Soft X-Rays and Extreme Ultraviolet Radiation: Principles and Applications

Chapter 1 Homework Problems

1.1 (a) Confirm that for a photon energy $\hbar\omega$, with corresponding wavelength λ in vacuum, the two are related by

$$\hbar\omega \cdot \lambda = 1239.842 \text{ nm} \cdot \text{eV}$$

Values for physical constants are given in Appendix A, page 419. (b) What wavelength in nm corresponds to photons of energy 543.1 eV? (c) What wavelengths in vacuum are associated with the K and L-absorption edges of neon, chlorine, cobalt, and ruthenium?

1.2 (a) Show that for a wavelength λ in vacuum, the number of photons N_p per joule of energy E is given by

$$N_p = 5.034 \times 10^{15} \text{ photons} \left(\frac{\lambda}{\text{nm}} \right) \left(\frac{E}{\text{joules}} \right)$$

(b) What number of photons is required for a total energy of 1 µJ at a vacuum wavelength of 530 nm (green light); 13.4 nm (EUV); 2.28 nm (soft x-ray); and 0.0620 nm (hard x-ray)?

1.3 Show that the photon flux F per watt of radiated power P can be written as

$$F = \left(5.034 \times 10^{15} \text{ ph/s} \right) \left(\frac{\lambda}{\text{nm}} \right) \left(\frac{P}{\text{watt}} \right)$$

where λ is the wavelength in vacuum.

1.4   If Cu $K_{\alpha 1}$ x-rays irradiate an aluminum foil, (a) with what energy in eV will K-shell photoelectrons be ejected from the Al atoms? (b) What characteristic lines of Al might subsequently be observed? (c) Which Auger electrons might be observed? Estimate the energy of a KL_2L_3 Auger electron. Hint: The binding energy of the L_3 electron with a vacancy in the K-shell is not exactly the same as the binding energy of the L_3 electron in an atom in the natural state. For further information on measurements of Auger electrons see: http://srdata.nist.gov/xps/main_search_menu.htm. (d) How would it be possible to differentiate photoelectrons from Auger electrons, in a more general case, when investigating materials with photons?

1.5 (a) What is the K-absorption edge of carbon in eV? (b) What is the corresponding wavelength in vacuum? (c) What is the photon energy of K_α emissions from a carbon atom? (d) Repeat this exercise for oxygen and iron.

1.6 (a) Compute and graph the transmission curves (linear transmission, log photon energy; 0-100% and 100 eV to 10 keV, respectively) for (a) 15 µm thick aluminum foil and (b) 75 µm thick Saran wrap (two common wraps for sandwiches, also common as x-ray filters). For Al use $\rho = 2.70$ g/cm^3; for Saran wrap (CH_2=CCl_2) use $\rho = 1.60$ g/cm^3 (total).

1.7 (a) Calculate the atomic densities of aluminum and silicon based on mass density and atomic weight values given in the Periodic Table of the Elements (inside back cover of this book). (b) Estimate the corresponding interatomic distances based on a geometric model. Compare these to the "nearest neighbor" values given in the Periodic Table. Refer to p.440 in the text by R. Leighton for further discussion (reference 27 of this chapter).

1.8   Calculate the first Bohr radius and the photon energy of characteristic emissions which decay to the n = 1 state (n_i = 4, 3, 2; n_f = 1) for a single electron carbon ion (nuclear charge Z = 6, five electrons removed). These are often referred to as hydrogen-like carbon emission lines, common in studies of hot plasmas.

1.9   a) Find the full width at half maximum* (in nm) of the attenuated projection of a solid gold (density = 19.3 g/cm^3) spheres with diameters of 10 nm, 20 nm, and 30 nm in vacuum. Also, find the maximum attenuation fraction through the sphere. Assume that the soft x-rays (energy = 520 eV) incident on the sphere have uniform intensity and are parallel to one another. Assume, also, that the detector has uniform sensitivity, has infinitely fine pixels sufficient to cover the area of the projection, and is located perpendicular to the incoming x-rays. Neglect any refraction that may occur. The following website can be used as a resource about x-ray properties of materials: http://www-cxro.lbl.gov/.

X-Rays   Detector
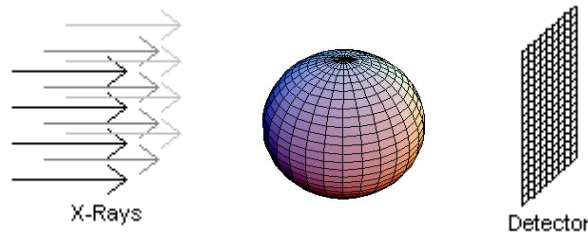
b) Repeat the calculations for x-rays at 520 eV through solid carbon spheres (density 2.27 g/cm^3) with diameters of 10 nm, 20 nm, and 30 nm.

c) Repeat the calculations for x-rays at 726 eV through solid iron spheres (density 7.87 g/cm^3) with diameters of 10 nm, 20 nm, and 30 nm.

* The full width at half maximum is a common parameter used to describe the width of a "bump" on a curve or function. It is the distance between points on a curve at which the function reaches half its maximum value. Reference: http://mathworld.wolfram.com/FullWidthatHalfMaximum.html