

日本学術会議 公開シンポジウム「新しい国際単位系(SI)」

日本学術会議講堂 12月4日 2018

「化学の標準変更について」

名古屋大学物質科学国際研究センター 異 和行

元素

化学

原子 分子

6×10^{23}

「万物の根源」

古代ギリシャ

Arkhe – アルケー

Classical Elements (Greek)

4大元素(空気、土、火、水)

The four elements
of “air”, “earth”, “fire”, and “water”

4大元素(万物の原型)

ギリシャのエンペドクレスの考案: 木を燃やすと、炎が赤く輝き、
その煙は空気と一体化し燃えた後には水が生じ燃えかすは土に帰する。

IUPAC Periodic Table of the Elements

1 H hydrogen 1.008 [1.0078, 1.0082]																	2 He helium 4.0026
3 Li lithium 6.94 [6.939, 6.997]	4 Be beryllium 9.0122	Key: atomic number Symbol name conventional atomic weight standard atomic weight										5 B boron 10.81 [10.806, 10.821]	6 C carbon 12.011 [12.009, 12.012]	7 N nitrogen 14.007 [14.006, 14.008]	8 O oxygen 15.999 [15.999, 16.003]	9 F fluorine 18.998	10 Ne neon 20.180
11 Na sodium 22.990	12 Mg magnesium 24.305 [24.304, 24.307]											13 Al aluminium 26.982	14 Si silicon 28.086 [28.084, 28.088]	15 P phosphorus 30.974	16 S sulfur 32.06 [32.059, 32.076]	17 Cl chlorine 35.45 [35.446, 35.457]	18 Ar argon 39.948
19 K potassium 39.098	20 Ca calcium 40.078(4)	21 Sc scandium 44.956	22 Ti titanium 47.867	23 V vanadium 50.942	24 Cr chromium 51.996	25 Mn manganese 54.938	26 Fe iron 55.845(2)	27 Co cobalt 58.933	28 Ni nickel 58.693	29 Cu copper 63.546(3)	30 Zn zinc 65.38(2)	31 Ga gallium 69.723	32 Ge germanium 72.630(8)	33 As arsenic 74.922	34 Se selenium 78.971(8)	35 Br bromine 79.904 [79.901, 79.907]	36 Kr krypton 83.796(2)
37 Rb rubidium 85.468	38 Sr strontium 87.62	39 Y yttrium 88.906	40 Zr zirconium 91.224(2)	41 Nb niobium 92.906	42 Mo molybdenum 95.95	43 Tc technetium 98	44 Ru ruthenium 101.07(2)	45 Rh rhodium 102.91	46 Pd palladium 106.42	47 Ag silver 107.87	48 Cd cadmium 112.41	49 In indium 114.82	50 Sn tin 118.71	51 Sb antimony 121.76	52 Te tellurium 127.60(3)	53 I iodine 126.90	54 Xe xenon 131.29
55 Cs caesium 132.91	56 Ba barium 137.33	57-71 lanthanoids	72 Hf hafnium 178.49(2)	73 Ta tantalum 180.95	74 W tungsten 183.84	75 Re rhenium 186.21	76 Os osmium 190.23(3)	77 Ir iridium 192.22	78 Pt platinum 195.08	79 Au gold 196.97	80 Hg mercury 200.59	81 Tl thallium 204.38 [204.38, 204.39]	82 Pb lead 207.2	83 Bi bismuth 208.98	84 Po polonium 209	85 At astatine 210	86 Rn radon 222
87 Fr francium 223	88 Ra radium 226	89-103 actinoids	104 Rf rutherfordium 261	105 Db dubnium 262	106 Sg seaborgium 263	107 Bh bohrium 264	108 Hs hassium 265	109 Mt meitnerium 266	110 Ds darmstadtium 267	111 Rg roentgenium 268	112 Cn copernicium 269	113 Nh nihonium 270	114 Fl flerovium 271	115 Mc moscovium 272	116 Lv livermorium 273	117 Ts tennessine 274	118 Og oganesson 275



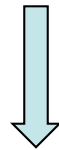
57 La lanthanum 138.91	58 Ce cerium 140.12	59 Pr praseodymium 140.91	60 Nd neodymium 144.24	61 Pm promethium 145	62 Sm samarium 150.36(2)	63 Eu europium 151.96	64 Gd gadolinium 157.25(3)	65 Tb terbium 158.93	66 Dy dysprosium 162.50	67 Ho holmium 164.93	68 Er erbium 167.26	69 Tm thulium 168.93	70 Yb ytterbium 173.05	71 Lu lutetium 174.97
89 Ac actinium 227	90 Th thorium 232.04	91 Pa protactinium 231.04	92 U uranium 238.03	93 Np neptunium 237	94 Pu plutonium 244	95 Am americium 243	96 Cm curium 247	97 Bk berkelium 247	98 Cf californium 251	99 Es einsteinium 252	100 Fm fermium 257	101 Md mendelevium 258	102 No nobelium 259	103 Lr lawrencium 260

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Classical Elements

四大元素 (空気、土、火、水)

五大思想 (水、土、火、風、空)



科学的元素・原子の世界

人間のロマン vs. 科学のロマン

“The truth may be puzzling. It may be counterintuitive.
It may not be consonant with what we desperately want to be true.
But our preferences do not determine what's true.”

By Carl Sagan

原子論(Atomism)

- * 古代ギリシャ(レウキッポス、**デモクリトス**、エピクロス)
- * イスラム理論神学: もはやそれ以上分割できない部分

ドルトン(Dalton)の原子説

1808年

質量保存の法則、定比例の法則を合理的に説明

- * すべての元素は原子(Atom)と呼ばれる
最小で分割不可能な粒子からできている。
- * 物質は異なる原子が一定の割合で結合してできる。
- * 同じ元素の原子は、大きさ、質量、形が同一である。
- * 化学変化は原子の集まり方が変わるだけで、
原子は無くなることも新しく生まれることもない。



ドルトンの原子説の破綻: ゲイ・リュサックの気体反応の法則、アボガドロの法則

ドルトンの原子説の破綻: ゲイ・リュサックの気体反応の法則

分子論



* アボガドロの法則 (1811)

同一圧力、同一温度、同一体積のすべての種類の気体には
同じ数の分子が含まれる。

* 証明: アルベルト・アインシュタイン(ブラウン運動の理論)

ジャン・ペラン(アボガドロ定数の測定)

/質量保存の法則/

* The amount of chemical substances is traditionally measured
by mass or volume.

* Since the introduction of relative atomic masses (also called
“atomic weights”) by John Dalton, chemists are able to express
their observations in a quantity that is proportional to the number
of elementary entities.



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IUPAC serves the international scientific endeavor in the dual function of a fundamental science and mission-oriented Union. The Union is in a unique position to contribute to the central interdisciplinary chemical sciences.



On the revision of the International System of Units

16 Nov 2018 – Today, on this final day of the 26th meeting of the General Conference on Weights and Measures (CGPM) at the Palais des Congrès in Versailles, a...

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The Revision of the International System of Units
VS
Chemistry (IUPAC)

[1] Roberto Marquardt, Juris Meija, Zoltán Mester, Marcy Towns, Ron Weir, Richard Davis and Jürgen Stohner,
[“Definition of the mole \(IUPAC Recommendation 2017\)”](#),
Pure Appl. Chem. 90(1), pp. 175-180 (2018).

[2] Roberto Marquardt, Juris Meija, Zoltán Mester, Marcy Towns, Ron Weir, Richard Davis and Jürgen Stohner,
[“A critical review of the proposed definitions of fundamental chemical quantities and their impact on chemical communities \(IUPAC Technical Report\)”](#),
Pure Appl. Chem. 89(7), pp. 951-981 (2017).

The Revision of the International System of Units VS Chemistry (IUPAC)

The quantities m_u (atomic mass constant), M_u (molar mass constant), A_r (relative atomic mass or “atomic weight”), m_a (atomic mass), M (molar mass), and **N_A (Avogadro constant)** are particularly important in chemistry, as chemists often determine amount of substance by weighing. These quantities are related for one particular entity X as follows:

$$M(X) = A_r(X) M_u \quad (1)$$

$$M(X) = N_A m_a(X) \quad (2)$$

$$m_a(X) = A_r(X) m_u \quad (3)$$

Combining eqs. (1)–(3) results in

$$M_u = N_A m_u \quad (4)$$

Since the introduction of relative atomic masses (“atomic weights”) by John Dalton, chemists are able to express their observations in a quantity that is proportional to the number of elementary entities.

The Revision of the International System of Units VS Chemistry (IUPAC)

“Mole (mol)”の定義(1971年)

1. モルは、0.012 キログラム(12グラム)の炭素12の中に存在する原子の数と等しい “*elementary entities*” を含む系の物質質量である。
2. モルを用いるとき、“*elementary entities*” は原子、分子、イオン、電子その他の粒子、またはこれらの粒子の集合体である。

モルを定義することで、物質質量と“*elementary entities*”の数をつなげる定数が定義される。そのような定数としてアボガドロ定数があり、1mol に含まれる構成要素の数をアボガドロ定数となる。アボガドロ定数を表す記号は N_A が用いられる。ある試料に含まれる“*elementary entities*” X のamount $n(X)$ は、“*elementary entities*”のnumber $N(X)$ と以下の関係で結ばれる。

$$n(X) = N(X) / N_A$$

amount $n(X)$ の単位は mol であり、number $N(X)$ は無次元量であるため、アボガドロ定数は mol^{-1} の単位をもつ。

Table 2: Change of the numerical value of the quantity which is presently known to be the Avogadro constant over time.

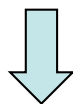
Name	Year	Numerical value	Notes
J.C. Magnenus	-1646	$\approx 2 \times 10^{23}$	Diffusion of incense Burnt in a church [20, 25]
Loschmidt	-1865	5.8×10^{23}	Mean free path in gases [23]
Röntgen, Rayleigh	-1890	$(6-7) \times 10^{23}$	[20]
Ostwald	-1899	6.3×10^{23}	[23]
Planck	1900	6.175×10^{23}	Black-body radiation [20]
Einstein,	1905/6	6.17×10^{23}	[20]
Smoluchowski	1908	6.0×10^{23}	
	1911	6.56×10^{23}	[23]
Perrin	1909	6.5×10^{23}	[20, 21]
Rutherford	1909	6.16×10^{23}	Counting α -particles [23]
Millikan	1917	6.064×10^{23}	Faraday's law [23]
DuNouy	-1924	6.003×10^{23}	[23]
Kappler	1931	6.059×10^{23}	[23]
Birge	1941	$6.023\ 38 \times 10^{23}$	Crystal lattice/XRCD ^b [23]
De Bièvre	2001	$6.022\ 133\ 9 \times 10^{23}$	[28]
Andreas <i>et al.</i>	2011	$6.022\ 140\ 78(18) \times 10^{23}$	Crystal lattice/XRCD ^b [29]
CODATA	2014	$6.022\ 140\ 857(74) \times 10^{23}$	Recommended [3]
CODATA	2017	$6.02214076 \times 10^{23}$	

The Revision of the International System of Units VS Chemistry (IUPAC)

新しい“Mole (モル)”の定義

系に含まれる構成要素の数を定義値とすることでモルを定義する。

新定義: モル (mol) は物質量の単位である。1 モルは正確に $6.02214076 \times 10^{23}$ の要素粒子を含む。この数値の単位は mol^{-1} で固定された数値である(アボガドロ数)。



モルはキログラムの定義に依存しない

以下の値は不確かさのある値となる。

- * ^{12}C のモル質量: 現行の定義では正確に 0.012 kg/mol である。
- * モル質量: 現行の定義では正確に 0.001 kg/mol である。
- * 0.012 kg の ^{12}C の物質質量: 現行の定義では正確に 1 mol である。

The Revision of the International System of Units VS Chemistry (IUPAC)

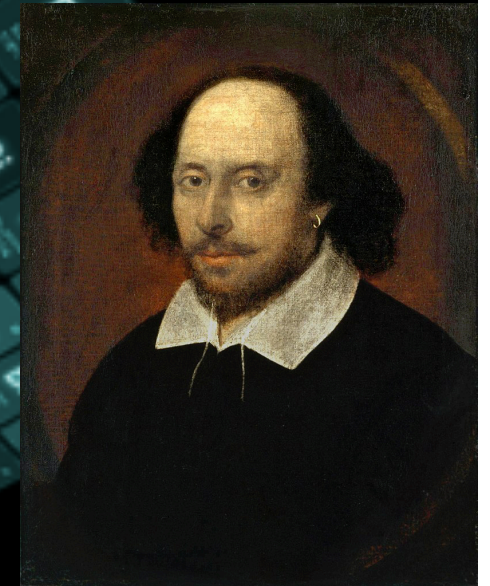
“Mole (モル)”

Professor Peter W. Atkins, founding Chair of IUPAC Committee on Chemistry Education, commented as followed: “I have always been puzzled by the widespread view that the mole is a difficult subject: it has always seemed to me that many instructors tell their students that it is a sophisticated concept, and the students then wonder what all the fuss is about, suspecting that they have misunderstood it or have not appreciated its subtlety. The new definition cuts to the core of the meaning of 1 mole, and is therefore to be welcomed. Although there are subtleties in its determination, there can no longer be any excuse for misunderstanding its definition.”



Prof. Peter Atkins
Oxford

***“It is as easy to count atomies
as to resolve
the propositions of a lover”***
by William Shakespeare <*As You like It*>



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Division II

IUPAC周期表の原子量の新しい定義

New Definition of Atomic Weights

C	12. 0107 (8)	¹² C	12 . 000 000 0 (0)	98. 93 (8)
		¹³ C	13 . 003 354 8378 (10)	1. 07 (8)

6	C	carbon
12.011		
[12.009, 12.012]		

17	9	F	fluorine
18.998			
17	17	Cl	chlorine
35.45			
[35.446, 35.457]			

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55 Cs caesium 132.91	56 Ba barium 137.33	57-71 lanthanoids	72 Hf hafnium 178.49(2)	73 Ta tantalum 180.9	³⁵ Cl 34. 968 852 68 (4)												
87 Fr francium	88 Ra radium	89-103 actinoids	104 Rf rutherfordium	105 Db dubnium	³⁷ Cl 36. 965 902 59 (5)												
seaborgium darmstadtium roentgenium copernicium nihonium tennessine oganesson																	



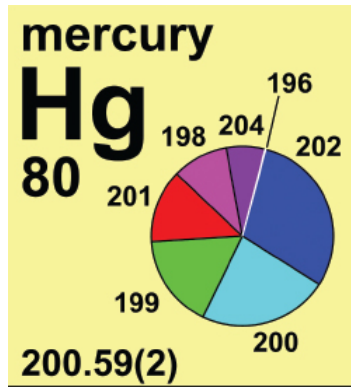
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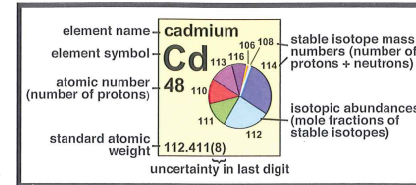
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IUPAC周期表の新たな原子量表記

Isotopic Abundances and Standard Atomic Weights



- Element has two or more stable isotopes. Atomic weight and isotopic abundances of element vary in naturally occurring materials. The lower and upper bounds of atomic weight have been assessed by IUPAC and are presented as the standard atomic weight within square brackets, [].
- Element has two or more stable isotopes and the standard atomic weight is not a constant of nature. The lower and upper bounds of the standard atomic weight have not been evaluated by IUPAC yet.
- Element has one stable isotope and its standard atomic weight is a constant of nature.
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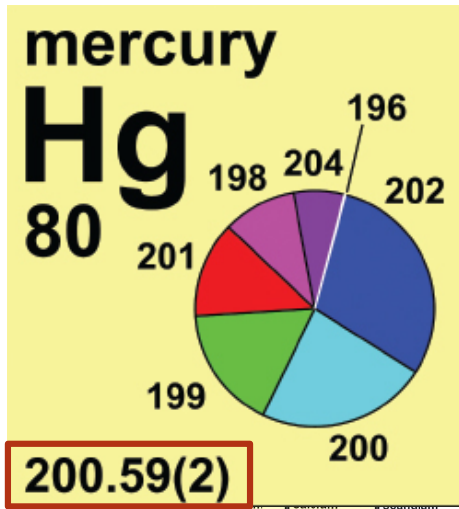
potassium K 19 39.0983(1)		calcium Ca 20 40.078(4)		scandium Sc 21 44.955 912(6)		titanium Ti 22 47.867(1)		vanadium V 23 50.9415(1)		chromium Cr 24 51.9961(6)		manganese Mn 25 54.938 045(1)		iron Fe 26 55.845(5)		cobalt Co 27 58.933 195(5)		nickel Ni 28 58.6934(4)		copper Cu 29 63.546(3)		zinc Zn 30 65.38(2)		gallium Ga 31 69.723(1)		germanium Ge 32 72.63(1)		arsenic As 33 74.921 60(2)		selenium Se 34 78.96(3)		bromine Br 35 79.904(1)		krypton Kr 36 83.796(2)																									
rubidium Rb 37 85.4678(3)		strontium Sr 38 87.62(1)		yttrium Y 39 88.905 85(2)		zirconium Zr 40 91.224(2)		niobium Nb 41 92.906 38(2)		molybdenum Mo 42 95.90(2)		technetium Tc 43 []		ruthenium Ru 44 101.07(2)		rhodium Rh 45 102.905 50(2)		palladium Pd 46 106.42(1)		silver Ag 47 107.8682(2)		cadmium Cd 48 112.411(8)		indium In 49 114.818(3)		tin Sn 50 118.710(7)		antimony Sb 51 121.760(1)		tellurium Te 52 127.60(3)		iodine I 53 126.904 47(3)		xenon Xe 54 131.293(6)		radon Rn 86 []																							
caesium (cesium) Cs 55 132.905 4519(2)		barium Ba 56 137.327(7)		lanthanoids 57 - 71 []		hafnium Hf 72 178.49(2)		tantalum Ta 73 180.947 88(2)		tungsten W 74 183.84(1)		rhenium Re 75 186.207(1)		osmium Os 76 190.23(3)		iridium Ir 77 192.217(3)		platinum Pt 78 195.084(9)		gold Au 79 196.966 569(4)		mercury Hg 80 200.59(2)		thallium Tl 81 [204.382; 204.385]		lead Pb 82 207.2(1)		bismuth Bi 83 208.980 40(1)		polonium Po 84 []		astatine At 85 []		radon Rn 86 []																									
francium Fr 87 []		radium Ra 88 []		actinoids 89 - 103 []		rutherfordium Rf 104 []		dubnium Db 105 []		seaborgium Sg 106 []		bohrium Bh 107 []		hassium Hs 108 []		meitnerium Mt 109 []		darmstadtium Ds 110 []		roentgenium Rg 111 []		copernicium Cn 112 []		ununtrium Uut 113 []		ununquadium Uuq 114 []		ununpentium Uup 115 []		ununhexium Uuh 116 []		ununseptium Uus 117 []		ununoctium Uuo 118 []																									
lanthanum La 57 138.905 47(7)		cerium Ce 58 140.116(1)		praseodymium Pr 59 140.907 65(2)		neodymium Nd 60 144.242(3)		promethium Pm 61 []		samarium Sm 62 150.36(2)		europium Eu 63 151.964(1)		gadolinium Gd 64 157.25(3)		terbium Tb 65 158.925 35(2)		dysprosium Dy 66 162.500(1)		holmium Ho 67 164.930 32(2)		erbium Er 68 167.259(3)		thulium Tm 69 168.934 21(2)		ytterbium Yb 70 173.054(5)		lutetium Lu 71 174.9668(1)		actinium Ac 89 []		thorium Th 90 232.038 06(2)		protactinium Pa 91 231.036 28(2)		uranium U 92 238.028 91(3)		neptunium Np 93 []		plutonium Pu 94 []		americium Am 95 []		curium Cm 96 []		berkelium Bk 97 []		californium Cf 98 []		einsteinium Es 99 []		fermium Fm 100 []		mendelevium Md 101 []		nobelium No 102 []		lawrencium Lr 103 []	



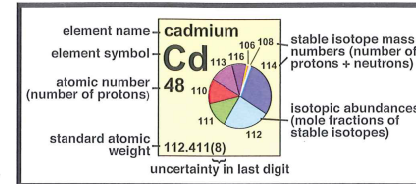
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K 19		Ca 20		Sc 21		Ti 22		V 23		Cr 24		Mn 25		Fe 26		Co 27		Ni 28		Cu 29		Zn 30		Ga 31		Ge 32		As 33		Se 34		Br 35		Kr 36	
Rb 37		Sr 38		Y 39		Zr 40		Nb 41		Mo 42		Tc 43		Ru 44		Rh 45		Pd 46		Ag 47		Cd 48		In 49		Sn 50		Sb 51		Te 52		I 53		Xe 54	
Cs 55		Ba 56		lanthanoids		Hf 72		Ta 73		W 74		Re 75		Os 76		Ir 77		Pt 78		Au 79		Hg 80		Tl 81		Pb 82		Bi 83		Po 84		At 85		Rn 86	
Fr 87		Ra 88		actinoids		Rf 104		Db 105		Sg 106		Bh 107		Hs 108		Mt 109		Ds 110		Rg 111		Cn 112		Uut 113		Uuq 114		Uup 115		Uuh 116		Uus 117		Uuo 118	
La 57		Ce 58		Pr 59		Nd 60		Pm 61		Sm 62		Eu 63		Gd 64		Tb 65		Dy 66		Ho 67		Er 68		Tm 69		Yb 70		Lu 71							
Ac 89		Th 90		Pa 91		U 92		Np 93		Pu 94		Am 95		Cm 96		Bk 97		Cf 98		Es 99		Fm 100		Md 101		No 102		Lr 103							



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IUPAC周期表の原子量の新しい定義

New Definition of Atomic Weights

ナイアガラの滝の水、イグアスの滝の水、ビクトリアの滝の水

水の重さが異なる！

0	15. 999 4 (3)	¹⁶ O	15. 994 914 619 56 (16)	99. 757 (16)
		¹⁷ O	16. 999 131 70 (12)	0. 038 (1)
		¹⁸ O	17. 999 161 0 (7)	0. 205 (14)



Division II



Council

ご清聴ありがとうございました。