

## ChE 891/2

### Experimental Methods in Nanotechnology

Homework 4  
Due 4 February 2008

1. Determine the average scattering angle for Rutherford scattering ( $\theta_R$ ) and isotropic scattering ( $\theta_I$ ) using the equations given in Browning *et al.* (J. App Phys 76 (1994) 2016)

$$\cos(\theta_R) = 1 - 2\alpha R/[1+\alpha-R] \qquad \cos(\theta_I) = 1 - 2R$$

where  $\alpha$  is the screening parameter and R is a random number between 0 and 1. Use a spreadsheet or similar and generate 50 – 100 angles and take their average and standard deviation. Use the equation given in their manuscript to determine  $\alpha = 7 \times 10^{-3} / E(\text{keV})$  with different energy levels from 0.1 keV to 100 keV and plot the average angle as a function of energy, do your results make sense? In class we derived this relation

$$\langle \cos(\theta_R) \rangle = 1 + 2\alpha + 2\alpha \times [1+\alpha] \log(\alpha/[1+\alpha])$$

Plot this equation with the above results, are they the same? Should they be?

**Extra credit:** Do a series expansion on the above equation in the limit of  $\alpha \rightarrow 0$  and give a useful result. When is this expansion valid?

2. The differential scattering cross section for Rutherford scattering is given as

$$d\sigma/d\Omega = \lambda_R^4 Z^2 / [64\pi^4 a_0^2 \sin(\theta/2)^4]$$

where  $\lambda_R$  is the relativity corrected electron beam wavelength, Z, the atomic number and  $a_0$  the Bohr radius. Integrate this over the solid angle to find the total cross section, can you get a results? Why or why not? Usually the differential scattering cross section is corrected for screening effects by

$$d\sigma/d\Omega = \lambda_R^4 Z^2 / [64\pi^4 a_0^2 \{\sin(\theta/2)^2 + \alpha\}^2]$$

Can you get a more appealing result now? Any comments?

3. In TEM you visualize the sample from “below” and the electrons are scattered through Z-contrast in the sample. For low-Z materials like polymers one typically stains the sample with strong oxidizers like RuO<sub>4</sub> or OsO<sub>4</sub>. Calculate the electron beam transmission for samples stained with Ru and Os and compare this to areas rich in carbon. Will you get a lot of contrast? Will the contrast be more for high or low beam energy?

4. Using a beam energy of 100 keV determine the average angle of scattering due to the relation given in Problem 1 above. Given the typical dimensions of a TEM below the sample (you need to find these), will the scattered beam hit the TEM screen to distort the image? Assume the material is carbon based. Will it be worse for a high Z-material?

*Please give the references to any archival journal or book in your homework solution.*