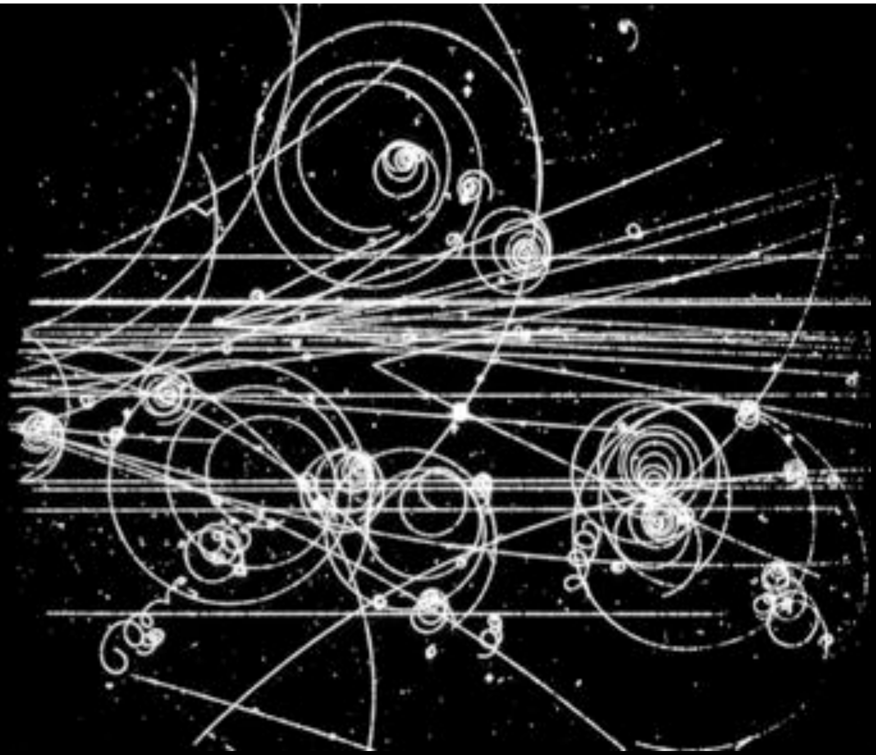
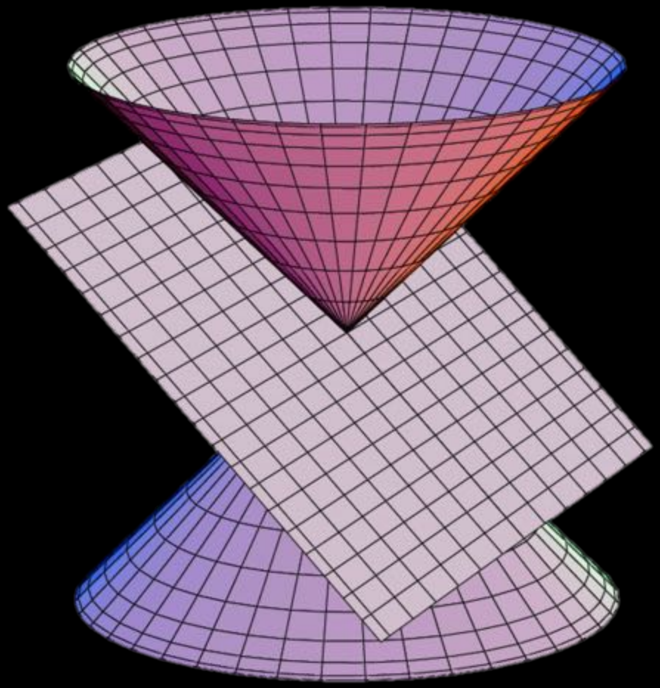




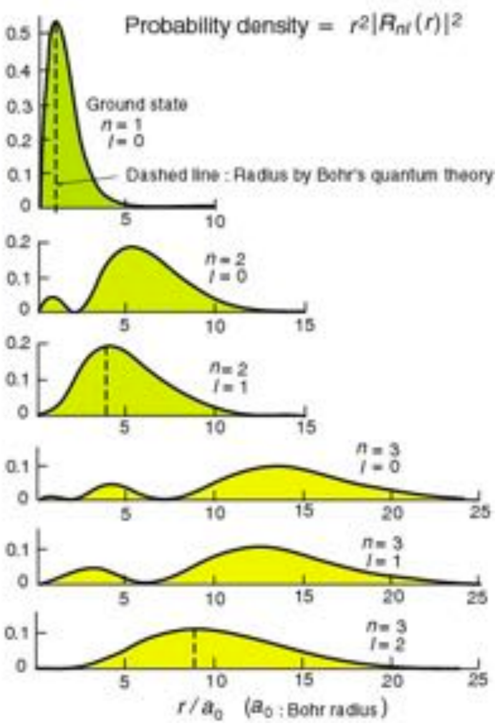
Modern Physics (Phys. IV): 2704

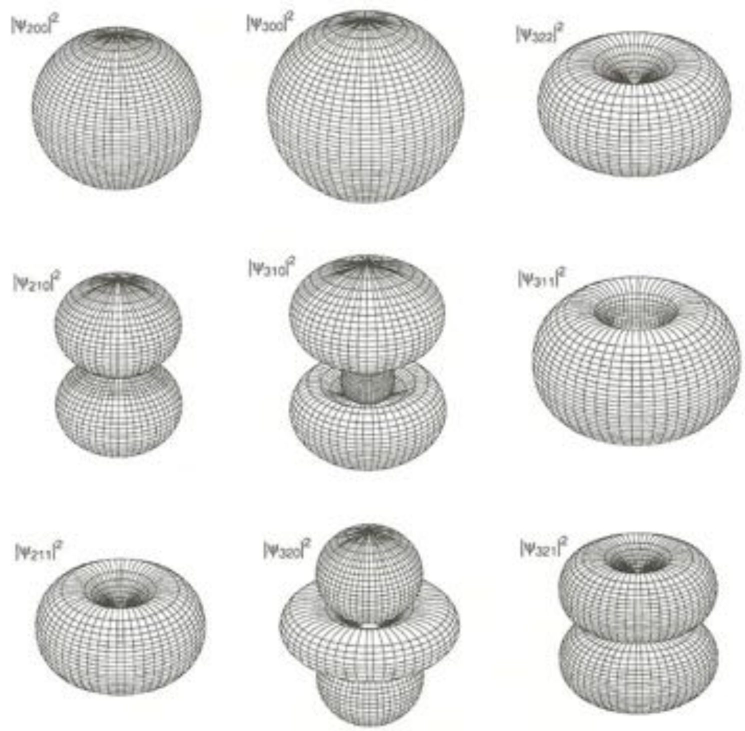
Professor Jasper Halekas
Van Allen 70
MWF 12:30-1:20 Lecture

Announcements

- Total homework grade (after dropping lowest score) uploaded to ICON
- Participation extra credit will be uploaded this afternoon
- Please remember to fill out course evaluations (30% response so far…)

Hydrogen Atom



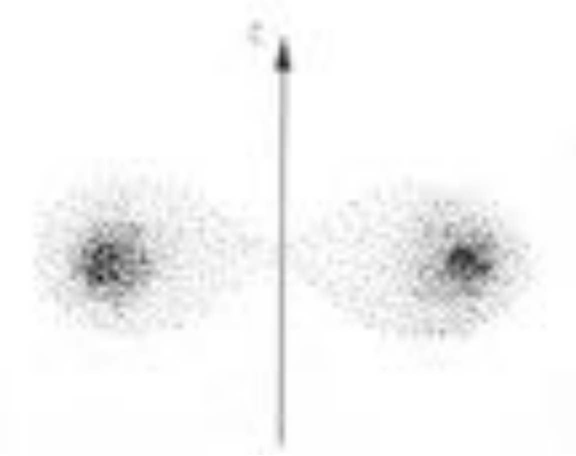


	n	l	m	s
1s	1	0	0	½, - ½
2s	2	0	0	½, - ½
2p	2	1	1, 0, -1	½, - ½
3s	3	0	0	½, - ½
3p	3	1	1, 0,-1	½, - ½
3d	3	2	2, 1, 0, -1, -2	½, - ½
4s	4	0	0	½, - ½
4p	4	1	1, 0, -1	½, - ½
4d	4	2	2, 1, 0, -1, -2	½, - ½
4f	4	3	3, 2, 1, 0, -1, -2, -3	½, - ½

n -> Energy
l -> Angular momentum
m_l -> Orientation of l
m_s -> Electron spin

Sample Question

- Does the wave function at the right represent one with a large or small L_z (z component of angular momentum)?



A. Large
B. Small
C. Can’t tell

Orbit in x-y plane

$\Rightarrow$ $\boxed{\text{high } |L_z|}$

Sample Question

The ground state wave function of the electron in a hydrogen atom is as shown at right. At what radius r from the nucleus are you most likely to find the electron?

$$\frac{1}{\sqrt{\pi}\, a_0^{3/2}} e^{-r/a_0}$$

A. $r = 0$
B. $r = a_0/2$
C. $r = a_0$
D. $r = 2a_0$

$$\rho(r) = r^2 R^2(r)$$

$$= r^2 \frac{1}{\pi a_0^3} e^{-2r/a_0}$$

$$d\rho(r)/dr = \frac{1}{\pi a_0^3}\left(2r\, e^{-2r/a_0} + r^2 \cdot \frac{-2}{a_0} e^{-2r/a_0}\right)$$

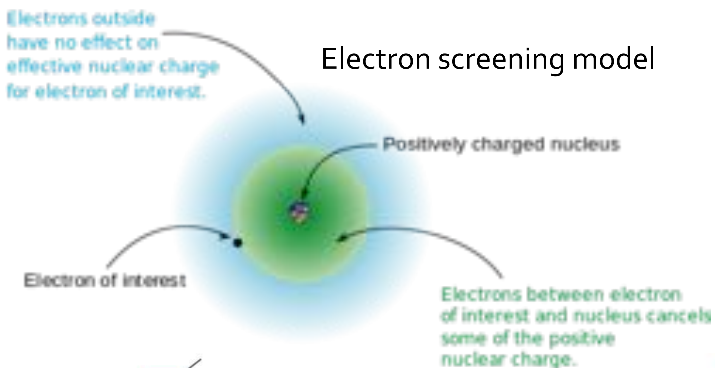
$$= 0$$

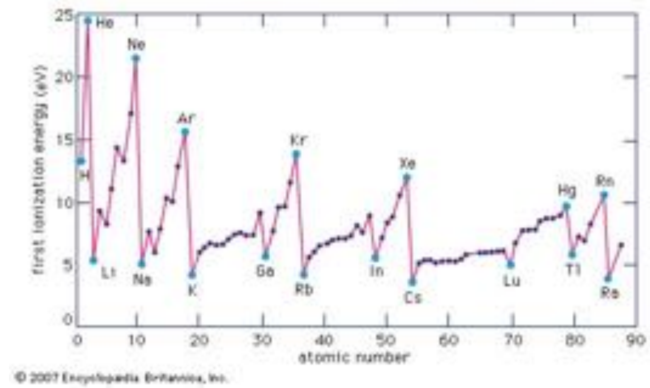
$$\Rightarrow 2r - 2r^2/a_0 = 0$$

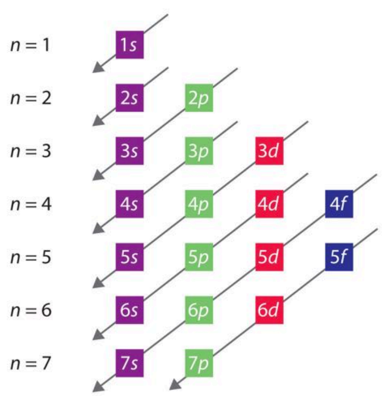
$$\Rightarrow \boxed{r = a_0}$$

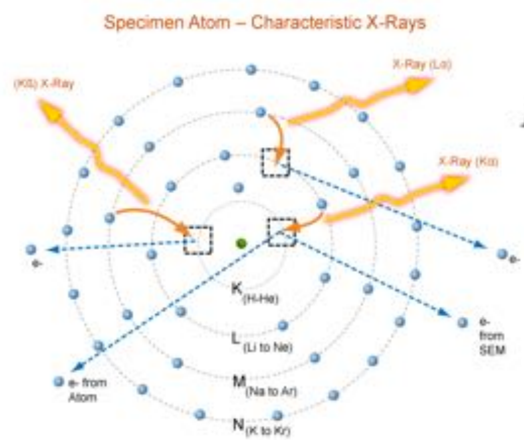
Many-Electron Atoms

- Pauli exclusion principle: No two electrons can have the same set of quantum #'s









"Moseley's Law" for K_α X-Rays

$$E = h\nu = E_i - E_f = \frac{m_e q_e^4 (Z-1)^2}{8h^2\varepsilon_0^2}\left(\frac{1}{1^2} - \frac{1}{2^2}\right)$$

$$E = 13.6*0.75*(Z-1)^2$$

$$E = 10.2*(Z-1)^2$$

Sample Question

- The sodium atom (Z=11) has a single electron in the 3s orbital. What is closest to the effective nuclear charge that this electron sees?

A. +e
B. -e
C. +5e
D. +10e

outer electron well screened

$$Z_{eff} \sim Z - 10$$

$$= \boxed{1}$$

Sample Question

- The K_α wavelength of an element with atomic number $Z = 17$ is 8. What is the atomic number of an element with a K_α wavelength of 32?

A. 3
B. 7
C. 9
D. 33
E. 65

$$\Delta E = (Z-1)^2 \cdot 13.6 \cdot (1 - 1/4)$$
$$= 10.2 \cdot (Z-1)^2$$

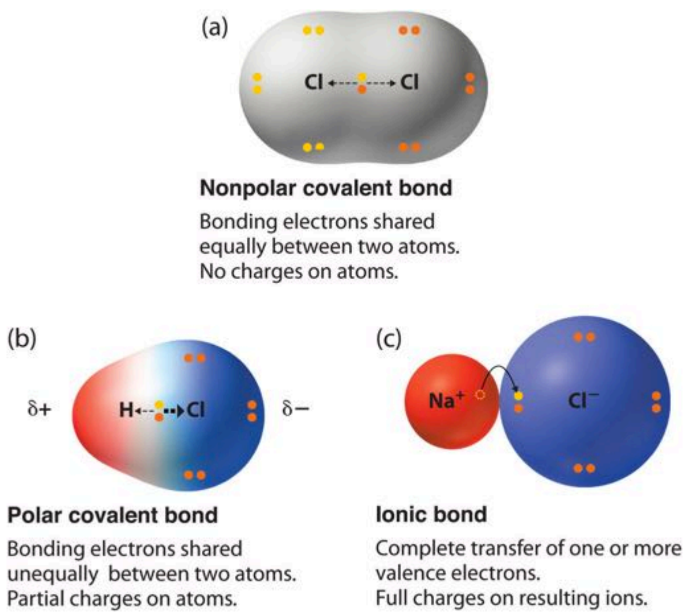
$$\lambda = hc/\Delta E = hc/10.2 \cdot (Z-1)^2$$

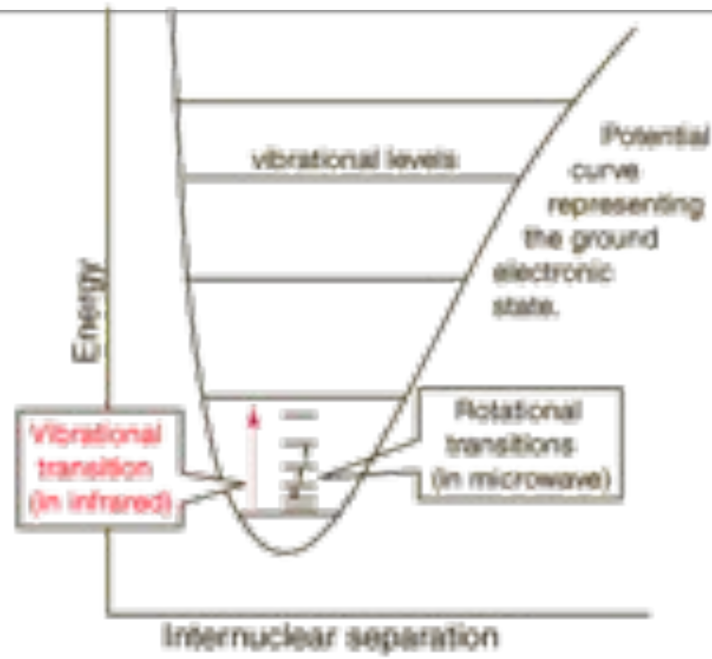
$$\frac{\lambda_2}{\lambda_1} = 4 = \frac{(Z_1-1)^2}{(Z_2-1)^2} = \frac{16^2}{(Z_2-1)^2}$$

$$\Rightarrow (Z_2-1)^2 = 16^2/4 = 64$$

$$\Rightarrow Z_2 - 1 = 8$$
$$\Rightarrow \boxed{Z_2 = 9}$$

Molecules





$E_L = L(L+1)\hbar^2/(2\mu R^2) = BL(L+1)$

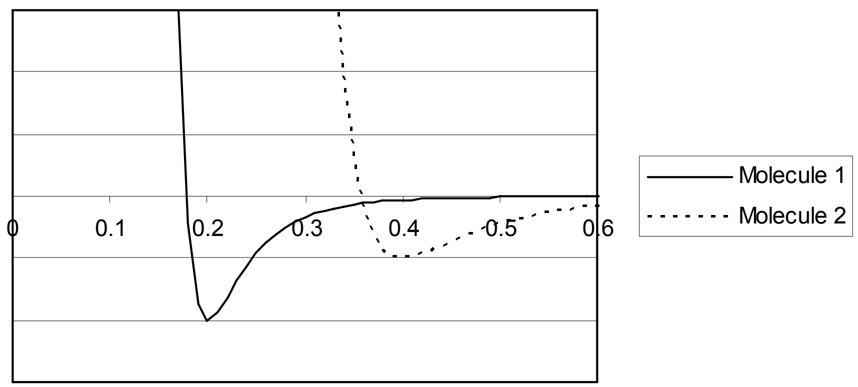
$E_N = (N+1/2)\,\hbar\omega$

$\Delta L = \pm 1$

$\Delta N = \pm 1$

Sample Question

The figure shows the energy curves of two different molecules that have the same reduced mass. Which molecule has the larger rotational moment of inertia?



A. Molecule 1
B. Molecule 2
C. Both are the same
D. No way to tell

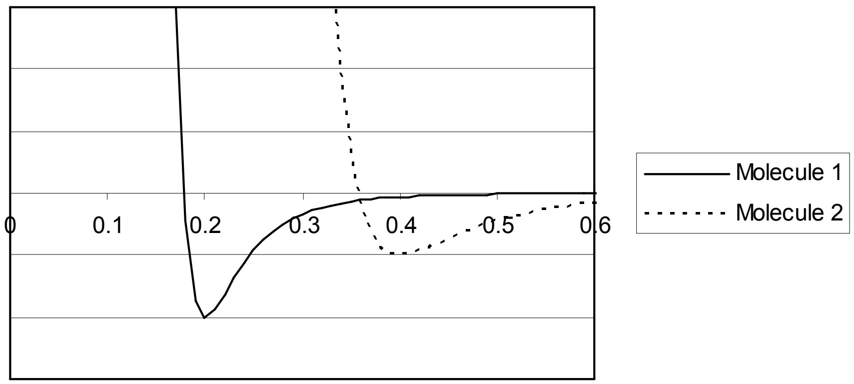
$$I = \mu R_{eq}^2$$

$$\mu_1 = \mu_2$$

$$R_{eq_2} > R_{eq_1} \Rightarrow \boxed{I_2 > I_1}$$

Sample Question

The figure shows the energy curves of two different molecules that have the same reduced mass. Which molecule has the larger vibrational energy spacing?



A. Molecule 1
B. Molecule 2
C. Both are the same
D. No way to tell

$$\Delta E_n = \hbar \sqrt{\frac{k}{\mu}}$$

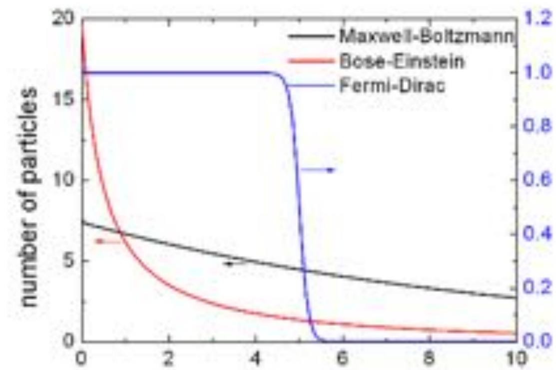
$$U \sim \frac{1}{2} k x^2$$

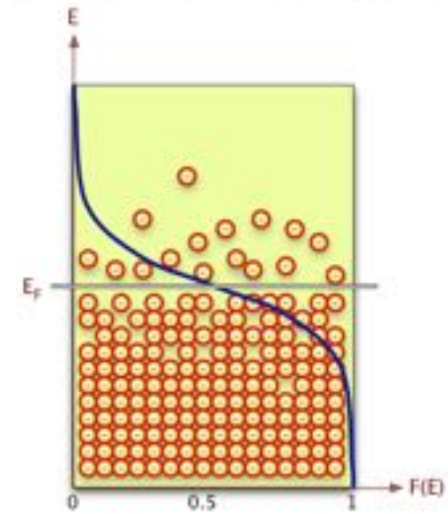
U_1 steeper $\Rightarrow k_1 > k_2$

$$\Rightarrow \boxed{\Delta E_{n_1} > \Delta E_{n_2}}$$

Statistical Physics

Points Compared	Maxwell-Boltzmann	Bose-Einstein	Fermi-Dirac
Statistics Applicable	Classical	Quantum	Quantum
Nature of particles	Identical & distinguishable	Identical & indistinguishable	Identical & indistinguishable
Examples	Molecules of a gas	i)Photons in a cavity ii)phonons in a solid	Free electrons in conductors
Properties of particles	Any spin wave functions do not overlap	Spin=0,1,2,3,4….. Overlap of wave functions	Spin=1/2,3/2, 5/2.. Overlap of wave functions
Distribution function	$f(E) = Ae^{-E/KT}$	$f(E) = \dfrac{1}{Ae^{E/KT}-1}$	$f(E) = \dfrac{1}{1+e^{(E-E_F)/KT}}$





Sample Question

- Let E represent the average energy of electrons in a certain block of metal at a temperature of 0 K. Now suppose the electrons are magically changed from spin 1/2 particles (fermions) to spin 1 particles (bosons). Would you expect the average energy of the spin 1 electrons in an otherwise identical block of metal at 0 K to be…

A. Greater than for spin 1/2
B. Less than for spin 1/2
C. The same as for spin 1/2
D. Cannot determine

At 0 K

$$\langle E \rangle_{BE} = 0$$

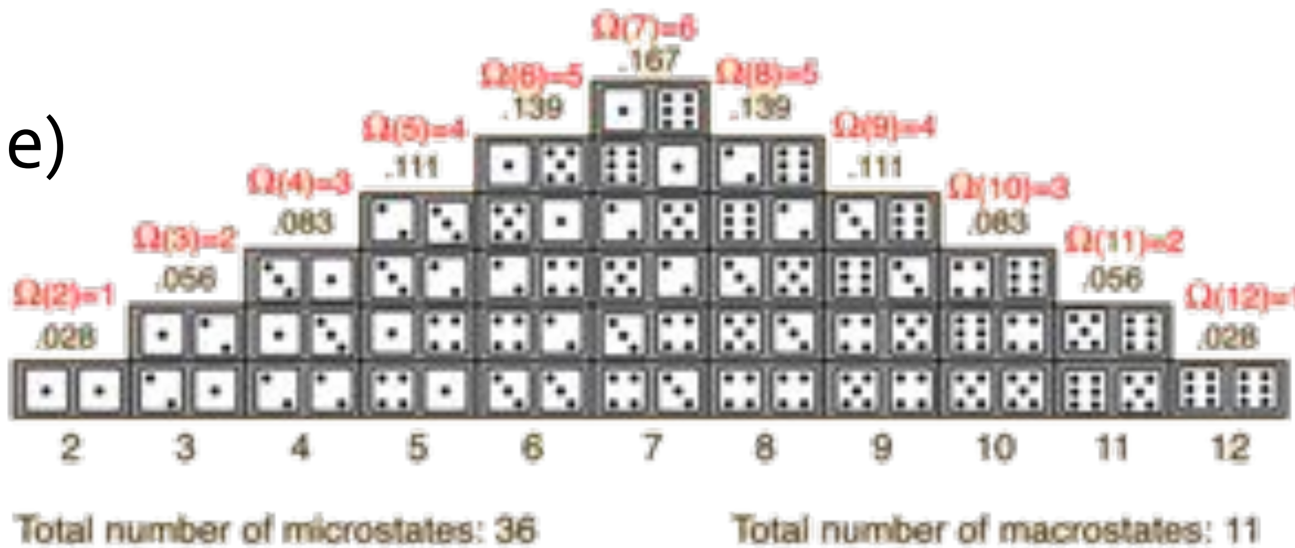
$$\langle E \rangle_{FD} \neq 0$$

so $\boxed{\langle E \rangle_{BE} < \langle E \rangle_{FD}}$

Sample Question

- For a system of two dice, the 11 macrostates and 36 microstates are shown below, assuming distinguishable dice. How many macrostates and microstates are there if the dice are indistinguishable fermions that can't have the same #?

A. 11, 36 (same)
B. 11, 30
C. 9, 30
D. 9, 15



Eliminate all doubles

$$36 = 6 \times 6$$

$$\Rightarrow 6 \times 5 = 30$$

- but since indistinguishable, order doesn't matter

so $\frac{6 \times 5}{2}$ = **15 microstates**

- All macrostates except 11 and 66, so **9 macrostates**