Chapter 6.1

Q1 (a) The mass of the nucleus is approximately $56 \text{ u} = 9.3 \times 10^{-26} \text{ kg}$. The radius is $R = 1.2 \times 56^{1/3} \times 10^{-15} = 4.6 \times 10^{-15} \text{ m}$. Hence the density is $\rho = \dfrac{9.3 \times 10^{-26}}{\dfrac{4\pi}{3}(4.6 \times 10^{-15})^3} = 2.3 \times 10^{17} \text{ kg m}^{-3}$. (b) The density of iron is about $7.9 \times 10^3 \text{ kg m}^{-3}$ so the nuclear density is 14 orders of magnitude larger. (c) We have that $2.3 \times 10^{17} = \dfrac{1.4 \times 2.0 \times 10^{30}}{\dfrac{4\pi}{3}R^3}$ and so $R = \left(\dfrac{1.4 \times 2.0 \times 10^{30}}{\dfrac{4\pi}{3} \times 2.3 \times 10^{17}} \right)^{1/3} = 14 \text{ km}$.

Q2 The mass of a nucleus of mass number *A* is approximately $A \text{ u} = A \times 1.661 \times 10^{-27} \text{ kg}$. The radius is $R = 1.2 \times A^{1/3} \times 10^{-15} \text{ m}$. Hence the density is $\rho = \dfrac{A \times 1.661 \times 10^{-27}}{\dfrac{4\pi}{3}(1.2 \times A^{1/3} \times 10^{-15})^3} = \dfrac{3 \times 1.661 \times 10^{-27}}{4\pi (1.2 \times 10^{-15})^3} = 2.3 \times 10^{17} \text{ kg m}^{-3}$, since *A* cancels out of the calculations.

Q3 The key idea is that the alpha particles are scattered, i.e. deflected, by the electric force between the positive charge of the alpha particles ($4e$) and the positive charge of the atom (Ze). This force is given by $F = k\dfrac{4Ze^2}{r^2}$. In the Thomson model the closest the alpha particle can come to the center of the positive charge is *R* the radius of the atom, a number of order 10^{-10} m. This gives a force that is too small to deflect the alpha particles by very large angles (but is sufficient to explain the small angle deflections). So to obtain the very large force needed for the large angle deflections the alpha particle must be able to approach the center of the positive charge much closer. This means the positive charge must be concentrated in a very small volume. In fact the force has to be about 10^{10} larger and so *R* must be $\sqrt{10^{10}} = 10^5$ smaller i.e. the radius of the nucleus must be of order 10^{-15} m.

Q4 The bright lines are formed when an electron makes a transition from a high energy state H to a lower energy state L. The photon emitted will have a wavelength determined from $\dfrac{hc}{\lambda} = \Delta E_{LH} \Rightarrow \lambda = \dfrac{hc}{\Delta E_{LH}}$ where ΔE_{LH} is the difference in energy between state H and L. The dark lines are formed when a photon is absorbed by an electron in a low energy state L which then makes a transition to a high energy state H. For the absorption to be possible the photon energy must equal the difference ΔE_{LH}. Hence this photon will have the same wavelength as the emission line wavelength.

Q5 Isotopes are nuclei of the same element (hence have the same proton (atomic) number) that differ in the number of neutrons, i.e. they have different nucleon (mass) number. The existence of isotopes is inferred from mass spectrometer measurements in which a beam of ionized atoms of a given element makes curved paths of different radii. This implies that although ions of the same element these ions have different mass i.e. have different numbers of neutrons in the nucleus.

Q6 $1-1=0$, $4-2=2$, $40-20=20$, $210-82=128$.

Q7 $3\text{ e}=3\times 1.6\times 10^{-19}=4.8\times 10^{-19}\text{ C}$.

Q8 Discrete energy means that the atom cannot have any continuous value of energy but rather one out of many (infinite in fact) separate i.e. discrete values. The existence of emission atomic spectra is the best evidence for the discreteness of energy in atoms, as explained in the textbook.

Q9 The force becomes negligibly small when the separation of two nucleons exceeds a certain distance (of order 10^{-15} m) called the range.

Q10 (a) Here we are at the limit of the range of the strong nuclear force and so the dominant force must be the electric force. (b) Here we are well within the range of the strong nuclear force so this is the dominant force.

Q11 A typical nucleus has a radius that is a few times larger than the range of the nuclear force. For example the radius of the nucleus of tin (Sn with mass number $A=119$) is $R=1.2\times 119^{1/3}\times 10^{-15}=5.9\times 10^{-15}\text{ m}$, i.e. about 6 times the range of the nuclear force. A proton within the nucleus thus feels the attraction from only those nucleons that are inside a sphere of radius 10^{-15} m centered on the proton in question. There is a fixed number of nucleons within this sphere and that number would be the same in any other nucleus provided the nucleus is not too small. The nucleons outside this sphere are irrelevant as far the nuclear force attraction on the proton in question is concerned.

Q12 The ratio (at any common separation is

$$\frac{F_e}{F_g}=\frac{\frac{ke^2}{r^2}}{\frac{Gm^2}{r^2}}=\frac{ke^2}{Gm^2}=\frac{9\times 10^9(1.6\times 10^{-19})^2}{6.67\times 10^{-11}(9.1\times 10^{-31})^2}=4\times 10^{42}$$

, which shows how much weaker the gravitational force is in microscopic physics where the masses involved are so small.