First Hour Exam 5.111

Write your name below. **Do not open the exam until the start of the exam is announced.** The exam is closed notes and closed book.

1. Read each part of each problem carefully and thoroughly.
2. Read all parts of each problem. **MANY OF THE LATTER PARTS OF A PROBLEM CAN BE SOLVED WITHOUT HAVING SOLVED EARLIER PARTS.** However, if you need a numerical result that you were not successful in obtaining for the computation of a latter part, make a physically reasonable approximation for that quantity (and indicate it as such) and use it to solve the latter parts.
3. A problem that requests you to “calculate” implies that several calculation steps may be necessary for the problem’s solution. You must show these steps clearly and indicate all values, including physical constants used to obtain your quantitative result. Significant figures must be correct.
4. If you don’t understand what the problem is requesting, raise your hand and a proctor will come to your desk.
5. Physical constants, formulas and a periodic table are given on the last page. You may detach this page **once the exam has started.**

---

Suggested time

1. 12 minutes (22 points) _____________
2. 10 minutes (16 points) _____________
3. 19 minutes (38 points) _____________
4. 9 minutes (24 points) _____________

Total (100 points) _____________

Name _________________________________
1. (22 points) **The photoelectric effect**

A beam of light with an intensity of 15 W is incident on a copper plate ($\phi = 7.43 \times 10^{-19}$ J). Electrons with a minimum wavelength of $3.75 \times 10^{-10}$ m are ejected from the surface of the copper.

(a) (12 points) Calculate the frequency of the incident light.
A beam of light with an intensity of 15 W is incident on a copper plate (\( \phi = 7.43 \times 10^{-19} \) J). Electrons with a minimum wavelength of 3.75 \( \times 10^{-10} \) m are ejected from the surface of the copper.

(b) (6 points) Calculate the maximum number of electrons that can be ejected by a 3.0-second pulse of the incident light.

(c) (4 points) If a new light source (\( E_i = 7.19 \times 10^{-19} \) J) with an intensity of 35 W is incident on the copper surface, what is the maximum number of electrons that can be ejected from a 6.0 second pulse of light?
2. (16 points) **One-electron atoms:**

Consider a Ca\(^{19+}\) ion with its electron in the 5\(^{th}\) excited state.

(a) (12 points) Calculate the longest wavelength of light that could be emitted when the Ca\(^{19+}\) electron transitions to a lower energy state. Report your answer with three significant figures.

(b) (4 points) Suppose the same transition as in part (a) took place in a hydrogen atom. Would the wavelength of emission be longer than, shorter than, or the same as your answer to part (a). Very briefly explain why. *(Note: This question does NOT require a calculation. Also, you do not need to use the answer to part (a) to answer this question.)*
3. (32 points) **Multi-electron atoms**

(a) (16 points) An x-ray photoelectron spectroscopy experiment with an unidentified element, $X$, displays an emission spectrum with four distinct kinetic energies: $5.9 \times 10^{-17} \text{ J}$, $2.53 \times 10^{-18} \text{ J}$, $2.59 \times 10^{-20} \text{ J}$, and $2.67 \times 10^{-20} \text{ J}$. (Assume the incident light has sufficient energy to eject any electron in the atom.)

(i) (4 points) Name all of the possible ground state atoms that could yield this spectrum.

(ii) (8 points) Calculate the binding energy of an electron in the 2p orbital of element $X$ if the x-rays used for the spectroscopy experiment had an energy of $2.68 \times 10^{-16} \text{ J}$.

(iii) (4 points) Consider both the filled and unfilled orbitals of element $X$. Determine the number of:

- total nodes in a 4d orbital:

- angular nodes in the 2p$_y$ orbital:

- degenerate 5p orbitals:
(b) (22 points) The first, second, and third ionization energies of phosphorus are 1011 kJ/mol, 1903 kJ/mol, and 2912 kJ/mol respectively.

(i) (8 points) Calculate the effective nuclear charge ($Z_{\text{eff}}$) experienced by a 3p electron in phosphorus.

(ii) (4 points) Would it be expected that the minimum energy necessary to eject a 3s electron from phosphorus in a photoelectron spectroscopy experiment be larger, smaller, or the same as the 4th ionization energy (IE$_4$) of phosphorus? Briefly explain your answer.
(iii) (4 points) Which experience less shielding, 3s-electrons or 3p-electrons in phosphorus? Very briefly explain why.

(iv) (4 points) On the plot below, graph the radial probability distribution for a phosphorus 3p orbital with a solid line. Label the $r_{mp}$, and point to each node with an arrow. Label the axes, but do not include numbers or units.

(v) (2 points) Is the $r_{mp}$ for a hydrogen 3p orbital longer or shorter than the $r_{mp}$ for a 3p phosphorus orbital? Very briefly explain why.
4. (24 points) **Periodic trends and miscellaneous short answer**

(a) (5 points) Consider the **second** ionization energies (IE$_2$) for the following 3$^{\text{rd}}$ row elements: Si, S, Mg, Al.

(i) Which has the highest IE$_2$?

(ii) Which has the third highest IE$_2$?

(b) (5 points) Order the following atoms and ions in order of **increasing** atomic radius: Cl, Te, Te$^{2-}$, S. Note: use the $<$ symbol for clarity.

(c) (6 points) Give the electron configuration expected for the following atoms or ions. *You may use the noble gas configuration as a means to abbreviate the full configuration."

(i) Pb ($Z = 82$)

(ii) Mo ($Z = 42$)

(iii) Zr$^+$ ($Z = 40$)
(d) (4 points) In one sentence (or less!), briefly explain the physical interpretation of $\Psi^2$ for a hydrogen atom.

(e) (4 points) How many electrons in a single atom can have the following two quantum numbers: $n = 7$, $m_r = -3$?
c = 2.9979 \times 10^8 \text{ m/s}

h = 6.6261 \times 10^{-34} \text{ J s}

N_A = 6.022 \times 10^{23} \text{ mol}^{-1}

m_e = 9.1094 \times 10^{-31} \text{ kg}

a_0 = 5.292 \times 10^{-11} \text{ m}

1 \text{ amu} = 1.66 \times 10^{-27} \text{ kg}

\lambda = \frac{h}{p}

R_H = 2.1799 \times 10^{-18} \text{ J}

\Re = \frac{R_H}{h} = 3.2898 \times 10^{15} \text{ Hz}

E = \frac{p^2}{2m}

E_n = -\frac{Z^2 R_H}{n^2}

E_{nl} = -\frac{Z_{\text{eff}}^2 R_H}{n^2}

1 \text{ W} = 1 \text{ J s}^{-1}

1 \text{ J} = 1 \text{ kg m}^2 \text{ s}^{-2}

1 \text{ eV} = 1.6022 \times 10^{-19} \text{ J}

for s wavefunction:

\text{RPD} = 4\pi r^2 \Psi^2 \text{dr}

for n_f < n_i……

v = \frac{Z^2 R_H}{h} \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right)

for n_f > n_i……

v = \frac{Z^2 R_H}{h} \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right)