MATERIA OPTATIVA Y DE DOCTORADO

FÍSICA DEL ATTOSEGUNDO

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PRINCIPLES OF LASER-ATOM INTERACTION

UNIT I
TIME SCALES IN ATOMIC PROCESSES

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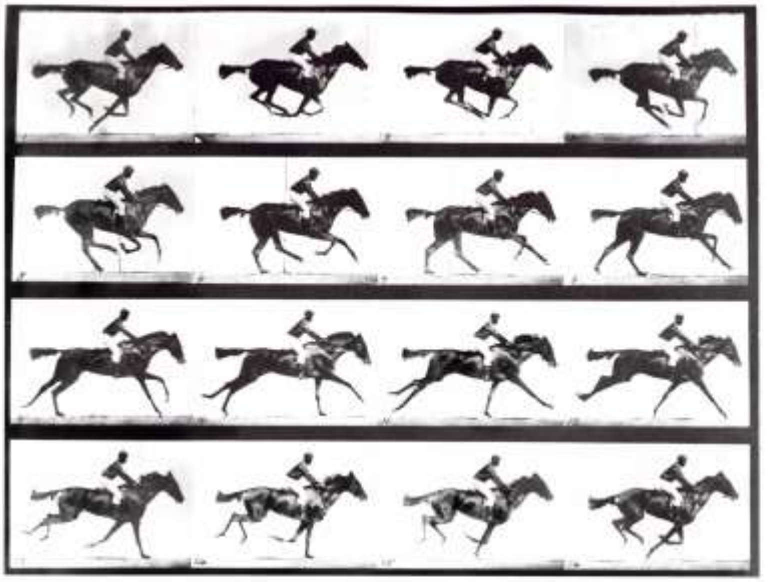

Eadweard Muybridge en el siglo XIX con la fotografia del caballo al galope. Obturador en milisegundos

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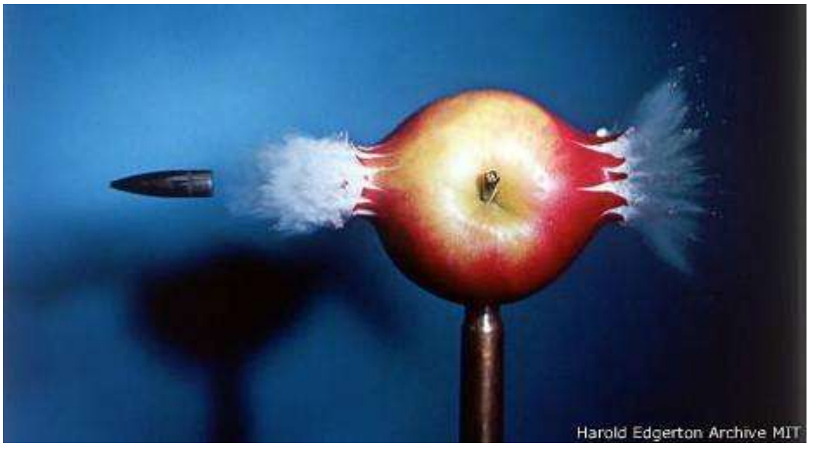

Harold Edgerton en el siglo XX con lámpara flash y fotografía estrobosopica, microsegundos

Time Scales in Atomic Processess

news and views

Atomic photography

Louis F. DiMauro

No ordinary camera can capture the motion of electrons inside an atom. But the advent of ultrafast laser pulses brings the necessary 'shutter speed' for snapping them as they tumble between energy levels close to the nucleus.

Louis DiMauro, Nature **419**, 789 (24 October 2002)

v ~ 150 km/h

exposure time ~ 5 ms

~ 0.1 ms to resolve the ball

And to freeze an atom in motion?

Time Scales in Atomic Processess (cont.)

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Hydrogen Atom

A quick estimate of v_0 and a_0

Electronic motion in an atom (virial theorem):

$$\langle T_{kin} \rangle = -\frac{1}{2}\langle V_{pot} \rangle = E_{bind}$$

Average velocity:

$$T_{kin} = \frac{m_e v_0^2}{2} = E_{bind} = 13.6eV$$

$$v_0 = \sqrt{\frac{2Ry}{m_e}} = \sqrt{\frac{27.2116eV}{0.511MeV/c^2}} = \alpha c$$

$v_0 = c/137$

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Time Scales in Atomic Processess (cont.)

Average distance (Bohr radius):

$$\langle V_{pot} \rangle = -2Ry = -\frac{e^2}{4\pi\varepsilon_0 a_0}$$

$$a_0 = \frac{e^2}{8\pi\varepsilon_0 Ry} \approx 0.529 \times 10^{-10} m$$

Orbit time:

$$\tau_{orbit} = \frac{2\pi a_0}{v_0} = 2\pi \frac{0.529 \times 10^{-10}}{3 \times 10^8} \times 137 s$$

$\sim 2\pi \times$ **24.188 x 10^{-18} s** atomic unit of time

~ 150 *as*

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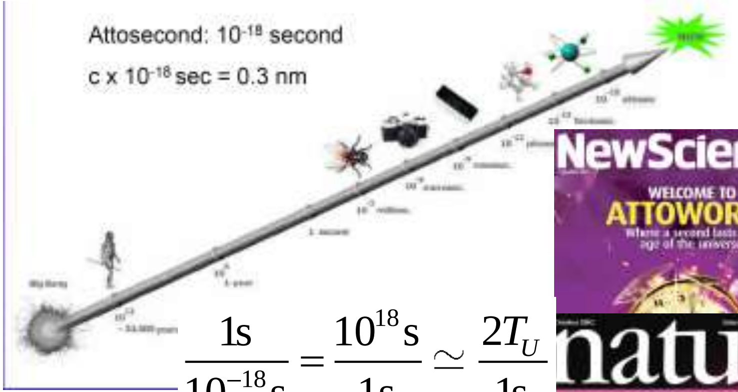
Time Scales in Atomic Processess (cont.)

Attosecond: 10^{-18} second

c x 10^{-18} sec = 0.3 nm



$$\frac{1s}{10^{-18}s} = \frac{10^{18}s}{1s} \simeq \frac{2T_U}{1s}$$

The attosecond is as far from our own experience as the age of the Universe!

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Time-Dependent Quantum Interferences

Transition energies and time scales

$$\Psi(r,t) = e^{-iE_1 t}\phi_1(r) + e^{-iE_2 t}\phi_2(r)$$

$$\rho(r,t) = |\Psi(r,t)|^2 = |\phi_1|^2 + |\phi_2|^2 + \phi_1^* \phi_2 e^{i(E_2-E_1)t} + h.c.$$

Interference terms

Electron density beat period

$$\tau = \frac{2\pi}{|E_2 - E_1|}$$

atomic units: $\hbar = m_e = 1$

Time Scales in Atomic Processess (cont.)

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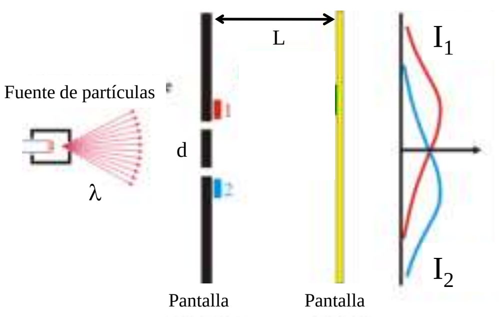
Experimento de la doble rendija

Partícula: $I(x) = I_1(x) + I_2(x) \propto |E_1(x)|^2 + |E_2(x)|^2$



Onda: $I(x) \propto |E_1(x) + E_2(x)|^2$

W. Rueckner y P. Titcomb, Am. J. Phys. **64**, 184 (1996).

Time Scales in Atomic Processess (cont.)

"The most beautiful experiment"

Physics World (September 2002)

1961, Clauss Jönsson: Double slit experiment with electrons (Am. J. Physics **42**, 4 1974).

Time Scales in Atomic Processess (cont.)

Characteristic times of quantum systems

	ΔE	τ
valence electrons in atoms	13 eV	150 as
valence electrons molecules	similar as in atoms	
vibrational motion of nuclei in molecules	$\sim$ 100 meV	$\sim$ 20 fs
inner shell electrons	$\sim$ 1 keV	$\sim$ 2 as
nuclear fusion $d + t \to He^{++} + n$	17 MeV	$\sim 10^{-7}$ as

Other time scales

Solids: thermalization and relaxation – a wide range of time scales

Clusters: ionization and electron detachment – fast !
Coulomb explosion ~ 100 fs

Attosecond physics is the physics of valence electrons

(for the time being)