EuChemS
European Chemical Society

The 90 Elements that make up everything

Support notes for teachers (for the updated version of the EuChemS Periodic Table 2021)

In 2019, as a contribution to the International Year of the Periodic Table, the European Chemical Society (EuChemS) released a new kind of Periodic Table, which can be used free of charge as a Wallchart, as handouts to learners or in electronic format. This EuChemS Periodic Table has recently been updated to introduce the concept of sustainability (in the subtitle) and to highlight the unique position of carbon (C).
It is expected that, where a wallchart is used, the new Periodic Table will hang beside a traditional one.

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), germanium (Ge), 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 The Periodic Table of Videos[1]

Areas

The Periodic Table *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 imaging, the Tc 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. One, plutonium (Pu) has important uses in fast breeder nuclear reactors.
- 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.

Structure

In this table there are no gaps between beryllium (Be) and boron (B) nor between magnesium (Mg) and aluminium (Al). The lanthanides 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 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 travels 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 ^{o}C) and so need liquid helium (boiling point -269 ^{o}C) to cool them.
    - One of the main uses of these magnets is in Magnetic Resonance Imaging (MRI) for medical diagnosis.
    - 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.

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

- These resources containing carbon (C), tin (Sn), tantalum (Ta), tungsten (W) and gold (Au) are highlighted in dark grey in *The 90 natural elements* table. They can also be found in countries where there is no conflict, although their supply is limited.
- Carbon’s (C) multiple colour coding reflects its distinctive position at the crossroads of a very large natural cycle and a very large anthropogenic usage with considerable geo-strategic 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, estimated reserves of oil and gas are estimated to last around 50 years,[4] but much larger resources are potentially available).
    - 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 chemicals and materials. Large-scale extraction of fossil carbon 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 red colour, because it causes climate change, which is presently a large threat to human civilization.
    - 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 "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 usable lifetime of the goods manufactured from the elements is an essential part of the United Nation's 17 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 used 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.
    - Indium is already highly dispersed around the planet. Its highest concentration is in zinc containing ores, so it is a by-product of zinc extraction. This source will only last for about 20 years, then the price of indium will rise significantly.[6]
    - Methods to re-collect indium efficiently must therefore be developed and alternative transparent conducting coatings using earth abundant elements are in great need.
- 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 minerals are depleting fast and as most of the phosphate ends up in run-off from fields or human urine and sewage, it is really important to develop methods for the recovery of phosphate.
- 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. Recycling, which is relatively easy for lithium, needs to be stepped up in order to keep the supply going in the future also to sustain the manufacturing of batteries that store the peak production of renewable electricity technologies such as wind and photovoltaics.

Smart phones are used by almost everyone now.

- Take another look at the Periodic Table and you will see a phone symbol on 31[7] 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 metals from conflict resources, tin (Sn), tantalum (Ta), tungsten (W) and gold (Au), are used in smart phones so their traceability in phones is crucial.
- ~ 10 million smart phones are changed in the European Union alone every month — imagine how many that is throughout the work.
- 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 them are being dispersed.

Should people really upgrade their phones every 2-3 years?

Some ideas for further investigation by learners

- Try to find out what the elements beyond uranium are, and whether they have any uses. Some have only been made in the last few years.
- Find out why there is more uranium (U) and thorium (Th) than there is of the other elements around them (to do with half-lives).
- Find out about some of the other elements that are coloured red, orange or yellow in the table; what they are used for and how they might be protected.
- Find out how many smart phones are recycled in your country.

Learning Intentions

- To understand that only 90 elements make up the building block of everything around us,
- To know that these elements are present in widely varying amounts,
- To know that some are being used very fast and that we may not have them readily available within a short time,
- To know that some elements come from places where wars are fought over the minerals,
- To know that all of these are in mobile phones,
- To understand the very special position of carbon (both good and bad) amongst all the elements
- To know that other sources can be used to avoid using conflict minerals,
- To know that we have it in our hands to ensure that we have the elements we need in the future,
- To understand the principles of traceability and the circular economy,
- To become champions for sustainability and the circular economy.

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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 comes 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/endangeredelements/ It has 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 Energy, Full report – Statistical Review of World Energy 2021 (bp.com)

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

6 https://www.nrel.gov/docs/fy16osti/62409.pdf

7 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