PC2232 Physics for Electrical Engineers: Tutorial 5

Question 1:

(a) If the photon and electron each have the same energy of 20.0 eV, find the wavelength of each.

(b) If a photon and an electron each have the same wavelength of 250 nm, find the energy of each.

(c) You want to study an organic molecule that is 250 nm long using either a photon or an electron microscope. Approximately what wavelength will you use, and which probe, the electron or the photon, is likely to damage the molecule the least?

Question 2:

The spacing between adjacent atoms on the surface of a nickel crystal is 0.215 nm. If the line of atoms lays along the x-direction, we can regard the uncertainty in the x-coordinate of each atom as approximately half the spacing. The mass of a single nickel atom is 9.75×10^{-26} kg.

(a) Estimate the minimum uncertainty in the x-component of momentum of a nickel atom in the crystal.

(b) If the magnitude of the momentum of a nickel atom is equal to the uncertainty found in part (a), what is its kinetic energy? Express the result in joules and in electron-volts.

(c) If every atom in a 1.00 kg nickel crystal had kinetic energy found in part (b), what would be the combined kinetic energy (in joules) of all the atoms? (The motion of each atom is in a random direction, so the centre of mass of the crystal has zero momentum on average.)

(d) If all of this kinetic energy could be converted to gravitational potential energy, how high would the nickel crystal rise?

Question 3:

Electrons are accelerated through a 20 V potential difference, producing a monoenergetic beam. This is directed at a double-slit apparatus. A series of electron detectors are located beyond the double slit. With slit 1 alone open, 100 electrons per second are detected at all detectors. With slit 2 alone open, 900 electrons per second are detected at all detectors. Now both slits are open.

(a) What is the de Broglie wavelength of the electrons?

(b) How many electrons per second will be detected at the centre of the interference pattern?

(c) The first minimum in the detector count occurs at detector X. How many electrons per second will be detected at this detector?

Question 4:

A CD-ROM is used instead of a crystal in an electron diffraction experiment. The surface of the CD-ROM has tracks of tiny pits with a uniform spacing of 1.60 μm.

(a) If the speed of the electrons is 1.26×10^4 m/s and they strike the surface at normal incidence, at which values of θ with respect to the normal will first and second orders of intensity maxima appear?

(b) The electrons in these maxima hit a piece of photographic film, oriented parallel to the CD-ROM and 50.0 cm away. What is the spacing on the film between the maxima?

Question 5:

We can use the uncertainty principle to estimate the radius of the smallest 'orbit' that the electron in the hydrogen can take. Let us denote this by a. You may take it to be the uncertainty of position of the electron.

(a) Write down the uncertainty of the linear momentum of the electron. Treat this as the linear momentum of the electron.

(b) At this distance from the nucleus, what are the electrostatic potential energy U and total energy of the electron E?

(c) For what numerical value of a would the total energy E be minimum?

Question 6: (Optional)

For relativistic particles the de Broglie relation $\lambda = h/p$ still holds, but the magnitude of momentum p is related to the total energy E by $E^2 = (pc)^2 + (mc^2)^2$. The kinetic energy is $K = E - mc^2$.

(a) Show that the de Broglie wavelength of a particle of kinetic energy K and rest mass m is

$$\lambda = \frac{hc}{\sqrt{K\left(K + 2mc^2\right)}}. \qquad (1)$$

(b) Find the approximate expressions for λ as a function of K in the special cases

- $K \ll mc^2$, (nonrelativistic limit), and

- $K \gg mc^2$, (extreme relativistic limit).

(c) Calculate the de Broglie wavelength for a proton with kinetic energy 7.00 GeV.

(d) Repeat part (c) for an electron with kinetic energy 25.0 MeV.