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The inception of ARKAT USA and ARKIVOC has been made possible by the unpaid efforts of the ARKAT USA directors and the ARKIVOC editors and referees and by an initial personal financial gift. We are now working to put the organization on a self-supporting basis, and we believe that this goal can, indeed, be achieved to create a permanent ongoing organization for the benefit both of chemistry and of humanity worldwide.

"Heavy Metals"—A Meaningless Term

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Introduction

Over the past two decades, the term "heavy metals" has been used increasingly in various publications and in legislation related to chemical hazards and the safe use of chemicals. It is often used as a group name for metals and semimetals (metalloids) that have been associated with contamination and potential toxicity or ecotoxicity. At the same time, legal regulations often specify a list of heavy metals to which they apply. Such lists may differ from one set of regulations to the other, or the term may be used without specifying which heavy metals are covered. In other words, the term "heavy metals" has been used inconsistently. This practice has led to general confusion regarding the significance of the term. The inconsistent use of the term "heavy metals" reflects inconsistency in the scientific literature. It is, therefore, necessary to review the usage that has developed for the term, paying particular attention to its relationship to fundamental chemistry. Without care for the scientific fundamentals, confused thought is likely to prevent advances in scientific knowledge and to lead to bad legislation and to generally bad decision-making.

A Review of Current Usage of the Term "Heavy Metal"

Table 1 lists all the current definitions of the term "heavy metal" that the author has been able to trace in scientific dictionaries or in other relevant literature. It must be noted that frequently the term has been used without

an associated definition, presumably by authors who thought that there was agreement about the meaning of the term. The table shows how wrong this assumption is and explains some of the confusion in the literature and in related policy and regulations. It should also be noted before going further that the term "heavy metal" has even been applied to semimetals (metalloids) such as arsenic, presumably because of the hidden assumption that "heaviness" and "toxicity" are in some way identical. This example further illustrates the confusion that surrounds the term.

Before 1936, the term was used with the meanings "guns or shot of large size" or "great ability" [1,2]. The oldest scientific use of the term to be found in the English literature, according to the *Oxford English Dictionary*, is in *Bjerrum's Inorganic Chemistry*, 3rd Danish edition, as translated by Bell in collaboration with Bjerrum, published in London in 1936 [3]. It is worth noting that no comparable inorganic chemistry textbook published since seems to have used Bjerrum's classification, and it has not been included in the IUPAC *Compendium of Chemical Terminology* [4], which is the gold standard of terminology for chemists.

Bjerrum's definition of heavy metals is based upon the density of the elemental form of the metal, and he classifies heavy metals as those metals with elemental densities above 7 g/cm^3. Over the years, this definition has been modified by various authors, and there is no consistency. In 1964, the editors of Van Nostrand's *International Encyclopedia of Chemical Science* [5] and in 1987, the editors of Grant and Hackh's *Chemical Dictionary* [6] included metals with a specific gravity greater than 4. A little later, in 1989, 1991, and 1992, Parker [7], Lozet and Mathieu [8], and Morris [9] chose a defining specific gravity "greater than 5". However, Streit [10] used a specific gravity of 4.5 as his reference point, and Thornton [11] chose 6. The *Roempp Chemical Dictionary* [12] gives 3.5 as a possible defining specific gravity. However you work with these definitions, it is impossible to come up with a consensus. Accordingly, this basis for defining heavy metals must be abandoned as yielding nothing but confusion.

At some point in the history of the term, it has been realized that density or specific gravity is not of great significance in relation to the reactivity of a metal. Accordingly, definitions have been formulated in terms of atomic weight or mass, which brings us a step closer to the periodic table—traditionally the most sound and scientifically informative chemical classification of the elements. However, the mass criterion is still unclear. Bennet [13] and Lewis [14] opt for atomic weights greater than that of sodium, i.e., greater than 23, thus starting with magnesium, while Rand *et al.* [15] prefer metals of atomic weights greater than 40, thus starting with scandium. Lewis [14] also suggested that forming soaps with fatty acids is an important criterion of "heaviness". This suggestion, together with the absurdity of classifying magnesium as a heavy metal when there has developed a conventional association of heaviness with toxicity, makes the Bennet and Lewis definition untenable. As for starting with scandium, it has a specific gravity of just under 3 and so would not be a heavy metal under any of the definitions based on density. Thus, again we have no consistent basis for defining the term.

Another group of definitions is based on atomic number. Here there is more internal consistency because three of the definitions cite heavy metals as having atomic numbers above 11, that of sodium. Interestingly, one of them comes from the chapter by Lyman in Rand (1995) [16] and contradicts the definition favored by Rand himself cited in the previous paragraph. The problem with citing metals of atomic number greater than sodium as being "heavy" is that it includes essential metals, such as magnesium and potassium, and flatly opposes the historic basis of definition tied to density or specific gravity, because it includes elements of specific gravity lower than any one that has been used as a defining property by other authors. Burrell's definition [17] even includes the semimetals arsenic and tellurium and the nonmetal selenium.

A fourth group of definitions is based on other chemical properties, with little in common: density for radiation screening, density of crystals, and reaction with dithizone. This litany brings us to the definitions based vaguely on toxicity. One of these definitions [18] even refers to heavy metals as an "outdated term". The same authors also point out, as we have already noted in Table 1, that the term has been applied to compounds of the so-called heavy metals, including organic derivatives where the biological and toxic properties may reflect more on the organic moiety than on the metal itself, thus making the term even more misleading than usual in the literature.

With the above in mind, it is not surprising that the most widely used textbook in toxicology, *Casarett and Doull's Toxicology* [19], never uses the term "heavy metal". It is not surprising either that Phipps, one of the authors whose definitions are cited in the table, calls the term "hopelessly imprecise and thoroughly objectionable" [20], or that, recently, vanLoon and Duffy conclude that "there is no chemical basis for deciding which metals should be included in this category (heavy metals)" [21]. What is surprising is the persistence of the term and its continuing use in literature, policy, and regulations, with widely varying definitions leading to confusion of thought, failure in communication, and considerable waste of time and money in fruitless debate.

Conclusion

The term "heavy metal" has never been defined by any authoritative body such as IUPAC. Over the 60 years

Table 1 Definitions of heavy metal: Survey of current usage (April 2001).

Definitions in terms of density (specific gravity)
- metals fall naturally into two groups—the light metals with densities below 4, and the heavy metals with densities above 7 [3]
- metal having a specific gravity greater than 4 [5]
- metal of high specific gravity, especially a metal having a specific gravity of 5.0 or greater [22]
- metal with a density greater than 5 [23]
- metal with a density greater than 6 g/cm^3 [24]
- metal of specific gravity greater than 4 [6]
- metal with a density of 5.0 or greater [25]
- metal whose specific gravity is approximately 5.0 or higher [7]
- metal with a density greater than 5 [8]
- (in metallurgy) any metal or alloy of high specific gravity, especially one that has a density greater than 5 g/cm^3 [9]
- metal with a density higher than 4.5 g/cm^3 [10]
- metal with a density above 3.5–5 g/cm^3 [12]
- element with a density exceeding 6 g/cm^3 [11]

Definitions in terms of atomic weight (mass)
- metal with a high atomic weight [26]
- metal of atomic weight greater than sodium [13]
- metal of atomic weight greater than sodium (23) that forms soaps on reaction with fatty acids [14]
- metallic element with high atomic weight (e.g., mercury, chromium, cadmium, arsenic, and lead); can damage living things at low concentrations and tend to accumulate in the food chain [27]
- metallic element with an atomic weight greater than 40 (starting with scandium; atomic number 21); excluded are alkaline earth metals, alkali metals, lanthanides, and actinides [15]
- metal with a high atomic mass [28]
- heavy metals is a collective term for metals of high atomic mass, particularly those transition metals that are toxic and cannot be processed by living organisms, such as lead, mercury, and cadmium [29]
- metal such as mercury, lead, tin, and cadmium that has a relatively high atomic weight [30]
- rather vague term for any metal (in whatever chemical form) with a fairly high relative atomic mass, especially those that are significantly toxic (e.g., lead, cadmium, and mercury). They persist in the environment and can accumulate in plant and animal tissues. Mining and industrial wastes and sewage sludge are potential sources of heavy metal pollution [31].
- a metal such as cadmium, mercury, and lead that has a relatively high relative atomic mass. The term does not have a precise chemical meaning [32].
- metal with a high relative atomic mass. The term is usually applied to common transition metals such as copper, lead, or zinc [33].

Definitions in terms of atomic number

In biology:
- in electron microscopy, metal of high atomic number used to introduce electron density into a biological specimen by staining, negative staining, or shadowing [34]
- in plant nutrition, a metal of moderate to high atomic number, e.g., Cu, Zn, Ni, or Pb, present in soils owing to an outcrop or mine spoil, preventing growth except for a few tolerant species and ecotypes [34]

In chemistry:
- the rectangular block of elements in the Periodic Table flanked by titanium, hafnium, arsenic, and bismuth at its corners but including also selenium and tellurium. The specific gravities range from 4.5 to 22.5 [17].
- any metal with with an atomic number beyond that of calcium [35]
- any element with an atomic number greater than 20 [36]
- metal with an atomic number between 21 (scandium) and 92 (uranium) [16]
- term now often used to mean any metal with atomic number >20, but there is no general concurrence [20]

Definitions based on other chemical properties
- heavy metals is the name of a range of very dense alloys used for radiation screening or balancing purposes. Densities range from 14.5 for 76% W, 20% Cu, 4% Ni to 16.6 for 90% W, 7% Ni, 3% Cu [37].
- intermetallic compound of iron and tin ($FeSn_2$) formed in tinning pots that have become badly contaminated with iron. The compound tends to settle to the bottom of the pot as solid crystals and can be removed with a perforated ladle [38].
- lead, zinc, and alkaline earth metals that react with fatty acids to form soaps. “Heavy metal soaps” are used in lubricating greases, paint dryers, and fungicides [39].
- any of the metals that react readily with dithizone (C_6H_5N), e.g., zinc, copper, lead, etc. [40].
- metallic elements of relatively high molecular weight [41].

Definitions without a clear basis other than toxicity
- element commonly used in industry and generically toxic to animals and to aerobic and anaerobic processes, but not every one is dense or entirely metallic; includes As, Cd, Cr, Cu, Pb, Hg, Ni, Se, and Zn [42]
- outdated generic term referring to lead, cadmium, mercury, and some other elements that generally are relatively toxic in nature; recently, the term “toxic elements” has been used. The term also sometimes refers to compounds containing these elements [18].

Definitions preceding 1936
- guns or shot of large size [1]
- great ability [2]

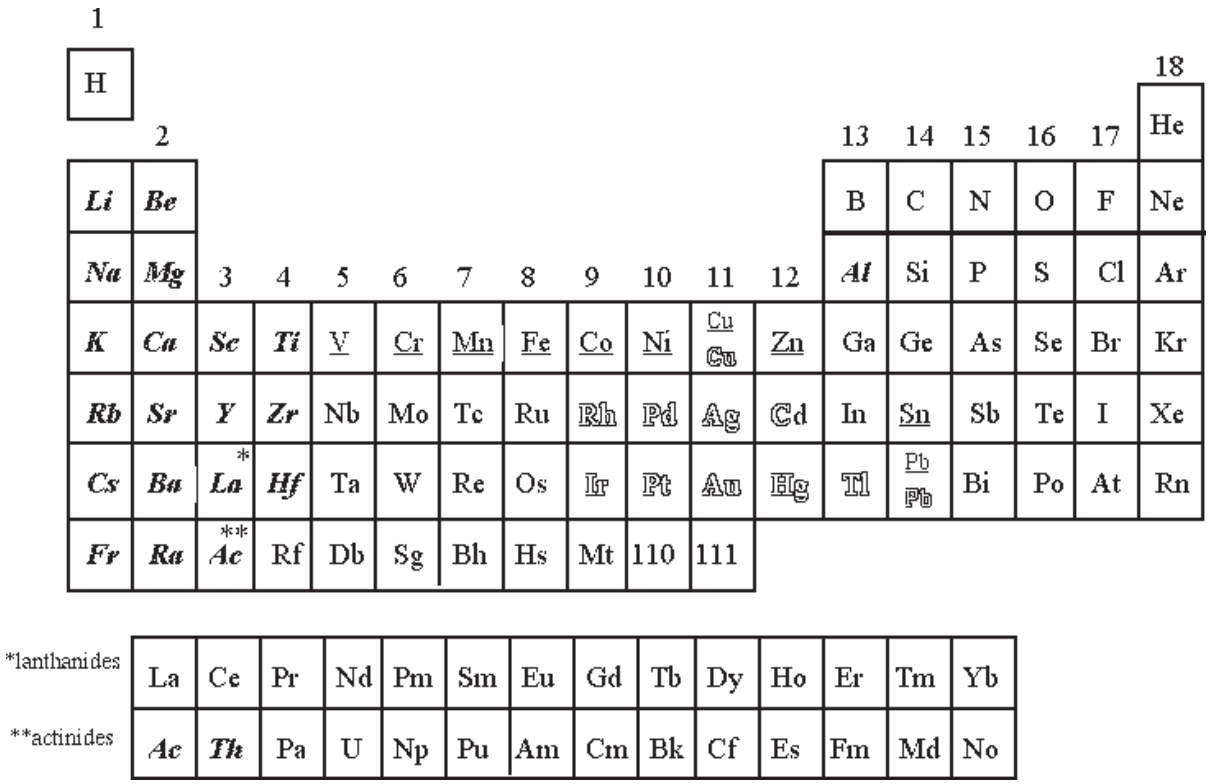

Fig. 1 Periodic table of the elements showing those metals classified as Class A, Class B, and Borderline metals. N.B.: Copper may be either Class B or Borderline, depending on whether it is Cu(I) or Cu(II), respectively. Lead may be either Class B or Borderline, depending on whether it is Pb(IV) or Pb(II).

or so in which it has been used in chemistry, it has been given such a wide range of meanings by different authors that it is effectively meaningless. No relationship can be found between density (specific gravity) or any of the other physicochemical concepts that have been used to define heavy metals and the toxicity or ecotoxicity attributed to heavy metals.

Understanding bioavailability is the key to assessment of the potential toxicity of metals and their compounds. Bioavailability depends on biological parameters and on the physicochemical properties of metals, their ions, and their compounds. These parameters, in turn, depend upon the atomic structure of the metals, which is systematically described by the periodic table. Thus, any classification of the metals to be used in scientifically based legislation must itself be based on the periodic table or on some subdivision of it. One possibility for such a system was suggested more than 20 years ago by Nieboer and Richardson [43] when they also condemned the use of the term heavy metals. Such a classification of metals by their Lewis acidity as *Class A (hard), Class B (soft),* or *Borderline* indicates the form of bonding in their complexes, and this designation determines the possibilities for complex formation and, thus, for toxicity. Class A metal ions, which are hard or nonpolarizable, preferentially form complexes with similar nonpolarizable ligands, particularly oxygen donors, and the bonding in these complexes is mainly ionic. Class B or soft metal ions preferentially bind to polarizable, soft ligands to give rather more covalent bonding. In general, it is noticeable that hard–hard or soft–soft combinations are preferred wherever possible.

Even if the term heavy metal should become obsolete because it has no coherent scientific basis, there will still be a problem with the common use of the term "metal" to refer to a metal and all its compounds. This usage implies that the pure metal and all its compounds have the same physicochemical, biological, and toxicological properties. Thus, sodium metal and sodium chloride are assumed by this usage to be equivalent. However, nobody can swallow sodium metal without suffering serious, life-threatening damage, while we all need sodium chloride in our diet. As another example, epidemiological studies show that chromium and its alloys can be used safely in medical and dental prostheses even though chromate is identified as a carcinogen.

Finally, it should be emphasized that nobody uses the term "carbon" to refer to all carbon compounds. If they did, carbon would have to be labeled as a human carcinogen because so many carbon compounds fall into this category. If metallic elements are to be classified sensibly in relation to toxicity, the classification must relate logically to the model adopted for carbon, and each metal species and compound should be treated separately in accordance with their individual chemical, biological, and toxicological properties.

Acknowledgment

This paper is based on a review of the usage of the term heavy metal carried out for Eurometaux by the author. This review is available from Eurometaux.

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