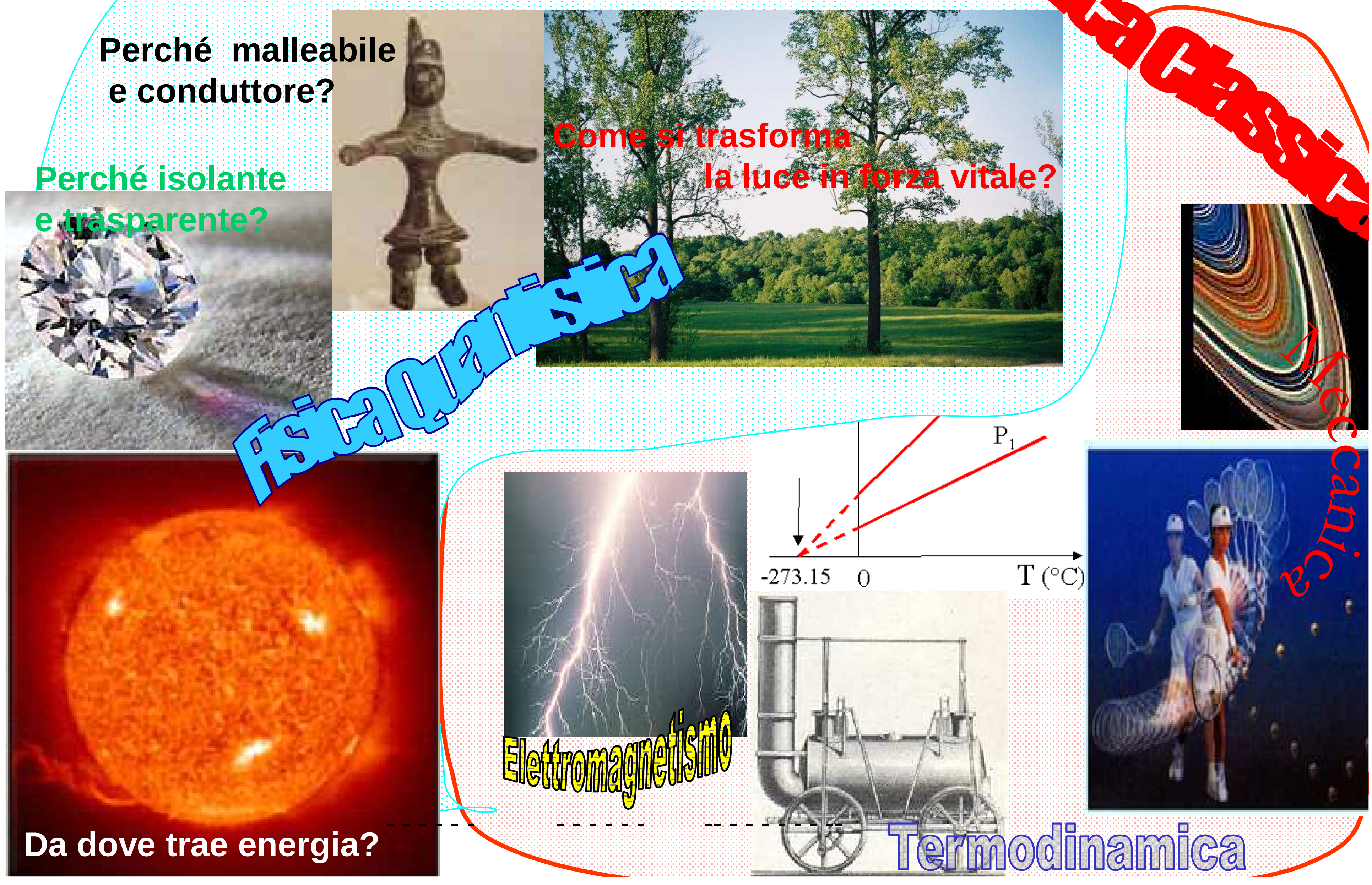
Casarano, 15/10/2009

Introduzione ad alcuni concetti di Fisica Moderna

L. Martina

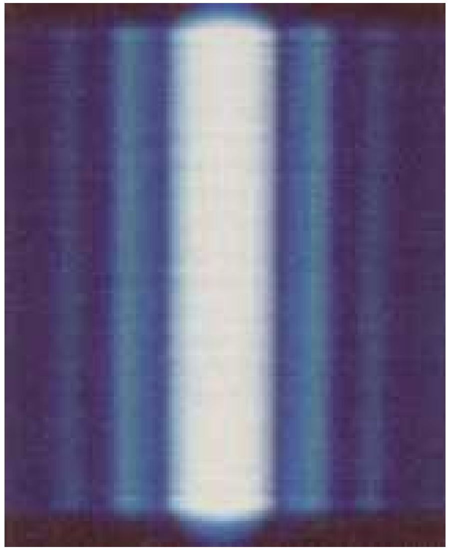
Dipartimento di Fisica - Università del Salento
e Sezione INFN - Lecce

La Natura è il Mondo dei Quanti



Micro-Macro Fisica

I concetti del Mondo dei Quanti ***non*** possono essere costruiti sulla sola osservazione e interpretazione dei fenomeni e delle evidenze sperimentali **dirette** (macroscopiche)



- Interazione **Radiazione – Materia** a livello microscopico
- Il mondo a noi **sensorialmente accessibile** è **necessariamente** "classico"
- La **coerenza interna** della Fisica richiede una forte **revisione critica** dei concetti della Fisica Classica.
- Il mondo dei fenomeni fisici ***non è*** lo stesso di prima!

Molecole e Moto Browniano

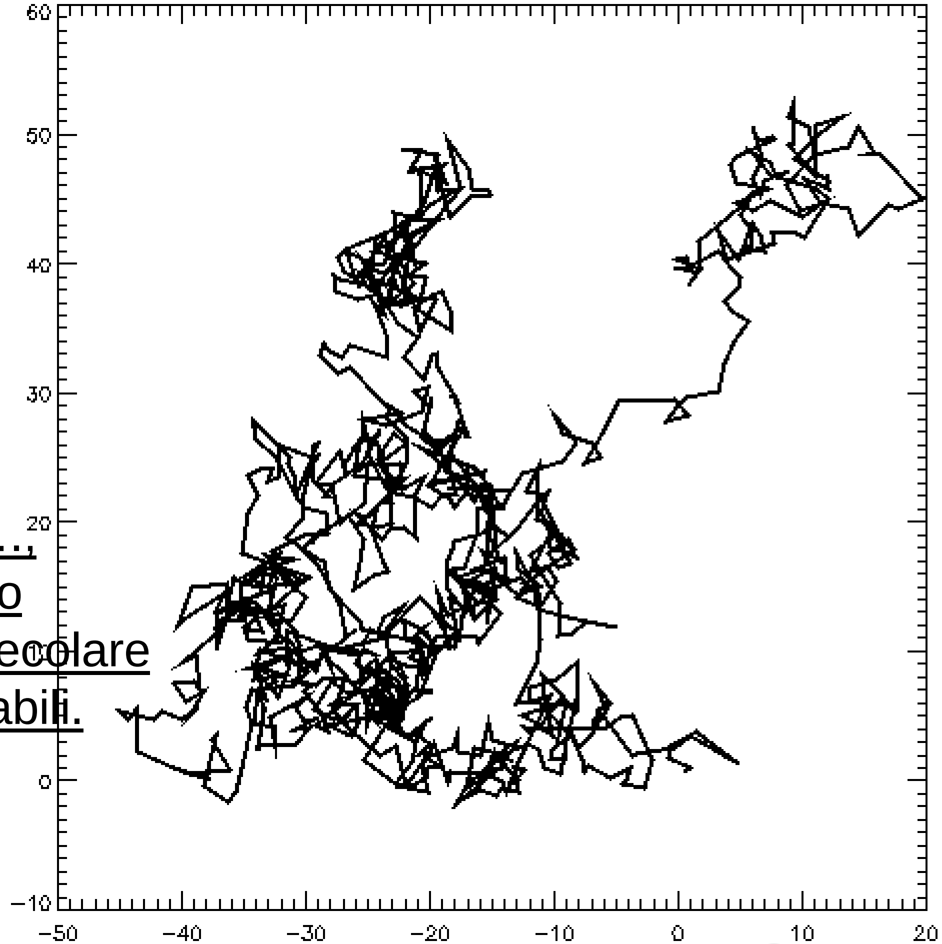
http://www.microscopy-uk.org.uk
/dww/home/hombrown.htm

mod

milk

In questo articolo dovremo mostrare che, ….., particelle di dimensioni visibili al microscopio sospese in un fluido, in seguito al moto molecolare del calore possono descrivere moti osservabili.

A. Einstein, *Ann. d. Phys*., 17 (1905) 549



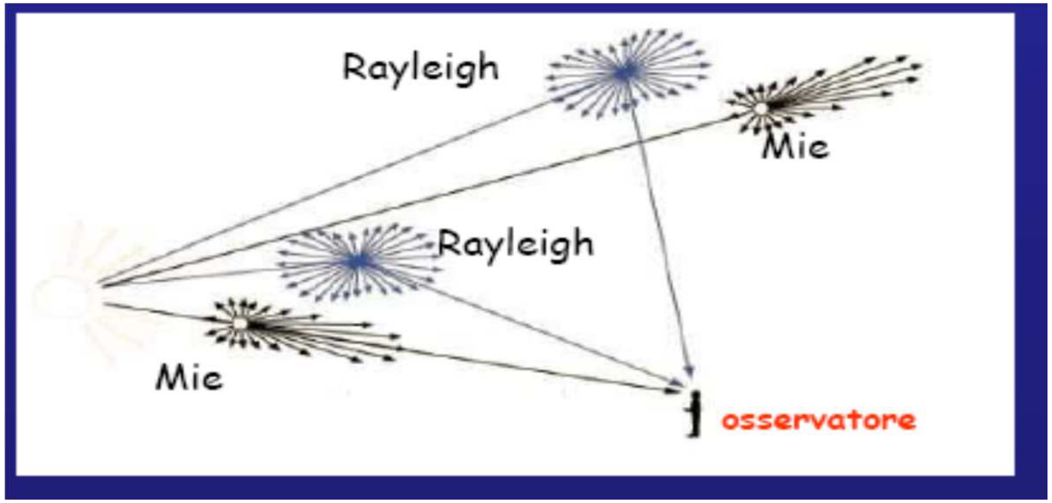
$$D = \frac{1}{2} \lim_{t\to\infty} \frac{\langle \vec{r}^2(t) \rangle}{t}$$

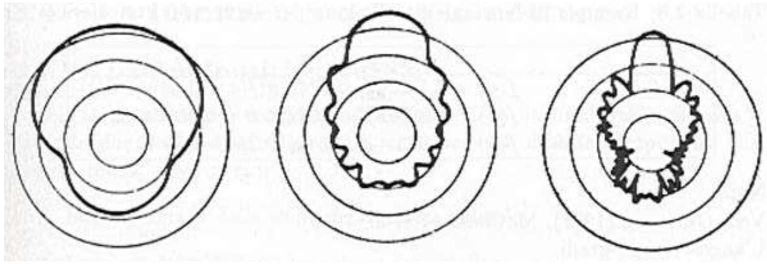
Coefficiente di diffusione

N_A = **Numero di Avogadro**
d = raggio della particella
η = coeff. di viscosita'

$$D = \frac{RT}{N_A} \frac{1}{6\pi\eta d}$$

Moto Browniano e Blu del Cielo





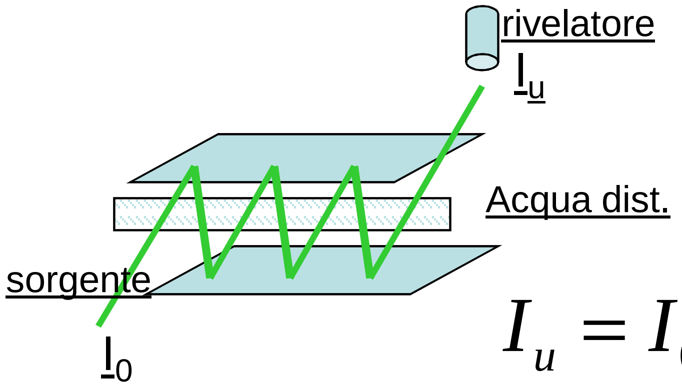
0.1 μm   0.6 μm   1.2 μm

$$\vec{p} = \alpha\,\vec{E} \qquad I = \frac{I_0}{r^2}\left(1+\cos^2\theta\right)\frac{\alpha^2}{2\lambda^4} \qquad I_b = I_0 e^{-h\,x} \qquad h = \frac{32\pi^2}{3}\frac{(\mu-1)^2}{\lambda^4\,n}$$

$$I_b = I_0 e^{-(a+h)\,x}$$

λ= 520 nm, a= 4.0 10^{-4} cm^{-1}, h= 1.3 10^{-4} cm^{-1}

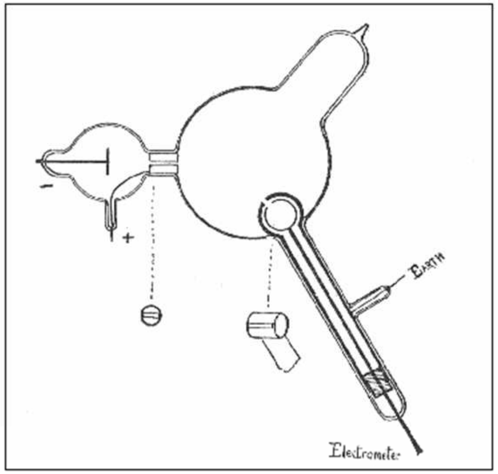
λ= 650 nm, a= 27.4 10^{-4} cm^{-1}, h= 0.5 10^{-4} cm^{-1}

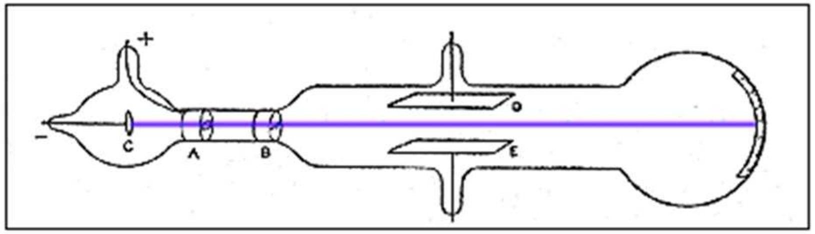


$$I_u = I_0\,\xi\,e^{-\tau\,\gamma\,n_r}$$

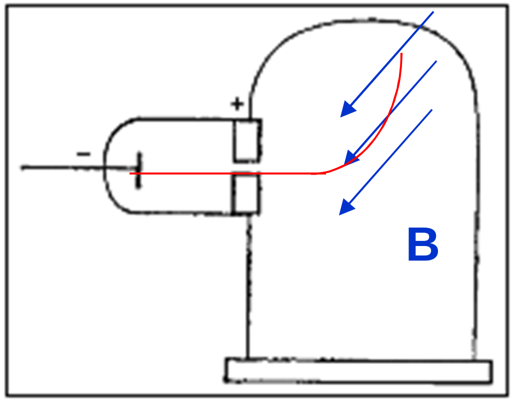
J. Perrin: " Les Atomes", (Paris, 1914)

La scoperta dell’elettrone





“We have in the cathode rays matter in a new state, a st
subdivision of matter is carried very much further tha
state: a state in which all matter... is of one and the s
being the substance from which all the chemical elen



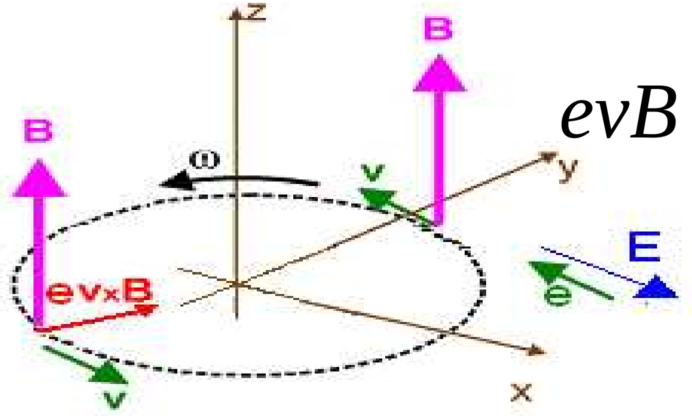
(J.J. Thomson, *"Cathode Rays,"* The London Phil. Mag. J. Science, V, Oct.1897)

$$\frac{e}{m} = \mathbf{-1.758\ 820\ 12(15) \times 10^{11}\ C\ kg^{-1}}$$

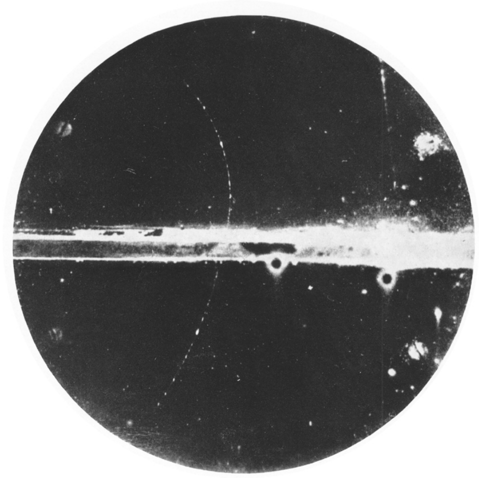
http://www.aip.org/history/electron/jjhome.htm

The NIST Reference on Constants, Units, and Uncertainty

Misuriamo e/m

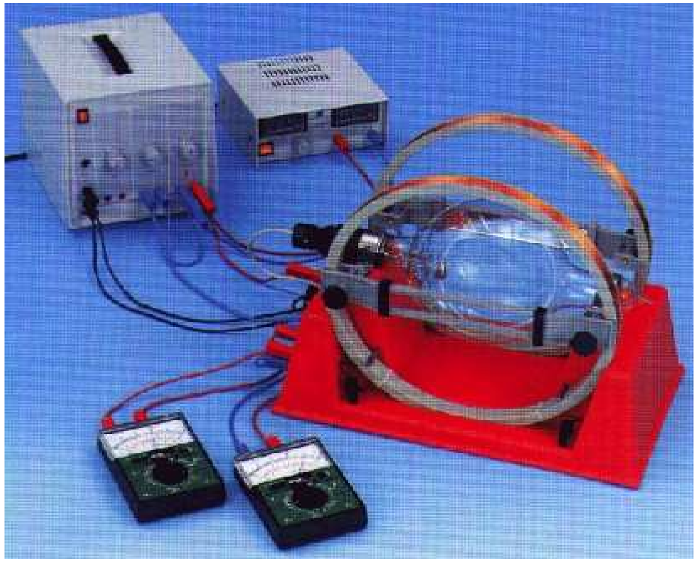


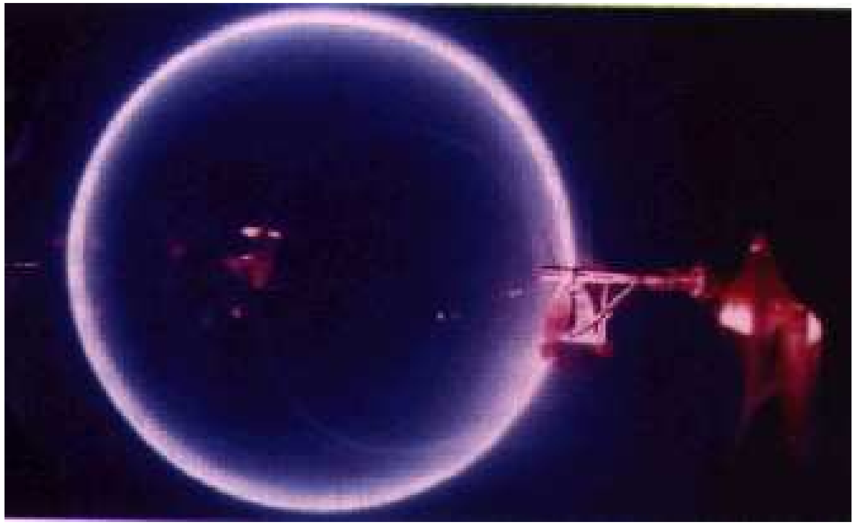
$$evB = \frac{mv^2}{r} \qquad \frac{mv^2}{2} = eV$$



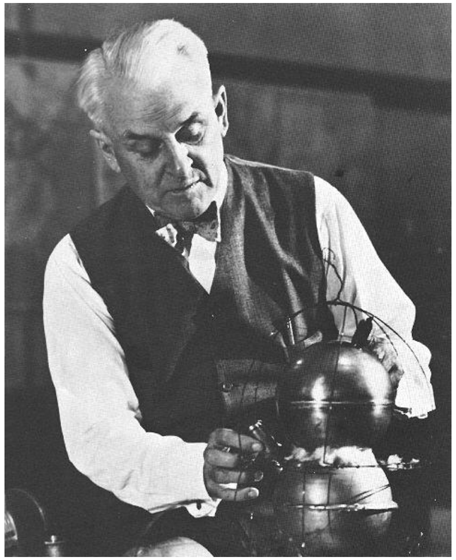
$$\boxed{\frac{e}{m} = \frac{2V}{B^2 r^2}}$$

tubo di Wehnelt
bobine di Helmholtz , alimentatori, voltimetri, amperometro
cavetti di collegamento

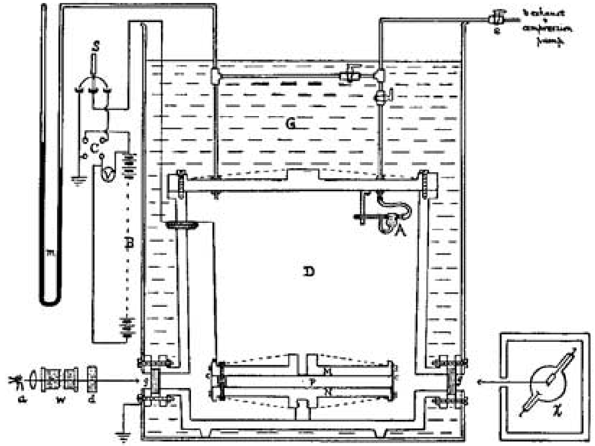




http://web.uniud.it/cird/secif/mec_q/mq.htm

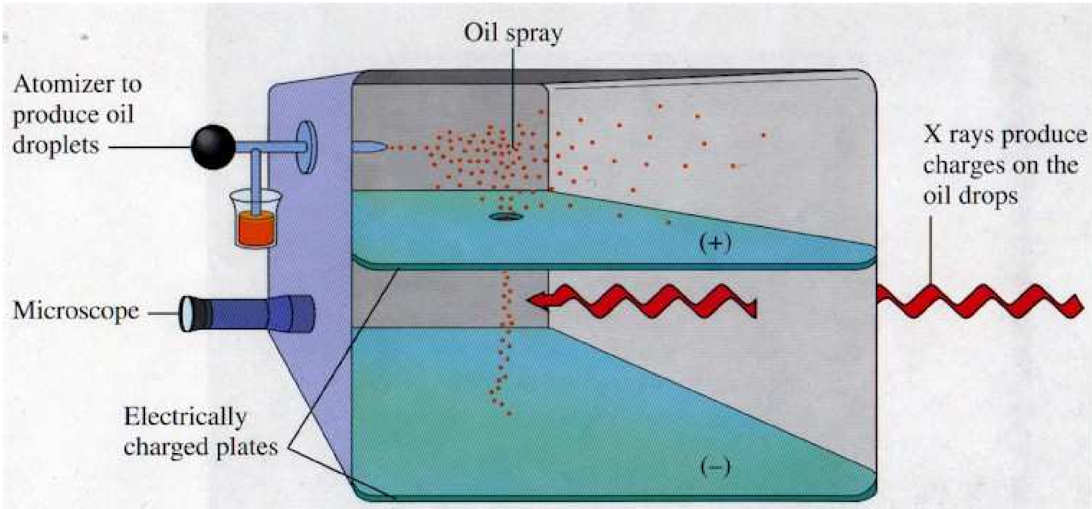


L'esperienza di Millikan



***e* = 1.602 176 53(14) x 10^{-19} C**

The NIST Reference on Constants, Units, and Uncertainty

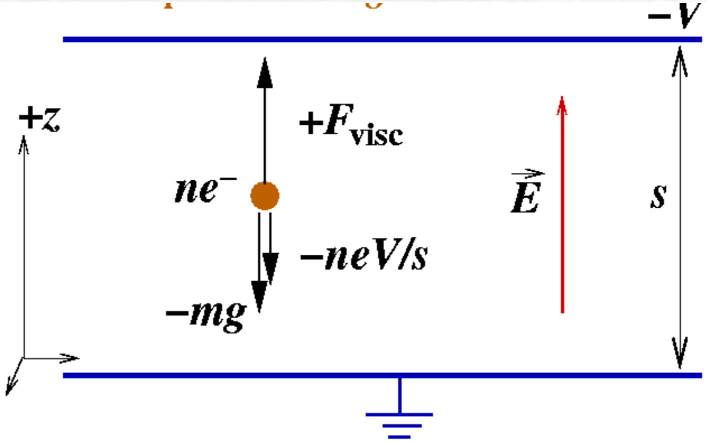


$$F_{visc} = 6\pi r \eta v \quad \text{velocità limite } v:$$

$$\frac{4}{3}\pi r^3 \rho g = 6\pi r \eta v$$

$$r = \sqrt{\frac{9\eta v}{2\rho g}}$$

$$QE = m\,g; \qquad E = U/d: \quad Q = \frac{18\pi d}{U}\sqrt{\frac{\eta^3 v^3}{2\rho g}}$$



http://www.aip.org/history/gap/Millikan/Millikan.html

Quantizzazione della carica !!!

ON THE ELEMENTARY ELECTRICAL CHARGE AND THE AVOGADRO CONSTANT.

By R. A. Millikan.

Table IV.

Drop No. 6.

Sec.	Sec.	Sec.	t_{F_e} Sec.	$\frac{1}{t_F}$	$\left(\frac{1}{t_{F'}}-\frac{1}{t_F}\right)$	n'	$\frac{1}{n'}\left(\frac{1}{t_F'}-\frac{1}{t_F}\right)$	n	$\frac{1}{n}\left(\frac{1}{t_g}+\frac{1}{t_F}\right)$
11.848	39.9	80.2	80.708	.01236				18	.005366
11.890	11.2	22.4	22.366		.03234	6	.005390		
11.908			22.390	.04470				24	.005371
11.904	11.2	22.4	22.368		.03751	7	.005358		
11.882	70.6	140.4	140.565	.007192	.005348	1	.005348	17	.005375
11.906	39.9	e 79.6	79.600	.01254				18	.005374
11.838			34.748		.01616	3	.005387		
11.816			34.762	.02870				21	.005376
11.776			34.846						
11.840			29.286					22	.005379
11.904	14.6	29.3	29.236	.03414	.026872	5	.005375		
11.870	69.3	137.4	137.308	.007268	.021572	4	.005393	17	.005380
11.952	17.6	34.9	34.638	.02884				21	.005382
11.860					.01623	3	.005410		
11.846			22.104	.04507				24	.005386
11.912			22.268		.04307	8	.005384		
11.910			500.1	.002000				16	.005387
11.918			19.704		.04879	9	.005421	25	.005399
11.870			19.668	.05079	.03874	7	.005401		
11.888			77.630					18	.005390
11.894	38.9	77.6	77.806	.01285	.01079	2	.005395		
11.878	21.0	42.6	42.302	.02364				20	.005392
11.880					Means		.005386		.005384

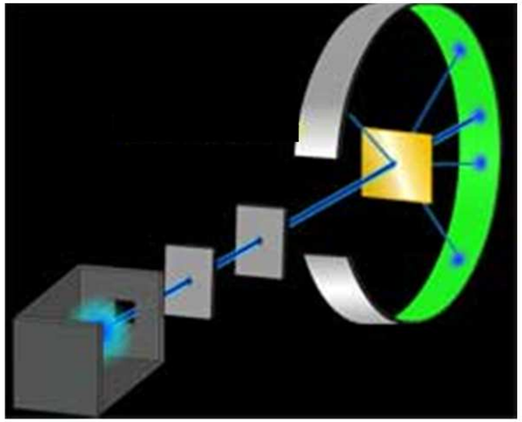
Duration of exp. = 45 min.,
Plate distance = 16 mm.,
Fall distance = 10.21 mm.,
Initial volts = 5,088.8.
Final volts = 5,081.2.
Temperature = 22.82° C.,
Pressure = 75.62 cm.,
Oil density = .9199.
Air viscosity[1] = $1,824 \times 10^{-7}$,
Radius (a) = .000276 cm.,
l/a = .034.
Speed of fall = .08584 cm./sec.,
$e_1 = 4.991 \times 10^{-10}$.

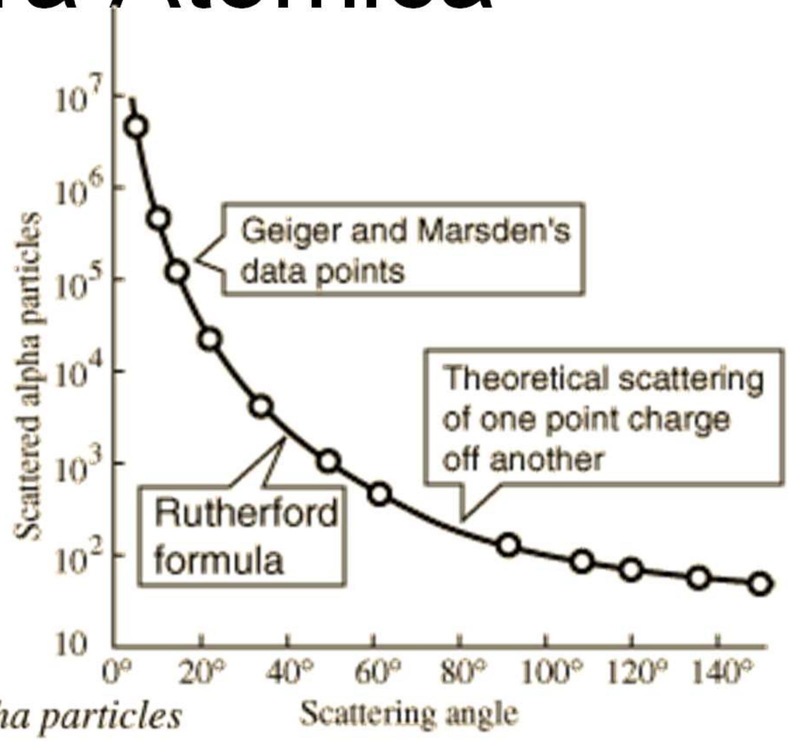
The NIST Reference on
Constants, Units, and Uncertainty

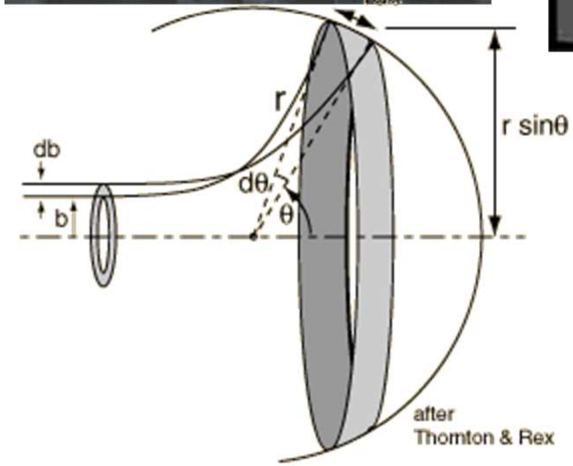
Fundamental Physical Constants

	$1.602\ 176\ 487 \times 10^{-19}$ C
Standard uncertainty	$0.000\ 000\ 040 \times 10^{-19}$ C
Relative standard uncertainty	2.5×10^{-8}

La Scoperta della Struttura Atomica







$$N(\theta) = \frac{N_i n L Z^2 k^2 e^4}{4 r^2 KE^2 \sin^4(\theta/2)}$$

N_i = number of incident alpha particles

n = atoms per unit volume in target

L = thickness of target

Z = atomic number of target

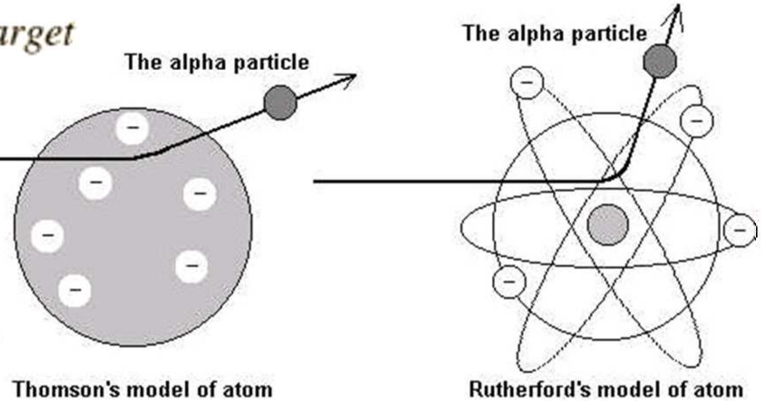
e = electron charge

k = Coulomb's constant

r = target-to-detector distance

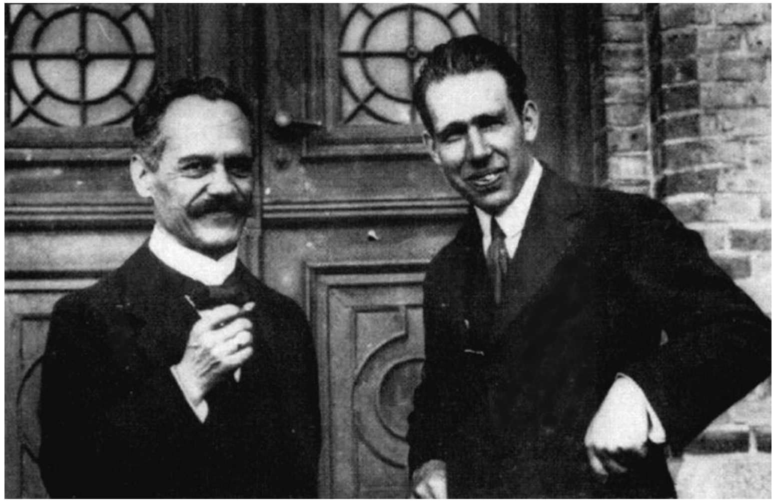
KE = kinetic energy of alpha

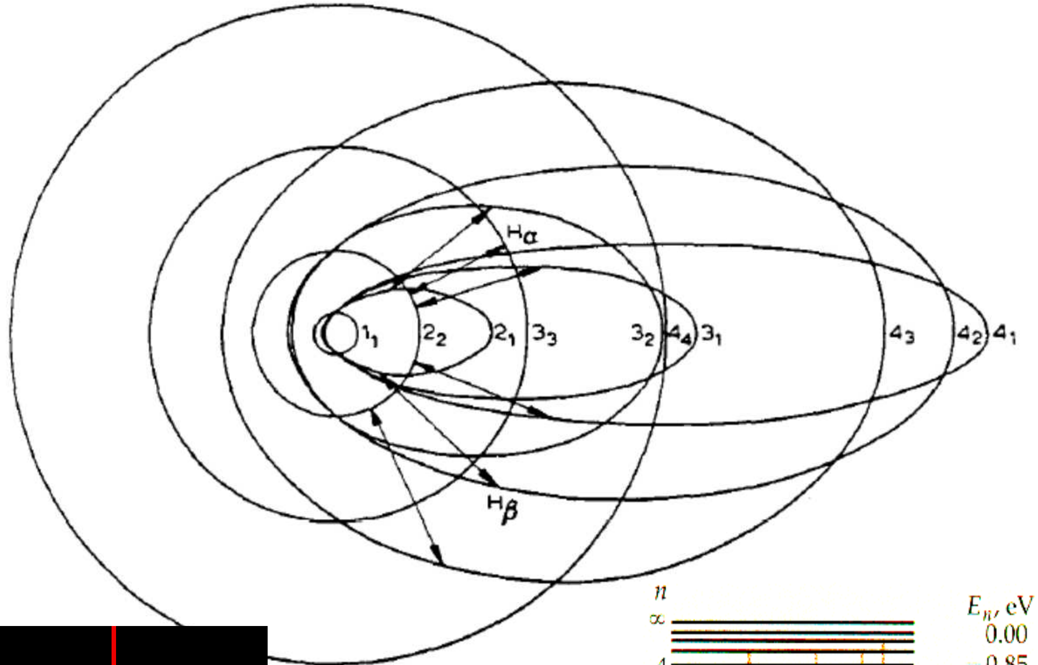
θ = scattering angle

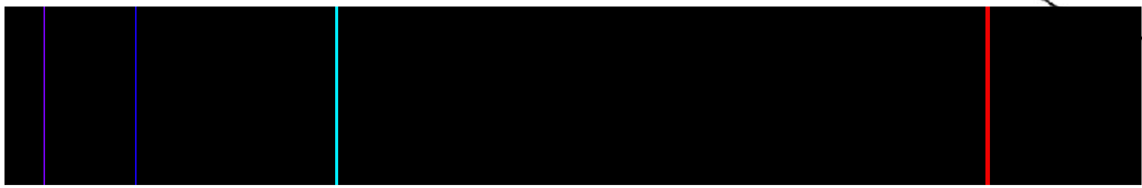


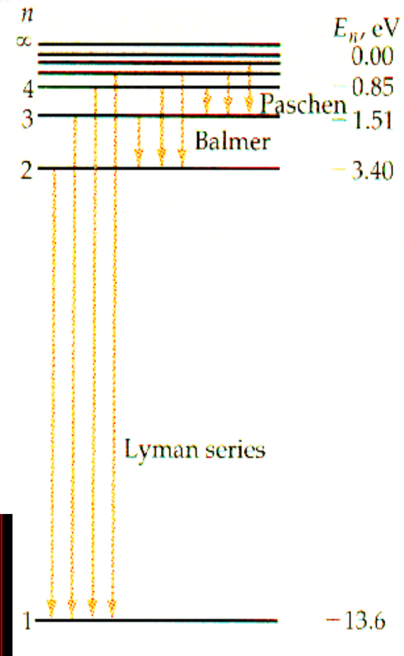
Incoerenza con la Fisica Classica!!

Modell Atomico di Bohr





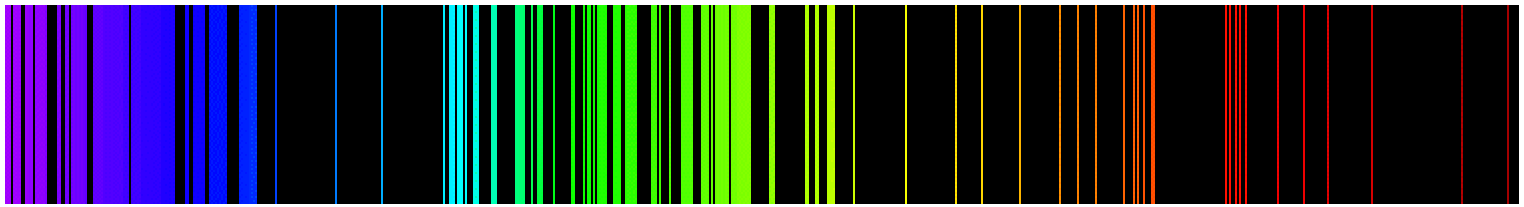




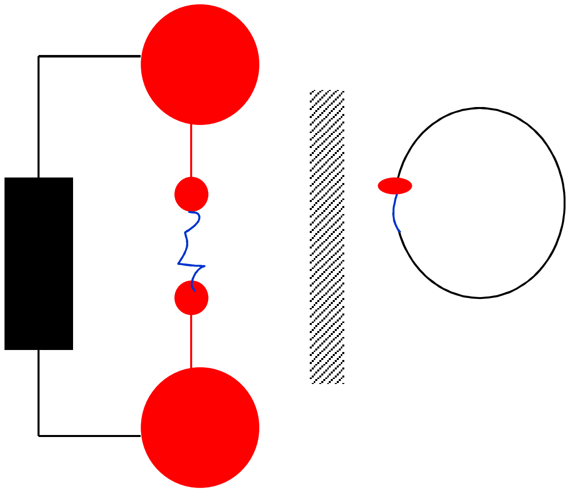
Formula di Balmer

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \quad n = 3, 4, \ldots$$

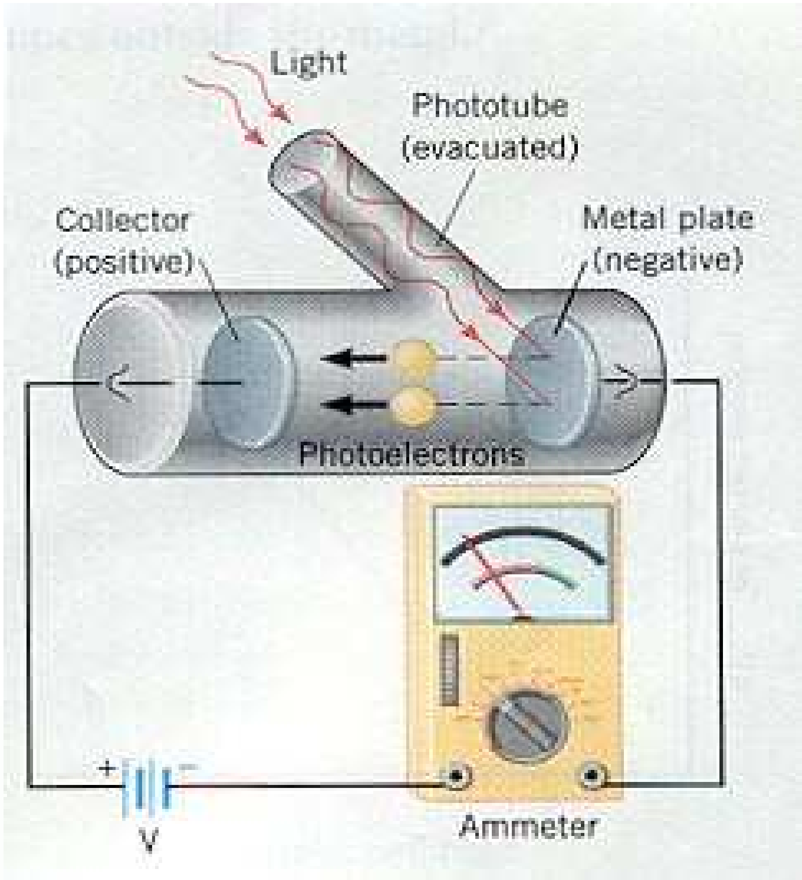
$$\nu = N^2 K \left(\frac{1}{n''^2} - \frac{1}{n'^2}\right).$$

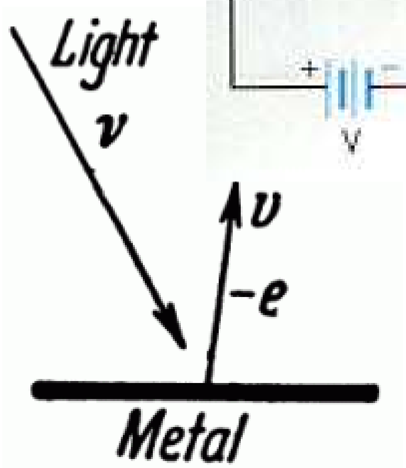


L'effetto Fotoelettrico



Quarzo	SI
Gesso	SI
Vetro	Ridotta
Legno	Nulla

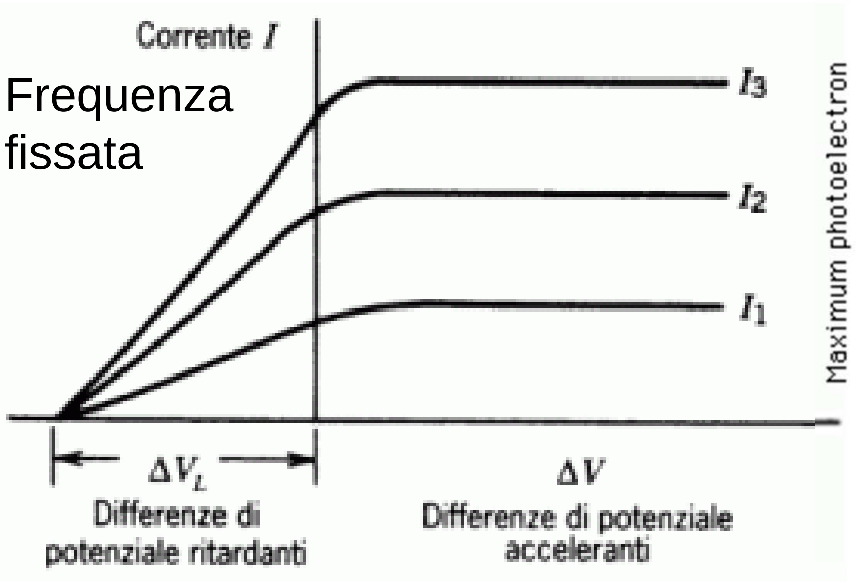


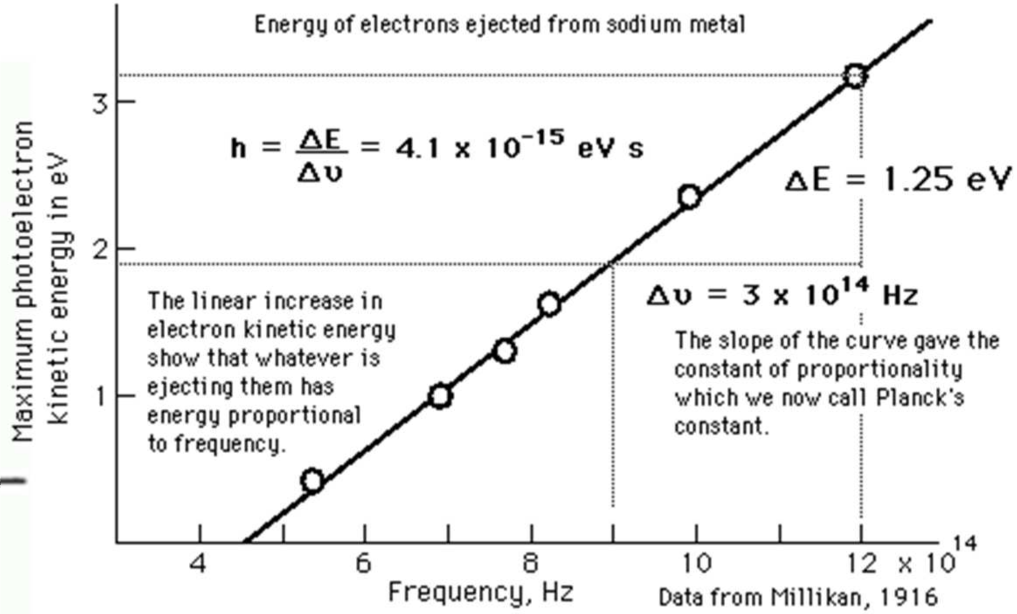


Hertz, 1887

Lenard
1899 - 1902

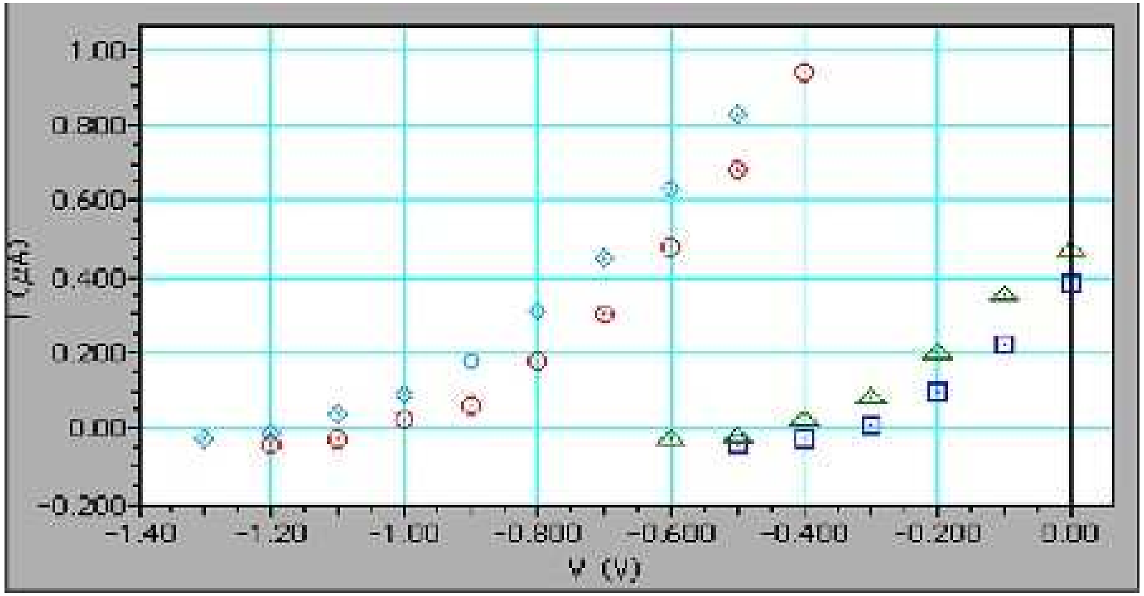
Relazioni caratteristiche dell'effetto fotoelettrico

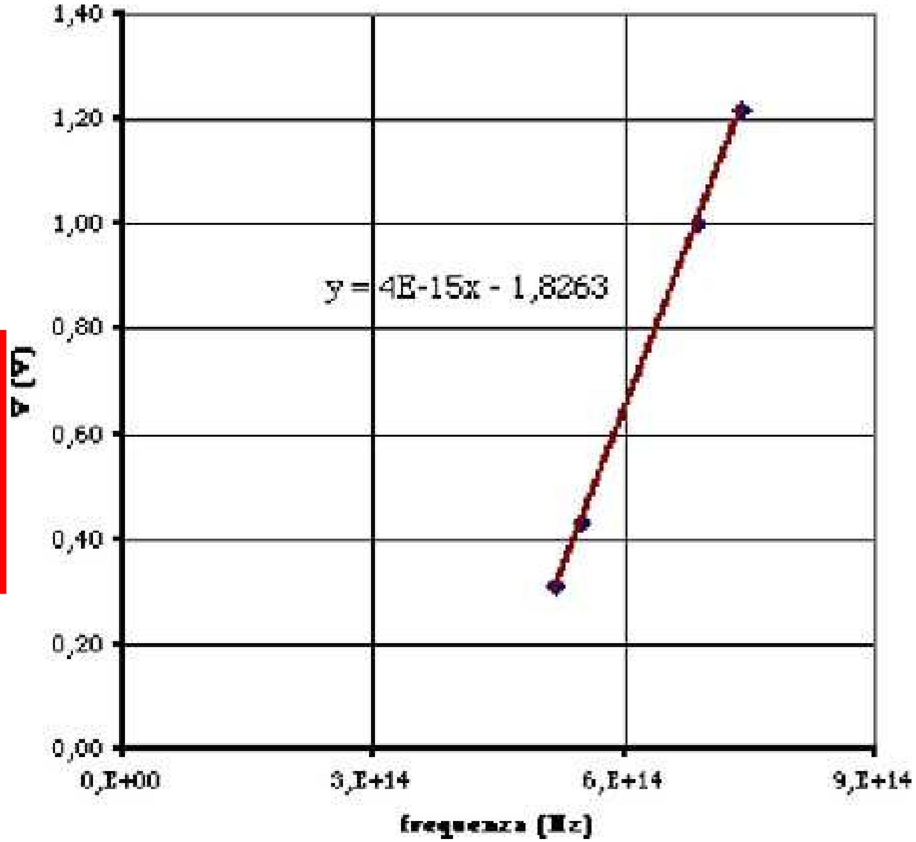




- **Solo luce con frequenza > frequenza di soglia produce una corrente**
- **La corrente è attivata in tempi < 10^{-6} s**
- **L'azione "puntuale" della luce incidente**
- **Proporzionalita' tra corrente e intensità luminosa incidente**
- **Il potenziale di arresto è proporzionale alla frequenza della luce incidente**

Incoerente con la Fisica Classica !!!



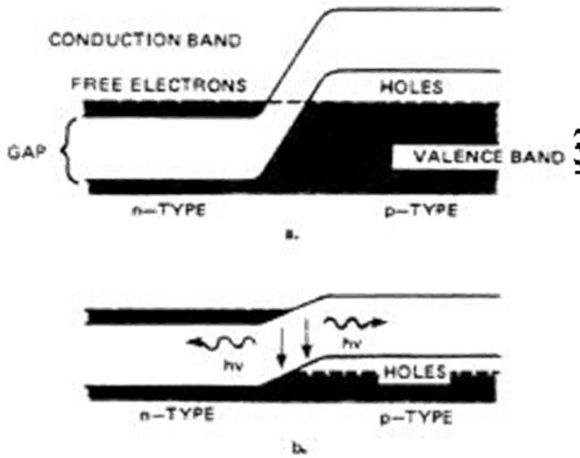


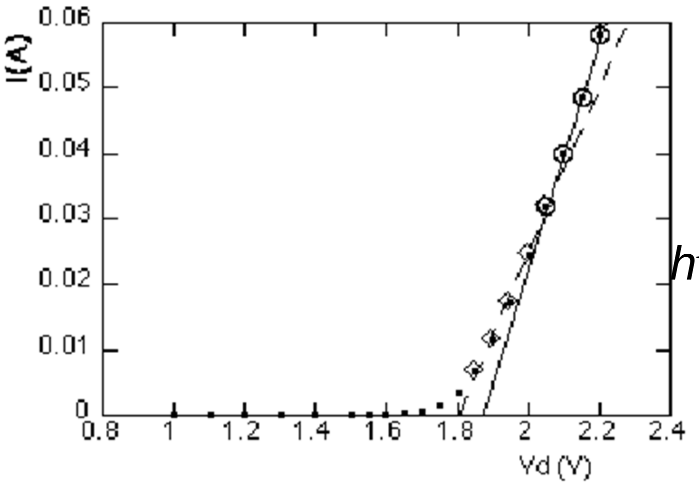
$E = w + eV_r$.

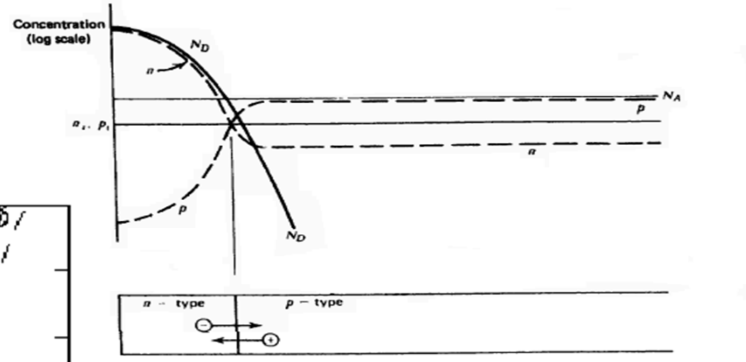
$$\boxed{E = h\nu \quad \text{Einstein – Planck}}$$

$$V_r = -\frac{w}{e} + \frac{h}{e}\nu$$

Misura della costante di Planck







$h\nu = eV_{diodo} + \text{cost}$

$GaAs_{1-x}\,P_x$
1.43 eV per x=0
2.26 eV per x=1;

$\lambda(\mu m) \approx hc/E_g \approx 1.24/E_g(eV)$

$850 > \lambda > 550$ nm

$$eV_d = h\nu + Q$$

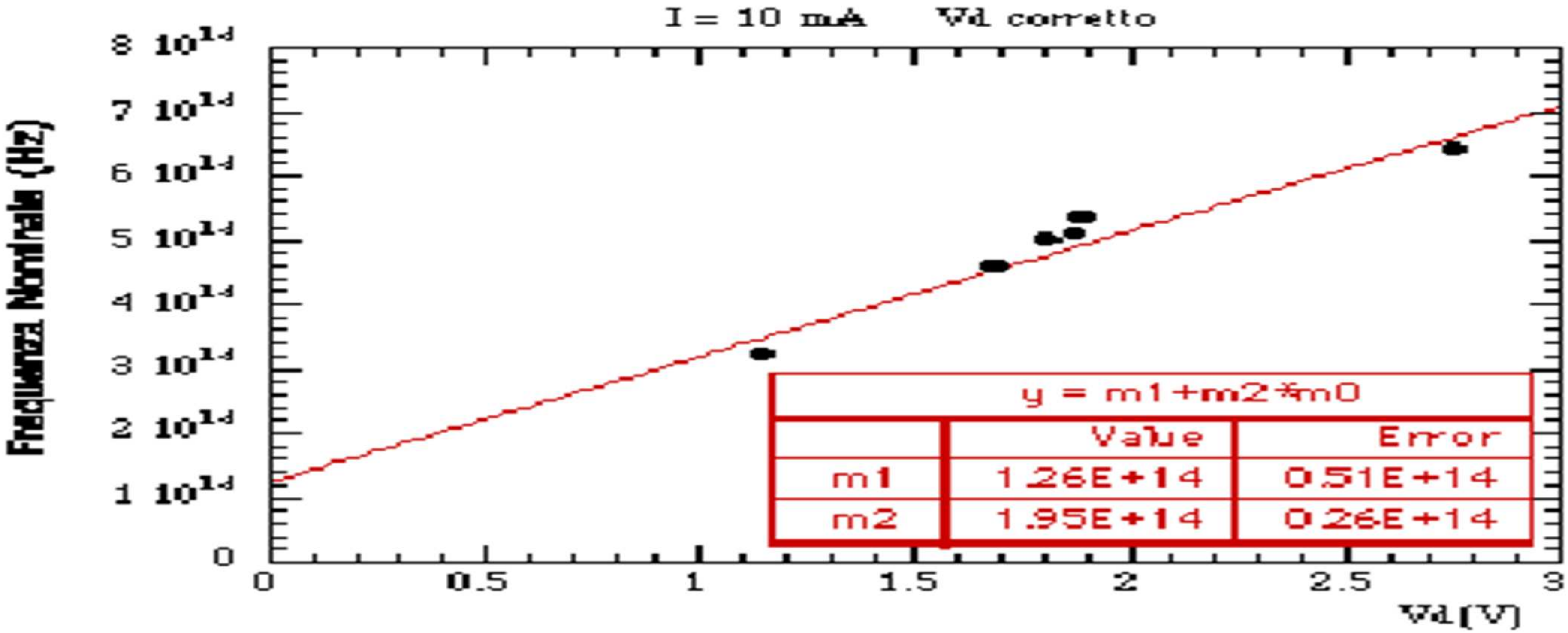
V_d: d.d.p. effettivamente applicata alla giunzione pn

Q: calore, altre transizioni non luminose

$$V_d = V_{diodo} - R_s\, I_d$$

$I_{LED1} = I_{LED1}$ ---→ $Q(I_{LED1}) = Q(I_{LED2})$

$$\nu = (e/h)\, V_d + \text{cost}$$



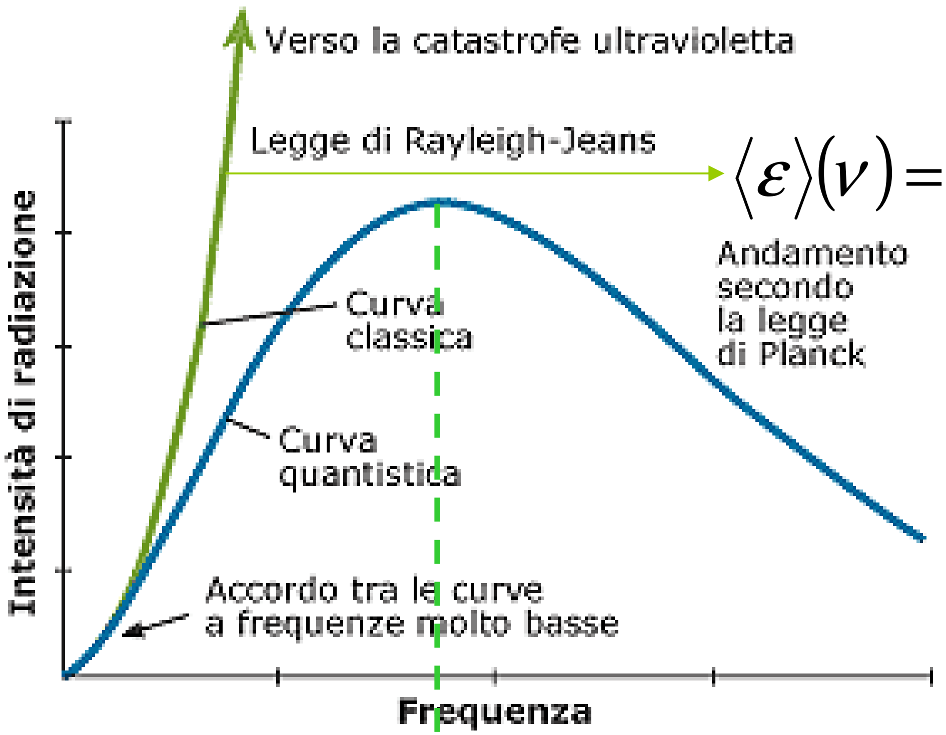
e/*h* = 2.418×10^{14} s-1V-1.

$h/e = (3.99 \pm 0.22) \times 10^{-15}$ V s

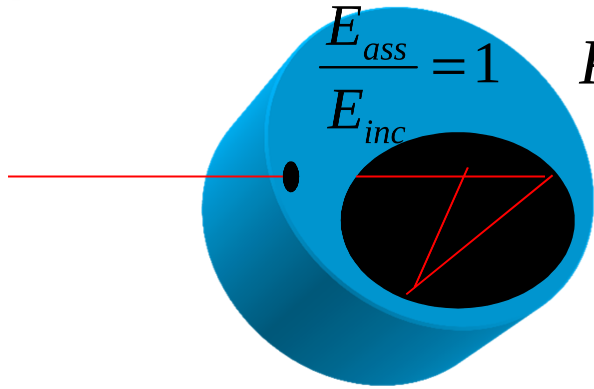
$e = 1.6021 \times 10^{-19}$ Coulomb

$h = (6.39 \pm 0.35) \times 10^{-34}$ J s.

Spettro di Corpo Nero



$$\langle \varepsilon \rangle (\nu) = \frac{\int_0^\infty E\, e^{-E/kT}}{\int_0^\infty e^{-E/kT}} \approx \nu^2 T$$



$$\frac{E_{ass}}{E_{inc}} = 1 \qquad P_{emiss} = f(T)$$

L.Wien $\lambda_{\max} T = \sigma_{SB}$

Ipotesi di Plank (1900): per ogni data frequenza, il sistema materiale può scambiare con la radiazione **multipli interi** di un quanto fondamentale

Ipotesi di Planck dei Quanti (1900)

$$\boxed{\Delta E = h\nu}$$

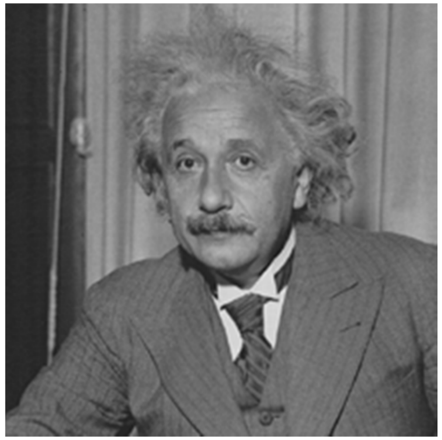
$$\langle \varepsilon \rangle (\nu) \approx \frac{h\nu^3}{e^{\frac{h\nu}{k_B T}} - 1}$$

¡ Fotoni !

Elettromagnetismo Classico

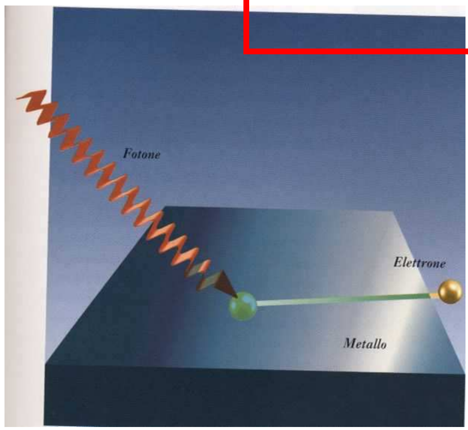
$$p = \frac{E}{c}$$

Einstein (1905)



$$\boxed{E = h\nu, \quad p = \frac{h}{\lambda}}$$

Relazioni Planck - Einstein

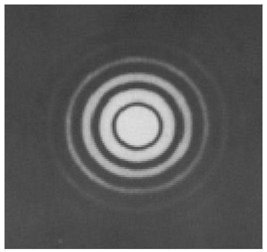


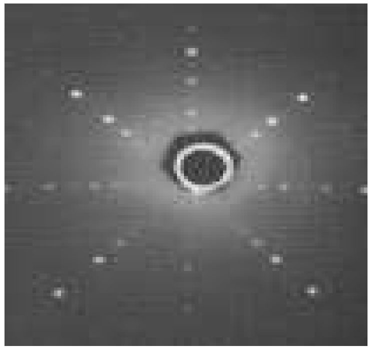
$$E^2 - p^2c^2 = m_0^{\ 2}c^4$$

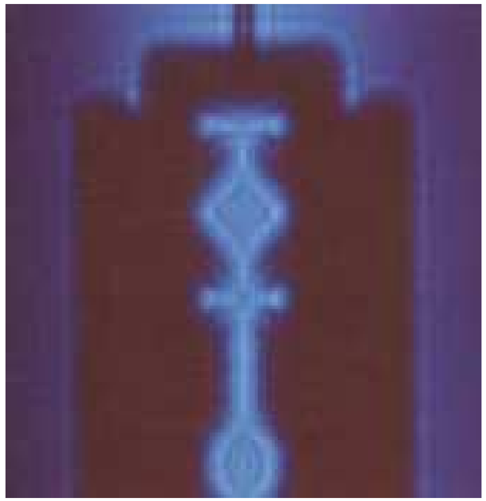
Invariante Relativistico

$$\boxed{m_{fotone} = 0}$$

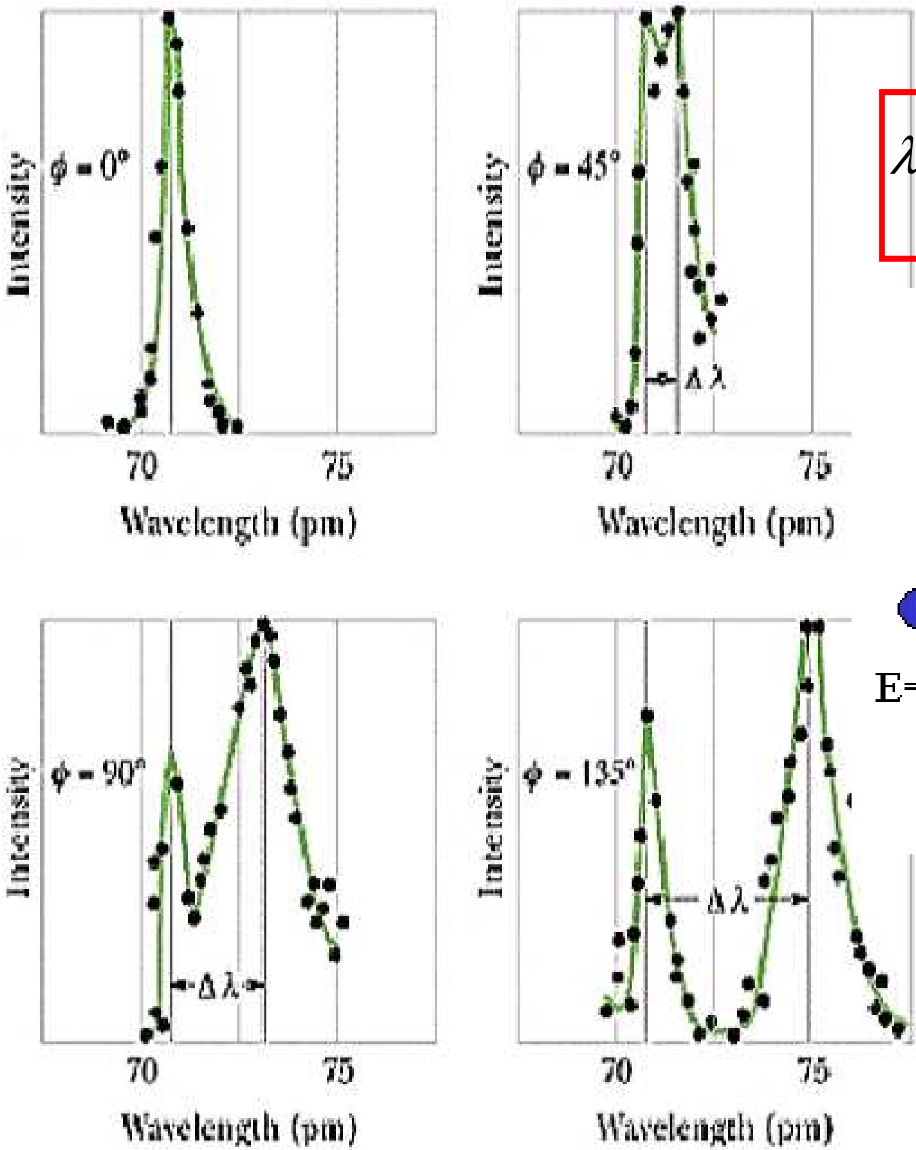
… e la DIFFRAZIONE !?!



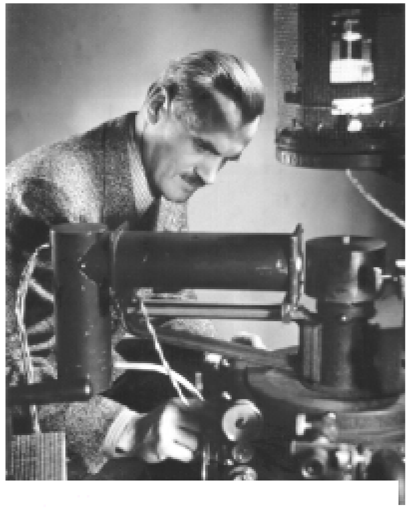


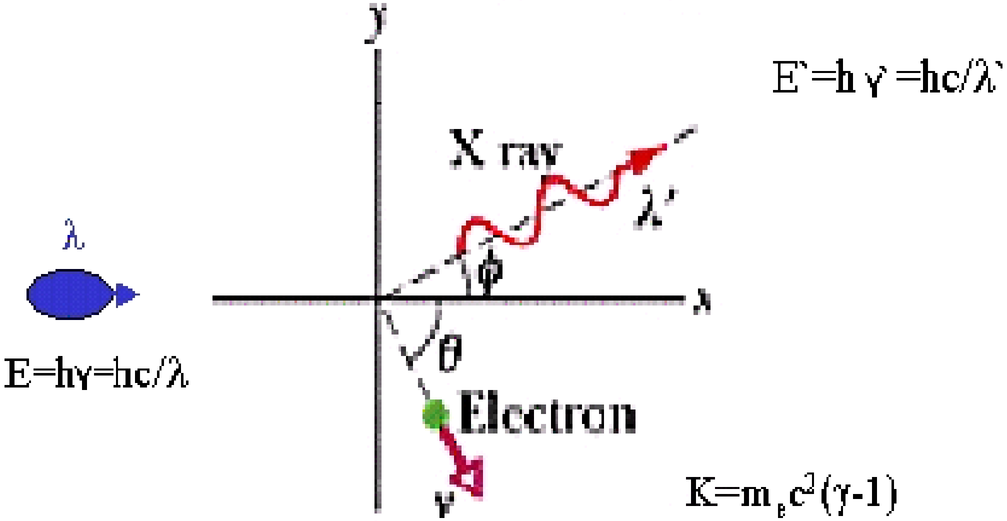


Effetto Compton



$$\boxed{\lambda' - \lambda = \frac{h}{m_{el} c}\left(1 - \cos\theta\right)}$$



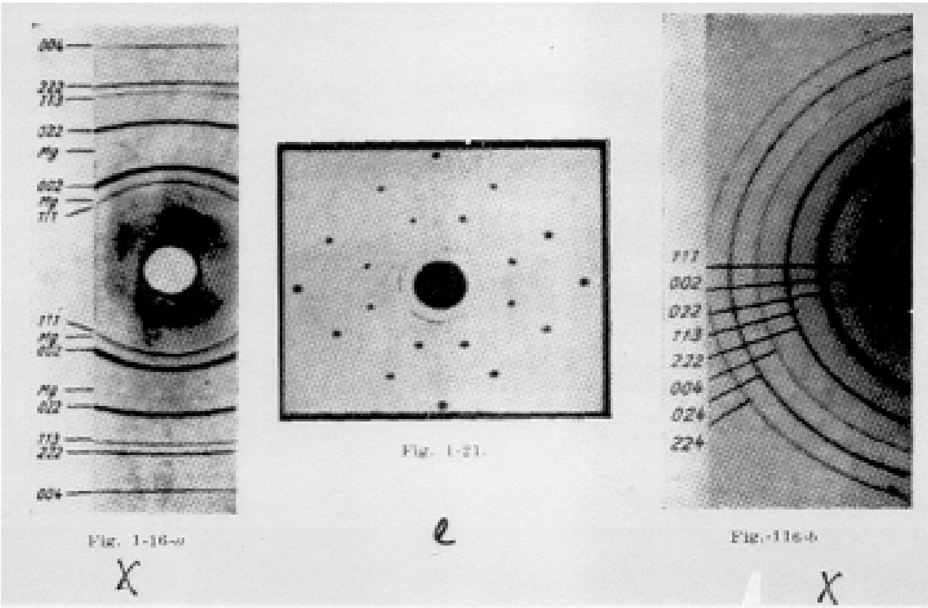


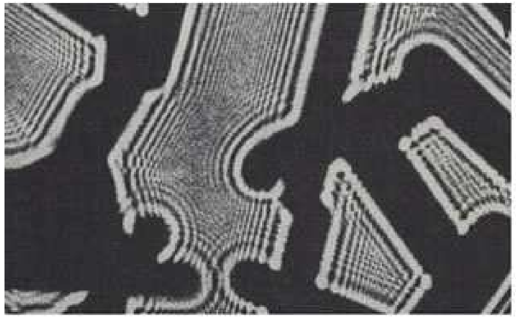
•Cons. dell'energia $E = E' + K$

•Cons. Quantità di moto $\vec{p}_X = \vec{p}_X{}' + \vec{p}_e$

$$p_X = \frac{h}{\lambda},\ p'_X = \frac{h}{\lambda'},\ p_{el} = \gamma m_{el} v$$

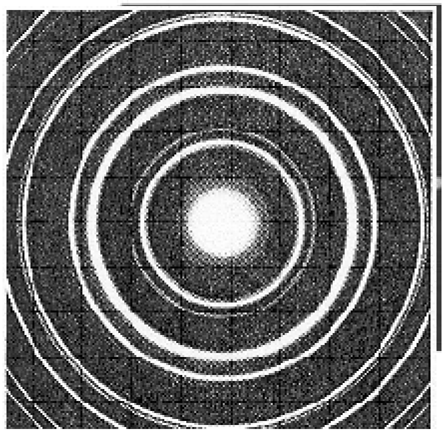
Diffrazione di luce e di particelle

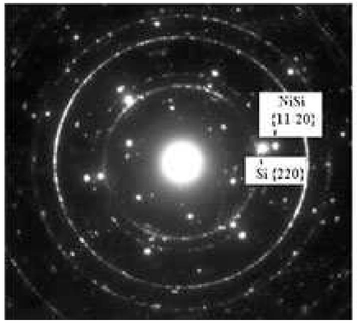




Diffrazione di elettroni su cristalli di ossido di Zn (Fresnel)

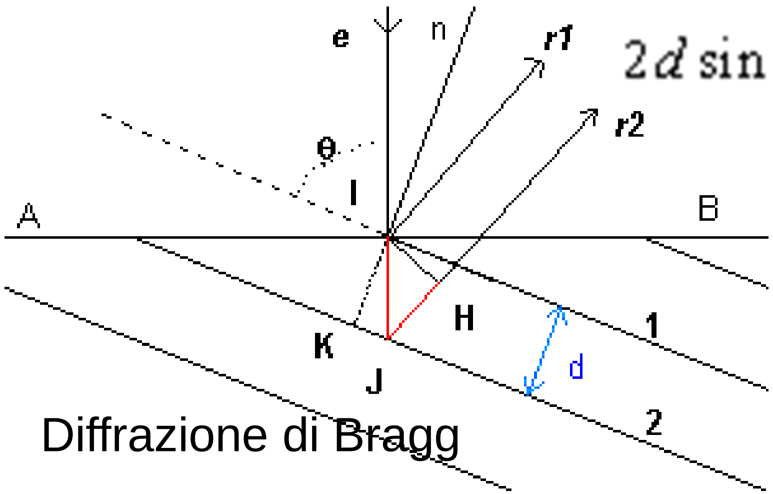
Elettroni su Au policristallino



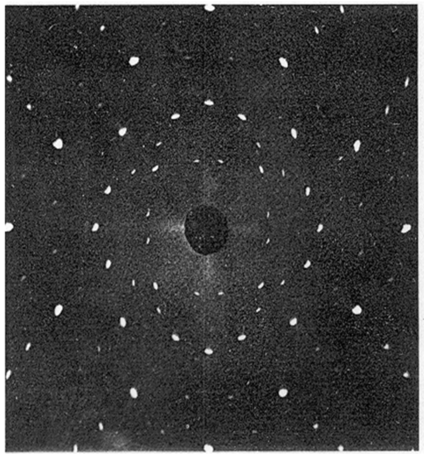


Diffrazione di elettroni su NiSi

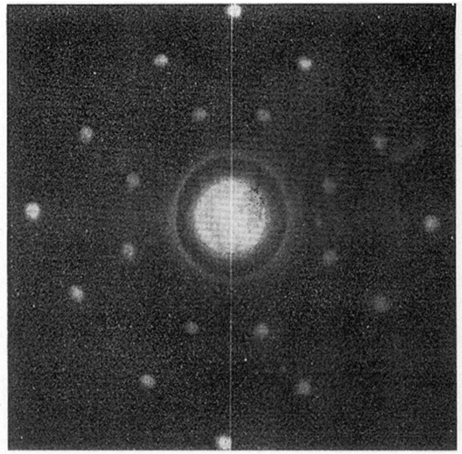
$$2d \sin\theta = n\lambda$$



Diffrazione di Bragg

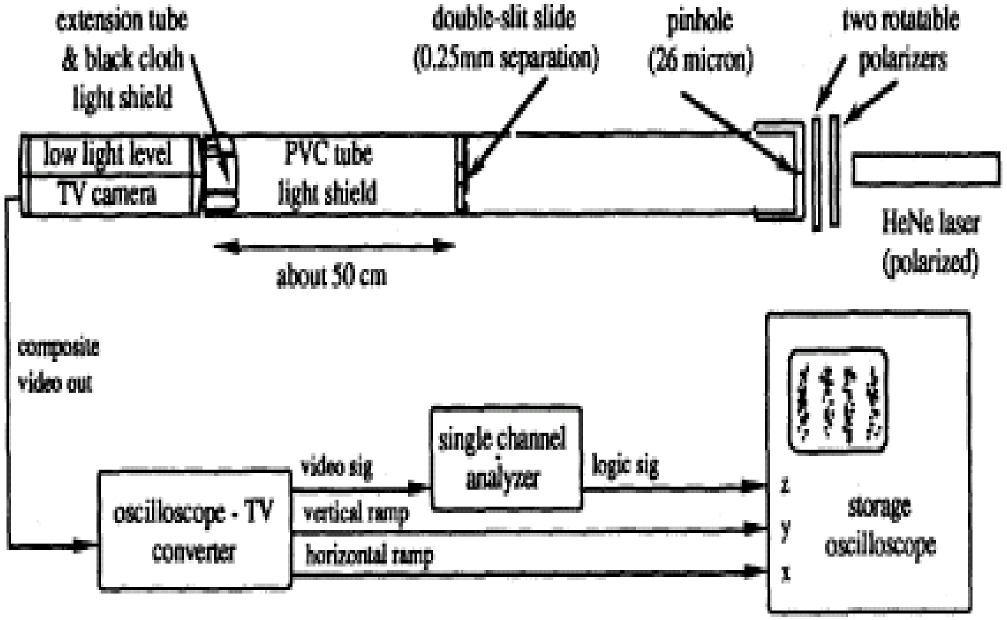


Raggi X su un monocristallo di NaCl



Neutroni termici su un monocristallo di NaCl

Diffrazione di singolo fotone



Wolfgang Rueckner and Paul Titcomb' Am. J. Phys. 64 (2), February 1996 184

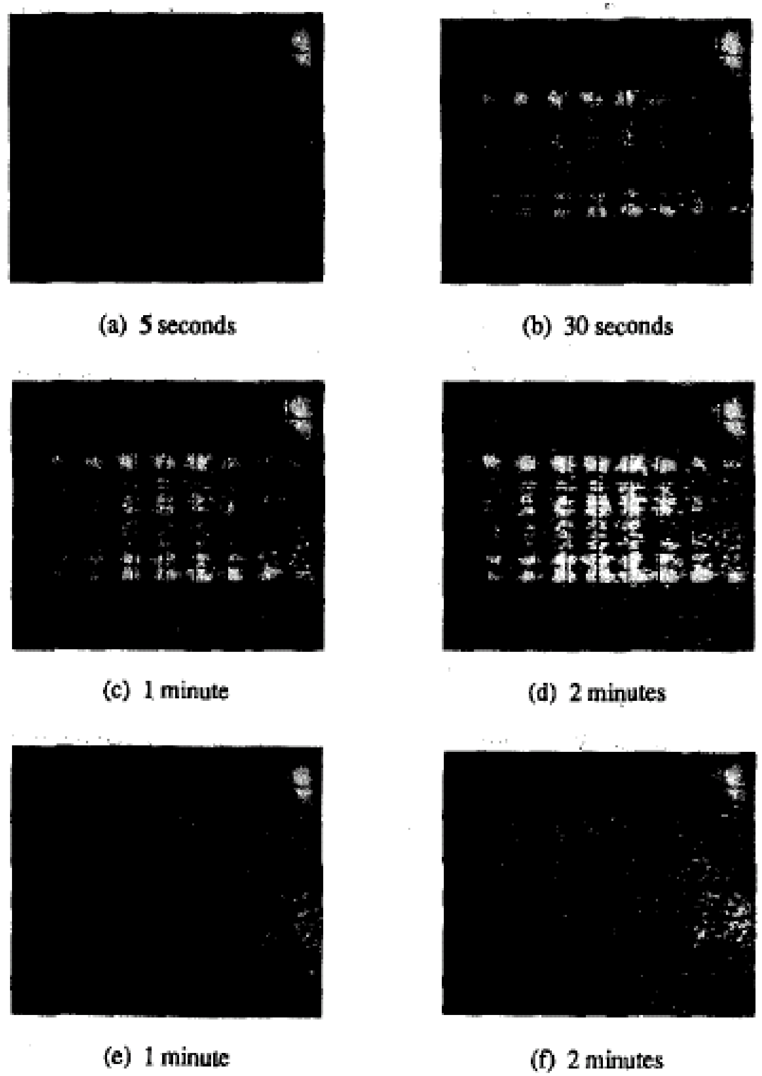
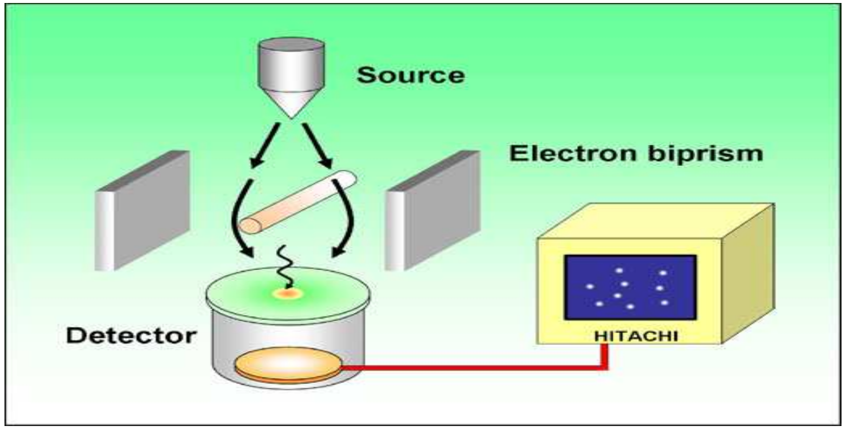
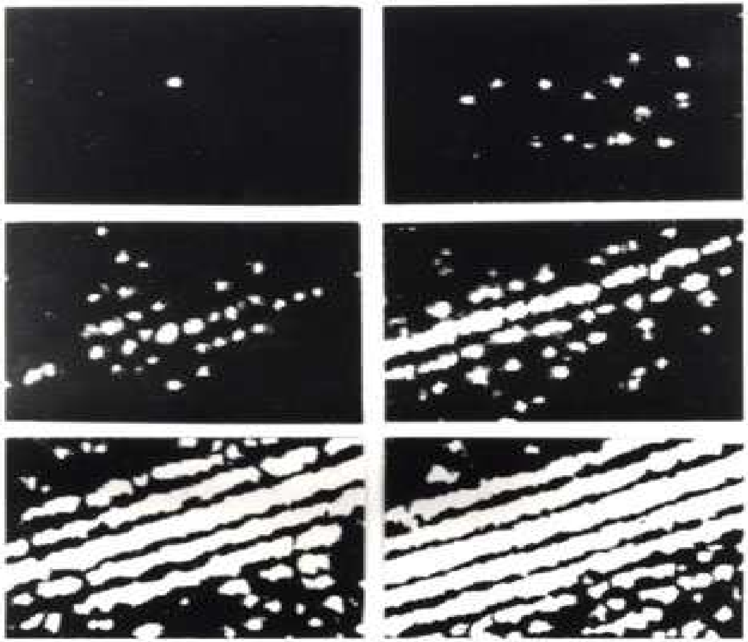


Fig. 2. Photographs of the storage oscilloscope display. (a)–(d) The accumulation of the double slit events; (e) one slit open followed by (f) the other slit open.

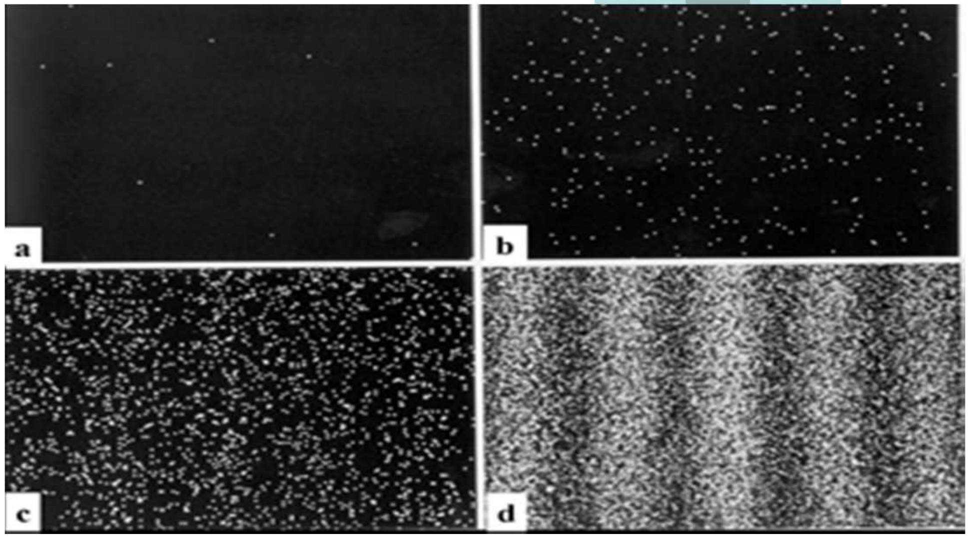
Elettrone su doppia fenditura



http://www.hqrd.hitachi.co.jp/em/doubleslit.cfm



P.G. Merli, G.F. Missiroli, G. Pozzi, *Am. J. Phys.* 44 (1976) 306-7.



http://physicsweb.org/articles/world/15/9/1/1

$\hbar$

- La Fisica possiede* una “costante di scala” :
  - il quanto d’azione

$$h = 6.626068 \times 10^{-34}\ m^2\ kg\ /\ s$$

determina la *granularità intrinseca* della natura,

- Relazioni di Planck – Einstein – de Broglie
  - proporzionalità fra grandezze descrittive di un **oggetto quantistico**

Grandezze “corpuscolari”

$$E = h\omega / 2\pi = \hbar\omega$$

$$p = h / \lambda = 2\pi\hbar / \lambda = \hbar k$$

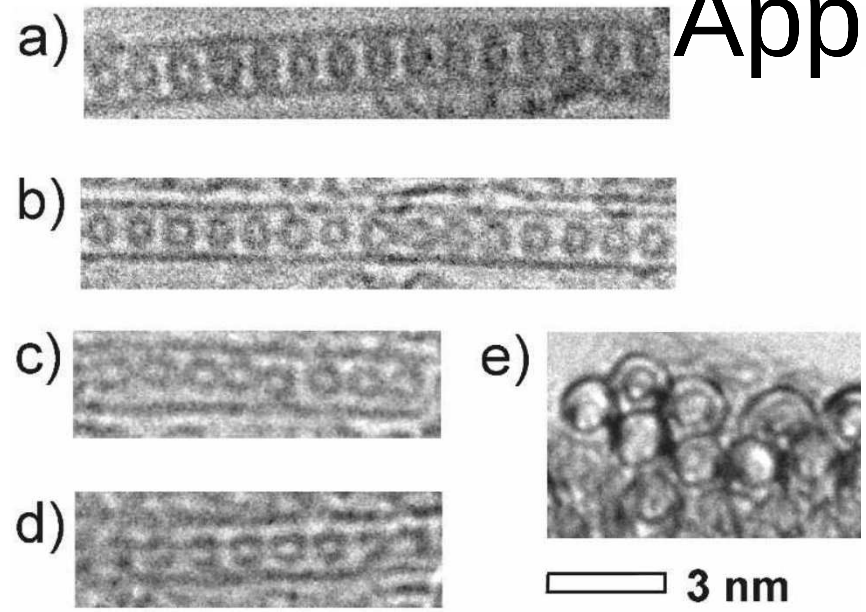
Grandezze “ondulatorie”

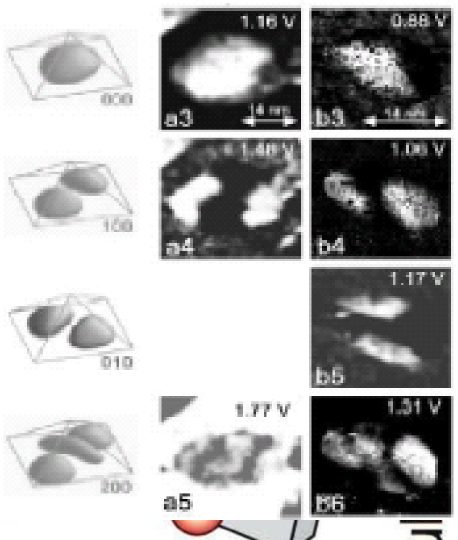
Complementarietà onda-corpuscolo

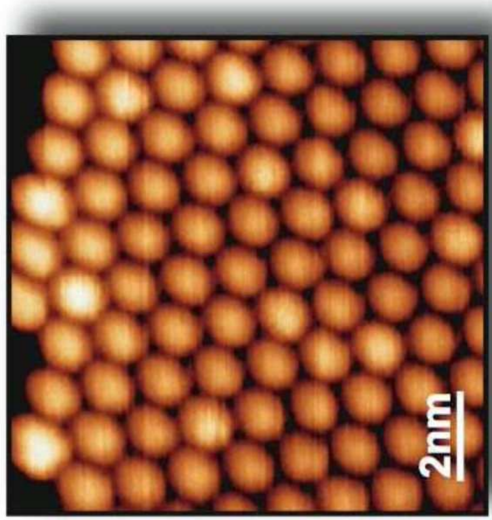
* Altre scale: **c = 299 792 458 m s^{-1}**

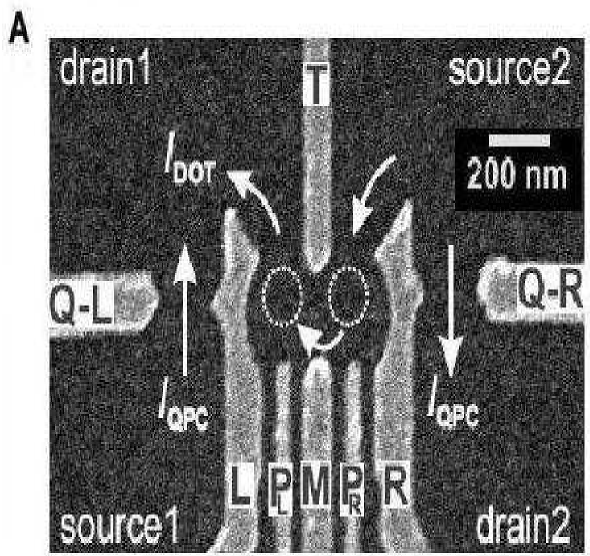
Relatività

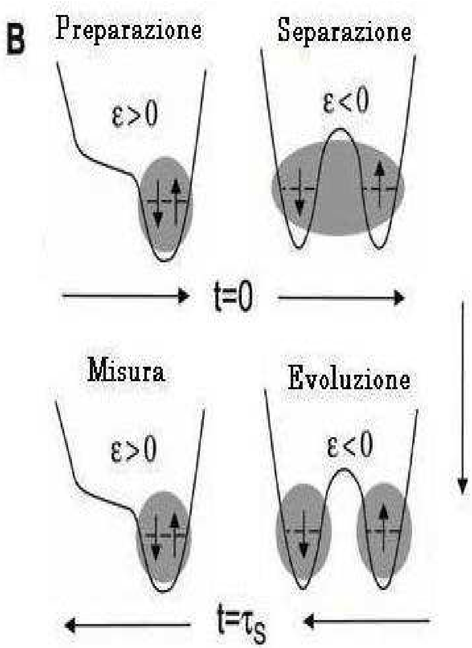
Applicazioni

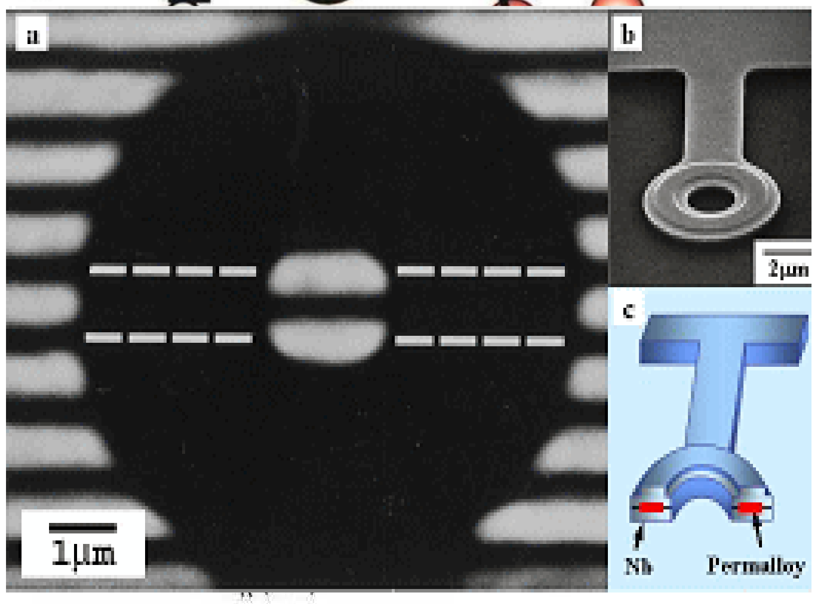


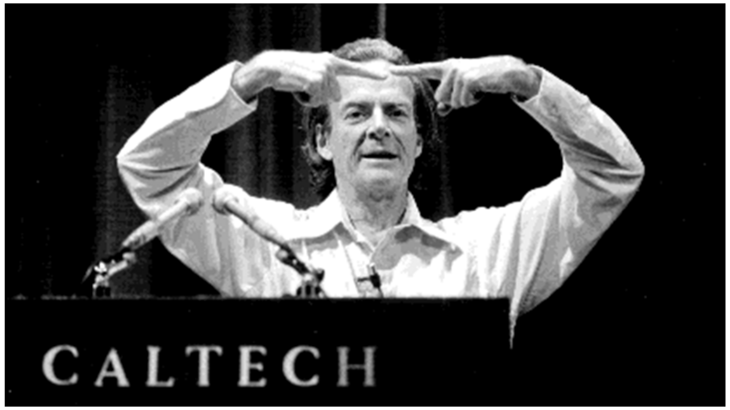












Noi sappiamo quale è il comportamento degli elettroni e della luce. Ma come potrei chiamarlo? Se dico che si comportano come particelle, dò un'impressione errata. Ma anche se dico che si comportano come onde. Essi si comportano nel loro proprio modo inimitabile che tecnicamente potrebbe essere chiamato il

*"**modo quanto meccanico**".*

Si comportano in un modo che non assomiglia a nulla che possiate aver mai visto prima. La vostra esperienza con cose che avete visto prima è incompleta. Il comportamento delle cose su scala molto piccola è

***semplicemente diverso**.*

(R. P. Feynman)