22.01 Problem Set 6 - Charged Particles

Complete all the assigned problems, and do make sure to show your intermediate work.

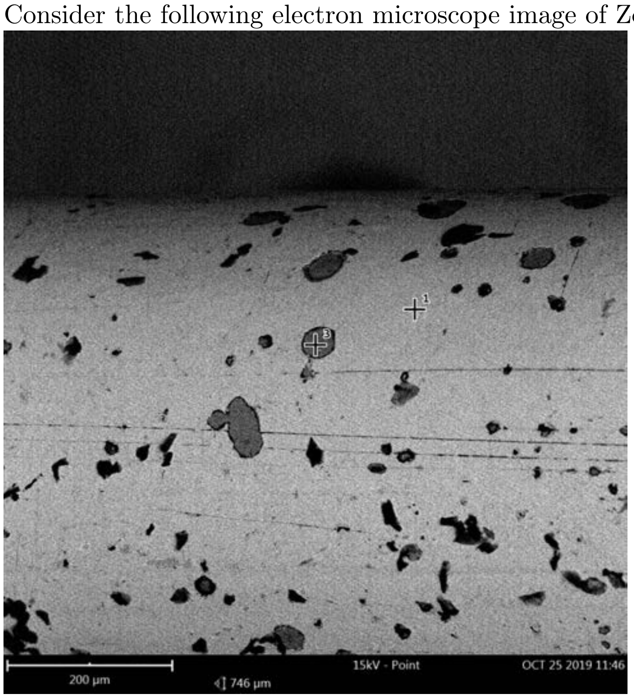
1 (65 points) Skill Building Problems

1.1 Short Answers (5 points each)

Learning Objective: These problems will get you to express details of the physics of charged particle interactions in your own words, and apply this intuitive knowledge to analyze a real SEM micrograph.

1. Explain, using stopping power expressions and cross sections, why the energy loss due to ionization drops off so sharply with increasing energy, while radiation loss increases linearly.

2. Consider the following electron microscope image of Zoe's earring from the streets of Milan:



Where is the gold in this image, and how do you know, based on your knowledge of electron interaction mechanisms with matter? Back up your answer with a relevant quantitative estimate of electron interactions.

3. Using an image processing program (such as GIMP, ImageJ, or others), measure the relative brightnesses of various types of spots in the images. Hint: In GIMP, use the ***Colors→Info→Histogram menu*** to get brightness histograms of selected regions. Can you guess the average atomic number of each of the spots? In other words, is brightness linearly proportional to the type of electron interaction(s) that you are interested in?

4. Explain, using photon attenuation and proton stopping power, why protons are far more effective at damaging a localized tumor. Draw any applicable range relations and/or attenuation graphs to make your point.

1.2 Numerical Problems (5 points each)

Learning Objective: These problems will drill your ability to calculate stopping powers analytically, allowing you to check your work with a NIST-standard database. They also ask you to explain a few intuitive quantities in your own words.

1. Calculate and graph (hopefully using a spreadsheet) the electronic stopping power of protons in lead vs. their energy, over a range between 10 keV and 1,000 MeV in half orders of magnitude (10 keV, 33 keV, 100 keV, 333 keV ...). You can check your work using the ***PSTAR Stopping Power and Range Tables for Protons.*** Ignore any relativistic effects.

2. Calculate and graph the ratio of bremsstrahlung stopping power to the electronic stopping power for the cases above, as a function of energy. At what energy would radiative (bremsstrahlung) stopping become the dominant mechanism of energy loss for protons in lead? Ignore any relativistic effects.

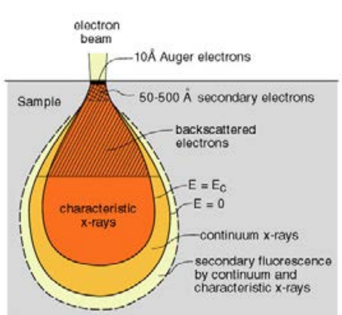
3. Calculate and graph the ratio of nuclear stopping power vs. electronic stopping power for the cases above, as a function of energy. At what energy would nuclear stopping become the dominant mechanism of energy loss for protons in lead? Ignore any relativistic effects.

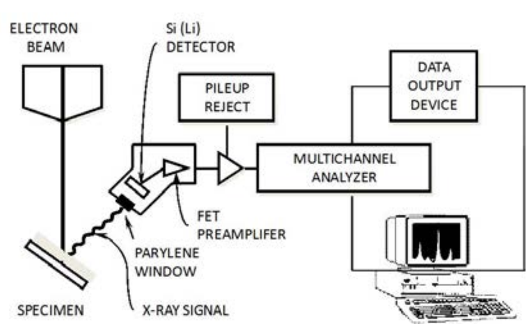
4. **(15 points)** Using your answers above, develop (by hand, or using a spreadsheet) a graph of the range of protons in lead, by combining your three stopping powers into a *total stopping power*, fitting a simple function to it, and using the relationship between stopping power and range. Check your answers by using the PSTAR Stopping Power and Range Tables for Protons. What, if any, discrepancies do you see?

2 (50 points) Noodle-Scratchers

Learning Objective: Using all your accumulated knowledge of charged particle stopping and photon interactions in detectors, re-create the true *x-ray spectrum emitted from a material in an electron microscope, which is not what shows up on the screen during analysis.*

For this question, consider the scanning electron microscope (SEM) which we demonstrated in lab last Friday. Here is a diagram showing how it works, to help you solve this problem:





Here, consider an SEM analyzing a specimen of stainless steel with the following parameters:

$E_{e^- \text{ beam}}$	**Material (at. %)**	**EDX Window**	**EDX Detector/Sample Angle**	**Detector Material**
30 keV	72Fe-18Cr-10Ni	7 μm Be	30 degrees	Si

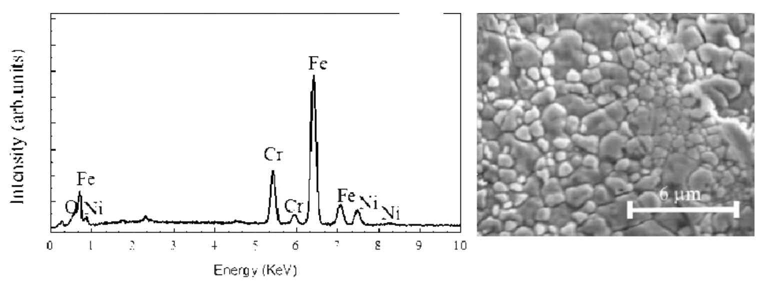
You may make the following assumptions:

- All characteristic x-rays are created at the end of the range of the electrons
- There is no straggling (variation in range) of the electron beam
- The electron beam is so narrow, that it can be considered as a point beam (infinitely thin)

1. **(15 points) Develop and graph a theoretically predicted photon emission spectrum when operating this SEM, in other words, what you expect to see shown on the screen. Here, consider the x-ray spectrum produced at the *characteristic x-ray* interaction region.**

2. **(15 points) Using the *observed* spectrum below, work backwards to determine what the *real* spectrum would have been (not what is shown on the screen, but what is actually emitted from the sample). Compare your answer to part (1) above, specifically calculating your *calculated* elemental distribution compared to the real one. Hint: Use the Web Plot Digitizer to "steal" the data from the spectrum in this image.**

3. **(5 points) What element is the little, unidentified peak in the EDX spectrum between 2-3 keV?**



Source: N. Abdelkatar et al. "Study of Cavitation Erosion Experiments on Thermally Oxidized Rutile Phase TiO_2 Films on Stainless Steel." J. Eng. Mater. Technol., 5(1):1-6, 2017