Don't Panic

Fundamental Photon Physics! (40%)

1. Know your electromagnetic spectra!
Please describe what types of physical processes (or dynamics) are observable using the following wavelength regimes of radiation:

a. X-Ray	d. Terahertz	g. Visible
b. Radio	e. Infrared	h. Ultra-violet
c. Microwave	f. Near-infrared (this one is tricky)	**(16)**

2. Now order the above in terms of increasing energy. **(8)**

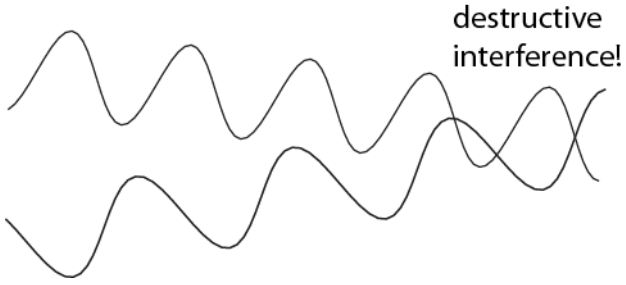
3. Einstein showed that $E^2 = m^2c^4 + p^2c^2$. Can you apply this equation to the energy of a photon: $E = hc/\lambda$ and show that light has a momentum of $p = h/\lambda$? **(5)**

4. When a molecule absorbs light for any reason, does the process of absorption happen instantaneously or does it take some time to do so? **(4)**

5. Here is a calculator question:
a) What is the momentum of a 500 nm photon? What is its energy?
b) If an electron at rest absorbs the photon, what is its velocity? (Hint: conserve energy via $E = ½ mv^2$)
c) What is the momentum of the electron after it absorbs the light?
d) The answer to ***c*** does not match the momentum in ***a***. This is a problem- you can't conserve the energy and momentum of a photon simultaneously if a free particle absorbs light.
Thus, can you thus describe what happens or doesn't happen if I shine light on an electron? **(8)**

6. Light has one unit of angular momentum (ℓ=1). Consequently, there are $2\ell + 1$ "sub" quantum states m_ℓ that range from:
$m_\ell = \{-\ell, (-\ell+1), \ldots, 0, \ldots, +\ell\} = \{-1, 0, 1\}$
For light, $m_\ell = +1$ corresponds to left circularly polarized light, and $m_\ell = -1$ is right circularly polarized light. ***But there is no $m_\ell = 0$ state!*** Now here is the question- why is that the case? Hint: For $m_\ell = 0$, the electric field of light would rotated forward and backward in the direction of propagation. **(4)**

7. We taught you about constructive and destructive interference in high school. We said that if light waves destructively interfere, then the photons cancel each other out, which is why light scattering off a diffraction grating creates a series of bright and dark spots. ***Hold on***- a diffraction grating causes photons to "cancel"? Doesn't that mean "destroyed"? If so, then diffraction gratings should cause the energy of the universe to slowly decay to nothing. I don't think that is right. Can you explain then what is really meant by "destructive interference", and how it is that the "valleys" of light scattering off a diffraction grating are formed when it is not due to photons cancelling each other out? **(5)**



Fun with Wavefunctions! Are Wavefunctions Fun? No. No they are not. (40%)

8. Eigenfunctions of the same Hamiltonian are orthonormal. Consequently, there is no overlap, say, between the 1s and 2s states of hydrogen. Does this mean that the electrons can never be in the same space? If that is not what is meant by "non-overlapping", then what does it mean? **(5)**

9. The fact that a spatial wavefunction is not single-valued has been interpreted to mean that a particle is several places at once. Likewise, the Schrodinger cat problem is presented to mean that the cat is both alive and dead at the same time. ***None of this is probably true.*** Please describe these scenarios correctly. **(5)**

10. Can you have wavefunctions that are functions of something other than space? In other words, can you write a wavefunction that is a function of momentum, i.e. Ψ(p)? **(2)**

11. Here are two hypothetical wavefunctions:

a) $\Psi = N \cdot e^{-a \cdot x^2/2}$ b) $\Psi = N \cdot x \cdot e^{-a \cdot x^2/2}$

What does the "N" thing do? What does N equal to in both cases (note that there is no restriction on the value of x)? **(10)**

12. What is <x> for the two wavefunctions above? **(10)**

13. Given that the first three wavefunctions of the harmonic oscillator are: $\Psi_0 = N_0 \cdot e^{\frac{-m \cdot \omega \cdot \pi \cdot x^2}{h}}$, $\Psi_1 = N_1 \cdot x \cdot e^{\frac{-m \cdot \omega \cdot \pi \cdot x^2}{h}}$, and $\Psi_2 = N_2 \cdot \left(1 - \frac{4 \cdot \pi \cdot m \cdot \omega \cdot x^2}{h}\right) \cdot e^{\frac{-m \cdot \omega \cdot \pi \cdot x^2}{h}}$ can you show that $\Psi_0 \leftarrow \Psi_0$ and $\Psi_0 \leftarrow \Psi_2$ and transitions are forbidden yet $\Psi_0 \leftarrow \Psi_1$ is allowed using the dipole operator $\mu \approx x$, where x is an operator? You should be able to just state that the transition moment has some value, or, its 0. **(10)**

14. If rotation and vibration are not coupled, you can calculate the vibrational and rotational wavefunctions separately. Is it correct to state that the total wavefunction is the sum of the two or do they multiply? For instance, if |x> to represent the vibrational state, |j> to represent the rotational state, is the total wavefunction or $\Psi = |x\rangle + |j\rangle$ or $\Psi = |x\rangle \cdot |j\rangle$? **(8)**

Physical Chemistry History! (10%)

15. How did Lord Kelvin determine that the lowest temperature possible is 0 K?
16. How did Rutherford figure out the structure of the atom?
17. Did Einstein believe that quantum mechanics was correct?
18. Name one physical chemist whom you think ***should*** win the Nobel Prize and state why (1 sentence).
19. Name a physical chemist whom is presently the leader of a large country.

Safety! (10%)

20. a. What is a Chemical Hygiene Plan?
b. Do you know where your lab's chemical hygiene plan is? (yes or no only!)
21. What is an MSDS?

22. On your honor, do you know where the nearest fire extinguisher and safety shower are in your work area are? (yes or no only!)
23. Name one significant danger of tetrahydrofuran.
24. Is the energy of a laser pulse, or its power, the determining factor if it can blind you?
25. What do you think is more dangerous? A. The mineral mercury sulfide (cinnabar), which is in the solid state or B. Dimethyl mercury, which is a liquid comprised of separate molecules. Explain your answer.

This is all you need for the test.

Seriously, it is. Don't make things too hard.

Constants:

Joule (J) = $kg \cdot m^2/s^2$
Speed of light (c) = 3.0×10^{8} m/s
Plank's constant (h) = 6.626×10^{-34} J·s
$\hbar = h/2\pi = 1.055\times10^{-34}$ J·s
electron mass = 9.11×10^{-31} kg
proton mass = 1.67×10^{-27} kg
neutron mass = 1.675×10^{-27} kg
photon mass = 0.00 kg
photon momentum = h/λ
photon energy = $h\nu = h\cdot c/\lambda$
frequency of light (ν) = c/λ
$k_B = 1.38\times10^{-23} J/K$

$$\int_{-\infty}^{\infty} \text{even\_function} \cdot \partial x \neq 0 \qquad \int_{-\infty}^{\infty} \text{odd\_function} \cdot \partial x = 0$$

$$\int_0^c e^{-ax^2}\partial x = \frac{1}{2}\sqrt{\frac{\pi}{a}}\cdot erf(c\sqrt{a}) \qquad \int_0^{\infty} e^{-ax^2}\partial x = \frac{1}{2}\sqrt{\frac{\pi}{a}} \qquad \int_0^{\infty} x\ e^{-ax^2}\partial x = \frac{1}{2a} \qquad \int_{-\infty}^{0} x\cdot e^{-ax^2}\partial x = -\frac{1}{2a}$$

$$\int_0^c x^2 e^{-ax^2}\partial x = \left(\frac{\pi}{16a^3}\right)^{1/2}\cdot erf\left(ca^{1/2}\right) - \frac{c}{2a}e^{-c^2a} \qquad \int_{-\infty}^{\infty} x^3\cdot e^{-ax^2}\partial x = 0$$

$$\int_{-\infty}^{\infty} x^2\cdot e^{-ax^2}\partial x = \frac{1}{2}\sqrt{\frac{\pi}{a^3}} \qquad \int_{-\infty}^{\infty} e^{-ax^2}\partial x = \sqrt{\frac{\pi}{a}} \qquad \int_0^{\infty} x^2\cdot e^{-ax^2}\partial x = \frac{1}{4}\sqrt{\frac{\pi}{a^3}}$$