CHAPTER 43
NUCLEAR PHYSICS

Discussion Questions

Q43.1 The electric charge of the protons causes the transition energy for a spin flip to depend on the chemical environment of the protons. The purpose of the proton MRI is to study that environment. Neutrons have no charge so their spin flip energy is insensitive to their chemical environment.

Q43.2 The second term represents the decreased binding of nucleons on the surface of the nucleus whereas the first term represents binding of nucleons in the interior of the nucleus. The surface area of a sphere is $4\pi R^2$ whereas the volume is $\frac{4}{3}\pi R^3$. Therefore, as the nucleus becomes larger a smaller fraction of the nucleons are on the surface.

Q43.3 When nucleons are combined to form a nucleus some of their mass is converted into the binding energy of the nucleus.

Q43.4 When $Z > N$ there is too much Coulomb repulsion between pairs of protons for the nucleus to be stable.

Q43.5 The magic numbers for which there are known elements are 2, 8, 20, 28, 50 and 82. The elements with these values of Z are helium, oxygen, calcium, nickel, tin and lead. The nuclei of these elements are unusually stable.

Q43.6 No. As the number of electrons increases so does the nuclear charge Ze and the binding energy of each of the innermost electrons increases roughly as Z^2. The binding energy per electron for uranium is much larger than it is for hydrogen.

Q43.7 Radioactive decay must be energetically allowed. Proton or neutron decay normally isn't energetically allowed.

Q43.8 The interior of a star undergoing helium fusion is much hotter than the interior of a younger star that is undergoing hydrogen fusion. The Coulomb repulsion of helium nuclei ($Z = 2$) is four times that of hydrogen ($Z = 1$) for the same separation and much higher temperatures are needed to give the helium nuclei sufficient kinetic energy to overcome the Coulomb repulsion and get close enough to fuse.

Q43.9 $^{214}\mathrm{Pb}$ is an unstable isotope of lead. Other isotopes of lead are stable ($^{206}\mathrm{Pb}$, $^{207}\mathrm{Pb}$, and $^{208}\mathrm{Pb}$).

Q43.10 The nuclei with the shorter lifetimes are less abundant.

Q43.11 α particles are much more massive. A β particle with the same energy has a much greater speed.

Q43.12 (a) Nucleon number unchanged, atomic number increases by 1 so this is β^- decay. (b) Nucleon number decreases by 4 and atomic number decreases by 2 so this is α decay. (c) Nucleon number unchanged and atomic number decreases by 1 so this is β^+ decay.

Q43.13 An electron has charge $-e$ and has nucleon number zero. A positron has nucleon number zero and charge $+e$ so it can be represented as ${}^{0}_{+1}\beta$. A neutrino has nucleon number zero and no charge so can be represented as ${}^{0}_{0}\nu$. An antineutrino has nucleon number zero and no charge so can be represented as ${}^{0}_{0}\overline{\nu}$.

Q43.14 The alpha, beta or gamma decays are associated solely with the nucleus and are unaffected by the electronic structure of the atom. Electron capture however involves capture of an orbital electron and is affected by the chemical binding of the atom since the chemical binding affects the orbital electrons.

Q43.15 The atomic electron that receives the energy has enough energy to break free from the atom; it can get energy greater than its binding energy. If this is an inner electron an x ray photon can be emitted when an outer shell electron in the atom falls into the inner-shell hole.

Q43.16 Human activity has burned carbon containing compounds in coal and oil and released this carbon into the atmosphere as CO_2 .

Q43.17 Biological material that was recently alive has an activity of 0.255 Bq or greater per gram of carbon. Older samples have a much lower activity per gram of carbon because of radioactive decay of the ${}^{14}C$ in the sample. Contamination with modern material would give a falsely high activity and cause an underestimation of the age of the sample. Older samples have a smaller activity and the relative effect of contamination is larger.

Q43.18 ${}^{226}Ra$ is being continually produced as a decay product from other more long-lived radioactive nuclei. One example is the ${}^{238}U$ decay series shown in Fig.43.7.

Q43.19 This is explained by Fig.43.2. When lighter nuclei fuse to form a nucleus lighter than ${}^{62}Ni$ the binding energy per nucleon in the product nucleus is greater than in the two original nuclei and energy is released. When a heavy nucleus splits into two pieces, each heavier than ${}^{62}Ni$, the binding energy per nucleon increases and energy is released.

Q43.20 The binding energy per nucleon is greater in the daughter nuclei than in the parent nucleus (see Fig.43.2). Therefore, a large amount of energy is released in the fission and this energy appears as kinetic energy of the daughter nuclei.