



# Paradoxes and paradigms: elements and compounds – similar names, very different energetics

## Part 3, cesium to radon (Cs-Rn) Z = 55–86

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### Abstract

In this paper we continue to review the phonetic similarity of trivial names of chemical substances and the names of the elements in the periodic table. Thermochemical properties are explicitly considered. We review elements from cesium to radon (Cs-Rn) Z = 55–86.

**Keywords** Elements · Names · Compounds · Differences · Chemical Energetics

### Introduction

The phonetic similarity of the sound of a trivial name of a chemical substance to the name of the element or its species can easily lead to a false idea of the actual composition or structure of a compound. In the chemical community, however, trivial and totally unsystematic names are preferred to the admittedly complicated systematic names. There often, however, is still some similarity of names but in most cases, the only common property is that these compounds are "chemicals". They often do not even share origin, e.g., "inorganic" as opposed to "organic". This seeming contradiction becomes even more apparent when thermochemical information such as the heat (or more properly enthalpy)

of formation is also considered. We note that there are over  $10^8$  known chemical species, and many more if one includes DNA and protein sequences and fragments. In contrast, there are calorimetrically derived thermochemical data for not many more than  $10^4$ , and certainly less than  $10^5$ , species. The extremely challenging demand for careful measurements on highly pure samples has resulted in very few contemporary laboratories whose goal and activity are to measure and understand these quantities. Relatedly and admittedly, one of the most important research activities of the authors has been the understanding, but never the measurement, of the quantities that arise from these studies.

In the present study in *Structural Chemistry*, we continue our efforts to find a compound with a subjective phonetic sound similarity for each element of the periodic table. In the first part [1] (of four parts), we discussed the elements from hydrogen (H) to argon (Ar) (Z = 1 to 18). In the second part (of four parts), we discussed the elements from potassium (K) to xenon (Xe) (Z = 19 to 54) [2]. In the current Part 3 of this review, we discuss cesium (Cs) to radon (Rn) (Z = 55 to 86). Given our interest in thermochemistry, the question arises as to how we chose which compounds to consider. In most cases, primary sources were used as reference sources for thermochemical data; however, in some cases, secondary sources, i.e., the "Domalski compendium" [3], the "Wagman et al. compendium" [4], or the "Pedley compendium" [5] were used. It is to be acknowledged that the "missing" data are quite ancient and we admit surprise at its absence in these sources. We wish to encourage the

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**Table 1** Elements from cesium (Cs) to radon (Rn) ( $Z = 55$  to  $86$ ) arranged according to the increasing order of atomic number accompanied with examples of compounds with ‘similarly’ sounding names but entirely different composition

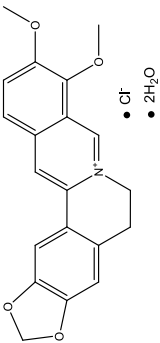
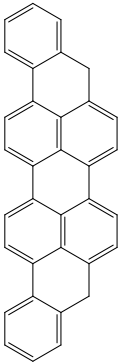
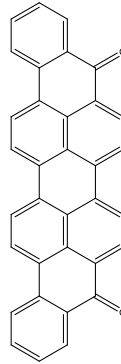
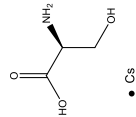
Element / Symbol / $Z$ / compound	Molecular formula	Systematic/semisystematic name	CASRN	Energetics quantity / Reference/Comments
<b>CESIUM, Cs, <math>Z = 55</math></b> coesite	$\text{SiO}_2$	silicon dioxide	13778-38-6	$\Delta H_f(s) = -907(1) \text{ kJ mol}^{-1}$ [9]
<b>BARIUM, Ba, <math>Z = 56</math></b> berberine hydrochloride dihydrate	$[\text{C}_{20}\text{H}_{18}\text{NO}_4]^+\text{Cl}^- \cdot 2\text{H}_2\text{O}$	5,6-dihydro-9,10-dimethoxy-benzo[g]-1,3-benzodioxolo[5,6-a]quinolizinium chloride dihydrate	633-65-8	$\Delta H_f(s) = -1335(1) \text{ kJ mol}^{-1}$ [10]
				
<b>LANTHANUM, La, <math>Z = 57</math></b>				
violanthrene; violanthrone	$\text{C}_{34}\text{H}_{20}$ ; $\text{C}_{34}\text{H}_{16}\text{O}_2$	5,10-dihydroanthra[9,1,2-cde]benzo[1rst]pentaphene; anthra[9,1,2-cde]benzo[1rst]pentaphene-5,10-dione	81-31-2; 116-71-2	$\text{p}K_a(\text{violanthrene}) = 7.3$ [11]; $\text{p}K_a(\text{violanthrone}) = 7.6$ [11]
				
				
<b>CERIUM, Ce, <math>Z = 58</math></b>				
serine cesium ion (1:1) complex	$\text{C}_3\text{H}_7\text{NO}_3 \cdot \text{Cs}^+$		1015696-86-2	$\Delta G$ (two gas phase isomers of $\text{C}_3\text{H}_7\text{NO}_3 \cdot \text{Cs}^+$ : charged solvated and salt bridged in ca. 5:1 ratio) $\approx$ $3 \text{ kJ mol}^{-1}$ [12]
<b>PRASEODYMIUM, Pr, <math>Z = 59</math></b> (di)chlorine	$\text{Cl}_2$		7782-50-5	$\Delta H_f(g) = 0.0 \text{ kJ mol}^{-1}$ (by definition) In that “praseo” and “chlor” translate as shades of green (in classic “Greek” and dymium, like “di”, “dos” and “duo” means two, praseodymium is word-related to (di)chlorine as “the green twin”)

Table 1 (continued)


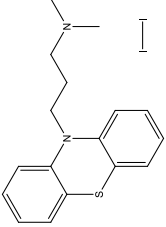
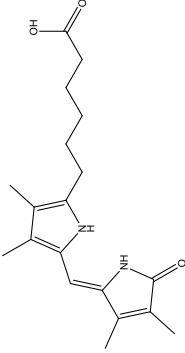
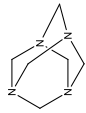
Element / Symbol / Z / compound	Molecular formula	Systematic/semisystematic name	CASRN	Energetics quantity / Reference/Comments
<b>NEODYMIUM, Nd, Z = 60</b> neopentane	C <sub>5</sub> H <sub>12</sub>	2,2-dimethylpropane 	463-82-1	$\Delta H_f(l) = -190(1) \text{ kJ mol}^{-1}$ [5] $\Delta H_f(g) = -168(1) \text{ kJ mol}^{-1}$ [5]
diamond	C		7782-40-3	$\Delta H_f(s) = 2 \text{ kJ mol}^{-1}$ [13] Both neopentane and diamond have been used as reference species in the study of the energetics of compounds with quaternary carbon, > C < [14]
<b>PROMETHIUM, Pr, Z = 61</b> promazine	C <sub>17</sub> H <sub>20</sub> N <sub>2</sub> S·I <sub>2</sub>	<i>N,N</i> -dimethyl-10 <i>H</i> -phenothiazine-10-propanamine, compd. with iodine (1:1) 	88787-14-8	For the aqueous solution phase reaction $\Delta G_{\text{rxn}}(\text{promazine}, \text{CASRN} = 58-40-2, + \text{I}_2 \rightarrow \text{promazine}\bullet\text{I}_2) = -79 \text{ kJ mol}^{-1}$ [15]
<b>SAMARIUM, Sm, Z = 62</b> [6]-semirubin	C <sub>19</sub> H <sub>26</sub> N <sub>2</sub> O <sub>3</sub>	5-[( <i>Z</i> )-(1,5-dihydro-3,4-dimethyl-5-oxo-2 <i>H</i> -pyrrol-2-ylidene)methyl]-3,4-dimethyl-1 <i>H</i> -pyrrole-2-hexanoic acid 	303732-40-3	Dimerization in CHCl <sub>3</sub> , $K_D \approx 25,000 \text{ M}^{-1}$ at 22 °C [16]
<b>EUROPIUM, Eu, Z = 63</b> urotropine	C <sub>6</sub> H <sub>12</sub> N <sub>4</sub>	1,3,5,7-tetraazaadamantane, hexamethylenetetramine 	100-97-0	$\Delta H_f(s) = 124(1) \text{ kJ mol}^{-1}$ [17] $\Delta H_f(g) = 204(1) \text{ kJ mol}^{-1}$ [17]
<b>GADOLINIUM, Gd, Z = 64</b> gallium lithium (1:2)	GaLi <sub>2</sub>		39343-49-2	$\Delta H_f(s) = -59(2) \text{ kJ mol}^{-1}$ [18]

Table 1 (continued)

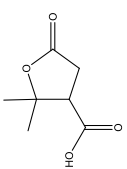
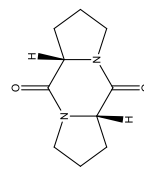
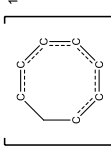
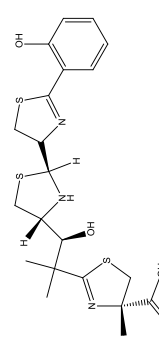
Element / Symbol / Z / compound	Molecular formula	Systematic/semisystematic name	CASRN	Energetics quantity / Reference/Comments
<b>TERBIUM, Tb, Z = 65</b> terebic acid	$C_7H_{10}O_4$	tetrahydro-2,2-dimethyl-5-oxofuran-3-carboxylic acid 	79-91-4	$\Delta H_f(s) = -929 \text{ kJ mol}^{-1}$ [3]
<b>DYSPROSIUM, Dy, Z = 66</b> cyclopropylproline	$C_{10}H_{14}N_2O_2$	octahydro-5 <i>H</i> ,10 <i>H</i> -dipyrrolo[1,2- <i>a</i> :1',2'- <i>d</i> ]pyrazine-5,10-dione, (5 <i>aR</i> ,10 <i>aR</i> )-rel- 	36588-47-3	$\Delta G$ <i>trans</i> cyclopropylproline more positive than <i>cis</i> by > 15 kJ mol <sup>-1</sup> [19]
<b>HOLMIUM, Ho, Z = 67</b> (mono)homotropylium ion	$[C_8H_9]^+$	cyclooctatrienylium ion 	32731-02-5	NMR studies show $\Delta G_{\text{stabilization}}$ of homoaromatic cation over the classical cyclooctatrienylium ion = 89 kJ mol <sup>-1</sup> . Electrochemically, $\Delta G_{\text{redn}}(R^+ + H^+ + 2e^- \rightarrow RH)$ , (homotropylium ion $\rightarrow$ bicyclo[5.1.0]octa-2,5-diene) homotropyliene, 14 M H <sub>2</sub> SO <sub>4</sub> ) = -0.92 V while that of tropylium ion, is -1.23 V [20]. We note our surprise, and indeed disappointment, that the proton affinity of cyclooctatetraene remains unreported.
<b>ERBIUM, Er, Z = 68</b> yersiniabactin	$C_{21}H_{27}N_3O_4S_3$	2-[(2 <i>S</i> )-2-[(4 <i>R</i> )-2-[(4 <i>R</i> )-4,5-dihydro-2-(2-hydroxyphenyl)-4-thiazolyl]-4-thiazolidinyl]-2-hydroxy-1,1-dimethylethyl]-4,5-dihydro-4-methyl-4-thiazolecarboxylic acid, (4 <i>S</i> ) 	152166-40-0	$\Delta H_f(s, 2\text{-thiazolidine-2-thione}) = 3(2) \text{ kJ mol}^{-1}$ [21] $\Delta H_f(g, 2\text{-thiazolidine-2-thione}) = 97(4) \text{ kJ mol}^{-1}$ [21]

Table 1 (continued)


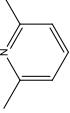
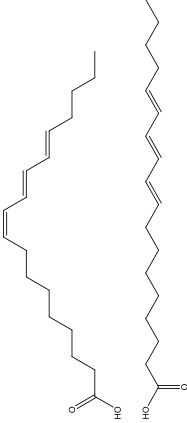
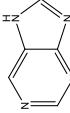
Element / Symbol / Z / compound	Molecular formula	Systematic/semisystematic name	CASRN	Energetics quantity / Reference/Comments
<b>THULIUM, Tm, Z = 69</b> toluene	C <sub>7</sub> H <sub>8</sub>		108-88-3	$\Delta H_f(lq) = 12(1) \text{ kJ mol}^{-1}$ [5] $\Delta H_f(g) = 50(1) \text{ kJ mol}^{-1}$ [5]
<b>YTTERBIUM, Yb, Z = 70</b> yttrium bromide	YBr <sub>3</sub>	yttrium (III) bromide	15923-89-4	$\Delta H_f(s) = -846(6) \text{ kJ mol}^{-1}$ [22]
<b>LUTETIUM, Lu, Z = 71</b> 2,6-lutidine	C <sub>7</sub> H <sub>9</sub> N	2,6-dimethylpyridine 	108-48-5	Steric strain of 2,6-lutidine complex with BF <sub>3</sub> = 36 kJ mol <sup>-1</sup> [23]
<b>HAFNIUM, Hf, Z = 72</b> hydrogen difluoride ion	[HF <sub>2</sub> ] <sup>-</sup>	bifluoride ion	18130-74-0	$\Delta H_f(g)([HF_2]^-) = -713(7) \text{ kJ mol}^{-1}$ [24] Herbert H. Hyman (personal communication) told me that he found in the early days of computer searching for data in the literature, looking for information about hydrogen fluoride resulted concomitantly with information about hafnium
<b>TANTALUM, Ta, Z = 73</b> tin telluride	SnTe	tin(II) telluride	12040-02-7	$\Delta H_f(s) = -61 \text{ kJ mol}^{-1}$ [4] $\Delta H_f(g) = 161 \text{ kJ mol}^{-1}$ [4]
<b>TUNGSTEN, W, Z = 74, as “tungsten”</b> tungstand oil; $\alpha$ -eleostearic acid; $\beta$ -eleostearic acid	C <sub>18</sub> H <sub>30</sub> O <sub>2</sub> ; C <sub>18</sub> H <sub>30</sub> O <sub>2</sub>	9,11,13-octadecatrienoic acid, (9Z,11E,13E); 9,11,13-octadecatrienoic acid, (9E,11E,13E) 	506-23-0; 544-73-0	Heating tungstand oil resulted in rearrangement of $\alpha$ -eleostearic acid to form its all-trans $\beta$ -isomer [25].
<b>TUNGSTEN as “wolfram”</b> wulfenite	PbMoO <sub>4</sub>	lead(II) molybdate	14913-82-7	$\Delta H_f(s)(PbMoO_4) = -1060(2) \text{ kJ mol}^{-1}$ [26]
<b>RHENIUM, Re, Z = 75</b> purine	C <sub>5</sub> H <sub>4</sub> N <sub>4</sub>		120-73-0	$\Delta H_f(s) = 169(3) \text{ kJ mol}^{-1}$ [27]

Table 1 (continued)

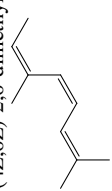
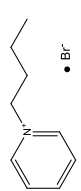
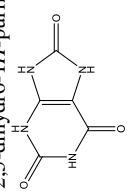

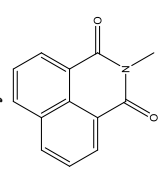
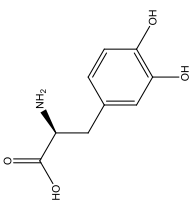
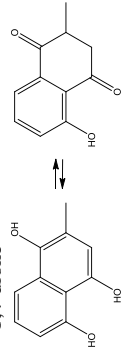
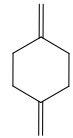
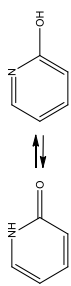
Element / Symbol / Z / compound	Molecular formula	Systematic/semisystematic name	CASRN	Energetics quantity / Reference/Comments
<b>OSMIUM, Os, Z = 76</b> <i>cis</i> -allo-ocimene	C <sub>10</sub> H <sub>16</sub>	(4 <i>Z</i> ,6 <i>Z</i> )-2,6-dimethyl-1,2,4,6-octatriene 	17202-20-9	$\Delta H_f(\text{lg}) = -24(5) \text{ kJ mol}^{-1}$ [5]
<b>IRIDIUM, Ir, Z = 77</b> <i>n</i> -butylpyridinium bromide	[C <sub>9</sub> H <sub>14</sub> N] <sup>+</sup> Br <sup>-</sup>		874-80-6	$\Delta H_f(\text{lg}) = -165 \text{ kJ mol}^{-1}$ [28]
<b>PLATINUM, Pt, Z = 78</b> lanthanum phosphide	LaP		25275-74-5	$\Delta H_f(\text{s}) = -390 \text{ kJ mol}^{-1}$ [29]
<b>GOLD, Au, Z = 79, as "gol"</b> "fools gold" - pyrite	FeS <sub>2</sub>	iron(II) disulfide	1309-36-0	$\Delta H_f(\text{s}) = -174(2) \text{ kJ mol}^{-1}$ [30]
<b>GOLD as "aurum"</b> uric acid	C <sub>5</sub> H <sub>4</sub> N <sub>4</sub> O <sub>3</sub>	2,5-dihydro-1 <i>H</i> -purine-2,6,8(3 <i>H</i> )-trione 	69-93-2	$\Delta H_f(\text{s}) = -619(1) \text{ kJ mol}^{-1}$ [5]
<b>MERCURY, Hg, Z = 80</b>				
<b>MERCURY as "merc"</b> butyl mercaptan	C <sub>4</sub> H <sub>10</sub> S	butanethiol 	109-79-5	$dH_f(\text{lg}) = -125(1) \text{ kJ mol}^{-1}$ [5] $dH_f(\text{g}) = -88(1) \text{ kJ mol}^{-1}$ [5]
<b>MERCURY as "hydrargyrum"</b> aqua silver(1+); diaqua silver(1+); triaux silver(1+); tetraqua silver(1+)	[AgH <sub>2</sub> O] <sup>+</sup> ; [AgH <sub>4</sub> O <sub>2</sub> ] <sup>+</sup> ; [AgH <sub>6</sub> O <sub>3</sub> ] <sup>+</sup> ; [AgH <sub>8</sub> O <sub>4</sub> ] <sup>+</sup>		68433-65-8; 34406-45-6; 79001-03-9; 79082-24-9	$\text{Ag}^+(\text{H}_2\text{O})_n + \text{H}_2\text{O} \rightarrow \text{Ag}^+(\text{H}_2\text{O})_{n+1}$ [31] $\Delta H_{\text{hydration}}(n=1) = 134(8) \text{ kJ mol}^{-1}$ [31]; $\Delta H_{\text{hydration}}(n=2) = 54(10) \text{ kJ mol}^{-1}$ [31]; $\Delta H_{\text{hydration}}(n=3) = 47(10) \text{ kJ mol}^{-1}$ [31]
<b>THALLIUM, Tl, Z = 81</b> <i>N</i> -methyl-1,8-naphthalimide	C <sub>13</sub> H <sub>9</sub> NO <sub>2</sub>	2-methyl-1 <i>H</i> -benz[ <i>de</i> ]isoquinoline-1,3(2 <i>H</i> )-dione 	2382-08-3	$\Delta H_f(\text{s}) = -306(4) \text{ kJ mol}^{-1}$ [32]; $\Delta H_f(\text{g}) = -196(4) \text{ kJ mol}^{-1}$ [32] Surprisingly, there are no experimentally determined measurements of the enthalpy of formation of the isoelectronic phenalene or any of its derivatives.

Table 1 (continued)

Element / Symbol / Z / compound	Molecular formula	Systematic/semisystematic name	CASRN	Energetics quantity / Reference/Comments
<b>LEAD, Pb, Z = 82</b> <b>LEAD as»lead«</b> L-DOPA	$C_9H_{11}NO_4$	L-3-(3,4-dihydroxyphenyl) alanine 	59-92-7	$\Delta H_f(s) = -936(8) \text{ kJ mol}^{-1}$ [33]
<b>LEAD as»plumb«</b> $\alpha$ -dihydroplumbagin; $\beta$ -dihydroplumbagin	$C_{11}H_{10}O_3$ ; $C_{11}H_{10}O_3$	3-methyl 1,4,5-naphthalenetriol; 5-hydroxy-2-methyl-1,2,3,4-tetrahydronaphthalene-1,4-dione 	58274-93-4; 74413-19-7	Both forms are separately isolable, the dione tautomer is the more stable by $14 \text{ kJ mol}^{-1}$ [34]
<b>BISMUTH, Bi, Z = 83</b> 1,4-bis(methylene)cyclohexane	$C_8H_{12}$		4982-20-1	$\Delta H_f(g) = 64 \text{ kJ mol}^{-1}$ [35]
<b>POLONIUM, Po, Z = 84</b> “poly- <i>N</i> ”	$[N_3]^-$	azide	14343-69-2	“poly- <i>N</i> ”: azide (as a salt) is the simplest, isolable polynitrogen species, i.e., with $\geq 3$ nitrogens [36].
<b>ASTATINE, At, Z = 85</b> AsTe	As = Te	arsenic monotelluride	12044*33-6	$D(\text{As} = \text{Te}) \approx 307 \text{ kJ mol}^{-1}$ [37]
<b>RADON, Rn, Z = 86</b> 2-pyridone; 2-pyridinol	$C_5H_5NO$ ; $C_5H_5NO$		142-08-5; 72762-00-6	$\Delta H_f(g)$ (g, 2-pyridone $\rightarrow$ 2-pyridinol) = $1(10) \text{ kJ mol}^{-1}$ [38]

remeasurement of these enthalpies of formation. Given there are many “exotic” compounds that have been recently synthesized and for which there are no measurements at all, we welcome the desired enthalpies of formation and any other thermochemical data about them.

The reader may suspect that there are alternative choices of compounds with appropriate names, and some even with the desired calorimetric measurements. Many of these compounds, for instance, are of contemporary interest to the pharmaceutical and agricultural chemistry communities. However, even with the use of “generic” names, we abstain from the use of these species and associated trivial and unsystematic names because we are loathe to “advertise” one corporation over another.

We acknowledge now our interest in etymology, but it is our view that giving the word origins for unsystematic and trivial names would be an excessive diversion of our activity. In addition, in many cases, we do not know the desired origin, nor do we know how to find it. We note a lengthy and thorough multipart recent study on the origin of the names of the elements [6–8], and while we laud this study, we do not wish to emulate it for the names of the compounds.

With the above discussion of our disclaimers as to the authors’ thermochemical interests, choice of compounds, and etymological concerns, we now refer the reader to Table 1 and conclude the current paper by beginning with Part 4 for the element francium (Fr) to oganesson (Og),  $Z=87$  to 118.

## Conclusions

Compounds that have similar phonetic semi-systematic or trivial names to that of the elements have been studied in terms of their composition, structure, and chemical energetics. This review, which follows part 1, revels even deeper differences between expected and actual composition of compounds. Nevertheless, what it is not surprising is that, semi-systematic or trivial names are widely preferred by the chemical community because of complicated nature of systematic names.

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**Data availability** Not applicable.

## Declarations

**Ethical approval** We did not perform any experiments when preparing this article, so neither ethics review nor informed consent was necessary.

**Consent to participate** All authors agreed with participation in research and publication of the results.

**Consent to publish** All authors have approved the manuscript before submission, including the names and order of authors.

**Competing interests** All authors declare that they have no conflicts of interest.

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