Completing the Shell Model of the Atom - Key

The table shown below gives ionization energies for the elements Na through Ar. Note that the electrons are identified using the *ns* and *np* notation.

	Ionization Energies in MJ/mol				
Element	1s	2s	2p	3s	3p
Na	104	6.84	3.67	0.50	
Mg	126	9.07	5.31	0.74	
Al	151	12.1	7.79	1.09	0.58
Si	178	15.1	10.3	1.46	0.79
P	208	18.7	13.5	1.95	1.01
S	239	22.7	16.5	2.05	1.00
Cl	273	26.8	20.2	2.44	1.25
Ar	309	31.5	24.1	2.82	1.52

Questions to Ponder.

The PES spectrum for potassium, K, has six peaks with the following energies and relative abundances of electrons.

	1s	2s	2p	3s	3p	???
Ionization Energy (MJ/mol)	347	37.1	29.1	3.93	2.38	0.42
Relative Abundance	2	2	6	2	6	1

The first five peaks are assigned to the 1s, 2s, 2p, 3s, and 3p subshells. Are the ionization energies for these five subshells consistent with the data for the elements in the first table? Briefly explain.

Yes. Each ionization energy is slightly larger than the corresponding values for Ar, consistent with the greater charge for potassium's nucleus.

The sixth peak in the PES spectrum of K has an ionization energy of 0.42 MJ/mol. Is this electron in a new subshell of the n = 3 shell (which we will call the 3d subshell) or is it in the first subshell of the n = 4 shell (that is, a 4s subshell)? To help you answer this equation, look for patterns in the data for Ar as you move between subshells in a given shell (e.g. 2s $\rightarrow$ 2p or 3s $\rightarrow$ 3p) and as you move between shells (e.g. 1s $\rightarrow$ 2s, or 2s $\rightarrow$ 3s). Although you may know the answer to this from earlier chemistry courses, justify your answer using an argument based on ionization energies.

The trends in IEs suggest that electrons in the same shell have similar IEs, but that each new shell produces a significant change in IE. For example, the 2s and 2p electrons in K have IEs of 37.1 and 29.1, while the IEs for the 2s and 3s electrons are 37.1 and 3.93. An IE of 0.42 is inconsistent with a 3s or 3p electron and must come form a new shell; thus, we predict that it is a 4s electron.

The PES spectrum for scandium, Sc, has seven peaks with the following energies and relative abundances of electrons.

	1s	2s	2p	3s	3p	???	4s
Ionization Energy (MJ/mol)	433	48.5	39.2	5.44	3.24	0.77	0.63
Relative Abundance	2	2	6	2	6	1	2

For K we found that the electron configuration is $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$. The second-to-last peak in the PES spectrum for Sc is either a 3d or a 4p subshell. Which is it? Although you may know the answer to this from earlier chemistry courses, justify your answer using an argument based on ionization energies.

This is a bit trickier because the IE is closer to a 4s electron than it is to a 3s or 3p electron. However, the IE for a 4s electron should be less than that for a 4p electron given that this is the trend we see in other shells. The peak, therefore, must be a 3d electron. This suggests that the presence of the 4s electrons affects the ionization energy of the 3d subshell, an observation to which we will soon return.

Many of the elements known as transition metals form stable cations with a charge of +2. For example, in the first row of the transition metals we find Ti^{2+}, V^{2+}, Cr^{2+}, Mn^{2+}, Fe^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+}, and Zn^{2+}. Explain why so many of these transition metals favor the formation of a +2 cation.

The fact that 3d electrons appear to have a lower ionization energy than the 4s electrons means that the most easily removed electrons for these transition metals are the two 4s electrons. Thus, it isn't surprising that transition metals easily form a +2 ion as these two electrons have the smallest ionization energy.