DEGREE IN COMPUTER ENGINEERING

PHYSICS **EXERCISES CH 2**

Atoms and solids

e=1.6×10^{-19} C

$h = 6.626 \times 10^{-34}$ Js

$c = 2.998 \times 10^{8}$ m/s

mass of the electron: 9.11×10^{-31} *kg*

mass of the proton: 1.67×10^{-27} *kg*

1. Find out the electron configuration of the: a) Ar atom; b) K atom; c) Fe^{3+} ion.
The periodic table of the elements can be found at: *www.webelements.com/webelements/scholar/index.html*

2. (a) Write down the electron configuration of the Si atom and compare it with that of $_{32}Ge$. (b) How many neutrons and protons are there in the nucleus of the $^{29}_{14}Si$ isotope? (c) How many electrons? (Discuss your answer).

3. Find the electron configuration of the $^{89}_{39}Y^{3-}$ ion. How many protons, electrons and neutrons are there on this ion? What is its atomic number? Find its mass number.

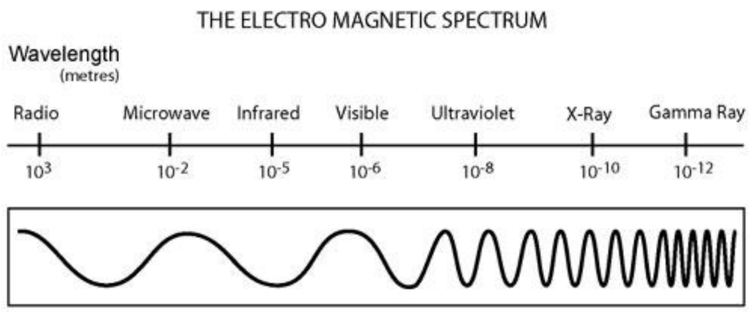
4. Use Bohr's model to calculate the wavelength of the radiation emitted when an electron in the H atom jumps from the second excited state (n=3) to the first excited state (n=2).

5. Bohr's model accurately predicts the energy levels of the H atom. However, it can be extended to obtain the energy levels of any atom, roughly. Under certain approximations (neglecting the interaction between electrons), the energies of the atoms of other elements are given by:

$$E = \frac{-13.6 \cdot Z^2}{n^2} \text{ (eV)}$$

Being Z the atomic number. The values given by this equation are not very precise, but they can be useful to make estimations.

Estimate the frequency and wavelength emitted by an electron in the $_{74}W$ atom when it jumps from the n = 3 level to the n = 1 level. Search the electromagnetic spectrum to find to which radiation it corresponds.



6. Apply your previous concepts on mechanics to obtain the mechanical energy E(r) of the electron in the H atom as a function of the radius r of the orbit. Suppose that the electron moves on a circular orbit (with uniform circular motion) around the proton under the influence of the electrostatic force between them.

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Data:

Magnitude of the electrostatic force: $F_e = \dfrac{ke^2}{r^2}$ Potential energy of the electron: $U = -\dfrac{ke^2}{r}$

$k=9\times10^9\ Nm^2/C^2$

Tip: See Paul A. Tipler, Physics for Scientists and Engineers, 4th Edition, Chapter 37

7. The radius of the n=1 orbit in the H atom is a_o=0.053 nm (Bohr's radius). What is the radius of the n=5 orbit, expressed as a function of a_o? (Apply the result obtained in exercise 6).

8. You are an electron sitting at the top of the valence band in a Si atom, longing to jump across the 1.14 eV energy gap that separates you from the bottom of the conduction band and all of the adventures it may contain. What you need, of course, is a photon. What is the maximum photon wavelength that will get you across the gap?

9. Find out the maximum wavelength of a photon in order to make an electron on the upper part of the valence band of a Ge atom jump to the conduction band.
(E_g = 0.74 eV)

10. A photon of wavelength 3.35 μm has just enough energy to raise an electron from the valence band to the conduction band in a lead sulfide crystal. Find the energy gap between these bands in lead sulfide.

11. Find the energy gap between the valence and conduction bands in Cu.

12. Calculate the density of carriers in a metal such as Cu, assuming there is one free electron per atom.

Data:
Density of Cu = 8.93 g/cm^3 Molar mass of Cu = 63.5 g/mol
Avogadro's number = 6.02×10^{23} atoms/mol

13. Calculate the intrinsic carrier concentration of silicon at room temperature (T = 300 K) and compare it with the one obtained for a metal (exercise 12).

Data:
Density of states for Si at room temperature $N_C = 2.8 \times 10^{19}$ cm^{-3}; $N_V = 1.04 \times 10^{19}$ cm^{-3}
E_g = 1.12 eV
Boltzmann constant $k_B = 1.38 \times 10^{-23}$ J/K = 8.614×10^{-5} eV/K

14. A Si semiconductor has been doped with a typical concentration of 1 part per million (ppm) of As atoms. Knowing that at RT all impurities of As are ionized, find

(a) The number of Si atoms per cubic centimetre.
(b) The number of electrons per cubic centimetre donated by the impurities.
(c) Compare this result with the intrinsic carrier concentration of Si at RT.

Data:
Density of Si = 2.33 g/cm^3
Molar mass of Si= 28.1 g/mol

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ANSWERS

1. [Ar]: $1s^2\ 2s^2\ p^6\ 3s^2\ p^6$ [K]: $1s^2\ 2s^2\ p^6\ 3s^2\ p^6\ 4s^1$ [Fe^{3+}]: $1s^2\ 2s^2\ p^6\ 3s^2\ p^6\ d^3\ 4s^2$

2. a) [Si]: $1s^2\ 2s^2\ p^6\ 3s^2\ p^2$ [Ge]: $1s^2\ 2s^2\ p^6\ 3s^2\ p^6\ d^{10}\ 4s^2\ p^2$

b) 14 protons and 15 neutrons

c) it depends on the state of the atom (neutral or ionized). If neutral, 14 electrons.

3. [Y^{3-}]: $1s^2\ 2s^2\ p^6\ 3s^2\ p^6\ d^{10}\ 4s^2\ p^6\ d^4\ 5s^2$ *Z=39, N=50, 42 electrons.*

4. λ = 656 nm (visible)

5. λ = 1.88×10^{-11} m; f= 1.6×10^{19} Hz; X-ray region.

6. $E(r) = -\frac{1}{2}\frac{ke^2}{r}$

7. $25a_o$

8. λ = 1.09 μm (infrared)

9. λ = 1.68 μm (infrared)

10. 0.37 eV

11. There is no gap between the bands, as Cu is a conductor.

12. $n = 8.47 \times 10^{22}\ cm^{-3}$

13. $n_i = 6.6 \times 10^9\ cm^{-3}$

14. a) 5×10^{22} atoms/cm^3

b) $n_e = 5 \times 10^{16}\ cm^{-3}$