Conceptual Physics Review (Chapters 38-40) Solutions

Chapter 38

- Give two examples of models for light.
- Describe the Bohr model of the atom and describe the current model of the atom.
- Describe the photoelectric effect, and explain which model of light it supports.
- Give evidence for the wave nature of electrons.
- Describe the wave properties of all matter, using de Broglie's formula for wavelength.
- Explain why the radius of an atom is not directly proportional to the mass of the atom.
- Explain what the atomic spectrum of an element reflects about its atomic structure.
- Determine the energy emitted by an electron that produces visible light of a given wavelength or frequency.

Chapter 39

- Describe atomic nuclei, including what forces hold them together and why certain nuclei are unstable and therefore undergo spontaneous radioactive decay.
- Distinguish among the three types of rays (alpha, beta, and gamma) given off by radioactive nuclei.
- Compare the penetrating powers of the three types of radiation.
- Interpret the symbols used to label isotopes of an element.
- Explain what is meant by the half-life of an element.
- Predict how much of a given sample of radioactive isotope will remain at the end of some multiple of the half-life.
- Given the symbol for a radioactive isotope and the particle it gives off, predict the product of the decay.
- Explain how carbon dating works.
- Explain why the center of the earth is warm.

Chapter 40

- Describe the role of neutrons in causing and sustaining nuclear fission.
- Explain how nuclear fission can be controlled in a reactor.
- Describe the equivalence of mass and energy.
- Distinguish between nuclear fission and nuclear fusion, and explain which elements undergo which process.
- Explain how it is possible that a neutron in a nucleus can have less mass than the same neutron alone, not in a nucleus.
- Define binding energy, and know which element has the greatest binding energy per nucleon.
- Describe the drawbacks of nuclear fission as a source of energy.
- Describe the drawbacks and the advantages associated with nuclear fusion as a source of energy.

Labs

Review the Atomic Spectra Lab and the Half-Life Lab

Homework

Review all homework problems from the textbook and all worksheets from chapters 38, 39, & 40.

Questions and Problems

1. When looking at the atomic spectrum for Argon, I observed a bright line in the violet region that has a wavelength of 455 nm.

a. Calculate the frequency of the visible light with that wavelength.

c=*λf*, so *f*=*c*/*λ*, = 3.0e8 m/s / 455e-9 m = **6.59e14 Hz**

b. Calculate the energy of a photon of visible light with that wavelength.

E=*hf*, = (6.6e-34 J•s)(6.59e14 Hz) = **4.35e-19 J**

c. What does this energy have to do with the energy levels in the Argon atom, according to the Bohr model of the atom?

This energy corresponds to both a) the amount of energy it takes to cause one of Argon's electrons to jump up a specific number of energy levels, and b) the amount of Energy released (as a photon) when that same electron falls back down to where it started.

2. According to de Broglie, all matter has wavelike properties, just as all waves have particle-like properties. If I am jogging at a speed of 5.0 meters per second and my mass is 75.0 kg, calculate my de Broglie wavelength.

λ=h/p = h/mv = (6.6e-34 J•s)/((75.0 kg)(5.0 m/s)) = **1.76e-36 m**

3. Calculate and compare the de Broglie wavelengths for a proton and an electron, each traveling at 3.00×10^7 m/s. You may recall that the mass of an electron is 9.11×10^{-31} kg and the mass of a proton is 1.67×10^{-27} kg.

Electron: *λ*=*h*/*p* = h/mv = (6.6e-34 J•s)/((9.11e-31 kg)(3.00e7 m/s)) = **2.41e-11 m**

Proton: *λ*=*h*/*p* = h/mv = (6.6e-34 J•s)/((1.67e-27 kg)(3.00e7 m/s)) = **1.32e-14 m**

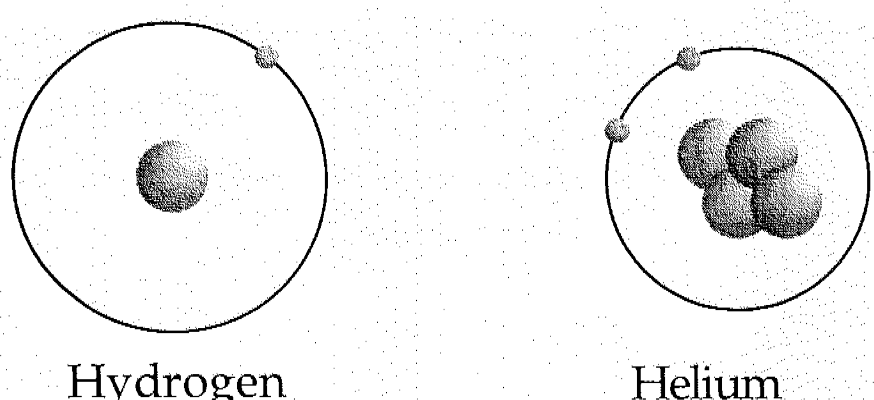
4. Explain the results of the photoelectric effect experiment. Use an analogy if you can, comparing red photons to feathers and blue photons to cannonballs or hockey pucks or something else. Be creative. Pretend you're explaining it to your grandparent, so it is very clear. Discuss the effects of increasing the intensity of the red light and the blue light.

Okay, going with a similar analogy: red photons are like ping-pong balls, blue photons are like bowling balls, and the electrons are like superballs sitting on the floor.

First Point: It takes a certain amount of energy to get the superballs to bounce off the floor, and the ping-pong balls--the red photons--don't have the ability to get the superballs bouncing, no matter how many of them fall down on the floor.

Second Point: If you *do* have bowling balls hitting the floor and causing some of the superballs to bounce up, the more bowling balls there are (which corresponds to an increasing brightness), the more superballs will get bounced up off the floor.

5. Explain why a helium atom has a smaller radius than a hydrogen atom. Draw a picture of each atom to aid your explanation.



The hydrogen atom only has a single proton in the nucleus that attracts the electron. The helium atom has two protons in the nucleus, which together exert a stronger force on each electron in the atom; thus, the electrons are pulled into a slightly smaller-sized shell.

6. What evidence supports the theory that electrons in atoms exist at discrete energy levels? Which theory about the nature of electrons (particle or wave) is better supported by the discreteness of electron energy levels?

Spectral lines are evidence that electrons exist only at discrete energy levels: for a given element, the electron can only jump up or down according to the shell arrangements for atoms of that element, producing characteristic spectral lines. This is perhaps best explained by considering the electron as a *wave*, which only resonates at certain energy levels.

7. Describe what happens when an atom undergoes alpha decay.

When an atom undergoes alpha decay, 2 protons and 2 neutrons--the equivalent of a Helium nucleus--are ejected from the "parent" atom. The atom that's left behind has 2 fewer protons, and 2 fewer neutrons.

8. Describe what happens when an atom undergoes beta decay.

This is a little more complicated! When an atom undergoes beta decay, a neutron in the parent turns into a proton, an electron, and an anti-neutrino. The anti-neutrino goes flying off (we don't care about it, for now), the electron goes flying off (the beta-particle), and the proton stays in the nucleus. The fact that we have a proton where we had a neutron before means that the atomic *mass* of the atom stays the same, but the atomic *number* (the number of protons) is different, which means, of course, that we have a different type of atom!

9. Write an equation for a tritium nucleus undergoing beta decay.

$$^{3}_{1}H \rightarrow ^{0}_{-1}e + ^{3}_{2}He$$

(The anti-neutrino has not been written here.) Note that the atomic masses and the atomic numbers on the right side have the same sum as the masses and numbers on the left side

10. Write an equation for a U-238 nucleus undergoing alpha decay.

$$^{238}_{92}\mathrm{U} \rightarrow ^{4}_{2}\mathrm{He} + ^{234}_{90}\mathrm{Th}$$

Note that you don't have to *remember* that U-238 decays into Thorium. As long as you know that alpha emission means that a Helium nucleus is ejected, you can calculate the new atomic mass and number, and then just look up on the Periodic Table to find out what element has atomic number 90--that's Thorium!

11. Write an equation for a beryllium-8 nucleus undergoing alpha decay.

$$^{8}_{4}\mathrm{Be} \rightarrow ^{4}_{2}\mathrm{He} + ^{4}_{2}\mathrm{He}$$

12. Radium-226 has a half-life of 1620 years.

a. What does this mean?

A half-life of 1620 years means that half of the original mass of radium that you start with will have decayed into other products in 1620 years.

b. What fraction of an original sample of radium-226 will remain after 3240 years?

After 3240 years, only ½ of the ½, or ¼ of the original mass will remain.

c. How many years does it take a sample of radium-226 to decay to 1/16 its original size?

1/16 = (1/2)(1/2)(1/2)(1/2)= 4 half lives = 4 x 1620 years = 6480 years.

13. Explain what two types of forces act within the nuclei of atoms. Describe the relative strengths of each type of forces, including what happens to each force over a given distance.

The *electric force* between protons acts over relatively long distances, and causes the protons in the nucleus of the atom to repel each other. Fortunately, the *strong nuclear force* that acts between all nucleons (protons and neutrons) is sufficiently strong to hold the nucleus together, as long as the nucleons are not too far apart from each other.

14. Complete the following nuclear reactions, and identify the type of reaction.

a. $^{228}_{88}Ra \rightarrow \_\_\_ + ^{0}_{-1}e$

This is a *beta-decay*--we can tell because an electron has been emitted--so that means that a neutron must have changed to a proton as well. In the missing atom, the mass number won't have changed, but there will be one additional proton. The missing atom must be $^{228}_{89}Ac$, actinium.

b. $^{209}_{84}Po \rightarrow ^{205}_{82}Pb + \_\_\_$

Not sure what kind of decay this is, but let's check the atomic masses and numbers to see what comes out: 209-205 = 4, and 84-82 = 2, so the other product must be $^{4}_{2}He$, as we might have suspected. That would make this an *alpha decay*.

15. Explain how carbon dating works. Be sure to specify what types of objects can be dated by this method.

Wow! This is a long, complicated process, but here are the basics: Carbon-dating works with any thing that was once alive, both plants and animals. As long as plants are alive, they take in CO_2, which in addition to the common C-12, has radioactive C-14 in it. So, anything that is a plant, or eats plants, or eats animals that eat plants, has C-14 in it. As soon as the living thing dies, the C-14 stops getting replenished, and starts decaying. It has a half-life of 5730 years, so by comparing the amount of decaying C-14 relative to other elements in the sample, we can tell how old the sample is, approximately.

16. Define binding energy. What element's nucleus has the greatest binding energy per nucleon? How does binding energy per nucleon relate to the mass per nucleon in the nucleus?

Binding energy can be described in several different ways. Binding energy is equal to the amount of energy that it takes to separate nucleons from their nucleus. It's also the mass-equivalent of the difference between the sum of the masses of particles in a nucleus, compared with the sum of their masses when they're *not* in the nucleus. The binding energy is responsible for the energy released by a nuclear reaction when atoms are split, or combined.

Iron (Fe) has the greatest binding energy per nucleon, which means that it has the least mass per nucleon in the nucleus. "Binding energy" and "mass per nucleon" are inversely related.

17. What has more mass, 6 protons and 6 neutrons all separated from each other or a carbon-12 nucleus? What accounts for the difference in mass?

The 6 protons and 6 neutrons separated all have *more* mass than they do in the nucleus. This is because when they're in the nucleus, some of their mass is actually binding energy (see answer to #16 above).

18. Describe the fission of a U-235 nucleus, from start to finish. Include an explanation of the relative strength of different forces in the nucleus before and after a lone neutron is absorbed by the nucleus. Describe the products of the reaction.

1. At the beginning, the U-235 has relatively strong nuclear forces holding it together--the strong nuclear force is greater than the electric force.
2. A neutron is absorbed into the U-235 nucleus, which makes it unstable--now the electric force of repulsion is greater than the strong nuclear force of attraction.
3. The unstable U-235 decays into two "daughter" products with smaller atomic masses, as well as a few neutrons.
4. These new neutrons, in turn, can go off to hit other U-235 nuclei, and cause them to fission as well, producing a chain reaction.

19. Describe how a chain reaction can occur in a fission reactor and explain how the size of the piece of uranium can affect the chances of a chain reaction taking place.

The beginning of the chain reaction is described in step 4 above: neutrons produced during the fission of a U-235 nucleus go on to produce fission in other nuclei. This process is governed by how much U-235 there is in the uranium sample (more U-235 means more fission will happen, less U-235 means less fission will happen, because the new neutrons get absorbed by the U-238, which doesn't split).

This process also depends on the size of the sample that is undergoing fission. If the sample is too small, then the new neutrons won't have the chance (statistically) to run into another nucleus and cause *it* to fission before they've escaped the sample completely. A larger sample, of *critical mass*, will allow a sufficient number of neutrons to strike new nuclei, producing the desired chain reaction.

20. In a breeder reactor, nonfissionable U-238 is converted into more fissionable Pu-239. Write three reactions to describe this three-step process. In the first step, U-238 combines with a neutron to form U-239. In the second step, U-239 undergoes beta decay. In the third step, the product of the second step undergoes beta decay. The final product of step three should be Pu-239.

$$^{1}_{0}n + ^{238}_{92}U \rightarrow ^{239}_{92}U$$
$$^{239}_{92}U \rightarrow ^{239}_{93}Np + ^{0}_{-1}e$$
$$^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e$$

The three steps are shown in a single equation above. A neutron converts the U-238 to U-239, which subsequently undergoes beta decay to produce Neptunium. The Neptunium then undergoes beta-decay to produce Plutonium.

21. Does iron undergo fission, fusion, both, or neither? Explain your answer.

Iron doesn't undergo either fission or fusion--it has the highest binding energy, which means that it takes more work to tear apart the nucleus than is converted to energy in the process. It also has the least mass per nucleon of any element--fission and fusion both occur only when the products have less mass per nucleon than the parent.