ECE2 Spring 2019 Midterm

Q1.

A. $E = \frac{1}{2}mv^2 = \frac{1}{2} \times 9.11\times10^{-31}\,kg \times (5\times10^6\,cm/s)^2$

$= 1.139\times10^{-21}\,J$

Or you can use $P=mv$
$\lambda = \frac{h}{P}$
etc.

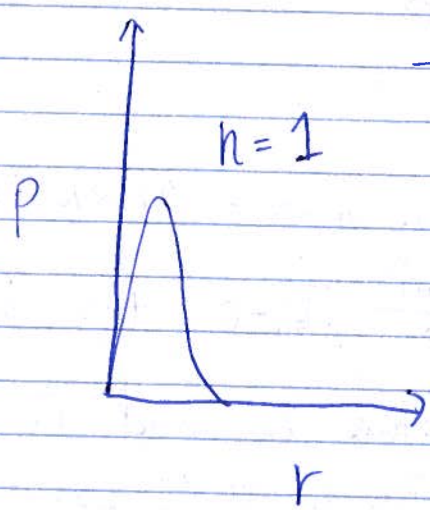
wavenumber $k = \sqrt{\frac{2mE}{\hbar^2}} = \boxed{4.32\times10^8\ m^{-1}}$

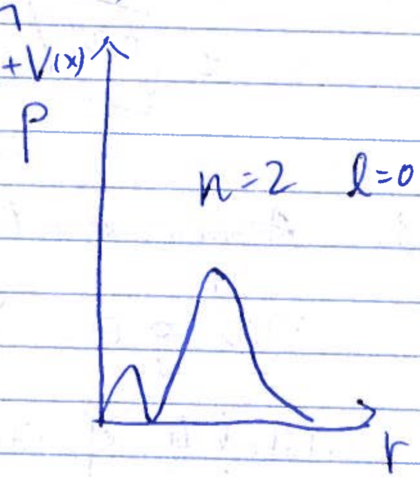
wavelength $\lambda = \frac{2\pi}{k} = \boxed{1.45\times10^{-8}\ m}$

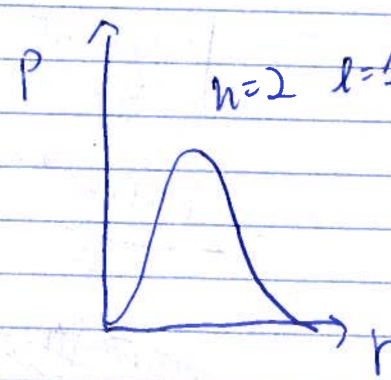
period $T = \frac{\lambda}{v} = \frac{1.45\times10^{-8}m}{5\times10^{-6}cm/s} = \boxed{2.9\times10^{-13}\ s}$

B. 1-D non-relativistic time-dependent S.E:

$$i\hbar\frac{\partial}{\partial t}|\Psi(t,x)\rangle = \underbrace{\hat{H}}_{-\frac{\hbar^2}{2m}\frac{d^2}{dx^2}+V(x)}|\Psi(t,x)\rangle$$







Q2.

A. $E_F = 7.0\,eV$ @ 300k

probability of an energy level 7.15eV is occupied by an electron

$$= \frac{1}{1+e^{(E-E_F)/kT}}$$

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$$= \frac{1}{1+e^{(7.15eV - 7.0eV)/0.0257eV}}$$

$$= 2.9\times10^{-3}$$

$$= \boxed{0.29\%}$$

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B. Assume hole effective mass $= 9.11\times10^{-31}$ kg

DOS $g(E) = \frac{4\pi(2m)^{3/2}}{h^3}\sqrt{E_v - E}$ for holes 5

total # of states between E_v and $E_v - 3kT$ 10

$$= \int_{E_v-3kT}^{E_v} g(E)\,dE = \int_{E_v-3kT}^{E_v} \frac{4\pi(2m)^{3/2}}{h^3}\sqrt{E_v-E}\,dE$$

$m^* = 0.56$

$\times 1.11 \times 10^{25}$

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with the electron

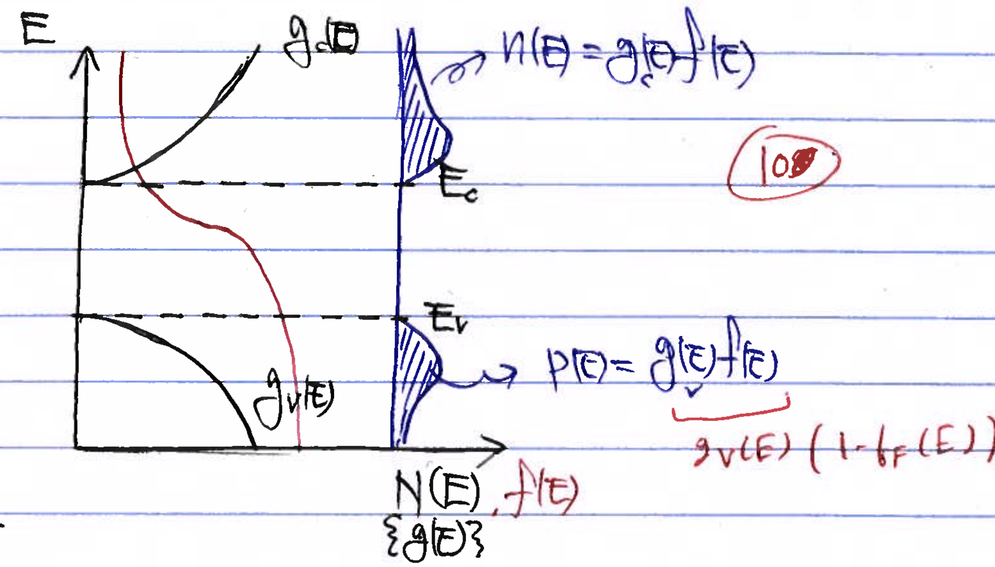
$\boxed{9.697\times10^{25}}$

$$= -\frac{4\pi(2m)^{3/2}}{h^3}\,\frac{2}{3}(E_v-E)^{\frac{3}{2}}\Big|_{E_v-3kT}^{E_v}$$

$$\cancel{= \frac{4\pi(2m)^{3/2}}{h^3}\frac{2}{3}\left[E_v^{3/2} - (E_v-3kT)^{3/2}\right]}$$

$$= -\frac{4\pi(2m)^{3/2}}{h^3}\,\frac{2}{3}\left[\;[redacted]\; - (3kT)^{3/2}\right] = \frac{4\pi(2m)^{3/2}}{h^3}\,\frac{2}{3}(3kT)^{3/2}$$

3A.



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$$N(E) \propto \sqrt{E}$$
$\{g(E)\}$

$$n_0 = N_c \exp\left[-(E_c - E_F)/kT\right]$$ 5

3B. $$N_c = 2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2} = 2\left(\frac{2\pi \times 1.08 \times 9.109\times10^{-31} \times 1.38\times10^{-23} \times 300}{(6.626\times10^{-34})^2}\right)^{3/2} = 2.81\times10^{19}\ \text{cm}^{-3}$$

Assume that $n_0 \approx N_d = 6\times10^{15}$

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$$E_c - E_F = kT \ln\frac{N_c}{N_d} = 0.0259 \ln\frac{2.81\times10^{19}}{6\times10^{15}} = \boxed{0.219\ \text{eV}}$$

$$E_c - E_F + kT = kT \ln\frac{N_c}{N_d + \Delta N} = 0.219 - 0.0259 = 0.0259 \ln\frac{N_c}{N_d + \Delta N}$$

$= 0.1431$; $-$

$$N_d + \Delta N = N_c \exp\left[-\frac{0.219 - 0.0259}{0.0259}\right] = 1.625\times10^{16}\ \text{cm}^{-3}$$ 5

$$\Delta N = 1.625\times10^{16} - 6\times10^{15} \approx 1\times10^{16}\ \text{cm}^{-3}$$

$$\boxed{\Delta N \approx 1\times10^{16}\ \text{cm}^{-3}}$$ 5