1. $P_\nu \propto \Omega(E - E_\nu)$

By Taylor-Series Expansion,

$$\ln[\Omega(E-E_\nu)] = \ln[\Omega(E)] - E_\nu \frac{\partial \ln\Omega}{\partial E} + \ldots\ldots$$

($E_\nu << E$ so latter terms are neglected)

$$= \ln[\Omega(E)] - E_\nu \times \left(\frac{1}{k_B T}\right)$$

$$\beta = \frac{1}{\Omega}\frac{\partial \Omega}{\partial E} \Rightarrow \int_E \beta\, \partial E = \int_\Omega \frac{\partial \Omega}{\Omega} \Rightarrow \text{Integrating,}$$

$$\therefore \boxed{\ln\Omega \propto \beta E} \Rightarrow \frac{\partial \ln\Omega}{\partial E} = \beta = \frac{1}{k_B T}$$

$$\therefore \Omega(E-E_\nu) \approx e^{\ln[\Omega(E)] - E_\nu \beta}$$

$$= \Omega(E)\, e^{-\beta E_\nu}$$

Since $P_\nu \propto \Omega(E - E_\nu)$,

$$P_\nu \propto \Omega(E)\, e^{-\beta E_\nu} \Rightarrow P_\nu \propto e^{-\beta E_\nu}$$

2. No. of microstates =

(No. of combinations of N rooks placed in a straight line with 2V spaces) × (permutations of all these rooks in a st line of 2V spaces)

$$= {}^{2V}C_N \times {}^{2V}P_N$$

$$= \boxed{\frac{(2V!)^2}{((2V-N)!)^2\, N!}}$$

3. $Q(N,\beta) = \sum_i e^{-\beta E_n}$

For each E_n, $\exists$ only ONE microstate (due to the given constraint)

$\therefore E_n = n\Delta$

$$Q(N,\beta) = \sum_{n=0}^{N} e^{-\beta n \Delta}$$

This is a geometric series

$$\boxed{Q(N,\beta) = \frac{1-e^{-\beta\Delta(N+1)}}{1-e^{-\beta\Delta}}}$$

$$\langle n \rangle = \sum P_n \times n$$

$$= \sum_{n=0}^{N} \frac{e^{-\Delta\beta n}}{Q} \times n$$

$$= \frac{1}{Q} \sum n e^{-\Delta\beta n}$$

$\hookrightarrow$ Arithmetico-Geometric Series

$$Q\langle n \rangle = e^{-\Delta\beta} + 2e^{-2\Delta\beta} + 3e^{-3\Delta\beta} + \dots + Ne^{-N\Delta\beta}$$

$$e^{-\Delta\beta} Q\langle n \rangle = e^{-2\Delta\beta} + 2e^{-3\Delta\beta} + \dots (N-1)e^{-N\Delta\beta} + Ne^{-(N+1)\Delta\beta}$$

$(-)$

$$(1-e^{-\Delta\beta})Q\langle n \rangle = \frac{1-e^{-\beta\Delta(N+1)}}{1-e^{-\beta\Delta}} + Ne^{-(N+1)\beta\Delta}$$

$$\therefore \langle n \rangle = \frac{1}{Q}\left[\frac{(1-e^{-\beta\Delta(N+1)})}{(1-e^{-\beta\Delta})^2} + \frac{Ne^{-(N+1)\beta\Delta}}{1-e^{-\Delta\beta}}\right]$$

~~At very large~~

$$\langle n\rangle = \frac{1}{1-e^{-\beta\Delta}} + \frac{Ne^{-(N+1)\beta\Delta}}{1-e^{-(N+1)\beta\Delta}}$$

At very large N,

$$Ne^{-(N+1)\beta\Delta} \rightarrow 0$$

$$e^{-(N+1)\beta\Delta} \rightarrow 0$$

$$\therefore \boxed{\langle n\rangle = \frac{e^{\beta\Delta}}{1-e^{\beta\Delta}}}$$

$$\boxed{\beta\Delta = 3.894\times 10^{-2}}$$

$\therefore$ $\langle n\rangle$ = 26.183 links are open on avg

at T = 298K & Δ = 0.001eV

4. For these BIONS,

$$Z = \sum_{n_1, n_2 \ldots n_j} \prod_j e^{-\beta(\varepsilon_j - \mu)(2n_j)}$$

$$= \prod_j \sum_{n_j=0}^{\infty} e^{-\beta(\varepsilon_j - \mu)(2 \times n_j)}$$

[since it takes only even number of particles]

(This is a geometric series)

$$= \boxed{\prod_j \frac{1}{1 - e^{-2\beta(\varepsilon_j - \mu)}}}$$

$$\langle n_j \rangle = \frac{\sum (2n_j) \times \left(\prod_j e^{-\beta(\varepsilon_j - \mu)(2n_j)}\right)}{Z}$$

$$= \frac{1}{Z} \frac{\partial Z}{\partial(-\beta\varepsilon_j)}$$

$$= \frac{\partial(\ln Z)}{\partial(-\beta\varepsilon_j)}$$

$$= \boxed{\frac{2}{e^{2\beta(\varepsilon_j - \mu)} - 1}}$$

$$\frac{\left(\frac{1}{1 - e^{-2\beta(\varepsilon_j - \mu)}}\right)}{-\beta\varepsilon_j}$$

5.

$$\boxed{\beta = \frac{1}{K_B T} = \frac{1}{8.617\times10^{-5}\times300} = 38.683\,eV^{-1}}$$

$$\langle n_1\rangle = \frac{1}{1+e^{\beta(\varepsilon_1-\mu)}}$$

$$= \frac{1}{1+e^{(0.5-0.7)\times38.683}} = \frac{1}{1.0004365533}$$

$$= \boxed{0.9995636372 \text{ particle}}$$

$$\cancel{= \frac{1}{1+0.99843}}$$

$$\cancel{= 0.5013 \text{ particles}}$$

$$\langle n_2\rangle = \frac{1}{1+e^{(0.3)\beta}} = \frac{1}{1.09634\times10^{5}} = \boxed{9.1212\times10^{-6} \text{ particles}}$$

6.

$$G = \begin{cases} a\left(1-\frac{T}{T_c}\right)^2 & T < T_c \\ a\left(1-\frac{T}{T_c}\right)^2 + b\left(1-\frac{T}{T_c}\right)^3 & T \geq T_c \end{cases}$$

- G is continuous at $T = T_c$. $[G = 0$ when $T = T_c]$

$$\frac{\partial G}{\partial T} = \begin{cases} -\frac{2a}{T_c}\left(1-\frac{T}{T_c}\right) & T < T_c \\ -\frac{2a}{T_c}\left(1-\frac{T}{T_c}\right) - \frac{3b}{T_c}\left(1-\frac{T}{T_c}\right)^2 & T \geq T_c \end{cases}$$

- $\frac{\partial G}{\partial T}$ is continuous at $T = T_c$

$$\frac{\partial^2 G}{\partial T^2} = \begin{cases} \frac{2a}{T_c^2} & T < T_c \\ \frac{2a}{T_c^2} + \frac{6b}{T_c^2}\left(1-\frac{T}{T_c}\right) & T \geq T_c \end{cases}$$

- $\frac{\partial^2 G}{\partial T^2}$ is continuous at $T = T_c$

$$\frac{\partial^3 G}{\partial T^3} = \begin{cases} 0 & T < T_c \\ -\frac{6b}{T_c^3} & T \geq T_c \end{cases}$$

$\frac{\partial^3 G}{\partial T^3}$ is DISCONTINUOUS at $T = T_c$.

$\therefore$ $\boxed{\text{The order of phase transition} = 3}$

7. (i) Energy gap $= \frac{hc}{\lambda} = \frac{1242}{632.8} = \boxed{1.9627 \text{ eV}}$

(ii) We know ~~sn/spon~~

$$A = \frac{1}{\text{lifetime}} = 10^{10} \ s^{-1}$$

Also,

$$\frac{A}{B} = \frac{2h\nu^3 n_0^3}{c^3} = \frac{2hn_0^3}{\lambda^3}$$

$$= \frac{2\times 6.626\times 10^{-34}\times 1}{10^{-30}\times (6328)^3}$$

$= \cancel{13.252\times10^{-4}}$

$= \cancel{\boxed{1.3252\times10^{-3}\ \text{Js}/m^3}}$

$= \boxed{5.229\times10^{-15}\ \text{kg/ms}}$

$$\frac{1.3252\times10^{-4}}{6.328^3\times10^9}$$

0.05229×10^{-13}

5.229×10^{-15}

$\therefore B = \frac{A}{1.3252\times10^{-3}} = \cancel{\boxed{7.546\times10^{12}\ m^3}}$

$= \cancel{\boxed{7.546\times10^{12}\ m^3/\text{Js}^2}}$

$$\frac{kg\,m^2}{s^2}\cdot\frac{s}{m^3}$$

$$\therefore B = \frac{10^{10}}{5.229\times10^{-15}}$$

$= 1.912\times10^{24}\ m/kg$

(iii) $\Delta E \, \Delta t = \frac{h}{4\pi} \Rightarrow \Delta\nu \, \Delta t = \frac{1}{4\pi} \Rightarrow \boxed{\Delta\nu = \frac{1}{4\pi \Delta t}}$

Also,

$$\delta\nu = \frac{c}{2n_o d} = \frac{c}{2d}$$

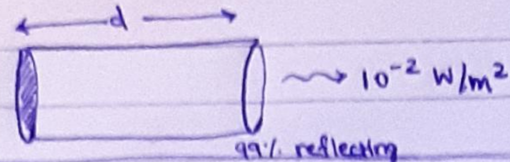
$\therefore$ No. of modes $= \frac{\Delta\nu}{\delta\nu} = \frac{d}{2\pi c \, \Delta t} = \frac{1}{2\pi \times 3 \times 10^8 \times 10^{-10}}$

$$= \frac{100}{6\pi}$$

$$\Rightarrow 5.3052$$

$\approx$ $\boxed{\text{5 resonant frequencies}}$

8.



~~% of Power~~ = $I \times A \times$ ~~99%~~ [Consumed Power]

$= 10^{-2} \times 10^{-4}$ ~~99%~~

$= 10^{-6}$ W = Energy / Time

$\therefore$ ~~$10^{-4} \times 10^{-2} = 10^{-6}$ W~~ $\cancel{\boxed{0.99 \times 10^{-6}\ W}}$

$P = \frac{nE_p}{t} = \frac{nE_p}{(d/c)} = \frac{nE_pc}{d}$ [E_p = energy of photon]

$\therefore n = \frac{Pd}{E_pc} = \frac{10^{-4} \times 10^{-1} \times 0.99}{10^{-1} \times 1.6 \times 10^{-19} \times 3 \times 10^{8}}$

$= \frac{10^{7} \times 0.99}{4.8} = \cancel{\boxed{2.065 \times 10^{6}\ \text{photons}}}$

→ ~~Power consumed by the laser~~

~~$= 99\% \times$ Power Output~~ $= \cancel{\boxed{10^{-4}\ W}}$

$= 99\% \times 10^{-6}$

$= \cancel{\boxed{9.9 \times 10^{-8}\ W}}$

→ Energy of beam = Intensity × Area × Time

$= 10^{-2} \times 10^{-4} \times \frac{2d}{c}$

$= 10^{-6} \times \frac{10^{-1}}{3 \times 10^{8}} = 3.33 \times 10^{-16}$ J

$= \cancel{\frac{3.33 \times 10^{-16}}{1.6 \times 10^{-19}}\ eV}$

=

$\therefore$ Energy of beam inside cavity (E_B) $= \frac{3.33 \times 10^{-16}}{1\%}$

$= 3.33 \times 10^{-14}$ J $= \frac{3.33 \times 10^{-14}}{1.6 \times 10^{-19}}$ eV $= \boxed{4.96 \times 10^{5}\ eV}$

$\therefore$ No. of photons $= \frac{E_B}{E_p\ (\text{Energy of 1 photon})} = \frac{4.96 \times 10^{5}}{0.1} = \boxed{4.96 \times 10^{6}\ \text{photons}}$

$\rightarrow$ Power ~~output~~ consumed $= I \times A$

$= 10^{-2} \times 10^{-4}$

$= 10^{-6}\ W$