1. **Heat Capacity of Diatomic Molecules and the Equipartition Theorem.**

   The heat capacity of diatomic molecules shows an interesting dependence on temperature.

   (a) Using the data given below for the hydrogen molecule $\text{H}_2$, plot the constant-temperature heat capacity $C_V$ for $\text{H}_2$ from 10 K to 10000 K using the formula given in the lectures.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>State</th>
<th>$\tilde{\omega}$ (cm$^{-1}$)</th>
<th>$\Theta_v$ (°K)</th>
<th>$B$ (cm$^{-1}$)</th>
<th>$\Theta_r$ (°K)</th>
<th>$k \times 10^{-5}$</th>
<th>$D_0$ (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{H}_2$</td>
<td>$^1\Sigma_g^+$</td>
<td>4320</td>
<td>6215</td>
<td>59.3</td>
<td>85.3</td>
<td>5.5</td>
<td>103.2</td>
</tr>
</tbody>
</table>

   (b) In arriving at the formula used in part (a), did we use any approximation to evaluate the rotational part of the partition function? If so, is this approximation justified at low temperatures (e.g. 10 K)? at moderate temperatures (e.g. 200 K)? at high temperatures (e.g. 1000 K)? Explain your answers.

   (c) The rotational part is not computed accurately at low temperatures. Can you think of a way to do the calculation correctly for the rotational part at low temperatures? Using this, recalculate $C_V$ as a function of $T$ from 10 K to 10000 K as in part (a) and plot it. Does this look different from your first plot? Explain the difference(s).

   (d) The classical equipartition theorem says that every degree of freedom should contribute $k/2$ to $C_V$. For a diatomic molecule, there are 3 translations, 1 vibration and 2 rotations, so the total $C_V$ should be $3k$ regardless of $T$. Is your graph in part (c) consistent with this assertion? Explain why the equipartition theorem is wrong and suggest how the classical equipartition theorem can be corrected to account for quantum effects.

2. **Spectrum of Photon Gas in a 3-d Blackbody.**

   (a) Derive a formula for the spectrum of the blackbody. The spectrum $\rho(\omega, T)$ is defined as the energy per unit volume per unit frequency, i.e. $\rho(\omega, T)d\omega$ is the energy per unit volume inside the frequency range $\omega$ and $\omega + d\omega$ at temperature $T$.

   (b) Plot the spectrum $\rho(\omega, T)$ of the blackbody at three temperatures $T = 300$ K, 3000 K and 30000 K.

   (c) Assume the tungsten wire inside an incandescent light bulb is a blackbody, estimate the approximate temperature of the wire in order for it to emit white light. (Does your answer make sense given the melting temperature of tungsten?)

   (d) After the initial big bang, the universe is still undergoing rapid expansion today. Because of this expansion, the universe cools. The current temperature of the universe is 2.7 K. Assuming the universe is a blackbody, it would then emit electromagnetic waves within a characteristic frequency range. In which part of the electromagnetic spectrum does this frequency range lie?

3. **Problems 4.18, 4.19 and 4.20 in Chandler**