## Topics in final

1. Paraxial approximation and slowly varying envelope approximation; Gaussian beam propagation; q parameter and its relation to various parameters $(1/q = 1/R - j\lambda/(\pi w^2)$, $w = w_o\sqrt{1+(z/z_o)^2}$, $z_o = \pi w_o^2/\lambda)$; power and divergence angle of Gaussian beam

2. Gaussian beam with ray matrix: Relate $q_{out}$ to $q_{in}$ with ray matrix; Able to identify condition on q at focus of a lens.

3. Gaussian beam in spherical cavity: Radius of curvatures of Gaussian must fit those of mirrors for a **stable** cavity; able to identify the location of minimum spot size; resonant condition for the phase of high order modes $k_{m,n,q}d - (m+n+1)\left[\tan^{-1}(z_2/z_o) - \tan^{-1}(z_1/z_o)\right] = q\pi$; longitudinal mode spacing $\Delta\nu_{FSR}$ and transverse mode spacing $\Delta\nu_{FSR}\left[\tan^{-1}(z_2/z_o) - \tan^{-1}(z_1/z_o)\right]/\pi$.

4. Density of modes: 1D (mode/ unit length / unit freq); 2D (mode / unit area / unit freq); 3D (mode / unit volume /unit freq).

5. Energy levels and thermal distribution: Discrete energy levels; interaction of electron spin and

orbit momenta causes degeneracy of energy state; interactions with external matter (e.g. other atoms or lattice) getting stronger from gas (atoms and molecules) to solid state result in discrete states transformed into manifolds or even energy bands; Boltzmann distribution as a model for occupation of discrete energy levels.

6. Radiative process: spontaneous emission ($A_{21}$), stimulated emission ($B_{21}$), absorption ($B_{12}$); blackbody radiation has wider bandwidth $\delta\nu$ than gain (active) medium bandwidth $\Delta\nu$; in laser, $\delta\nu \ll \Delta\nu$; $A_{21}/B_{21} = 8\pi n^3 \nu^3 h/c_o^3$, $A_{21} = 1/t_{sp}$, $B_{21} g_2 = B_{12} g_1$; $W_i = nc\sigma/V = n_{ph} c\sigma$,

7. Homogeneous and inhomogeneous line shape: $\sigma = A_{21} \lambda_o^2 g(\nu)/(8\pi n^2)$ where $g(\nu)$ is lineshape function with $\int g(\nu) d\nu = 1$; homogeneous $1/\tau_{total} = 1/\tau_1 + 1/\tau_2 + 2/\tau_c$ and has Lorentzian distribution $g(\nu) = \Delta\nu/[2\pi((\nu - \nu_o)^2 + (\Delta\nu/2)^2]$, all atoms react the same way; inhomogeneous Gaussian distribution ($\Delta\nu_D \gg \Delta\nu$), multiple groups of atoms react differently, e.g. Doppler effect.

8. Small signal gain coef.: Amplitude $\gamma_o = \sigma(N_2 - N_1 g_2/g_1) = \sigma\Delta N$; phase $\phi(\nu) = (\nu - \nu_o)\gamma/\Delta\nu$

9. Gain saturation and rate equations: be able to set up rate equations for an atomic energy level diagram; homogeneous $\gamma = \gamma_o/(1+\phi/\phi_s)$; inhomogeneous $\gamma = \gamma_o/(1+\phi/\phi_s)^{1/2}$; origin of saturation from population inversion or difference $\Delta N = \Delta N_o/(1+\phi/\phi_s)$ where $\phi_s = 1/(\tau_s \sigma)$; 1) $N_2$ depletion; 2) finite number of atoms $\Delta N_o \propto R\tau_{sp}$ where R is pump rate and pump power $= h\nu_p RV$; 4 level system steady state $\Delta N \approx N_2$; 3 level system steady state $N_2 \approx (N_{total} + \Delta N)/2$.

10. Oscillation condition: amplitude, $\gamma_o > \alpha_r$ or round trip power transmission equal to one $|r|^2 = 1$; phase, round trip phase change = $2\pi$q or $k_o n2d + 2l_g \phi(\nu) = 2\pi q$ for a FP cavity with gain medium length $l_g$ < d of the cavity.

10. Steady state laser response: at steady state $\gamma = \alpha_r$; $\phi = \phi_s(\gamma_o \alpha_r^{-1} - 1) = \phi_s(\Delta N_o\ \Delta N_t^{-1} - 1)$ for $\gamma_o > \alpha_r$, otherwise $\phi = 0$; Output power $P_o = h\nu T\phi A/2$; photon number density $n_{ph} = (n_{ph})_s(\Delta N_o\ \Delta N_t^{-1} - 1)$; Output photon flux $\Phi_o = \eta_e(R - R_t)V$ where extraction efficiency $\eta_e = \alpha_{m1}/\alpha_r$; overall efficiency $P_o/P_p$ where $P_p$ is electrical power; slope efficiency $\eta_s = dP_o/dP_p$;