22.01 Fall 2015, Problem Set 6 (Normal Version)

Due: November 2, 11:59PM on Stellar

August 26, 2015

Complete all the assigned problems, and do make sure to show your intermediate work. Please upload your full problem set in PDF form on the Stellar site. Make sure to upload your work at least 15 minutes early, to account for computer/network issues.

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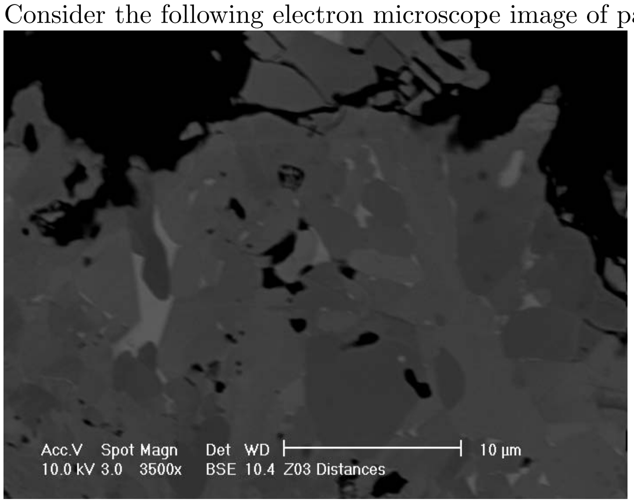
1 Conceptual Questions

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. Explain the quantitative differences in stopping power of electrons as they reach relativistic speeds. What energy cutoff do you consider relativistic, and why?
3. Consider the following electron microscope image of palladium diffusion into zirconium carbide:



   Where is the palladium 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. Using an image processing program, measure the relative brightnesses of various types of spots in the images. 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?

2 Applied Questions

In these questions, consider the differences between x-ray and proton cancer therapy

1. Explain, using attentuation and 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.

2. One way of ensuring a uniform dose to a tumor of finite size (not small) is called intensity modulated radiation therapy (IMRT), where the proton beam is modulated in energy and/or angle to shift the Bragg peak to different specific locations. The goal is to maximize dose to the whole tumor, while minimizing the dose to surrounding tissue. For the following questions, assume we are trying to treat a tumor 1cm in diameter, surrounded by 5cm of healthy tissue.

   (a) Derive a relationship between the required energy and the atomic mass of a singly charged ion required to reach the center of the tumor. This will tell you how big of an accelerator one needs to use each type of ion.

   (b) Now derive a relationship between the amount of ionization of each of these ions at their starting energy and within the Bragg peak. This gives ratio of the amount of damage to the tumor compared to the surrounding tissue directly from the ions themselves.

   (c) Consider the cases of electrons, protons, carbon ions, and iron ions. Which type of ion is most suitable for use in IMRT, and why? Hint: Consider other mechanisms of ion energy loss in tissue, and compare how intense they would be in a relative sense.

   (d) Develop an expression or graph for the amount of time the beam needs to spend at each depth of the tumor to apply the same dose at every location. Assume a one-dimensional tumor.