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Questions

a) Explain the implication of the Kramers-Kronig relations with respect to the physical effects related to real and imaginary part of the complex dielectric function $\epsilon(\omega)$.

b) Consider the simplest model of Hydrogen atom, disregarding relativistic and spinor effects. Please sketch the spectrum of the Hydrogen atom. How do the energy eigenvalues depend on the quantum numbers?

c) Please sketch the spectrum of an one-dimensional quantum mechanical harmonic oscillator. How do the energy eigenvalues depend on the quantum number? Discuss the ground state of the quantum mechanical harmonic oscillator. zero point energy

d) A friend of yours claims that he found a medium with constant complex dielectric function $\epsilon(\omega)$ for all positive frequencies. Do you believe him? If yes, which medium could it be? Prove you answer with the help of Kramers-Kronig relations.

e) What is a response function of the medium? Which properties of the response function are necessary to derive the Kramer-Kronig relations?

f) In time domain, one can relate the polarization $\mathbf{P}(t)$ and the electric field $\mathbf{E}(t)$ via the response function $R(\tau)$. Write down the general relation between $\mathbf{P}(t)$ and $\mathbf{E}(t)$ for a linear, isotropic, homogeneous dielectric medium. Give also the relation between the response function $R(\tau)$ and the dielectric function $\varepsilon(\omega) = 1 + \chi(\omega)$.

g) The dielectric function

- Sketch the real and imaginary part of the dielectric material close to a resonance frequency and label the regions of normal and anomalous dispersion.

- The dielectric functions of dielectrics and metals exhibit a completely different behaviour. Why?

- Sketch the real and imaginary part of silver in the near UV and explain all physical quantities appearing.

- Explain the physical reason for the high reflectivity of metals in the VIS region. What changes in the UV – and why?

h) Molecules

- What are typical frequency ranges of purely rotational and purely vibrational spectra?

- Explain the main idea of Frank-Condon principle for a diatomic molecule with only one vibrational degree of freedom.

- Sketch the excitation and de-excitation of that molecule, using an energy configuration diagram of the molecule in the electronic ground state and in an excited state.

- Sketch the typical emission and absorption spectra of the optical transitions between the electronic ground state and an excited state of the molecule, taking into account the vibrational degree of freedom. Please give some short explanations.

- Why emission spectrum of the molecule is approximately the 'mirror' of the absorption spectrum when reflected about the centre frequency $\hbar\omega_0$ (zero phonon line)? How is the center frequency ω_0 defined?

i) Bloch's theorem plays an important role in the quantum mechanical treatment of solid materials. Under which conditions does it apply. Give one formulation of the theorem and explain its meaning.

j) Give a short explanation why a crystalline solid exhibits a band structure instead of discrete energy levels.

k) What is the main difference between metals, insulators and semiconductors in terms of the electronic energy spectrum?

l) Please explain the difference between a direct and an indirect band transition, Use a figure for illustration.

m) Which Bravais lattice do you find if you take the reciprocal lattice of the reciprocal lattice?

n) Explain what happens with the electronic energy levels in the presence of an external static magnetic field $\vec{B}$. Sketch a term scheme showing all dipole allowed transition between the n = 3 and n = 2 energy levels in this case (n is the principal quantum number).