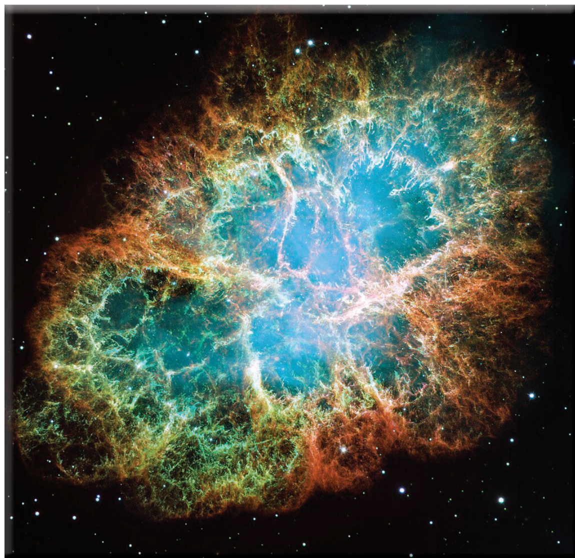
On the Likelihood of Many Naturally Occurring Transuranic Elements

by John M. Boyer, PhD, RFSPE

Author's Note: The text content of this article originally appeared in *MC^2: Journal of Mensa Canada*. Volume 56, Number 5, Nov./Dec. 2023, pp. 6-8. This article exemplifies the type of experiences you may enjoy upon joining the ISPE Goodreads Gang, and it also exemplifies an activity that corresponds to "Material published outside ISPE to promote Society/attract membership" on the ISPE Advancement Application.



Introduction

In considering recently how I could do more as a Mensa Canada member, I thought of sharing an activity in which I'm involved that is part of another high-IQ organization called the International Society for Philosophical Enquiry (ISPE). Within ISPE, we have formed a members-only group on the Goodreads platform, a book club that we call the Goodreads Gang—or, simply, the 'Gang. Every two months, 'Gang members nominate, select, read, and discuss a book. The two-month cadence was chosen to allow everyone time to fit this activity into their other reading and busy lives. I'm sure that, as a fellow Mensan, you love intellectually stimulating reading, and this activity can augment that experience with an ability to share your thoughts with and gain additional perspectives from other highly gifted people in your own 'Gang—a real win-win arrangement! To help you assess the veracity of this claim, my intent in this paper is to give a concrete example of the types of books that could be selected and kinds of discussions that could occur in a book club such as the one in ISPE or such as one you could establish or join in your own Mensa chapter or region.

The most recent book completed by the ISPE Goodreads Gang was *The Disappearing Spoon* by Sam Kean.[1] It is a well-researched book by an articulate author who has done a fantastic job presenting the concepts and stories around the discovery and utility of many elements in the periodic table. In the next sections, I'll start off with preliminary information on chemistry that can be gleaned from Kean's book (or any chemistry class), followed by basic information on naturally occurring and so-called synthetic or man-made elements. Then, I'll present an extract of one of my 'Gang discussion posts about Kean's book on some naturally occurring "synthetic" elements. Finally, I'll present new content in furtherance of that post and in support of this article's title.

Preliminaries

Chemical elements are substances that can occur as single units called atoms that comprise a set number of protons and a variable number of neutrons in a nucleus as well as a number of electrons that is typically equal to the number of protons, which are arranged in levels and shells orbiting the nucleus. For example, each oxygen atom has a nucleus with eight protons and eight neutrons as well as eight electrons orbiting the nucleus. Many elements have subtle variations called isotopes that vary based on how many neutrons accompany the proton(s) in the nucleus. For one example, there are three main isotopes of hydrogen, the atoms of which contain one proton and between zero and two neutrons in the nucleus, plus one electron orbiting the nucleus. Another example is cesium, which has many known isotopes, especially including a non-radioactive isotope used in atomic clocks and another that is radioactive waste material from nuclear reactors.

Often, atoms of one or more elements chemically bond into larger single units, called molecules, by sharing electrons. For example, one oxygen atom can share an electron with each of two hydrogen atoms to form a molecule of water (denoted H_2O). Sometimes, atoms of an element share electrons with other atoms of the same element, such as an oxygen atom sharing two electrons with another oxygen atom to form a molecule of O_2, which is the form of oxygen that we breathe.

Atoms of elements with larger nuclei can also be constructed from atoms with smaller nuclei in a process called nuclear fusion. For example, the sun creates the energy we need to live on earth by a nuclear fusion process that fuses hydrogen atoms into helium atoms, which have two protons in their nuclei. Every second, the sun fuses about 600 million tons of hydrogen into helium, and in the process releases the energy equivalent of about four million tons of mass.[2] One gets the tiniest sense of the staggering size of the sun when one contemplates that this has happened within our sun for every second of the last four and a half billion years and will continue for every second of the next four to five billion years.

The "Natural" Elements versus the "Synthetic" Elements

Although our sun is immense in comparison to ourselves, it is but of middling size in the grand scheme of things. Stars that are many times the size of our sun can generate enough pressure in their cores to cause nuclear fusion of heavier elements once they run out of hydrogen, all the way up to iron and nickel. Beyond this size (26 to 28 protons in the nucleus), nuclear fusion ceases to produce energy needed to offset the inward gravitational collapse of a massive star. A collapse that does not ignite fusion of heavier elements can trigger a shock wave that blows away many solar masses of material in a supernova explosion.[3]

According to many sources, including Kean,[1] supernova explosions have created virtually all elements of the periodic table that we find in nature, up to uranium, the atoms of which have 92 protons in their nuclei. When the shock waves of different supernovae intersect, new star systems coalesce, seeded with all the heavy elements produced during the stars' explosions, and it is for this reason that these elements have been called "natural" elements.

Elements with nuclei containing more than 92 protons are called transuranic elements, and they are generally considered to be "synthetic" because they are not found in nature, which is comprised virtually entirely of all the elements we inherited when our solar system was born. Instead, these elements are regarded as being man-made, i.e., human-made. For example, plutonium atoms have 94 protons in their nuclei, and plutonium was discovered by being synthetically produced in the early 1940s.[4]

Some Naturally Occurring "Synthetic" Elements

Upon reading the statement in Kean's book that uranium is the heaviest naturally occurring element, I wondered why heavier elements are not produced in a supernova explosion. In general, it is increasingly difficult to create ever bigger nuclei because positively charged protons repel each other. More and more neutral neutrons provide buffering within a nucleus, but at some point it's just too much energy to keep too many protons in the same nucleus. Yet, this is only a reason why there might be a maximum atomic number, not why some heavy elements with atomic numbers known to be feasible, such as plutonium and fermium, are not produced by a natural phenomenon like a supernova explosion.

Although uranium is purportedly the heaviest element found on earth that is produced by the so-called rapid neutron-capture process, or r-process,[5] of a supernova explosion, there is another natural process called a neutron star merger[6] that has even higher energy, enough to produce even heavier elements like neptunium and plutonium. In fact, the delightful, color-coded periodic table in the Wikipedia page for the r-process[5] shows that even most uranium comes from neutron star mergers rather than supernova explosions. Furthermore, there is a natural geological process that causes trace amounts of plutonium to develop within uranium ore deposits[7] (for example, a plutonium atom can result during the radioactive decay of a uranium atom, which produces thorium and helium, and occasionally the helium could careen into and fuse with another uranium atom in the ore deposit, resulting in the plutonium atom).

Although neptunium and plutonium are produced by natural processes, there are two factors that have caused them to often be called human-made elements. The first is that the half-life durations, or radioactive decay rates, of neptunium and plutonium are short enough that no detectable amounts of these elements would remain from among the matter in the primordial soup from which the earth formed about 4.55 billion years ago. The second is that the natural processes by which these elements can occur were not discovered until well after they were discovered by being created with the synthetic processes developed and performed by human beings. In light of the discovery of these natural phenomena, the Nobel Prize-winning discoverer of plutonium, Glenn Seaborg, has stated that "perhaps we should rethink the number of naturally occurring elements and recognize that rather than 92, there are really 94 such elements."[7]

On the Likelihood of Many Naturally Occurring "Synthetic" Elements

Not only can plutonium be generated naturally by the rapid neutron-capture process, but this r-process is also part of the synthetic creation of heavier elements up to fermium, with an atomic number of 100. Given that the half-life durations of elements heavier than plutonium are drastically shorter than plutonium (except two of eight isotopes of curium with similar half-life durations), one naturally wonders whether trace amounts of these heavier elements occur naturally in supernova explosions and neutron star mergers and then simply decay into nothingness long before humans have a chance to detect them.

It appears that a statistically reliable answer can be found in the means by which fermium was first discovered, which was in the fallout from the first successful test of a hydrogen bomb;[8] einsteinium was also found in the same fallout. Consider for a moment the size of a solar mass based on the description above that the sun could burn over 600 million metric tons of hydrogen for every second of about nine billion years. Then, consider that a supernova explosion blows several solar masses' worth of material across many light years. By comparison, this hydrogen bomb test—always a horrible decision—involved so little energy that it left the earth entirely intact, despite the earth being a measly 1/333,000th of a solar mass. If such a cosmically puny nuclear explosion produced the likes of fermium and einsteinium, then these heavy elements must be a statistically certain outcome of a supernova explosion's r-process as well.

Although the phrase "likelihood of many" has already been satisfied by the statistical certainty argument above that the r-processes of supernova explosions (and neutron star mergers) create heavy elements up to fermium, it is still worthwhile considering even heavier elements. It is easy to peruse the Wikipedia pages of these elements using the links from the Wikipedia periodic table.[9] In such a perusal, one can see that the half-life durations of these elements are ridiculously short, measured in days, hours, minutes, seconds, and often even milliseconds. If these elements are created in a supernova explosion or neutron star merger, as I suspect, then all traces of them would vanish by radioactive decay far too quickly for humanity to measure with current technology. Perusing these pages also reveals that our synthetic methods for creating all heavier elements above fermium still involve bombarding the nuclei of heavy elements with the nuclei of lighter elements. Again, within the practically incomprehensible amount of matter and energy involved in a supernova explosion or similar event, what is the likelihood of similar bombardments *never* happening during the event? Essentially zero.

Conclusion

In the end, it is far more reasonable, from a statistical perspective, to assume that every element that can possibly exist can be and already has been created by natural processes, even if we humans haven't witnessed those natural processes yet. Regarding what can possibly exist, there appears to be a hard limit near the atomic number of 137, because some electrons in such a big atom would need to travel faster than the speed of light.[1] The fact, then, that humanity has developed only synthetic processes for creating elements up to atomic number 118, means simply that we are, in all *likelihood*, still about eighteen elements behind Mother Nature!

It is also my hope, dear reader, that you will take away from this article a better sense of the kind of additional information one may encounter or produce when having a shared experience with a book like Kean's. If so, then hopefully you, too, will be inspired to found or join a book club group like the Goodreads Gang in ISPE.[10]

NOTES

1. Sam Kean, *The Disappearing Spoon: And Other True Tales of Madness, Love, and the History of the World from the Periodic Table of the Elements* (Boston, MA: Little, Brown and Company, 2010).

2. Please see https://en.wikipedia.org/wiki/Nuclear_fusion

3. Please see https://en.wikipedia.org/wiki/Supernova

4.Please see https://en.wikipedia.org/wiki/Plutonium

5. Please see https://en.wikipedia.org/wiki/R-process

6. Please see https://en.wikipedia.org/wiki/Neutron_star_merger

7. Please see https://www.scientificamerican.com/article/do-transuranic-elements-s/

8. Please see https://en.wikipedia.org/wiki/Fermium

9. Please see https://en.wikipedia.org/wiki/Periodic_table

10. Please see https://www.thethousand.com/ **Ω**