EuChemS
European Chemical Society

The 90 Elements that make up everything

Support notes to the updated EuChemS Periodic Table (2023)

In 2019 as a contribution to the International Year of the Periodic Table, the European Chemical Society released a new kind of Periodic Table. Over the years this document has been updated – following scientific discussions in dedicated workshops – to introduce the concept of sustainability (in the subtitle and in the colours of C, N and P), to highlight the unique position of carbon (C) and to flag a greater risk of shortage of lithium as we move to a greater use of lithium batteries.

The Periodic Table that we usually use is one developed by Dmitri Mendeleev and published in 1869. It orders the elements in groups where each element has similar properties and in rows where different shells of electrons are being filled.

- The elements appear in order of their atomic number (number of protons in the nucleus)
- Mendeleev based his Table on the 61 elements known at that time but had to leave some gaps. These elements (gallium (Ga), scandium (Sc) and germanium (Ga)) were subsequently discovered and had the properties that Mendeleev predicted for them
- Much more detail and videos concerning all the different elements can be found at Periodic Table of Videos[1]

Availability

Areas

The 90 natural elements that make up everything (and they do really make up EVERYTHING) has been drawn so that the area occupied by each element gives an indication of the amount of that element in the Earth's crust and atmosphere.

- The areas relate to numbers of atoms of each element on a logarithmic scale.[2]
- There are actually 92 elements in the chart. Two of these elements, technetium (Tc) and promethium (Pm), which are coloured white, are not included in the 90. These are radioactive elements that are mostly synthetic, although very small amounts of Tc do occur naturally.
  - Technetium (Tc) is very important for imaging soft tissue such as the heart and it is made through radioactive decay of a longer-lived isotope of Molybdenum (Mo). The formed isotope of Tc has a lifetime of 6 h, just long enough to emit the gamma rays that are needed for imaging and detection by a gamma ray camera, after which it is harmlessly excreted.
- The other synthetic elements from 93 to 118, after uranium (U), which complete the bottom row of the periodic table have been excluded.
  - *Can you find out what these elements are? Some have only been made in the last few years.*
- The areas for all elements are approximate and for the least abundant and synthetic ones, technetium (Tc), promethium (Pr), polonium (Po), astatine (At), radon (Rn), francium (Fr), radium (Ra), actinium (Ac) and protactinium (Pa), the areas are exaggerated otherwise they would be invisible.
  - *Can you find out why there is more uranium (U) and thorium (Th) than there is of the other elements around them?*

Structure

In this table there are no gaps between beryllium (Be) and boron (B) nor between magnesium (Mg) and aluminium (Al). The lanthanoids appear in their correct place between lanthanum (La) and hafnium (Hf).

Colours

The table is colour coded[3] to show that in some cases we are consuming elements very fast and if we continue to do so their availability will become limited (unless we work on finding ways to recycle them).

- Of course, we do not actually run out of the element. The problem is that it gets dispersed (diluted) and more difficult to use (harvesting and recycling issues).
- **Helium (He)** is the only element that can be lost. It is so stable and light that when it gets into the atmosphere it goes to the edge of the atmosphere where it is knocked out, escaping earth's gravity, and is lost into space. So, we genuinely do lose helium
    - Helium (He) has important uses in high field magnets, which use superconductors that only work at temperatures below that of liquid nitrogen (boiling point -196 ºC) and so need liquid helium (boiling point -269 ºC) to cool them.
    - One of the main uses of these magnets is in Magnetic Resonance Imaging (MRI).
    - Another important use of helium is to dilute oxygen in the “air” that deep-sea divers breathe. Unlike nitrogen, helium does not dissolve in the blood so it does not cause any harm on decompression.
    - Special methods have been developed to recover rather than lose the helium that is breathed out by divers or used to cool magnets.
    - The use of helium for making birthday balloons should be avoided because when they go down the helium is lost forever.
- **Carbon (C)**
    - The multiple colour coding for carbon reflects its distinctive position at the crossroads of a very large natural cycle and a very large anthropogenic usage with considerable geostrategic stakes:
    - **Green**: Carbon is plentiful in carbonate rocks, as atmospheric and ocean-dissolved CO_2, in vegetation and soil, as well as in the fossil reservoirs (at current prices, level of technology and use, known reserves of oil and gas are estimated to last around 50 years,[4] but much larger resources are potentially available).
    - **Deep red**: Fossil reserves devoted to energy uses are by far the largest portion of the carbon inventory related to human activities, before biomass for food, limestone for cement, fossil resources for fuels, chemicals and materials. Large-scale extraction and burning of fossil carbon (coal oil and gas) imbalances the natural carbon cycle, compromising climate stability. Anthropogenic CO_2 emissions exceed the planet’s capacities to cycle it in biomass via photosynthesis or absorb it in oceans. This gives the deep red colour, because it causes climate change, which is presently a major threat to human civilization as well as to other species.
    - **Grey**: The still largest contributor to the global primary energy supply, oil, is extracted in some countries without the taint of conflict. However, several wars were and are fought over oil and revenues from oil are used to fund wars. The situation for carbon is, therefore, similar to that of other “conflict elements”, for which armed conflicts are connected to their extraction in some parts of the world.

- **Cobalt** (Co) mostly comes from mines in the Democratic Republic of the Congo but not in conflict areas. It is often mined by children in dreadful conditions. It is not currently classified as a conflict mineral, but its status is under constant review.
- A major initiative involves tracing the "life" of these elements, from mining through purification, converting them into components for the manufacture of goods, sales, resales and eventually what happens to the goods when they become waste. This process is termed 'traceability' and it is only through this very careful kind of record-keeping that we shall be able to be certain that our everyday goods have not been made from minerals where people died to provide them.

Expanding the lifetime of the goods that are manufactured from the elements is an essential part of the United Nation's Sustainable Development Goals.[5] In a circular economy, used consumer goods are repaired, reused and recycled.
One time use and then discard cannot continue. Three examples of elements that can cause potential problems are presented below.

- **Indium (In)** is present in every smart screen that we use today as part of a transparent indium tin oxide conducting film.
  - Indium is also used in lasers for fibre optics, for cold welding of electrical components and in blue LEDs
  - At current usage rates, indium will be used up in about 30 years and will become very expensive to collect and purify.
  - Methods to re-collect indium efficiently must, therefore, be developed and alternative transparent conducting coatings using earth abundant elements are in great need.
- **Lithium (Li)** availability could cause concern because it is used in many rechargeable batteries. For instance, if all cars sold today were electric and used lithium batteries, then 800,000 tons of lithium would be required per year. Lithium demand has increased over 10-fold from 2010 to 2024 but, in parallel, increased exploration has expanded available reserves. In the years to come, demand is expected to further increase so there is a rising threat from increased use, hence the orange colour. Recycling, which is possible for lithium, needs to be dramatically increased in order to maintain supplies into the future, also to sustain the manufacturing of batteries that store the peak production of renewable electricity technologies such as wind and photovoltaics. However, the development of sodium batteries, may decrease the relative importance of lithium in the medium-long term. The situation is evolving.
- **Tantalum (Ta)** is used in microcapacitors to control surges in current and protect the mother board in most smart phones. It can come from mines where wars are fought over the mineral rights or the proceeds of the mining are used to fund wars. However, it is also mined in Canada so phone companies use traceability to ensure that the tantalum they use only comes from Canada. Even so, at the current rate of use, tantalum would be fully dispersed in 50 years and before that the temptation to use conflict tantalum will increase significantly

Maybe you could research some of the other elements that are coloured red in on the table, find out what they are used for and how they might be protected?

Sustainability

Although some elements may not be so threatened by dispersion, they can still be unsustainable for other reasons. These reasons include originating from conflict regions and overuse.

Conflict resources come from mines or other deposits in countries where wars are fought over the ownership of the mineral rights or the proceeds from the extraction are used to fund wars.

- These resources contain carbon (C), tin (Sn), tantalum (Ta), tungsten (W) or gold (Au), which are highlighted in grey in *The 90 natural elements* table. They can also be found in countries where there is no conflict, although their supply is limited. Traceability is used to ensure that material coming from conflict areas is avoided, although this is less effective for carbon (C) as oil.

Overuse

There are three elements that humans are using in such a way that they are exceeding planetary boundaries, which means they are causing irreversible damage to the environment. They are coloured in deep red.

- **Carbon (C)**. Although plentifully abundant in the form of carbonate and CO_2, carbon is causing global warming and climate change.

- **Nitrogen (N)**, in the form of ammonia and its derivatives is used extensively all over the world as a fertiliser
    - Ammonia and other agricultural chemicals allow about 4 billion extra people to be fed.
    - However, its overuse leads to run off into rivers and oceans causing eutrophication, the growth of green algae on water sources. The algal bloom that develops stops oxygen entering the water underneath killing all plant and fish life below it.
    - More targeted application of ammonia to reduce the amount used whilst retaining the beneficial effects on plants is urgently required.

- Phosphorus (P) is an essential element of our body. It is used as a fertiliser and added to the land in the form of phosphate minerals so that there is enough for it to be taken up by plants.
    - Most of the phosphate ends up in run-off from fields or human urine and sewage and contributes to eutrophication, it is really important to develop methods for the recovery of phosphate and for reducing the amount applied to fields.

Smart phones are used by almost everyone now.

- Take another look at the Periodic Table and you will see a phone symbol on 31[6] different elements, all of which are used in smart phones (some reports claim as many as 70).
- The supply of 17 of these elements may give cause for concern in years to come
- All the elements from conflict resources, carbon (C), tin (Sn), tantalum (Ta), tungsten (W) and gold (Au), are used in smart phones so their traceability in phones is crucial.
- Did you know that ~ 10 million smart phones are purchased in the European Union alone **every month** — imagine how many that is throughout the world; *can you find out how many it is in your country?*
- Many exchanged smart phones are sent to the developing world for reuse, but eventually they end up in landfill sites or with children sitting in roads trying to extract the gold using strong acid whilst the phone carcases pile up beside the road.
- Think how much of the scarce elements within the phones are being dispersed.
- Longer usage times, easy repair and ethical recycling of smart phones must be a priority

Next time you are offered an upgrade of your smart phone, think again and ask yourself whether you really need it or whether you might keep the one you have for a year or two more and make your personal contribution to conserving these important scarce elements.

Be a champion for sustainable development and the circular economy; protect endangered elements!

February, 2024

[1] http://www.periodicvideos.com/

[2] Data from the *CRC Rubber Handbook*, as listed in https://en.wikipedia.org/wiki/Abundances_of_the_elements_(data_page) . The data for nitrogen are modified to include atmospheric nitrogen

[3] The data for these colours come from a Periodic Table original put together by the *Knowledge Transfer Network* and published by *Compound Interest* at https://www.compoundchem.com/2015/08/19/endangered-elements/ The data have been updated by reference to V. Zepf, B. Achzet, and A. Reller in *Competition and conflicts on resource use*, Eds S. Hartard and W Liebert, Springer, Cham, 2015, Chap 18, p. 239; https://link.springer.com/content/pdf/10.1007%2F978-3-319-10954-1.pdf

[4] BP Statistical Review of World Energy Full report – Statistical Review of World Energy 2021 (bp.com)

[5] https://www.un.org/sustainabledevelopment/

[6] Data taken from a Periodic Table original put together by the *Knowledge Transfer Network* and published by *Compound Interest* at https://www.compoundchem.com/2014/02/19/the-chemical-elements-of-a-smartphone/ It has been updated by reference to M. Poliakoff and S. Tang, *Phil. Trans. Roy. Soc. A*, 2014, **373**, 0211; http://rsta.royalsocietypublishing.org/content/roypta/373/2037/20140211.full.pdf