Unit I Exam

On the following pages are six problems that explore how an atom's properties depend upon its electronic structure, and the experimental data that informs our model of an atom's electronic structure. Read each problem carefully and consider how you will approach it before you put pen or pencil to paper. If you are unsure how to answer a problem, then move on to another; working on a new problem may suggest an approach to the one that is more troublesome. If a problem requires a written response, be sure that you answer in complete sentences and that you directly and clearly address the question. No brain dumps allowed! Generous partial credit is available, but only if you include sufficient work for evaluation and that work is relevant to the question.

Problem	Points	Maximum	Problem	Points	Maximum
1		17	4		15
2		8	5		16
3		16	6		28
			Total		100

Constants, equations, and Slater's rules are on a supplemental handout. A periodic table also is available.

Problem 1. For each of the following prompts, provide a **single** example of an element that fulfills the stated condition. If no element meets the condition, then write `NONE`. Limit your elements to those in the first four rows of the periodic table (H through Kr). **Do not use any element more than once!**

- has no unpaired electrons
- whose core electron configuration is expressed as [Ne]
- has exactly six electrons in a *d*-orbital
- is deflected by a magnetic field
- has exactly two unpaired valence-shell electrons
- is in the same period as bromine
- has three peaks in its photoelectron spectrum
- has a valence shell that contains only *p* electrons
- is in the same group as Mg but with a larger radius
- forms an ion with a charge of +2 that has the same electron configuration as a noble gas
- has exactly three core electrons
- has an electron with $n = 4$ and $l = 1$
- has the largest first ionization energy
- has a Z of 15

Problem 2. Consider the following five sets of quantum numbers for electrons a–e. For each prompt below the table, identify the appropriate electron(s) by their letters and explain your reasoning in one sentence. You will use each electron just once.

electron	n	l	m_l	m_s
a	2	0	0	$+1/2$
b	3	2	0	$+1/2$
c	2	1	-1	$+1/2$
d	3	2	$+1$	$-1/2$
e	3	3	$+2$	$+1/2$

Assuming that all five electrons are from the same atom and, therefore, have the same Z, which ...

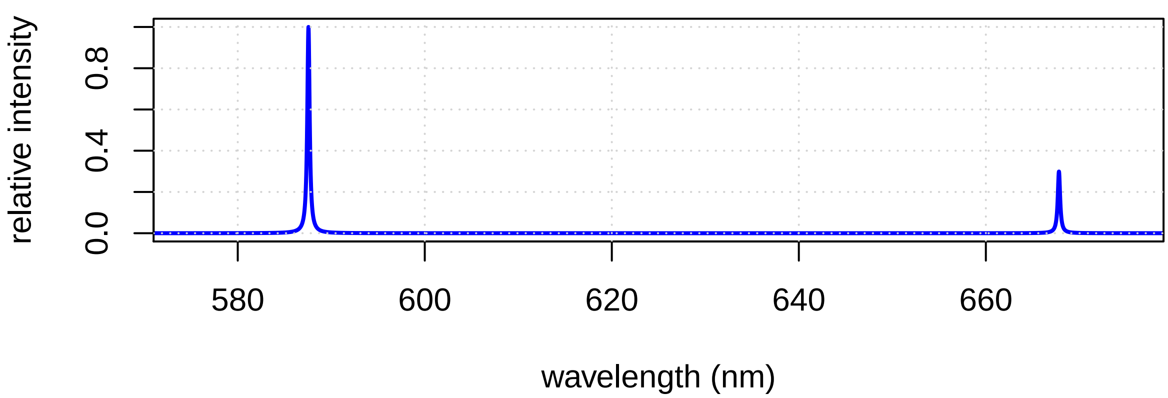
...electron has an impossible set of quantum numbers?

...electron has the greatest ionization energy?

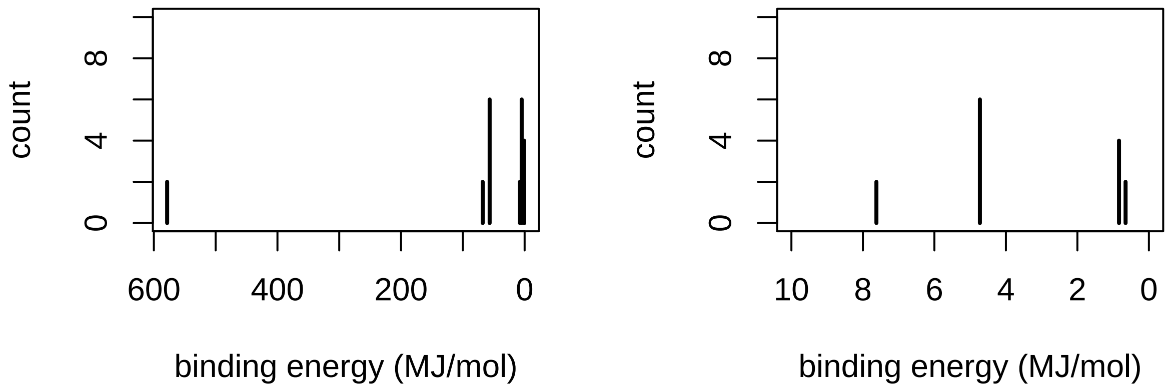
...electron is in a p orbital?

...two electrons have identical energies

Problem 3. Shown below is part of the atomic emission spectrum for helium, showing emission intensity as a function of wavelength. There are two peaks in this region of the spectrum, one at a wavelength of 588 nm and one at 668 nm. Select the peak whose photons have the smallest energy and report that energy in Joules. In one sentence, explain why you selected this peak.



Problem 4. The figures below show two views for the photoelectron spectrum of the element X. The view on the left shows the full spectrum and the view on the right shows only those peaks with binding energies less than 10 MJ/mol.



Identify the element X and explain your reasoning in 2–3 sentence.

Selecting the appropriate spectrum, draw a circle around the peak(s) in the spectrum that corresponds to X's valence electron(s). In one sentence, explain the reason for your choice.

What are the quantum numbers n and l for the peak with a binding energy of approximately 8 MJ/mol? In one sentence, explain the reason for your choice.

Problem 5. The first ionization energies, IE_1, for fluorine and chlorine are 1650 kJ/mol and 1250 kJ/mol, respectively. Using Slater's rules, calculate Z_{eff} for a valence electron in each element. Are your results for Z_{eff} consistent with the relative first ionization energies of the two elements? Defend your conclusion in 2–3 sentences. If your results for Z_{eff} are not consistent with their relative ionization energies, then offer a reason that can account for their relative ionization energies.

Problem 6. The table below lists several properties of the elements in the third row of the periodic table. IE stands for ionization energy and the subscript indicates the source of ionization: removal of first electron, removal of a second electron, removal of a third electron, and removal of a single $3s$ electron. AVEE is the average valence electron energy. **Choose 4 of the 5 prompts below the table** and provide a thoughtful answer in 2–4 sentences each. Be sure you clearly indicate which four prompts you wish for me to evaluate.

property	Na	Mg	Al	Si	P	S	Cl	Ar
IE_1 (kJ/mol)	496	738	578	787	1012	1000	1251	1521
IE_2 (kJ/mol)	4562	1451	1817	1577	1907	2252	2298	2666
IE_3 (kJ/mol)	6910	7733	2745	3233	2914	3357	3822	3931
IE_{3s} (kJ/mol)	496	738	1090	1460	1950	2050	2440	2820
AVEE (kJ/mol)	496	738	920	1125	1416	1350	1590	1845
radius (pm)	190	145	118	111	98	88	79	71

Explain the trend in the values for IE_{3s} as you move from Na $\longrightarrow$ Ar.

Explain why the values for IE_1 and IE_{3s} are the same for sodium, but different for aluminum.

Explain why the values for IE_1 increase by approximately 200 kJ/mol per element for the elements Na $\longrightarrow$ P and for the elements S $\longrightarrow$ Ar, but are essentially identical for the elements P and S.

Explain why the radius increases in steps of approximately 10 pm for the elements Ar $\longrightarrow$ Al but increases by much larger steps for the elements Al $\longrightarrow$ Na.

Explain why IE_2 for Na is approximately $10\times$ greater than its IE_1, but IE_2 is just $2 - 3\times$ greater than IE_1 for other elements in this period.