Year 12 Science: Atomic and nuclear physics: the nucleus, radiation and $E = mc^2$

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. How many protons and how many neutrons are in $^{239}_{94}\text{Pu}$?

2. Complete the alpha decay: $^{241}_{95}\text{Am} \rightarrow ? + {}^{4}_{2}\text{He}$.

3. Iodine-131 ($Z = 53$) is a beta emitter. Write the product.

4. What fraction of a radioactive sample is left after 4 half-lives?

5. Which radiation is stopped by a sheet of paper, and why does it travel so short a distance?

Task: answering like an Excellence report

Write a short answer to each question, then compare it with the model answers.

6. A uranium-235 nucleus absorbs a neutron and splits into barium-141 ($Z = 56$), krypton-92 and some neutrons. How many neutrons are released?

7. Explain where the energy released in this fission comes from, and how a reactor keeps the rate of fission steady.

Fix the mistake

8. Correct this statement: "In beta decay, one of the atom's orbiting electrons is thrown out."

9. Correct this statement: "After two half-lives, all of the sample has decayed."

10. Correct this statement: "Gamma rays are the most ionising because they go through everything."

11. Correct this statement: "In fission the mass number is lost and turned into energy."

Answer key (for parents and tutors)

1. How many protons and how many neutrons are in $^{239}_{94}\text{Pu}$?
   94 protons and 239 − 94 = 145 neutrons.

2. Complete the alpha decay: $^{241}_{95}\text{Am} \rightarrow \, ? + \, ^{4}_{2}\text{He}$.
   A = 241 − 4 = 237, Z = 95 − 2 = 93: $^{237}_{93}\text{Np}$ (neptunium-237).

3. Iodine-131 (Z = 53) is a beta emitter. Write the product.
   A stays 131, Z = 53 + 1 = 54: $^{131}_{54}\text{Xe}$ (xenon-131), with $^{0}_{-1}\text{e}$.

4. What fraction of a radioactive sample is left after 4 half-lives?
   $(½)^4 = 1/16$.

5. Which radiation is stopped by a sheet of paper, and why does it travel so short a distance?
   Alpha: its +2 charge and large mass make it ionise strongly, and every ionisation uses up some of its energy, so it is stopped after a very short distance.

6. A uranium-235 nucleus absorbs a neutron and splits into barium-141 (Z = 56), krypton-92 and some neutrons. How many neutrons are released?
   Before: A = 235 + 1 = 236 and Z = 92. After: Z of krypton = 92 − 56 = 36, and A left over = 236 − 141 − 92 = 3, so 3 neutrons are released: $^{1}_{0}\text{n} + \, ^{235}_{92}\text{U} \rightarrow \, ^{141}_{56}\text{Ba} + \, ^{92}_{36}\text{Kr} + 3\,^{1}_{0}\text{n}$.

7. Explain where the energy released in this fission comes from, and how a reactor keeps the rate of fission steady.
   The total mass of the barium, krypton and three neutrons is slightly less than the mass of the uranium and the neutron it absorbed. That missing mass Δm is released as energy $E = \Delta mc^2$, mostly as kinetic energy of the fragments, which heats the fuel; because c^2 is so large, a tiny Δm gives a huge energy. Each fission releases 3 neutrons, so the rate could grow very fast; control rods absorb the spare neutrons so that on average one from each fission causes the next, and a moderator slows neutrons so they can be captured. Connecting the mass loss to the energy, and the neutron count to the control of the chain reaction, is what makes this Excellence.

8. Correct this statement: "In beta decay, one of the atom's orbiting electrons is thrown out."
   The beta electron comes from the nucleus, where a neutron turns into a proton and an electron, so Z goes up by 1.

9. Correct this statement: "After two half-lives, all of the sample has decayed."
   Each half-life halves what is left, so after two half-lives a quarter is still there.

10. Correct this statement: "Gamma rays are the most ionising because they go through everything."
    Gamma is the least ionising; it penetrates furthest precisely because it rarely interacts with atoms.

11. Correct this statement: "In fission the mass number is lost and turned into energy."
    Mass number and atomic number are both conserved; the energy comes from the products having slightly less mass, by $E = mc^2$.