

Elements of Heroism

by *Suze Kundu*

In today's periodic table, 118 elements stand side by side, neatly arranged in rows and columns, mapping out their relative size, proudly sharing their family's traits, and showcasing their relative reactivity and predicted behaviour in different situations. Back in 1869 when Dmitri Mendeleev devised the arrangement of elements we use to this day, there were notable gaps left for elements that had not yet been discovered. As the arrangement of the elements was based on a range of physical and chemical properties, it was easy to predict some of the properties of the missing elements. It was in these gaps that both scientists and artists alike dared to dream about elemental discoveries with both predicted and unpredicted properties. Comic book and science fiction writers in particular had fun postulating some of the possible elements that would give their superheroes the characteristics they required to carry out their tasks. They created fictional elements in place of some of the as yet undiscovered elements, many of which now share properties with elements that exist today.

Fictional elements feature in a range of superhero worlds. Invariably, these materials possess materials characteristics that solve a particular problem or meet a specific need. Many of these made-up elements could fit logically into the periodic table, resembling an existing element. However, let's start with an element that currently has no place on today's periodic table, owing to the definition of 'element' we use; neutronium. The number of protons in a single atom from a collection of identical atoms defines an element. For example, if the atoms of a pure element happen to all contain six protons, that atom is defined as a carbon atom, regardless of how many neutrons and electrons it may possess; variation in the number of neutrons gives rise to a range of isotopes with different relative atomic weights and the potential for instability and radioactive decay in those with more neutrons than protons in the nucleus.

If an atom is made solely of neutrons, it does not fit this definition of an element, as its atomic number is zero. Such an element would occupy position zero on the periodic table with one fewer proton than hydrogen, the first element in the periodic table. Where would this element go? Does it exist purely as a collection of single particles? Can it be referred to it as an atom if it has no protons, no nucleus, and no electrons orbiting it? Can neutronium particles clump together in a stable form? Do differently-sized clusters behave

the same? Can we still call all of these materials neutronium, or do they require more specific names? Without electrons or any sort of electrical charge generating an attractive force, how can these particles bind together? Is there a maximum size of clump? Despite the several tricky questions that arise when we begin to talk about this particular fictional element, neutronium has made several appearances in many episodes of *Star Trek*.

Neutronium doesn't waste any space with near-empty orbitals, unlike like a hydrogen atom. Given this, it is highly compressible, therefore it is no surprise that this fictional element is extremely dense. Is neutronium strong? In *Star Trek*, yes, however most materials utilise weak intermolecular, or indeed interatomic, forces to bind individual atoms together, if not a covalent bond where electrons are shared between atoms. If there are no attractive forces between atoms, and no electrons available for bonding, the particles cannot bind to one another, nor can they repel each another. As such, it is unlikely that this form of neutronium could withstand large impact forces. It is however so dense that it can distort time and space.

This form of neutronium has been hypothesised to be a real-life material found within small, dense



Widmanstätten pattern in a meteorite at the American Museum of Natural History (credit: Dr Suze Kundu)

neutron stars. If we define neutronium as a collection of single neutron particles, clusters of neutron particles give rise to dineutronium, trineutronium, tetraneutronium, pentaneutronium, and so on, each named for the number of neutron particles that have bound together. Whether we can call them isotopes of the same material depends on whether we can indeed say that neutronium is an element with atomic number zero. This hypothetical clustering is only possible within neutron stars, where the gravitational force is strong enough for particles to bind together for short amounts of time.

This description of neutronium does not match the material properties of the neutronium in *Star Trek*. Given the fact that the material is used as a strong armour for ships and machinery, it must be a material whose atoms are tightly bound together. Without this, it simply would not be able to withstand an attack. While its density may have contributed to its name, the material seems to be almost indestructible in the low gravity conditions of space. Under such low gravitational force, hypothesised neutronium would immediately dissipate away as the particles would resist remaining in their highly compressed state. It may be possible to artificially create a large gravitational force, but if it were strong enough to hold neutronium particles together, it would also be destructive to all other materials, not to mention creatures on the ship. It is therefore thought that the neutronium in *Star Trek* more closely resembles a much heavier element on the periodic table, such as the transuranic elements, or even an alloy like stainless steel with high density and tensile strength. Similarly, the so-called deuteronium employed as a fuel in Cardassian vessels would make a terribly energy-inefficient choice if the fuel were as dense as the similarly named dineutronium described here.

While there is no place for neutronium in the periodic table as we know it, creators of some fictional elements have been so bold as to occupy the place of existing elements on the table. If we once again look at *Star Trek*, the source of a huge amount of research inspiration, we find an element called dilithium with atomic number 87, which in our world corresponds to the element francium. Dilithium is somewhat of a misnomer, as it is not simply two lithium atoms bonded together, but an element all of its own. Dilithium has the ability

to keep matter and antimatter separate within what is known as the warp core, a piece of kit a little like a reactor that

generates enough useful energy to allow the *Star Trek* crew to navigate their ship through space at a speed faster than light (in ways that are, thankfully for us, better confined to physics journals). By controlling the amount of interaction between matter and antimatter, these two substances that would otherwise violently explode on contact have the energy of such a reaction liberated in a controlled manner through sustained low-level annihilation. This is what powers the huge space ships seen whizzing through space in the show.

Not content with having invented just one element, another of the many other fictional elements in *Star Trek* is trillithium, which is a by-product of these propulsion systems. Trillithium is able to inhibit nuclear reactions, such as this fusion of matter and antimatter in the warp core, thus working in beautiful synergy with dilithium as a handy engineering control for maximum safety onboard the ship. Though such materials have not yet been discovered, they continue to provide inspiration for technological advances in nuclear power in the world today.

Another element found within the realm of superheroes is kryptonite. This element exists in a range of shades, though the most familiar colour is green. Kryptonite usually glows, and its radiation is harmful to Superman's species, though it does not have as much of an impact on humans. While this element is not found on the periodic table, we have a similarly named noble gas element in krypton, which shares the same name as the alien planet that kryptonite originated from. Superman famously had some sort of allergy to this



Images Credits, see page 3.



material. As the meteorite that brought kryptonite in the universe was the only source, Superman was able to trace the mineral back to his home planet and discover his own origin story. In a similar way, there are certain areas in the world where terrains have such specific elemental compositions that samples can be analysed and traced back to their geographical origins.

Similarly, a number of real-life oddities on Earth are meteorites. The Earth's heavy bombardment from meteorites some 4 billion years ago gave rise to many 'alien' discoveries, such as the Widmanstätten patterns displayed in the Arthur Ross Hall of Meteorites at the American Museum of Natural History. Such crystal grain patterns had never been seen before. These strangely patterned rocks arrived here in the same way as kryptonite; hitchhiking inside a chunk of space rock.

We have two of those aforementioned neutron stars to thank for the presence of many precious metal elements on Earth. Most elements heavier than iron, and not synthetically produced, were formed when two neutron stars collided, throwing out enough energy for lighter atoms to fuse together to make heavier atoms of new elements. The Earth formed from many fragments of rock containing these elements, and these elements sank down into the Earth's crust owing to their relatively higher density, while lighter elements and compounds floated to the top to form the Earth's crust. However, we are still able to mine precious metals held in rocks on the surface of the Earth thanks to the continued influx of similar meteorites containing these elements that landed on Earth and settled into the Earth's crust, ready for us to mine them.

Having looked at elements that are comparable to existing real elements in name or property, let's focus on a mysterious element that possesses many desirable properties for its Middle Earth users; Mithril, which features in the Lord of the Rings trilogy of books. With a range of amazing chemical and physical properties that you would be hard-pressed to find in any one single element in the real world, mithril has a range of applications, from decoration to armour. With such versatility and reliability, this element was revered and hunted by many in Middle Earth. Mithril is a shiny, silvery metal, which is said to gleam and glow in moonlight, and can be shaped easily to make anything from an ornate door frame to a crown, and from a stone-set ring like Narya, one of the three rings of the elves of Middle Earth, to several rings connected as chain mail, like the chainmail shirt that Frodo sports under his regular elven clothes.

It is rare for any metal to retain a shiny surface as, over time, oxygen in the air oxidises the metal, forming a thin and protective oxide layer on the surface.

This reduces the reactivity of the metal, and can also change its properties if, for example, the oxide is less shiny, is brittle, or does not conduct heat or electricity in the same way as the metal would. As mithril remains so shiny, it either does not oxidise, or mithril oxide is also very shiny and possesses many other properties of the elemental metal itself.

For mithril to be used in chain mail, it must be strong and tough to be able to protect the wearer in combat, malleable enough for rings to be shaped or have a low enough boiling point for rings to be cast from it, and light enough to wear without impediment to stealth and swiftness in battle. If we were to try and recreate something as strong and light on Earth, we could look to titanium, but its similarities stop at its low density and high strength, as it is inflexible and not malleable. The closest material is an alloy of stainless steel with a nanocarbon content high enough to make it both strong and light, but that can also be cast into tiny rings ready to be interlinked. The biggest challenge would be keeping the material shiny, as most materials tarnish over time and with use.

As researchers continue to experiment with metals that are both light and strong for use in cars and aeroplanes to increase their energy efficiency and reduce pollution, mithril has inspired another exciting area of research; wearable tech. In 2003 the MIThril group at the MIT Media Lab were working on human-computer interactions for technology worn by people for health and communications [1]. One such piece of technology was a wearable helmet that delivered real-time diagnostic information to the wearer, while also protecting them and allowing them to interact with the various components of wearable tech on their bodies [2]. A helmet with an onboard computer immediately reminds me of Iron Man, and a range of fictional elements which reside in the Marvel Cinematic Universe, or MCU.

In the MCU we see many leaps of technological faith, but some of it could be attributed to cutting-edge science being carried out today. For example, in the MCU, Captain America's iconic shield is made of pure vibranium. Black Panther, who hails from Wakanda where the meteorite containing vibranium fell, has a thin and armoured suit made of fabric woven with vibranium. According to the 2018 film 'Black Panther,' vibranium is "the strongest substance in the universe." It must also be very light if it is carried around as a shield, thrown at enemies, and worn as an agile smart-suit. Though Captain America's shield develops some bumps and scratches from Black Panther's claws it was, at least until recently, seen as being virtually indestructible. That was of course until Infinity

War and EndGame, the MCU's two-part culmination of a series of movies leading up to the moment they need to restore half the world's population after the evil Thanos indiscriminately turned them to dust.

Thanos was able to break Captain America's shield, suggesting that his gauntlet is either made of vibranium, or a material even stronger than vibranium. We also see Tony Stark's Iron Man help defeat Thanos by removing the Infinity Stones from his gauntlet. How is that possible? Fan theories suggest that they could simply have migrated to Tony's gauntlet if the two were made of a similar nanomaterial. Given that Tony Stark's father Howard first made a shield for Captain America, and that Tony presented Captain America with a new shield in EndGame, it is not difficult to believe that there may have been enough scrap vibranium lying around for him to have fashioned some wearable tech out of it.

The creator of the shield, Howard Stark, tells Captain America that vibranium is a third as dense as steel alloy. Presumably it can also be spun into fibres that can be woven into a mesh if it used in Black Panther's armoured suit. Information in the MCU also tells us that this suit is capable of withstanding the impact of most weapons. Comparing this strength and density to a real-life element, titanium would once again be close [3]. However, even though it is robust and resistant to scratching and denting, it would simply be too heavy with around two thirds of the density of steel.

Vibranium is able to absorb the energy of an impact, store it and release it later, effectively behaving like a capacitor. It is also able to spread a large amount of energy across the shield or the suit, rather than through it, so any impact from a weapon would be dissipated across the body rather than towards and through it. With this many wonder properties, it is hard to believe that there is an Earth-bound element that could possibly match these properties. Beautifully, it is the element that connects every element in the periodic table that also provides a potential connection to our fictional world.

I mentioned carbon at the start of this essay. Elemental carbon is able to form a range of polymorphs, from diamond to graphite, and a range of intricate cage-like

balls and straw-like tubes. If we were to isolate one of these monoatomic layers of carbon we have graphene, which would be a good substitute for vibranium, which can also behave like a capacitor, and also has low density and high tensile strength.

Given that this is a celebration of the periodic table of elements, there has been no mention of alloys, however the fictional alloys and composites featured in superhero worlds have some of the most fascinating and extreme physical and chemical properties, and deserve their own future article when we celebrate such materials. Fictional elements were created by people who dared to look at existing research and think outside the box to solve their particular problem. On both an atomic scale as well as a professional scale, the best chemistry happens when elements work together. New compounds and novel composites can give rise to new developments and applications, while working as a team on different aspects of the same problem can lead to faster development of real-life solutions to the global challenges that we face. For elements, as well as for chemists, there is only one way to sum this up; Avengers, Assemble. 🌐

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