Supplementary Problems for PC 251

1.1. Add the following to your write up of problem 1.10.
b) If the three observers were each 100 m from the B, at what time would each of them hear the sound of the explosion?
c) Now imagine that instead of firing a revolver, B flashes a light at time t = 0. At what time would each observer see the flash of light for the situation described in the problem?
d) Is there any modification of the physical parameters of the problem that can change your answer to part c? Ie, what if the wind blows harder? What if B starts walking at the moment she flashes the light? Something else?
e) What is the fundamental reason that sound waves can travel at variable velocities but light waves cannot?

3.1. Use the data in panel (a) below to calculate the ratio of the atomic number of gold to silver and compare to the real value.

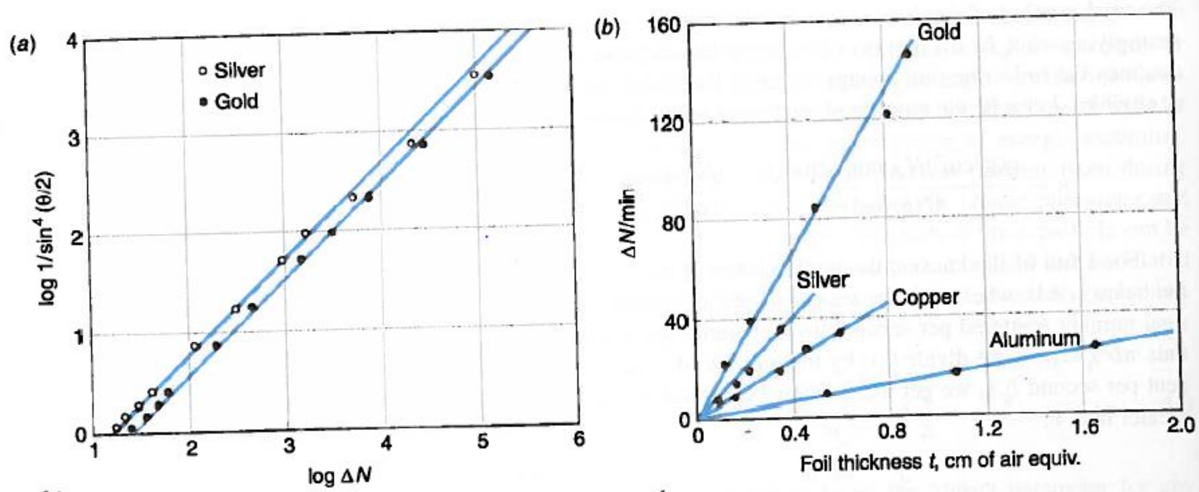

Figure 4-9 (*a*) Geiger and Marsden's data for α scattering from thin gold and silver foils. The graph is a log-log plot to show the data over several orders of magnitude. Note that scattering angle increases downward along the vertical axis. (*b*) Geiger and Marsden also measured the dependence of ΔN on t predicted by Equation 4-6 for foils made from a wide range of elements, this being an equally critical test. Results for four of the elements used are shown.

3.2. Explain how the scattering data shown in panels a and b above demonstrates that the nucleus is small compared to the size of the atom. Do this by: a) explaining how the data support the validity of the Rutherford scattering equation and then b) explaining how the Rutherford scattering equation implies that the nucleus must be small compared to the atom.

3.3. In an α scattering experiment, 10^5 α particles per minute each with energy 5.2 MeV are directed at a gold foil that is 2 μm thick. The α particle detector is located 12 cm from the foil and has an area of 1.0 cm^2. How many α particles will be counted in 10 minutes by the detector when it is placed at an angle of 45° to the incoming beam?

3.4 Do you expect the number of particles scattered in the Rutherford experiment to increase indefinitely with the thickness of the foil? To answer this, sketch a plot of what would happen as you make the foil thicker and thicker and thicker and explain the shape of your plot.

4.1. Explain the ultraviolet catastrophe using some words and sketches. In particular, be sure to explain both why the classical and quantum predictions agree at long wavelengths/low frequencies and why they disagree at short wavelengths/high frequencies.

4.2. In the photoelectric effect, it is observed that the existence of photoelectrons does not depend on the light's intensity but does depend on the light's frequency. Using only classical physics explanations, just the opposite is expected. By "existence" it is meant that photoelectrons are being produced at any rate, however minimal, from the electrode. Explain why

a) classically we expect a minimum light intensity for photoelectrons to exist.
b) quantum mechanically we do not observe a minimum light intensity for photoelectron to exist.
c) classically we do not expect a minimum frequency for photoelectrons to exist.
d) quantum mechanically we expect a minimum frequency for photoelectrons to exist.

4.3. In Chapter 4, experiments were presented that demonstrate both the particle and the wave nature of light. Of the following figures, which demonstrate the particle and which the wave nature of light and why?

a) Figure 4.3
b) Figure 4.9
c) Figure 4.11
d) Figure 4.14

5.1 Using Bohr's model of the atom, calculate the following quantities. Be careful with signs.

a) Calculate the orbital radius (in nm) of the electron in the ground state.
b) Calculate the potential energy of the electron in this ground state (in eV).
c) Calculate the kinetic energy of the electron in the ground state (in eV).
d) What is the total energy of the electron in the ground state (in eV)?
e) You want to excite an electron in the ground state to the $n = 3$ level. What is the minimum kinetic energy (in eV) that a free electron colliding with an atom needs to have to do this?
f) What is the orbital radius in nm of the electron when it's at this higher level?
g) If an electron drops down from the $n = 6$ level to the $n = 2$ level, and then to the ground state of hydrogen, what wavelengths of light will be emitted? What part of the EM spectrum are these wavelengths in?

5.2 Read the section that starts on page 536 of your textbook about the Sizes and Shapes of Nuclei and use these to continue problem 5.26 as follows.

c) Calculate the size of a silver nucleus and comment on whether a muonic silver atom could be used to better understand the nuclear structure of silver.
d) We can estimate that whenever the radius of the muon's $n=1$ orbit is about twice the radius of the nucleus, then the muon interacts in a significant enough way with the nucleus to make it a good probe of nuclear structure. Note that for lighter elements $A = 2Z$ is a good approximation. Approximately what is the lightest element for which muonic interaction will work to probe nuclear structure? What two factors change to make muonic interaction not work as well for lighter elements?

e) If you could invent a particle that would work for probing the nuclear structure of lighter elements all the way down to hydrogen, what properties would it have as compared to the muon? A qualitative answer will suffice here.

6.1 As a supplement to problems 6.9, 6.12, and 6.15 from the book, calculate the wavelength of a 3 eV photon and compare to the wavelength of a 3 eV electron. Calculate the wavelength of a 2 MeV photon and compare to the wavelength of a 2 MeV electron. Comment on how your answers validate the results of problem 6.12.

6.2 Assume the X-rays of problem 6.22 are plane waves travelling along the x direction. Assume that the electric field strength has a maximum value of E_o, and is 0 and about to increase at x= 0 and t = 0. Find the value of the electric field in terms E_o of at x = 1 nm and t = 1 fs.

6.3 Continuing problem 6.32 from the book, let λ = 3a.
a) Calculate numerical values for $A_0 – A_4$.
b) Use the Phet simulation https://phet.colorado.edu/en/simulation/legacy/fourier to plot the square wave function using its Fourier coefficients. Take a screen shot of your plot to turn in with your homework.
c) The Phet simulation doesn't have the ability to include the A_0 coefficient. Given this, what is the difference between your Phet plot and the plot in figure 6.10 in the book?

7.1. As a supplement to the problem 7.9 from the book please do the following
a) add t = 0 s to the y(x,t) and v(x,t) graphs you are making.
b) Explain how the v(x,0) graph relates to the y(x,0) you plotted.
c) Explain how the v(x,0.05s) graph relates to the y(x,0.05s) you plotted.

7.2. As a preamble to the problem 7.26 from the book, first draw the potential described in equation 7.42. Show where the energy of the particle in the box lies. Then start with the time-independent Schrodinger equation (7.39), and show that for a particle in the infinite box you drew, that the Schrodinger equation reduces to the differential equation given in part a of problem 7.26. Find an expression for k in terms of the energy of the particle E and fundamental constants.

7.3. Explain with words what the answer to 7.30b is and what the answer to 7.34 is. These are both positions, and both give an answer of a/2. What is the conceptual difference between the values calculated?

8.1 For problem 8.33 part c, show the spherical harmonic Y_{22} is normalized. You need not do any of the other spherical harmonics.

8.2. Continuing problem 8.36, what are the allowed angular momentum, z component of angular momentum and energy values if ℓ =3.

8.3. For the wave function given in 8.40
a) write down a general expression that can be used to normalize this wave function for all n.
b) Then for the specific case of n = 1, evaluate the expression and show that you get the correct normalized wave function as given in Table 8.2.

8.4. Use the expression for the probability density of the 1s state to find the most probably value of r for that state.

9.1. Make an energy level diagram with quantum numbers labelled (n,l,m) and spin for the electron (use up and down arrows for this) for all electron levels in the atom up to and including n =3. This diagram will look like a combination of Figure 10.3 and Figure 10.7 (ground state). What atom does this diagram represent?

10.1 Continuing problem 10.16 from your book,

a) On your energy level diagram, give the quantum numbers (n,l,m,ms) for all the spin down electrons in the 2p state and for the first excited state electron.

b) Use Figure 10.8 to find the ionization energy for neon. Use this value to find the effective nuclear charge felt by an electron in the 2p state.

c) Explain why your answer to b is reasonable for neon.

d) Explain why a high ionization energy and a filled shell makes neon a very non-reactive element.