Part A. (80 %)

1. (10 %) (Ray Optics) Numerical Aperture of an Optical Fiber

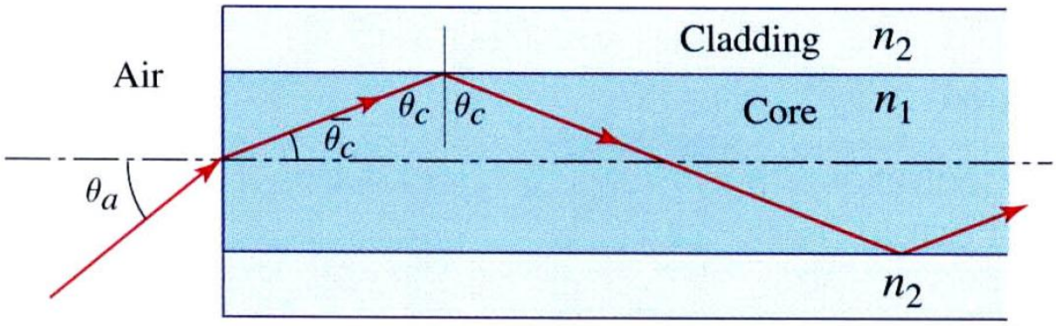
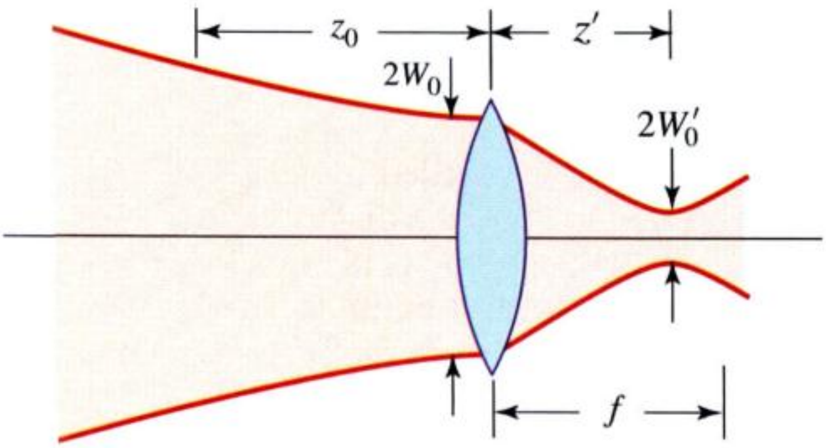


Figure 1.2-18 Acceptance angle of an optical fiber.

Please derive $\mathrm{NA} = \sin\theta_a = \sqrt{n_1^2 - n_2^2}$

2. (10 %) (Wave Optics) Please derive Snell's law. (Hint: using "the wavefronts of the two waves match", or the Fermat's Principle.)
3. (10 %) (Beam Focusing) For a lens placed at the waist of a Gaussian beam, as shown below. Please derive the waist W_0' and distance z_0' of the transmitted beam.



4. (10 %) (Reflection and Refraction)

$$\mathrm{r}_x = \frac{n_1\cos\theta_1 - n_2\cos\theta_2}{n_1\cos\theta_1 + n_2\cos\theta_2}, \qquad \mathrm{t}_x = 1 + \mathrm{r}_x, \tag{6.2-8}$$

TE Polarization

$$\mathrm{r}_y = \frac{n_1\sec\theta_1 - n_2\sec\theta_2}{n_1\sec\theta_1 + n_2\sec\theta_2}, \qquad \mathrm{t}_y = (1 + \mathrm{r}_y)\frac{\cos\theta_1}{\cos\theta_2}. \tag{6.2-9}$$

TM Polarization

Fresnel Equations

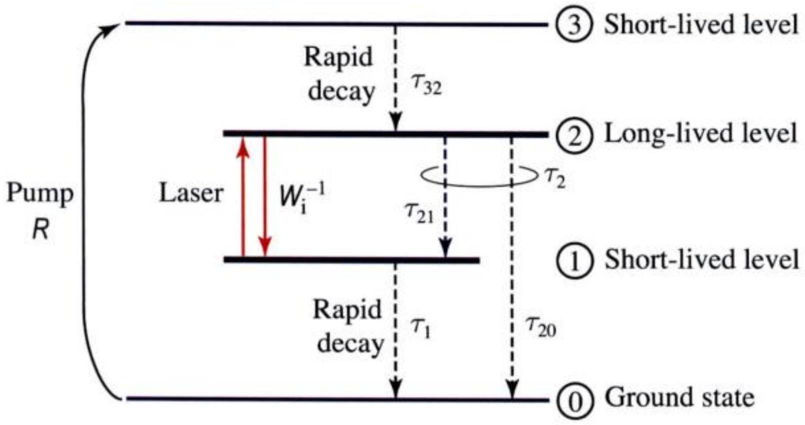
Please derive Brewster Angle, and calculate it at the n_1/n_2 interface when $n_1=1$, and $n_2=1.5$.

5. (10 %) (Resonator Optics)

   Please derive the Density of Modes of 3D resonator ($M(\nu) = \frac{8\pi\nu^2}{c^3}$)

6. (10 %) (Photon and Atom)
   Please plot the radiation processes of the spontaneous emission, stimulated emission, and absorption.

7. (10 %) (Lasers)



   Please write down the rate equations of level 1 and level 2.

8. (10 %) (Lasers)
   Please explain the difference of "Q-switched laser" and "Mode-locked Laser".

Part B. (70 %)

9. (10%) (Fermi level)
   Given the thermal equilibrium carrier concentrations in the conduction and valance bands as $n = N_c \exp\left(-\frac{E_c - E_f}{kT}\right)$ $\quad p = N_v \exp\left(-\frac{E_f - E_v}{kT}\right)$ where $N_{c,v} = 2\left(2\pi m_{c,v} kT / h^2\right)^{3/2}$

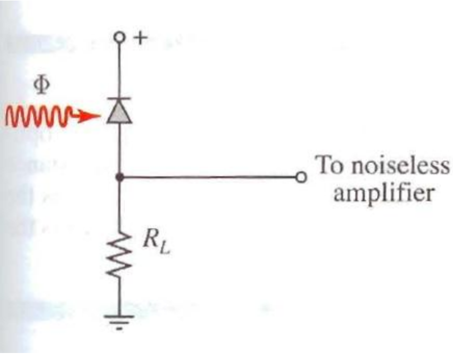
   (a) Find the expression for the ***Fermi level*** E_f of an *intrinsic* semiconductor
   (b) Find the expression for the ***Fermi level*** of a doped semiconductor as a function of the *doping level* (E_D donor level) and E_f from (a) when m_c=m_v

10. (10%) (Laser diodes)
    Among the ***threshold current*** for InGaAsP homostructure laser diode I_{homo}, Heterostructure laser diode I_{hetero} , and Multi-Quantum-Well laser diode I_{MQW} , which one is the *largest* and which one is the *smallest*? Please explain ***why***?

11. (10%)(Photodiode Detector)
    For a particular p-i-n photodiode, a pulse of light containing $6\text{x}10^{12}$ incident photons at wavelength λ_0=1550 nm gives rise to , on average, $2\text{x}10^{12}$ electrons collected at the terminals of the device. Determine the ***quantum efficiency*** η and the ***responsivity*** $\Re$ of the photodiode at this wavelength.

12. (10%) (Photo detector SNR of resistance limited optical receiver)

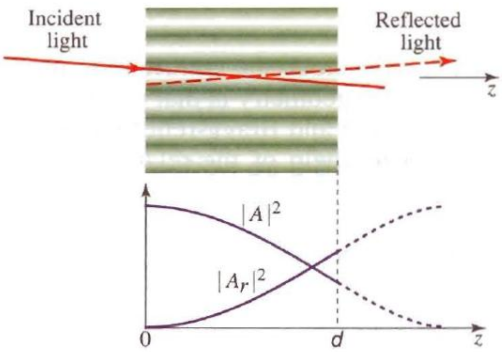
Assume that the optical receiver shown in the Fig. makes use of an ideal p-i-n photodiode (η =1) and the resistance R_L=50 at T=300^0 K. The bandwidth is B=100MHz. At what value of ***photon flux*** Φ is the photoelectron-noise current variance equal to the resistor thermal–noise current variance? What is the corresponding ***optical power*** at λ_0=1550 nm?

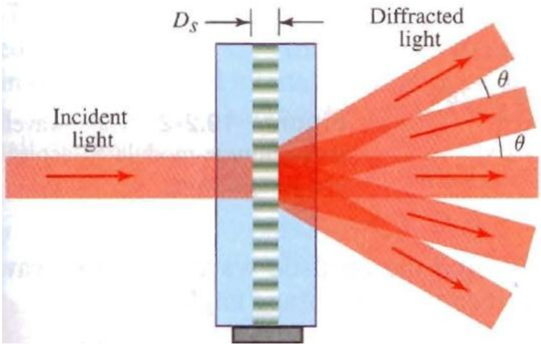


$\sigma_q = \frac{\sigma_r}{2Be}$, $\sigma_q \approx \frac{\sqrt{B}}{100}$, $SNR = \frac{\left(e\bar{G}\eta\Phi\right)^2}{2e^2\bar{G}^2\eta B\Phi F + \sigma_r^2}$,G=1, F=1

13(10%) Acoustic-Optics

Describe the *difference* in the diffraction of an optical plane wave by a ***thick*** acoustic beam (plane wave acoustic beam) and a ***thin*** acoustic beam.





14(10%) Electro-Optics

(a)Explain what is ***Pockels*** effect and what is ***Kerr*** effect.

(b) Explain the ***intensity modulation*** in a Mach-Zehnder interferometer with an electro-optic phase modulator

15(10%) Nonlinear Optics

(a) Explain the ***phase matching condition*** in ***Second Harmonic Generation***.

(b) Explain ***Optical Phase Conjugation*** using ***Four Waves Mixing***.