TAP 525- 4: A binding energy calculator

This model removes the drudgery from the calculation of binding energies. There are three sheets. Sheet 1 does the calculations.



Sheet 2 holds the common data – masses for neutrons, protons, electrons, the value of one atomic mass unit in kilograms and the speed of light



Sheet 3 holds a sample of isotope data.



What to do:

Enter the values for the chosen isotope into the pale yellow boxes in sheet 1, following the tips in the comment boxes, and the binding energy is calculated and displayed in the pale blue box.

You will need to double click on the boxes and have a computer running Excel

Practical advice

This is provided as a constructed calculator, together with some useful data.

External reference

This activity is taken from Advancing Physics chapter 18, File 30T

TAP 525-5: Binding energy of nuclei

Looking for patterns

You will use the data in a spreadsheet to calculate the binding energy of a set of nuclei. You will then produce a plot to show how the binding energy per nucleon varies with mass of the nucleus.

You will need

* computer running a spreadsheet
* data provided in spreadsheet format

Building the spreadsheet

Take a look at the four columns in the spreadsheet data. The first is simply the name of some of the stable elements. This is followed by a column showing the atomic number (*Z*, the number of protons in the nucleus) and a column giving the mass number (A, the total number of nucleons, i.e. protons plus neutrons). Finally there is a column giving the actual atomic mass. The units of this column are atomic mass units, which are defined as exactly one-twelfth of the mass of a carbon-12 atom. The atomic mass unit (u) is also called the unified atomic mass constant, and has a value of 1.660 5402  10–27 kg.

Use this information to calculate the binding energy of each nucleus. The binding energy is simply the difference in energy between a nucleus and its constituent parts. This energy change can be measured as a change in the mass of the nucleus. A useful shortcut is that a mass difference of 1 atomic mass unit is equivalent to 931 MeV (million electron volts) of energy.

To find the binding energy you will need to subtract the mass of the constituents from the atomic mass. The constituents are Z protons, (A – Z) neutrons and Z electrons (electrons are included in the atomic mass). The masses of these in atomic mass units are:

* mass of neutron = 1.008 665 u
* mass of proton = 1.007 277 u
* mass of electron = 0.000 548 u

Create new columns in the spreadsheet giving the number of neutrons and the mass of the constituents. Now calculate the binding energy of the entire nucleus and the binding energy per nucleon. Plot this last quantity against mass number (not atomic number).

Double click on the chart below, you will need a computer running Excel.



There are four columns in the spreadsheet data.

* The name of some of the stable elements.
* The atomic number (Z, the number of protons in the nucleus).
* The mass number (A, the total number of nucleons: protons plus neutrons).
* The actual atomic mass. The units of this column are atomic mass units, which are defined as exactly one-twelfth of the mass of a carbon-12 atom. The atomic mass unit is also called the unified atomic mass constant, and has a value of 1.660 5402 x 10–27 kg.

You will have

* 1. A spreadsheet giving the binding energy of a selection of nuclei.
  2. A graph of binding energy per nucleon against mass number.

Practical advice

Only a selection of stable nuclei have been included, and the data have been pre-sorted so they are in mass number order rather than atomic number order, and should therefore produce a graph very readily. Students need to be encouraged to change the default settings in their spreadsheet to make the graph clearer and more easily read - an example from Excel is included here. There are some obvious spikes in the graph, which students should be encouraged to think about.

This chart is a springboard for discussing why binding energies are negative, why fission and fusion release energy and why certain nuclei are more stable than others. The chart given here indicates some of the key features.

Alternative approaches

Use the chart given and ask students to investigate different parts of it - the long slow slope showing where fission releases energy, the steeper slope where fusion releases energy and the spikes at 4He, 12C and 16O. These are particularly important for stellar fusion.

Social and human context

It has often been claimed that our Universe is a fluke because the values of certain fundamental constants are closely tuned to values that produce a Universe we can live in. One of these claims is that the fusion of helium in stars to produce carbon and hence all the heavier elements of which we are made requires a lucky coincidence of energy levels between 4He, 8Be (which is unstable and forms for a short time) and 12C. However, a glance at the chart shows that elements such as 12C and 16O are very close to being clusters of helium nuclei so it is, perhaps, no surprise that the relevant energy levels are close to coincidence. A good reference on this, and other aspects of basic laws, is:

Dreams of a Final Theory by Steven Weinberg (published by Vintage).

External reference

This activity is taken from Advancing Physics chapter 18, 140s

TAP 525- 6: Binding energy per nucleon

The graph below shows the binding energy per nucleon against nucleon number. Elements with a high binding energy per nucleon are very difficult to break up. Iron 56 has the highest binding energy per nucleon of any element and this which explains why there is so much of it in the universe.

0 20 40 60 80 100 120 140 160 180 200 220 240

Mass number (A)

9

8

7

6

5

4

3

2

1

Energy released by fission

Energy released

by fusion

Binding energy per nucleon (MeV)

The part of the curve to the left shows that two light elements can produce energy by fusion while the part of the curve to the right shows that a heavy element can produce energy by fission.

Therefore if a reaction takes place where the products are closer to the base then the original nucleus (nuclei) then energy is given out.

For helium the binding energy per nucleon is 28.3/4 = 7.1 MeV.

The helium nucleus has a high binding energy per nucleon and is more stable than some of the other nuclei close to it in the periodic table.

Some of the binding energies per nucleon for some common elements are shown in the following table.

Element Mass of Nuclear Binding Binding Energy

nucleons Mass Energy per Nucleon

(u) (u) (MeV) (MeV)

Deuterium 2.01594 2.01355 2.23 1.12

Helium 4 4.03188 4.00151 28.29 7.07

Lithium 7 7.05649 7.01336 40.15 5.74

Beryllium 9 9.07243 9.00999 58.13 6.46

Iron 56 56.44913 55.92069 492.24 8.79

Silver 107 107.86187 106.87934 915.23 8.55

Iodine 127 128.02684 126.87544 1072.53 8.45

Lead 206 207.67109 205.92952 1622.27 7.88

Polonium 210 211.70297 209.93683 1645.16 7.83

Uranium 235 236.90849 234.99351 1783.80 7.59

Uranium 238 239.93448 238.00037 1801.63 7.57

A very useful web site containing a huge nuclear database is to be found at:

<http://nucleardata.nuclear.lu.se>

It may be more helpful to consider the binding energy per nucleon diagram in the form shown in Figure 2 where reactions tend to move the nuclei towards the valley at the bottom of the curve. (In this case note that the binding energies per nucleon are given as negative values).

Figure 2

0 20 40 60 80 100 120 140 160 180 200 220 240

0

-1

-2

-3

-4

-5

-6

-7

-8

Energy released by fission

Energy released

by fusion

Binding energy per nucleon (MeV)

Mass number (A)

4 He

56 Fe

16 O

12 C

238 U

148 La

85 Br

External reference

This activity is taken from Resourceful Physics