Thermo & Quantum Mechanics
Thermodynamics Equations

- $\Delta U = Q + W \quad \text{1st Law}$
- $W = -\int P \, dV$
- $dQ = T \, dS \quad \text{for reversible processes}$
- $\Delta U = mC_v \Delta T$
- $\Delta S_{\text{universe}} \geq 0 \quad \text{2nd Law}$
- $H = U + PV \quad \text{Enthalpy}$
- $\Delta H = mC_p \Delta T$
- $PV = nRT = nk_B N_A T \quad \text{Ideal gas law}$
Problem 1

O₂ gas goes through the cycle A -> B -> C -> A as shown in the figure. If the gas goes through one full cycle, which of the following is true for the gas?

(a) ∆U = ∆H = 0, ∆S > 0, W > 0, Q < 0
(b) ∆U = ∆H = 0, ∆S > 0, W < 0, Q > 0
(c) ∆U = ∆H = ∆S = 0, W < 0, Q > 0
(d) ∆U = ∆S = 0, ∆H > 0, W > 0, Q < 0
(e) 0 < ∆U < ∆H, ∆S > 0, W < 0, Q > 0
Problem 2

A container is separated into 2 equal volumes by a membrane. The right side of the membrane is filled with 1 mole of N\textsubscript{2} gas, and the left side is filled with 1 mole of C0\textsubscript{2} gas. The membrane is broken and the two gasses are allowed to mix. What is the change in entropy?

(a) 0
(b) 2R Ln(2)
(c) R Ln(2)
(d) C\textsubscript{v} \Delta T/T
(e) C\textsubscript{p} \Delta T/T
Quantum Mechanics

- Schrödinger equation
- Uncertainty Principle
- Harmonic oscillator
  \[ H = \frac{p^2}{2m} + \frac{1}{2} m \omega^2 = \Box a a^* a + \frac{1}{2} \]
- Infinite Square Well
- Delta function potential
- Angular Momentum Operators
- Hydrogen (like) Atom
- 1st order perturbation
- So on ...

\[ \frac{\Box^2}{2m} \psi + V \psi = E \psi \]

\[ \sigma_a \sigma_b \geq \left( \frac{1}{2i} \langle [\hat{A}, \hat{B}] \rangle \right)^2 \]

\[ E = \Box a (n + \frac{1}{2}) \]

\[ \psi_n = \sqrt{\frac{2}{a}} \sin \left( \frac{n \pi x}{a} \right) \]

\[ E_n = - \left[ \frac{\mu}{2 \Box^2} \left( \frac{Ze^2}{4 \pi \varepsilon_0} \right)^2 \right] \frac{1}{n^2} \]
Problem 1

A diatomic molecule is initially in the state \( \Psi(\theta, \varphi) = (5Y_{1}^{1} + 3Y_{5}^{1} + 2Y_{5}^{-1})/(38)^{1/2} \), where \( Y_{l}^{m} \) is the spherical harmonic. What is the probability of measuring \( m=1 \)?

(a) 25/38
(b) 3/38
(c) 8/(38)^{1/2}
(d) 34/38
(e) 4/5
Quantum Mechanics

Problem 2

A molecule is in the state $\Psi(\theta, \phi) = (3/4\pi)^{1/2} \sin \theta \cos \phi$. What is the expectation value for the operator $O = [L_+, L_-]$?

(a) 0
(b) $\hbar^2$
(c) $2\hbar^2$
(d) $3/2 \hbar^2$
(e) $3\hbar^2$
Problem 3

The operator $O= (a^* + a)^2$ operates on the a wave quantum harmonic oscillator in state $|n=4\rangle$. What is the expectation value for this operator?

(a) 9  
(b) 8  
(c) 0  
(d) $2\pi$  
(e) 4
Quantum Mechanics

Problem 4

Muonic hydrogen is when a muon instead of an electron is orbiting the proton. The muon is approximately 200 time heavier than the electron. What is the ground state energy of a muonic hydrogen?

(a) -2448 eV
(b) -13.6 eV
(c) Muons decay, and therefore muonic hydrogen does not exist.
(d) -2720 eV
(e) 27200 eV
Two hydrogen atoms with spin $\mathbf{s}_1$ and $\mathbf{s}_2$ have the interaction Hamiltonian $H = -a \mathbf{s}_1 \cdot \mathbf{s}_2$ where $J > 0$. The atoms are placed in a uniform magnetic field $B$. What is their ground state energy?

(a) $-(J/2)[(S_1 + S_2)(S_1 + S_2 + 1) - S_1(S_1 + 1) - S_2(S_2 + 1)]$

(b) $-\gamma B S_1 - \gamma B S_2$

(c) $-\gamma B S_1 - \gamma B S_2 - (J/2)[(S_1 + S_2)(S_1 + S_2 + 1) - S_1(S_1 + 1) - S_2(S_2 + 1)]$

(d) $-\gamma B S_1 - \gamma B S_2 - J[S_1(S_1 + 1) + S_2(S_2 + 1)]$

(e) $-\gamma B S_1 - \gamma B S_2 - JS_1 S_2$
Answers

Thermo
1) C
2) B

QM
1) D
2) A
3) A
4) A
5) C