Episode 524: Stable nuclides

Hundreds of nuclides are known; this episode looks at the pattern of stability using an N-Z plot, and considers the need for an additional, attractive force to hold the nucleus together.

Summary

Discussion: Which stable nuclides exist? (10 minutes)

Student Activity: Using Excel to generate an N-Z plot. (20 minutes)

Discussion: Interpreting the graph. (5 minutes)

Worked example: Calculating the force between protons. (10 minutes)

Discussion: The nature of the strong nuclear force. (5 minutes)

Worked example + student example: Calculating nuclear densities. (15 minutes)

Discussion:

Which stable nuclides exist

Rehearse and extend your students' existing knowledge. Nuclei are composed of N neutrons and *Z* protons – collectively *A* = N + *Z* nucleons. Explain (or revise) nuclide notation; for example:

The heaviest stable element is bismuth-83, ${}^{209}_{83}Bi$. How many protons and neutrons in this nucleus? (83 and 126)

There are 90 naturally-occurring elements between hydrogen (*Z* = 1) to uranium (*Z* = 92). Is there anything odd about this? (Two are "missing"; these are purely artificial and man made, ${}^{99}_{43}Tc$ (technitium) and ${}^{63}_{61}Pm$ (promethium). Both are radioactive with relatively short half lives on a geological time scale, and thus would have decayed long ago.)

All elements beyond Z = 92 are man-made. So far (as of February 2004) the record is Z = 116.

Student activity:

Using Excel to generate an N-Z plot

Use a spreadsheet to generate a plot of N versus *Z* for stable nuclides. To save time (and transcription errors!) you could prepare an Excel spreadsheet with the data below already entered (columns for the element name, A, Z and, anticipating work to follow, the nucleus mass in atomic mass units u – see below).

Representative stable nuclides

${}^{2}_{1}H$	${}^{3}_{2}He$	${}^{6}_{3}Li$	${}^{9}_{4}Be$	${}^{11}_{5}B$	${}^{15}_{7}N$
${}^{19}_{9}F$	${}^{24}_{21}Mg$	${}^{36}_{17}Cl$	${}^{56}_{26}Fe$	${}^{75}_{33}As$	${}^{89}_{39}Y$
${}^{100}_{42}Mo$	${}^{113}_{48}Cd$	${}^{126}_{52}Te$	${}^{141}_{59}\mathrm{Pr}$	${}^{160}_{66}Dy$	${}^{180}_{72}Hf$
${}^{197}_{79}Au$	${}^{212}_{83}Bi$	${}^{238}_{92}U$			

TAP 524-1: Stability: Balanced numbers of neutrons and protons

Discussion:

Interpreting the graph

Describe the graph. (It is linear ($N \propto Z$) up to Z ~ 20, then increasingly N > Z – there is a 'neutron excess'. The neutron excess is crucial in explaining nuclear stability, and for setting up a chain reaction in the exploitation of nuclear energy.

Think about the Coulomb repulsion between protons. What are the neutrons doing in there? (Neutrons must help overcome the strong repulsion between the protons, partly by 'diluting them', but also providing an attractive force to balance the electric repulsion. Hence the name strong nuclear force.

Worked example:

Calculating the force between protons

If Coulomb's law has been covered, calculate the repulsive force between two protons that just 'touch', so the separation of their centres r is the diameter of a proton (1.4×10^{-15} m).

$F_e = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$ where $q_1 = q_2 = +e = 1.6 \times 10^{-19}$ C

$F_e \sim 100$ N

Discussion:

The nature of the strong nuclear force

Explain the need for the strong nuclear force to balance the Coulomb repulsion. This force must be attractive – it overcomes the coulomb repulsion; independent of electric charge – it acts between nn, pp and np; and very short range ~ 1fm = 10^{-15} m.

Worked example + student example:

Calculating nuclear densities

Calculate the density of a nucleon:

nucleon mass ~ 1.7×10^{-27} kg; radius ~ 1.4×10^{-15} m; density $\rho \sim 1.4 \times 10^{17}$ kg m^{-3}

This is enormous compared to the density of everyday matter. Ask your students to repeat the calculation for He-4 (or give data for other nuclides):

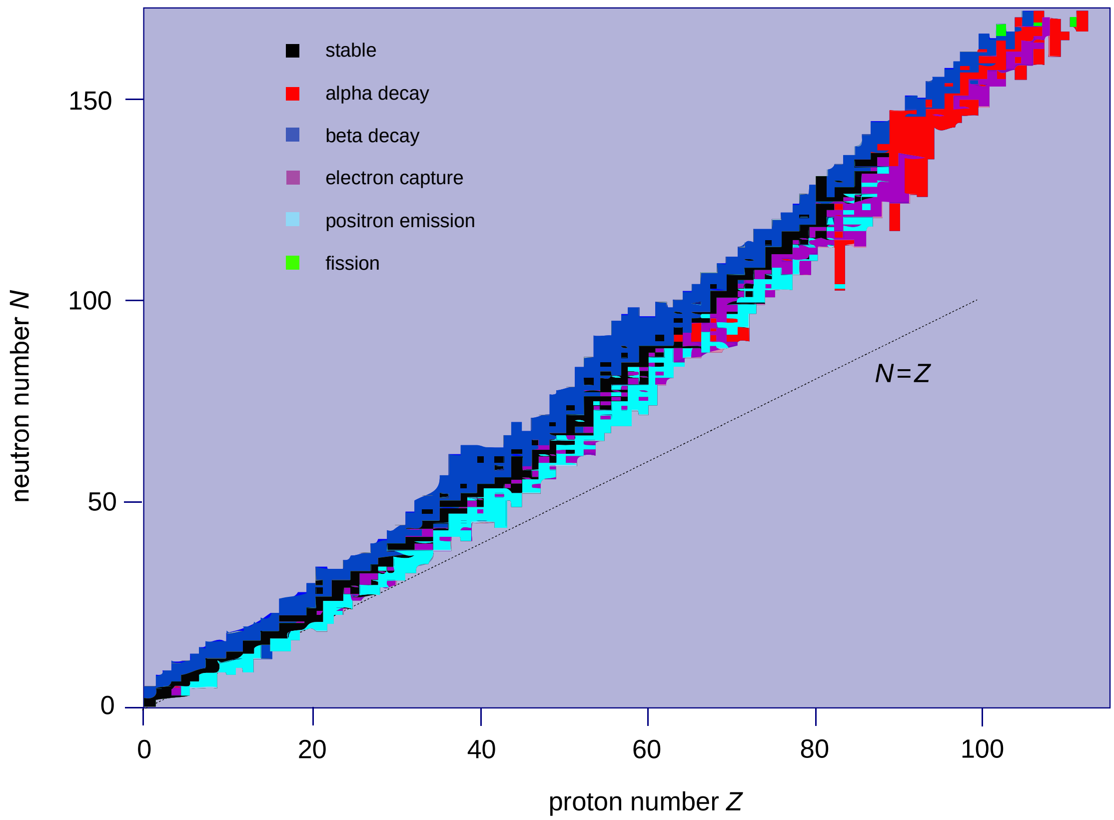
Nuclide mass ~ 6.6×10^{-27} kg; radius ~ 2×10^{-15}m; density ~ 1.6×10^{17} kg m^{-3}

So the density is roughly the same for all nuclei. This is summed up in the relationship:

$r = r_0 A^{1/3}$ with $r_0 = 1.4$ fm

TAP 524-1: Stability: Balanced numbers of neutrons and protons

Stable and unstable nuclei: balance of numbers of protons and neutrons



This plot of neutron number against proton number shows nuclei decay paths, and the trend of stable nuclei.

Practical advice

The diagram could be used as an OHT and discussed in class

External reference

This activity is taken from Advancing Physics chapter 18, 50O