'Heavy metal'—time to move on from semantics to pragmatics?

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Despite the repeated calls to stop, most notably in a technical publication of the International Union for Pure and Applied Chemistry (IUPAC), the use of the term 'heavy metal' appears not to have declined in the scientific literature and there is little evidence that the IUPAC instructions and those of other publications have had any measurable impact on this widespread usage. Indeed, the use of the term is increasing rather than declining. Four options are presented to solve this dilemma.

1. Introduction

For many decades, the term 'heavy metals' has been used in numerous areas, including the scientific literature and legislation. The term was formerly associated with big ordnance sizes (*i.e.* 'guns or shots') and/or great abilities. The oldest recorded scientific use dates back to 1936[1] when Bjerrum[2] provided the first chemical definition of the term by using elemental density. However, this single definition was not supported and numerous new definitions were developed. Today, the term can frequently be found in newspapers, consultancy reports, standard textbooks, legal frameworks and, surprisingly, many peer-reviewed articles, describing a variety of different elements, and of course in rock music.

Today this term presents itself as an ill-defined umbrella term for various elements (primarily transition metals, but also some non-metals). There is still no authoritative or even rudimentarily uniform definition available. For instance, Beier[3] defines a 'heavy' metal as a metal with a density of >4.5 kg dm^{-3}; Nies[4] with >5 g cm^{-3}, Alloway and Ayres[5] with >6 g cm^{-3}, Bjerrum[2] with >7 g cm^{-3}. Duffus[1] lists 40 different definitions, the majority based on various chemical and physical properties, particularly different densities (ranging from 3.5–7 g cm^{-3} as threshold level) and relative atomic mass (ranging from 23–40 as threshold level). As a result, the number of elements considered to be 'heavy metals' varies between studies. Depending on the chosen definition, many dozens of elements are considered to be 'heavy metals' (for example 53 in ref. 4) and referees and editors are confronted with the phrase being used for elements in vastly different places of the Periodic Table.[6]

In addition, not all 'heavy metals' are metals in the first place—arsenic and antimony, for example, are usually classified as 'heavy metals', regardless of the fact that they are metalloids (semi-metals). Other elements are seemingly categorised randomly. Uranium (an actinoid), for example, is sometimes not included at all, sometimes considered as a 'heavy metal'[7] and sometimes listed alongside this group.[8]

'Heavy metals' are usually considered to be in some way hazardous, but there is no scientific basis to support such a generalisation.[1] The term has also been criticised on the grounds that the term is regularly used synonymously with 'trace metals' (often completely interchangeable within the same paper), but without any distinction between essential and non-essential species[9]—which, however, might be more reasonable than previously assumed, as several of the traditional classifications have recently been questioned. More recent research has indicated biological effects for (and adverse long term effects caused by a diet poor in) elements previously believed to be non-essential, including arsenic, cadmium and lead.[10]

Over the last few decades, concerns about the indiscriminate usage of this term have been voiced. In 1980, Nieboer and Richardson, after using the term themselves in earlier papers,[11] wrote one of the first major critiques of the term[12] and proposed to abandon it altogether. In the following year, the term 'heavy metals' was called 'hopelessly imprecise and thoroughly objectionable'[13] (it is not without irony, however, that this harsh verdict was published in a book titled 'Effects of *Heavy Metal* Pollution on Plants'). In a landmark paper '"Heavy metals"—A Meaningless Term?' (IUPAC Technical Report) Duffus[1] criticised explicitly the use of the term 'heavy metals' as ambiguous and pointless. Other authors have

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Environmental impact

The term 'heavy metal' is considered imprecise at best, meaningless at worst, its use is strongly discouraged. Nevertheless, the term is increasingly used in the scientific literature and no evidence could be found to suggest that IUPAC strictures have had a noticeable impact. It has been argued that a proposed replacement for this term may seem non-intuitive to environmental scientists; and last year the ten most common sources of this disputed term included renowned environmental journals with a considerable impact. This perspective paper aims to stimulate a discussion about the term's ongoing unscientific usage in environmental sciences and four options are presented.

endorsed these recommendations and Chapman[14] suggested that both authors and editors need to rigorously edit out the term 'heavy metals'.

Different alternatives have been suggested. According to Hodson,[15] the best chemical based classification to replace the non-descriptive term 'heavy metal' is to make use of the Periodic Table. This is undoubtedly correct, but detailing s-, p-, d- and f-block elements is not particularly convenient compared with a quick and easy umbrella term. It is therefore questionable if this approach will be generally adopted. Another classification uses metal ions and groups them into 'class A/hard/oxygen-seeking', 'class B/soft/nitrogen–sulfur-seeking', and 'borderline/intermediate' ions.[12,16] This scheme has the undoubted benefit of biological, toxicological and environmental relevance.[15] However, although there is a general agreement between scientists, this terminology is not absolute, either, and may additionally seem non-intuitive to environmental scientists.[15] Another approach is to simply avoid the term altogether and to enumerate all metals involved in a study, or to use less objectionable umbrella terms (like 'metals and/or metalloids' or 'elements in this study') if too many elements are involved.[17] This should work well for the vast majority of research studies.

To sum up, the term 'heavy metal' is considered imprecise at best and misleading at worst; its use is strongly discouraged.[1,6,12,14,15,17,18] The outspoken critics include the International Union for Pure and Applied Chemistry (IUPAC), the 'world authority on chemical nomenclature, terminology, standardized methods for measurements, atomic weights and other critically evaluated data'.[19] Regarding chemical nomenclature, 'what IUPAC says goes'.[15] Therefore, these suggestions have much more than just a recommendatory character and a broad implementation into practice should be expected. It is time to investigate what, if anything, has changed.

2. Methodology

Using the scientific literature databases Thomson Reuters' Web of Knowledge and Elsevier B. V. Scopus, the actual use of the term 'heavy metal' was evaluated.

In order to analyse the usage of the term, it has to be put into relation with the remarkable increase in publications in the past four decades. Therefore, the numbers of papers using the term 'heavy metal' were compared with the number of papers covering such elements. Owing to the lack of a single 'heavy metal' definition, the choice of search terms was obviously somewhat ambiguous. For this literature based evaluation, the elements arsenic, cadmium, chromium, copper, lead, nickel, tin and zinc were chosen as being representative of the problem.

Occurrences in titles and topics (title and/or abstract, and/or keywords) over the past 40 years were analysed. It should be noted, however, that the topic search in the Web of Knowledge not only incorporates author keywords, but also Keywords Plus®: words or phrases which frequently appear in the cited references of an article, but not necessarily in the article itself. Since authors and referees have only indirect influence on these, this particular section in the Web of Knowledge should be considered with some caution.

3. Results

3.1 Frequency of usage

The number of ISI Web of Knowledge listed articles dealing with such metals in general has increased at an exponential rate in the last three decades ($y = 7911.4 \times 10^{0.062x}$ for Web of Knowledge and $y = 12\,671 \times 10^{0.058x}$ for Scopus, both with a coefficient of determination of $r^2 > 0.9$, Fig. 1).

This rise is consistent with the total number of papers and not owing to an increased interest in metals. Likewise, the use of the term 'heavy metal' in topics and titles has increased at an exponential rate since 1970 ($0.82 < r^2 < 0.93$).

The increase in 'heavy metal' usage is steeper than the observed increase in papers covering such elements, especially in the Web of Knowledge database. Although Scopus lists a higher absolute number of publications in this area (on average 1.5 times as many compared to the Web of Knowledge), the use in titles and topics is comparable in both datasets. The only notable difference is that the Scopus database indicates a decrease of occurrences of 'heavy metals' between 1983 and 1992, while the Web of Knowledge shows a very constant increase between 1970 and 2009.

In 2009, 19 756 (Web of Knowledge) and 19 329 (Scopus) publications used one of the elements in the title. Compared to that, 6372 (Web of Knowledge: 32%) and 4822 (Scopus: 25%) used the term 'heavy metal' in title, abstract or keywords, with a clear increasing trend. Given that the Web of Knowledge uses additional Keywords Plus®, 25% is likely the more appropriate assessment; especially considering that the data for the use in titles are very similar in both databases. The relative use of the term in the title peaked around 1984 and occurrences subsequently dropped until 1990 (Scopus) and 1999 (Web of Knowledge). Both databases show a steady increase from then until today.

After the first major criticism by Nieboer and Richardson,[11] use of this inappropriate umbrella term dropped according to the Scopus database. The Web of Knowledge database registers only minor decrease in relative numbers. However, this partial compliance was only temporary and lasted for approximately a decade when usage started rising again. The IUPAC technical report in 2002 shows no noteworthy impact in either of the databases, the trend remains increasing in both relative and absolute numbers.

3.2 Manner of usage

As use of the term is still widespread and increasing, it would be interesting to know whether the term has been used more carefully in recent years, for example by clearly stating which elements are considered to be 'heavy metals' and why, and preferably by citing one of the 40 definitions. Unfortunately, no significant evidence could be found suggesting a less arbitrary usage.

Is it the case that this unscientific term is used more commonly in less well known and cited journals? Hardly: in the 2009 dataset, the ten most common sources of 'heavy metal*' (where * corresponds to a wildcard search) in the title included some of the most renowned environmental journals with a considerable impact, like "*Journal of Hazardous Materials*" (Impact Factor 2008: 2.975, 'ranked 1st in civil engineering'), "*Chemosphere*" (Impact

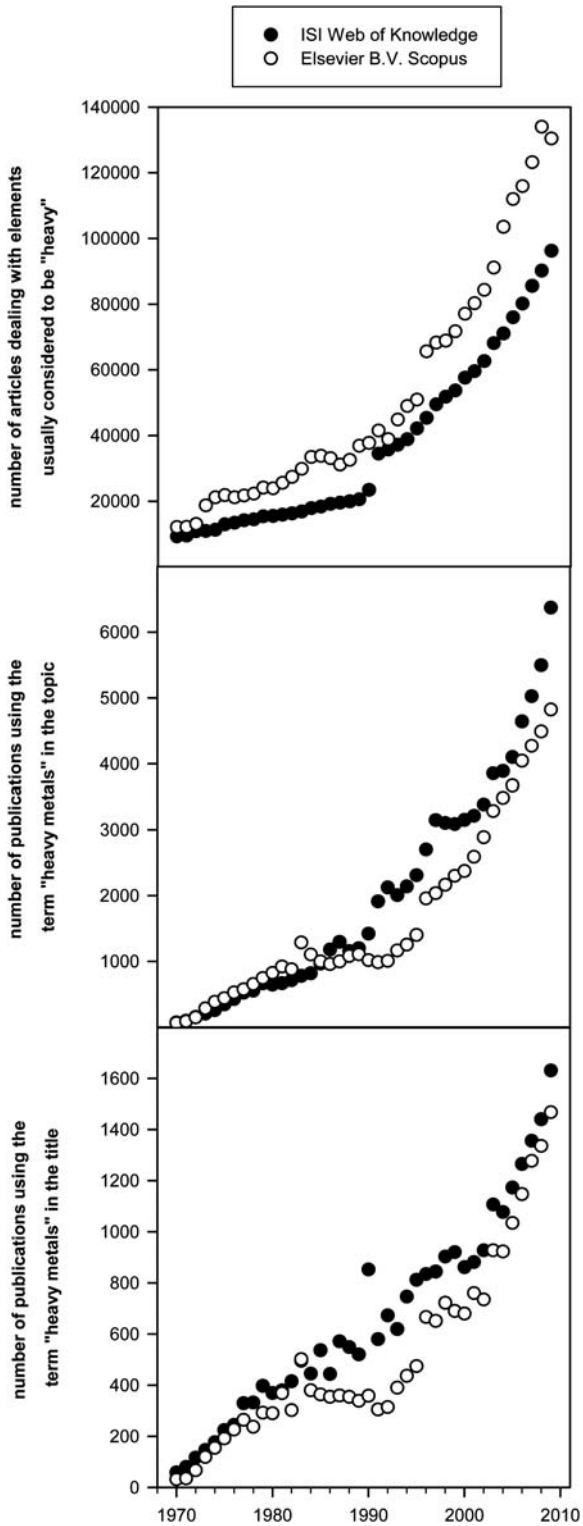

Fig. 1 Total numbers of publications dealing with elements commonly considered to be 'heavy metals' (top), number of publications actually using the term in the topics (middle) and the title (bottom) respectively. Sources: ISI Web of Knowledge ©2009 Thomson Reuters and Scopus ©2010 Elsevier B. V.

Factor 2008: 3.054, '3rd most cited in environmental sciences') and "*Geochimica et Cosmochimica Acta*" (Impact Factor 2008: 4.235, '#1 most cited in geochemistry and geophysics'). Together these three make up 12% of all occurrences in the titles listed in ISI Web of Knowledge database for 2009.

4. Discussion and conclusions

4.1 Situation

Despite the strong recommendations not to use the term in serious scientific studies, many authors still use 'heavy metals' to describe metals and non-metals in their respective studies. Some thousand articles make it through the peer-review process of respected journals and the term is on the rise. Most importantly, the data showed no measurable impact of the review by Duffus[1] in 2002 on the common usage. Despite the repeated calls to cease the practice, most notably in this IUPAC technical publication, the usage has not declined in recent years, neither in absolute nor in relative numbers.

The search for the total numbers of related papers per year was very broadly based and included all publications which are directly or indirectly dealing with at least one of the metals usually considered to be a 'heavy metal'. Studies dealing with only one or two metals are not as much in need of an umbrella term as studies covering 10 different elements.

It should be noted that in the Web of Knowledge database the search for 'heavy metal*' in the topic resulted in a number of papers which do not use the term at all, including a paper of the authors of this article,[20] in which the term certainly did not appear. This effect is caused by Keywords Plus®: words or phrases which frequently appear in the cited references of an article, but not necessarily in the article itself. Since a search of keywords and/or abstracts alone is not possible with ISI Web of Knowledge, the topic search in this database must therefore be considered with some caution. Still, it gives a good indication of the broad usage of the term. Also, there are reports of referees who had to deal with manuscripts which do not use the term in title or abstract, but more than 40 times in the main text.

The use in titles, often in renowned journals, is particularly noteworthy. Even in public, non-scientific encyclopaedias like Wikipedia, the problems associated with this term are noted explicitly. So how is it that in so many renowned and peer-reviewed journals—regardless of scientific criticism and general awareness—this term reappears on a regular basis? The problem is that despite best efforts this term seems to have been 'vernacularised' in science. It probably also troubles some writers that titles like 'properties of nitrogen–sulfur seeking and intermediate ions' are not as effective as a head-turner compared to 'toxicity of heavy metals'. Regardless of the calls to end it, 8 years after Duffus's review the term is more common than it was 8 years before.

4.2 Solution

So how can this problem be solved? Not easily, owing to the term's entrenchment in science and legislation. Based on the development of the usage, it can be concluded with some certainty that the term will continue to be used despite its substantial failings. As long as no clear definition of that term is given, the usage will remain misleading and ambiguous, as

different research articles will continue to refer to different elements, metals and non-metals alike, by the same collective name. Editors and referees were encouraged to rigorously edit out the term 'heavy metals'[14] and some editors have already suggested in editorials[6] that its authors use the term for rock music alone. Unfortunately, the wider impact has so far been negligible and the term has proven to be very resilient. The only auspicious course of action seems to be if editors would come together to analyse the situation and mutually change their respective journal policies in order to find a sensible option to solve this long-standing problem. As long as respected journals continue to tolerate—thereby effectively sanctioning—indiscriminate usage, no progress can be expected.

In the following, four options are presented, the first two based on replacing the term altogether, the last two based on conciliating it.

Option 1. Replacing the term 'heavy metals' with a well-reasoned and scientifically defendable terminology. This approach has been tried, and failed. The proposed terminologies (based on the Periodic Table or on a metal ion classification) were not adopted, at least not on a reasonably broad basis.

Option 2. Circumventing the problem. Most publications not using that umbrella term rather avoid the terminology altogether, referring simply to metals or elements. This is a reasonable approach—it is not precise, but at least it is accurate. Most importantly, this is probably the only approach that eventually might successfully suppress the term 'heavy metals'.

Option 3. Deciding on one single scientific definition. Although this would be an ideal approach, it is unlikely to be adopted. Since the introduction of this loanword into sciences in 1936, one definition after another has been developed, and it is not particularly probable that a general agreement regarding a single atomic mass, atomic number, density or similar criterion will be reached any time soon.

Option 4. Accepting that the term is used without a mutually accepted scientific rationale and simply defining a set of elements by their linguistic prevalence, rather than by a set of highly sophisticated scientific criteria on which nobody agrees. This does not mean capitulating, but rather (linguistically speaking) to move on from semantics to pragmatics. By choosing the ten elements most commonly considered to be such, arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, tin and zinc should be called 'heavy metals', all other elements not. It is basic and, of course, to a certain degree arbitrary, but at least it would be uniform and based on a mutual understanding—which would be a great step forward.

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