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Feature Articles

Chemical Terms in History: Polysemy and Meaning Transfers

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Abstract. The vocabulary of the chemical sciences consists in part of words and phrases many of which are of a technical nature while others are derived from or related to everyday language. Many of the words are so-called polysemes, that is, they are used with different meanings either in common language or in the technical language of other sciences. The study of the origin and migration (or transfer) of words in science provides additional insights in how science has developed historically and interacted with the cultural domain. One type of word migration is between the scientific and socio-cultural domains, while another is restricted to the transfer between different scientific disciplines or sub-disciplines. This paper discusses and exemplifies a select number of chemically related words and phrases from a historical perspective. Among them are commonly known words such as 'radical,' 'catalyze,' and 'litmus test' which are used not only as technical terms in chemistry but also, in figurative and metaphorical senses, in everyday language.

Keywords: history of chemistry, language, words, polysemy, semantic shifts, radical, bromide, DNA

1. INTRODUCTION

When chemists speak of the language of their science they typically refer to the nomenclature related to the numerous chemical compounds and how their names and symbols have changed over time. What once was known as 'fixed air' is now called carbon dioxide CO_2; what is commonly known as just alcohol is ethanol C_2H_5OH in chemical language. Lavoisier's chemical revolution in the 1780s traditionally hailed as the beginning of so-called modern chemistry was to a large extent based on a radical reform of chemical nomenclature. The collaborative work *Méthode de Nomenclature Chimique* from 1787 was not only "a momentous contribution to the world-wide vocabulary of Western science," as it has been called,[1] but also an integral and most important part of the chemical revolution.

However, there are other ways in which a focus on words and phrases may elucidate the historical development of chemistry and science generally. One of them is to pay attention to what linguists call 'semantic shifts,' an expression that refers to words which migrate from the scientific domain to common language and as a consequence change their meaning. But it can also be the other way around, that is, a commonly known word which is adopted as a technical term in a particular area of science. A third variant of semantic shifts occurs when a technical term in one branch of science is reused in another branch, what may be called internal word migration. Although the term in question is the same, when reused it occurs with a different meaning. As pointed out by the linguist Carolynn Van Dyke, the reuse or recycling of words is not a one-way transfer since recycled scientific terms will often return to the domains, scientific or non-scientific, from which they originally came.[2]

More generally, this study is part of a larger project focusing on the etymological and terminological components of the natural sciences through history.[3] In science as elsewhere, words are more than just words. Like other communicative cultural forms, science depends crucially on the chosen language and the words of which it consists. Since the history of science is echoed in the development of its language, an examination of the latter will inevitably provide additional insights in how various branches of science have developed over time.

2. POLYSEMIC TERMS IN CHEMISTRY

Words and phrases generally have multiple coexisting meanings, a phenomenon known as *polysemy* ('many signs' in ancient Greek, πολύ σήμα). Ordinary language is polysemic insofar that most of its words admit of more than one meaning. The few which do not are called monosemic. Polysemic terms abound in science if not quite as frequently as elsewhere. An everyday word often turns up in a scientific context with a specialized and very different meaning, which may cause confusion to chemistry and other science students. Polysemy turns out to be an obstacle in science learning and has for this reason attracted critical attention in educational and didactic contexts.[4] As an American chemistry teacher half-jokingly commented:

> Thus, 'gas' is not what you put in your car, nor is an 'Ideal Gas' one which gives good mileage; 'precipitation' refers to the formation of solids and not to rain; 'acids' are not psychedelic drugs and 'basic' does not mean fundamental; not all pleasant-smelling chemicals are 'aromatic'.[5]

There are several other words in this category of multiple meanings which are used in both scientific contexts and everyday language. If used in a technical sense, their meanings often differ from one area of science to another. Familiar terms such charge, matter, resonance, force, power, and specific (as in 'specific heat') are random examples.

Other polysemic terms of chemical and biochemical relevance are 'culture,' 'mole,' 'solution,' and 'spontaneous' (more examples are discussed below). Apart from its general meaning, since the 1880s *culture* also refers to the production of bacteria or other microorganisms in the biological laboratory. A *mole* is a small animal primarily living of earthworms but also a chemical unit given by Avogadro's number of molecules or other particles.[6] The *molar* concentration is the number of moles per unit volume, an adjective, whereas the noun molar refers to a tooth. When we think to have found the answer to a problem, we have found its *solution*. In mathematical usage the solution to the cubic equation $x^3=8$ is $x=2$, but in chemistry the term typically refers to a substance dissolved in water or some other liquid. Again, the common meaning of *spontaneous* is an immediate and unconstrained action or thought. On the other hand, thermodynamically favored chemical reactions (e.g. $2H_2+O_2 \rightarrow 2H_2O$ at room temperature and in the absence of a catalyst) are said to occur spontaneously even though they occur with a reaction rate close to zero.[7]

The word *earth* is polysemic given that it appears in different contexts with each their separate meanings. As used by astronomers and geologists the term chiefly refers to our planet and as such it is often written with capital first letter, Earth. In an agricultural context the term is a synonym for 'soil' and to Empedocles and the ancient Greeks it was an elemental principle on par with 'air,' 'water,' and 'fire.' Chemists and mineralogists in the eighteenth century typically used the term 'earth' in both its singular and plural form (earths), namely as a designation of substances later identified as metallic oxides or carbonates. As a reminiscence of the past we still speak of the 'rare earths' but now as a group of metallic chemical elements largely identical to the lanthanide series in the periodic table.

3. INTERNAL WORD MIGRATION

As mentioned, in many cases words and phrases do not migrate between the social and scientific spheres but within the latter, that is, between different fields or subfields of science. It is not uncommon that a technical term originating in one scientific discipline is subsequently adopted with a different meaning in another discipline. One example among many is the term *pyrene* (or pyrena) which in botany denotes a fruitstone within a drupe, whereas in chemistry the same word refers to an organic compound consisting of four benzene rings with the stoichiometric formula $C_{16}H_{10}$ (Fig. 1). The botanical pyrene is derived from Greek 'pyren' or 'pyreno' (πυρήν) meaning fruitstone, whereas the chemical pyrene refers to 'pyr' or 'pyro' (πύρ) meaning fire. Of a somewhat different kind is the history of the term *plasma,* which entered scientific language as blood plasma and much later migrated from medicine to physics as the name for the very different phenomenon of a fourth state of matter.[8]

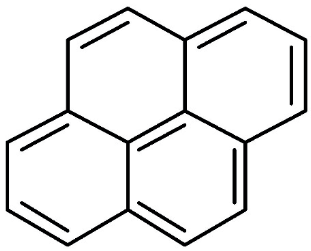

Figure 1. The structural formula of pyrene.

A word migration of an approximately similar kind can be followed in the term *chain reaction* which today is mostly associated with the fission process in which nuclear energy and new neutrons are generated explosively in a lump of enriched uranium. However, 'chain reaction' was originally coined in 1921 to describe the reaction kinetics of photochemical and other processes (e.g. $H_2+Cl_2 \rightarrow 2HCl$). It was a widely used term in chemistry and biochemistry years before it was adopted with a new meaning by the nuclear physicists at the end of the 1930s. Later again the term was used in a variety of figurative and metaphorical senses.[9]

Darwinian evolution theory provides an interesting case of how characteristic words and phrases belonging to the biological realm migrated temporarily to chemistry in the last quarter of the nineteenth century. Among those who explicitly invoked Darwin's biological theory in more than just a rhetorical sense was the Austrian physical chemist Leopold Pfaundler, the Danish thermochemist Julius Thomsen, and the British chemist William Crookes.[10] For example, in an address to the 1886 meeting of the British Association for the Advancement of Science Crookes advocated what he called 'inorganic Darwinism' including the suggestion that the known elements were "the gradual outcome of a process of development, possibly even a 'struggle for existence'."[11] Moreover, stating that "The array of the elements cannot fail to remind us of the general aspect of the organic world" he mentioned as an example "the Monotremata [platypus, echidnas] of Australia and New Guinea, and among the elements the metals of the so-called rare earths."

In some cases, science words just happen to be duplicated with a new meaning and in a new field without any connection to or knowledge of the earlier use of the term. If so, the term does not 'migrate' from one field to another – as plasma did – but is independently introduced in two fields with different meanings. As one example, consider the short-lived neologism *metabolon* that Ernest Rutherford and Frederick Soddy coined in 1903 for unstable decay products of radioactive elements. The very same term was independently reinvented 82 years later by the Hungarian-born American biochemist Paul Srerer when looking for a term describing various molecular complexes of metabolic enzymes:

> Communication about such complexes might be facilitated if a single word were available for them. … It seemed clear that no simple word could convey in its own structure the concepts I have discussed so … I propose, therefore, the word 'metabolon' for a 'supramolecular complex of sequential metabolic enzymes and cellular structural elements'.[12]

In what follows I present nine brief case studies (4.1-4.9) of words which in one way or other illustrate how the meaning of scientific terms have changed over time and often crossed the barrier between scientific and everyday language. Most of the examples, which are here limited to the English language and given in no particular order, refer to fields of chemistry and their history.

4.1. ENERGY

Although not specifically a chemical term, since the 1860s *energy* has been a fundamental concept in chemistry. It is often stated that in the scientific sense, 'energy' was coined by the English polymath Thomas Young in a lecture of 1802 although at the time he referred only to the kinetic energy (or, to be precise, to the *vis viva* given by mv^2 and not $\frac{1}{2}mv^2$).[13] Several decades later, with the discovery of energy conservation, 'energy' was adopted as a key term in the physical sciences except that initially it was mostly called *force* in English, *Kraft* in German, and *puissance* in French. It took until the 1870s before 'energy' became the favored term among physicists, chemists, and other scientists.

However, 'energy' had entered the English language long before if as a religious and metaphysical term or sometimes as an expression for the active powers of either nature or humans. The painter, poet and mystic William Blake composed in the early 1790s a book in which 'energy' appeared in a sense completely different from the one we now associate with the term. "Energy is Eternal Delight," Blake declared," adding that "Energy is the only life and is from the Body and Reason is the bound or outward circumference of Energy."[14] A generation earlier, the 1720 edition of Edward Phillips' dictionary *New World of Words* explained:

> Energy, effectual Working, Efficacy, Force: In *Rhetorick*, a Figure wherein great Force of Expression is us'd: In a Medicinal Sense, a stirring about, or Operation of the Animal Spirits and Blood.[15]

As late as 1842 – the year of J. Robert Mayer's first formulation of the principle of energy conservation – the *Encyclopaedia Britannica* defined energy as "a term of Greek origin, signifying the power, virtue, or efficacy of a thing. It is also used figuratively, to denote emphasis of speech."[16] But then things changed. Thirty-seven years later, the same authoritative dictionary included a detailed 7-page article on energy in its modern sense.[17]

According to a recent study, the term energy originated in a cultural context from which it migrated to the fields of science and then, eventually, migrated back to culture with a new meaning.[18] Although 'energy' today mostly refers to the physical entity dating from the mid-nineteenth century – an entity which has for long become a commodity and the consumption of which we pay for – the old meanings have persisted and new have been added. We may still speak of energy as a personal quality, say 'a man of great energy' and we understand, more or less, what is meant by 'mental energies' or a metaphorical phrase like 'the city was buzzing with energy.' Although energy has no color, we speak metaphorically and sensibly of the renewable 'green energy' versus the 'black energy' based on coal and natural gas. The polysemic term energy is all over in our language, scientific as well as non-scientific. While in 1800 it occurred with a frequency of 40 times per million words in written English, and in 1900 with 80 times, today the frequency is about 200 per million words, which makes it one of the 500 most common words (OED, *Oxford English Dictionary*).

4.2. LITMUS TEST

One of the simplest and most common experiments in elementary chemistry is the *litmus test* in which the acidic or basic character of a solution is demonstrated by means of a litmus paper. If the paper turns blue, the solution is basic (pH > 8.3) and if it turns red the solution is an acid (pH < 4.5). The English name 'litmus' for a substance extracted from various lichens is derived from old Norse *litmos* meaning 'moss used for dyeing' and was in the seventeenth century typically spelled 'lytmos' or 'lyttmosse' (OED). It may have been known as an indicator by Robert Boyle, but it was only with the French chemist Antoine Fourcroy in the 1780s that the litmus test was used systematically for analytical purposes.[19] In 1803 Humphrey Davy referred in one of his investigations to the manufacture of crystals of gallic acid, and "a fluid came over, which reddened litmus-paper."[20] Eventually, the qualitative test became a standard remedy in nineteenth-century school chemistry.

As a figurative term or metaphor emancipated from its chemical meaning 'litmus test' only entered the English language in the second half of the twentieth century, typically in the sense of a crucial indication that something is actually the case or has succeeded. 'The passing of the bill was a litmus test for the new government,' a newspaper may report. Or we may be told that with the solar eclipse observations of 1919 Einstein's theory of general relativity passed a litmus test, which in this sense corresponds to a so-called crucial experiment. Such phrases with somewhat different connotations are very common in today's plain language. *Britannica Dictionary* defines a litmus test normatively, namely as "something (such as an opinion about a political or moral issue) that is used to make a judgement about whether someone or something is acceptable."[21] Indeed, in this sense the term litmus test has been employed in American political language since the mid-twentieth century. To give just one more example of non-chemical use of the term, in 1985 the famous German philosopher and sociologist Jürgen Habermas published an article with the title "Civil Disobedience: Litmus Test for the Democratic Constitutional State."[22] That is, by making a direct analogy to the chemist's test of acidity, Habermas argued that civil disobedience was a crucial test of whether a nation was truly democratic or not.

4.3. 'GOOD CHEMISTRY'

When two persons are said to have a 'good chemistry,' it typically means that they easily come along, enjoy being together, or have an intuitive feeling of what the other is thinking. If Johnny tells Linda that 'Well, there just wasn't any chemistry between us,' Linda knows what he means. An American newspaper reported about a basketball team: "Injuries have hurt our chemistry, and team chemistry is such a delicate thing."[23] It is not obvious what chemistry has to do in phrases like these, but there is help to find in George Bernard Shaw's play *You Never Can Tell* from 1897. Gloria says to Valentine, "I hope you are not going to be so foolish – so vulgar – as to say love," to which Valentine replies:

> No, no, no. Not love: we know better than that. Let's call it chemistry. You can't deny that there is such a thing as

> chemical action, chemical affinity, chemical combination – the most irresistible of all natural forces. Well, you're attracting me irresistibly – chemically.[24]

The old polysemic word *affinity* is the key term. Around 1700 it was associated with human relationships and not with the reactivity of chemical substances, such as illustrated by the definition in *World of Words*: "Affinity, Kindred or Alliance by Marriage; Relation or Agreeableness between several Things."[25]

Apart from its many other connotations the concept of affinity has played a crucial role in the history of chemistry, where it originally was an expression for the 'sympathy' between two chemical substances of the same 'affection.' Only by the mid-eighteenth century did chemists begin to speak of the affinity of a substance for other substances *unlike* it rather than *like* it. The poorly defined concept could be conceived as a kind of force causing some substances to combine and others not. Later attempts to turn the elusive affinity into a measurable quantity resulted in elaborate electrical and thermal theories of 'elective affinity' until it was largely replaced by the free energy of current chemical thermodynamics.[26]

There is another common expression with scientific and semantic roots similar to the one of 'good chemistry.' If two or more people understand each other well or can easily cooperate – are 'of the same mind' – they are said to be 'on the same wavelength.' The idiom, which has been in use since the 1920s, alludes to the reception of radio programs at a particular wavelength sent through 'the ether.'[27] It would make no sense before the invention of radio. Although 'good chemistry' is usually a phrase referring to the mutual feelings between people, recently it has also been employed to express in a figurative manner a person's 'body chemistry' (or personality) as in the perfume brand simply called Good Chemistry.[28]

4.4. VITRIOLIC

In the eighteenth century, strong sulfuric acid was known as 'oil of vitriol' or 'vitriolic acid' because it was manufactured from sulfates or 'vitriols,' a name that comes from the Latin word *vitrum* for glass. The sulfate crystals looked like pieces of colored glass. Iron sulfate $FeSO_4$ was called 'green vitriol' and earlier 'vitriol of Mars,' and copper sulfate $CuSO_4$ was 'blue vitriol' or 'vitriol of Venus.' Stannous sulfate alias tin(II) sulfate $SnSO_4$ was known as 'vitriol of Jove,' a reference to the planet Jupiter or the Roman god of the same name. In the more systematic nomenclature of the late eighteenth century, Latin-based names such as *magnesia vitriolata* ($MgSO_4$) and *vitriolicum potassinatum* (K_2SO_4) were commonly used.[29] The term *vitrum* was also known from the new science of electricity, where the electric fluid generated by the friction of glass was known as *vitreous* and the one related to wax as *resinous*. These now obsolete words soon became known as, respectively, positive and negative electrical charges, a terminology introduced by Benjamin Franklin in about 1750.

Another common substance was the 'caustic soda' or what later became sodium hydroxide (NaOH). While sulfuric acid is a strong acid and sodium hydroxide a strong base, the two substances have in common that they are highly corrosive and therefore dangerous. The words are used figuratively in approximately the same sense, namely to denote speech or behavior which is bitterly critical, harshly condemnatory, or sarcastic in an unkind way. The OED defines the figurative senses of the two adjectives as follows: "vitriolic: Extremely sharp, caustic, or scathing; bitterly ill-natured or malignant," and "caustic: That makes the mind to smart; said of language, wit, humor, and, by extension, of persons; sharp, bitter, cutting, biting, sarcastic."

A person may launch 'a vitriolic attack' against some other person by making use of a 'caustic rhetoric.' More recently the metaphoric phrase 'oxygen of publicity' has crept into the language as an expression for how the mass media may indirectly boost questionable or harmful causes. In a speech of 1985, Britain's prime minister Margaret Thatcher said that "we must try to find ways to starve the terrorist and the hijacker of the oxygen of publicity on which they depend."[30]

4.5. BROMIDE

To chemists, a bromide is a salt containing the negative bromide ion Br^- just as a chloride contains the ion Cl^-. Sodium bromide is NaBr, potassium bromide KBr. But in literary usage the same word signifies a cliché, a banality, or a feel-good phrase, for example 'Time heals all wounds,' 'Boys are boys,' and 'You don't look a day over fifty.' Any connection between the two very different meanings? Yes, there is one.

In the mid-nineteenth century is was discovered that potassium bromide in particular had calming effects and could be used as a sedative, a remedy for headache, and even, so it was claimed, to treat epilepsy and forms of hysteria. In 1869, an American professor of medicine reported in *Scientific American*:

> Of all the sleep-producing agents at our disposal, the bromide of potassium is most deserving the name of hypnotic. A healthy adult may take from twenty to thirty grains three times a day; the latter dose is not too large. … Bro-

> mide of potassium occasionally produces also a great lowness of spirits, and a disposition to cry. It should be administered very much diluted.[31]

Although the detrimental effects of the substance had become clear by the 1880s, its popularity and overuse continued for several decades. The active ingredients in Nervine, a sedative used for a number of nervous disturbances, was potassium bromide mixed with sodium and ammonium bromides. Bromo-Seltzer or just 'bromo' based on sodium bromide and acetanilide was very popular as a pain reliever for headaches and hangovers in particular (Fig. 2).[32] Only in 1975 did the U.S. health authorities outlaw bromides in over-the-counter medicines. With the popularity of bromine-based medicine followed that 'bromide' came to be used figuratively for anything or anyone that might put one to sleep because of commonness or plain dullness.[33]

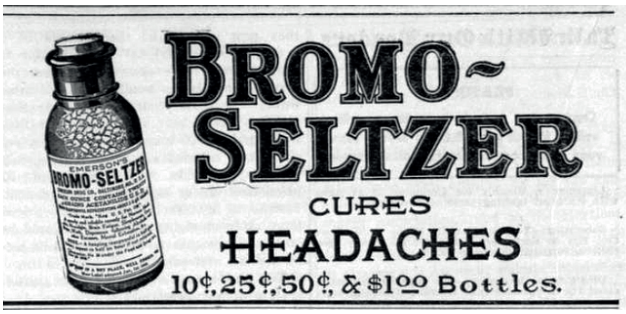

Figure 2. An advertisement for Bromo-Seltzer manufactured by Emerson Drug Co., Baltimore. Google Pictures.

As early as 1906, an American author, Gelett Burgess, published a humorous booklet with the full title *Are You a Bromide? Or, the Sulphite Theory Expounded and Exemplified According to the More Recent Researches into the Psychology of Boredom Including Many Well-Known Bromidioms Now in Use*. While boring and utterly predictable people were *bromides*, the much rarer group of people thinking by them themselves and speaking accordingly were *sulphites*. Coining the word *bromidioms*, a shortening of bromide-idioms, Burgess listed a large number of such expressions. One of them was "This world is such a small place, after all, isn't it?" and others were "That dog understands every word I say" and "Now, this thing really happened!"[34]

4.6. HYBRIDIZATION

The terms *hybrid* and *hybridization* appear in half a dozen sciences, most notably in biology (genetics), linguistics, and chemistry, but also in computing, geology, and particle physics. More recently 'hybrid' has become popular as a name for a car or other vehicle powered by a combustion engine and one or more electric motors. In the case of linguistics, a hybrid word (also called a *hybridism*) is one that etymologically derives from two or more languages. Many English words combine Latin and Greek parts and are thus hybrids, random examples being *television* and *chloroform* (Greek-Latin), and *calorimeter* and *terminology* (Latin-Greek). The language of quantum mechanics includes German-English hybrid words such as *eigenvalue* and *eigenstate*.

'Hybrid' and 'hybridization' (the formation of a hybrid) are usually associated with the offspring resulting from cross breeding, say a mule from a horse and a donkey, and in this sense they are well known and have been used for long. It is less well known, at least in the general public, that they also have a significant place in the chemists' vocabulary as terms describing the bonds that keep atoms together in a molecule. To explain the structure of methane CH_4, chemists in the early 1930s reasoned that the 2*s* and 2*p* orbitals of the carbon atom hybridize to form overlapping sp^3 orbitals.[35]

It is widely agreed that this concept from the early MO (molecular orbital) theory of quantum chemistry was introduced by the eminent chemist Linus Pauling, who in a letter to Charles Coulson claimed that he had "discovered (or invented)" the concept of hybridization as early as 1928.[36] However, at the time he did not employ the terms 'hybridization' and 'hybrid' which first appeared in print in a 1931 paper written by another Nobel Prize-winning chemist, namely Robert Mulliken:

> All the outer orbits are so much modified that we no longer should distinguish 2*s* and 2*p* orbits, but may better think, in CH4, in terms of four new 2-quantum orbit-types, each of a sort of hybrid of 2*s* and 2*p*, with 2*p* predominating in the mixture. … If the molecule is sufficiently stable, a hybridization of *s* and *p* electrons may occur.[37]

Pauling was most likely inspired by the biologists' familiar use of the terms. In 1931 he was invited to give a seminar to a group of biologists, and, according to historian of science Mary Jo Nye: "Wide-ranging readings in biology soon spilled over in his thinking about the chemical bond. The 'changed quantization' of 1928 and 1931 became widely known as 'hybridization' by the late 1930s."[38] Without going into further details it is obvious that in this case the terms were borrowed from much earlier usage, namely from farmers' breeding of animals. The chemists simply adopted a familiar terminology which they extended to a new area of atomic and molecular chemistry. The extension was scarcely noticed by people outside the chemical community and definitely not by the general public.

4.7. CATALYSIS

Contrary to 'hybrid,' the word *catalysis* and associated terms like 'catalyze' and 'catalyst' are largely chemical in origin and were subsequently transferred to other areas including everyday language. They go back to Jöns Jakob Berzelius, the famous Swedish chemist who was also a prolific chemical wordsmith responsible for neologisms such as 'isomer,' 'halogen,' 'protein,' and 'polymer.'[39] In his *Jahres-Bericht* of 1835 he pointed out, as others had done before him, that small amounts of a substance might drastically increase the reaction rate without being consumed in the reaction.[40] Ascribing this class of remarkable phenomena to a "new force in inorganic and organic nature, bringing into being chemical activity," he said:

> So long that its nature and relations are unknown it will be convenient to consider it a new force, and to give it a name. I will, using a derivation well known in chemistry, call it the *catalytic force* (katalytiska kraft; katalytische Kraft) of the bodies, and the decomposition it produces *catalysis*, just as the separation by ordinary chemical affinity is called analysis.[41]

Notice that Berzelius did not claim his terms to be proper neologisms as they were derivations "well known in chemistry." The word catalysis is derived from Greek *katalysis* (κατάλυσις) meaning 'dissolution' or 'to dissolve' and with approximately this meaning, or sometimes with the connotation 'destruction,' it can be found in the seventeenth century in both chemical and non-chemical contexts. In his influential Latin work *Alchemia* from 1597, Andreas Libavius used 'catalysis' but in the sense of the decomposition of base metals into silver and gold.[42] Whereas Berzelius defined or redefined 'catalysis' and 'catalytic,' the noun 'catalyst' for a catalytic agent came into use only in the early years of the twentieth century. According to OED it first appeared in print in 1902.

As it turned out only many years later, the mere presence of a catalyst is not enough for its action. It does take part in the reaction it catalyzes, but is reformed before the reaction is over. Berzelius' terms soon became very important in chemistry and biochemistry, and from about 1940 they also turned up with extended meanings. An American newspaper referred in 1943 to the new science of supersonics which "may usher in a new age of chemistry with radio being used as a catalytic agent."[43] The words also gained a footing in common language, typically as something or someone causing an event to happen. Thus, an individual or an organization may be said to catalyze a movement by spearheading innovative ideas and inspiring others to take action. The figurative meaning is close to but not quite the same as the chemical notion of catalysis, where a catalyst speeds up the reaction but does not cause or activate it.

4.8. RADICAL

The term *radical* exists both as a noun and, what is more common, as an adjective. It has its origin in the Latin word *radix* for 'root,' which is reflected in one of the meanings of 'radical,' namely the root or base of something. We have the word in the edible vegetable 'radish' and also in the verb 'eradicate' meaning to root something out. This is also the connection to the algebraic 'square *root*,' where the symbol in $\sqrt{x}$ is called a radical and the number x a radicand. More generally, the expression $x^{1/n}=\sqrt[n]{x}$ is the nth root of x.

In present usage the term 'radical' is often associated with politics and the social arena. Extreme political views and corresponding ideologies are said to be radical and the same term is applied as a noun for persons adhering to such views. In this political and religious sense 'radical' has been known since about 1800 but only became common in the 1960s. Sympathizers of the radical views of Islamic State (IS) are often said to have been *radicalized*. Einstein's theory of relativity was considered too radical by many contemporary physicists, meaning that it was a revolutionary break with the past.

The term also appears prominently in the history of chemistry, but with a variety of meanings which seem to have no connection to the mentioned examples. Thus, in chemistry there is no concept of *radicalization* – the process of making or becoming increasingly more radical – such as there is in the socio-political sphere. Nor is the noun *radicalism* as in 'left-wing radicalism' a chemical term. When modern chemists speak of a radical, they are referring to an atom, molecule, or ion with one or more unpaired valence electrons such as the chlorine atom Cl·, the hydroxyl radical HO·, and the methylene molecule $:CH_2$. Such particles are highly reactive and under normal conditions they can exist only for a very short time.

The concept of radicals entered chemical language in 1782 with a work by the French chemist Guyton de Morveau, who based the name on the Latin *radix*.[44] Morveau's notion was completely different from ours, as he essentially used it to denote the principle or 'acidifiable base' of an acid or, in the language of Lavoisier, the part of the acid containing oxygen. In his famous textbook *Traité Élémentaire de Chimie* from 1789 Lavoisier also wrote of, for example, the 'muriatic radical' for what later became chlorine.[45] While Lavoisier's use of 'radical' for an element did not win approval, the term persisted for a combination of elements involving carbon and hydrogen in organic compounds. For example, in this sense the idea of radicals became an integral part of Berzelius' electrochemical system. "In the case of plant substances, the radical generally consists of carbon and hydrogen, and in the case of animal substances of carbon, hydrogen and nitrogen," he wrote.[46] In the period from about 1810 to 1850 chemists generally thought of radicals as those stable and pre-existing parts of a chemical substance, whether simple or complex, that persisted with unchanged identity through chemical reactions.

Without going into the complicated history of the nineteenth-century radical theory,[47] the concept named 'radical' by contemporaneous chemists was entirely different from what modern chemists associate with the term. In recent years there has been much public attention to so-called *free radicals* and their effects on health. Free radicals generated in the body may be harmful in a number of ways. However, their physiological actions can be countered by antioxidants donating an electron to the radical and thus neutralizing it. To the extent that the general public knows about the chemical term 'radical' it is most likely in connection with the health aspects of free radicals and antioxidants. Although 'free radicals' have migrated from the chemists' laboratories to commercial health and beauty clinics, the meaning of the term has not changed to any extent.

4.9. DNA

An *acronym* is a word which is usually, but not always, formed by the initial letters of a longer word or phrase as in IUPAC (*I*nternational *U*nion of *P*ure and *A*pplied *C*hemistry) and DDT (*d*ichloro*d*iphenyl*t*richloroethane). The term itself is a neologism of recent origin as it only appeared in print in early 1943. Although abbreviations of this kind were known earlier, they only entered the language of science significantly after World War II and have since then increased explosively in number and variation.[48] One of the earliest and most widely used scientific acronyms is DNA, an abbreviation of *d*eoxyribo*n*ucleic *a*cid which according to OED dates from 1944. However, not only can DNA be found in the literature two years earlier in a paper by the American biochemist Seymour Cohen, so can the related acronym RNA (*r*ibo*n*ucleic *a*cid).[49]

It took more than a decade before the abbreviated form DNA was adopted by biochemists and molecular biologists, but with James Watson's and Francis Crick's sensational discovery of the double-helix DNA structure the acronym became increasingly popular. Incidentally, in their landmark paper in *Nature* from 1953 Watson and Crick still referred to 'deoxyribose nucleic acid' and only used D.N.A. (not DNA) once.[50] At the time of the Watson-Crick discovery the acronymic term DNA was a decade old and the substance had been known since 1871. In experiments completed two years before his paper appeared, the 25-year-old chemically trained Swiss physiologist Friedrich Miescher succeeded in isolating an impure form of DNA from the nuclei of white blood cells. What Miescher called *nuclein* was essentially the same as our DNA.[51]

The abbreviated form of deoxyribonucleic acid has been remarkably successful not only in the biochemical and medical sciences but also beyond. According to an analysis based on more than 24 million scientific article titles and 18 million article abstracts published between 1950 and 2019, the DNA acronym appeared about 2.44 million times.[52] Nearly half a million scientific papers include DNA in its title (Web of Science). As another measure of its success, in the period from about 1980 to 2020 the term DNA has appeared in the general book literature with a frequency of approximately 45 per million words, which makes it as frequently used as common words such as efficient, egg, and shop (Fig. 3).[53]

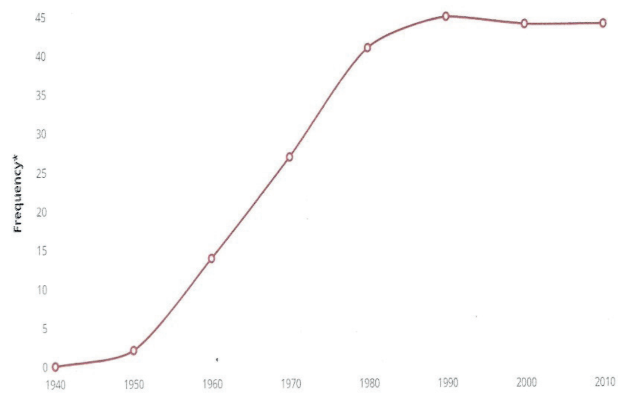

Figure 3. The word frequency of the abbreviation DNA in ppm between 1940 and 2010. Source: OED.

Moreover, metaphoric and figurative senses of the term DNA have for long been part of everyday language with the acronym effectively functioning as an independent word, a so-called pseudo-neologism. It is used by ordinary speakers or writers without knowing of or caring about its origin in the more cumbersome word 'deoxyribonucleic acid.' There is little doubt that had it not been for the abbreviated form this would not have happened. Nor would word formations such as 'DNA fingerprint' and 'DNA profiling' have been possible. In an interview of 2015 Barack Obama said, "the legacy of slavery … casts a long shadow. And that's still part of our DNA that's passed on."[54]

Today DNA is often used figuratively as signifying the essence of a person or a thing, as in 'it is part of her DNA' or in an advertisement saying 'we build good cars because it's in our DNA.' It is hard to imagine an advertisement with the alternative 'we build good cars because it's in our deoxyribonucleic acid.' As the term 'good chemistry' is used commercially in the perfume industry, so is it the case with DNA suggesting that a particular perfume expresses the user's personality. "People are individuals … [and] I match an individual's DNA print into the fragrance," says a perfume designer.[55]

5. CONCLUSION

In this paper I have called attention to certain linguistic concepts such as polysemy, semantic shifts, and word migration as resources in the history of science and the history of chemistry in particular. These and related concepts are illustrated in a concrete manner by examples of chemical terms and their histories ranging from the sixteenth to the twentieth century. To summarize, in transfer or migration processes a term *X* appears in one domain and is later adopted – in the sense borrowed – in another domain with a different meaning. One of the domains in question can be the common language, but the transfer process can also occur between two fields of science, say astronomy and chemistry or geology and physics. Moreover, it sometimes happens that *X* is independently reinvented in one domain without any connection whatsoever to the previous use of *X* in another domain. When a polysemis term is recycled it does not generally imply that the older meaning is abandoned. On the contrary, it frequently happens that two or more meanings of *X* peacefully coexist for a longer period of time.

To understand scientific texts of the past and avoid anachronisms one must be aware that many of the key terms have changed semantically and often drastically so. Because a certain key term was coined in the 1830s and subsequently became very popular it does not mean that the concept described by the term remained the same. Thus, Michael Faraday's 'ion' from 1834 differed significantly from the entity of the same name introduced by Svante Arrhenius about fifty years later. Whereas the latter conceived the ion to be an electrically charged particle always present in a solution of an electrolyte, Faraday's concept of an ion was very different.[56]

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