(1) Explain how the existence of a finite zero-point vibrational energy is related to the uncertainty principle. (5%)

(2) The asymmetry in the binding energy curve accounts for thermal expansion of solids. How can information from molecular spectra be used to determine the shape of this curve? (12%)

(3) Explain in physical terms the origin of the selection rules. (8%)

(4) Which of the following elements would you expect to have energy levels divided into singlet and triplet states: Al, Ar, Ca, Ti, Au? Explain. (6%)

(5) Would you expect $H_3$ to exist in a bound state? $He_2$? Explain. (5%)

(6) Derive an expression giving the ratio of the energy of a transition from the lowest to the first excited vibrational level to the energy of a transition from the lowest to the first excited rotational level for a diatomic molecule. (14%)

(7) In the finite crystal, the crystal vibration is quantized; i.e., for each vibration mode with frequency $\omega$, only those energies corresponding to integral multiples of $\hbar\omega$ are allowed. Let $E_n = n\hbar\omega$ be the energy of the nth excited state, and $P_n \propto \exp(-E_n / kT)$ be the probability of the vibration to be in the energy state $E_n$.

(a) Calculate the probability for the vibration mode with energy $n\hbar\omega$ and frequency $\omega$ in the crystal at temperature T. (5%)
(b) Calculate the average energy for this vibration mode. (5%)
(c) Calculate the average number of phonons corresponding to this vibration mode. (5%)

(8) Maxwell-Boltzmann, Bose-Einstein, and Fermi-Dirac are the three statistical distributions used to describe systems with fixed total energy and number of particles.

(a) Describe the characteristics of particles that are suited for each distribution. (4%)
(b) Consider a system with two particles, 1 and 2, one of which is in state $a$ and the other in state $b$. For particles that conform to each distribution, express the wave function of the system as the combination of each particle. (3%)
(c) Like (b), express the wave function of the 2-particle system if both particles stay in the same state. (3%)

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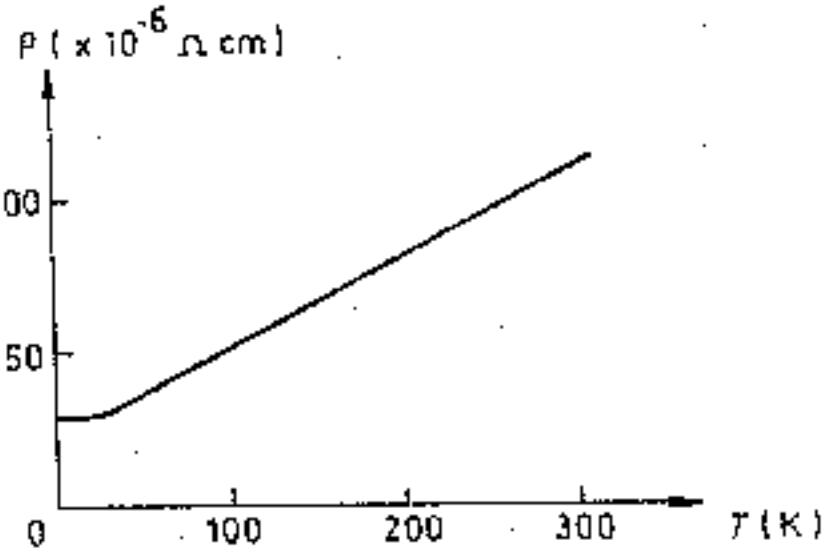
(9) The following figure is a rough plot of the electrical resistance of a solid ($ErRhB_4$, impure, but not purposely damaged).

(a) Describe the main physical processes that account for the resistivity, and explain the temperature dependence of the resistivity in the region near 0 °K, near 25 °K, and near 300 °K. (9%)

(b) Estimate the mean free path and mean free time at T= 0 and 300 °K, assuming free electron mass and carrier concentration is $10^{23}$ $cm^{-3}$. (6%)



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(10) The following figure shows the energy contours in eV in the first and second Brillouin zones of a hypothetical square lattice. On your answer sheet, sketch similar figure and indicate the occupied energy levels to show (a) an insulator, (b) a conductor with free electron as charge carrier, and (c) a conductor with free hole as charge carrier. (10%)