Lecture 2: Atom-field interaction

Static field:

Magnetic field:	Zeeman effect
Electric field:	DC polarizability

Time dependent field (light):

Light shift:	Optical potential
Scattering:	Radiation force

Zeeman effect

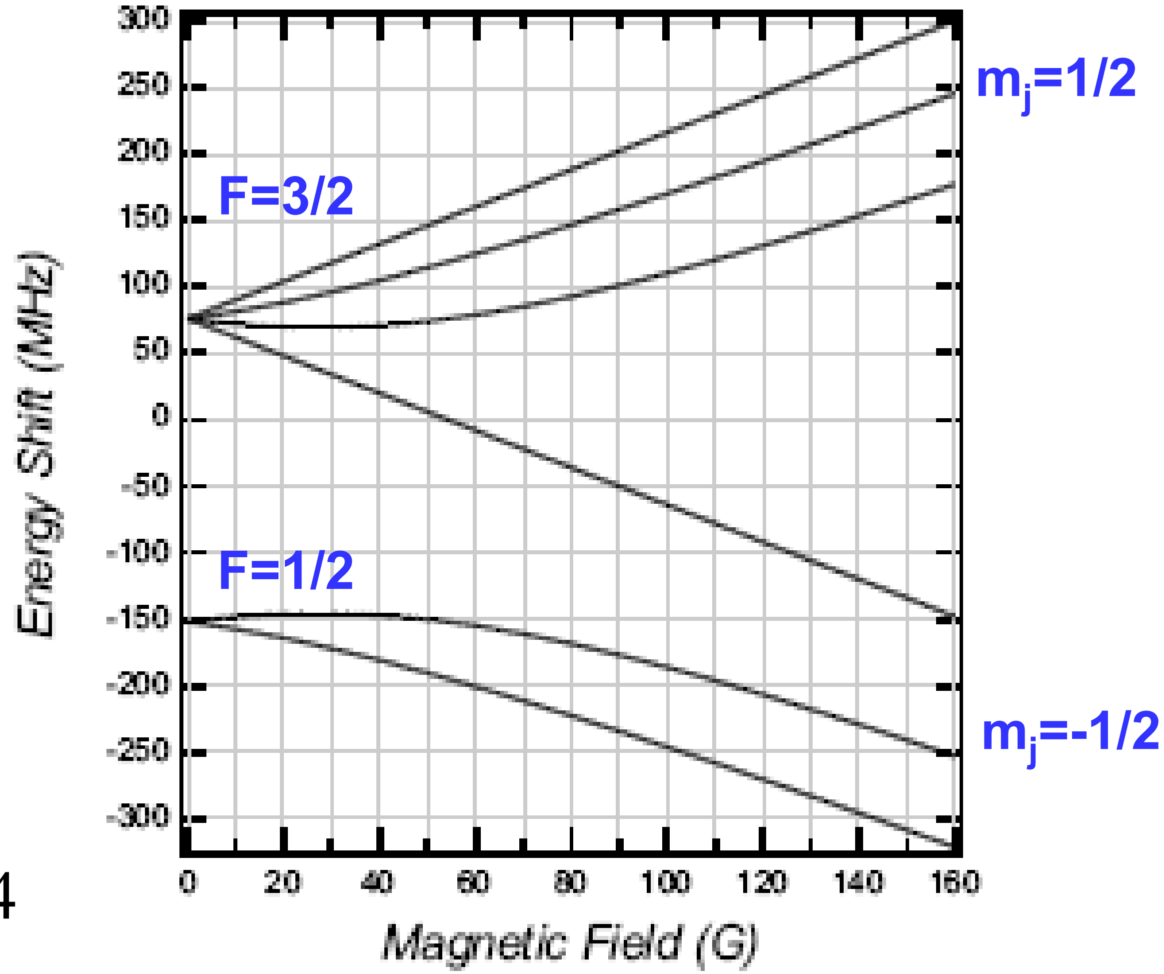
$$V = -\mu \cdot B$$

$$\vec{\mu} = -\mu_B\left(g_s\vec{S} + g_L\vec{L} + g_I\vec{I}\right)$$

$$S = \frac{1}{2}$$
$$L = 0$$
$$I = 1$$
$$F = L + S + I$$

$$g_s = 2.002$$
$$g_L = 1.000$$
$$g_i = 0.0004$$

^{6}Li
$2^2S_{1/2}$



Zeeman effect in the ground state

$$H = A\, S \cdot L + B\, S \cdot I \; - \; \mu \cdot B$$

$$\vec{\mu} = -\frac{\mu_B}{\hbar}(g_s S + g_L L + g_i i)$$

^{6}Li

$2^2P_{3/2}$

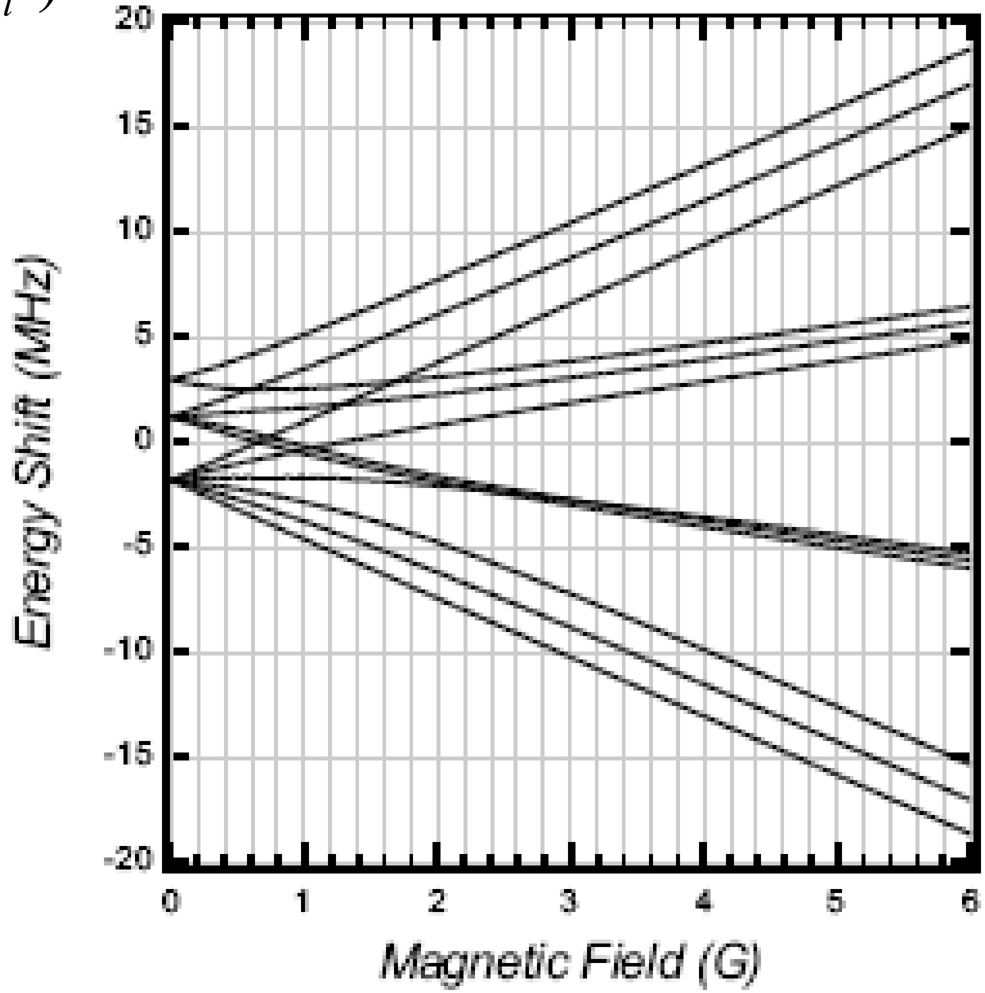
F=1/2
F=3/2
F=5/2

$$S = \frac{1}{2} \qquad g_s = 2.002$$

$$L = 1 \qquad g_L = 1.000$$

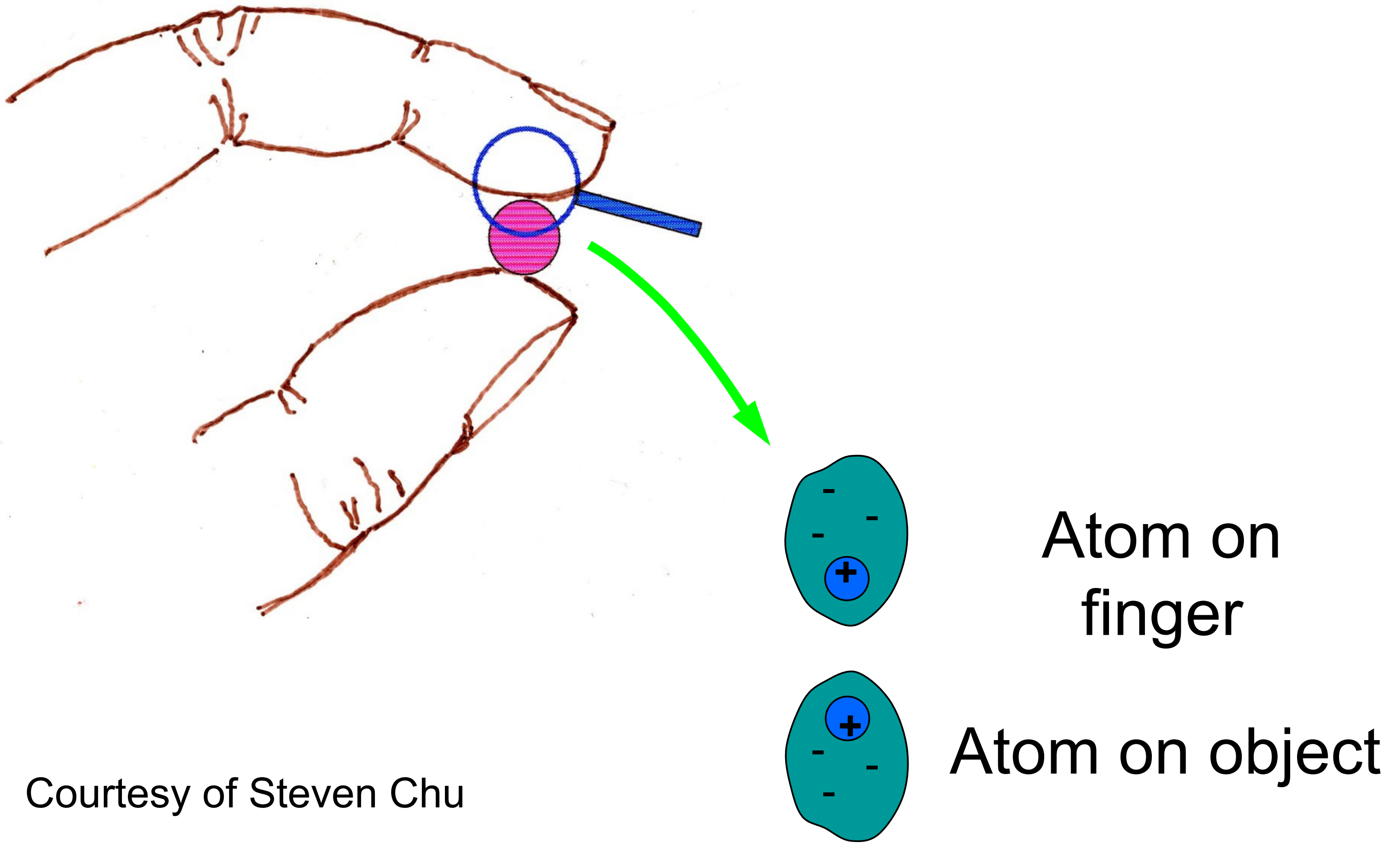
$$I = 1 \qquad g_i = 0.0004$$

$$F = L + S + I$$

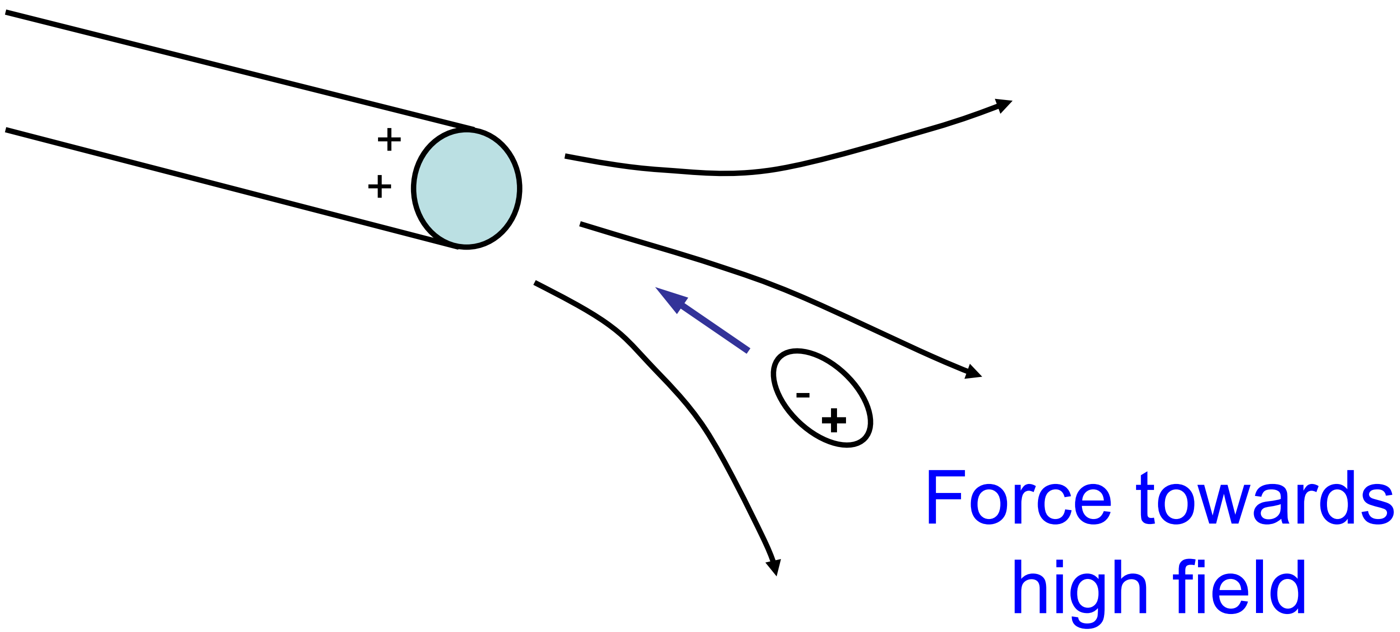


m_j=3/2
m_j=1/2
m_j=-1/2
m_j=-3/2

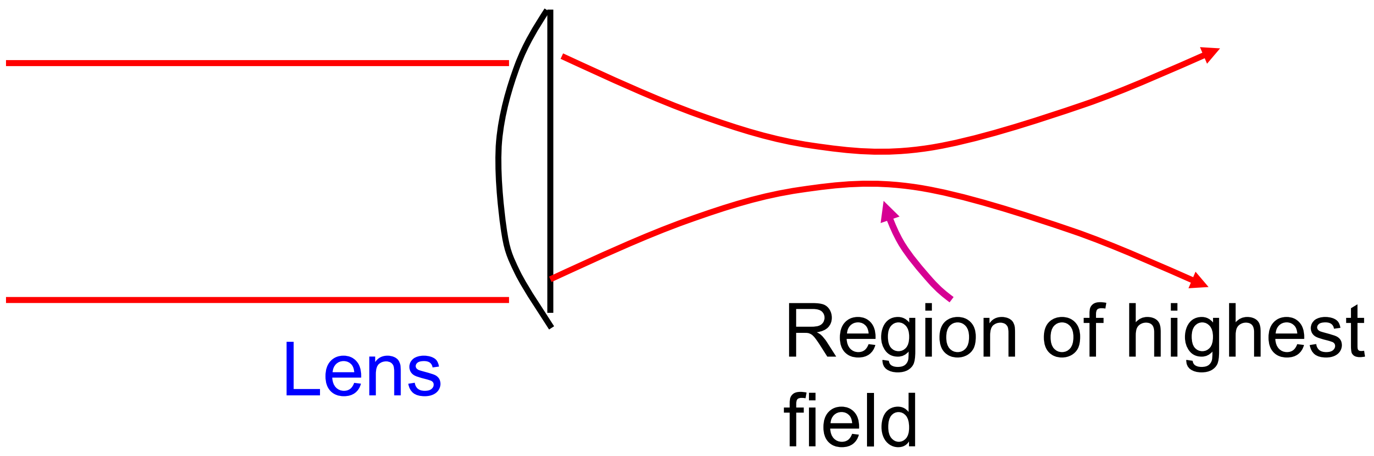
Electrostatic force

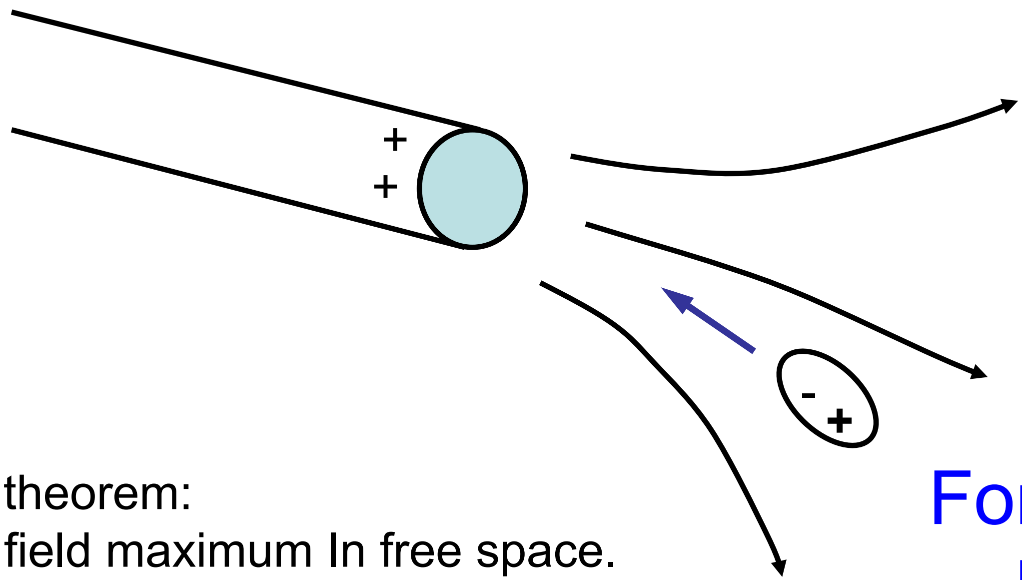


Courtesy of Steven Chu



Optical tweezer

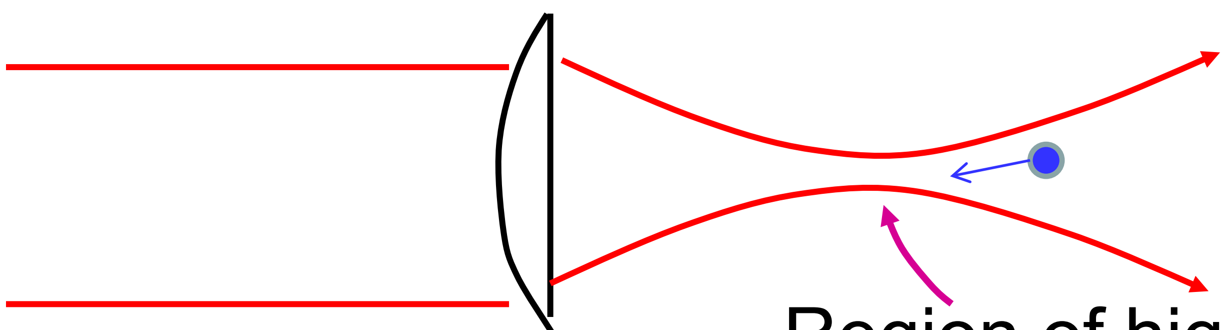




P=αE

Force towards high field

Earnshaw's theorem:
No 3D local field maximum In free space.



Lens

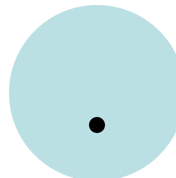
Region of highest field

Is the atom-light interaction attractive?

Attraction or repulsion?

↑ E: electric field

Lorentz Model :



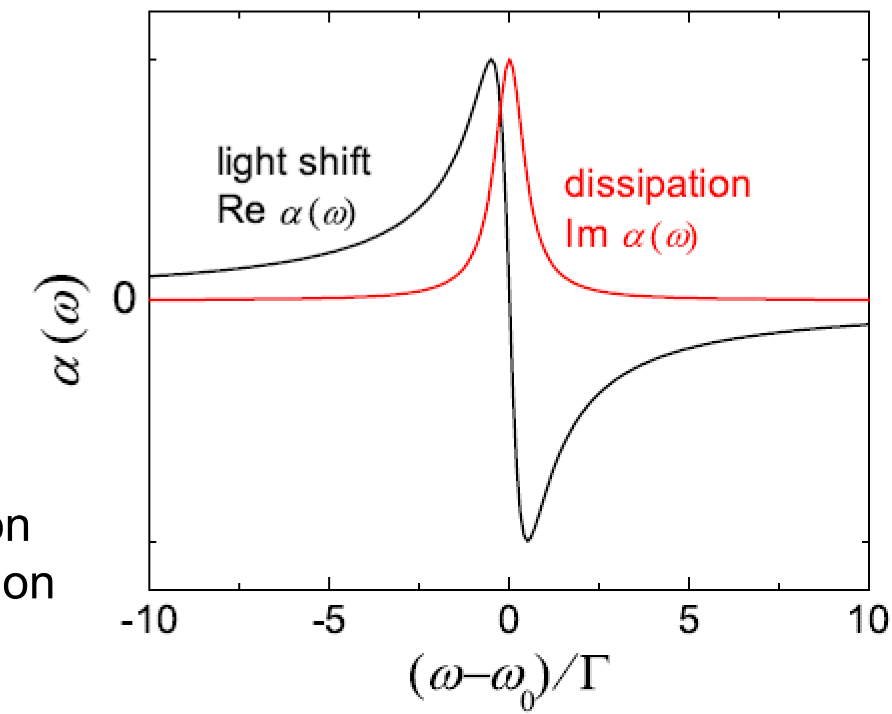
↑ x: charge displacement

$$\mathrm{m}\ddot{x} = F = eE(t) - m\omega_0^2 x - 2\beta\dot{x}$$

Dipole moment: $p \equiv ex = \alpha(\omega)E$

Dipole energy:

$$E = -p \cdot E = -Re[\alpha(\omega)]E^2$$
$$\equiv -\alpha_{AC} I$$



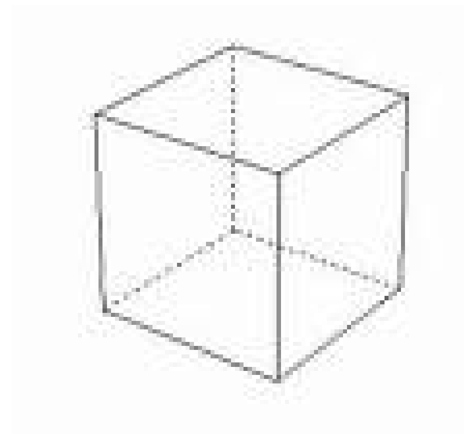
$\Rightarrow$

Below resonance (red detuned): attraction

Above resonance (blue detuned): repulsion

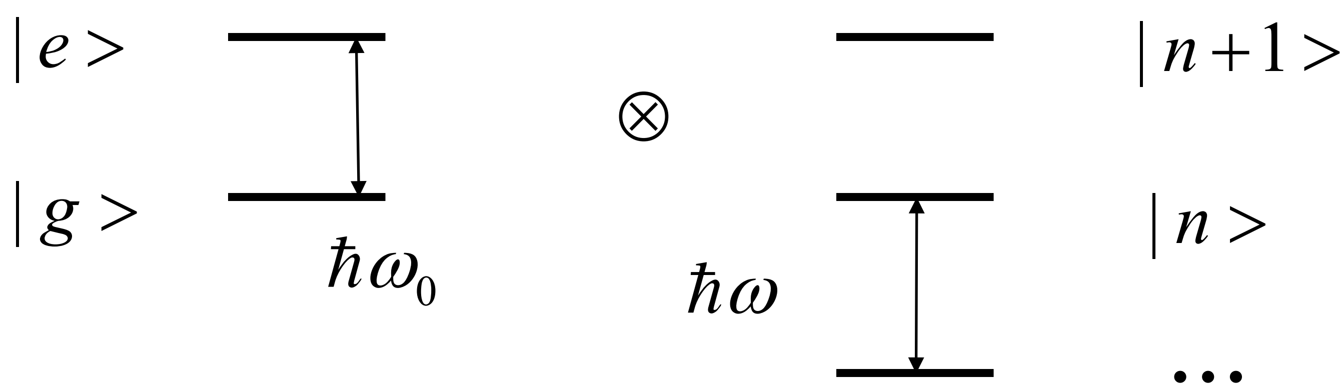
Full Quantum treatment: Dressed atom picture

$\bullet \qquad + $

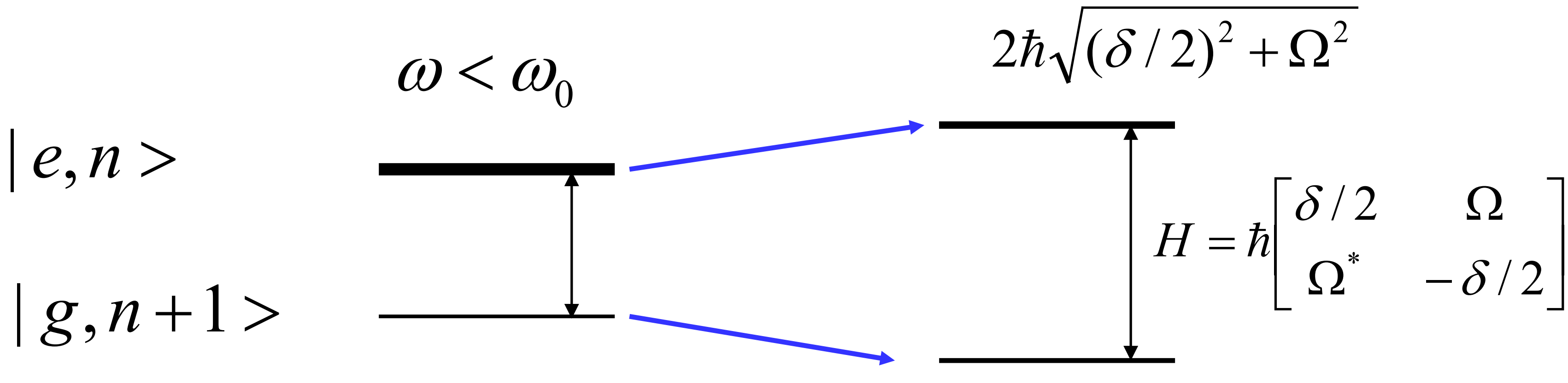


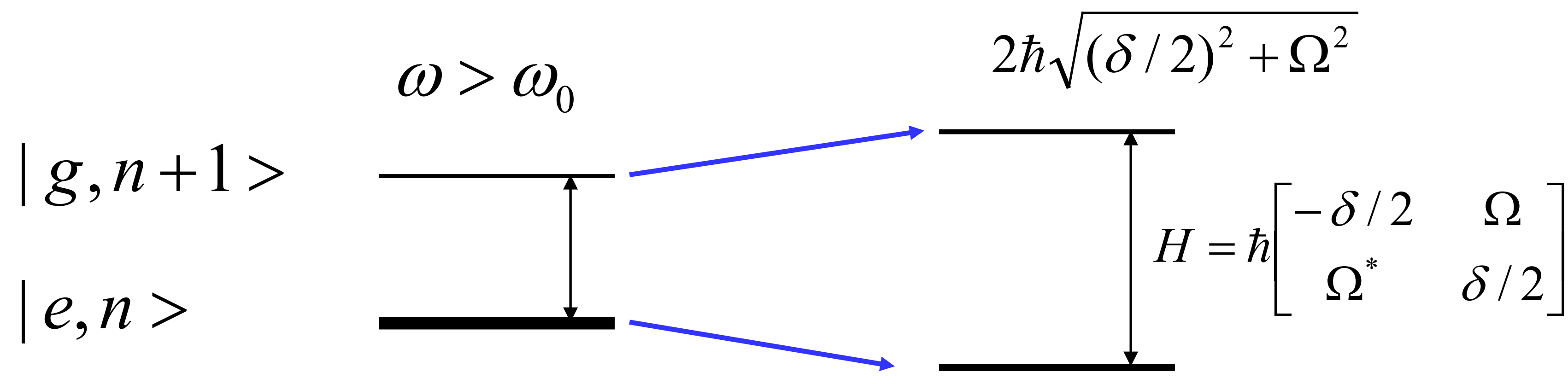
$$| \, system > = | \, atom > \otimes | \, field >$$

Atom **field**

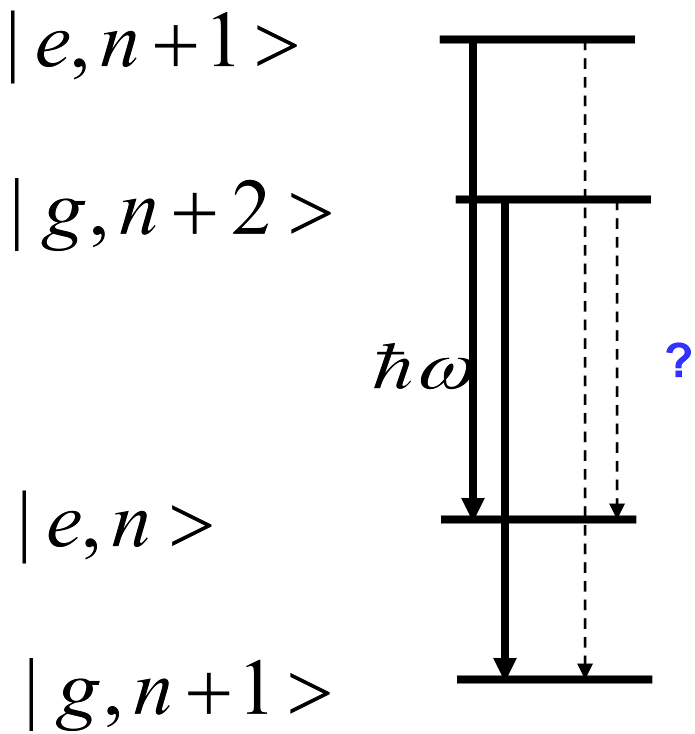


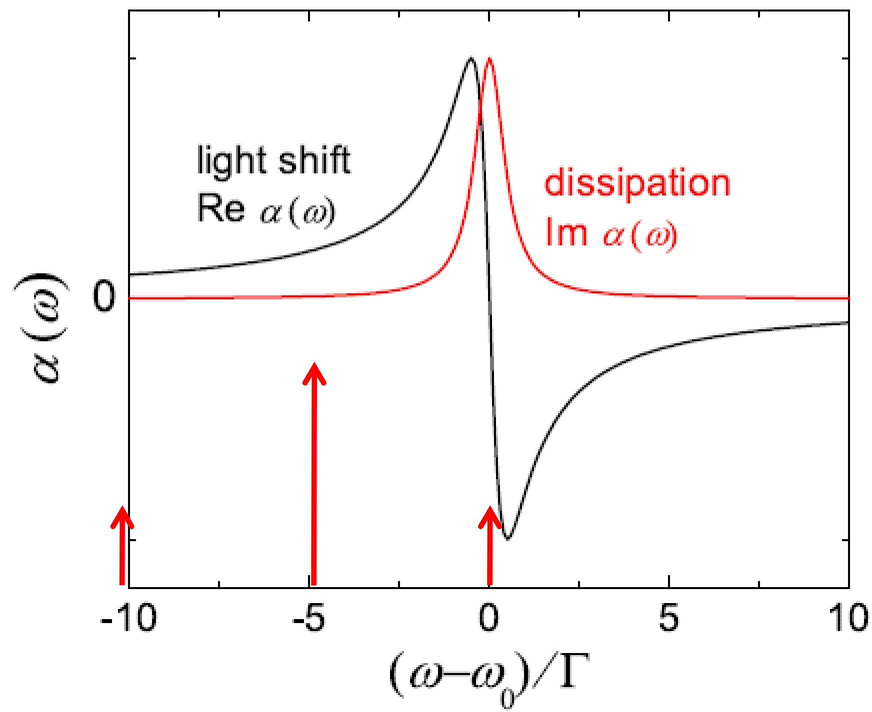
Light shift with laser detuning $\delta = \omega - \omega_0$

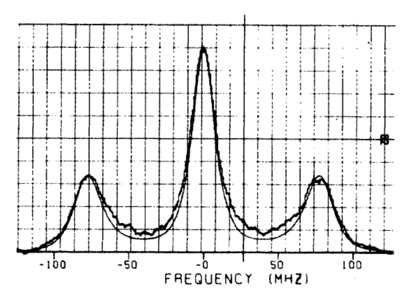




Spontaneous Emission





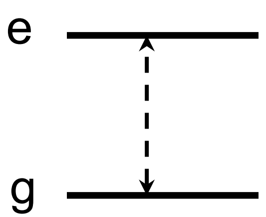


Mollow triplet

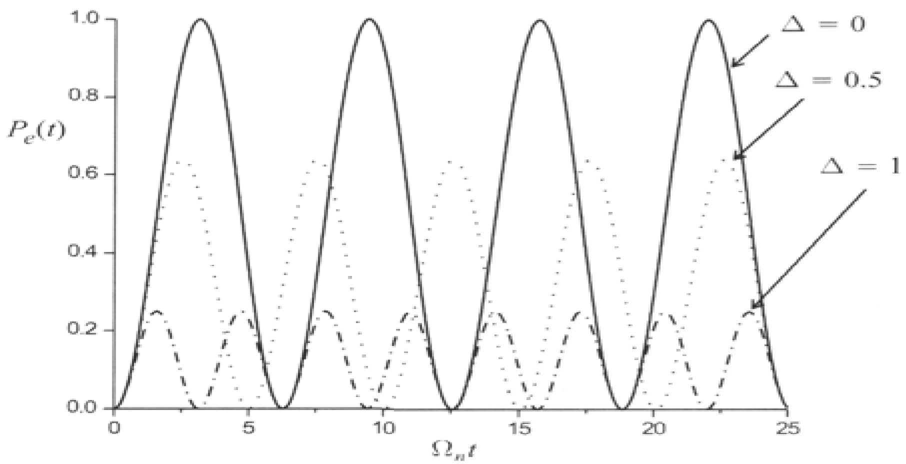
Grove et al., PRA 15, 227 (1977)

$$H = H_0 + \vec{d} \cdot \vec{E}(t)$$

$$= H_0 + \hbar\Omega \cos \omega t$$

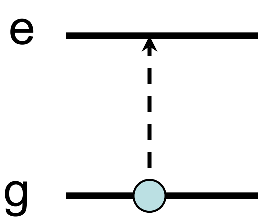


$$\hbar\omega_0 = E_e - E_g$$

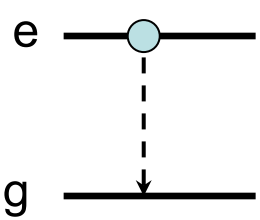


(no decay is assumed here)

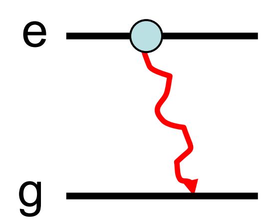
Stimulated absorption



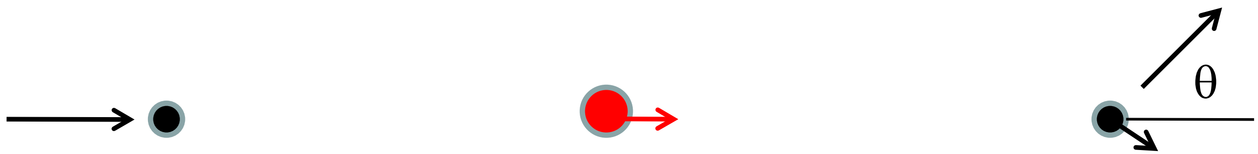
Stimulated emission



Spontaneous emission



Scattering ≈ absorption + emission



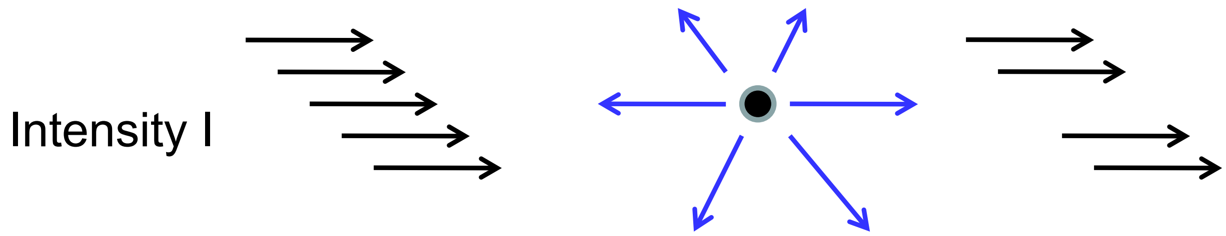
t=0 t1 t1+t2

$E_{recoil}=p^2/2m$

$E_{recoil}=E_{recoil}\ (1-\cos\theta)^2$

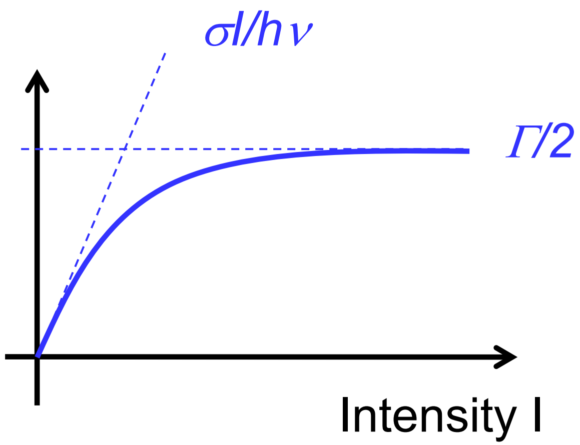
t2=1/Γ: natural lifetime of the excited state (typically 30 ns)

t1=?



Scattering rate $s = n_e \Gamma = \sigma I / h\nu$

n_e: excited state population
σ: cross section
$h\nu$: photon energy



$$s = \Gamma n_2 = \frac{\Gamma}{2}\frac{p}{1+p}$$

p: saturation parameter

Saturation parameter $$p = \frac{I}{I_s}\frac{1}{1+4\Delta^2/\Gamma^2}$$

I_s: saturation intensity