Lasers

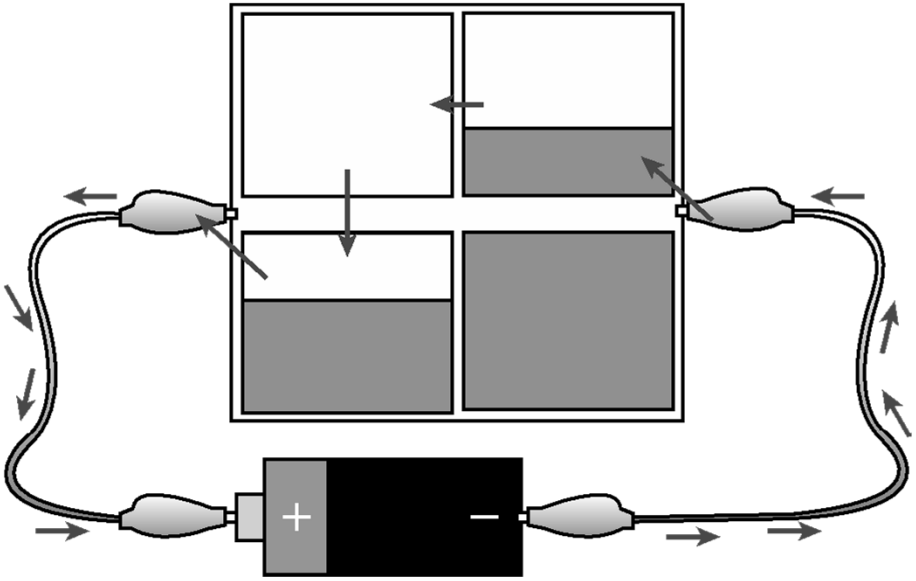
Stimulated Emission

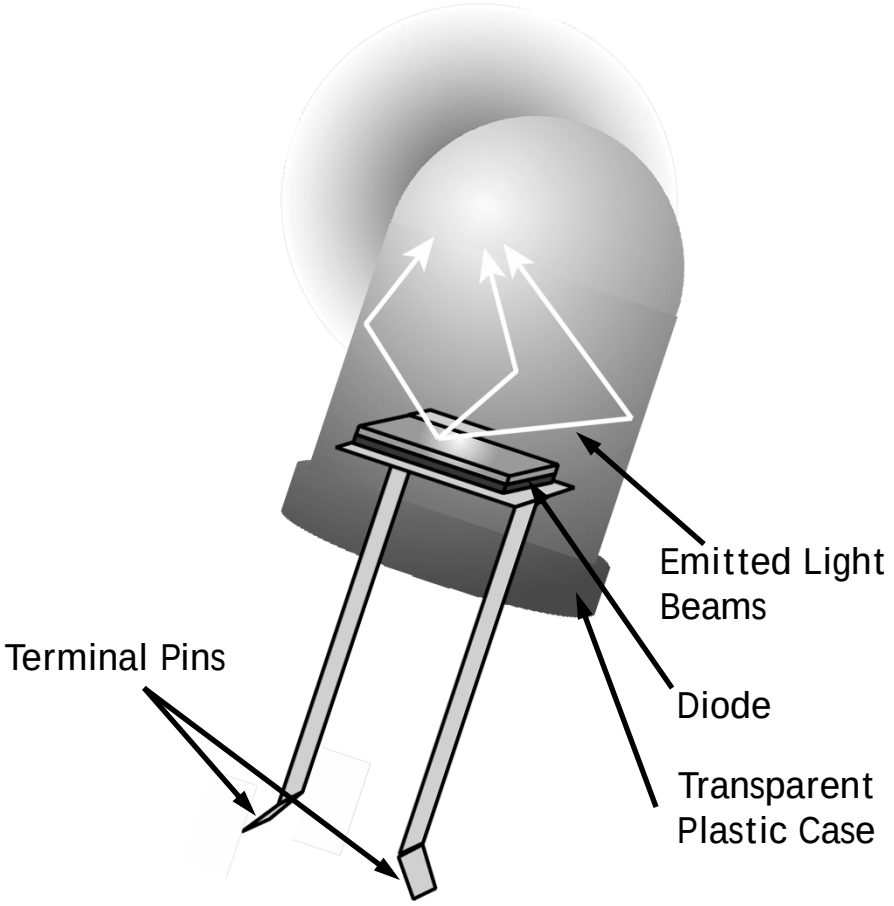
Lasers: Trapping Photons

Terahertz Lasers

Course Overview

P-N Junctions and LEDs

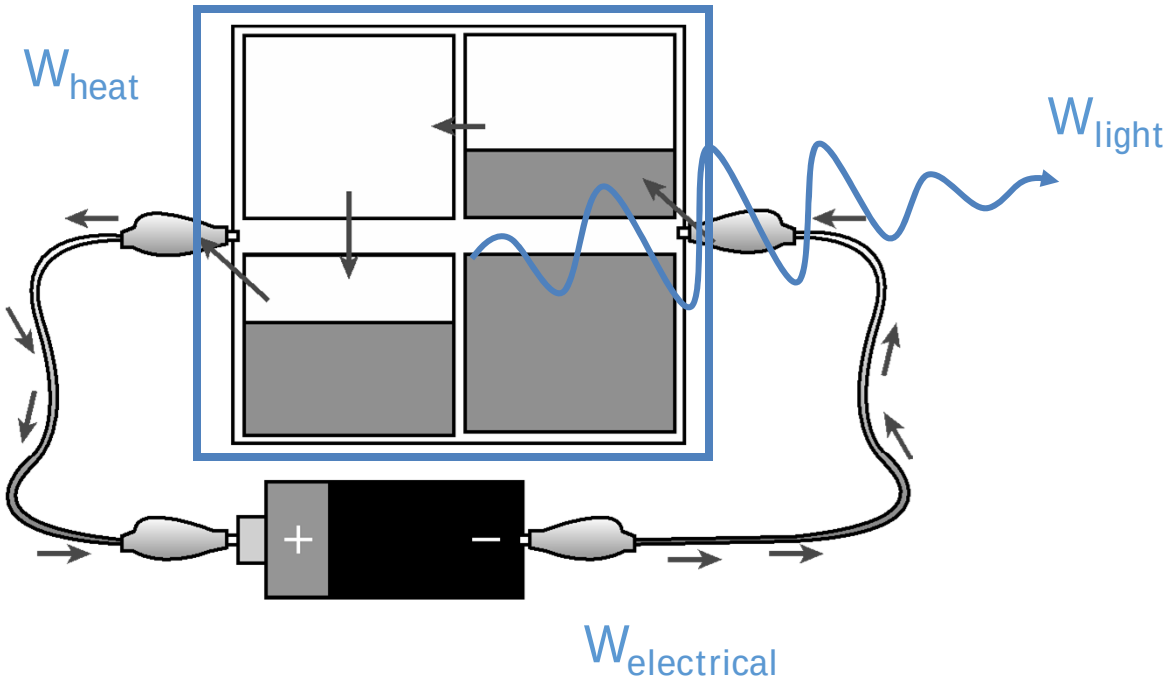




High energy electrons (n-type) fall into low energy holes (p-type)

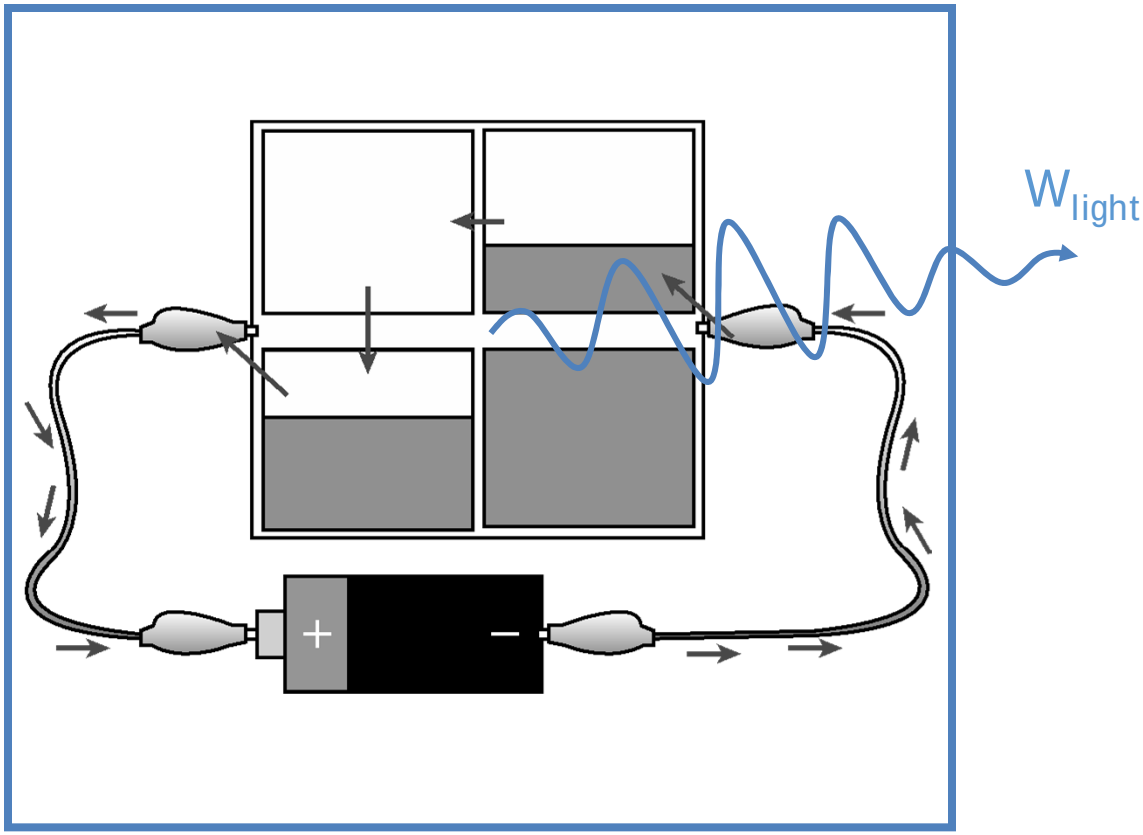
Energy Conservation

W_{stored} = _____

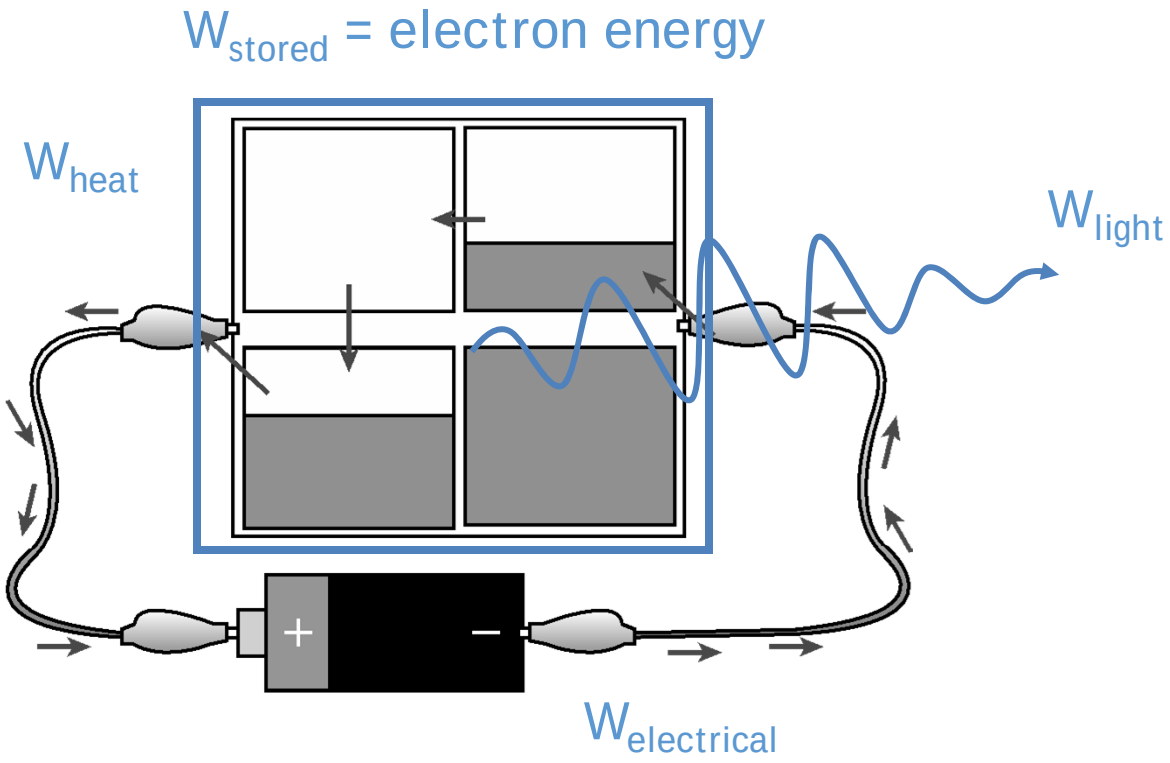


Energy Conservation

W_{stored} = _____



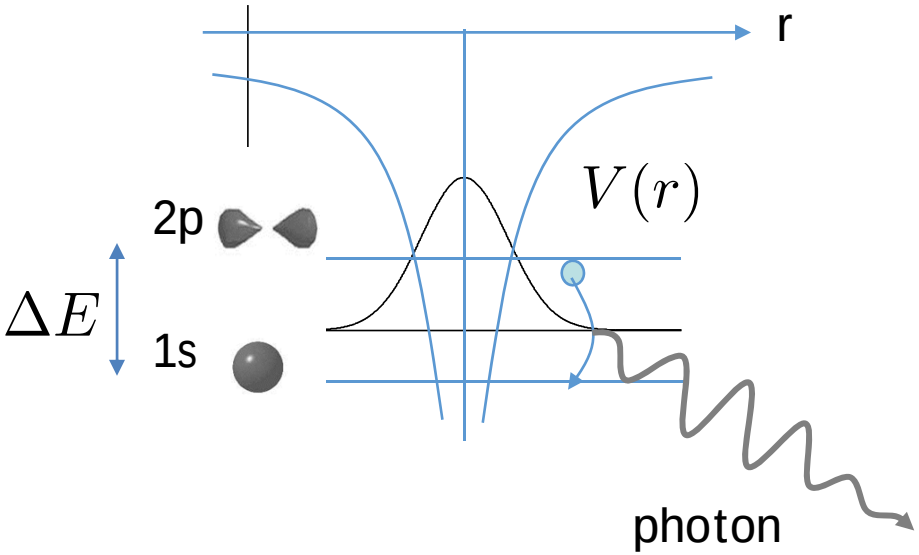
Through and Across Variables

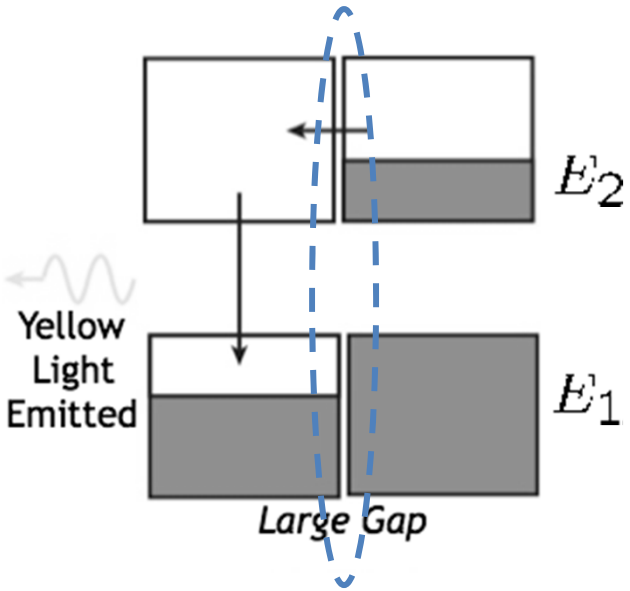


	THROUGH	ACROSS
ELECTRICAL		
LIGHT		

Atomic Transitions

$$\Psi = c_{1s}\phi_{1s}e^{iE_{1s}t} + c_{2p}\phi_{2p}e^{iE_{2p}t}$$





Light Emission from Magnets

Maxwell's Equations couple H and E fields..

$$\oint_C \vec{E} \cdot d\vec{l} = -\frac{d}{dt}\left(\int_S \vec{B} \cdot d\vec{A}\right)$$

$$\oint_C \vec{H} \cdot d\vec{l} = \int_S \vec{J} \cdot d\vec{A} + \frac{d}{dt}\int_S \epsilon\vec{E} \cdot d\vec{A}$$

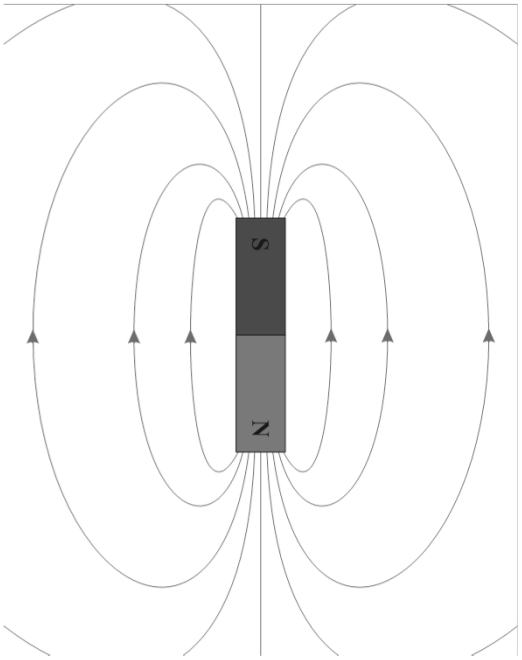
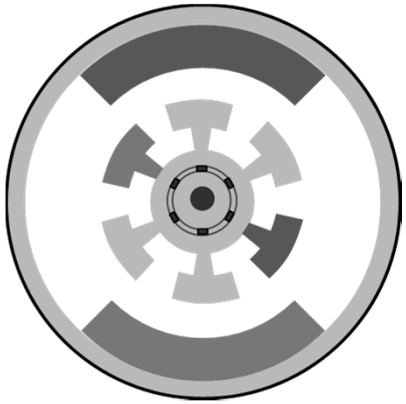
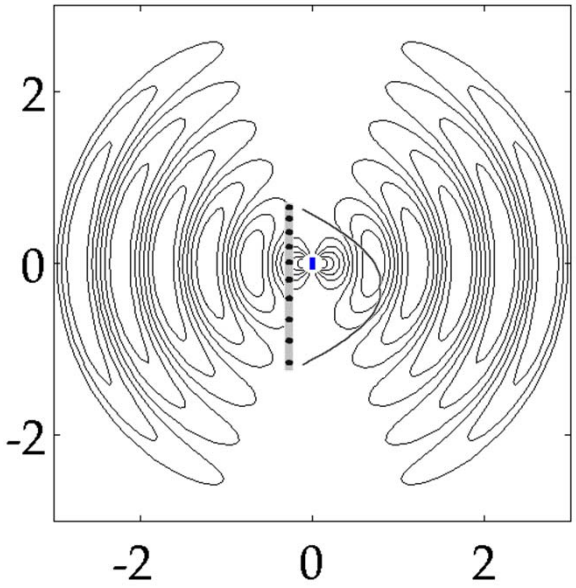


Image in the Public Domain



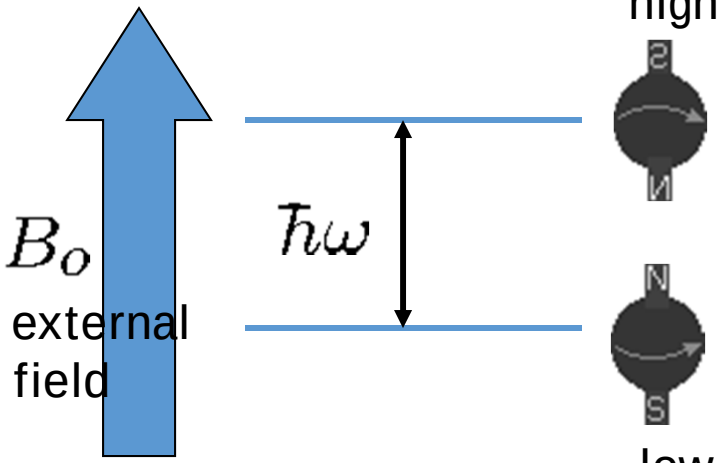
Radiation was missing from our quasi-static approximation

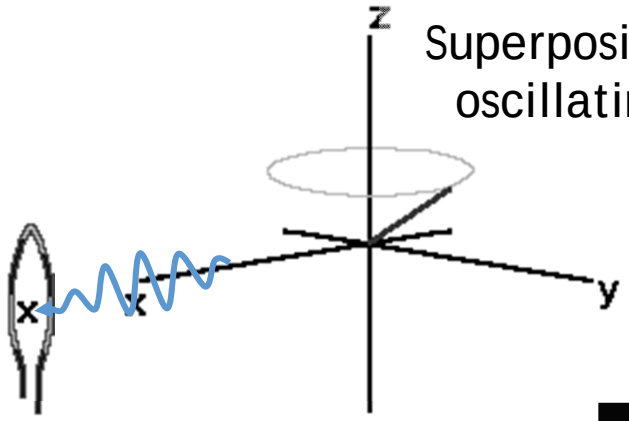


http://juluribk.com/2010/01/14/radiation-from-dipole/

Courtesy of Bala Krishna Juluri and Sophocles Orfanidis. Used with permission.

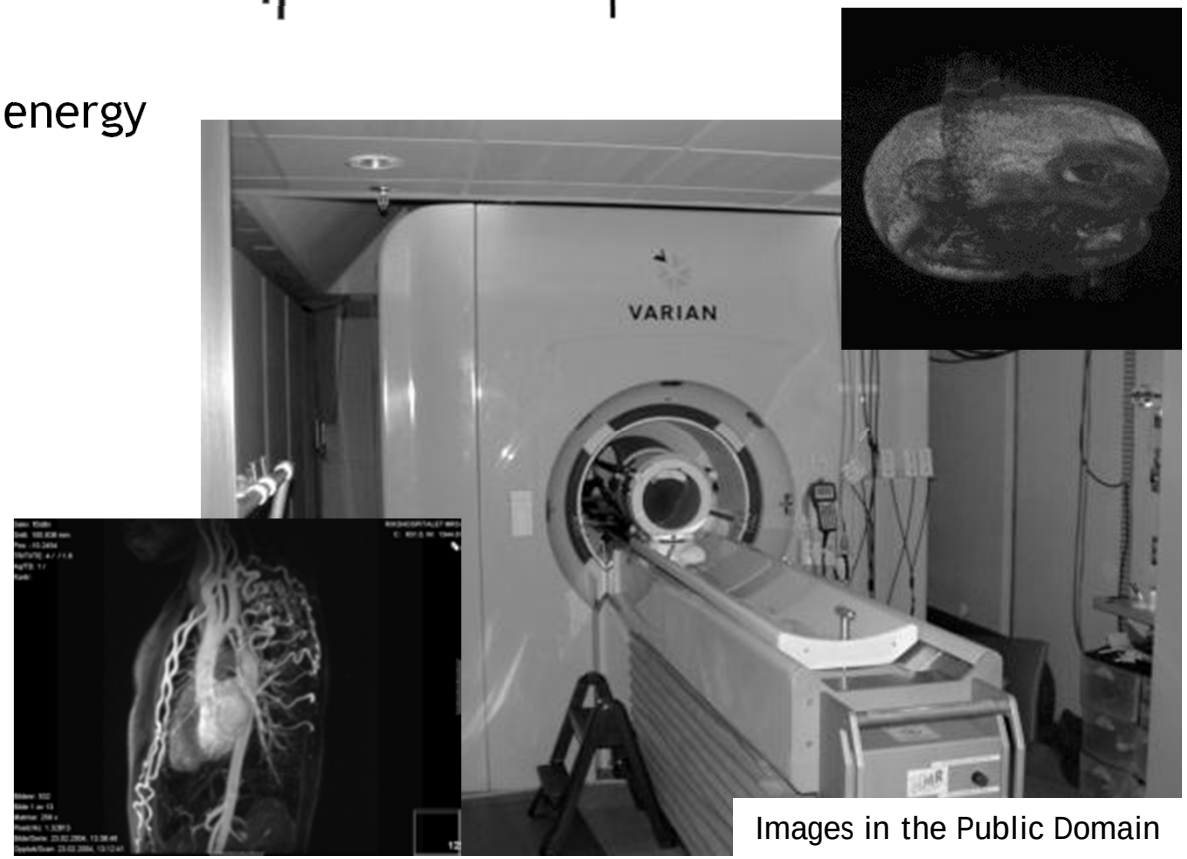
Light Emission from Magnets





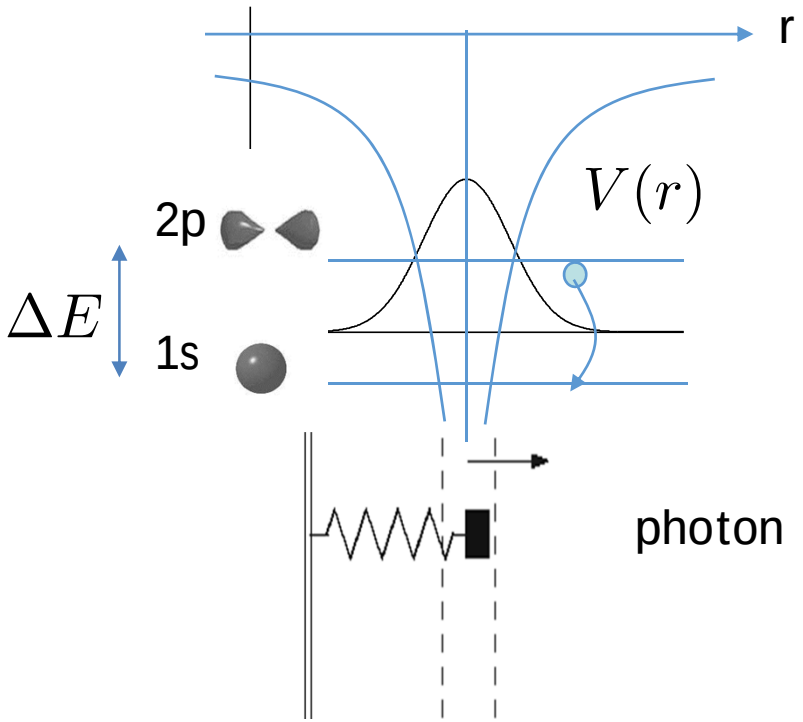
Superposition state = oscillating magnet

Nucleus	Resonance Frequency (1.5Tesla) MHz
^{1}H	63.86
^{2}D	9.81
^{13}C	16.05
^{14}N	4.62
^{19}N	6.57
^{23}F	60.07
^{31}Na	16.89
^{31}P	25.86



Images in the Public Domain

Solar Cells and Photodetectors

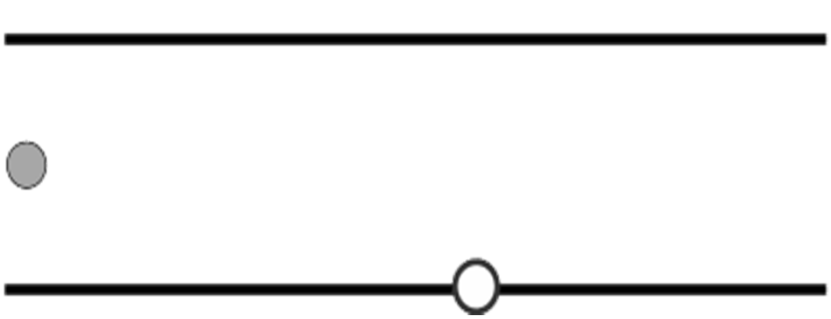


Classical: Oscillating electric field drives charge oscillation

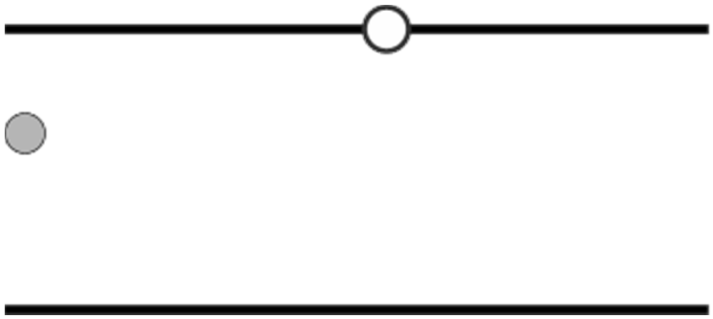
Quantum: Electric field creates superposition of energy states
– which have an oscillating charge density

Reverse Absorption: Stimulated Emission

ABSORPTION



STIMULATED EMISSION



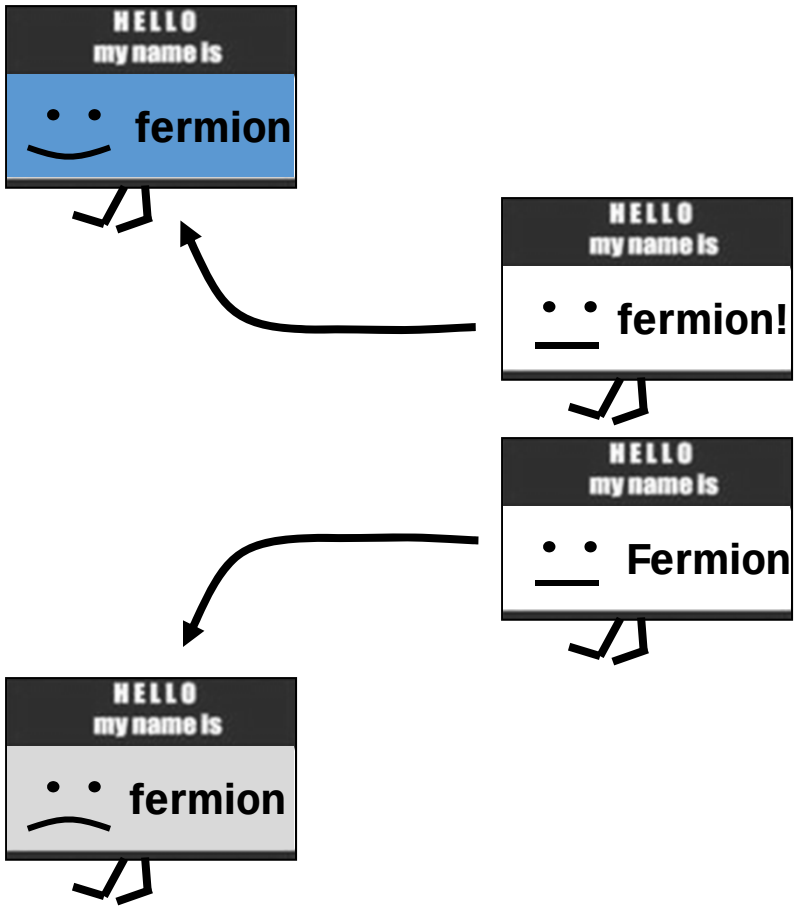
How do you choose the color, direction, and phase of the generated photon ?

GENERATED PHOTON IS
AN EXACT DUPLICATE OF THE INCOMING PHOTON

Quantum Mechanics and Stimulated Emission

Pauli Exclusion and electrons (fermions)

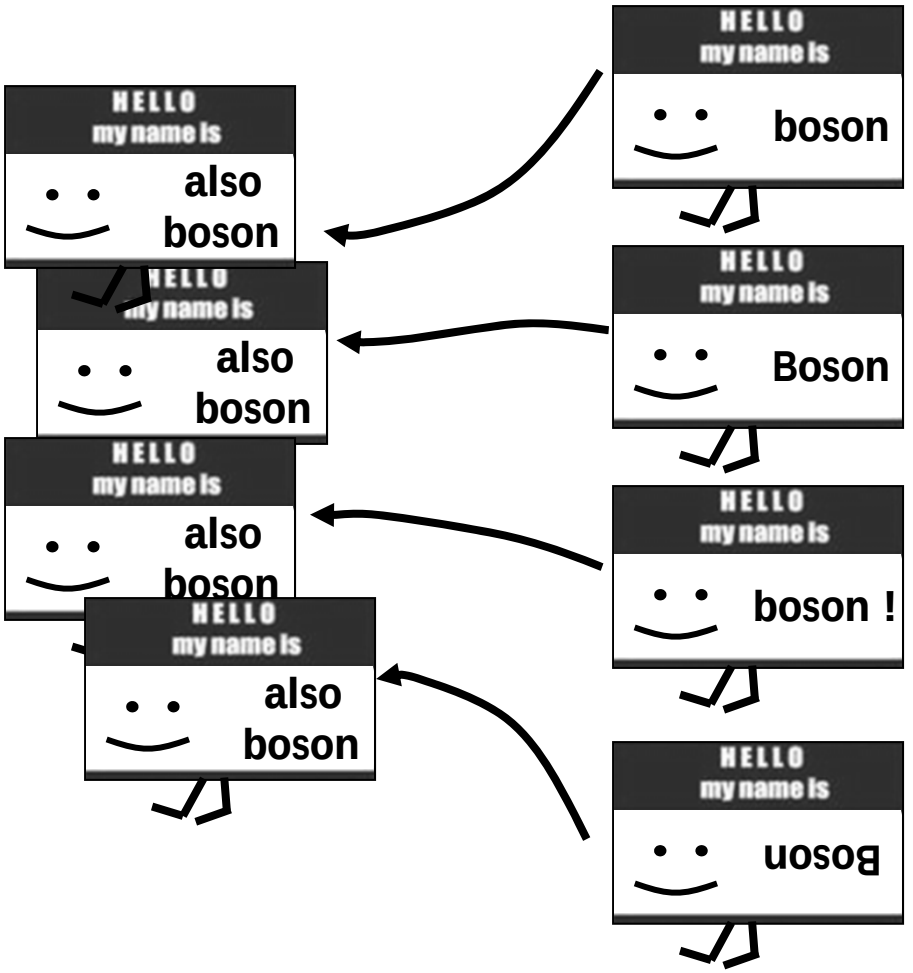
'Two is a crowd !'



FERMIONS GO TO DIFFERENT STATES

Stimulated emission and photons (bosons)

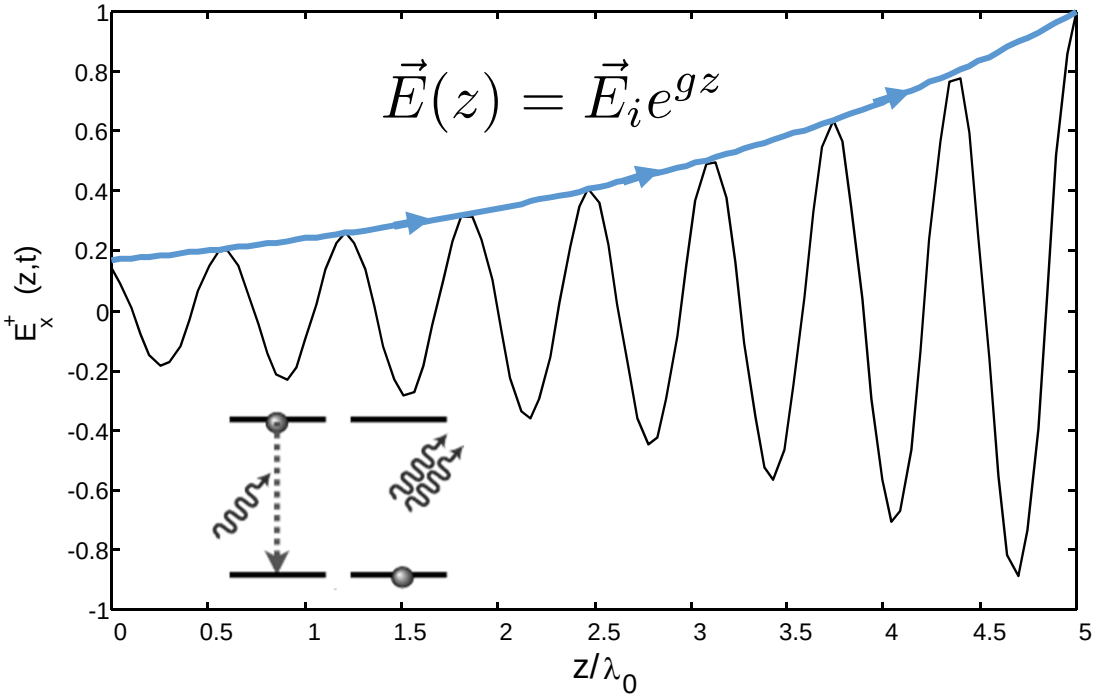
'The More the Merrier !'



BOSONS PREFER TO BE IN THE SAME STATE

Quantum Mechanics and Stimulated Emission

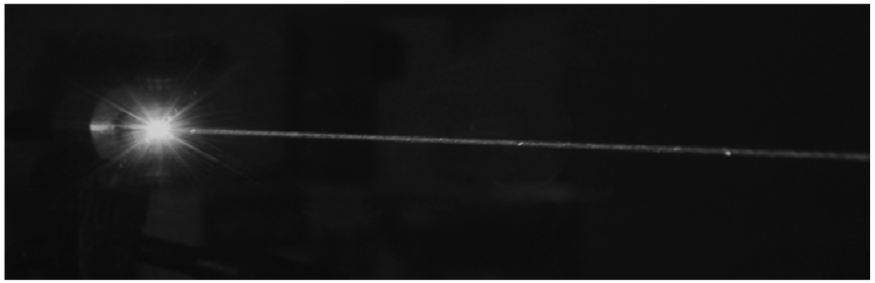
$$\tilde{\beta} = \frac{\tilde{n}\omega}{c} = \beta + jg$$



$$I(z) = I_o e^{+2gz}$$

Lasers

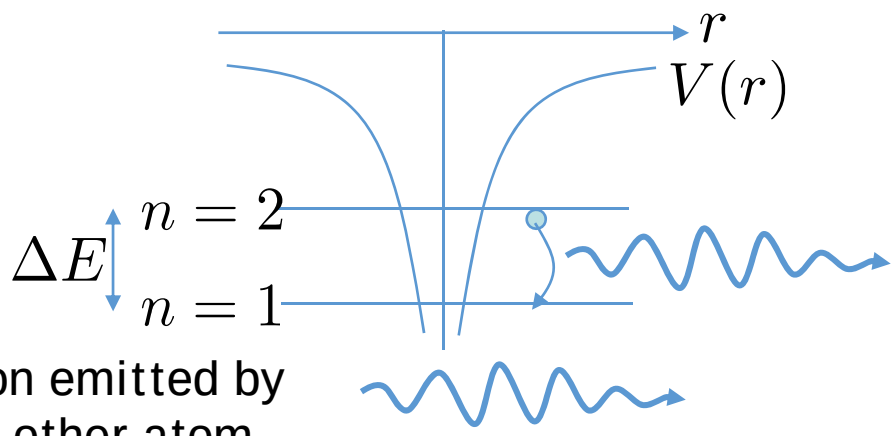
The astounding phenomenon is "Stimulated Emission"
– a purely quantum phenomenon !



Identical photons with the same frequency moving in the same direction –

Result is a
coherent light source with a highly directional beam !

Stimulated Emission: If one photon is present it is more likely that an atom will emit a second identical photon! In a laser there is a cascade that causes emission of many identical photons!

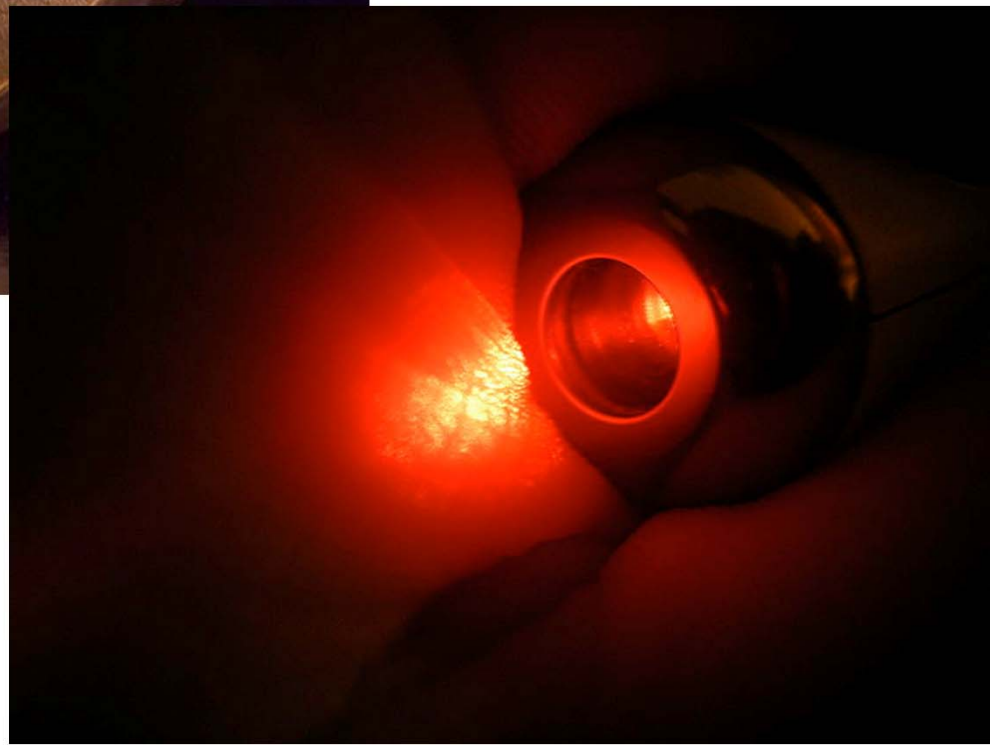


Photon emitted by some other atom

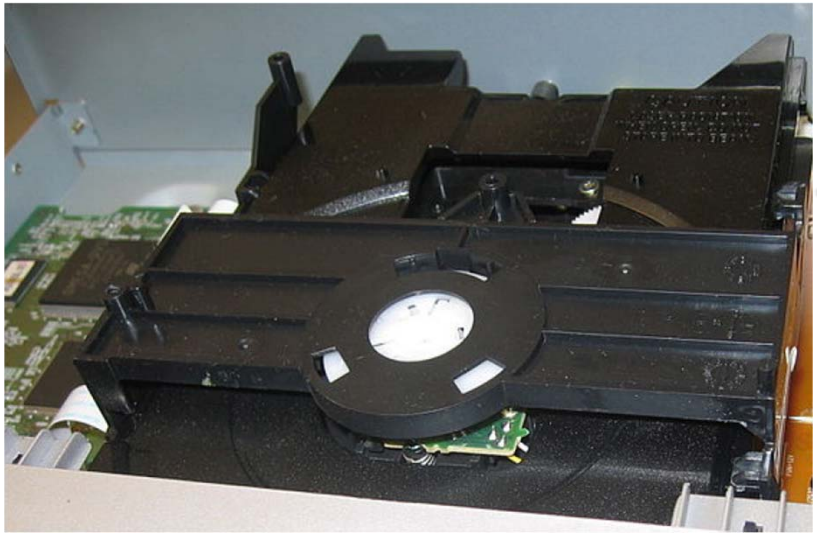
Two identical photons!

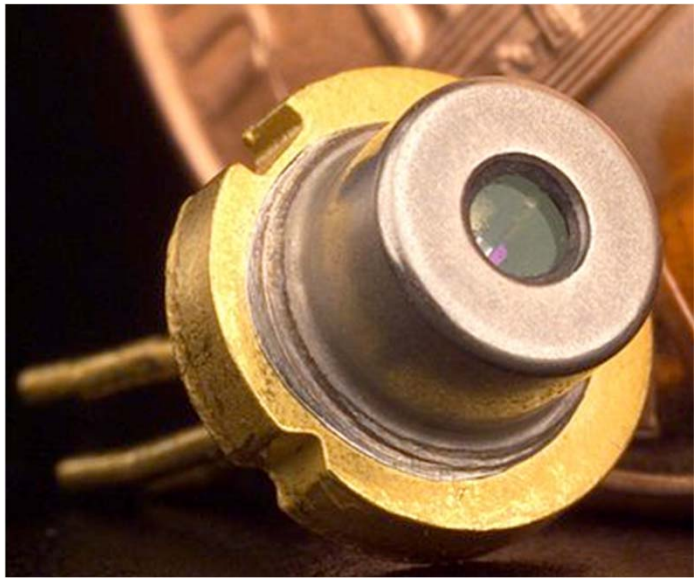
Semiconductor Lasers

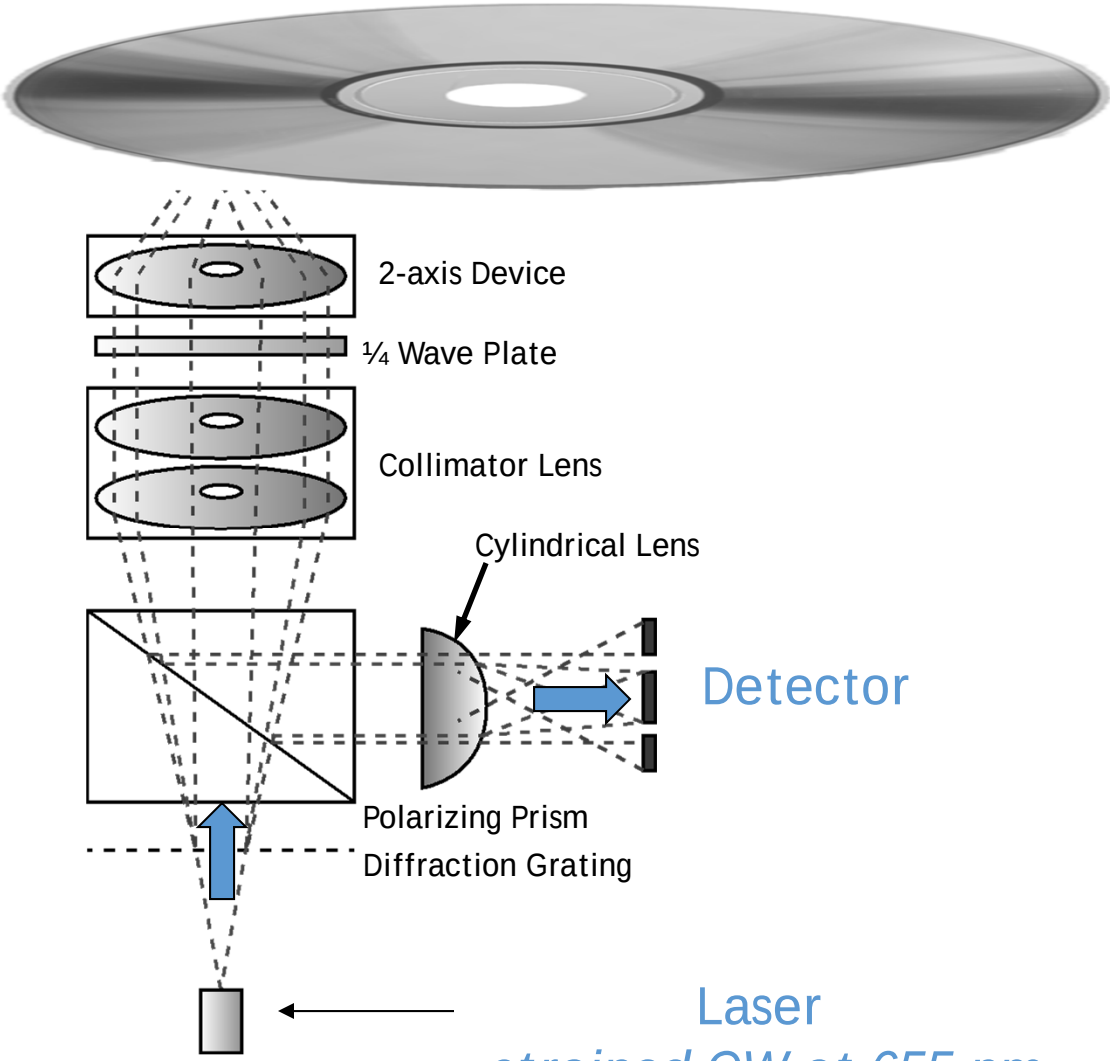
All images are in the public domain



Active Devices for DVD Players

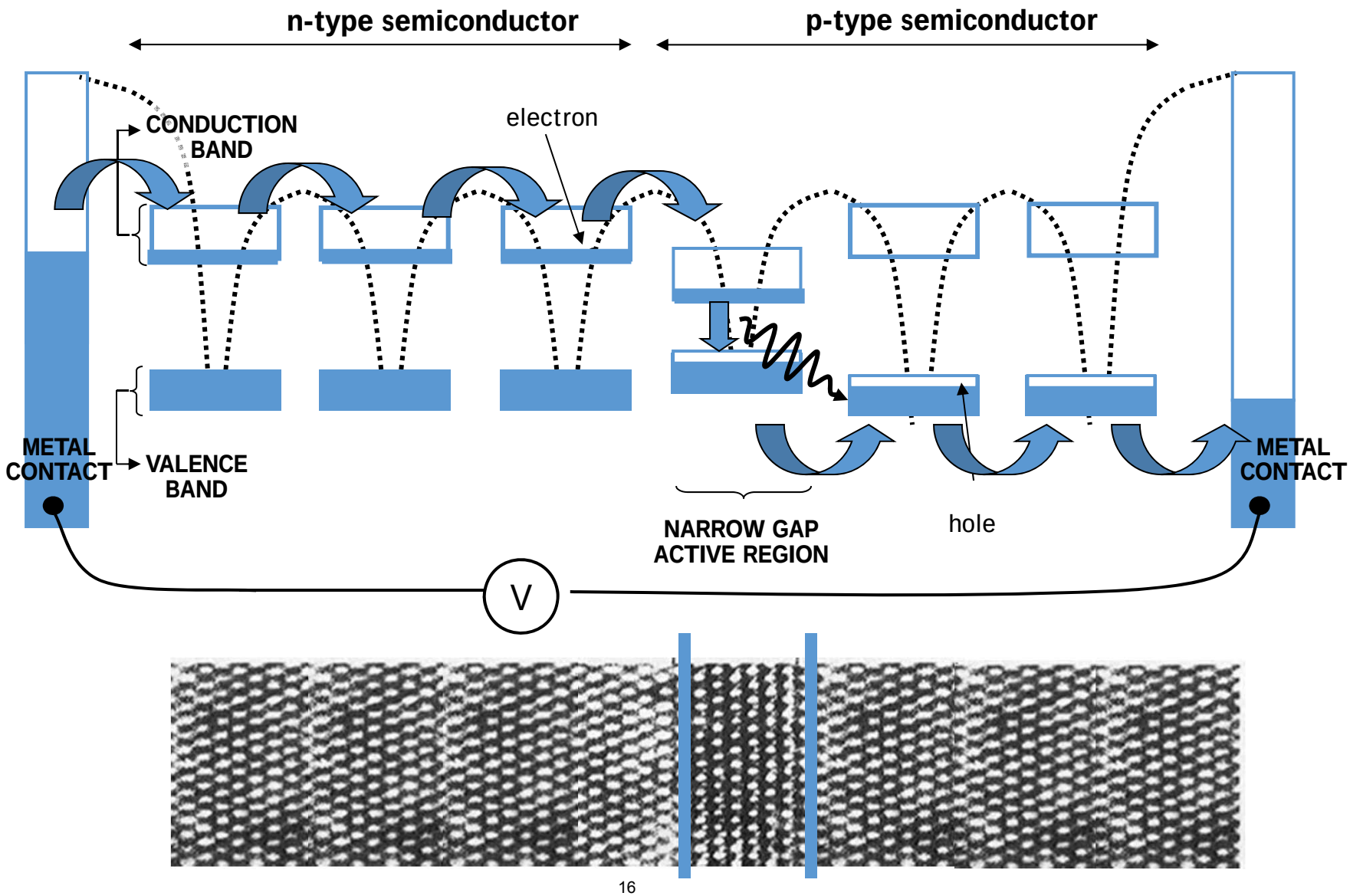






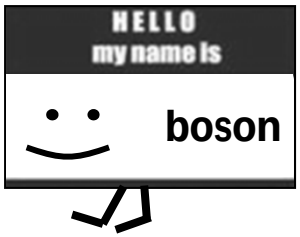
All images are in the public domain

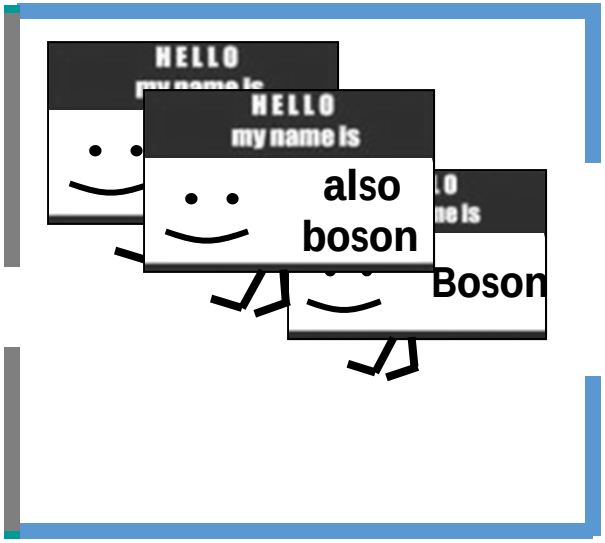
Quantum Well Lasers

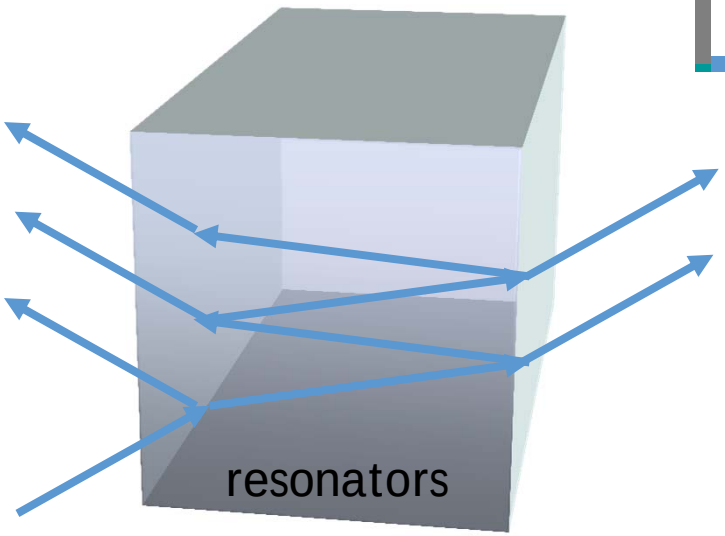


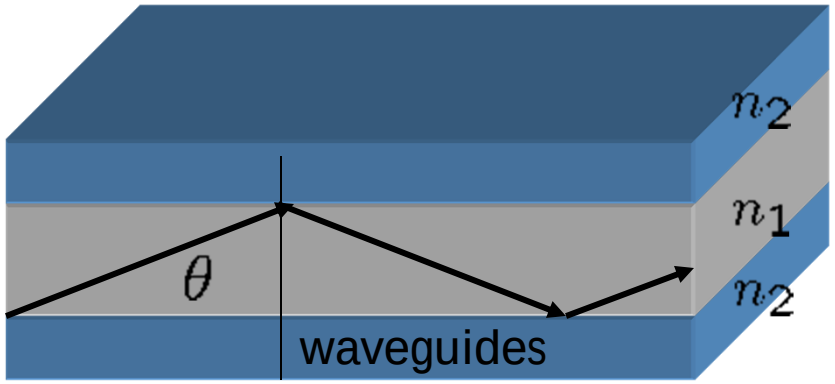
Trapping Photons: Mirrors and Waveguides

How do we keep photons around for long enough time so they have a chance to stimulate an emission ?

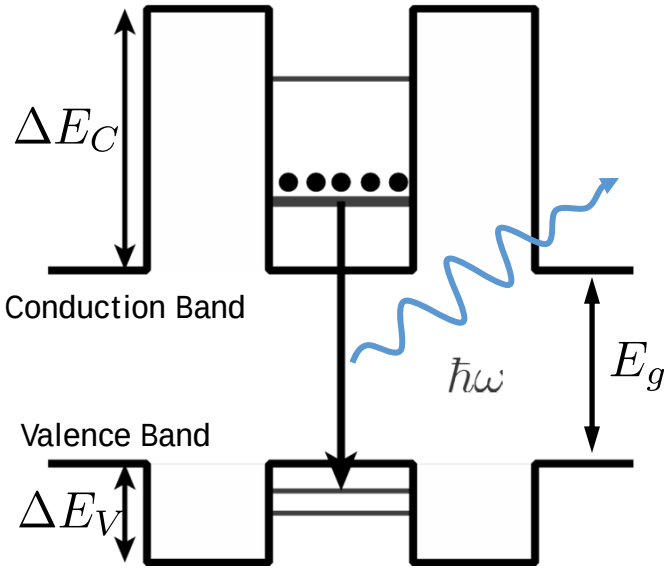






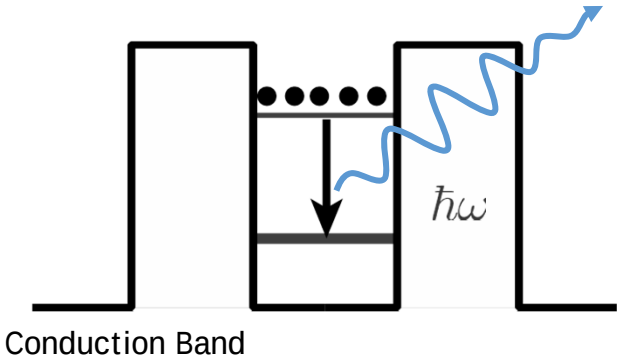


Longest Wavelength Semiconductor Lasers



INTERBAND LASER:

- $\hbar\omega$ set by bandgap
- Bipolar: electron-hole recombination
- Opposite band dispersion

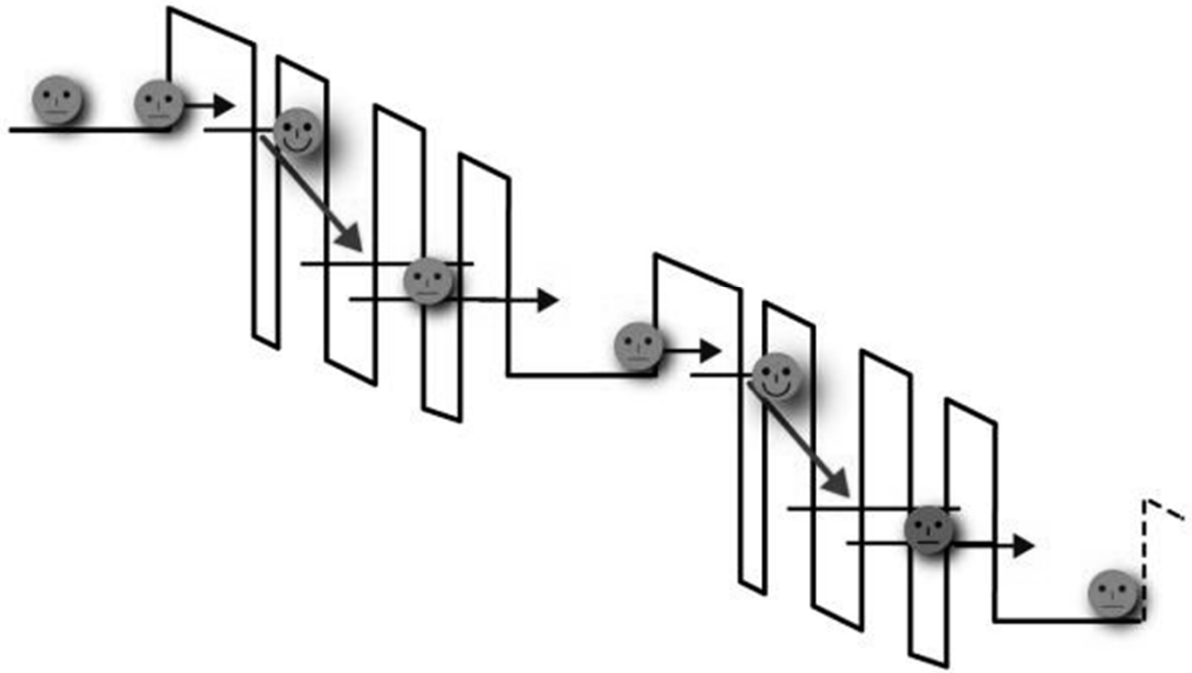


INTERSUBBAND LASER:

- $\hbar\omega$ chosen by design
- Unipolar: electrons make intraband transitions
- Same subband dispersion

Quantum-Cascade Lasers

(slide courtesy of Prof. Jerome Faist at Univ. Neuchâtel)

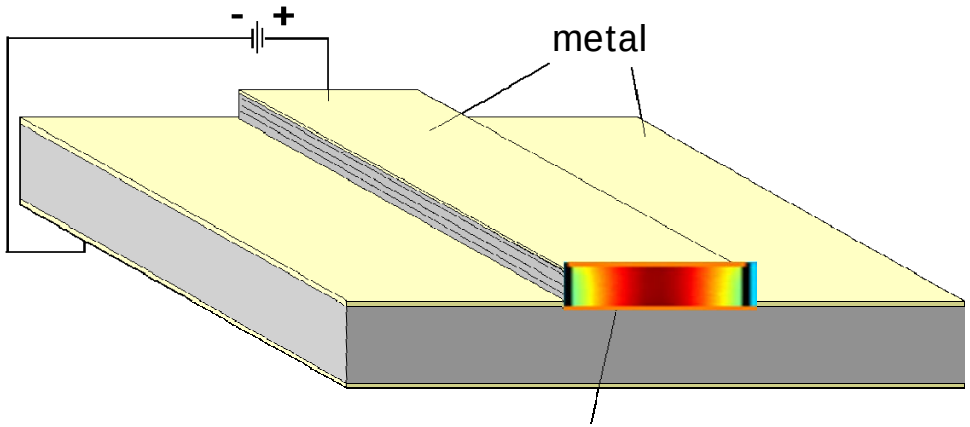


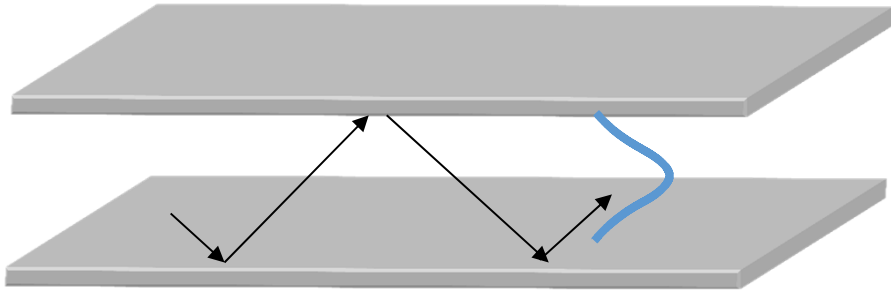
Cascade: N repetitions of a period

→ 1 electron traveling through this structure may generate N photons

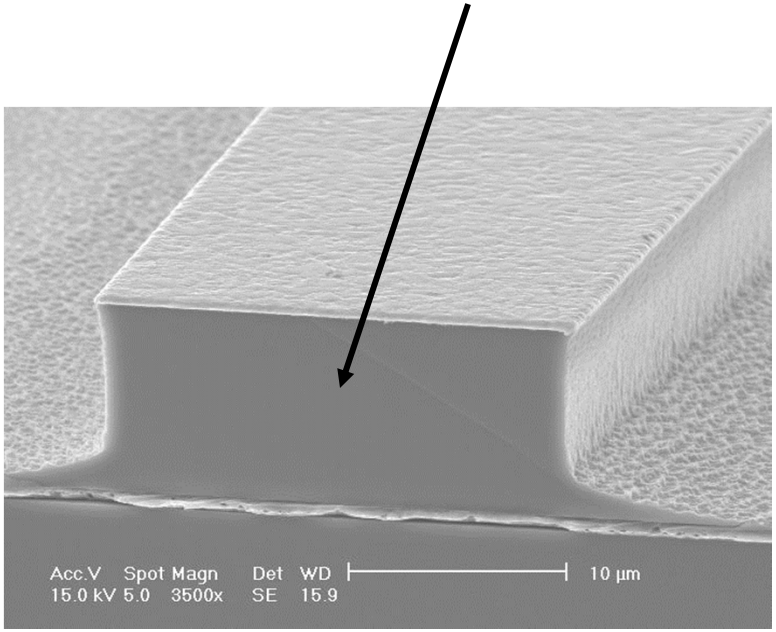
Groupe de physique mésoscopique
Institut de physique,
Université de Neuchâtel

Metal Mirror Waveguides

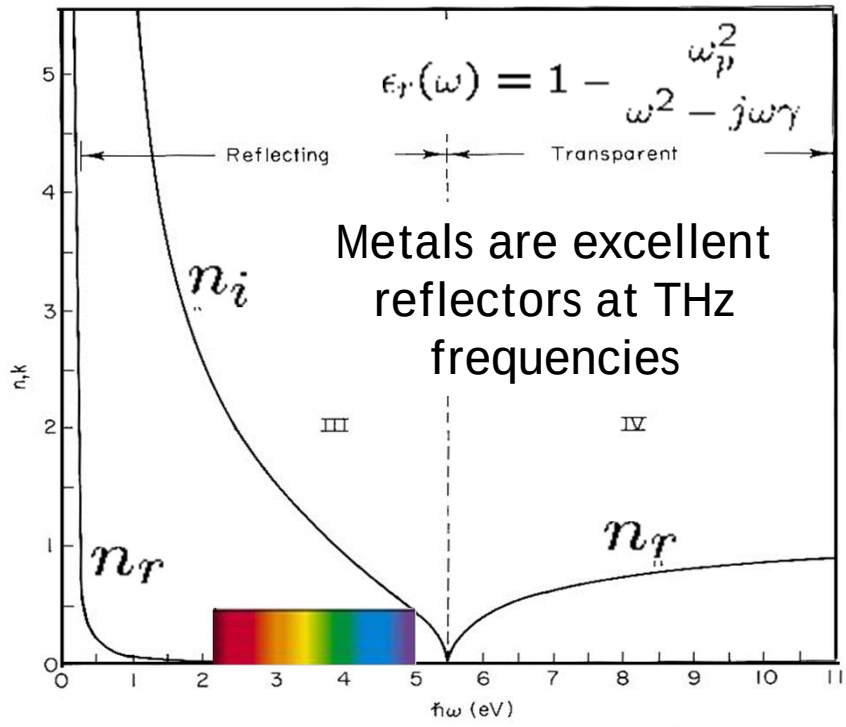




Quantum wells



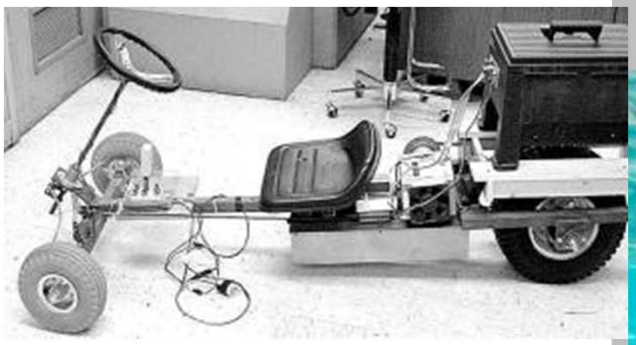
Courtesy of Qing Hu, Millimeter-wave and Terahertz Devices Group at MIT. Used with permission.

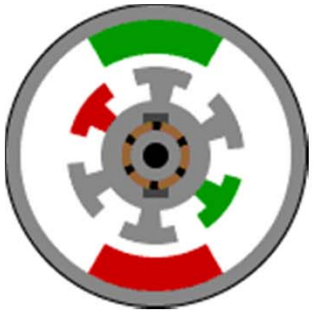


6.007 – Applied E&M – From Motors to Lasers

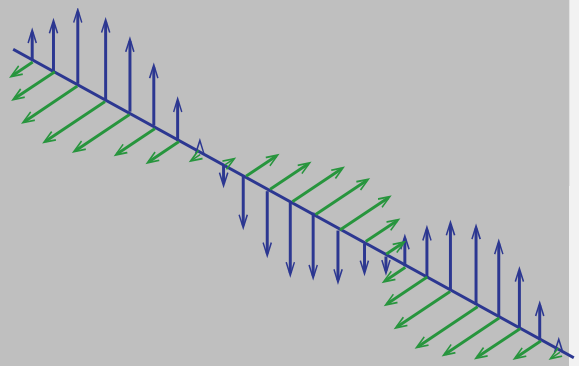
The course encompassed THREE THEMES with FIVE related **LABS**

WORK AND ENERGY

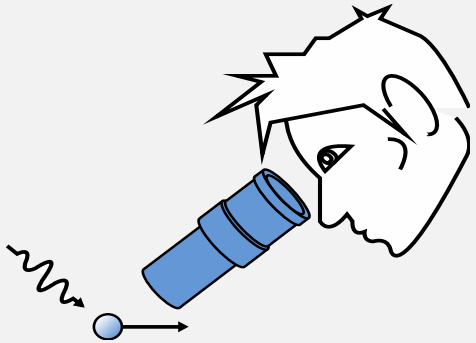


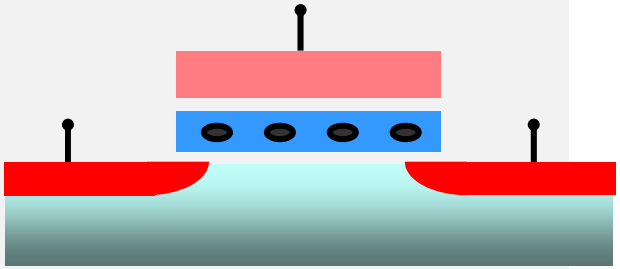


ELECTRODYNAMICS



QUANTUM MECHANICS





6.007 – Applied E&M – From Motors to Lasers

The course encompassed THREE THEMES with FIVE related **LABS**

WORK AND ENERGY

ENERGY CONVERSION and STORAGE
- Energy Conservation
- Across and Through Vars.
- Energy Storage

•• LAB: MOTORS ••

ENERGY/POWER/WORK in BASIC CIRCUIT ELEMENTS
- Electric/Magnt Materials
- Energy Method for Motors
- Magnetostatic / Electrostatic Machines
- Micro-Electro Machines

•• LAB: COIL GUN ••

- Limits of Statics

ELECTRODYNAMICS

EM WAVES
- Wave Equation
- Energy in the EM Waves
- Polarized Light

MATERIALS RESPONSE
- Lorentz Oscillator
- Reflection, Absorption
- Complex Refractive Index
- Evanescent Waves

•• LAB ••
LIQUID CRYSTAL DISPLAY

DEVICES AND PHYSICS
- Polarizers/Birefringence

•• LAB: FIBEROPTICS ••

- Photon as a Quantum of Energy

QUANTUM MECHANICS

MEASUREMENT AND UNCERTAINTY
- Photon Momentum
- Heisenberg Microscope

ELECTRON EIGENSTATES
- Calculating Wavefunctions
- Particle in a Box
- Atoms and Quantum Dots

QUANTUM ELECTRONICS
- Tunneling (STM, Flash)
- Energy Bands/ Conduction
- Energy Band Transitions
- Photodetectors, Solar Cell
- LED and Lasers

•• LAB ••
TUNNELING TOUCHPAD

6.007 Electromagnetic Energy: From Motors to Lasers

Spring 2011