13.5

a.)

population inversion is required since the cross section for stimulated emission, and absorption is the same.

if $N_1 > N_2$, photons will ~~be absorbed~~ cause $N_1 \to N_2$ transitions more often than stimulating emission.

b.) Usually lower is better since in a 4-level system, thermal photons may cause population of N_1

13.12

C^{+5} is like Hydrogen atom with $Z=6$.

$$E_n = -13.6\text{ eV}\,\frac{Z^2}{n^2} = 490\text{ ev}\cdot\frac{1}{n^2}$$

$$E = \frac{hc}{\lambda} = \frac{1240\text{ eV-nm}}{18\text{ nm}} = 68.9\text{ eV}$$

$n_2 \to n_1$

$n_2 = 3$

$n_1 = 2$

gives correct energy.

13.17

$\lambda = 633$

$L = 0.1 m$

a.) if L changes by $\frac{\lambda}{2}$, this changes the mode by 1

$$\Delta L = \frac{\lambda}{2} = L(8 \times 10^{-6} K^{-1}) \Delta T$$

$$\Delta T = \frac{\lambda}{2L(8 \times 10^{-6} K^{-1})} = 0.4 K$$

b.) as per example 13.2

$$\frac{\Delta\lambda}{\lambda} \approx \sqrt{\frac{2kT}{Mc^2}}$$ for neon at $T = 300 K$

$$\Delta\lambda = \lambda \sqrt{\frac{(2)(.0259 \text{ eV})}{20 \cdot 1 \times 10^9 \text{ eV}}} = 10^{-3} \text{ nm}$$

number of modes is ~

$$\Delta q = \frac{2L}{\lambda - \Delta\lambda} - \frac{2L}{\lambda + \Delta\lambda} \approx 1 \text{ mode}$$

Intensity will make small changes as it moves from one mode to another

if $\Delta q \ll 1$ there would be sharp changes in Intensity

and $\Delta q \gg 1$ no changes in intensity

13.28

$\lambda = 1.06\ \mu m$

metastable state $\tau = 0.1\ ms$

$E_2 - E_1 = \frac{1}{4}\ eV$

a.) if E_2 is populated by thermal energy, this makes it harder for population inversion.

At 400 K, allowing a 100 C increase over room temp,

$KT = .034\ eV$

$\Delta E = .25\ eV$

Maxwell boltzmann factor

$$e^{-\Delta E/KT} = 10^{-3}$$

cooling not that critical.

b.) The E_3 metastable lifetime does not affect maximum average continuous power. $E_3 \rightarrow E_2$ transitions are by stimulated emission, not spontaneous emission. the life time is for spontaneous emission

Limiting effect is how fast we can re-populate E_3 after a stimulated transition.

Assume other decays have $\tau \sim 10^{-8}\ s$.

$$P = \frac{E}{t} = \left(\frac{hc}{\lambda}\right)(N)\frac{1}{\tau} = \left(\frac{1240\ eVnm}{1064\ nm}\right)\left(\frac{1.6\times10^{-19} J}{1 eV}\right)\left(10^{17}\right)10^{8}\ s^{-1}$$

$= 2\ MW$ - not realistic, although KW Nd:YAG is common

12, 5

$$E_F = 9.39 \text{ eV}$$

$$n = \frac{8\sqrt{2}\,\pi\, m^{3/2}}{h^3}\left(\frac{2}{3}E_F\right)^{3/2}$$

$$n = \frac{8\sqrt{2}\,\pi\,(mc^2)^{3/2}}{h^3c^3}\left(\frac{2}{3}E_F\right)^{3/2}$$

$$= \frac{8\sqrt{2}\,\pi\,(0.511\times10^6\text{ eV})^{3/2}}{(1240\text{ nm}\cdot\text{eV})^3}\left(\frac{2}{3}\cdot 9.39\text{ eV}\right)^{3/2}$$

$$= 107\ \frac{\text{electrons}}{\text{nm}^3}$$

$$\rho = \left(7.13\times10^3\ \text{Kg/m}^3\right)\left(\frac{\text{m}}{10^9\text{nm}}\right)^3\left(\frac{1000\text{g}}{1\text{Kg}}\right)\left(\frac{N_A}{\underset{\underset{65.4\ \text{g/mole}}{\uparrow}}{65.4\text{g}}}\right) = 66\ \text{atoms/nm}^3$$

gives ~ 1.6 electron/atom

#2.22

$E_g > \frac{hc}{\lambda}$ for visable wavelengths

in Diamond, but not in silicon

Diomond $E_g = 5.5$ eV

Si $E_g = 1.1$ eV

lowest energy visable ~

$$\frac{1240 \text{ eV}\cdot\text{nm}}{700 \text{ nm}} = 1.7 \text{ eV}$$

highest energy visable

$$\frac{1240 \text{ eV}}{400 \text{ nm}} = 3.1 \text{ eV}$$

12.24

$V = \pm 1\ V$

$T = 300\ K$

current in direction of $n \rightarrow p$ region

$$I_1 = (I_n + I_p)\, e^{eV/kT}$$

$p \rightarrow n$

$$I_2 = -(I_n + I_p)$$

$$\frac{I_1}{I_2} = -e^{\pm 1/kT} = 10^{17} \text{ or } 10^{-17}$$