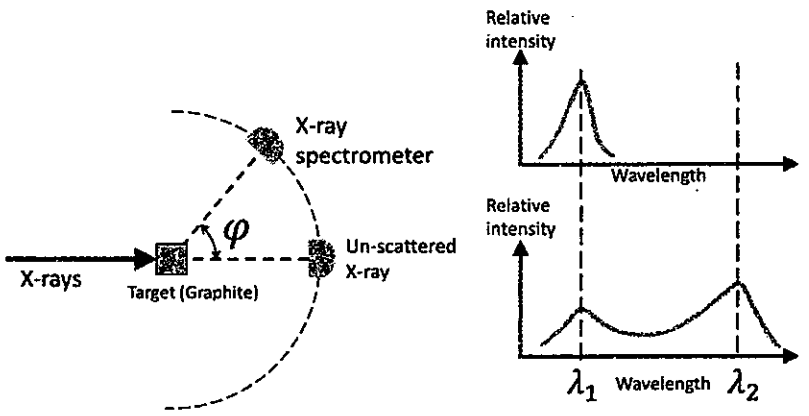
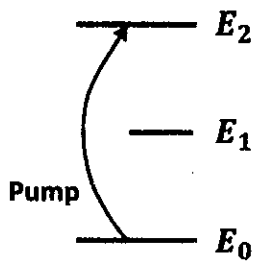
1. A setup is shown here to test the scattered and un-scattered X-ray spectrum at different angles, and we observed a different spectrum of scattered X-ray spectrum at various angles, as shown in the figure below.
(a) (2 pts) What is this phenomenon called?
(b) (3 pts) If the X-ray's wavelength is 4.5 pm, what is the corresponding energy of one X-ray photon?
(c) (5 pts) if $\varphi = 135^{o}$, $\lambda_1 = 4.5\,pm$, what will λ_2 be?



2. (10 pts) An electron has a kinetic energy of 2 MeV. (a) Find its speed according to classical and relativistic mechanics. (electron rest mass: 9.11×10^{-31} kg) (b) what is its corresponding de Broglie wavelength?

3. We are building a three-level laser with the choices of three different materials: A, B, and C. Their energy level separations (in eV) and lifetimes of the levels (in second) are listed in the Table below. (a) (2 pts) Without any pump, will any of these materials become a laser in their natural forms? (b) (8 pts) If we start a pump that can move any atoms in E_0 (ground state) immediately to the E_2 state, we know that there is no chance for atoms in E_2 to fall back to E_0 directly in these three materials. Our target is to build a laser whose emission is red color. Which material will be your choice? Please identify the possible laser transition and state your reason clearly.



	material A		material B		material C	
state	energy	lifetime	energy	lifetime	energy	lifetime
E_0	0	10000	0	10000	0	10000
E_1	1.2	0.001	0.45	0.001	1.95	0.001
E_2	2.4	10^{-8}	2.4	10^{-8}	2.4	10^{-8}

4. (10 pts) If p is a linear momentum operator and x is the position of a particle, find out the expectation value of this expression:

$$\langle px\rangle - \langle xp\rangle$$

5.(10 pts) We artificially formed a hydrogen-like atom with N times of original nucleus' mass. The Balmer's series of emission lines can be seen in Table below. Please use the data to find out the most possible N (N is an integer). The Rydberg number is $1.096 \times 10^{7}\ m^{-1}$.

Lines (in nm)	Hydrogen	New atom
H_α	656.7908	656.4685
H_β	486.5117	486.2730

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6. (8 pts) Which of the following sets of quantum numbers (n, l, m_l, m_s) is not allowed for hydron? Explain the reason for getting the full points. (a) $(2, 2, -1, +\frac{1}{2})$, (b) $(3, 1, +2, -\frac{1}{2})$, (c) $(4, 1, +1, -\frac{3}{2})$, (d) $(2, -1, +1, +\frac{1}{2})$

7. (12 pts) Consider an atom with 6 electrons at the 3*d* level. (a) For the 6 electrons, give the maximum possible total m_l and the total m_s in that configuration. (b) To maximize the total m_s for the 6 electrons, calculate the largest possible total m_l in that configuration.

8. (10 pts) Assume Maxwell-Boltzmann distribution in a system with three nondegenerate energy states: a ground state at E = 0 and excited states at energies of 0.045 eV and 0.135 eV. Find the relative numbers of particles in the three states at a temperature of 650 K. Assume k=8.617×10^{-5} eV/K.

9. The Nobel Prize in Physics 2014 was awarded to the topic of blue light-emitting diodes (LEDs) in the III-N material system. Actually, by mixing GaN (Eg= 3.4 eV) and InN (Eg= 0.7 eV) in different proportions, we can vary the emission wavelength of the LEDs.

(a) (6 pts) Estimate the composition of x for a bulk $In_xGa_{1-x}N$ to produce an LED emitting green light of 550 nm.

(b) (8 pts) To enhance light-emitting efficiency, a multiple-quantum-well structure is usually needed. Please try to estimate the quantum well composition of $In_xGa_{1-x}N$ if the barrier of GaN is used. Compare the answer obtained in (a), assuming we try to maintain the wavelength of 550 nm.

(c) (6 pts) How many electrons are excited across the material in (a) by the absorption of a 662-keV gamma ray?

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