1. (10%) A particular object is observed to move through the laboratory at high speed. Its total energy and the components of its momentum are measured by lab workers to be (in SI units) $E = 4.5\times10^{17}$ J, $p_x = 3.8\times10^8$ kg·m/s, $p_y = 3.0\times10^8$ kg·m/s and $p_z = 3.0\times10^8$ kg·m/s. What is the object's rest mass?

2. (15%) Measurement of the wavelength at which the spectral distribution $R(\lambda)$ from a certain star is maximum indicates that the star's surface temperature is 3000 K. If the star is also found to radiate 100 times the power P_{sun} radiated by the Sun, how big is the star? (The subscript "sun" indicates sun.) The Sun's surface temperature is 5800 K. (Assuming the Sun and the star both radiate as blackbodies, their surface temperatures have been determined from the relation $\lambda_m T$ = constant = 2.898×10^{-3} m·K to be 5800 K and 3000 K, respectively.)

3. (10%) What is the de Broglie wavelength of (a) an electron accelerated from rest by a potential of 54 V, and (b) a 10 g bullet at 400 m/s.

4. (15%) Determine whether each of the following statements is correct or incorrect.

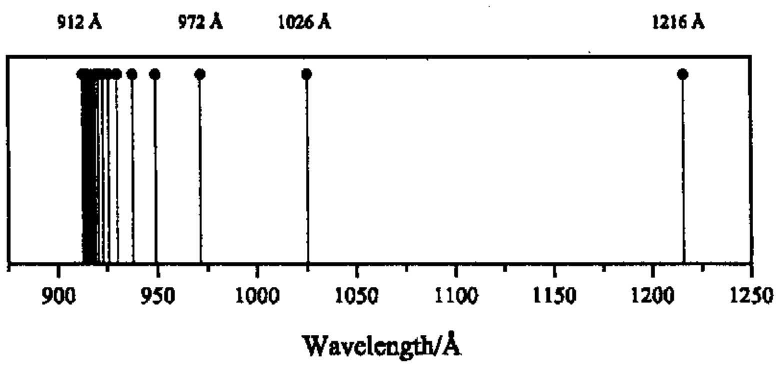
a) (3%) Four quantum numbers are used to specify the state, including spin, of an electron in an atom. According to the Huygen's Principle no two electrons in an atom can have the same four quantum numbers.

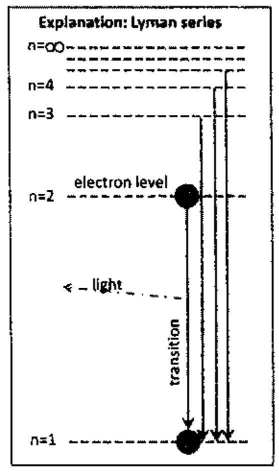
b) (3%) The band theory of solids explains the difference between the electrical conductivities of metals, insulators, and semiconductors.

c) (3%) A heavy nucleus splits into two lighter fragments in the process of fusion and two light nuclei combine to form a heavier nucleus in the process of fission.

d) (3%) Radioactivity involves the emission of α particles, β particles, and γ rays.

e) (3%) In the derivation of Compton's equation, conservation of energy and momentum is applied in the relativistic collision of an electron and a proton.





5. (20%) The above picture shows the energy of light that is emitted during transitions of electrons from an atomic orbit (n) and the lowest atomic orbit (n=1) in a hydrogen atom (called the "Lyman series").
   a) (5%) Based on your knowledge of particles in an infinite potential, explain why the lines are closer together for shorter wavelengths.
   b) (5%) What is the energy of the transition n=2→n=1 based on the figure? Express your answer in eV!
   c) (5%) Imagine the electron in a hydrogen atom to be like a particle in a box. Based on the energy difference between E(n=2) and E(n=1), what is the size of the box so that the electron would have the same transition energy?
   d) (5%) What is the error of the n=3→n=1 transition energy between the calculated particle in a box and the real hydrogen atom transition shown above?

6. (15%) A sodium surface has a work function of 2.28eV.
   a) (5%) What is the minimum wavelength of illuminating light that results in a photoelectric current?
   b) (5%) Imagine that a cluster of 100 sodium atoms ($m=3.6\times10^{-24}$kg) transfers all the energy gained during photoemission into kinetic energy. What would be the speed of the cluster after photoelectron emission?
   c) (5%) Shooting electrons at the sodium surface can also generate photoelectrons. What is the minimum speed of incoming electrons that can result in photoelectron emission?

7. (15%) Raman spectroscopy is a technique, that analyzes the energy loss of photons after interaction with a material. Graphene, for example, has a strong Raman transition at 330×10^{-3}eV .
   a) (5%) If green light ((l=532nm) is losing energy to graphene (a process called "Stokes process)", what is the wavelength of the outgoing light?
   b) (5%) Imagine that graphene is losing energy to the light(called "Anti-stokes process"), which wavelength would the outgoing light have?
   c) (5%) Would the graphene be warmer or colder after the "Anti-stokes process" of question (b)?

Useful constants

Electron mass	m_e=9.11×10^{-31}kg
Electron energy	1eV=1.602×10^{-19}J
Planck constant	$h = 6.626\times10^{-34}$ J·s
Electron charge	1.6×10^{-19} C