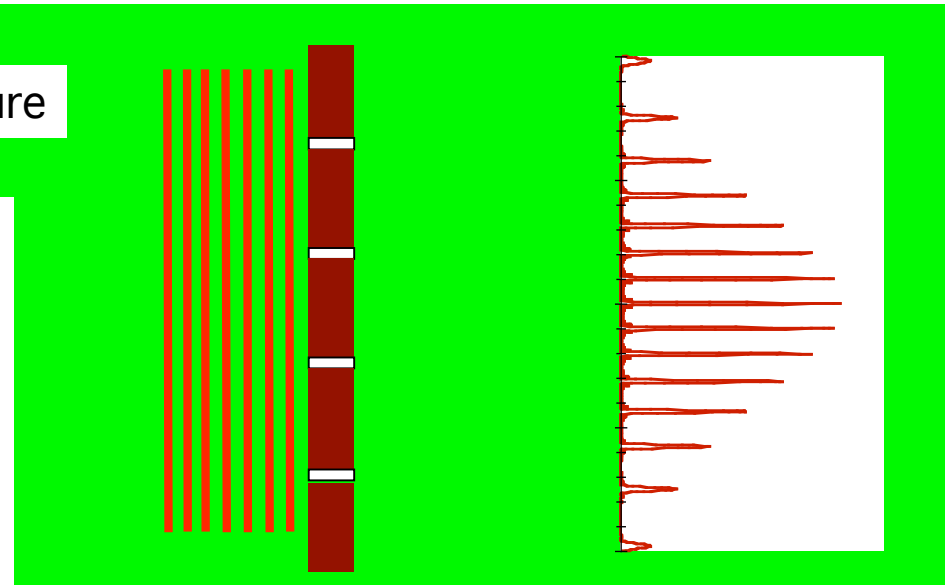
N fenditure



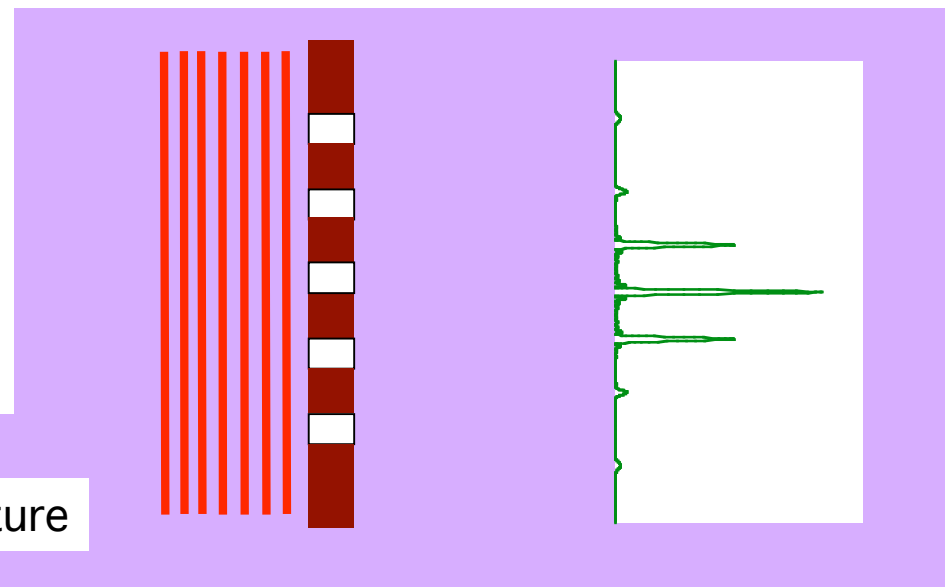
Diffrazione
+
interferenza

Reticoli di diffrazione (2)

Distanza tra le fenditure

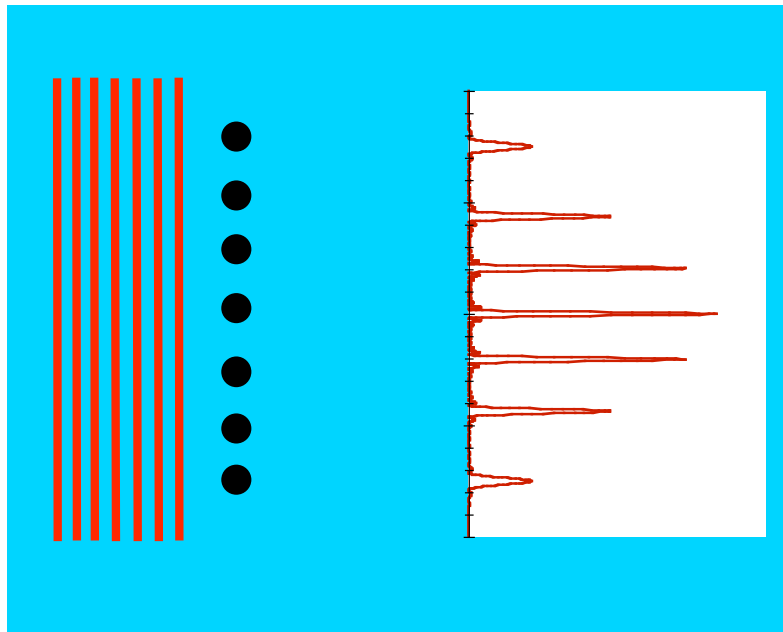
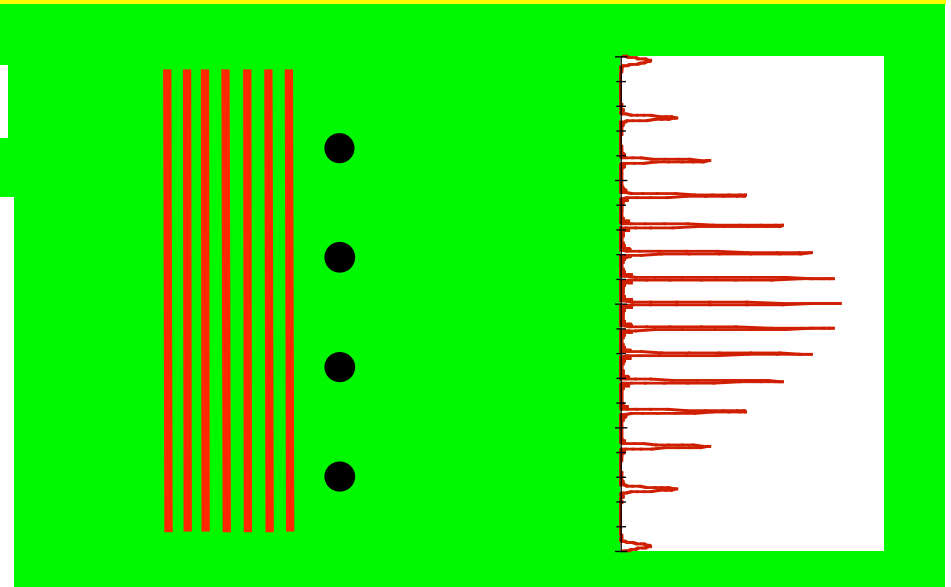


Larghezza delle fenditure

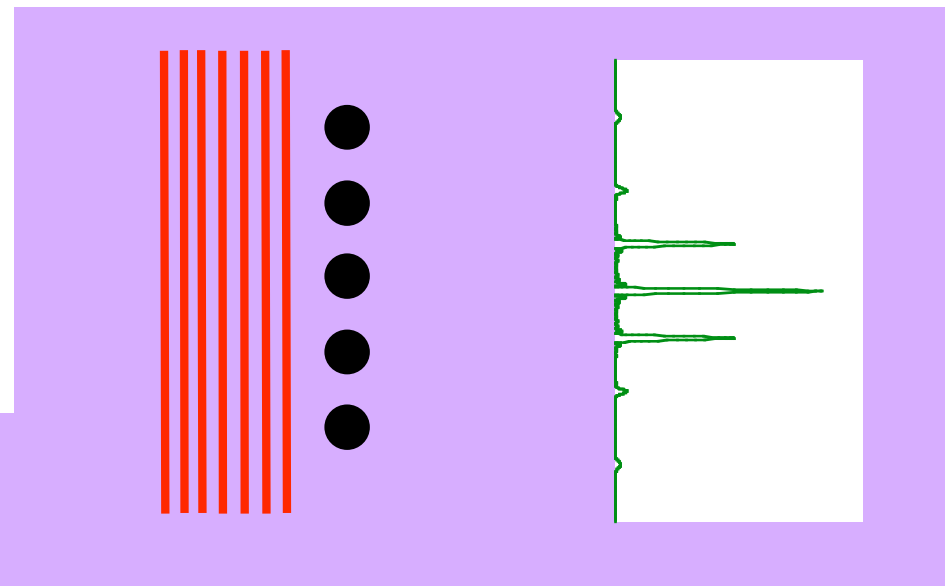


Reticoli di diffrazione (2)

Distanza tra gli atomi

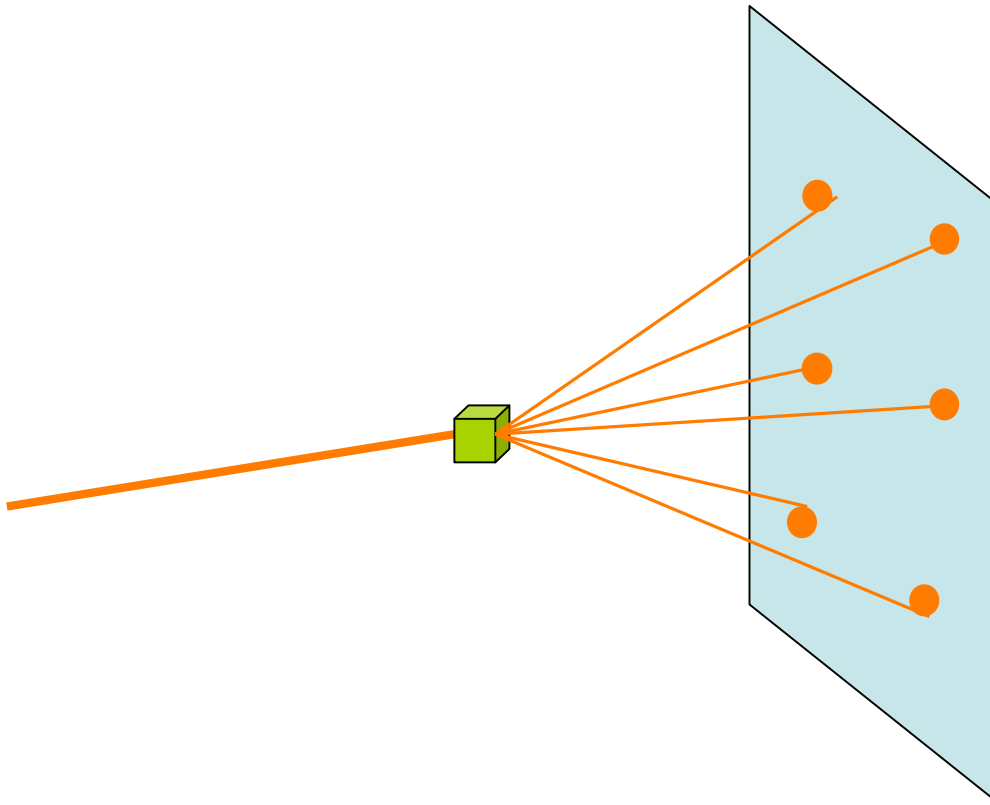


Dimensioni atomiche



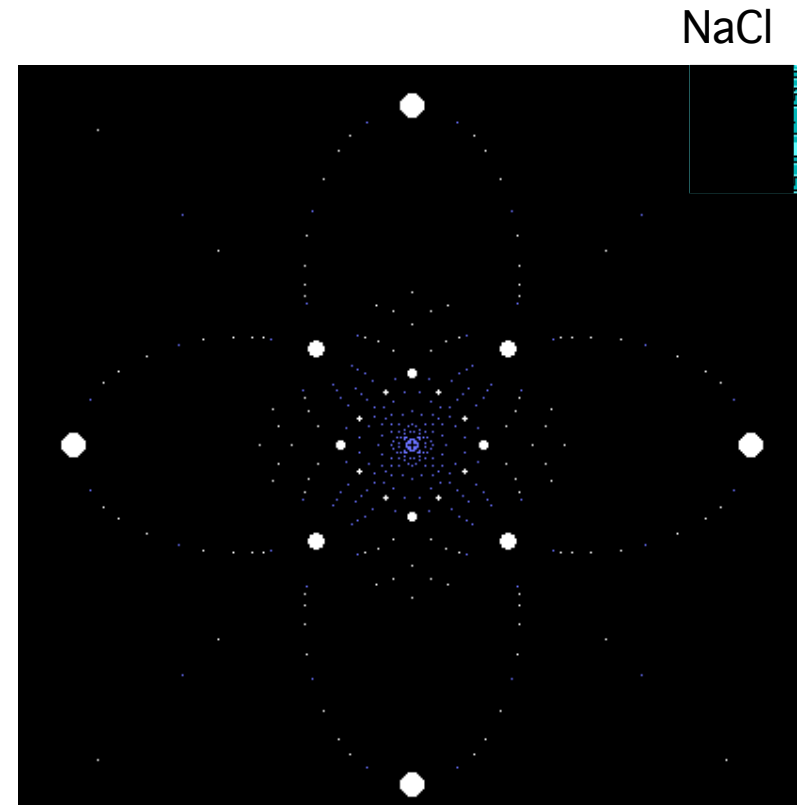
Diffrazione X da cristalli

Fenditure → centri diffusori (atomi)
1 dimensione → 3 dimensioni

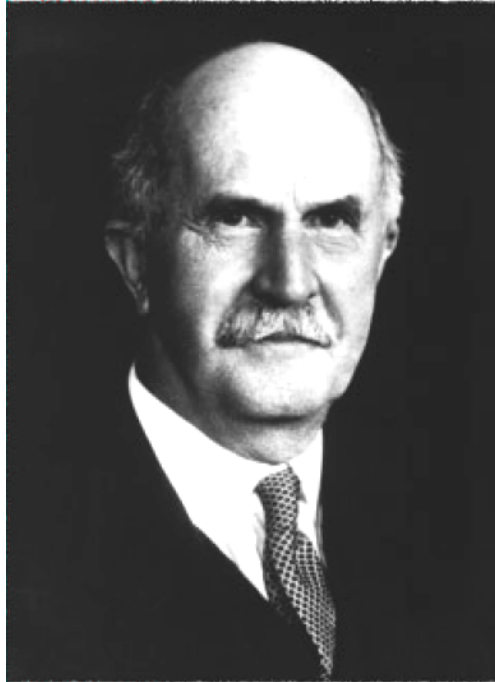


Monaco di Baviera, 1912:

- Max von Laue
- W. Friedrich & P. Knipping

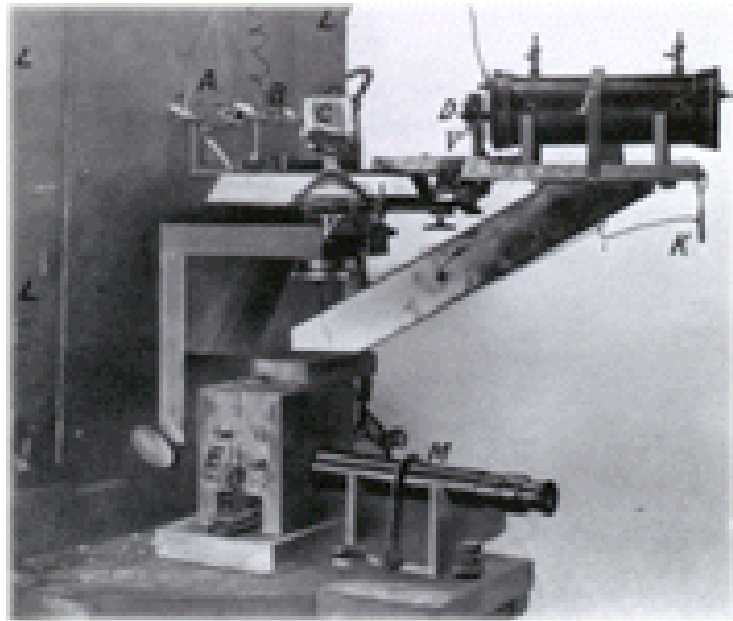


Cristallografia

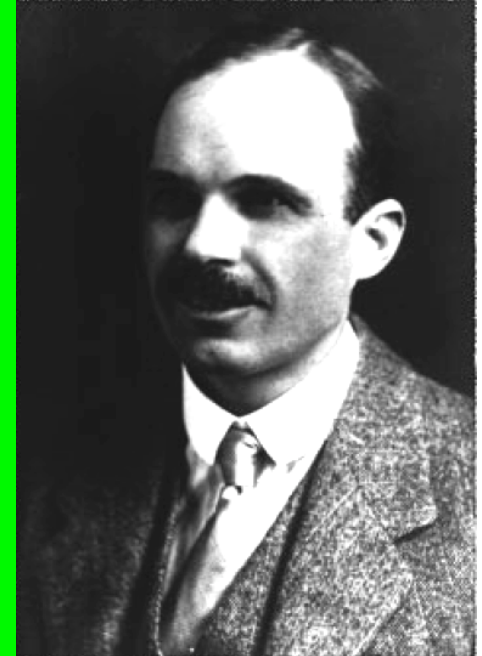


William Henry Bragg
(1862-1942)

Cambridge, 1912/13

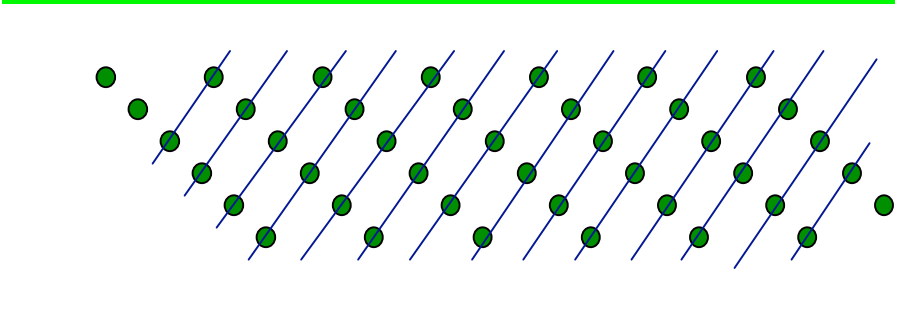
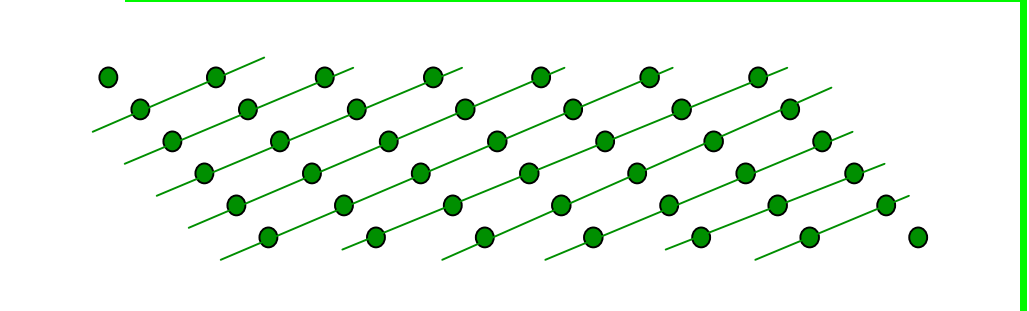
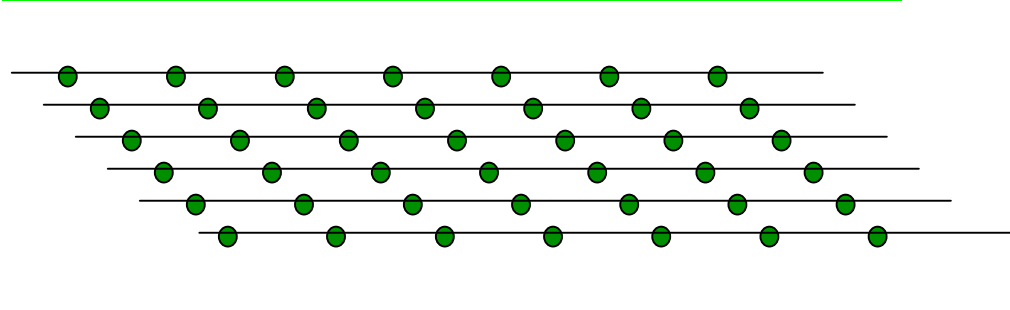
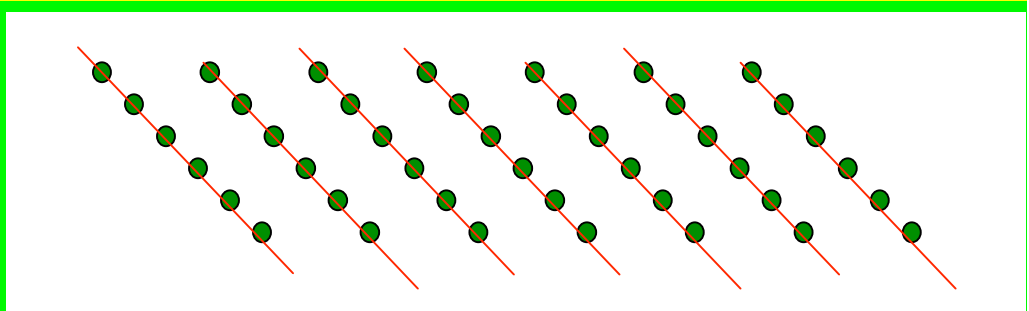


Uno spettrometro di Bragg

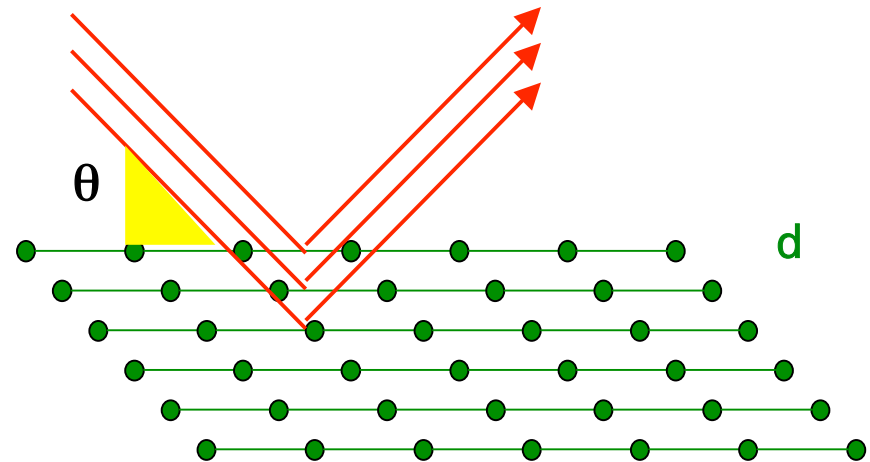
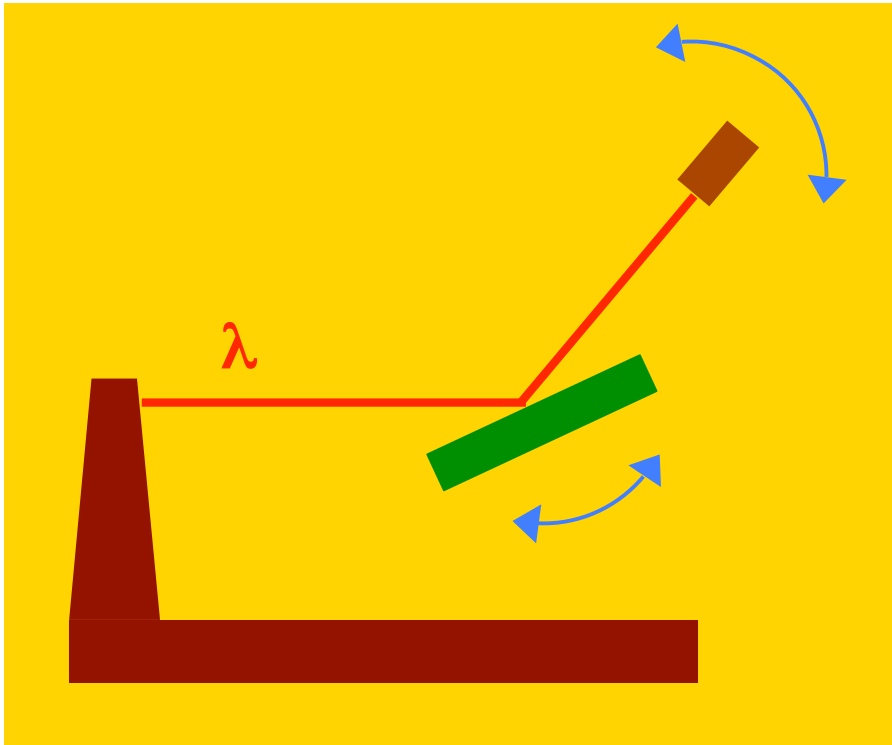


William Lawrence Bragg
(1890-1971)

Piani cristallini



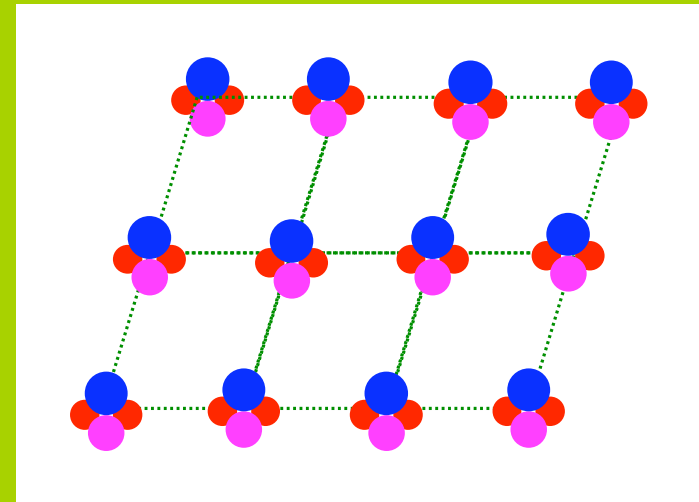
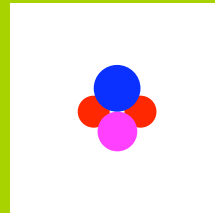
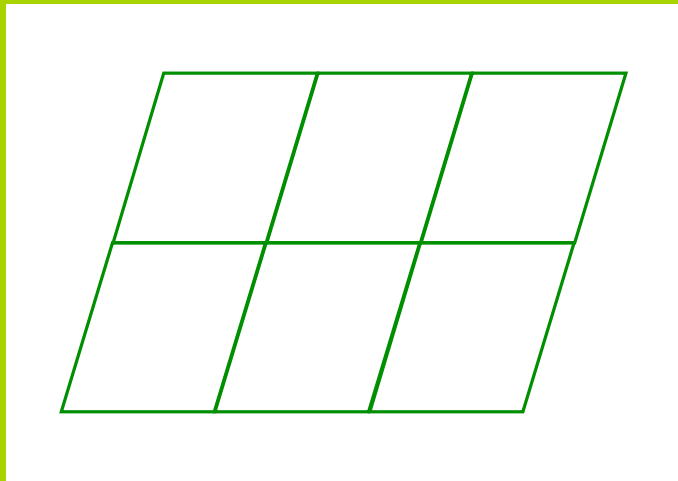
La legge di Bragg



$$2d_{hkl} \sin \theta = n \lambda$$

Condizione per interferenza costruttiva

La struttura dei cristalli



Reticolo geometrico

+

base

=

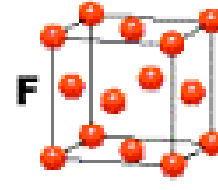
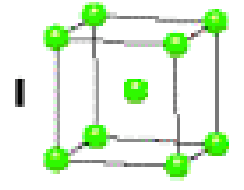
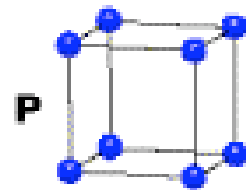
struttura cristallina

I reticoli cristallini

CUBIC

$$a = b = c$$

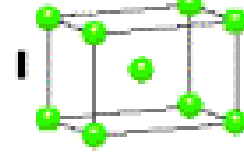
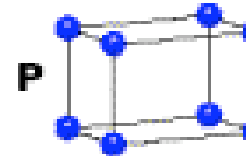
$$\alpha = \beta = \gamma = 90^\circ$$



TETRAGONAL

$$a = b \neq c$$

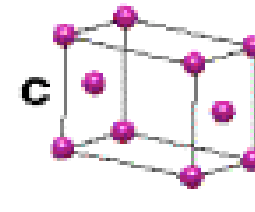
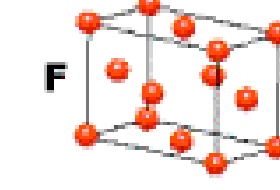
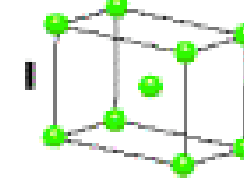
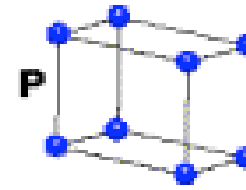
$$\alpha = \beta = \gamma = 90^\circ$$



ORTHORHOMBIC

$$a \neq b \neq c$$

$$\alpha = \beta = \gamma = 90^\circ$$

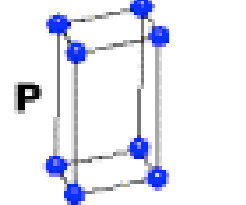


HEXAGONAL

$$a = b \neq c$$

$$\alpha = \beta = 90^\circ$$

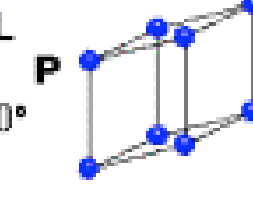
$$\gamma = 120^\circ$$



TRIGONAL

$$a = b = c$$

$$\alpha = \beta = \gamma \neq 90^\circ$$

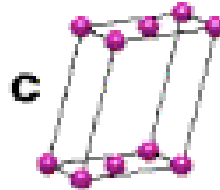
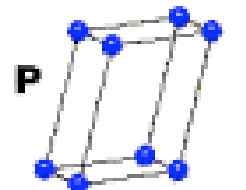


MONOCLINIC

$$a \neq b \neq c$$

$$\alpha = \gamma = 90^\circ$$

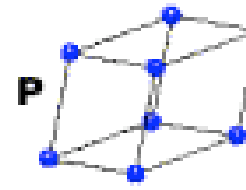
$$\beta \neq 120^\circ$$



TRICLINIC

$$a \neq b \neq c$$

$$\alpha \neq \beta \neq \gamma \neq 90^\circ$$



4 Types of Unit Cell

P = Primitive

I = Body-Centred

F = Face-Centred

C = Side-Centred

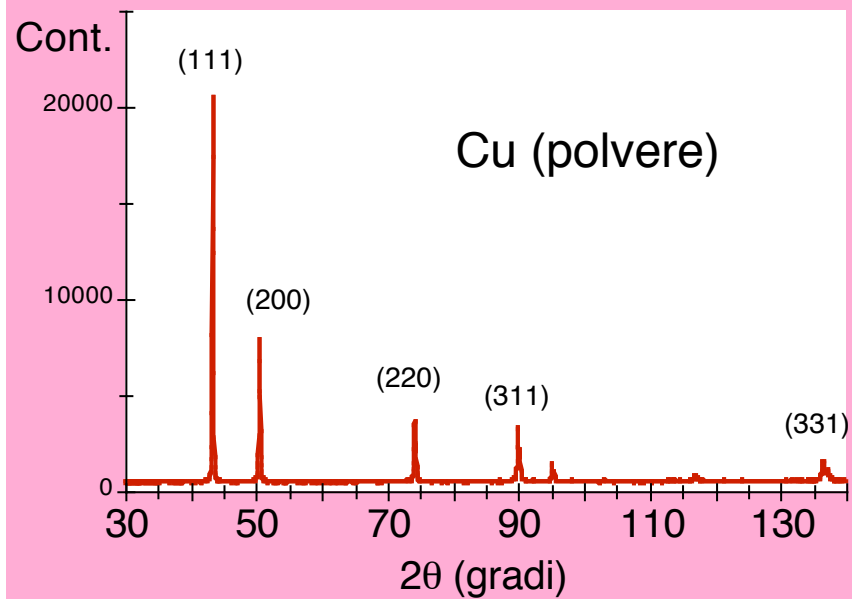
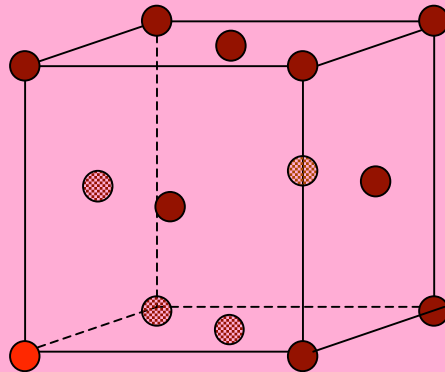
+

7 Crystal Classes

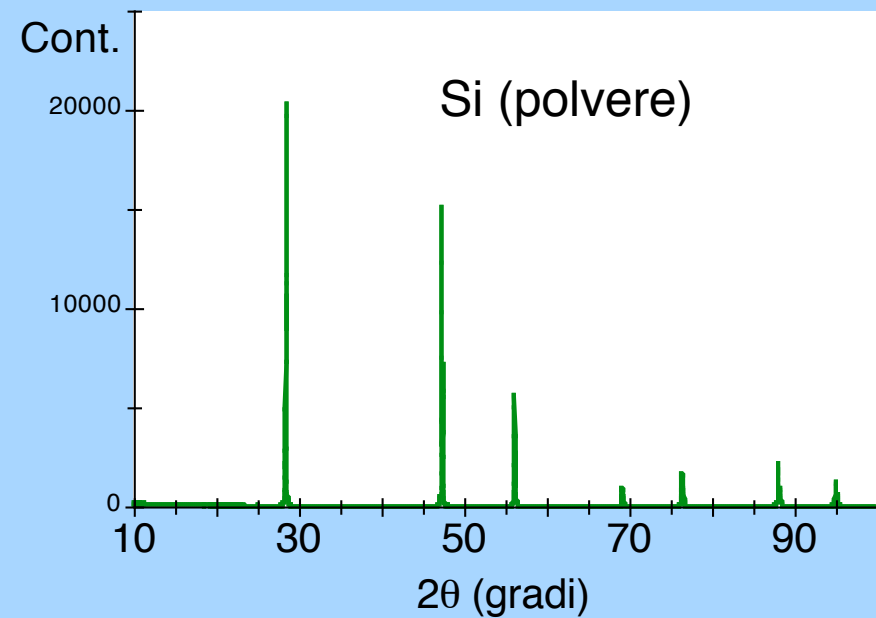
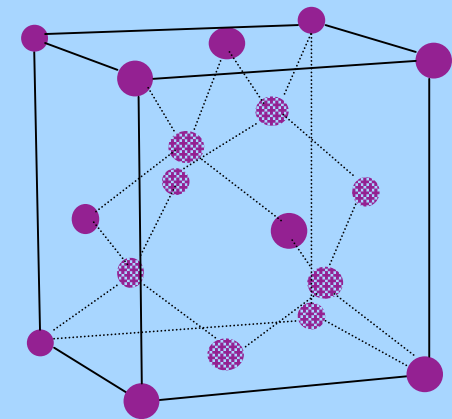
→ **14 Bravais Lattices**

Figure di diffrazione

Rame



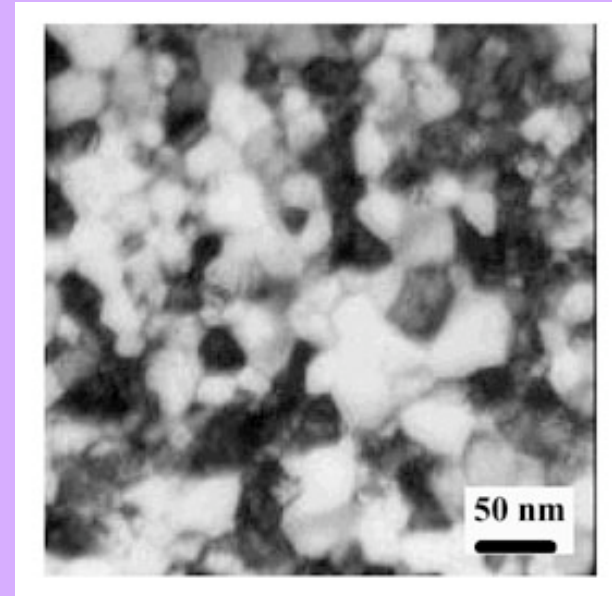
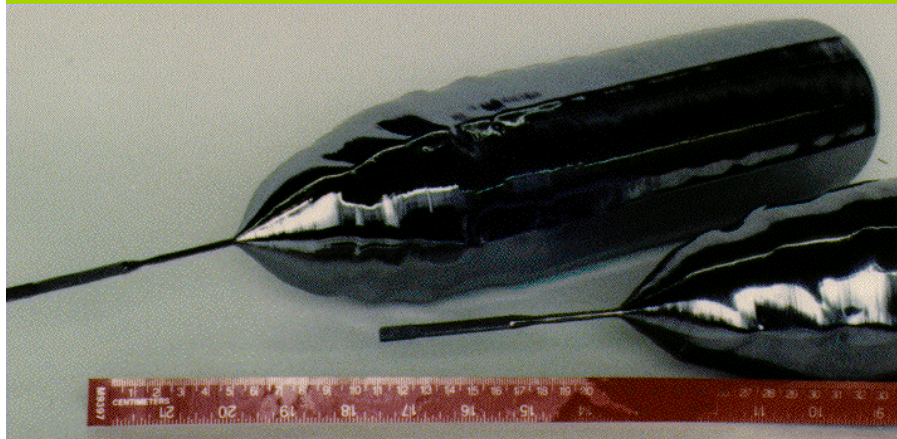
Silicio



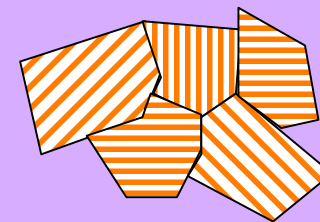
Macro e micro-cristalli



Silicio monocristallino, \varnothing 13 cm



Cromo, microscopia elettronica



Struttura a grani

La Fisica dello Stato Solido

Struttura microscopica dei materiali cristallini

Proprietà termodinamiche

- Calori specifici
- Dilatazione termica
- Conduzione termica

Proprietà elettriche

- Conducibilità elettrica
- Semiconduttori
- Superconduttori

Proprietà magnetiche

- Diamagnetismo
- Paramagnetismo
- Ferromagnetismo

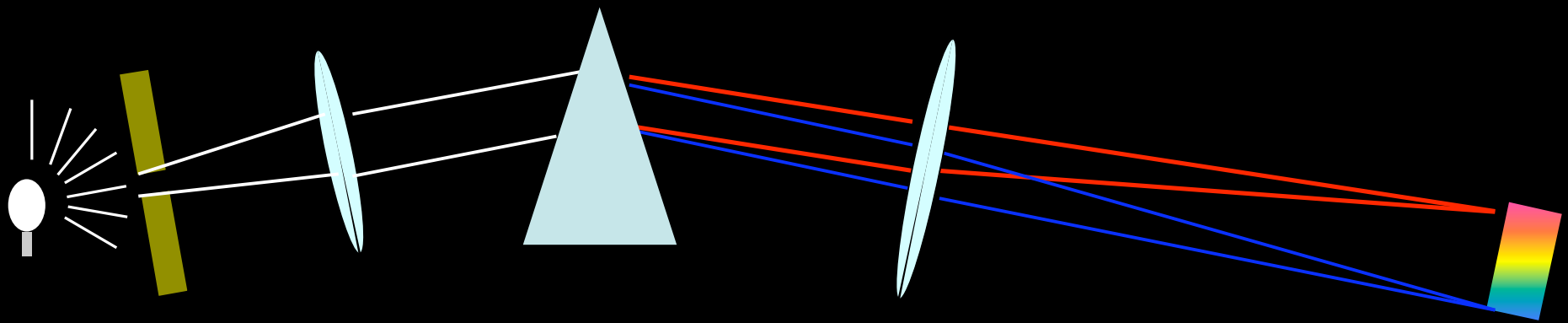


Applicazioni tecnologiche



Spettroscopia X

Spettroscopia ottica



Luce
bianca

Prisma:
dispersione
della luce

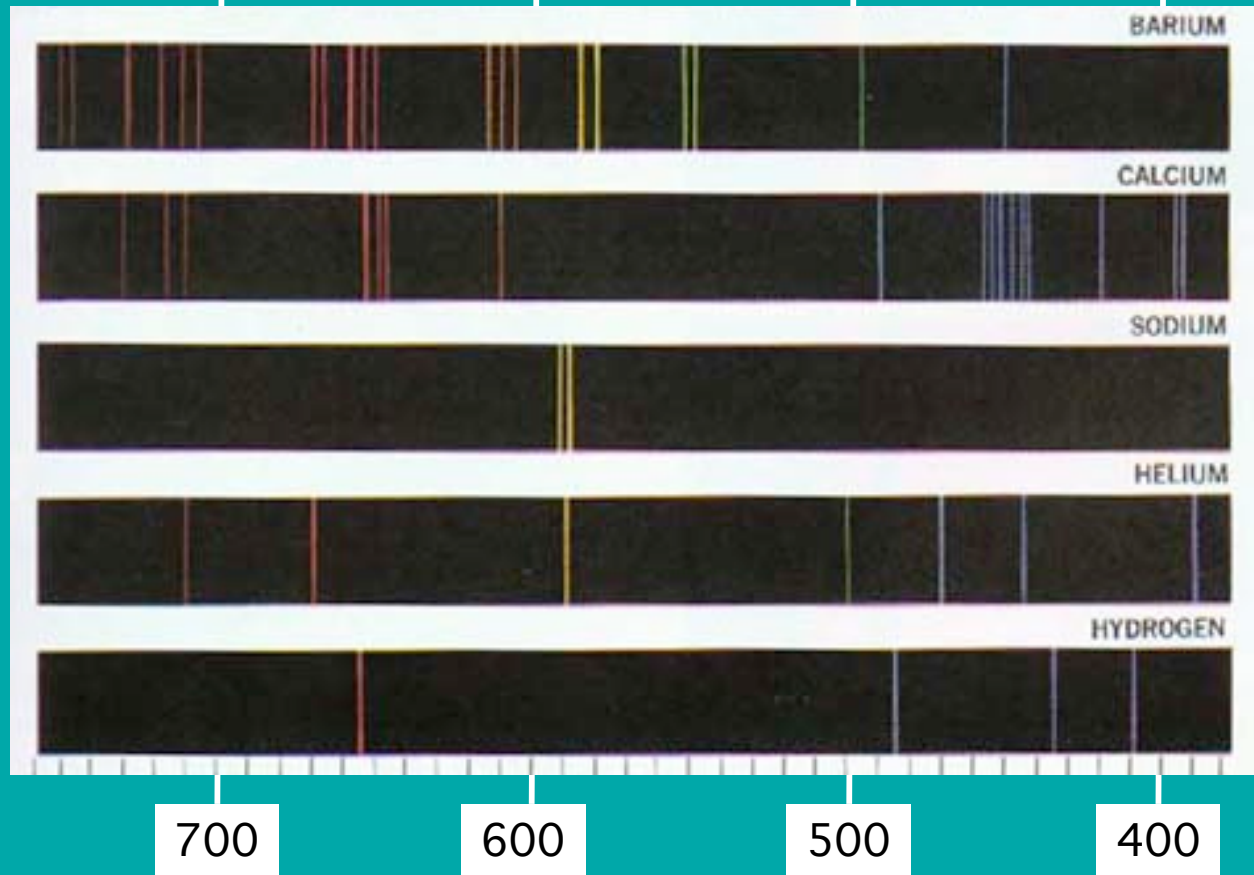
Spettro

Spettri atomici ottici

Lampada a incandescenza

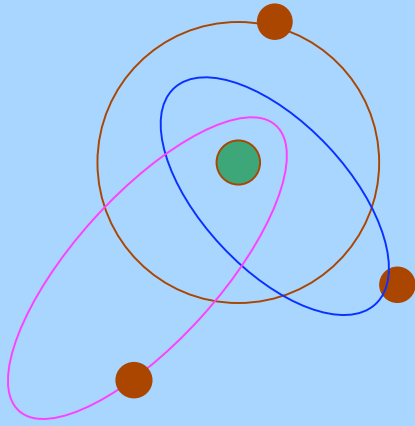


Spettri atomici di emissione

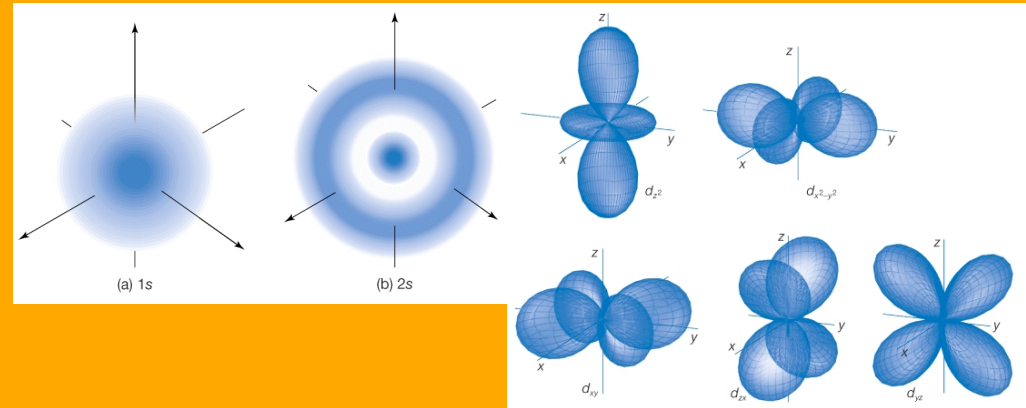


Lunghezza d'onda (nm)

La struttura dell'atomo



Modello di Bohr-Sommerfeld



Modello della meccanica quantistica

➤ Stati stazionari stabili

➤ Energie di legame degli elettroni: valori discreti

➤ Transizioni tra livelli energetici

$$E_1 - E_2 = h\nu$$

onde elettromagnetiche

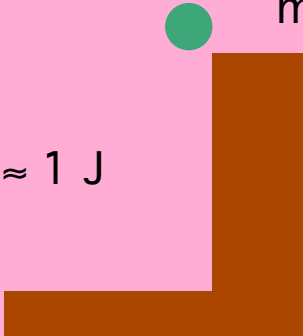
Ipotesi non classiche !

Unità di energia

Il joule (J)

$$1 \text{ J} = 1 \text{ N m}$$

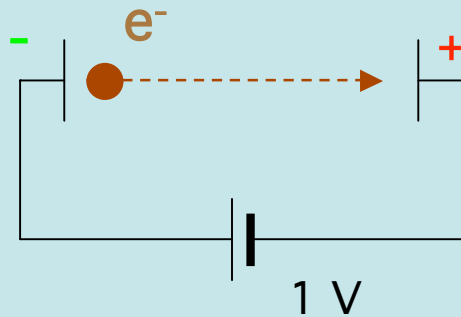
Unità SI



$E_p = mgh \approx 1 \text{ J}$

$m=0,1 \text{ kg}$

$h=1 \text{ m}$

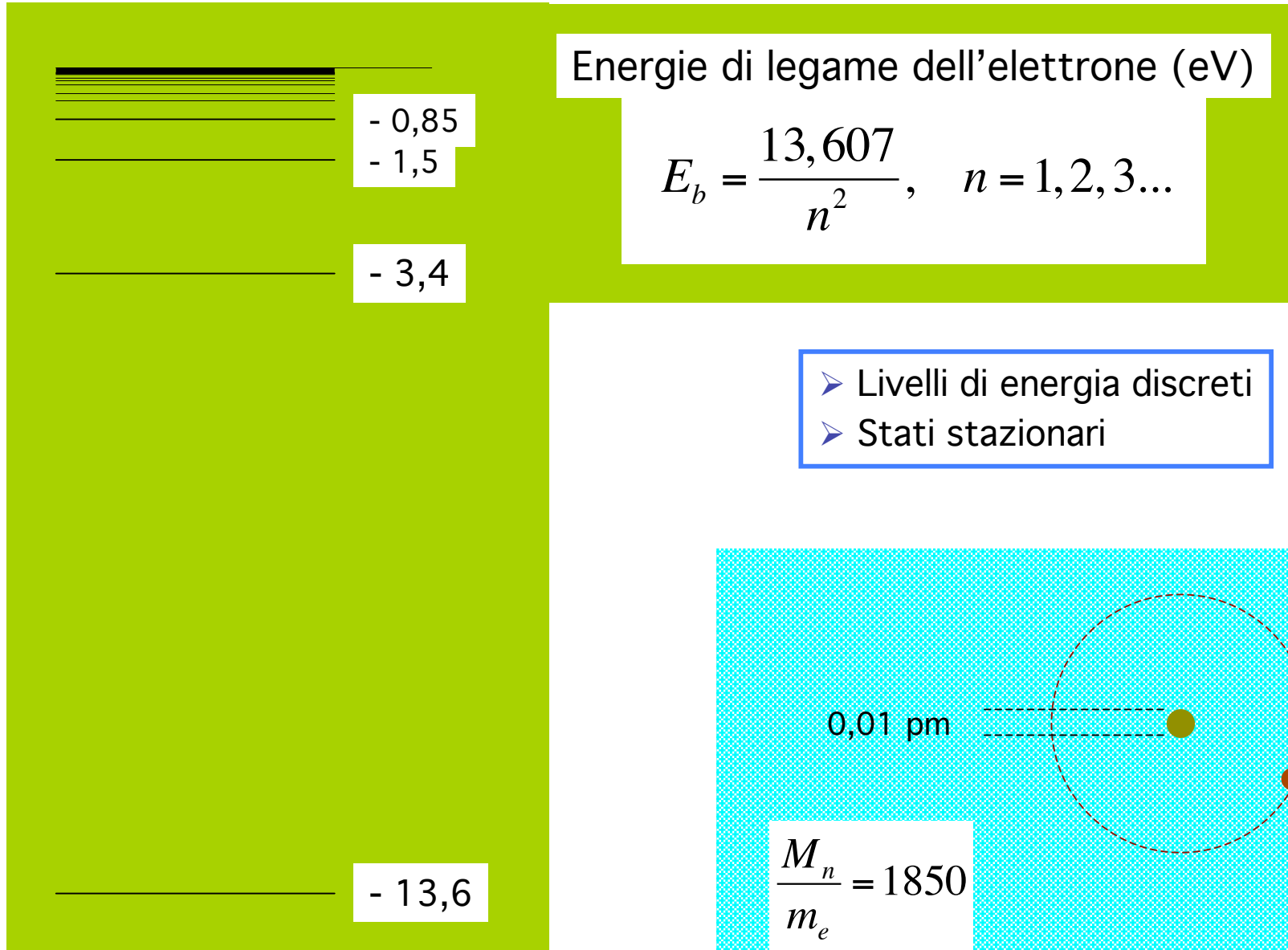


L'elettronvolt (eV)

$$1 \text{ eV} = 1.602 \, 176 \, 462 \, (63) \times 10^{-19} \text{ J}$$
$$\approx 1.6 \times 10^{-19} \text{ J}$$

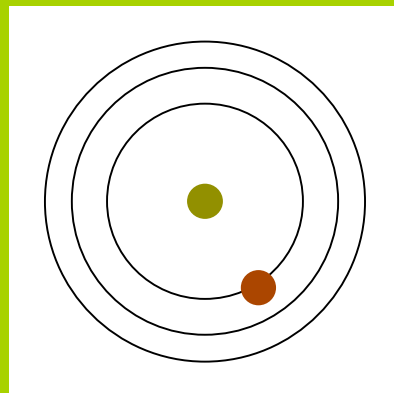
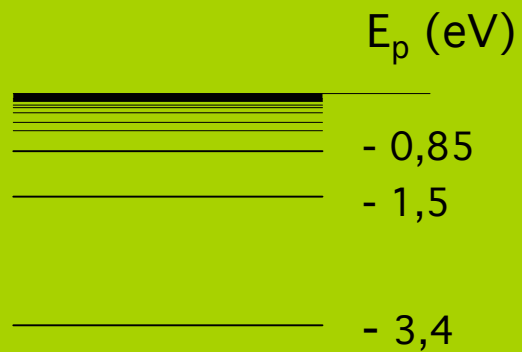
Unità non-SI ammessa all'uso

L' atomo di idrogeno

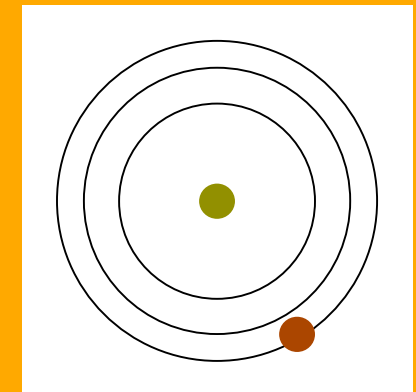
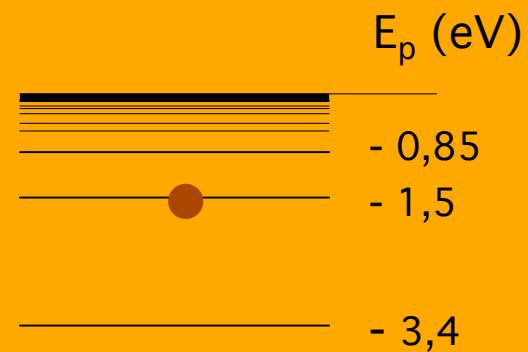


Stato fondamentale e stati eccitati

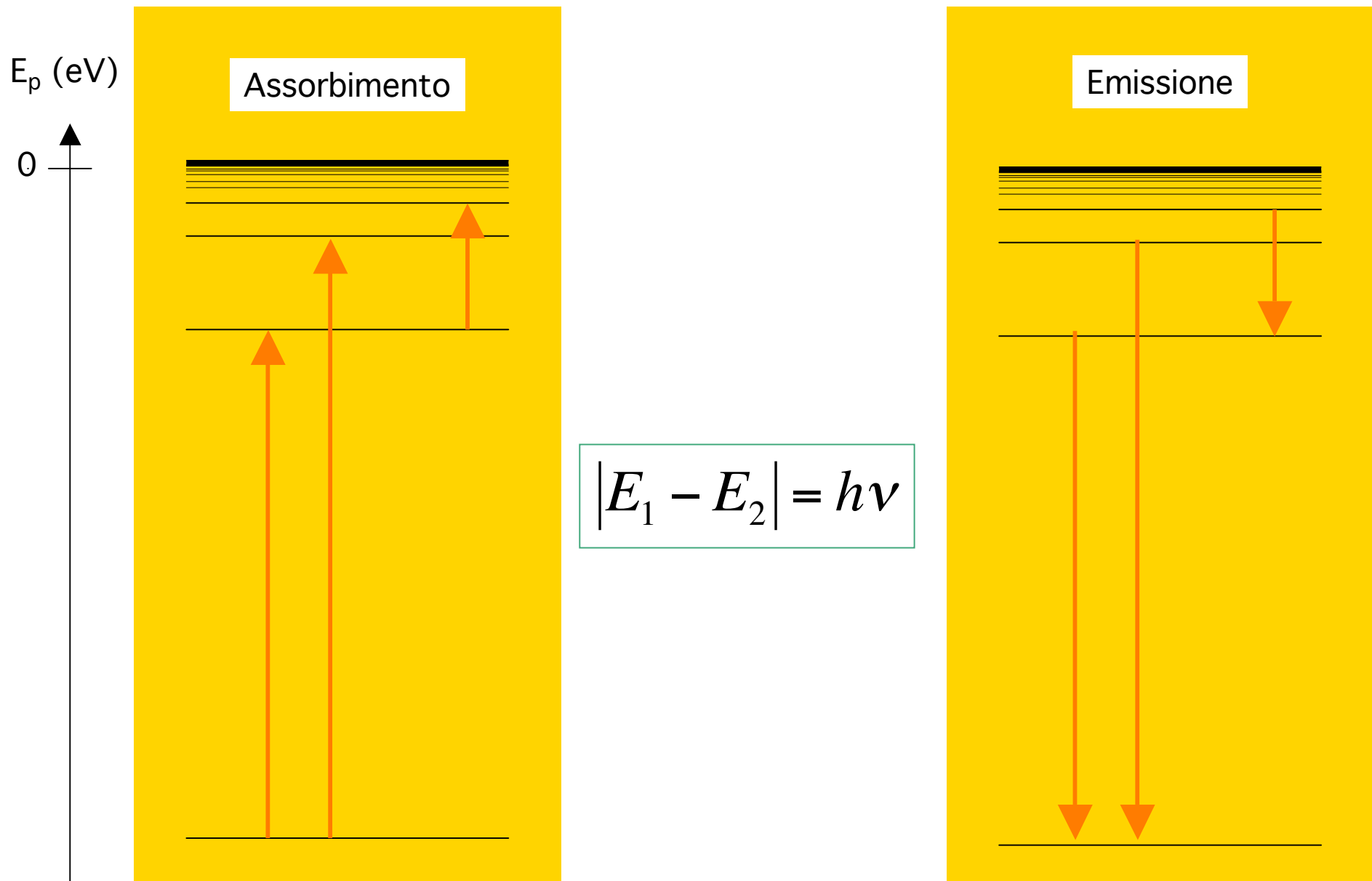
Stato fondamentale



Stato eccitato



Transizioni radiative



Quanti di radiazione

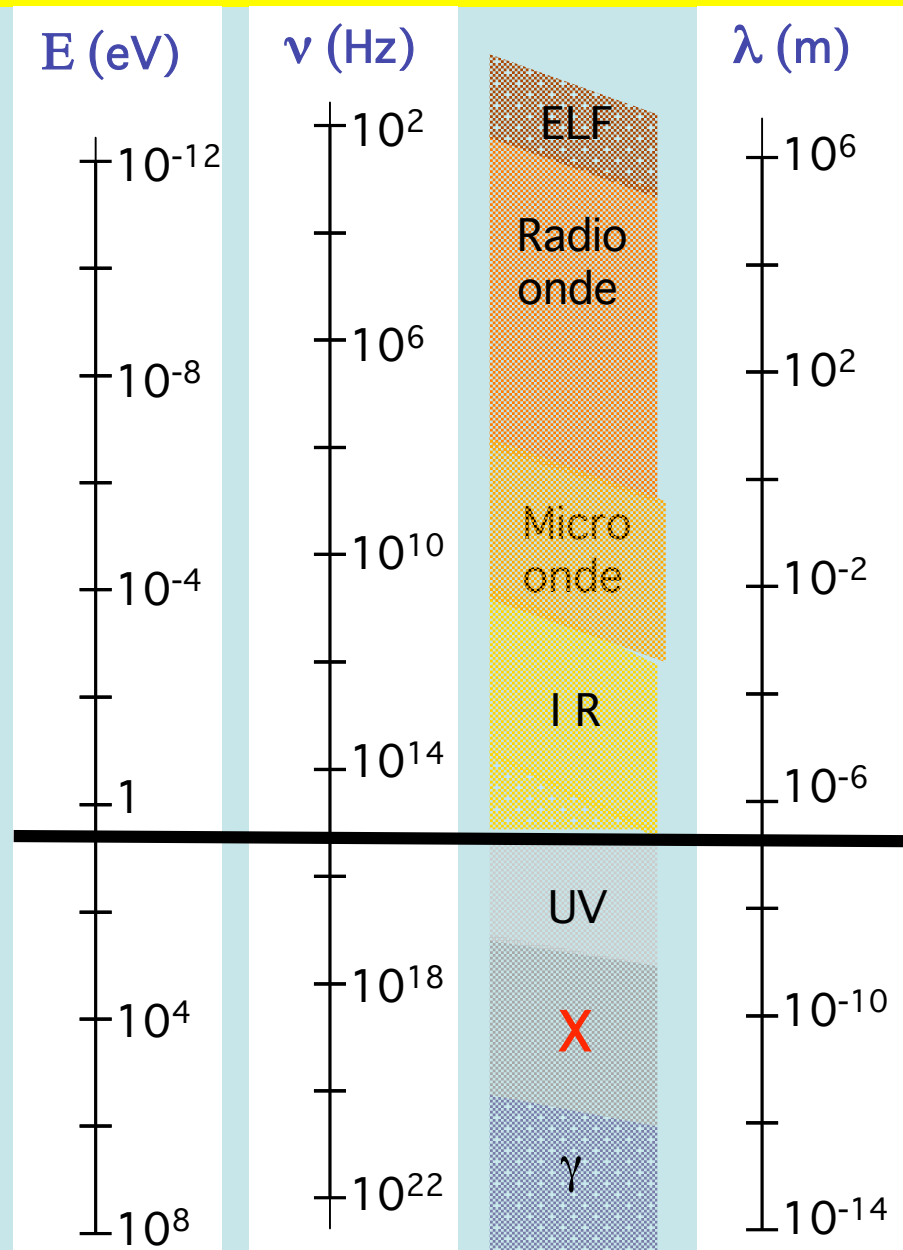
Energia

Frequenza

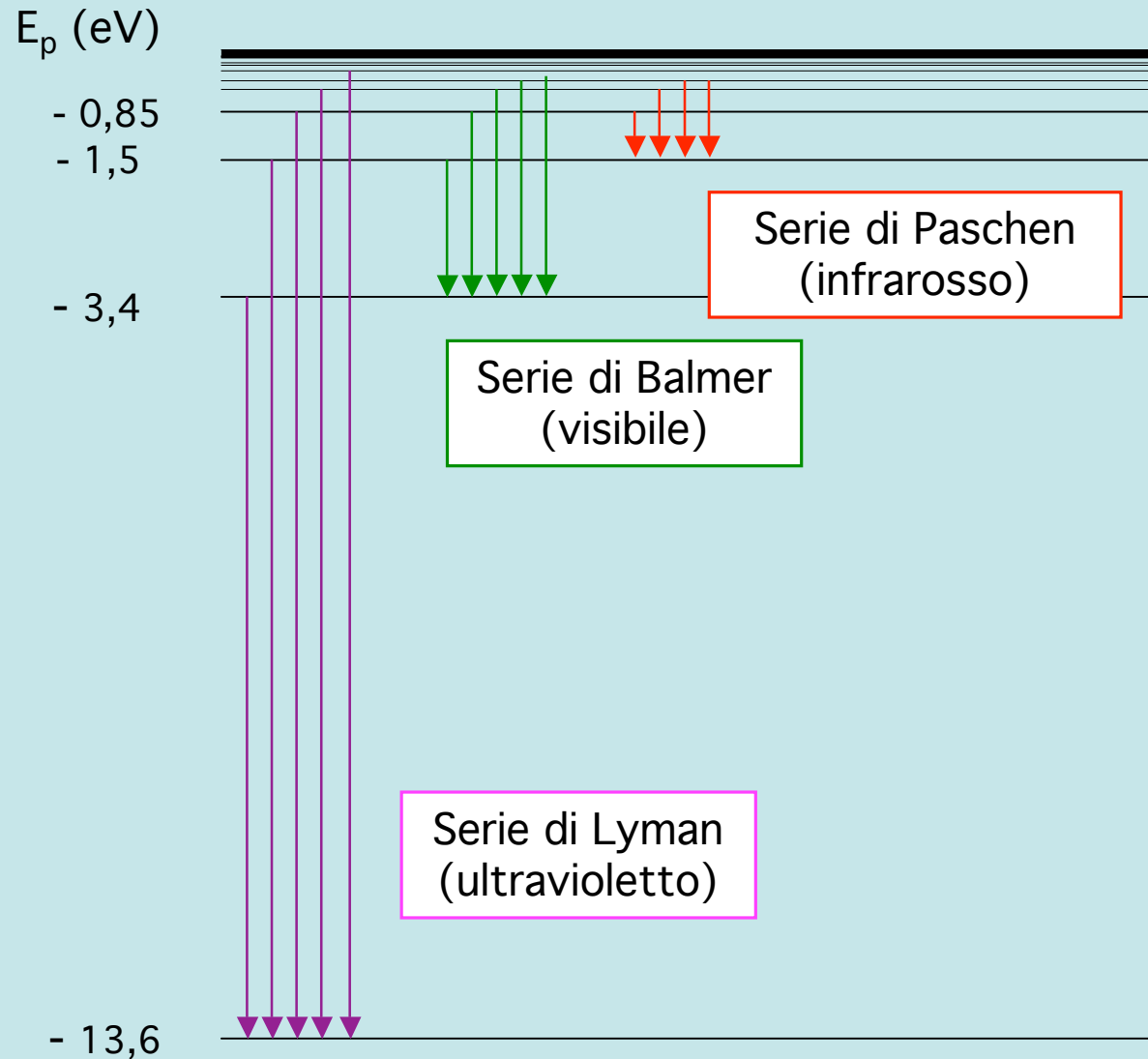
$$|E_1 - E_2| = h\nu$$

Costante di Planck:

$$h \approx 4,13 \times 10^{-15} \text{ eV/Hz}$$



Spettro dell'idrogeno

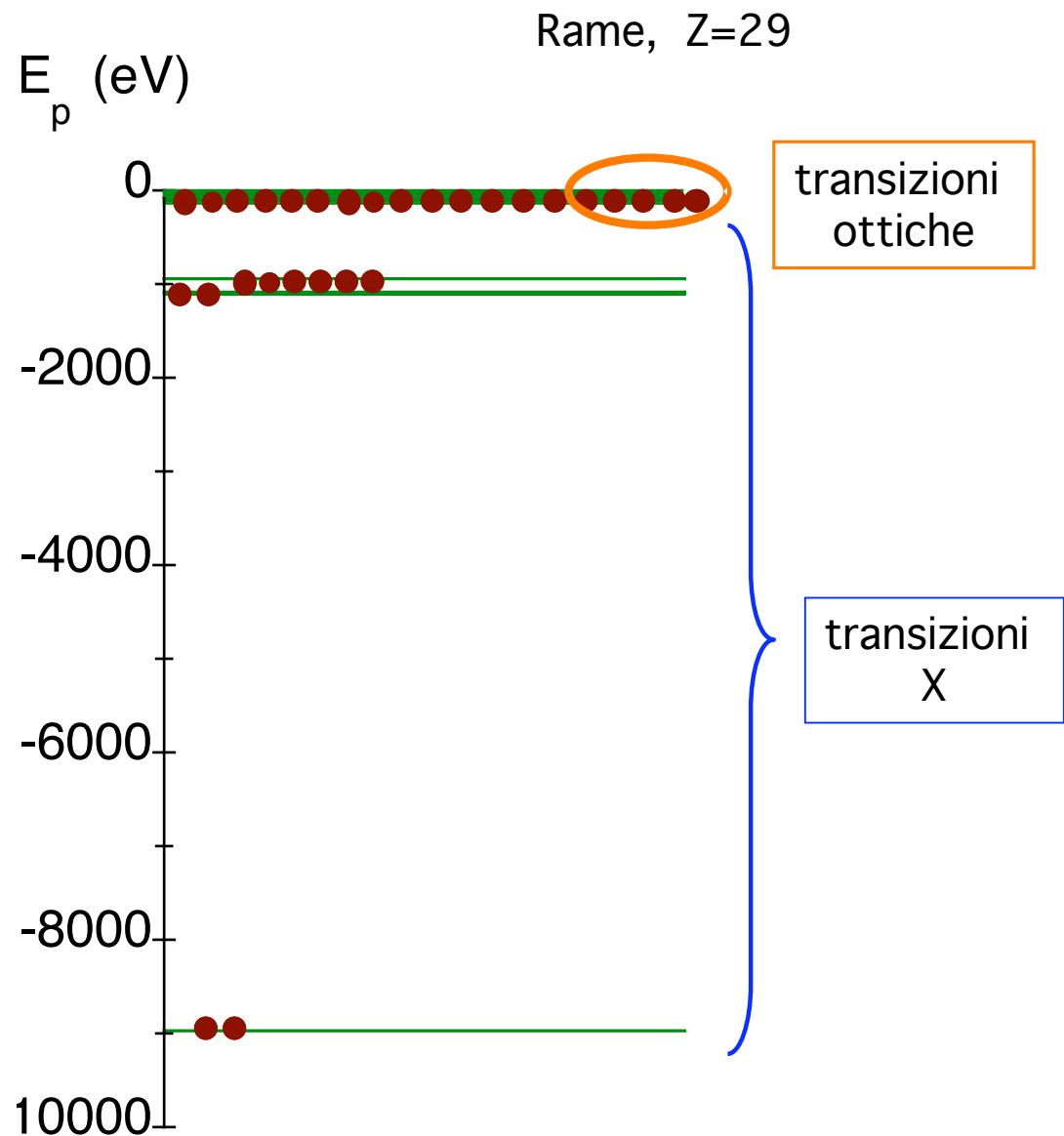


Atomi “pesanti”

Z elettroni
Carica nucleare $+Ze$

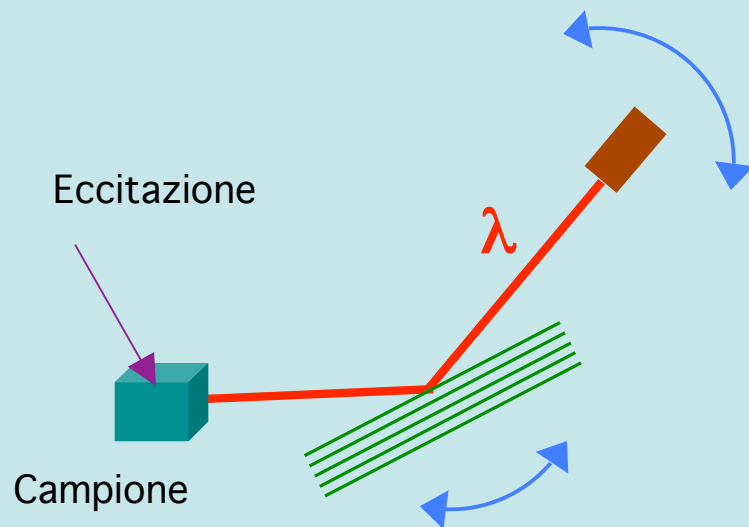
Interazione nucleo-elettroni
Energie di legame elevate

Interazioni tra elettroni
Livelli energetici complicati

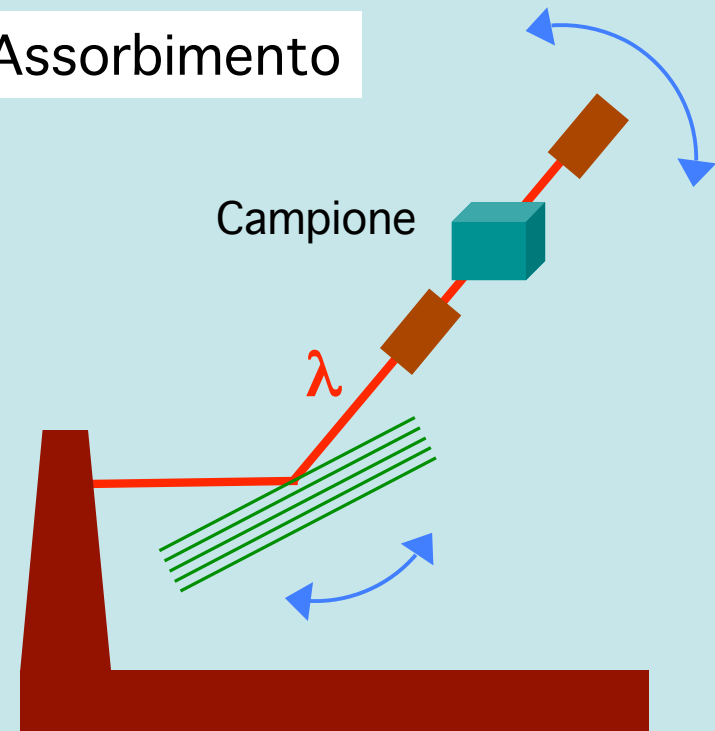


Spettroscopia X

Emissione



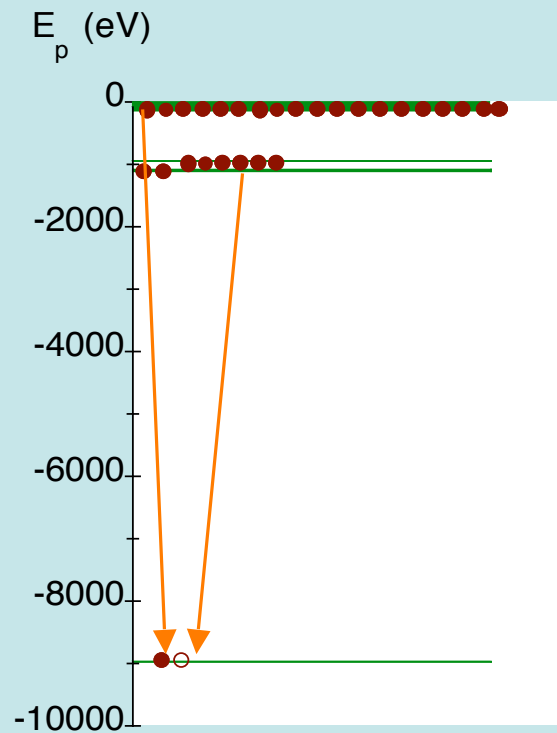
Assorbimento



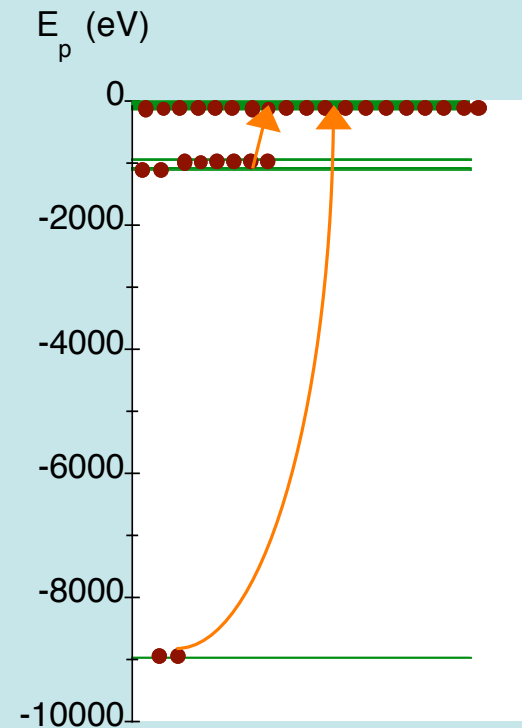
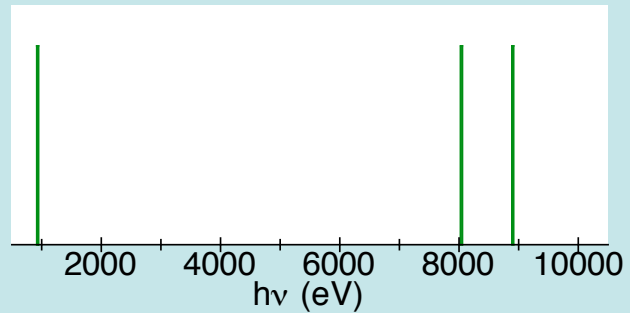
Monocromatore - Legge di Bragg

$$\lambda = 2d \sin \theta$$

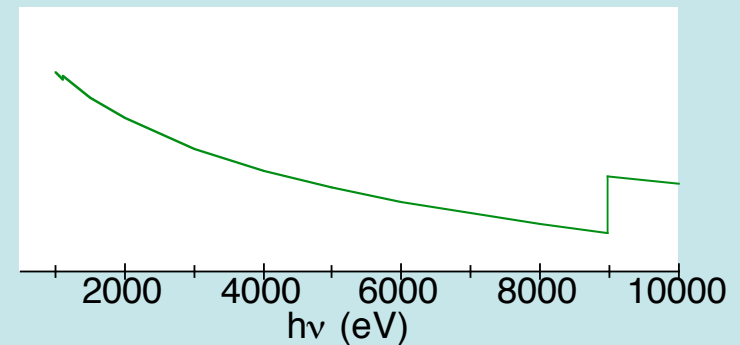
Emissione e assorbimento X



Spettri di emissione a righe



Spettri di assorbimento a soglie



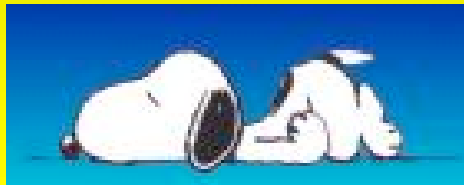
Ruolo della spettroscopia X

Verifica della teoria quantistica dell'atomo

Studio della struttura elettronica
di atomi e sistemi condensati

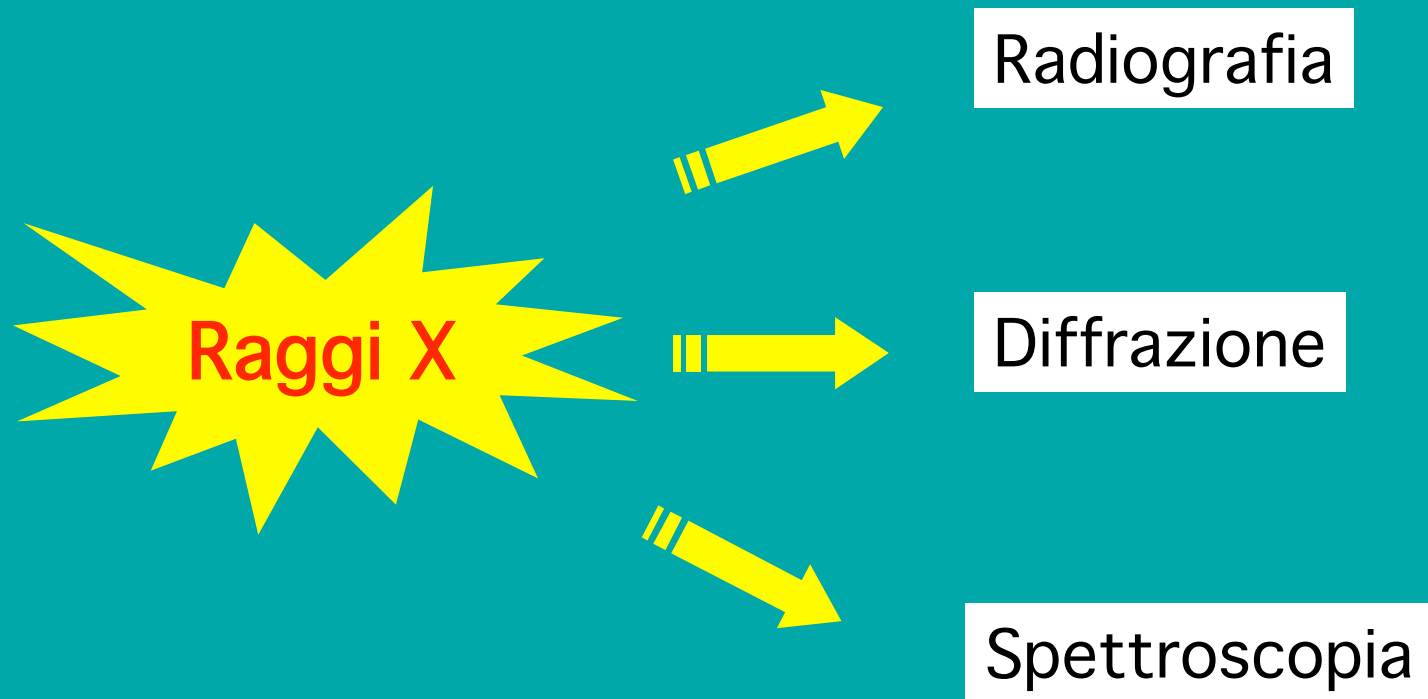
Analisi elementale delle sostanze
Righe e soglie caratteristiche

Tecniche recenti: studi strutturali di materiali disordinati



Conclusioni

L'uso dei raggi X



Nobel per ricerche con raggi X

1901	WK Roentgen	Fisica	Scoperta Raggi X
1914	M von Laue	Fisica	Diffrazione X da cristalli
1915	WH Bragg & WL Bragg	Fisica	Struttura dei cristalli
1917	CG Barkla	Fisica	Radiazione caratteristica
1924	KMG Siegbahn	Fisica	Spettroscopia X
1927	AH Compton	Fisica	Diffusione da elettroni
1936	P Debye	Chimica	Diffusione nei gas
1962	M Perutz & j Kendrew	Chimica	Struttura dell'emoglobina
1962	Watson, Wilkins, Crick	Medicina	Struttura del DNA
1979	Cormack & Hounsfield	Medicina	Tomografia assiale computerizzata
1981	KM Siegbahn	Fisica	Spettroscopia elettronica
1985	Hauptman & Karle	Chimica	Metodi strutturali diretti
1988	Deisenhofer, Huber, Michel	Chimica	Strutture di proteine della fotosintesi

I metodi della scienza

Come progredisce la scienza

Il rapporto teoria-esperimento

La nascita della Fisica Moderna

L'influenza dell'ambiente culturale ed economico

Le finalità della ricerca scientifica

Valore culturale e ricadute tecnologiche

La gestione della ricerca scientifica

Ricerca pura e ricerca applicata

Ricerca libera e ricerca su commissione

Libera diffusione dei risultati e brevetti

Ricerca settoriale e ricerca integrata