CHM676 Practice Questions

Mike Reppert

October 2019

1. True or false: The electric field at a given point in space is directly proportional to the force experienced by a moving charged particle with a very small positive charge.

2. Short Answer: Pick one of Maxwell's four (microscopic) equations (reproduced below), name the terms, and explain what it means physically.

$$\begin{aligned} \nabla \cdot \boldsymbol{e} &= 4\pi\varrho(\boldsymbol{x}, t) \\ \nabla \cdot \boldsymbol{b} &= 0 \\ \nabla \times \boldsymbol{e} + \frac{1}{c}\frac{\partial \boldsymbol{b}}{\partial t} &= 0 \\ \nabla \times \boldsymbol{b} - \frac{1}{c}\frac{\partial \boldsymbol{e}}{\partial t} &= \frac{4\pi}{c}\boldsymbol{j}(\boldsymbol{x}, t) \end{aligned}$$

3. Choose one: The Fourier transform splits signals into

A. Bite-sized pieces
B. Frequency components
C. A power series in small displacements
D. Absolute values

4. Short Answer: In electrodynamics, we often use a four-dimensional Fourier transform to write the electric field $\tilde{\boldsymbol{E}}(\boldsymbol{k}, \omega)$ in terms of ω and $\boldsymbol{k}$. What do the two symbols ω and $\boldsymbol{k}$ represent?

5. Short Answer: What does the Poynting vector $\boldsymbol{S}(\boldsymbol{x}, t)$ represent?

6. Short Answer: Maxwell's (microscopic) equations can be solved to produce the Inhomogeneous Wave Equation:

$$\left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right)\boldsymbol{e} = -4\pi\nabla\varrho - \frac{4\pi}{c^2}\frac{\partial \boldsymbol{j}}{\partial t}.$$

This equation can be solved analytically. But for most physical problems, this solution doesn't allow us to directly calculate the electric field in the presence of charged particles. Why not?

7. Short Answer: In the near field regime, inter-particle interactions are dominated by what potential?

8. Choose one: Material response in molecular spectroscopy is determined primarily by which of the following

A. The free charge density ρ
B. The polarization density $\boldsymbol{P}$
C. The free charge current $\boldsymbol{J}$

D. The magnetic field $\boldsymbol{B}$

9. Choose one: In our deduction of the response theory formalism, which of the following was **not** a physical constraint that we used to constrain the mathematical form for the dependence of $\boldsymbol{P}$ on $\boldsymbol{E}$?

A. Stability
B. Causality
C. Integrability
D. Locality

10. Choose one: Neumann's principle states that any symmetries present in a material must be reflected in its response tensors. For an isotropic medium, which of the following must vanish according to Neumann's principle?

A. $R^{(1)}_{xy}$
B. $R^{(2)}_{xxx}$
C. $R^{(3)}_{xyyy}$
D. All of the above
E. (a) and (b)

11. Choose one: In the Response Theory expansion

$$P^{(n)}_{\alpha}(t) = \sum_{\alpha_1,...,\alpha_n} \int_{-\infty}^{\infty} d\tau_n ... \int_{-\infty}^{\infty} d\tau_1 R^{(n)}_{\alpha_1...\alpha_n\alpha}(\tau_1, ..., \tau_n) \times E_{\alpha_1}(t - \tau_1 - ... - \tau_n) E_{\alpha_2}(t - \tau_2 - ... - \tau_n) ... E_{\alpha_n}(t - \tau_n).,$$

the time delays τ_i denote (most generally)

A. Time delays between laser pulses
B. Time intervals between field-matter interactions
C. Decay times for different molecular species
D. Times of great sorrow

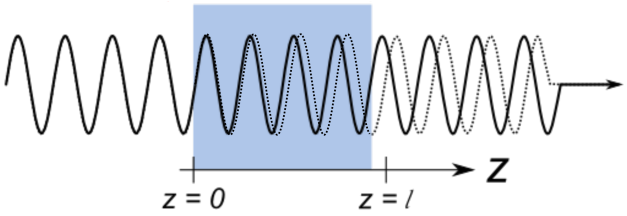
12. Short Answer: In isotropic media, what is the relationship between the linear response function $R^{(1)}$ and the linear susceptibility $\chi^{(1)}$?

13. Choose one: Which is the correct relationship between the linear susceptibility and the permittivity?

A. $\varepsilon(\omega) \equiv 1 + 2\pi\chi(\omega)$
B. $\varepsilon(\omega) \equiv 1 - 2\pi\chi(\omega)$
C. $\varepsilon(\omega) \equiv 1 + 4\pi\chi(\omega)$
D. $\varepsilon(\omega) \equiv \sqrt{1 + 4\pi\chi(\omega)}$

14. Short Answer: How is the refractive index $n(\omega)$ related to the permittivity $\varepsilon(\omega)$?

15. Short Answer: In the figure below, the solid curve represents an electric field propagating through a linearly-responsive medium; the dashed curve represents the field that *would* be present in the absence of the medium. Does the material response appear to be dominated by $\kappa(\omega)$ or $n(\omega)$?



16. Short Answer: The response-theory expansion for the polarization

$$P_\alpha(t) = \sum_{n=0}^{\infty} P_\alpha^{(n)}(t),$$

is an expansion in increasing powers of what quantity?

17. Short Answer: Is linear response expected to dominate light-matter interactions at low or high light intensities?

18. True or false: Maxwell's equations in vacuum support only longitudinal fields.

19. Choose one: Recall the frequency-sum restriction

$$\omega_{\text{sig}} = \omega_1 + \omega_2 + ... + \omega_n$$

relevant to the signal frequency generated in an n^{th}-order process. In a **5^{th}-order process** which of the following is a possible signal frequency for a system excited by a monochromatic laser with frequency ω_o?

A. $4\omega_o$
B. ω_o^5
C. $3\omega_o$
D. $2\omega_o$

20. Choose one: For a third-order process excited by an incident field with a well-defined $\boldsymbol{k}$-vector $\boldsymbol{k}_o$, there are four possible signal vectors (listed below). Which of them will generally **not** be phase-matched in an isotropic medium?

A. $\boldsymbol{k}_{\text{sig}} = +\boldsymbol{k}_o + \boldsymbol{k}_o + \boldsymbol{k}_o$
B. $\boldsymbol{k}_{\text{sig}} = -\boldsymbol{k}_o + \boldsymbol{k}_o + \boldsymbol{k}_o$
C. $\boldsymbol{k}_{\text{sig}} = +\boldsymbol{k}_o - \boldsymbol{k}_o + \boldsymbol{k}_o$
D. $\boldsymbol{k}_{\text{sig}} = +\boldsymbol{k}_o + \boldsymbol{k}_o - \boldsymbol{k}_o$

21. Short Answer: A sample exhibits absorption maxima at 650 nm and 655 nm? What is the frequency gap (in cm^{-1} between these peaks? (Any answer within 10% accuracy is acceptable.)

22. Choose one: Absorption spectra often look like the mirror image of the corresponding

A. Fluorescence excitation spectrum
B. Fluorescence emission spectrum
C. Both (a) and (b)
D. Neither (a) nor (b)

23. Choose one: In an incoherent process which quantity or quantities vanish?

A. The average field
B. The average intensity
C. The radiant energy
D. Both (b) and (c)
E. Both (a) and (b)

24. Choose one: By selectively exciting only a small subpopulation of resonant molecules, hole burning spectroscopy allows the experimenter to

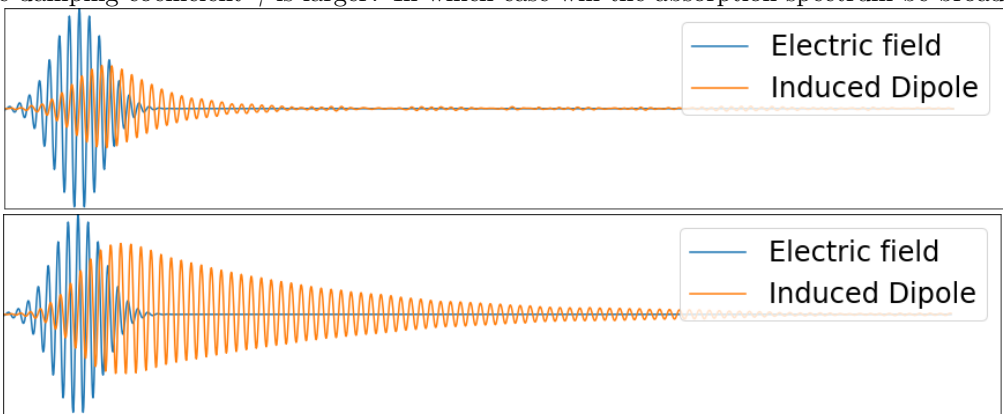
A. Measure room-temperature excited-state lifetimes
B. Distinguish between inhomogeneous and homogeneous broadening
C. Characterize electronic/vibrational interactions
D. All of the above
E. Both (b) and (c)

25. Choose one: At low temperatures, the bulk absorption spectrum is obtained from the single-site spectrum and the site-energy distribution function by

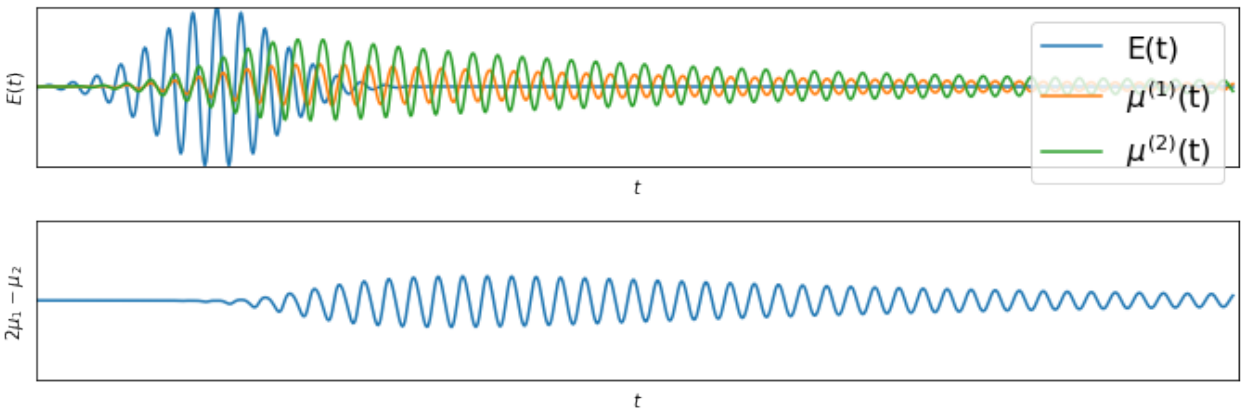
A. Fourier transformation
B. Convolution
C. Involution
D. Multiplication

26. Calculate: Show that $\nabla \cdot (\nabla \times \mathbf{v}(\mathbf{x})) = 0$, where $\boldsymbol{v}(x)$ is any three-dimensional vector-field.

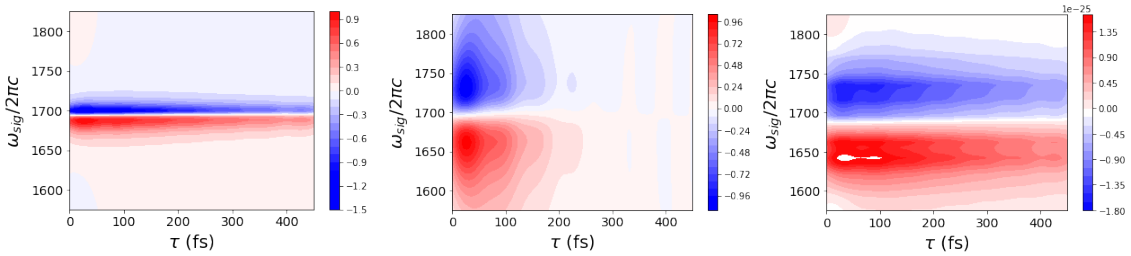
27. Short Answer: The figures below depict the response of a Morse oscillator (orange curve) to an external electric field (blue curve) in two different Langevin-dynamics simulations. In which case do you suspect the damping coefficient γ is larger? In which case will the absorption spectrum be broader?



28. Short Answer: The image below depicts the response of a Morse oscillator to an ultrafast laser field at low field amplitude (orange curve, $\mu^{(1)}$) or at twice the field amplitude (green curve, $\mu^{(2)}$). The lower curve plots the nonlinear part of the response, i.e., the scaled difference $2\mu^{(1)} - \mu^{(2)}$. Why do the two dipole-response curves become out of sync with each other, so as to produce a nonlinear signal? (Explain briefly in terms of motion on the Morse potential.)



29. Short Answer: The three images below represent pump-probe time series for three different systems. One has high dissipation and low dephasing. One has high dephasing and low dissipation. And one has low dissipation and low dephasing. Which one is which? Label all three.



30. Short Answer: Name one key advantage of nonlinear spectroscopies over linear absorption?