Physics and Chemistry of Sustainability II
The Marvelous Side of Chemistry

Introduction
Some Historical and Basic Aspects

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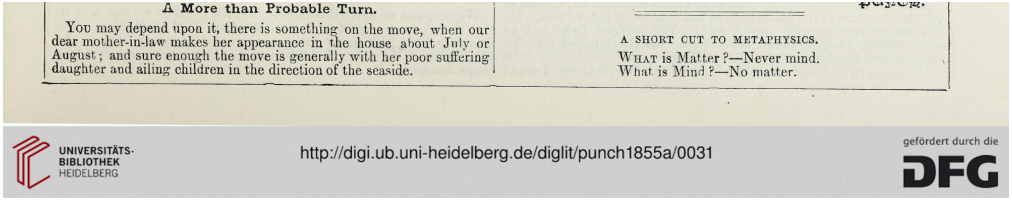
75 Years of Free Thinking.

What is matter? — Never mind.



A More than Probable Turn.

You may depend upon it, there is something on the move, when our dear mother-in-law makes her appearance in the house about July or August; and sure enough the move is generally with her poor suffering daughter and ailing children in the direction of the seaside.

A SHORT CUT TO METAPHYSICS.

What is Matter?—Never mind.
What is Mind?—No matter.

Punch, or The London Charivari, London, England, 14 Jul 1855 , page 19, column 2 (filler item, anonymous)
DOI: https://doi.org/10.11588/diglit.16616#0031

Since this lecture is part of a module in studies of science . . .

M Glick (journal editor), Editorial, *J Am Dent Assoc* **149** (2018) 829, DOI: https://doi.org/10.1016/j.adaj.2018.08.012
see also Gordon group website / GAMESS homepage: https://www.msg.chem.iastate.edu (at the bottom)
(accessed 17 Apr 2024)

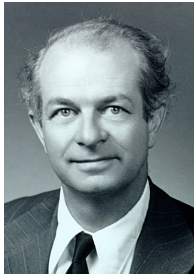
1954: Advice to Students: Always think for yourself!

Response by Linus Pauling, as spokesman for all
Nobel Laureates, to the university students of
Sweden, holding a torchlight procession in the
Blue Room of the City Hall, Stockholm. 10 P.M.
Friday, 10 December 1954

When an old and distinguished person speaks to you, listen to him carefully and with respect - but do not believe him. Never put your trust in anything but your own intellect. Your elder, no matter whether he has gray hair or has lost his hair, no matter whether he is a Nobel Laureate, may be wrong. The world progresses, year by year, century by century, as the members of the younger generation find out what was wrong among the things that their elders said. So you must always be skeptical - always think for yourself.

You will have some great problems to solve - the greatest of all is the problem of war and peace. I believe that this problem has been solved, by the hydrogen bomb - that there will never again be a world war - the knowledge that a world war would mean world-wide destruction, perhaps the end of civilization, will surely now lead to permanent peace.

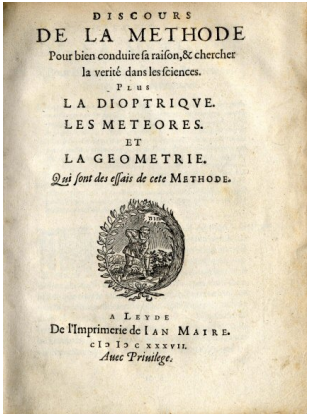
But it is your generation that will have the job of working out the means of preventing disaster, by improving the techniques of international negotiations, of developing safeguards against paranoic demagogues who might make nations rabid; you will have this great job to do - and I am confident that you can do it.



L Pauling (1901–1994) in the 1940s
1954 Nobel Prize in Chemistry
1962 Nobel Peace Prize

Text: Response by Linus Pauling, as spokesman for all Nobel Laureates, to the university students of Sweden, Dec 10, 1954, Stockholm
https://scarc.library.oregonstate.edu/coll/pauling/calendar/1954/12/10.html (accessed 17 Apr 2024)
Photo: https://en.wikipedia.org/wiki/Linus_Pauling (CC BY-SA 2.0, accessed 17 Apr 2024)

1637: On Scientific Method — during Thirty Years' War (1618–1648)



DISCOURS
DE LA METHODE
Pour bien conduire sa raison, & chercher
la verité dans les sciences.
PLUS
LA DIOPTRIQVE.
LES METEORES.
ET
LA GEOMETRIE.
Qui sont des essais de cette METHODE.

A LEYDE
De l'Imprimerie de IAN MAIRE.
CIↃ IↃ C XXXVII.
Avec Privilege.

see also: Bibliothèque Nationale de France (1st edition ▶)

Discourse on the Method of Rightly Conducting One's Reason and of Seeking the Truth in the Sciences (anonymously published in French, "langue vulgaire", 1637)

The Method:

- Exclude all doubt (rely on evidence)
- Divide difficulties/problems into as many parts as possible
- Begin with the simplest and easiest tasks, advance to the more complex tasks
- Make enumerations as complete, reviews as general as necessary in order to be assured that nothing is omitted

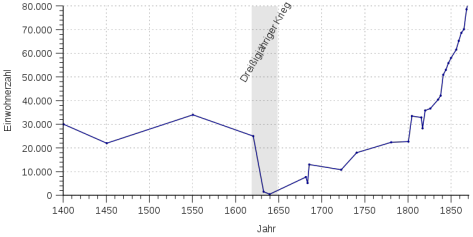
Three essays included(!), one on **Geometry** (Cartesian axes system, foundation of Analytical Geometry)

R Descartes (R Cartesius, 1596–1650)
1619/1620 member of the armed forces of the Catholic League during the conquest of Prague

"Common sense is the best distributed thing in the world, for everyone thinks being so well endowed with it that even those who are the most difficult to satisfy in every other way are not in the habit of desiring more of it than what they have." (English translation of 1st sentence, 1st paragraph of Part I)

Title page: https://en.wikipedia.org/wiki/Discourse_on_the_Method (public domain, accessed 17 Apr 2024)
Portrait: https://en.wikipedia.org/wiki/René_Descartes (painting by F Hals, public domain, accessed 17 Apr 2024)

1631: Magdeburg's Sacrifice



▲ Number of Inhabitants of Magdeburg vs. Time (1400–1870)

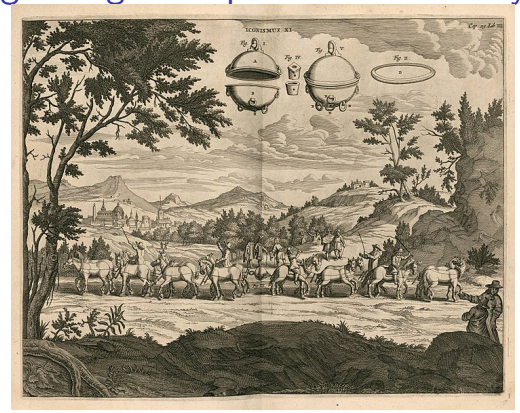
Magdeburg
One of the biggest German cities at the end of the Middle Ages
1597 the plague took 10.000 lifes
◀ 1631 Magdeburg's Sacrifice
1639 only 450(!!) inhabitants
1683 the plague took 2.650 lifes

May 20–24$^{\text{greg}}$, 1631: **Magdeburg's Sacrifice** (also called "Magdeburg's Wedding")
Destruction of the Protestant city by the Imperial Army and its allied forces (Catholic League); less than 4.000 of the $\sim$ 25.000 inhabitands survived (worst massacre of Thirty Years' War).

Picture: Engraving by D Manasser, 1632, https://en.wikipedia.org/wiki/Sack_of_Magdeburg (public domain, accessed 17 Apr 2024)
Diagram: https://de.wikipedia.org/wiki/Einwohnerentwicklung_von_Magdeburg (CC0, accessed 17 Apr 2024)

1650–1680: The Magdeburg hemispheres and the Boyle–Mariotte law

O von Guericke (1602–1686, until 1666 O Gericke) — Fled from his birth town before 1631, lost all his personal property when the city was incinerated during Magdeburg's Sacrifice



The Magdeburg hemispheres (1654) — a tool to demonstrate the force of atmospheric pressure — empirical proof of the existence of vacuum

R Boyle (1627–1692) — Learned about von Guericke's work from the book by Schott; experimental study of air together with R Hooke (Hooke's law)

Boyle's law or **Boyle–Mariotte law** (1662/1676, named after R Boyle and E Mariotte):

$$pV = \text{const} \qquad (\text{pressure } p, \text{ volume } V, \ m \text{ const}, \ T \text{ const})$$

Hyperbolas in a p-V-diagram (▶, note the use of Cartesian axes)

Portrait of von Guericke: https://en.wikipedia.org/wiki/Otto_von_Guericke (picture by A van Hulle, public domain, accessed 17 Apr 2024)
Picture: From a book by G Schott, 1657, https://en.wikipedia.org/wiki/Magdeburg_hemispheres (public domain, accessed 17 Apr 2024)
Portrait of Boyle: Oil painting by J Kerseboom, 1689, https://de.wikipedia.org/wiki/Robert_Boyle (public domain, accessed 17 Apr 2024)

- Science develops further during times of crisis (war times, times with difficulties in local/regional/national economy)
- But are crises really always necessary for (accelerating) the advancement of science?
- Can a better/good/excellent knowledge of science (maths/physics/chemistry/...) for everyone help?

Supertramp – Crisis? What Crisis? (1975)
(album front cover, ©A & M Records)

An almost perfectly sustainable application of an inert gas

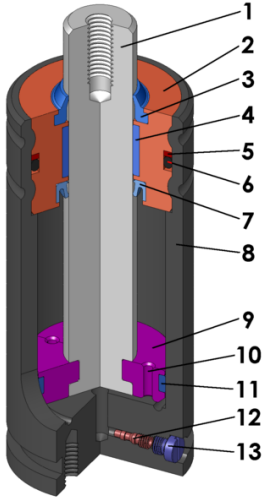
Boyle–Mariotte law:

$$pV = \text{const}$$

(T constant, m constant)

Gas spring ▶
(typical filling gas: N_2,
typical pressure range:
10 . . . 200 bar)

Other applications:
shock absorbers,
air-filled rubber tyres



1 – Piston rod
2 – Head cap
3 – Piston rod wiper
4 – Piston rod guide bushing
5 – Retaining ring
6 – O-ring
7 – Piston rod seal
8 – Cylinder
9 – Piston
10 – Flow-restriction orifice
11 – Piston guide bushing
12 – Valve
13 – Valve-sealing screw

Picture: https://en.wikipedia.org/wiki/Gas_spring (CC BY-SA 2.5, accessed 17 Apr 2024)

1346: Sustainability and Forestry — during 100-Years-War (1337–1453)

First-time appearances of “sustain. . .” in written form in Europe: A royal decree

≪ Les maîtres des eaux et forêts enquerront et visiteront toutes les forez et bois et feront les ventes qui y sont, en regard de ce que lesdites forez se puissent perpétuellement soustenir en bon estat ≫

“The masters of the waters and forests will survey and visit all the forests and woods and make the sales that are there, with regards to ensuring that the said forests can be perpetually maintained in good condition ”

Philip VI, king of France (29 May 1346):
Ordonnance de Brunoy

Philippe VI de Valois (1293–1350)
King of France (1328–1350)

Unfortunately, this did not stop deforestation in the decree’s region of validity!

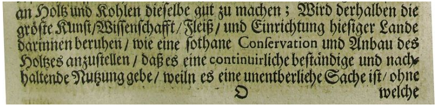
Source: https://fr.wikipedia.org/wiki/Ordonnance_de_Brunoy (initial translation with Deepl, modified, accessed 16 Apr 2025)
Image: https://fr.wikipedia.org/wiki/Philippe_VI_de_Valois (accessed 16 Apr 2025)

1713: Sustainability and Forestry

First-time appearances of “sustain…” in written form in Europe: An instruction book

Around 1700, the mining industry in the Ore Mountain region (Saxony & North Bohemia), at that time one of the largest mining regions in Europe, was threatened. It was not that the mines had been exhausted of their ores, the problem was an acute scarcity of timber. (Wikipedia)


Mit GOtt!
SYLVICVLTVRA OECONOMICA,
Oder
Haußwirthliche Nachricht und Naturmäßige
Anweisung
zur
Wilden Baum-Zucht/
Nebst
Gründlicher Darstellung/
Wie zuförderst durch Göttliches Benedeyen dem allenthalben und insgemein einreissenden
Grossen Holtz-Mangel/
Vermittelst Säe-Pflantz- und Versetzung vielerhand Bäume zu prospiciren/
Alles zu nothdürfftiger Versorgung des Hauß- Bau- Brau- Berg- und Schmeltz-Wesens/
Worbey zugleich eine gründliche Nachricht von den in Churfl. Sächß. Landen
Gefundenen Turff
Dessen Natürliche Beschaffenheit/ grossen Nutzen/ Gebrauch und nützlichen Verkohlung.
Von
Hannß Carl von Carlowitz/
Königl. Pohl. und Churfl. Sächß. Cammer-Rath und Ober-Berg-Hauptmann.
Mit Königl. Pohl. und Churfürstl. Sächß. allergnädigsten PRIVILEGIO.
LEIPZIG/
verlegts Johann Friedrich Braun 1713.


an Holtz und Kohlen dieselbe gut zu machen; Wird derhalben die größte Kunst/Wissenschafft/Fleiß/ und Einrichtung hiesiger Lande darinnen beruhen/ wie eine sothane Conservation und Anbau des Holtzes anzustellen/ daß es eine continuirliche beständige und nachhaltende Nutzung gebe/ weiln es eine unentberliche Sache ist/ ohne welche

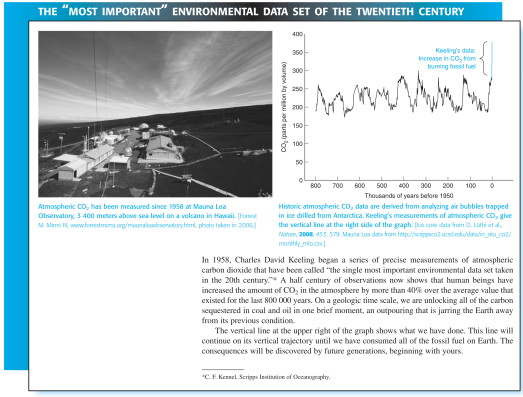
HC von Carlowitz (1645–1714): *Sylvicultura oeconomica* (1713, cover page and part of p 105) ▶
Commemorative plaque, created by B Freiesleben, at a house in Freiberg (Saxony, Germany)
Picture of plaque: https://de.wikipedia.org/wiki/Hans_Carl_von_Carlowitz (CC BY 3.0, accessed 17 Apr 2024)
Title page and text passage: de.wikipedia.org/wiki/Nachhaltigkeit_(Forstwirtschaft) (public domain, accessed 17 Apr 2024)

What is the meaning of words?

nachhalten (*verb*) – to last (to last for a longer time)
nachhaltig (*adj.*) – effective, enduring, (long) lasting, sustained, sustainable
nachhaltige Wirkung – (long) lasting effect
nachhaltig wirken – to have a (long) lasting effect
nachhaltige Bemühungen – sustained efforts
nachhaltige Entwicklung – sustainable development
Nachhaltigkeit – sustainability(?), longlastingness(?), effectiveness, efficiency

- "Sustainability" did connect – from its beginning (14th – 18th century) – economic and ecological aspects (and still does)!
- Remember: Deforestation occurred in the Ore Mountain region in the 17th century due to mining and smeltering activities
- **But:** Trees don't grow on/from wood chips or on/from recovered paper!
- As we know today, the main source of carbon (C) for all plants is carbon dioxide, CO_2, typically taken from the air
- Today, deforestation is still a highly important issue, now on the global scale

The Keeling Curve



THE "MOST IMPORTANT" ENVIRONMENTAL DATA SET OF THE TWENTIETH CENTURY

Atmospheric CO_2 has been measured since 1958 at Mauna Loa Observatory, 3 400 meters above sea level on a volcano in Hawaii. [Forest M. Mims III, www.forestmims.org/maunaloaobservatory.html, photo taken in 2006.]

Historic atmospheric CO_2 data are derived from analyzing air bubbles trapped in ice drilled from Antarctica. Keeling's measurements of atmospheric CO_2 give the vertical line at the right side of the graph. [Ice core data from D. Lüthi et al., *Nature*, **2008**, 455, 379. Mauna Loa data from http://scrippsco2.ucsd.edu/data/in_situ_co2/monthly_mlo.csv.]

In 1958, Charles David Keeling began a series of precise measurements of atmospheric carbon dioxide that have been called "the single most important environmental data set taken in the 20th century."* A half century of observations now shows that human beings have increased the amount of CO_2 in the atmosphere by more than 40% over the average value that existed for the last 800 000 years. On a geologic time scale, we are unlocking all of the carbon sequestered in coal and oil in one brief moment, an outpouring that is jarring the Earth away from its previous condition.

The vertical line at the upper right of the graph shows what we have done. This line will continue on its vertical trajectory until we have consumed all of the fossil fuel on Earth. The consequences will be discovered by future generations, beginning with yours.

*C. F. Keeling, Scripps Institution of Oceanography.

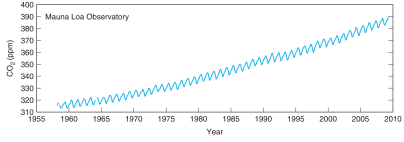


FIGURE 0-4 Monthly average atmospheric CO_2 measured on Mauna Loa. This graph, known as the *Keeling curve*, shows seasonal oscillations superimposed on rising CO_2. [Data from http://scrippsco2.ucsd.edu/data/in_situ_co2/monthly_mlo.csv.]

D Harris, *Quantitative Chemical Analysis*, 8th ed, Freeman, New York, 2010, pp 1 & 4

Q: How much is 400 ppm of CO_2?

Reminder: Assuming volume ratio, V/V, 1 ppm corresponds to 1 mL in 1 m^3
(1 m^3 = 1000 L = 10^6 mL)

(Demonstration with a container for milk, 500 mL, and a folding yardstick)

Q: How good are your skills in thinking in orders of magnitude (powers of ten) — from "very small" to "very large" (in space) or from "very short" to "very long" (in time)?

United Nations General Assembly: Transforming our World: the 2030 Agenda for Sustainable Development, 25 Sep 2015 ▶
Source: https://www.un.org/sustainabledevelopment/news/communications-material/ (accessed 17 Apr 2024)

- EN: Sustainable Development Goals (SDGs)
  DE: Ziele für nachhaltige Entwicklung
  FR: Objectifs de développement durable
- Most of these 17 SDGs (perhaps all of them) are very intimately linked to, or connected with chemistry and physics
- Public discussions / the daily/weekly news, if associated with these 17 SDGs, seem to largely ignore physics- and chemistry-related aspects
- Can we safely assume being well on the right track if basic knowledge in science gets/is/remains out of scope?
- Chemistry and physics provide important information for what one may like to call "the frame in which our life takes place", or "the stage on which our life evolves"

1 – No Poverty

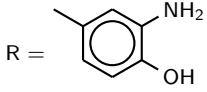
- Matter-related and energy-related aspects of poverty
- Enough money to pay for coverage of the most elementary needs related to
  food,
  clothing,
  lodging,
  heating and/or cooling,
  media supply (e.g. water, electricity, natural gas)

2 – Zero Hunger

- Sufficient supply of
  proteins,
  carbohydrates,
  lipids,
  micro nutrients (vitamins, trace elements),
  ...
- Food quality guaranteed?
- Food source?
- Agricultural production guaranteed?
- Transportation of food guaranteed?
- Distribution/delivery of food guaranteed?

3 – Good Health and Well-Being

- Matter- and energy-related conditions of good health and well-being
- Molecular Medicine
- Molecular Biology / Biochemistry
- ... but not only "bio":
  - 1910 salvarsan (*cyclo*-$(RAs)_n$, R = 3-amino-4-hydroxyphenyl, $n = 3$ or 5, antimicrobial drug, effective to treat e.g. syphilis)



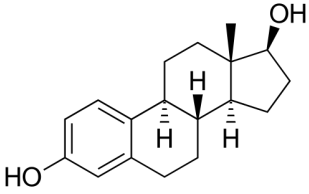
  - 1978 cisplatin ($[Pt(NH_3)_2Cl_2]$, anticancer drug)
- Access to good-quality medicine / dentistry

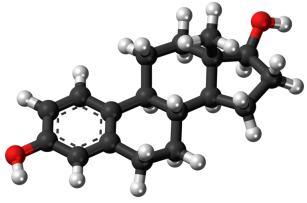
4 – Quality Education

- Quality of education in STEM (science, technology, engineering, mathematics), emphasizing the great importance of these subjects for the well-being of us humans as well as of other forms of life on this planet

5 – Gender Equality

- Assuming some sort of connection between biological sex and gender
- Estradiol – a steroid hormone, likely the most important sex hormone in mammals (both female and male individuals), but also found in other animal species, e. g. fish, crustaceans, insects



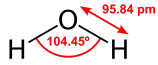


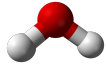
estradiol, $C_{18}H_{24}O_2$ ($M = 272.38$ g/mol)
structural formula with stereochemical information (left) and ball-and-stick representation (right)

https://en.wikipedia.org/wiki/Estradiol

6 – Clean Water and Sanitation

- Water





H_2O ($M = 18.02$ g/mol, mp 0 °C, bp 100 °C)

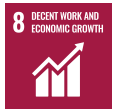
- Water quality:
  - drinking water
  - raw water
  - fresh water / brackish water / saline water (oceans) / brine water (Dead Sea)
- Chemical (physical / biological) water treatment
- Water supply network / Sewage water network (material of pipes, canals, etc.)
- Cleaning agents (detergents, tensides)
- Disinfection agents (silver salts / chlorine-based / alcohol-based / ...)

https://en.wikipedia.org/wiki/Water
AG Császár *et al*, *J Chem Phys* **122** (2005) 214305, https://doi.org/10.1063/1.1924506 (r_e structure data from 1945)

7 – Affordable and Clean Energy

- Which source of energy for which purpose (household / transportation on the road, by railway, by air freight, by ship / ...)
- Solar power? Fuel cell? Electric battery?
  Combustion engine (hydrogen/CNG/LPG/gazoline/oil/coal)?
- Side products and waste during production processes and under operating conditions?

8 – Decent Work and Economic Growth



- No material system can grow indefinitely ($t \to \infty$) and unboundedly ($R \to \infty$) in a finite world (planet Earth / solar system)

9 – Industry, Innovation and Infrastructure

- Any sort of material (matter) processed by the producing industry has some chemical composition

10 – Reduced Inequalities

- No (direct) link to Chemistry — Really?

11 – Sustainable Cities and Communities

- How to construct buildings? Concrete, bricks, steel, glass, wood, . . .?
- Urban Mining (old buildings, which are considered no longer useful, serve as sources of material for the construction of new ones)

12 – Responsible Consumption and Production

- Responsibility with respect to whom?
- Beware of entropy! Don't ignore entropy production!

13 – Climate Action

- Keeling curve (see above)
- Other greenhouse gases (N_2O, CH_4, ...)

14 – Life below Water

- Does this really need a hint to recognize its connection to (Bio-)Chemistry?

15 – Life on Land (and in the Sky)

- Does this really need a hint to recognize its connection to (Bio-)Chemistry?

16 – Peace, Justice and Strong Institutions

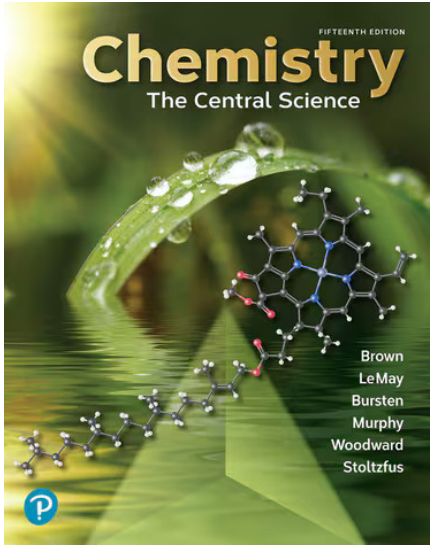
- No (direct) link to Chemistry — Really?
- Chemical Weapons?
- Organization for the Prohibition of Chemical Weapons (OPCW, 2013 Nobel Peace Prize)

https://en.wikipedia.org/wiki/Chemical_Weapons_Convention

17 – Partnerships for the Goals

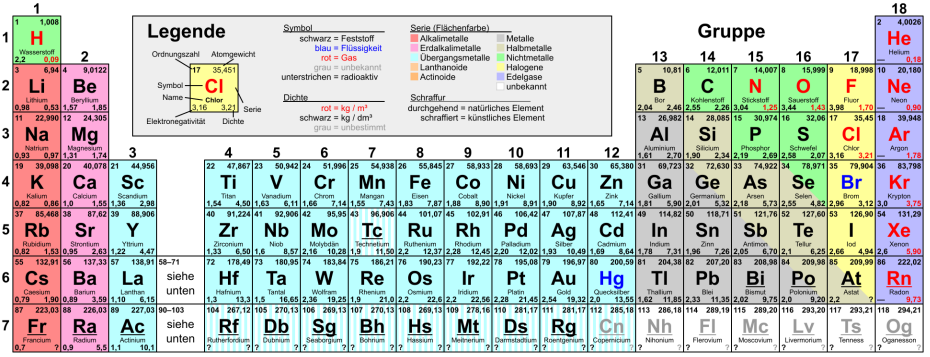
- No (direct) link to Chemistry — Really?

Chemistry: The Central Science



TE Brown, HE LeMay et al.: *Chemistry – The Central Science*, 15th ed, Pearson, 2023

Our “Construction Kit”: The Periodic Table of the Chemical Elements . . .

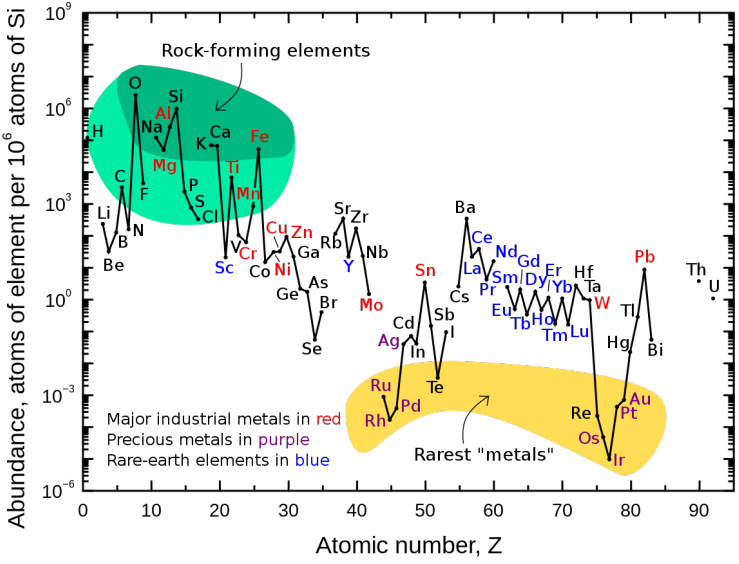


(rows = periods / columns = groups / current status: 118 elements / mostly metals, only approx. 20–25 nonmetals)

. . . is built up from “blocks” of width $4\ell + 2 = 2(2\ell + 1)$:
s block ($\ell = 0$), p block ($\ell = 1$), d block ($\ell = 2$), f block ($\ell = 3$)

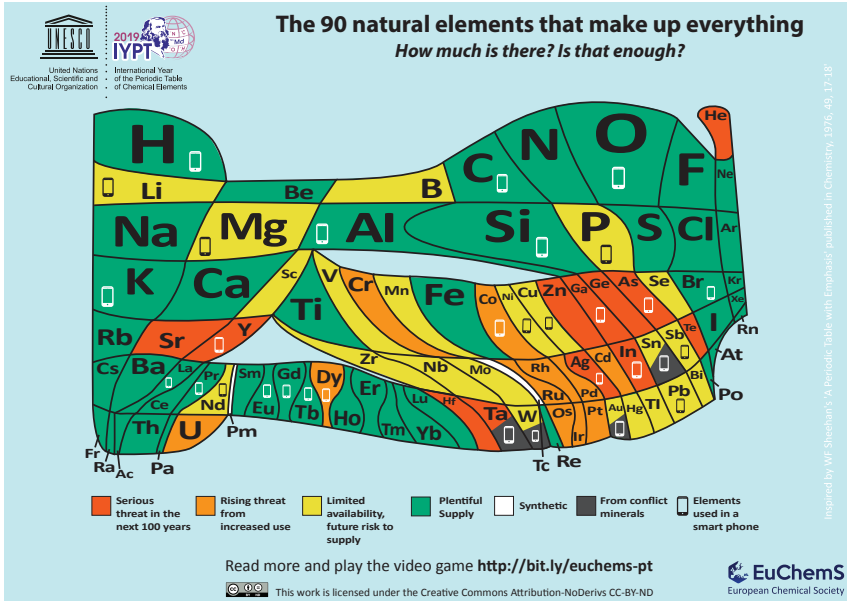
Source: https://de.wikipedia.org/wiki/Periodensystem (public domain, accessed 17 Apr 2024)

Abundance of the chemical elements in the Earth's crust

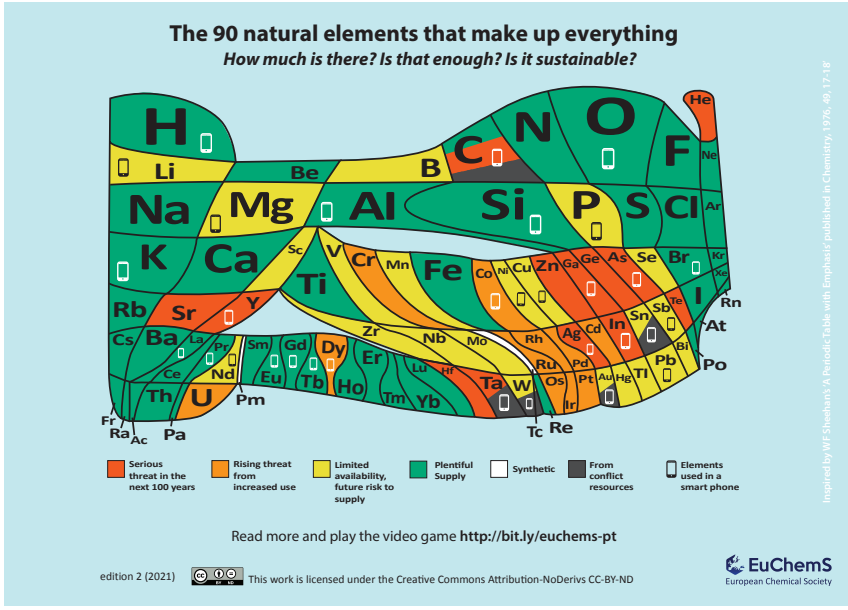


Only(O) > Strong(Si) > Athletes(Al) > In(Fe) > College(Ca) > Study(Na) > Past(K) ≈(?) Midnight(Mg)

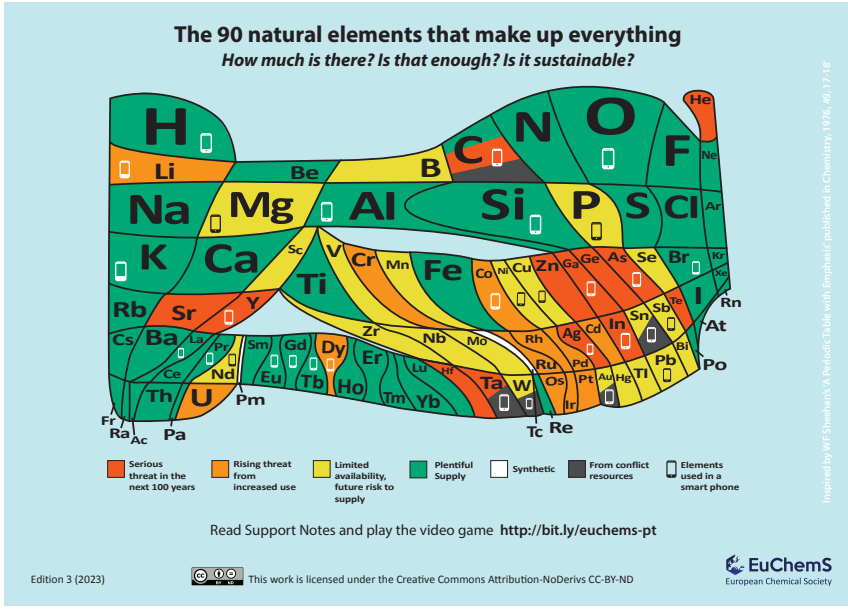
Source: https://en.wikipedia.org/wiki/Abundance_of_the_chemical_elements (public domain, accessed 17 Apr 2024)



European Chemical Society, 2018, https://www.euchems.eu/wp-content/uploads/2018/10/Periodic-Table-ultimate-PDF.pdf (accessed 17 Apr 2024)



European Chemical Society, 2021, https://www.euchems.eu/wp-content/uploads/2021/11/Endangered-ElementsCarbon-Updated.pdf (accessed 17 Apr 2024)



European Chemical Society, 2023, https://www.euchems.eu/wp-content/uploads/2023/06/PT2023_protected.pdf (accessed 17 Apr 2024)

List of countries and territoires by area / by population (2022)

Country/Territory	Total area / km^2
Russia	17,098,246
Antarctica	14,200,000
Canada	9,984,670
China	9,596,960
United States	9,525,067
Brazil	8,510,346
Australia	7,741,220
European Union	4,242,351
India	3,287,263
Total surface area	510,072,000

Country/Territory	Human population
China	1,409,670,000
India	1,392,329,000
European Union	450,359,450
United States	335,893,238
Indonesia	279,118,866
Pakistan	241,499,431
Nigeria	223,800,000
Brazil	203,080,756
Bangladesh	169,828,911
Russia	146,203,613
Sum	4,851,783,265
World Population (2022)	7,975,105,156

To be kept in mind:

- Surface area provides space e.g. for cultivation of food crops, for operation of power plants (solar, wind, hydrothermal, fossil, nuclear, ...). Surface area has resources (composed of around 80 different chemical elements) on surface or covers them underground.
- Every single human being wants her/his most basic needs (e.g. water, food, warmth, light) be met and satisfied, day by day.

Data Sources: CIA World Factbook (2022) / United Nations, World Population Prospects (2022)
https://en.wikipedia.org/wiki/List_of_countries_and_dependencies_by_area,
https://en.wikipedia.org/wiki/List_of_countries_and_dependencies_by_population
https://en.wikipedia.org/wiki/Earth, https://www.worldometers.info/world-population/world-population-by-year/

History and Basics

- 1713 – HC von Carlowitz (Saxony): Sustainability and Forestry
- 1789 – AL de Lavoisier (France, with support by his wife MA Paulze, see picture): Elements (first modern idea of ∼); Law of Conservation of Mass

$$\Delta m = m_{\text{after}} - m_{\text{before}} = 0$$

  for all chemical reactions
- 1793 – J Beckmann (professor at Göttingen): "Warenkunde" (knowledge about commercial goods, where to find them, how to handle them, how to probe their quality, etc.); coined the term "technology"

Picture: Portrait by JL David, 1788, https://de.wikipedia.org/wiki/Antoine_Laurent_de_Lavoisier (public domain)

History and Basics

1784/1795 – I Kant (22.04.1724–1804)

German postage stamp (1974)

1784: Essay "*Answer to the Question "What is Enlightenment?*"" (German: Was ist Aufklärung?). Kant's answer: "Enlightenment is man's emergence from his self-incurred immaturity (Unmündigkeit)."
Sapere aude! (actually a motto from Horace) – Habe Muth, dich deines eigenen Verstandes zu bedienen! – Dare to be wise! – Ose penser par toi-même!

1795: Essay "*Perpetual Peace*" (German: Zum ewigen Frieden)

https://en.wikipedia.org/wiki/Immanuel_Kant
https://en.wikipedia.org/wiki/Horace
https://en.wikipedia.org/wiki/What_Is_Enlightenment?

April 22: Earth Day

Annual event (since 1970) to demonstrate support for environmental protection

Unofficial Earth Day Flag, created by John McConnell (1915–2012),
includes The Blue Marble photograph taken by the crew of Apollo 17 on Dec 7, 1972

This year's Earth Day official theme is "Our Power, Our Planet" (2025)

https://en.wikipedia.org/wiki/Earth_Day

History and Basics

- 1810 – J Dalton (England): Modern idea of the atom; Stoichiometry ("measuring the elements")
- 1811 – A Avogadro (Italy): Same volumes V of different gases contain same number of gas particles (p, T both constant)
- 1834 – E Clapeyron (France): first formulation of the ideal gas law $pV = nRT$
- 1860 – Karlsruhe Congress (Germany): First international meeting of chemists; Avogadro's hypothesis accepted as correct; adoption of a common set of "atomic weights"
- 1869 – D Mendeleev (Russia) & L Meyer (Germany): First versions of the Periodic Table of the Elements
- 1960 – 1 mol of X has as many units (particles) of type X as there are atoms in 12 g of carbon isotope ^{12}C
- 2019 – 1 mol of X contains exactly(!) $6.02214076 \cdot 10^{23}$ particles of type X

Avogadro's constant (since 2019 defined exactly as given here):

$$N_A = 6.02214076 \cdot 10^{23}/\text{mol}$$

History and Basics

- 1824 – S Carnot (France): Efficiency η of a heat engine ($0 < \eta \leq 1$) depends on the temperature difference ΔT between the engine and its environment (work ΔW, amount of heat Q)

$$\Delta W = \eta\, Q\,, \qquad \eta = 1 - \frac{T_{\text{lo}}}{T_{\text{hi}}} = \frac{\Delta T}{T_{\text{hi}}}\,, \qquad \Delta T = T_{\text{hi}} - T_{\text{lo}}$$

- 1835 – WR Hamilton (Ireland): New formulation of Classical Mechanics; Hamilton's function H gives total energy, in simple cases, as the sum of kinetic and potential energies, T and V:

$$H = T + V$$

An object with mass m, moving at speed v: $T = (1/2)mv^2$ — Scaling laws: $m \to 2\,m$ (car, 600 kg $\to$ 1200 kg) causes $T \to 2\,T$,
but $v \to 2\,v$ (car, 100 km/h $\to$ 200 km/h) causes $T \to 4\,T$!

Do you enjoy (almost) complete freedom to move? To go to wherever you like?
We still have (in large parts around the globe) great freedom for individual traffic!

History and Basics

- 1842/1847 – R Mayer & H von Helmholtz (Germany): Law of Conservation of Energy (**1st law of thermodynamics**) in all (bio-)physical processes

$$\Delta E = E_{\text{after}} - E_{\text{before}} = 0$$

- 1850s/1860s – R Clausius (Germany): Introduced entropy (S) as new state function; in all observable processes, the entropy of a system never decreases (**2nd law of thermodynamics**)

$$\mathrm{d}S \geq 0$$

- 1870s – JW Gibbs (USA): Introduced chemical potential (μ); modern formulation of chemical thermodynamics based on "fundamental forms" (total differentials), e.g. for internal energy U and Gibbs free energy G of a system with C compounds:

$$\mathrm{d}U = T\mathrm{d}S - p\mathrm{d}V + \sum_{i=1}^{C} \mu_i \mathrm{d}n_i\,, \qquad \mathrm{d}G = -S\mathrm{d}T + V\mathrm{d}p + \sum_{i=1}^{C} \mu_i \mathrm{d}n_i$$

$\rightsquigarrow \mathrm{d}G = 0$ at reaction equilibrium ($\mathrm{d}n_i = 0$) under constant T and p

History and Basics

The three types of thermodynamic systems:

- isolated system (only approximately realized in the lab): neither mass nor energy can be exchanged with the environment, entropy increases until it reaches a maximum
- closed system (planet Earth [ignoring e.g. mass-increase due to meteorites])
- open system (my body; the house, in which I live; this village/city; this country; ...)

A type of system, which exchanges matter, but not energy, with its environment does not exist (moving matter has kinetic energy, matter above 0 K has thermal energy [latent heat]).
system + environment = universe

Diagrammatic presentation of the 3 types of systems

History and Basics

- 1864 – CM Guldberg & P Waage (Norway): Law of mass action, e.g. for

$$a\,\mathrm{A} + b\,\mathrm{B} \rightleftharpoons x\,\mathrm{X} + y\,\mathrm{Y}$$

at equilibrium (given temperature T; molar concentration of A $[A]$ etc.):

$$K(T) = \frac{[X]^x [Y]^y}{[A]^a [B]^b} = \text{const}$$

At equlibrium, the reaction mixture has reached maximum entropy.

- 1884/1888 – H Le Chatelier (France): A system in equlibrium, which is put under stress in some way, tries to evade that stress as much as possible when it adopts a new equilibrium (Le Chatelier's principle)

Two examples (Haber-Bosch ammonia synthesis, NO_2 equilibrium):

$$3\,\mathrm{H_{2\,|g}} + \mathrm{N_{2\,|g}} \rightleftharpoons 2\,\mathrm{NH_{3\,|g}}\ , \qquad 2\,\mathrm{NO_{2\,|g}} \rightleftharpoons \mathrm{N_2O_{4\,|g}}$$

Pressure increase pushes both equilibria to the right-hand side (volume reduction)

- 1943 – E Schrödinger (Dublin): What is Life?

  Q1: What is the physico-chemical basis of genetic inheritance?
  A1: Genetic information must be contained in an "aperiodic crystal".

  Q2: What is going on during metabolism?
  A2: A living organism succeeds, during all its life, from freeing itself from the entropy that it cannot avoid to produce while it is alive.

"Like so many works that have had a great impact on human thinking, it makes points that, once they are grasped, have a ring of almost self-evident truth; yet they are still blindly ignored by a disconcertingly large proportion of people who should know better. How often do we still hear that quantum effects can have little relevance in the study of biology, or even that we eat food in order to gain energy?"

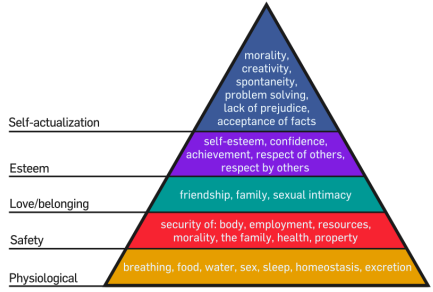
From the foreword to *What is Life?* by R Penrose (* 1931, Nobel Prize in Physics 2020) Cambridge University Press, 1992

What is Life? — For an animal, like us humans, living under aerobic conditions ...

- breathing ($O_2\downarrow$, $CO_2\uparrow$)
- drinking (H_2O) & eating (proteins, carbohydrates, lipids, fibres, ...)
- clothing (wool, cotton, nylon, ...)
- housing (wood, brick, ...)
- moving (by yourself?, by vehicle?, energy source?)
- reproducing (genetic code)

P Harris (Baloo) & B Reitherman (Mowgli): The Bare Necessities, The Jungle Book, Disney, 1967
Youtube link

- 1943 – A Maslow (USA): Hierarchy of needs



"One of the goals of education should be to teach that life is precious."
A Maslow, *Motivation and Personality*, 1954, Harper & Row, New York, p 255

- 1945 – K Popper (New Zealand): The Open Society and Its Enemies (2 vols.)
  A democratic system is a system where the change of the government takes place without the spilling of blood
- 1945 – Foundation of the United Nations (UN) (initially 51 member states; now 193 member states, as of 2023)

- 1968 L Onsager (Norway/USA) is awarded the Nobel Prize in Chemistry for his work on non-equlibrium thermodynamics ("Onsager reciprocal relations", 1931)
- 1977 I Prigogine (Belgium) is awarded the Nobel Prize in Chemistry for his contributions to non-equlibrium thermodynamics, particularly the theory of dissipative structures (1955)

https://en.wikipedia.org/wiki/Onsager_reciprocal_relations

- 1980 – The "Global 2000" Report to the President (commissioned by J Carter, largely ignored by his successor R Reagan)
- 1983/1987 – Brundtland* Commission (UN) & Brundtland* Report ("Our Common Future") contained a definition of the term "sustainable development":

  "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

https://en.wikipedia.org/wiki/The_Global_2000_Report_to_the_President
* named after former Norwegian Prime Minister Gro Harlem Brundtland (* 1939), who has chaired the Commission

- 1992 – HW Kendall (1990 Nobel Prize in Physics, with JI Friedman and RE Taylor) & Union of Concerned Scientists: World Scientists' Warning to Humanity, signed by about 1,700 scientists, including 104 Nobel laureates — a majority of the then living recipients of the Prize in the sciences

  "Human beings and the natural world are on a collision course. [...]
  We the undersigned, senior members of the world's scientific community, hereby warn all humanity of what lies ahead. A great change in our stewardship of the earth and the life on it is required, if vast human misery is to be avoided and our global home on this planet is not to be irretrievably mutilated."

- 2017 – WJ Ripple (Prof of Ecology, Oregon State University): World Scientists' Warning to Humanity – A Second Notice, signed by $>$ 15,000 scientists

  "To prevent widespread misery and catastrophic biodiversity loss, humanity must practice a more environmentally sustainable alternative to business as usual."

https://www.ucsusa.org/resources/1992-world-scientists-warning-humanity
https://scientistswarning.org

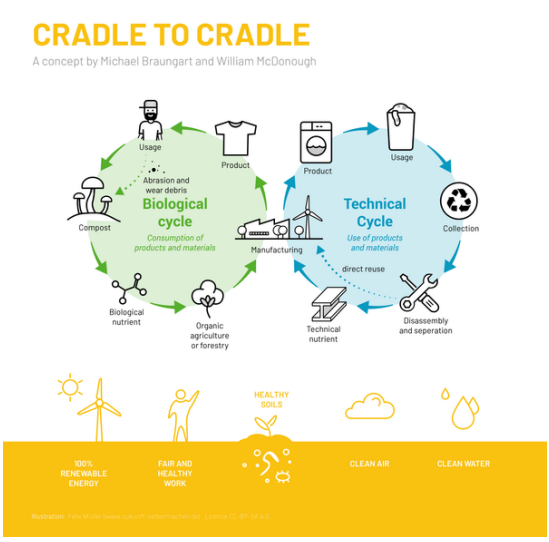
1998: Green Chemistry

- Prevention
- Atom Economy
- Less Hazardous Chemical Syntheses
- Designing Safer Chemicals
- Safer Solvents and Auxiliaries
- Design for Energy Efficiency
- Use of Renewable Feedstocks
- Reduce Derivatives
- Catalysis
- Design for Degradation
- Real-time Analysis for Pollution Prevention
- Inherently Safer Chemistry for Accident Prevention

Need to always think Chemistry together with Engineering → Green Chemistry & Green Engineering

P Anastas, J Warner: *Green Chemistry – Theory and Practice*, Oxford University Press, 1998, p 30
https://www.acs.org/greenchemistry/ (accessed 17 Apr 2024)

1998/2002: Cradle to cradle (C2C) — instead of "cradle to grave"

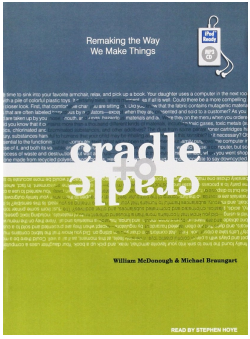


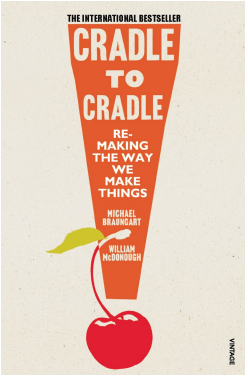
Why so late? (after more than 300 years of scientific development)

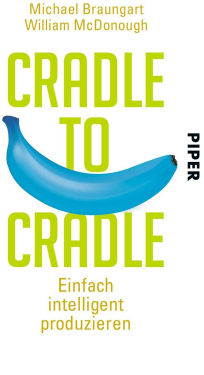
This cannot work literally 100%, there is always some loss (entropy production)

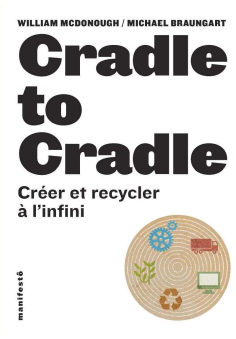
How about inorganic materials (e. g. glassware, ceramics, metals)?

W McDonough, M Braungart: newspaper article, 1998
W McDonough, M Braungart: *Cradle to cradle – remaking the way we make things*, North Point Press, 2002
Scheme: https://en.wikipedia.org/wiki/Cradle-to-cradle_design (accessed 17 Apr 2024)









US version — UK version — German version — French version

- 1920 – F Haber (1868–1934, 1918 Nobel Prize in Chemistry):
  The Recycling Principle:
  What is taken from the natural raw material base by technology must return to the source after its economic use, so that the original material "brought into new forms becomes usable anew", as he wrote at the time and as has become increasingly important since people have been striving for sustainability.

  EP Fischer: Ein Scheiterhaufen der Wissenschaft (A stake of science, German), Springer, Berlin, 2023, p. 55 (translated with Deepl)

- 2011 – R Kümmel (* 1939, theoretical physicist, Würzburg):
  The Second Law of Economics — Energy, Entropy, and the Origins of Wealth, Springer, New York, 2011

Any real-world system or structure depends on or is related to

- in-/out-flow of matter (or amount of substance):

$$\underline{j}_m(\underline{r}, t) \text{ or } \underline{j}_n(\underline{r}, t)$$

- in-/out-flow of energy:

$$\underline{j}_E(\underline{r}, t)$$

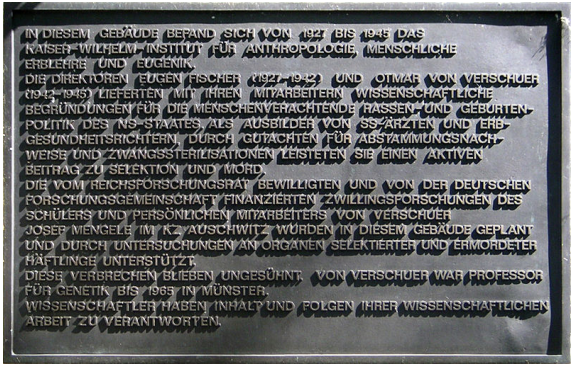
- non-negative entropy production (density):

$$\sigma_S(\underline{r}, t) \geq 0$$

during all the time of its "life" (creation or birth; normal operation and maintenance; final removal or death)

How much did you learn about all that during your studies in science up to now?
How good is, already now, your mastery of these concepts?

On Responsibility



English translation of the last sentence:
"Scientists are responsible for the content and consequences of their scientific work."

Memorial plaque at the building of the Otto Suhr Institute for Political Science, FU Berlin, Ihnestr. 22, Berlin-Dahlem (former Kaiser Wilhelm Institute of Anthropology, Human Heredity and Eugenics, 1927–1945, reminding us of that institute and its role during the time of National Socialism)
Picture (taken in 2005): https://de.wikipedia.org/wiki/Otto-Suhr-Institut (CC BY-SA 3.0, accessed 17 Apr 2024)

Preface

Green chemistry is not different from traditional chemistry inasmuch as it embraces the same creativity, and innovation that has always been central to classical chemistry. Green chemistry merely pursues those same ideals with additional considerations to those incorporated into the design and implementation of chemistry historically. These considerations, described in this book, reflect the power that the chemist holds not only over the disposition of the chemistry that is created, but also over all of the implications of the chemistry, from its creation, to its use, until its destruction and beyond. Beyond, because a chemist can not only design a substance to have certain characteristics during its useful life, but can also design what that substance will become (or break down into) after its useful life is over.

This book is not a moral judgment on chemistry but it does elucidate the obligations that chemists, as scientists, have in making choices when designing chemical methodologies. Chemistry itself can be neither 'good' nor 'bad' in a moral sense, as it is merely a natural phenomenon following physical laws. Chemists, however, possess the knowledge and skills to make decisions in the practice of their trade that can result in immense benefit to society or cause harm to life and living systems and they therefore have responsibility for the character of the decisions made. So, while the science of chemistry can be neither holy nor evil, people of either amoral, ignorant, or irresponsible character have misused chemistry and have created a popular disdain for the 'central science' and those who make it their trade.

Basic research in green chemistry is needed. The discovery and development of fundamental chemical transformations that are not harmful to the environment will be the driving force that moves this

area forward. Applications of these discoveries will be and have been utilized both for economic and scientific reasons. These methodologies have the potential to affect every aspect of life, just as the field of chemistry has done in the past. Because a synthetic methodology is not sentient, it does not know if it is going to wind up making a pharmaceutical, a paint, or a food additive and thus have a positive impact on all of those chemical products.

It is the chemist who makes these discoveries. It is the chemist who creates the tools, the synthetic methods, that are used throughout industry. Ultimately, because of this role, it is the chemist who has the responsibility for the character of the tools that are in the toolbox. Fortunately for society, it is these same chemists who are solely, uniquely qualified to make those decisions and those discoveries. Green chemistry utilizes the same skills that chemists have always used throughout the history of the science. This book strives to provide a basis and a framework for pursuing the science in the most creative, innovative, and responsible manner possible.

Boston P.T.A.
December 1997 J.C.W.

P Anastas, J Warner: *Green Chemistry – Theory and Practice*, Oxford University Press, 1998, preface (2nd paragraph, lines 5ff; last paragraph, completely)

Some topic-related thoughts from Berlin street art

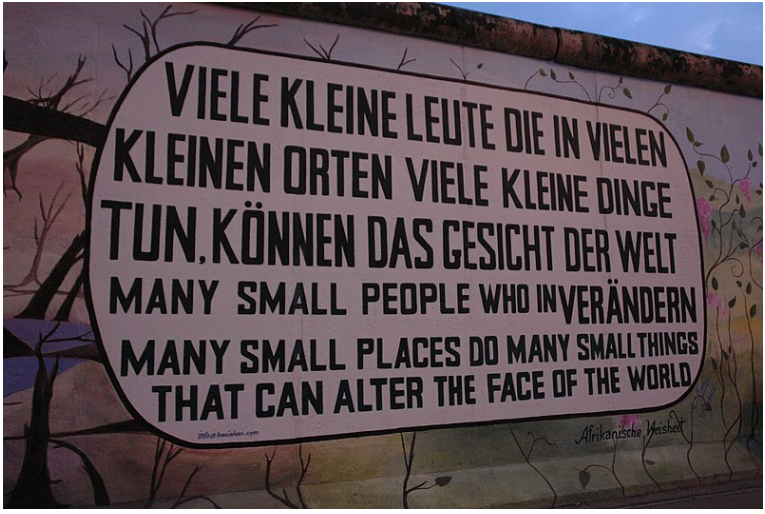
"Nature does not need us / But we need Nature"

A group of artists with B Wagin: *Weltbaum II – Werden, Sein, Vergehen*, 1985/1986
Street art mural, S-Bahn Savignyplatz, Berlin, pictures taken 2022 (left) and 2021 (right)

Street art mural created at the occasion of the 750-years anniversary of Berlin, 1987 — B Wagin (1930–2021),
https://en.wikipedia.org/wiki/Ben_Wagin
Landesdenkmalamt Berlin, 08.12.2022, ©Thorsten Dame (Link)
Berliner Zeitung, 09.06.2021, ©Berliner Zeitung / Jens Blankennagel (Link)

Some topic-related thoughts from Berlin street art

"Many small people doing many small things in many small places can change the face of the world."
— African wisdom



K Alavi & M Raoux (*without title*), 1990 / East Side Gallery, Berlin

Picture: https://es.wikipedia.org/wiki/East_Side_Gallery (CC BY-SA 3.0, accessed 17 Apr 2024)
see also: Google Arts & Culture, East Side Gallery (Link)

Demonstration(s) with objects from everyday life (if time permits)

• You won't like to buy or to invest in goods of inferior quality, but which reusability quality has the stuff that leaves your home/lab?

• Reusability by whom? By other man-made organizations? By other forms of life? Use for good or use for worse?

• Reusability on which typical time scale? We can't wait until plate tectonics will have changed Earth's surface completely in a natural way!

• Does any type of non-recyclable material really exist?

From a typical German bin for recyclable material:

"Please make sure that sales packagings are clean and without remains of content"

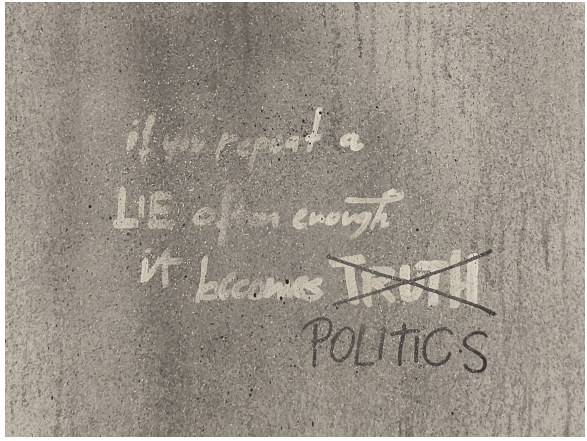
Picture taken by D Andrae, 23 Nov 2024

Take-home messages

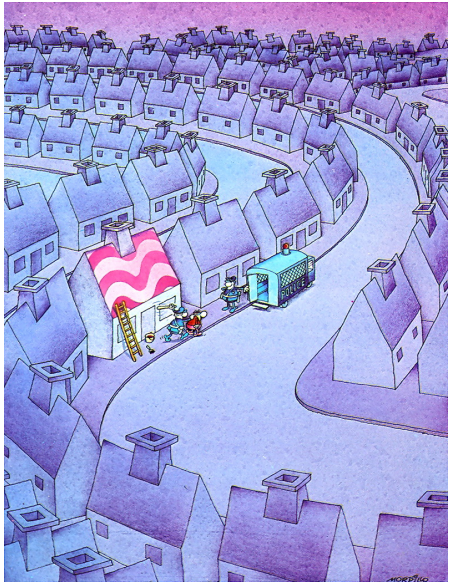
- We can create/destroy neither matter nor energy (conservation of mass/energy)
- Only three types of thermodynamic systems exist (isolated, closed, open)
- Flow of matter/energy is unavoidably linked to "losses" (entropy generation). Only in isolated systems, this ends when entropy has reached its maximum
- While matter/energy flow through open systems never stops producing entropy, it does (or can) create "structure" (patterns in space and/or time, life)
- When our usage of things/goods/stuff has come to an end: Which reusability quality has that stuff when it is released by us? Reusability quality for whom, for which (possibly other) forms of life on this planet?
- What about chemical elements (and their compounds) that play no (known/essential) role for life, like B or F? Prohibition?
- Enjoy life, every single day, and don't stop thinking for yourself

"Sustainability is good, if everyone contributes to it."

(from a recent advertisement campaign of a German drugstore chain)



From the exhibition *"The Mystery of Banksy — A Genius Mind"*, Bielefeld, Nov 2024 – Apr 2025
Picture taken by D Andrae, 22 Feb 2025



Mordillo, Cartoon No. 5, Éditions Jacques Glénat, 1976, p 41

Farewell, dear masters (f/m/d) of the 80 elements!*

Thank you for your attention!

Questions? Welcome anytime!

* ${}_{1}\mathrm{H} \ldots {}_{43}\cancel{\mathrm{Tc}} \ldots {}_{61}\cancel{\mathrm{Pm}} \ldots {}_{82}\mathrm{Pb}$