The University of Western Ontario
Department of Physics and Astronomy

P9826b Winter 2013

March 13, 2013

Homework Assignment #1 (due on March 25, 2013)

Problems:

1. (3 points) XPS spectrum for unknown sample is presented below with exact binding energies list. Identify the peaks (element and transition) at the listed binding energy positions.

B.E. Peak

1071.9 –

978.8 –

763.2 –

718.4 –

644.2 –

604.3 –

573.5 –

546.9 –

532.9 –

497.2 –

374.7 –

368.4 –

353.7 –

335.5 –

285.6 –

269.7 –

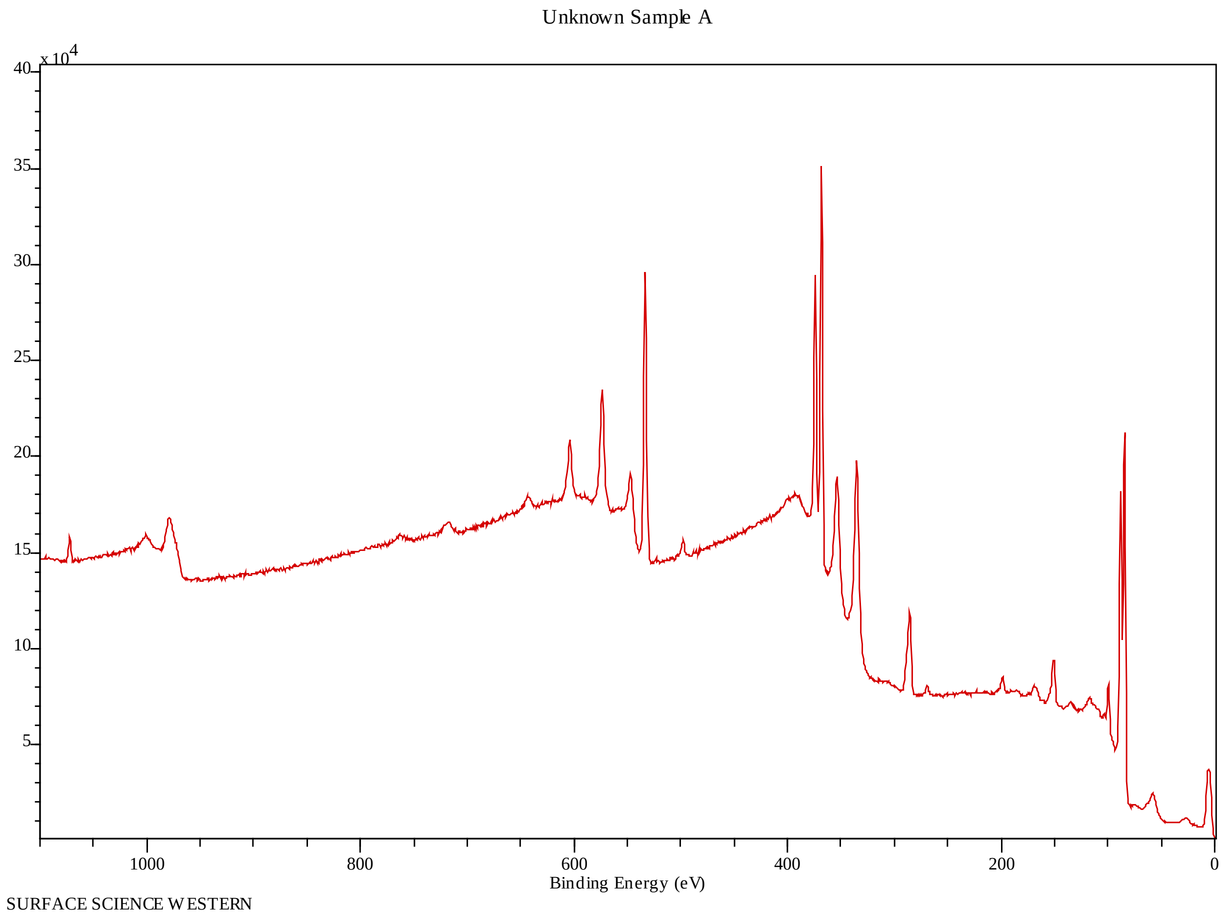
198.3 –

150.7 –

99.6 –

88.4 –

84.1 –



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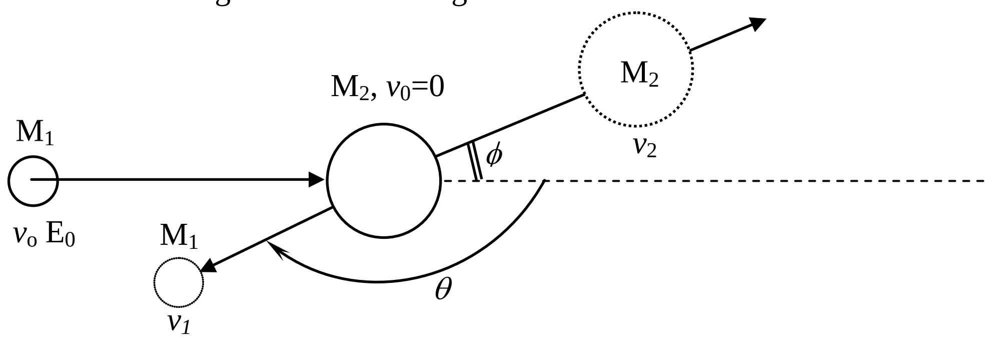
	1	2	3	4	5	Total
mark						
out of	3	4	3	2	3	15

2. (4 points) In Rutherford backscattering spectrometry, the kinematics of the collisions and the scattering cross section are independent of the chemical bonding, but only dependent on the masses of the target atoms. The diagram of the collision events is shown below:



In the collision, energy is transferred from the moving particle to the stationary target atom; the reduction in energy of the scattered particle depends on the masses of incident and target atoms and provides the signatures of the target atoms.
Assuming that an incident energetic particle of mass M_1 has velocity v_0 and energy E_0, and target atom of mass M_2 is at rest. After the collision, the values of the velocities v_1 and v_2, the projectile and target atoms are determined by the scattering angle θ and recoil angle ϕ.

One can write equations for conservation of energy, and conservation of momentum parallel and perpendicular to the direction of incidence (3 equations total, see lecture notes). One can go through a page of algebra to get the following expression for the energy of projectile (M_1) after collision:

$$E_1 = E_0 \left[\frac{\left(M_2^2 - M_1^2 \sin^2 \theta\right)^{1/2} + M_1 \cos\theta}{M_2 + M_1} \right]^2$$

(a) Assuming that $M_1 < M_2$, find the ration of $\frac{E_1}{E_0}$ at direct backscattering condition ($\theta = 180^0$).

Show the details of your calculations.

(b) Assuming collision where M_1=M_2, and the incident particle is at rest after the collision, with all the energy transferred to the target atom, a feature well known in billiards. Find the ration of $\frac{E_2}{E_0}$ as a function of M_1, M_2 and angle ϕ.

(c) Under which conditions the maximum value of $\frac{E_2}{E_0}$ (or the maximum energy transfer)?

(d) If you use alpha particles (M_1=4a.m.u.) with incident energy E_o=2MeV, detector is at $\theta=180^0$; and your target is ~100 Å thick gold film on top of silicon substrate$_)$, find your energy positions of Si and Au elements in Rutherford Backscattering spectrum. Draw RBS spectrum schematically but mark energy positions for all observed features.

3. (3 points) Silicon nanocrystals (Si-ncs) embedded in SiO_2 exhibit strong luminescence at room temperature and are of interest in the drive to produce silicon photonic devices that are compatible with silicon processing techniques. Formation of Si-ncs can be done using ion implantation of excess silicon into SiO_2 film, followed by high temperature annealing (nucleation and growth via Ostwald ripening).

(a) Your sample is composed of 100nm SiO_2 film on top of Si(001) substrate. Use SRIM to find the incident energy of Si ions to place excess Si atoms in the middle of SiO_2 layer (assume that implantation angle is 10 degrees).

(b) To achieve excess silicon in SiO_2 layer, one has to use implantation dose as high as $1E10^{17}$ Si atoms/cm^2. As a result of Si-ncs formation, SiO_2 layer expands or "swells", because of this effect thickness of SiO_2 layer becomes larger. Calculate this increase in SiO_2 layer thickness, assuming a simplified model when 100% of implanted Si form Si-ncs that are cubic in shape with the dimensions d=3 x lattice constant of Si (a_{Si}). As a reminder, Si has a diamond lattice structure with the lattice constant a=5.43Å). (Hint: you may choose to calculate (*i*) number of Si atoms in unit cell; (*ii*) how many Si atoms per cm^{-3}.)

(c) During implantation process, some fraction of Si and O atoms will be sputtered. Use SRIM to estimate the total sputtering effect by running SRIM simulation with 1000 incident ions, writing down sputtering yield of Si and O, and extrapolating to the dose of $1E10^{17}$ Si atoms.

(d) Compare your sputtering results in (c) with "swelling" results in (b), and comment on whether you should use your ion energy for the Si-ncs formation.

4. (*2 points*) <u>In your own words</u> explain the meanings of matrix effects in SIMS.

5. (*3 points*) (a) When measuring spherical particles of less than 10 nm on a substrate with an atomic force microscope, an experienced operator uses the height of the sphere to estimate the size of the object. Explain why, instead of using the measured lateral dimension (size) of the sphere, he/she selects to do so.

(b) Explain why phase shift imaging in AFM may be useful in differentiating composite materials. Hint: Think about AFM tip as of a forced oscillator.