PRINCIPLES OF LASER-ATOM INTERACTION

UNIT II NAÏVE INTRODUCTION TO LASERS

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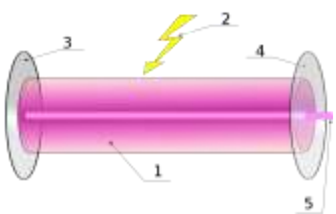
1st Semester 2024, Buenos Aires, Argentina

Origin

Laser invention: More than sixty years ago
16 May 1960 – Theodore Maiman observes pulsed laser in ruby

Light
Amplification by
Stimulated
Emision of
Radiation



1. Active media for the laser formation
2. Pumped energy to the laser
3. Reflectant mirror at 100%
4. Reflectant mirror at 99%
5. Emission of Laser beam

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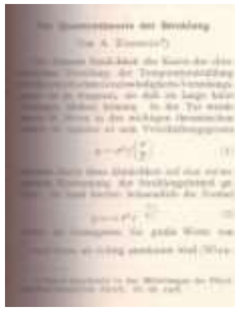
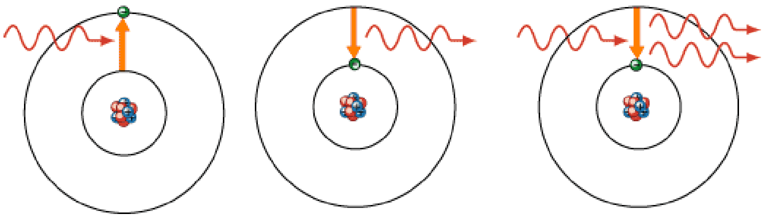
Theory

Albert Einstein
(1879-1955)

Einstein (1917):





spontaneous absorption   spontaneous emission   stimulated emission

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Theory (cont.)

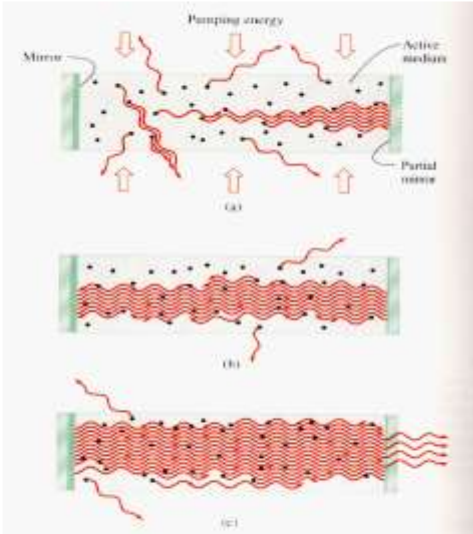
Exercise 1: (a) Consider a close container with atoms and radiation in equilibrium at temperature T. The atomic states are not degenerate with energy E_d and E_u, so that $E_u > E_d$. Derive Einstein's absorption $B_{d\to u}$, spontaneous emission $A_{u\to d}$, and stimulated emission $B_{u\to d}$ coefficients from the master equation:

$$\begin{cases} \dot{n}_{d\to u} = B_{d\to u} n_d \rho(\omega_{ud}) \\ \dot{n}_{u\to d} = A_{u\to d} n_u + B_{u\to d} n_u \rho(\omega_{ud}) \end{cases} \qquad (1)$$

where $\rho(\omega_{ud})$ is the energy density of the radiation, is $\omega_{ji} = (E_j - E_i)/\hbar$, $\dot{n}_{i\to j}$ the number of atoms doing the transition $i \to j$ per unit time due to the absorption or emission of radiation and n_i is the total number of atoms in state i. Hint: Consider the Boltzman and Planck distributions for the atomic levels and the radiation, respectively.
(b) Generalized the result in (a) for the case that E_d and/or E_u are degenerated.

Theory (cont.)

- *Inversion of population*: $n_u >> n_d$ through pumping.
- Stimulated emission: The emitted photon has the same phase, polarization, and direction as the incident

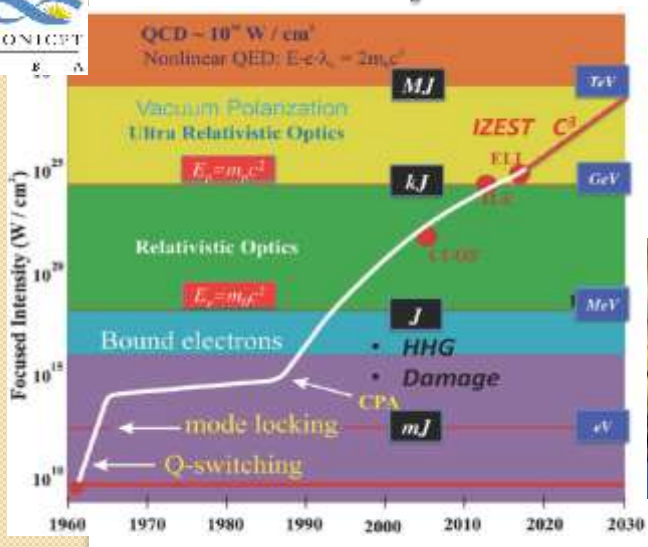


Media:

- Solid
- Liquid
- Gas
- Plasma
- Free electron laser (FEL)

Evolution (cont.)

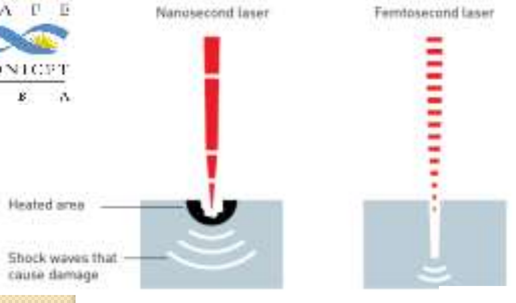
Intensity



2018

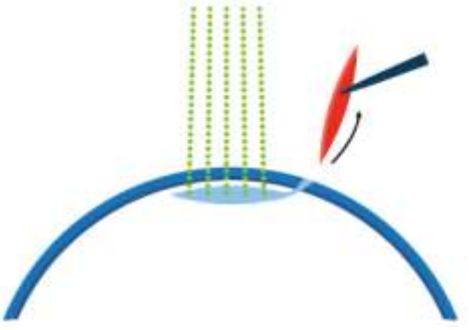
Irradiance of the Sun on the Earth surface: ~ 0.136 W/cm²

Láseres intensos en industria y medicina



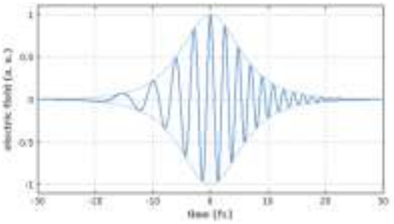
- Almacenamiento de datos
- Manufacturación de stents quirúrgicos, cilíndros micrometrizados de metal elongado que ensanchan y refuerzan los vasos sanguíneos, tracto urinario, etc.

- Procedimientos de cirugía refractiva para tratamiento de miopía y astigmatismo

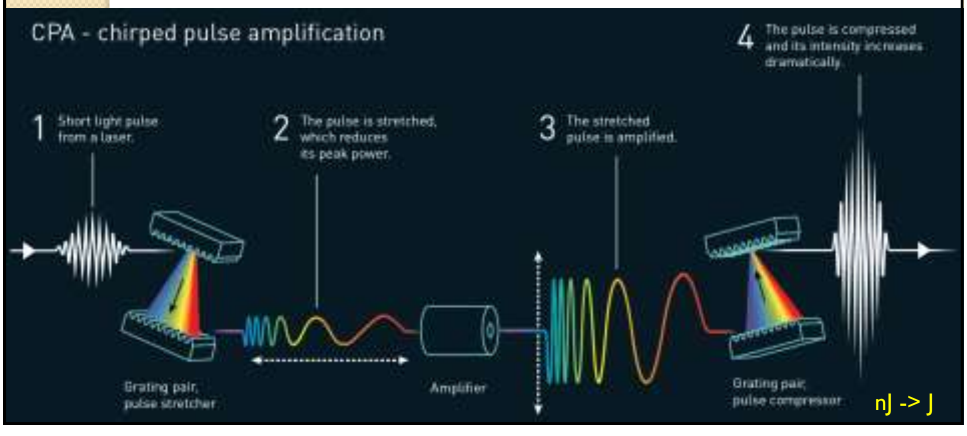


CHIRP PULSE AMPLIFICATION

Optical fiber: $n(\lambda)$ streches the pulse lowering its intensity. Then the pulse is amplified again without damaging the material and then it is compressed increasing the instensity.



nJ -> mJ



Evolution (cont.)

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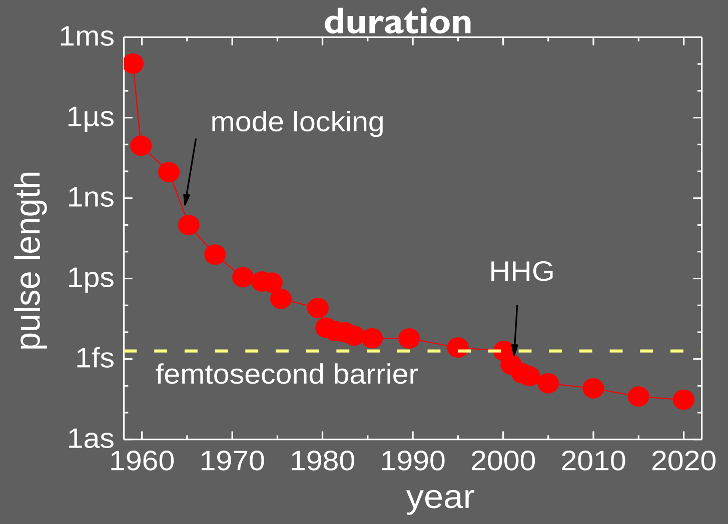
LASER PULSES



Evolution (cont.)

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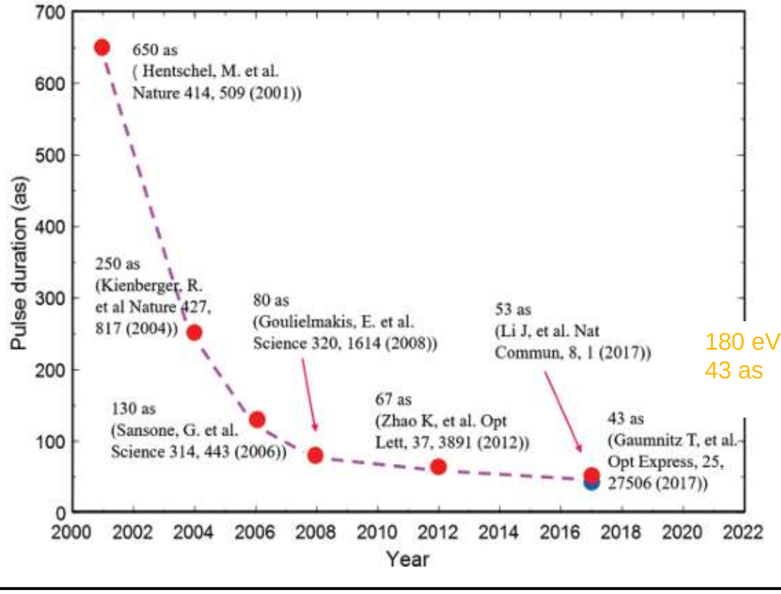
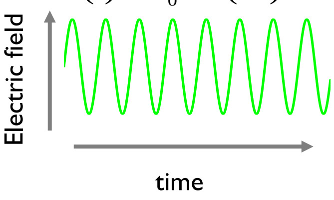


180 eV
43 as

Evolution (cont.)

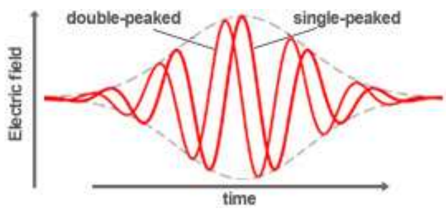
Long laser

$E(t) = E_0 \cos(\omega t)$



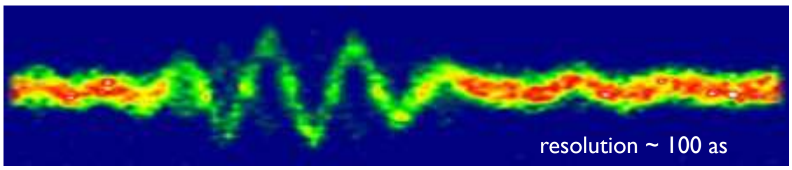
Short laser pulse

$E(t) = E_0 \sin^2(\pi t / \tau) \cdot \cos(\omega t + \varphi_{CE})$



Parámetros relevantes del láser: E_0, ω , τ, φ_{CE}

Attosecond oscilloscope: XUV + IR



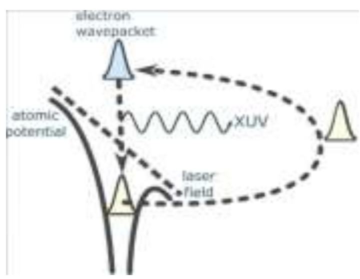
E. Goulielmakis *et al*, Science **305**, 1267 (2004)

Evolution (cont.)

Femto-second barrier

$$\left.\begin{aligned} \tau = nT = \frac{2\pi n}{\omega} \\ \hbar\,\omega = 1.55 \text{ eV} \end{aligned}\right\} \Rightarrow \tau_{\text{lim}} \simeq 3 \text{ fs}$$

High-order Harmonic Generation (Three-Step Model)



Exercise 2: Consider a 10 fs Gaussian pulse for which $\Delta\nu\tau = 0.44$.
(a) How much is the bandwith $\Delta\nu$? Answer: 4.4×10^{13} Hz
(b) How much is the banwidth $\Delta\lambda$ for a central wavelength of 800 nm? Answer: 94 nm.