# The periodic table

*Michael Hal Sosabowski*

This is Part II of our *School Science Review* periodic table theme; 2019 has been the International Year of the Periodic Table. In Part I, several articles gave an (often affectionate) account of the origins and development of the periodic table and our knowledge of the elements within. As the testimonial year draws to a close we can divert our gaze from the rear-view mirror and make some predictions about the future look and feel of the periodic table.

The hard reality is that, after a certain point in the periodic table, as elements get heavier, they become less stable. So much so that every element after lead in the table is radioactive. Until 2003, bismuth was regarded as the element with the highest atomic mass that is stable, but it was discovered to be extremely weakly radioactive: its only natural isotope, $^{209}_{83}Bi$, decays via α-decay with a half-life of $2.01 \times 10^{19}$ years – more than a billion times the age of the universe.

For elements at the lower end of the table, $A$, the mass number (the sum of nucleons, i.e. protons + neutrons), is twice $Z$, the atomic number (the number of protons). This means that for the most stable isotopes the number of protons is the same as the number of neutrons. This is why, on a plot of the number of protons vs the number of neutrons, the stable elements constitute the 'Valley of Stability' in the 'Sea of Instability', as was described in Part I (Scutt *et al.*, 2019). The Valley of Stability is bordered by 'Mountains of Instability': the positron ($\beta^+$) emitters (proton-rich nuclei) on the one side and the beta particle ($\beta^-$) emitters (neutron-rich nuclei) on the other (Figure 1). The reason for this becomes apparent when we consider that, within any nucleus, the Coulomb force repelling each proton from all others is at war with the strong nuclear force that is 'trying' to keep them together. At lower values of $A$, a (mere) single neutron per proton is able to dilute or stabilise the repulsive force generated by the protons. As $A$ increases, the neutron : proton ratio starts to increase, since more than one neutron per proton is required to dilute the repulsive force between protons. Examples of isotopic ratios are shown in Table 1.

**Table 1** Isotopic neutron : proton ratios

| Isotope | Neutron : proton ratio |
|---|---|
| $^{4}_{2}He$ | 1 : 1 |
| $^{12}_{6}C$ | 1 : 1 |
| $^{16}_{8}O$ | 1 : 1 |
| $^{56}_{26}Fe$ | 1.15 : 1 |
| $^{181}_{73}Ta$ | 1.48 : 1 |
| $^{208}_{82}Pb$ | 1.53 : 1 |
| $^{238}_{92}U$ | 1.59 : 1 |
| $^{243}_{95}Am$ | 1.56 : 1 |
| $^{294}_{118}Og$ | 1.49 : 1 |

This size-related instability means that the discovery of the most recent element, oganesson ($^{294}_{118}Og$), was produced in quantities of a mere four atoms (more correctly, nuclei), which have been found to have a half-life of 1 millisecond. In this context, that's almost an eternity – most of the heavy radioactive nuclei have far shorter half-lives; for example, the half-life of $^{212}_{84}Po$ is measured in nanoseconds. (For the sake of delightful over-extrapolation, all isotopes of hydrogen above tritium (which are, of course, synthetic) have half-lives measured in *yoctoseconds* ($10^{-24}$ s).)

The view could be taken that oganesson is the last page in a chapter, if not the book, since it is the final noble 'gas' and therefore makes a neat end to the periodic table. This may or may not be the case. The reality is that we are not expecting large swathes of new

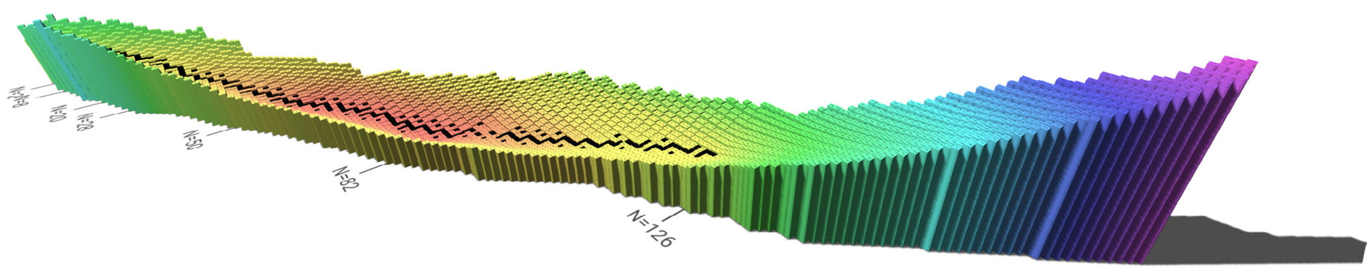


**Figure 1** The Valley of Stability bordered by the Mountains of Instability in the Sea of Instability; image: E. C. Simpson, The 3D Nuclide Chart, https://people.physics.anu.edu.au/~ecs103/chart3d/

elements, partly because they 'don't want' to be made, and also, as soon as they are, they decay because they are so unstable. The most recent elemental discoveries could only be made by examining decay products and extrapolating back to elucidate which new element *must have* decayed to produce them. Moreover, new elements are made by smashing smaller nuclei together in the hope that they fuse together. It is becoming increasingly difficult to make new elements since there are no stable target nuclei to bombard and attempt fusion with. We have got to the point where we need such heavy targets that they themselves are radioactive.

For example, oganesson-294 has been created by the following process:

$$^{249}_{98}\mathrm{Cf} + ^{48}_{20}\mathrm{Ca} \rightarrow ^{294}_{118}\mathrm{Og} + 3\mathrm{n}$$

(The sharper-eyed reader will notice the almost absurdly top-heavy isotope of calcium compared with the normal $^{40}_{20}\mathrm{Ca}$. $^{48}_{20}\mathrm{Ca}$ makes up 0.187% of natural calcium and undergoes very rare double beta-decay with a half-life of about $6.4 \times 10^{19}$ years.)

This may not be the whole story, though. We have known of the existence of 'magic numbers' of nucleons for a while. These are certain numbers of nucleons that confer particular stability on the nucleus; they are 2, 8, 20, 28, 50, 82 and 126 (somewhat analogous to the stability conferred by certain numbers of electrons in noble gas configurations). Might it be the case that element 126 (126 being the highest known magic number) is the 'Atlantis' in the Sea of Instability? Moreover, there is serious discussion of elements being viable up until (but not beyond) element 137. This element is often called feynmanium after Richard Feynman who first hypothesised that no nucleus (stable or otherwise) with an atomic number greater than 137 could ever exist, since its innermost electrons would need to orbit faster than the speed of light. For this reason, elements above 137 (137 being the fine structure constant; alpha) apparently cannot exist and above this value of $Z$ all nuclear stability bets are off.

As the International Year of the Periodic Table draws to a close, our opening article is penned by Gordon Woods who reflects on the year gone past. We then confine our attention to some biological aspects of the elements: James McEvoy describes the 'transition elements of life', followed by Rian Manville who focuses on potassium and its role in life. The final offering of this triumvirate is Angela Sheerin's exposition of the role of iodine in thyroid function.

We then divert our attention to the middle order of the theme, which reverts to plainly elemental matters. Dudley Shallcross *et al.* bring to the issue two noteworthy items concerning elements: 'Molecular nitrogen: inert but essential', and an essay concerning the various allotropes of oxygen, '$O^{\bullet}$, $O_2$ and $O_3$: the key to life on the Earth'.

The remaining themed articles look at table-wide topics and trends. We kick off with one of the absolute titans of the table, Theodore Gray, who gives a philosophical overview in his missive, 'The inevitable periodic table'. No periodic table themed journal issue would be complete without words from John Emsley, and he has co-authored with Michael Stephens and me on the 'periodic table of danger'. The penultimate article comes from the opening author, Gordon Woods, who outlines how to make a convenient teaching aid in the form of a folding paper version of the periodic table. Finally, with my four co-authors, I invite you along to *An Elemental Spectacle: A Guided Tour of the Darker Reaches of the Periodic Table*.

## Reference

Scutt, G., Okello, A., Scott, R. and Sosabowski, M. H. (2019) The periodic table of medicine. *School Science Review*, **101**(374), 71–80.

**Michael Hal Sosabowski** is Professor of Public Understanding of Science in the School of Pharmacy and Biomolecular Sciences at the University of Brighton. Email: M.H.Sosabowski@brighton.ac.uk