The Structure of Atoms

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1.

Element	Nucleon No.	Proton No.	Neutrons	Protons	Electrons
Nitrogen	14	7	7	7	7
Sodium	23	11	12	11	11
Potassium	39	19	20	19	19
Uranium	235	92	143	92	92

2. An atom of cobalt has a proton number of 27 and a nucleon number of 59.

   (a) Simply describe the structure of the cobalt atom.
   This cobalt atom comprises an exremely dense nucleus, of diameter $\sim 10^{-15}$ m, which contains 27 protons and 32 neutrons, bound together against the repulsion of the positively-charged protons by the short-range strong nuclear force. This contains over 99.9% of the mass of the atom. The rest of the atom, which occupies a sphere of diameter $\sim 10^{-10}$ m, is almost all empty space, with 27 tiny negatively-charged electrons to be found somewhere within it.

   Cobalt has several isotopes.

   (b) What are isotopes?
   Isotopes are variants of an element's nuclear structure, which have the same number of protons (and hence are the same elecment), but varying numbers of neutrons.

   (c) The symbol for the above isotope is written as $^{59}_{27}\text{Co}$. Write down two other possible isotopes of cobalt.
   $^{58}_{27}\text{Co}$, $^{60}_{27}\text{Co}$

   (d) Why are isotopes difficult to chemically separate?
   The chemical properties of an atom are determined almost entirely by the energy levels and arrangement of its outermost electrons, which are controlled by the charge on the central nucleus, $+Z$. Isotopes of an element have the same Z, and so their chemical properties are identical.

3. Uranium-235 and uranium-238 are isotopes of uranium, and they both have the proton number 92.

   (a) What do the numbers 235 and 238 represent?
   These represent the nucleon numbers (i.e. number of protons + neutrons) of the two isotopes.

   (b) What does 92 tell you about the nucleus of uranium?
   This tells you that the nucleus contains 92 protons, and therefore has a charge of $+92e$.

(c) What else does 92 tell you about the atom?
92 specifies the element as uranium, and gives the number of electrons needed to form a neutral atom.

(d) In which two ways are the two isotopes different?
The two isotopes' atoms have different masses (which allows them to be separated physically, e.g. by diffusion), and their nuclei have different numbers of neutrons. They also have different stabilities (both decay by α emission, but their half lives and emitted α particle energies are different: ^{235}U: 7.038×10^8 y, $E_\alpha = 4.679$ MeV; ^{238}U: 4.468×10^9 y, $E_\alpha = 4.270$ MeV) and natural abundances (natural uranium is made up of 99.3% ^{238}U and only 0.7% ^{235}U).

4. Which type of radioactive emission

(a) is positively charged?
α

(b) is not deflected by magnetic fields?
γ

(c) is the most penetrating?
γ

(d) is the most intensely ionizing?
α

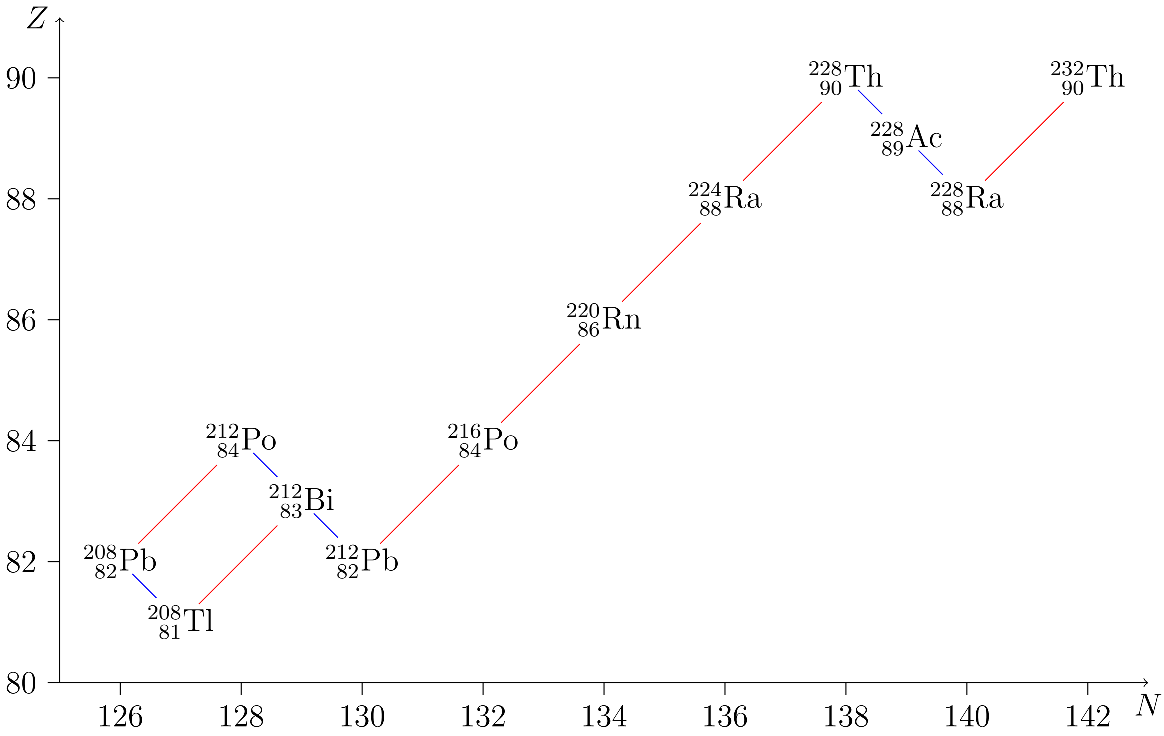
(e) cannot pass through cardboard?
α

(f) does not cause a change in mass number or atomic number?
γ

(g) has the greatest mass?
α

5. Draw an $N-Z$ decay graph for thorium-232 using the following data. Draw alpha decays with a red line and beta decays with a blue one.

thorium-232, radium-228, actinium-228, thorium-228, radium-224, radon-220, polonium-216, lead-212, bismuth-212, [polonium-212 (64%), thallium-208 (36%)], lead-208.



6. The isotope ^{235}U decays into another element, emitting an alpha particle. What is the element?
   $^{231}_{90}$Th (thorium)

   This element decays, and the next, and so on until a stable element is reached. The complete list of particles emitted in this chain is:

$$^{235}_{92}\text{U} \rightarrow [\alpha\beta\alpha\beta\alpha\alpha\alpha\alpha\beta\alpha\beta] \rightarrow \text{X}.$$

   What is the stable element X? (You could write down each element in the series, but there is a quicker way.)

   This is the quick way, introducing a **non-standard** column vector notation to keep things clear, in which

$$^{235}_{92}\text{U} \equiv \begin{pmatrix} 235 \\ 92 \end{pmatrix}.$$

   In this notation, the effects of α and β decays respectively are $\begin{pmatrix} -4 \\ -2 \end{pmatrix}$ and $\begin{pmatrix} 0 \\ +1 \end{pmatrix}$.

   In the decay chain, there are 7 α and 4 β, and so the final result is

$$\begin{aligned} &\begin{pmatrix} 235 \\ 92 \end{pmatrix} + 7\begin{pmatrix} -4 \\ -2 \end{pmatrix} + 4\begin{pmatrix} 0 \\ +1 \end{pmatrix} \\ =& \begin{pmatrix} 235 - 28 + 0 \\ 92 - 14 + 4 \end{pmatrix} \\ =& \begin{pmatrix} 207 \\ 82 \end{pmatrix} \equiv {}^{207}_{82}\text{Pb}. \end{aligned}$$