Nuclear Physics Practice Items

1. The species $^1_1\mathbf{H}$, $^2_1\mathbf{H}$, and $^3_1\mathbf{H}$ are

A. allotropes
B. homologs
C. isomers
D. isotopes

2. In 1932 J. Chadwick bombarded beryllium with α-particles and found that highly energetic, uncharged particles were emitted. This neutral radiation could in turn knock protons out of the nuclei of other substances. These particles were

A. positrons
B. neutrinos
C. beta particles
D. neutrons

3. The rest mass of a free proton is

A. greater than 1/12 the mass of a ^{12}C atom.
B. less than 1/12 the mass of a ^{12}C atom.
C. equal to the rest mass of a free neutron.
D. greater than the rest mass of a free neutron.

4. The decay rate of a radioactive sample is often referred to as its

A. half life
B. rate constant
C. activity
D. emissivity

5. Which of the following is the SI unit for the activity of a quantity of radioactive material?

A. becquerel (Bq)
B. curie (Ci)
C. sievert (Sv)
D. rutherford (Rd)

6. A particle moving through the water surrounding the core of a nuclear reactor emits Cherenkov radiation. Cherenkov radiation is emitted when a charged particle passes through a dielectric medium at a speed greater than the phase velocity of light in that medium. The index of refraction of water is 1.33. Determine the minimum speed at which the particle must be traveling through the water.

A. 0.67 c
B. 0.75 c
C. 1.00 c
D. 1.33 c

7. In α decay

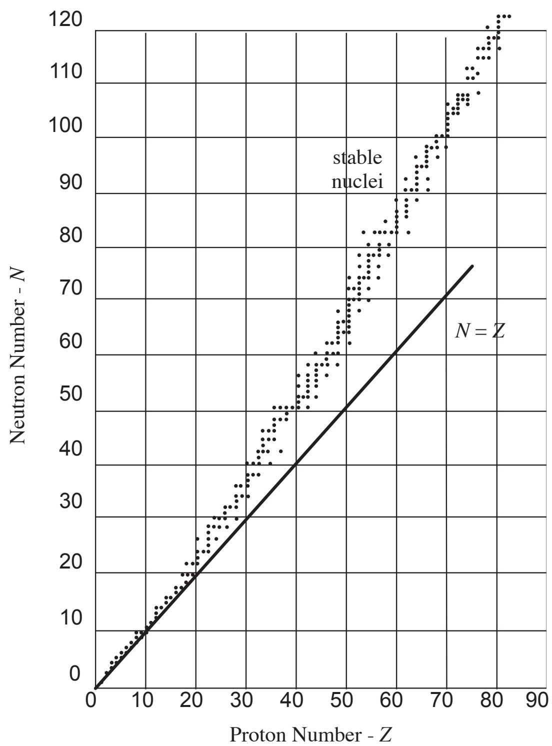
A. Z decreases by 1 and A does not change.
B. Z increases by 1 and A does not change.
C. Z decreases by 4 and A decreases by 2.
D. Z decreases by 2 and A decreases by 4.

8. Which of the following are β^- emitters with a long history of use as radiolabels within life sciences research?

A. ^{2}H, ^{14}C, ^{18}O, ^{32}P
B. ^{2}H, ^{13}C, ^{32}P, ^{35}S
C. ^{3}H, ^{14}C, ^{15}N, ^{35}S
D. ^{3}H, ^{14}C, ^{32}P, ^{35}S

9. Stable nuclides are represented by a narrow band of proton-to-neutron ratios on the graph of neutron number vs. proton number below. What type of radioactive decay would you expect to occur for the isotope of tin, $^{126}_{50}\mathbf{Sn}$?

A. β^+ decay
B. β^- decay
C. electron capture
D. α decay



10. Which of the following is the daughter nucleus produced by the β^+ decay of fluorine-18?

A. oxygen-18
B. neon-18
C. nitrogen-14
D. fluorine-17

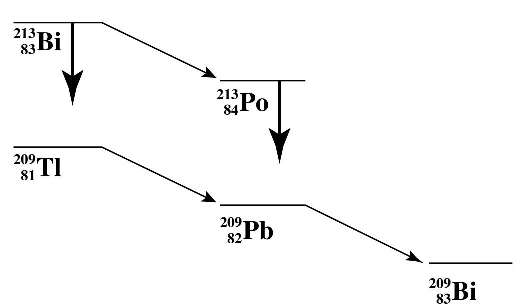
The following passage pertains to questions 11 - 15.

There can be therapeutic benefit to destruction or weakening of cells using radiation. Short-range radiotherapy is known as brachytherapy. Localization in the target organ may occur through the radionuclide being attached to a suitable biological compound. In most cases beta emitters are utilized.

An ideal therapeutic radioisotope is a strong beta emitter with just enough gamma to enable imaging. Lutetium-177 is prepared from ytterbium-176 which is irradiated to become Yb-177 (which decays rapidly to Lu-177). Similarly, yttrium-90 is used for treatment of cancer, particularly non-Hodgkin's lymphoma and liver cancer, and it is being used more widely, including for arthritis treatment. Lu-177 and Y-90 are becoming the main RNT agents.

With a short particle range and high linear energy transfer, α-emitting radionuclides demonstrate high cell-killing efficiencies. Development of therapeutic applications for α-emitting radionuclides is a major research area. For targeted alpha therapy (TAT), actinium-225 is often used, from which the daughter bismuth-213 can also be obtained (via three alpha decays) to label targeting molecules. The bismuth is obtained by elution from an Ac-225/Bi-213 generator in which the Ac-225 is firmly retained by the sorbent, and Bi-213 is eluted with various complexing agents. Bi-213 has a 46-minute half-life. The Ac-225 (half-life 10 days) is formed from radioactive decay of radium-225, the decay product of long-lived thorium-229, which is obtained from decay of uranium-233, which in turn is formed from thorium-232 by neutron capture in a nuclear reactor.

Bi-213 Decay Scheme



Ac-225 itself is an alpha-emitter and may be used directly, bonded to a protein or antibody such as anti-PSMA (anti-prostate-specific membrane antigen) for prostate cancer. Anti-Tac, a monoclonal antibody directed to the human interleukin 2 (IL-2) receptor, has been successfully conjugated to bismuth-212 (half-life 60.5 min) by use of a bifunctional ligand. The alpha decays of Bi-212 and Po-212 are the active ones destroying cancer cells over a couple of hours. Considerable medical research is being conducted worldwide into the use of radionuclides attached to highly specific biological chemicals such as immunoglobulin molecules (monoclonal antibodies). The eventual tagging of these cells with a therapeutic dose of radiation may lead to the regression of some diseases.

11. Which type of radioactive decay is involved in the conversion of $^{209}_{82}\mathbf{Pb}$ into $^{209}_{83}\mathbf{Bi}$?

A. β^+ decay
B. β^- decay
C. electron capture
D. α decay

12. Which of the following is an intermediate in the decay pathway from $^{225}_{89}\mathbf{Ac}$ to $^{213}_{83}\mathbf{Bi}$?

A. $^{209}_{81}\mathbf{Tl}$
B. $^{221}_{88}\mathbf{Ra}$
C. $^{217}_{85}\mathbf{At}$
D. $^{213}_{84}\mathbf{Po}$

13. 0.32 microCi was targeted by Bi-212-labeled anti-Tac to IL-2 receptor-positive adult T-cell leukemia line HUT-102B2. What was the residual activity of the Bi-212-labeled antibodies three hours after administration?

A. 0.02 microCi
B. 0.04 microCi
C. 0.08 microCi
D. 0.16 microCi

14. A sample of Ac-225 possessed an activity of 7.0 mCi at the time of shipment from Oak Ridge National Laboratory. Upon receipt at UCLA its activity was 2.9mCi. How much time elapsed during shipment?

A. 2 days
B. 4 days
C. 8 days
D. 12 days

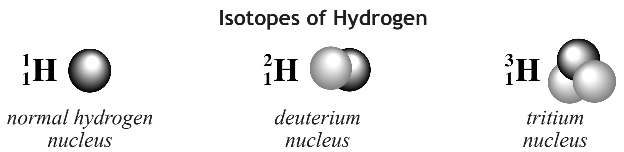
15. Which of the following is a factor that the radionuclides Lu-177 and Y-90 have in common?

A. Both Lu-177 and Y-90 may decay to a daughter nucleus in an excited state.
B. Compared to α emitters, Lu-177 and Y-90 emit particles which are less penetrating.
C. They are both positron emitters producing gamma photons through pair annihilation.
D. In their decay process, a proton changes to a neutron in the nucleus.

Nuclear Physics
Answers and Explanations

1. D

Isotopes are forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei.



2. D

Of the answer choices the only uncharged particles are neutrinos and neutrons. However, it is only through rare and special circumstances that the interactions of neutrinos with normal matter may be observed. Chadwick's experiment is credited as being the discovery of the neutron.

3. A

By definition one amu equals $\frac{1}{12}$ mass of a ^{12}C atom. The rest mass of a free proton is 1.0073 amu, and the rest mass of a free neutron is 1.0086 amu. This may seem contradictory given that there are six protons and six neutrons in the ^{12}C nucleus. How can there be less mass in the ^{12}C atom than there is in twelve free protons and neutrons. The binding energy of carbon-12 is the answer. This is around 92MeV which accounts for the missing mass energy equivalent of 0.064 amu in the difference between twelve free protons and neutrons versus the ^{12}C nucleus.

4. C

The rate of decay in disintegrations per second is called the activity of a sample. The activity depends on the number of nuclei present and their tendency to undergo decay, reflected by the decay constant λ of the radioactive species. Activity is directly proportional to the amount of nuclide present.

$$A = \frac{\Delta N}{\Delta t} = -\lambda N$$

A = activity (disintegrations per second)
N = number of radioactive nuclei
t = time
λ = decay constant

5. A

The SI unit of activity is called the becquerel (Bq):

$$1\text{Bq} = 1 \text{ decay/s}$$

The curie (Ci) (or, more commonly, milli- and microcuries) is often used instead. The curie was originally calibrated as the activity of one gram of radium.

$$1\text{Ci} = 3.7 \times 10^{10} \text{ decay/s}$$

The rutherford (Rd) is defined as an activity of one million decays per second. It is therefore equivalent to one megabecquerel.

The sievert (Sv) is the SI unit of ionizing radiation dose. It is a measure of the health effect of low levels of ionizing radiation on the human body. The sievert is important in dosimetry and radiation protection. One sievert carries with it a 5.5% chance of eventually developing cancer (based on a linear no-threshold model). One sievert equals 100 rem.

6. B

As described, Cherenkov radiation is emitted when a charged particle passes through a dielectric medium at a speed greater than the phase velocity of light in that medium. The index of refraction of a medium is defined as the ratio of the speed of light in a vacuum to the speed of light in the medium.

$$n = \frac{c}{v}$$

To determine the speed of light in a particular medium, divide the speed of light by the index of refraction.

$$v = \frac{c}{n}$$

$$v = \frac{c}{1.33} = \frac{c}{4/3} = \frac{3}{4}c$$

7. D

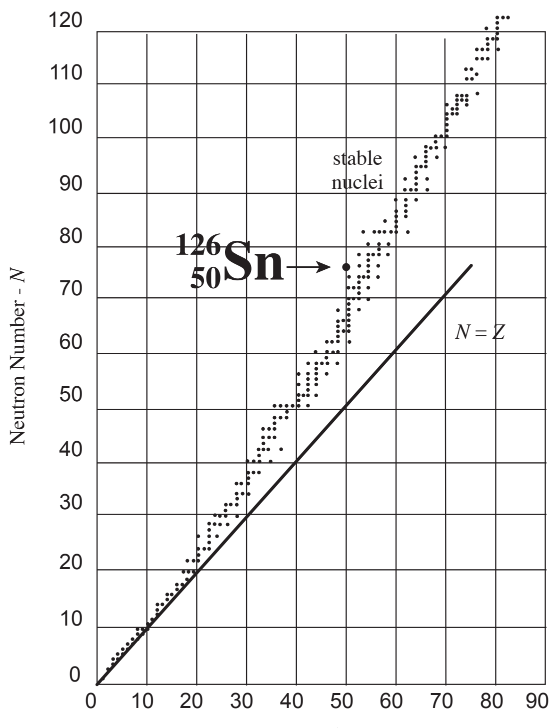
A nuclei undergoes alpha decay by emitting an α particle, which is identical to a helium nucleus – $^{4}_{2}He^{2+}$ – two protons and two neutrons. Atomic number, Z, decreases by 2 and mass number, A, decreases by 4.

8. D

^3H, ^{14}C, ^{32}P, and ^{35}S are β^- emitters. Although ^2H, ^{13}C, ^{15}N, and ^{18}O are also often utilized in life science research, those four are heavy stable isotopes, not radioactive. Unlike the β^- emitters, those isotopes are detected through their effect on the molecular weight of the substance into which they have been substituted.

9. B

The isotope of tin, $^{126}_{50}Sn$, referenced in the question is not within the island of stability. It has too many neutrons. For such radionuclides, β^- emission may occur, leading to a daughter nucleus closer to or within the island of stability. Through β^- emission a neutron in the nucleus will be transformed into a proton.



10. A

In ß$^+$ decay, a ß$^+$ particle, (a positron, the anti-particle of the electron) and a neutrino, v, are emitted. A proton changes into a neutron in the nucleus (Z decreases by 1 with A unchanged).

$$^{18}_{9}F \longrightarrow {}^{18}_{8}O + {}^{0}_{1}\beta^{+} + v$$

11. B

In ß$^-$ decay, a ß$^-$ particle, which is a high speed electron, and an antineutrino, $\bar{\upsilon}$, are emitted. A neutron changes into a proton in the nucleus (Z increases by 1 with A unchanged).

$$^{209}_{82}Pb \longrightarrow {}^{209}_{83}Bi + {}^{0}_{-1}\beta^{-} + \bar{\upsilon}$$

12. C

As the passage describes, bismuth-213 is obtained after three alpha decays from actinium-225. A nuclei undergoes alpha decay by emitting an α particle, which is identical to a helium nucleus – $^4_2He^{2+}$– two protons and two neutrons. Z decreases by 2 and A decreases by 4. The sequence of three alpha decays would begin with actinium-225 then to francium-221 then to astatine-217 and finally to bismuth-213.

13. B

Given that the half-life of B-212 is 60.5 minutes, as the passage indicates, a period of three hours is very close to three half lives. After three half lives, activity will have decreased from 0.32 microCi. to ⅛ value, or 0.04 microCi.

14. D

At the receipt of shipment the sample of actinium-225 has lost more than half of its original activity. In other words, a greater duration of time than a single half-life has passed. The half-life of actinium-225 is given in the passage as 10 days, 12 days is the amount of time which has passed.

15. A

As the passage indicates, they are both beta emitters whose decay reaction may lead to production of a gamma ray. Gamma decay occurs when a nucleus in an excited energy state, very often as the result of a prior decay event, emits a very high energy photon, a gamma ray, as it transitions to a lower energy state. For both of these isotopes, the majority of decay events land on the ground state daughter nucleus, but a percentage with each branches after beta decay to an excited state.