Physics 220 Laboratory 11 Spring 2009
SCANNING ELECTRON MICROSCOPE (SEM) and X-ray analysis of elements

Background

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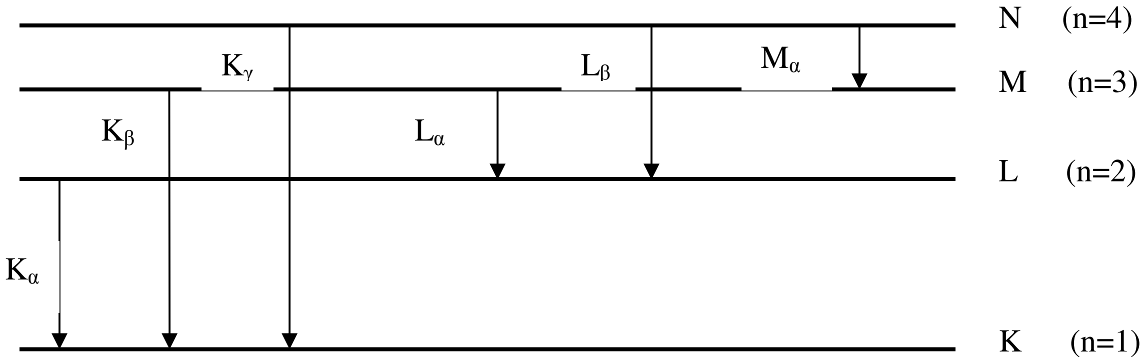
X–Rays from the Elements



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Suppose an electron is knocked out of the K shell. (A filled K shell has 2 electrons.) One of the electrons from the L shell (a filled L shell has 8 electrons) can drop down into the K shell and in doing so, emits a K_α x-ray. Of course, an electron from the M shell (a filled M shell has 18 electrons) could drop into the K shell emitting a K_β x-ray.

How can we find the energy of the x-ray photons emitted during these transitions? We can use the Bohr model to find the energies of the two states involved, and subtract, i.e.

$$E_\gamma = -(E_f - E_i) = -\left(-\frac{ke^2}{2a_o}\frac{Z^2}{n_f^2} - \left(-\frac{ke^2}{2a_o}\frac{Z^2}{n_i^2} \right) \right) = \frac{ke^2 Z^2}{2a_o}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right) = 13.6Z^2\left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right),$$

where k is the constant in Coulomb's Law, e is the charge on an electron, a_o is the Bohr radius, and n is an integer. However, since these are not hydrogen atoms, there are many electrons swarming around the nucleus. The inner electrons will shield the outer electrons from feeling the total charge

(Z) of the nucleus. Thus, there is an effective charge $Z_{eff} \leq Z$ that should be used in the above equation, i.e.

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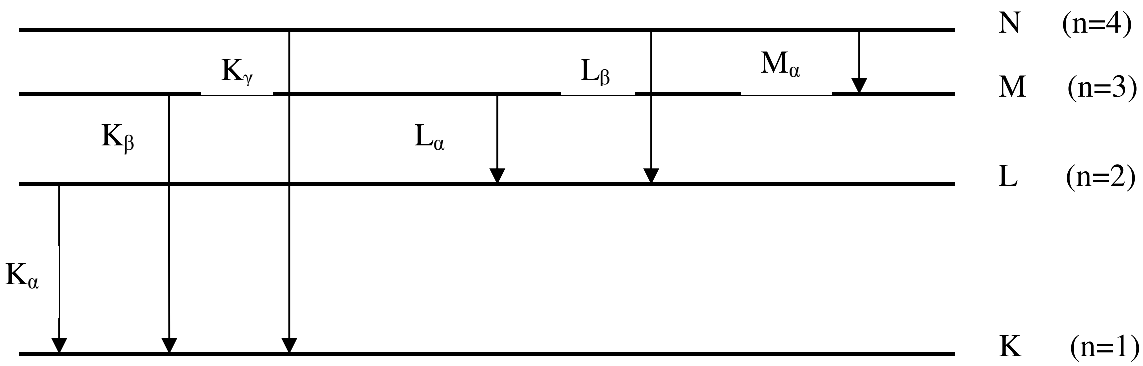

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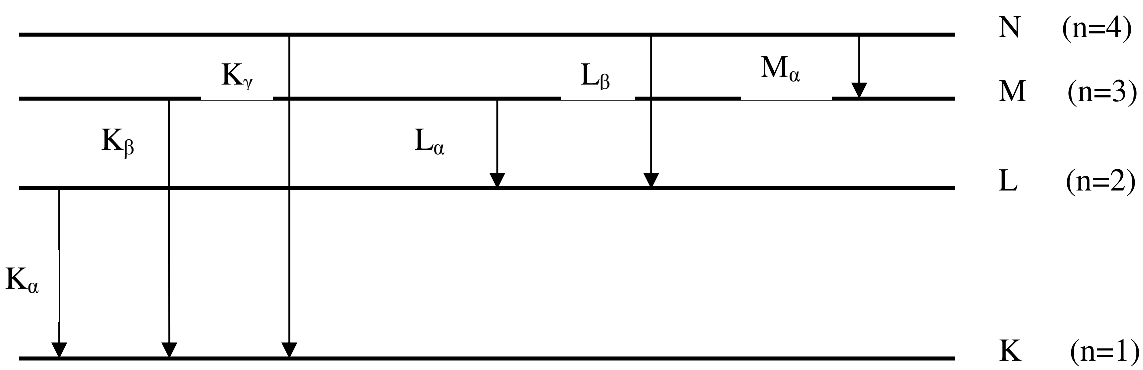

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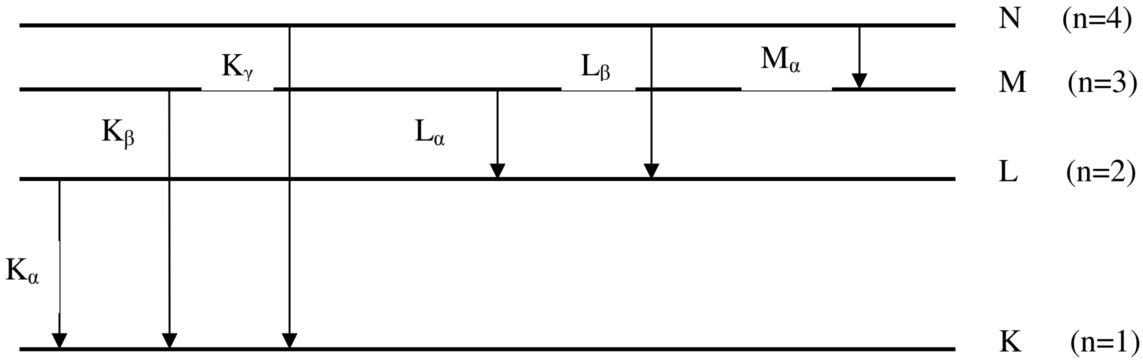

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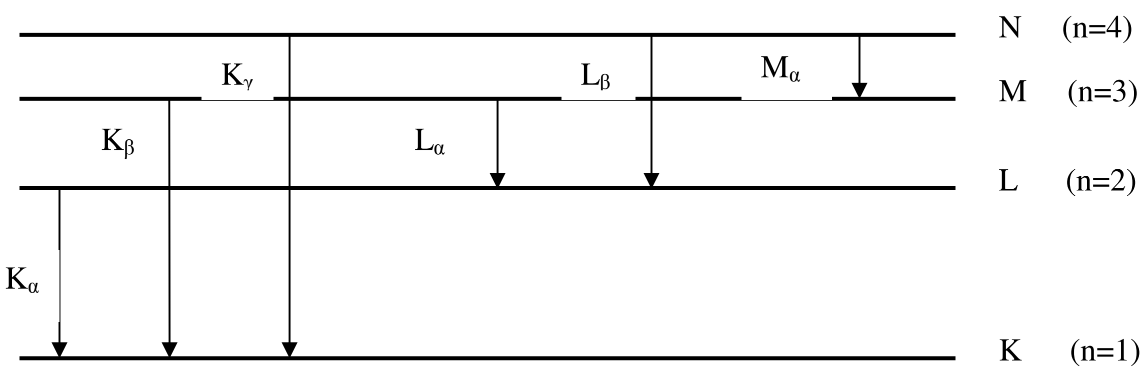

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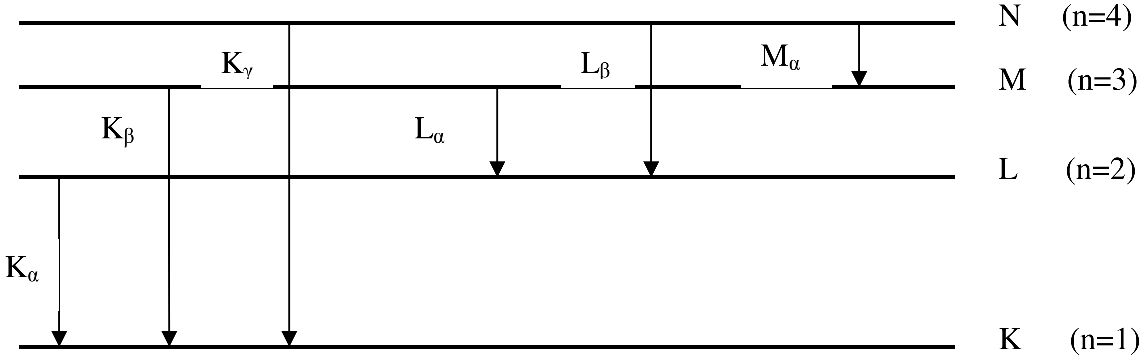

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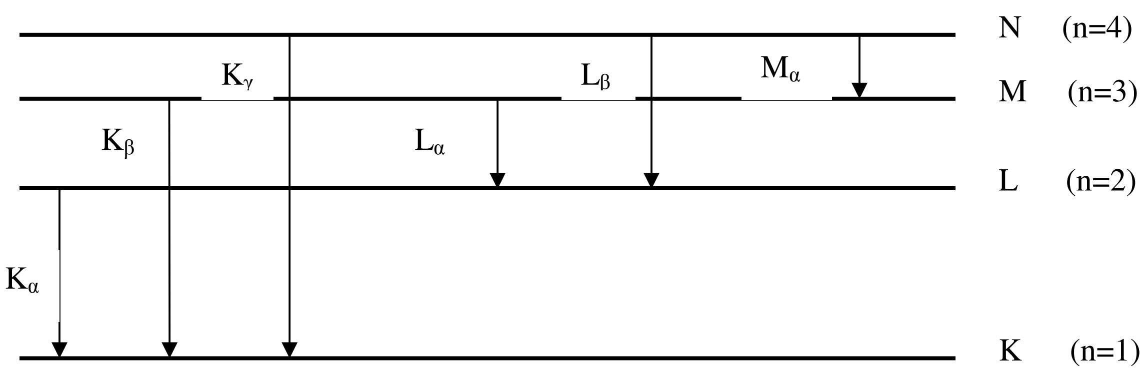

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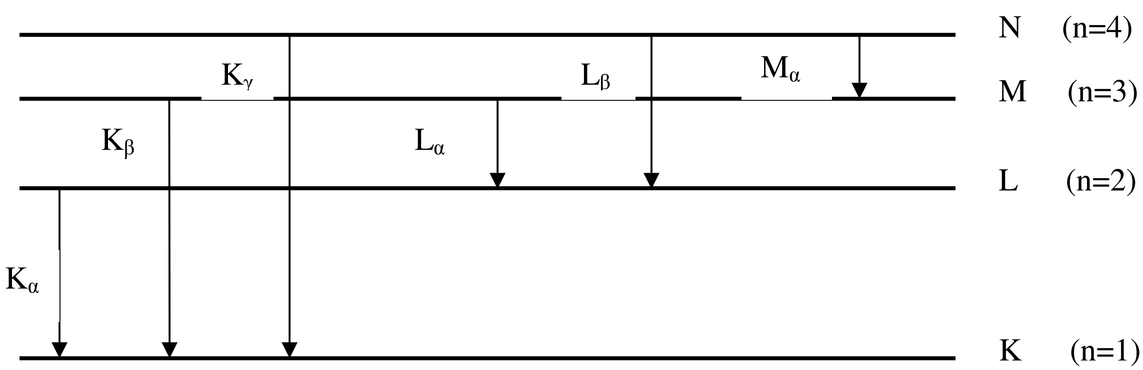

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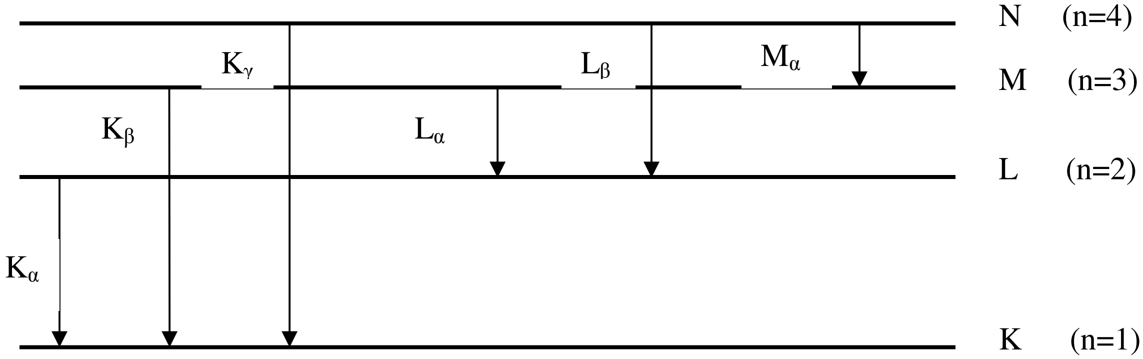

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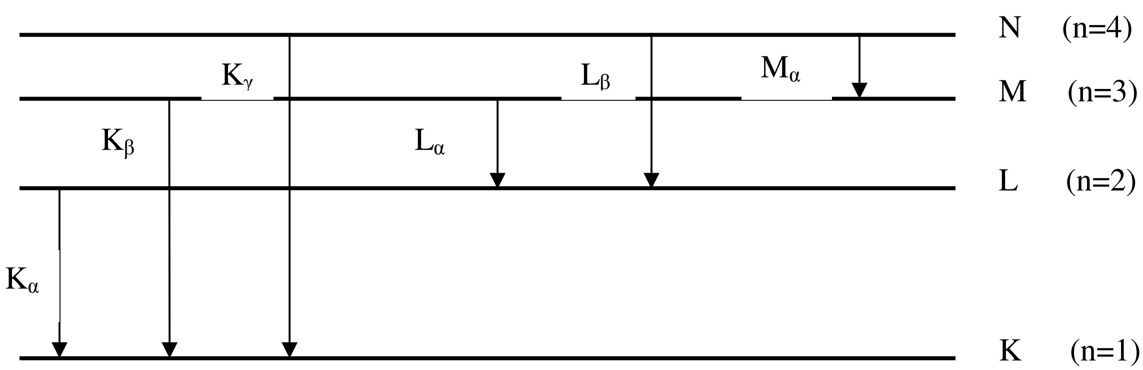

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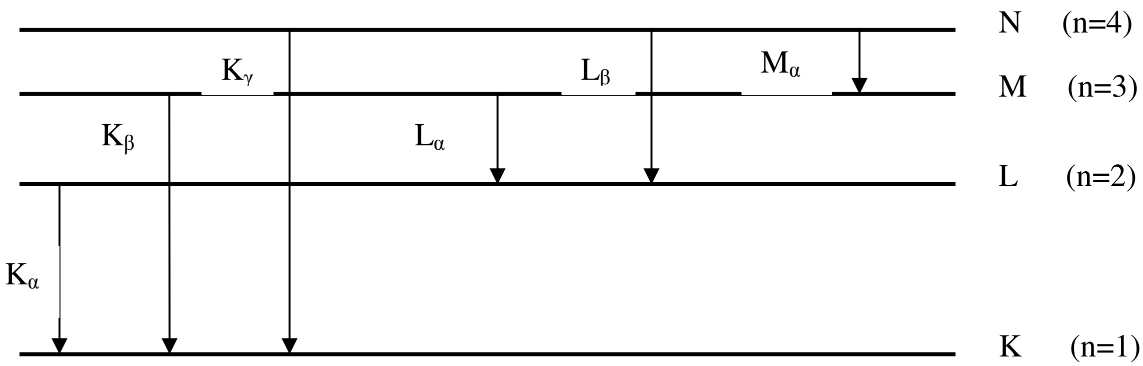

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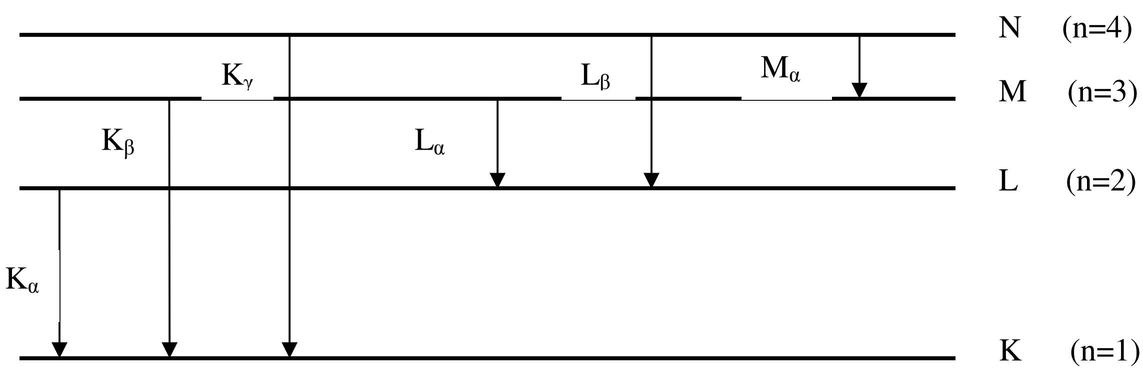

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Suppose an electron is knocked out of the K shell. (A filled K shell has 2 electrons.) One of the electrons from the L shell (a filled L shell has 8 electrons) can drop down into the K shell and in doing so, emits a K_α x-ray. Of course, an electron from the M shell (a filled M shell has 18 electrons) could drop into the K shell emitting a K_β x-ray.

How can we find the energy of the x-ray photons emitted during these transitions? We can use the Bohr model to find the energies of the two states involved, and subtract, i.e.

$$E_\gamma = -(E_f - E_i) = -\left(-\frac{ke^2}{2a_o}\frac{Z^2}{n_f^2} - \left(-\frac{ke^2}{2a_o}\frac{Z^2}{n_i^2} \right) \right) = \frac{ke^2 Z^2}{2a_o}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right) = 13.6Z^2\left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right),$$

where k is the constant in Coulomb's Law, e is the charge on an electron, a_o is the Bohr radius, and n is an integer. However, since these are not hydrogen atoms, there are many electrons swarming around the nucleus. The inner electrons will shield the outer electrons from feeling the total charge

(Z) of the nucleus. Thus, there is an effective charge $Z_{eff} \leq Z$ that should be used in the above equation, i.e.

$$E_\gamma = 13.6 Z_{eff}^2 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right).$$

In general, Z_{eff} is not simple to determine, although we can make some reasonable estimates. For example, we can predict the energy of the K_α x-ray relatively well using the following assumption. The electron making the K_α transition is shielded from the nucleus by the only remaining electron in the K (n=1) shell. Consequently, taking $Z_{eff} = Z-1$, the above equation becomes:

$$E_{K_\alpha} = 13.6 (Z-1)^2 \left(\frac{3}{4} \right)$$

where the 3/4 comes from taking $n_f = 1$ and $n_i = 2$. Similar analyses can be done for the other x-rays (K_β, L_α, etc.)

Lab Questions

1. Typically, electrons in the electron microscope are accelerated through a potential of 20 kV.
    a) What is the kinetic energy (in keV) of such an accelerated electron?
    b) What is its momentum in keV/c? (Are non-relativistic calculations OK here?)
    c) What is its wavelength?
    d) What is the approximate size of the smallest object resolvable by these electrons?

2. a) For a silicon atom, calculate the expected energies of the K_α, K_β, and L_α x-rays. Assume that Z_{eff}=Z-1 in each case.
b) Repeat a) for a tin atom.

3. For our SEM, the electrons in the beam typically have an energy of 20 keV. What range of x-ray energies can be produced by these electrons? How does this limit the use of our SEM for identifying atoms (or does it)?

4. Consider two elements close to each other in atomic number Z. Are the K_α x-rays from these two elements farther apart in energy if the elements are light (low Z), or heavy (high Z), or doesn't it matter? Explain your reasoning.

PROCEDURE

With the help of your instructor, set up the SEM for use. Examine several objects at different magnifications. At least one object should consist of several elements. Take x-ray spectra of these objects. In each spectrum, identify all the prominent lines and record their energy and intensity values.

For each sample, what are the elements have you identified? Which of these are you most confident are there? Which of these are you least confident are there, and why?

Choose three different elements you observed. For each of the x-ray lines produced by each element, use the measured x-ray energy to calculate Z_{eff} and compare to Z-1 (a table would be a nice way to organize these results). Comment on the agreement and on any trends you see.