Year 12 Physics

Tutorial 9.8.D – Artificial Transmutations Answers

1. Chadwick showed that what was thought to be radiation ejected from the beryllium had to have mass because it did not have sufficient energy to then eject protons from paraffin wax. Using the velocity of the ejected protons and the laws of conservation of energy and momentum, Chadwick calculated the mass of the unknown particle. It was just a little heavier than the proton. Chadwick explained the process occurring in the experiment as:
   $^{4}_{2}He + ^{9}_{4}Be \rightarrow ^{12}_{6}C + ^{1}_{0}n$
   Chadwick explained that when the neutrons emitted from the beryllium collided with the light hydrogen nuclei in the paraffin, the neutron came to a sudden stop and the hydrogen nucleus (proton) moved off with the same momentum as the neutron had before the collision.
2. The de Broglie wavelength of neutrons is comparable to the spacing of the atoms in an atomic lattice of some elements and compounds. Neutron diffraction experiments can determine the interatomic spacing in some materials in much the same way as the Braggs did with X-rays.
3. Mass defect is the mass lost by a nucleus when nuclei undergo transmutation. If a helium nucleus was to be assembled for its component parts, the mass of the nucleus would be slightly less than the mass of two individual protons and neutrons. The difference in mass is converted into energy according to $E=mc^2$. This energy is used to bind the nucleus together and is known as the binding energy.
4. $\Delta m=0.03040$ u and E = 28.3 MeV
5. Binding energy per nucleon is the energy input needed to break the atom apart into its constituent nucleons. The greater the binding energy per nucleon, the more energy is needed to break the nucleus apart so those nuclides with higher binding energies are more stable.
6. (a) Elements with atomic mass less than iron-56 will release energy when they are fused together to make heavier elements. In this way the binding energy per nucleon is increased and the heavier nuclei are more stable. Elements to the right of iron-56 will only lose energy and increase their binding energy per nucleon by undergoing fission and becoming lighter nuclei.
   (b) That the strong nuclear force is a force that exists between all nucleons.
   (c) The larger the nuclei, the more unstable they are due to the increase in the number of protons. If they are becoming more unstable they possess more energy so less energy is needed to break them apart. Hence the binding energy per nucleon decreases.
7. Fermi expected that uranium-235 would take up a neutron and then undergo beta decay to produce neptunium-236.
   $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{93}Np + ^{0}_{-1}e + \overline{\nu}$
8. Boron readily absorbs neutrons so as to prevent neutrons from making further fission possible for the unspent nuclear fuel.
9. Moderators slow down neutrons improving the chance of the neutron being captured by the nucleus. Examples include, water, heavy water and graphite.
10. Control rods absorb neutrons and prevent them from making further fission possible. Absorbing neutrons slows down the chain reaction and reduces that rate at which fission of the uranium-235 is occurring.

11. If neutrons are moving too fast, they tend to pass straight through nuclei without being absorbed and no fission occurs. Thermal neutrons have been slowed down by a moderator such as graphite so that they are absorbed and cause fission. While most neutrons in a fission reactor are present due to neutron production in fission, most nuclear reactors include a "starter" neutron source that ensures there are always a few free neutrons in the reactor core, so that a chain reaction will begin immediately when the core is made critical. A common type of start-up neutron source is a mixture of an alpha/gamma particle emitter such as americium-241 with a lightweight isotope such as beryllium-9 that will absorb an alpha particle and release a neutron.

12. (a) -1.2 MeV – energy is absorbed and mass is created to make the fusion possible. The alpha particles are accelerated to high speeds for fusion.

13. (a) If the neutrons produced at each fission stage are absorbed by other uranium nuclei, the number of fissions occurring increases exponentially with time and this is called a chain reaction. If the number of neutrons in the reactor becomes stable, the reaction is said to be self-sustaining and no further starter neutrons are required.
(b) 201 MeV
(c)

X	***Y***	***x***
$^{140}_{54}Xe$	$^{94}_{38}Sr$	2
$^{139}_{53}I$	$^{95}_{39}Y$	2
$^{134}_{52}Te$	$^{100}_{40}Zr$	2
$^{141}_{55}Cs$	$^{92}_{37}Rb$	3
$^{141}_{56}Ba$	$^{92}_{36}Kr$	3
$^{148}_{57}La$	$^{85}_{35}Br$	3
$^{147}_{59}Pr$	$^{86}_{33}As$	3
$^{127}_{50}Sn$	$^{107}_{42}Mo$	2

14. The total decay energy is the sum of the alpha particle and the recoiling daughter nucleus. The difference in energy is the energy imparted to the recoiling daughter nucleus.

15. See table

Positive Impacts	**Negative Impacts**
▪ Ended WWII ▪ Improved our understanding of nuclear processes ▪ Created a carbon free way of making electricity ▪ Created nuclear powered submarines ▪ Created research reactors for making medical and industrial radioisotopes	▪ Killed more than 300 000 people at the end of WWI ▪ Increased the amount of radioactive material in the atmosphere and on earth due to the fallout from bombs and test explosions ▪ Started the Cold War post 1950 and the arms race ▪ Enhanced the potential for the mass destruction of the environment and the loss of human life