

原子核で周期表を作つてみたら : エレメンタッチからニュークリタッチへ

A nuclear periodic table : from elementouch to nucleotouch



International Year
of the Periodic Table
of Chemical Elements

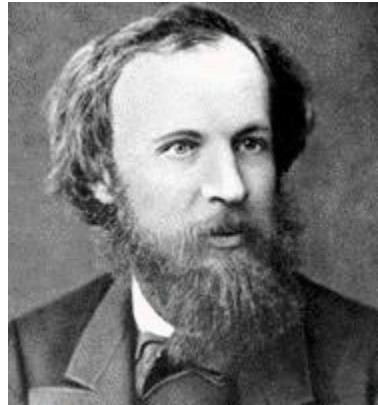
Kouichi Hagino
Yoshiteru Maeno
Kyoto University



1. Introduction: periodic table
2. Nuclear periodic table
3. A *magic* coincidence
4. Summary

Introduction: periodic table of elements

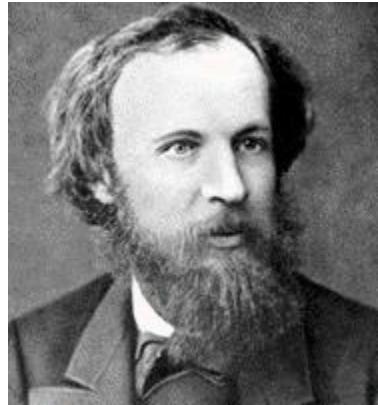
Group → 1 ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
	1 H																2 He		
1	3 Li	4 Be																10 Ne	
2	11 Na	12 Mg																18 Ar	
3	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
4	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
5	55 Cs	56 Ba	57 La	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
6	87 Fr	88 Ra	89 Ac	*	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
7				*	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
				*	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	



the original periodic table by Mendeleev (1869)

Ann. Suppl. 8, 133 (1871).

Reihen	Gruppe 1 R ₂ O	Gruppe 2 RO	Gruppe 3 R ₂ O ₃	Gruppe 4 RH ₄ RO ₂	Gruppe 5 RH ₃ R ₂ O ₅	Gruppe 6 RH ₂ RO ₃	Gruppe 7 RH R ₂ O ₇	Gruppe 8 — RO ₄
1	H=1							
2	Li=7	Be=9.4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5	
4	K=39	Ca=40	~44	Ti=48	V=51	Cr=52	Mn=55	Fe=56 Co=59 Ni=59 Cu=63
5	(Cu=63)	Zn=65	~68	~72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	~100	Ru=104 Rh=104 Pd=106 Ag=108
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(--)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195 Ir=197 Pt=198 Au=199
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —



the original periodic table by Mendeleev

Ann. Suppl. 8, 133 (1871).

Predictions of unknown elements

Reihen	Gruppe 1	Gruppe 2	Gruppe 3	Gruppe 4	Gruppe 5	Gruppe 6	Gruppe 7	Gruppe 8
	— R ₂ O	— RO	— R ₂ O ₃	RH ₄ RO ₂	RH ₃ R ₂ O ₅	RH ₂ RO ₃	RH R ₂ O ₇	— RO ₄
1	H=1							
2	Li=7	Be=9.4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5	
4	K=39	Ca=40	~ = 44	Ti=48	V=51	Cr=52	Mn=55	Fe=56 Co=59
5	(Cu=63)	Zn=65	~ = 68	~ = 72	As=75	Se=78	Br=80	Ni=59 Cu=63
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	~ = 100	Ru=104 Rh=104
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	Pd=106 Ag=108
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	— — — —
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195 Ir=197
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	Pt=198 Au=199
12	—	—	—	Th=231	—	U=240	—	— — — —

a discovery of Galium
(1874)

a discovery of Germanium
(1879)

Who invented the periodic table in the present form (the long form)?

1	1 H	Y. Maeno, K. Hagino, and T. Ishiguro, Found. of Chem. 23, 201 (2021)												2 He
2	3 Li	4 Be												5 B
3	11 Na	12 Mg												6 C
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn
6	55 Cs	56 Ba	57 La	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl
7	87 Fr	88 Ra	89 Ac	*	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh
			*	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er
			*	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm
														70 Tm
														71 Yb
														102 No
														103 Lr



Alfred Werner (1905)

a chemist of Univ. Zurich, Switzerland

1913: the first Nobel prize in Inorganic Chemistry

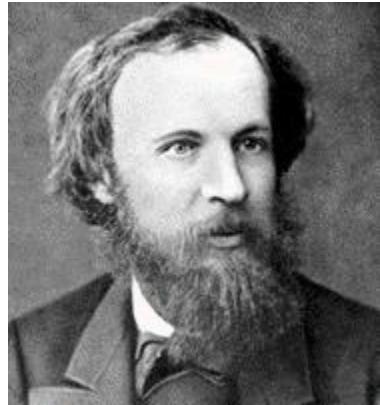
(遷移元素錯体の八面体形の構造: 錯体化学の創始者)

Any improvements?

1	H																			2 He
2	Li	Be																		10 Ne
3	Na	Mg																		18 Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br		36 Kr	
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I		54 Xe	
6	Cs	Ba	La	* 72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At		86 Rn	
7	Fr	Ra	Ac	* 104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og		
				* 58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu			
				* 90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr			

i) why are there such gaps?

ii) why in separated tables?
iii) why are similar elements separated?
another example: Ti-Sn



the original periodic table by Mendeleev

Ann. Suppl. 8, 133 (1871).

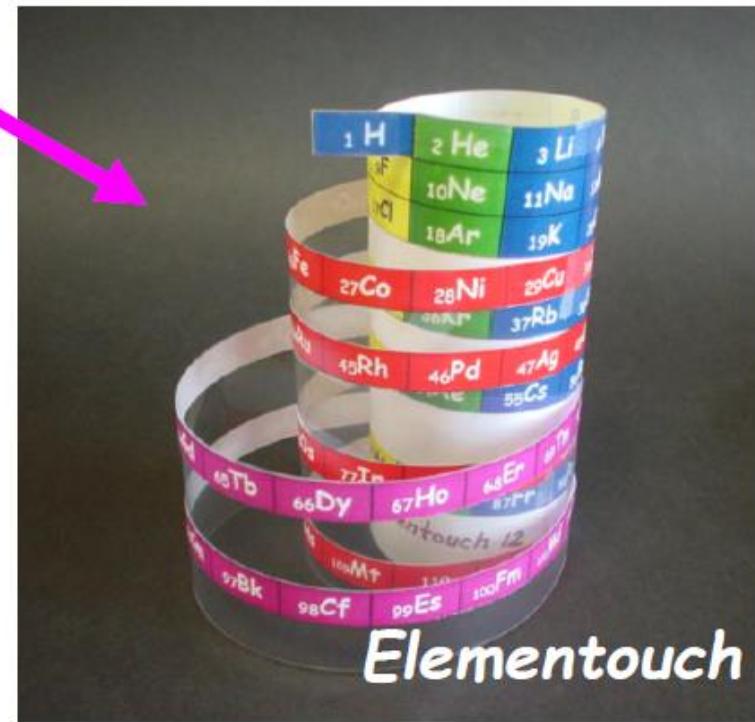
Reihen	Gruppe 1	Gruppe 2	Gruppe 3	Gruppe 4	Gruppe 5	Gruppe 6	Gruppe 7	Gruppe 8
	R_2O	RO	R_2O_3	RH_4 RO_2	RH_3 R_2O_5	RH_2 RO_3	RH R_2O_7	RO_4
1	H=1							
2	Li=7	Be=9.4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5	
4	K=39 (Cu=63)	Ca=40 Zn=65	~44	Ti=48 ~72	V=51	Cr=52	Mn=55	Fe=56 Co=59 Ni=59 Cu=63
5			~68	~72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	~100	Ru=104 Rh=104 Pd=106 Ag=108
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140				---
9	(--)	--	--	--	--	--	--	---
10	--	--	?Er=178	?La=180	Ta=182	W=184	--	Os=195 Ir=197
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	--	--	Pt=198 Au=199
12	--	--	--	Th=231	--	U=240	--	---

Elementouch



“Ribbon” of element symbols

The three problems are all resolved !

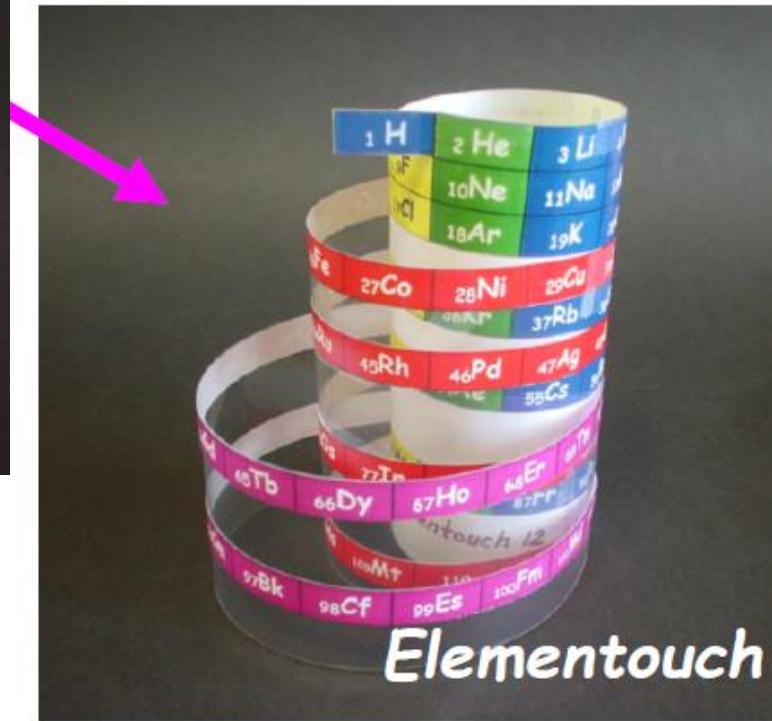


Y. Maeno, Butsuri 57, 681 (2002) (in Japanese)
Y. Maeno, K. Hagino, T. Ishiguro,
Found. of Chem. 23, 201 (2021)

Elementouch



The three problems are all resolved !



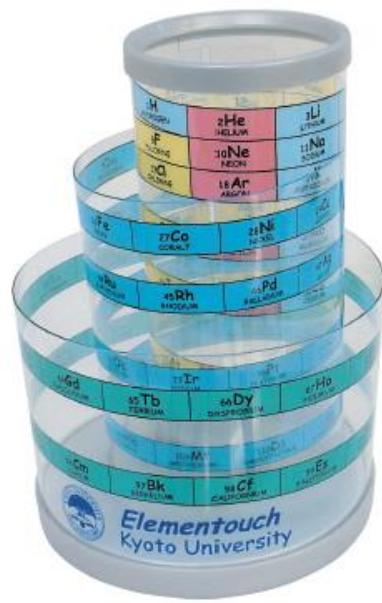
Y. Maeno, Butsuri 57, 681 (2002) (in Japanese)
Y. Maeno, K. Hagino, T. Ishiguro,
Found. of Chem. 23, 201 (2021)



<https://ss.scphys.kyoto-u.ac.jp/elementouch/images/illustration/>

Quantum Materials Lab., Kyoto University

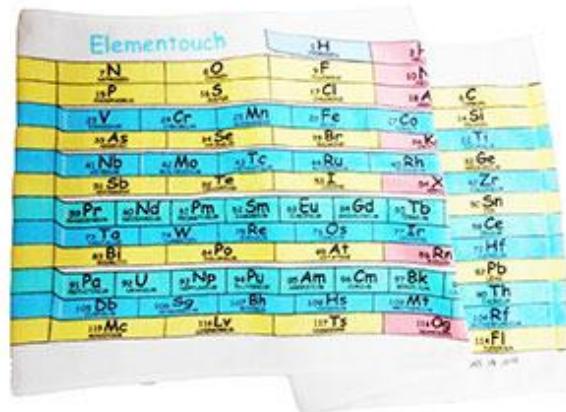
Kyoto-U. coop



pen stand



mug cup



towel

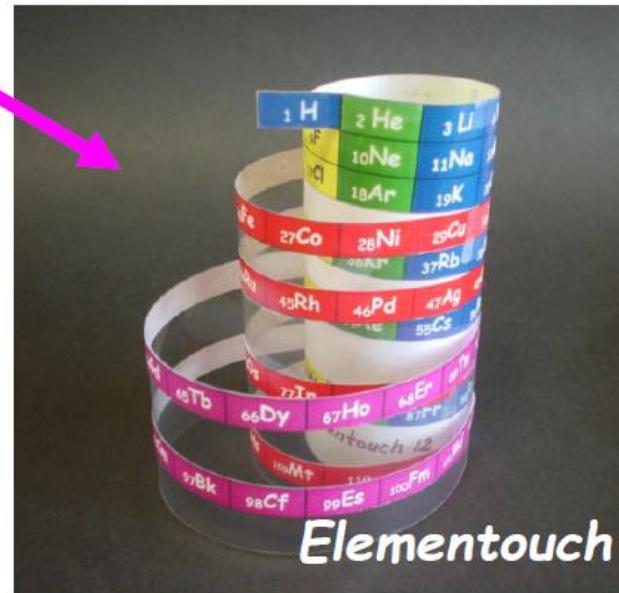


T-shirt

Elementouch



The three problems are all resolved !

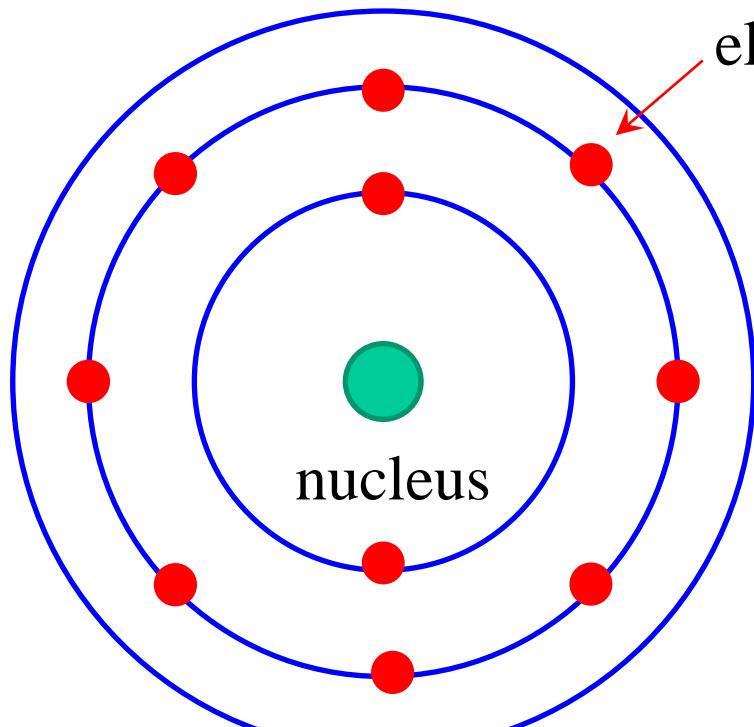


pictures from
Quantum Materials Lab.,
Kyoto University

the origin of periodicity

noble gas
(shell closures)

periodic table of elements



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----

rare gases

B	C	N	O	F	He
5	6	7	8	9	2
Al	Si	P	S	Cl	Ne
13	14	15	16	17	10
Zn	Ga	Ge	As	Se	Ar
30	31	32	33	34	18
Cd	In	Sn	Sb	Te	Kr
48	49	50	51	52	36
Hg	Tl	Pb	Bi	Po	Xe
80	81	82	83	84	54
Cn	Nh	Fl	Mc	Lv	Rn
112	113	114	115	116	86
					Og
					118

Bo	Dy	Ho	Er	Tm	Yb	Lu
55	66	67	68	69	70	71
Cf	Es	Fm	Md	No	Lr	
98	99	100	101	102	103	

Nuclear Shell Structures

spin-orbit interaction

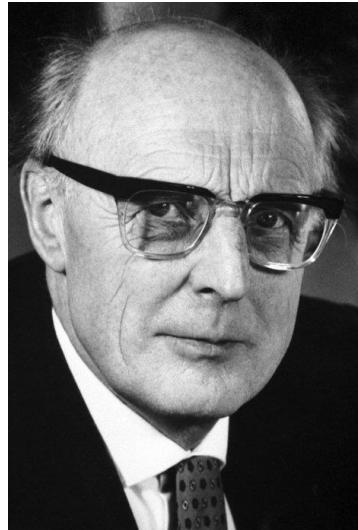
Magic Numbers

2, 8, 20, 28, 50, 82, 126

Shell Model



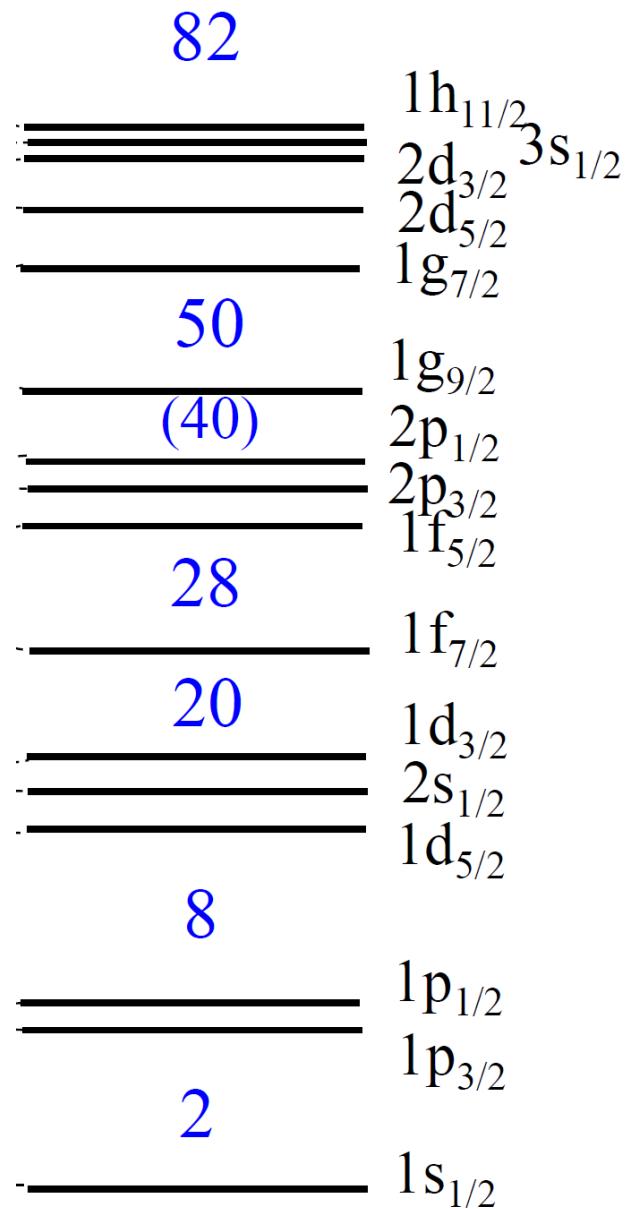
Mayer



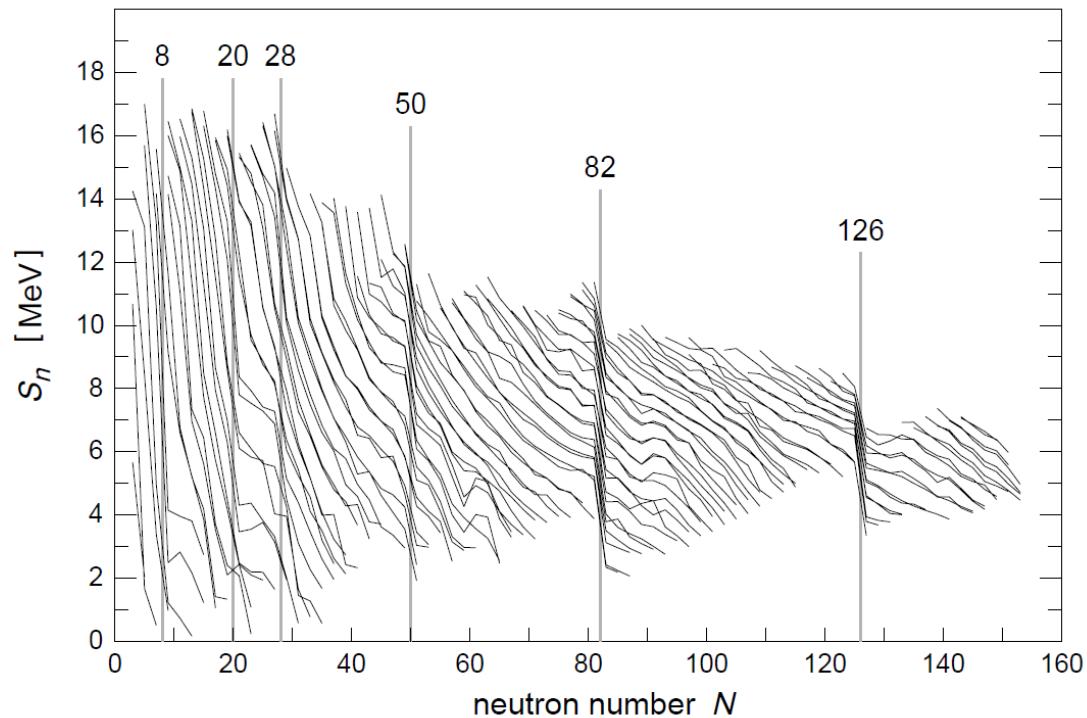
Jensen

Nobel Foundation archive

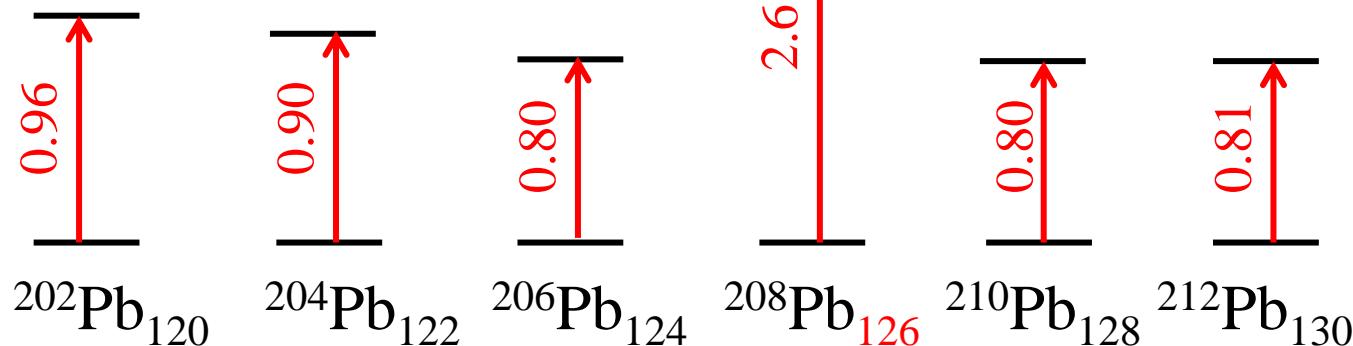
Nobel prize in Physics (1963)



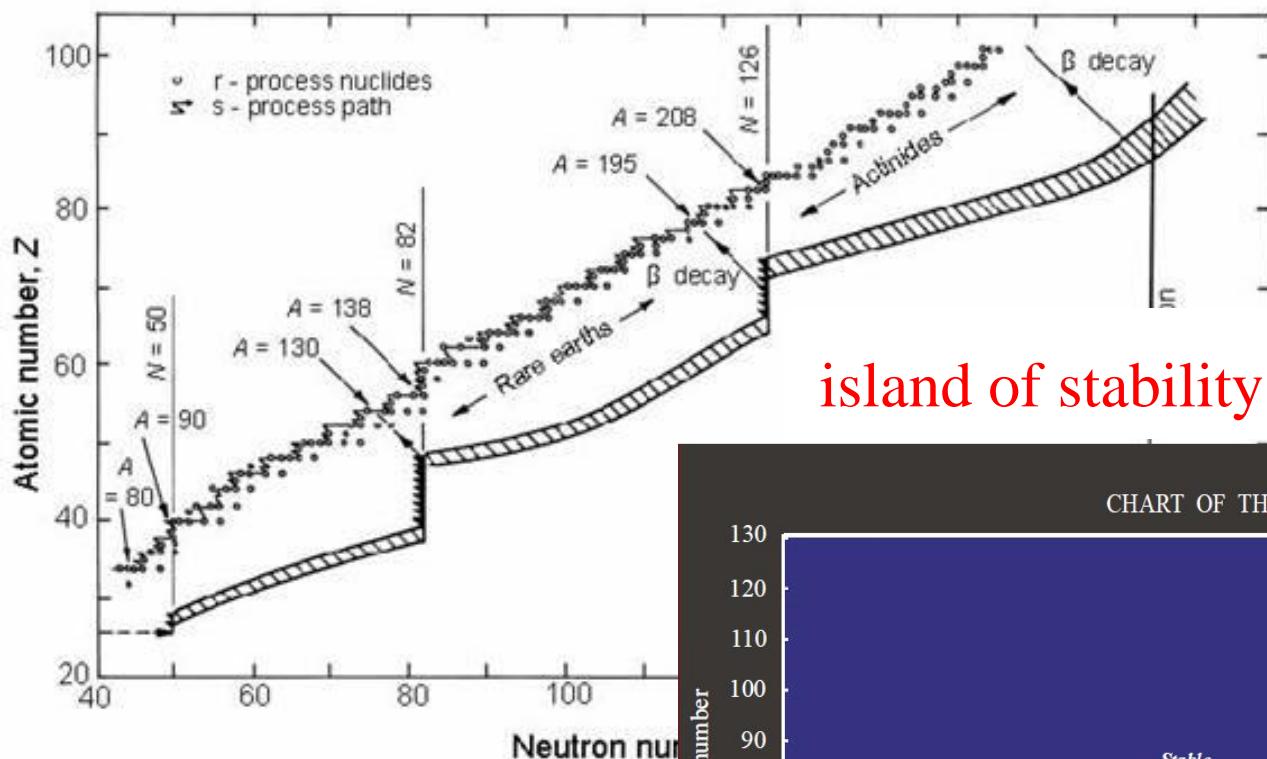
One-neutron separation energy



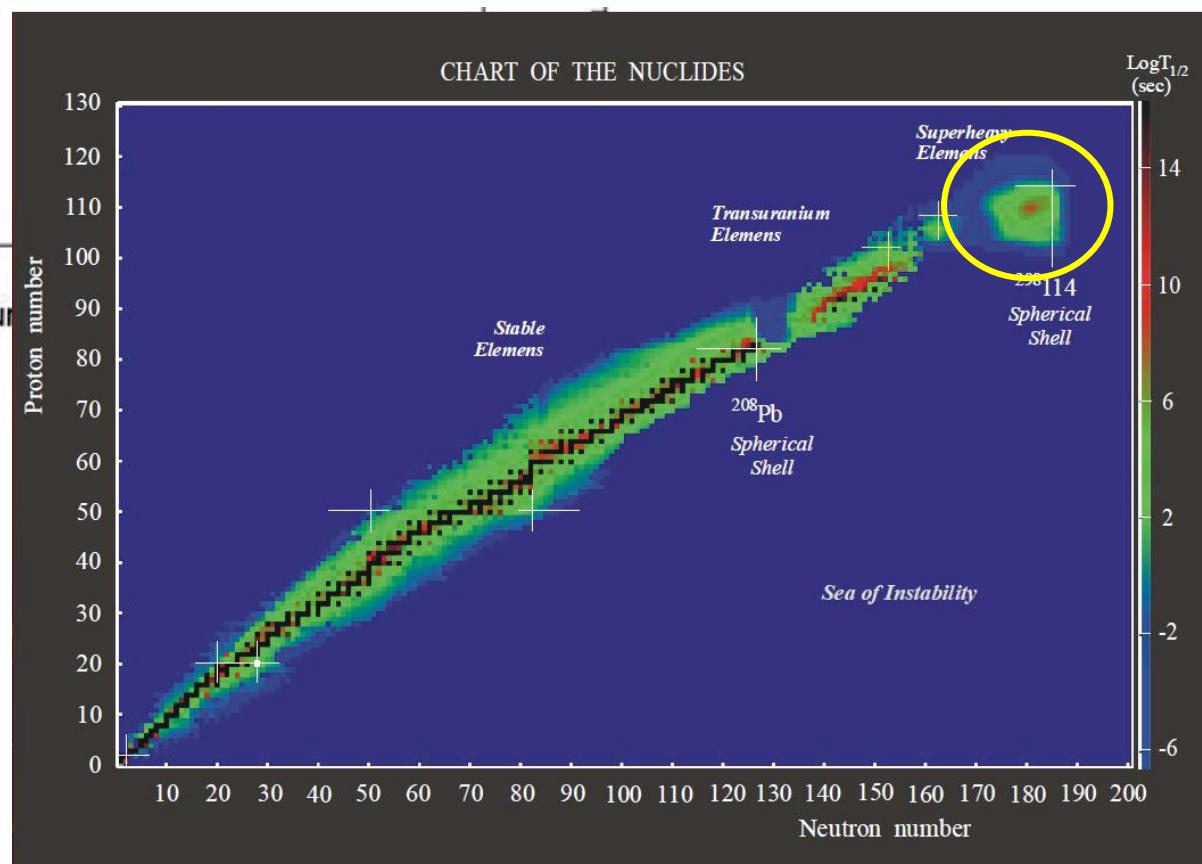
1st excited state of Pb isotopes



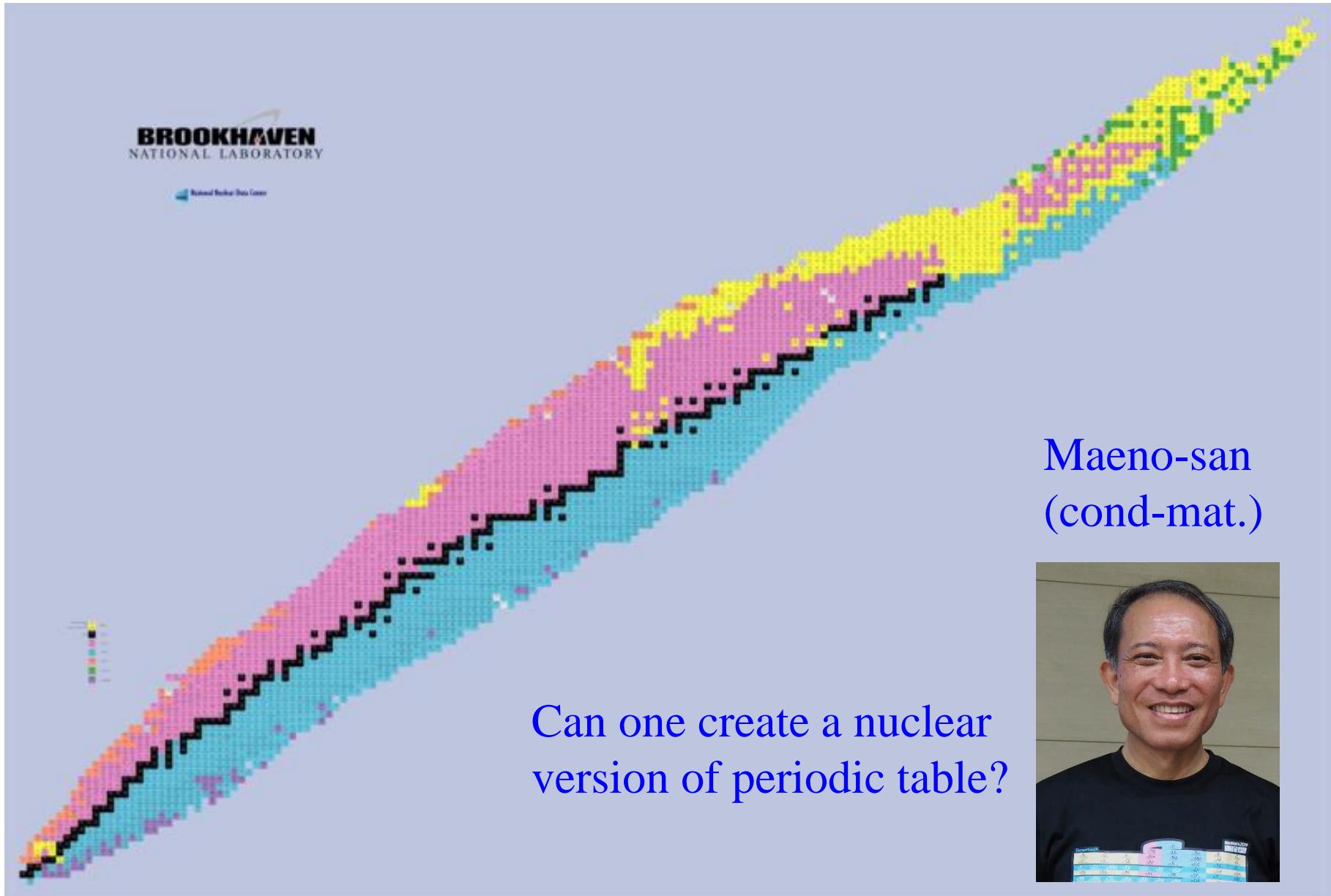
r-process nucleosynthesis (waiting point nuclei)



island of stability (superheavy nuclei)



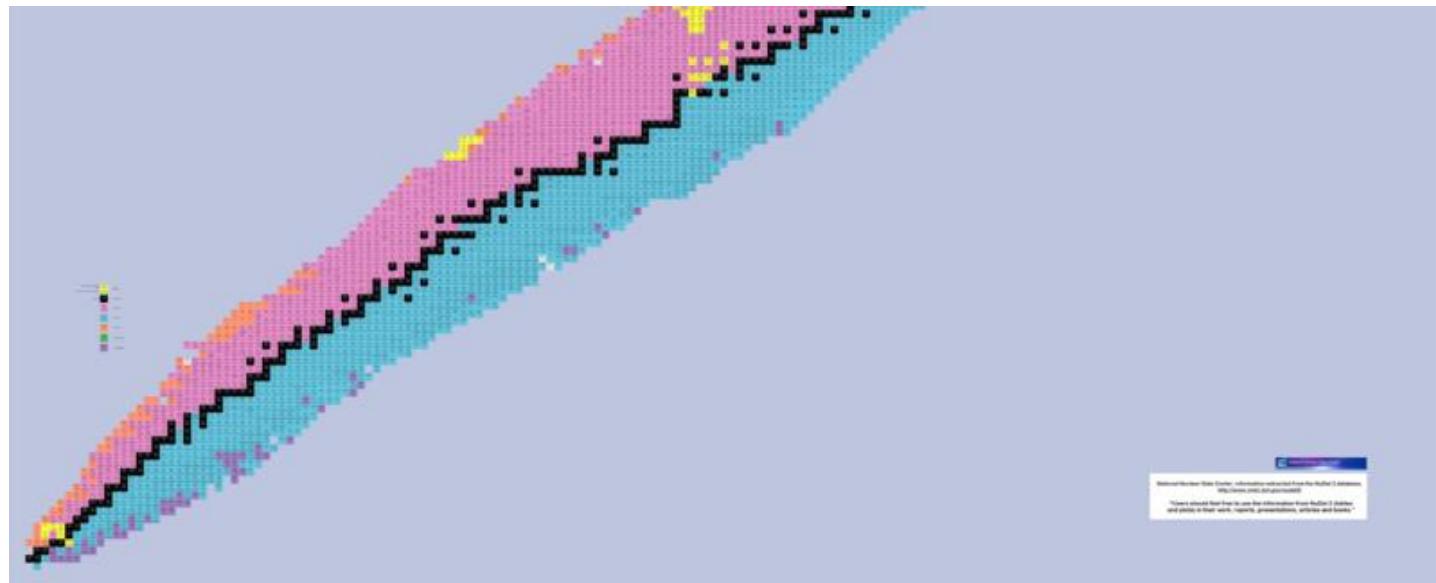
nuclear chart



Nuclear Periodic Table

Mapping a 2D nuclear chart onto a 1D table

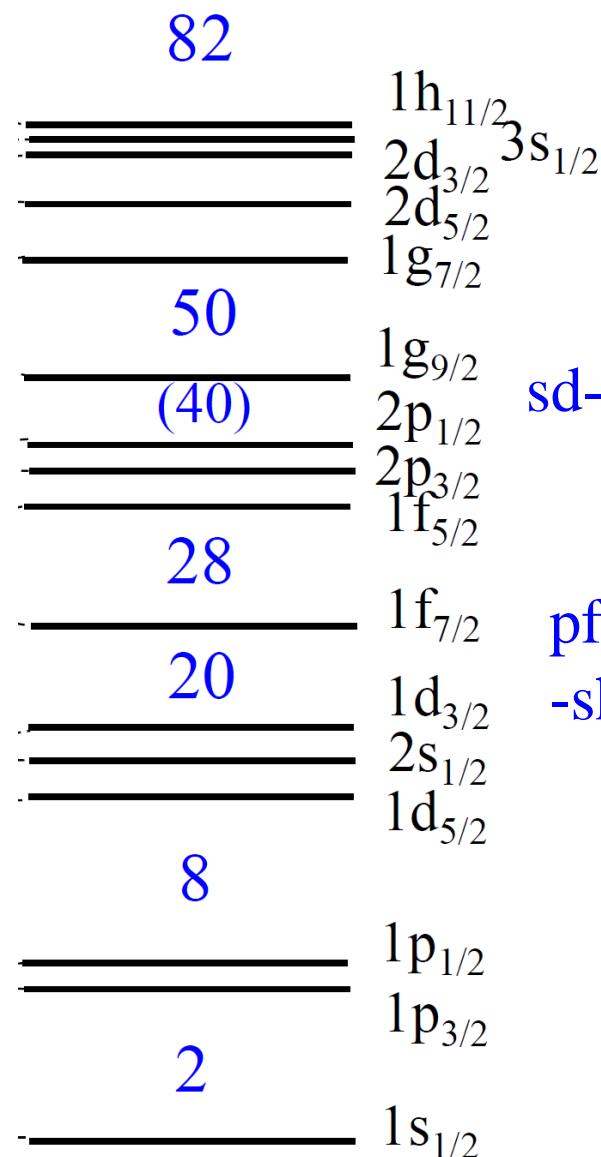
- ✓ consider protons to make a correspondence to PT of elements
- ✓ How to deal with neutrons?



→ Select the most ‘typical’ nucleus for each element

- the largest abundance
- the longest lifetime (if no stable nucleus)

Nuclear Periodic Table



Periodic table showing the mapping of nuclear shells to atomic structure:

- sd-shell** → F (9), Ne (10), Na (11), Mg (12)
- p-shell** → Li (3), Be (4), B (5), C (6), N (7), O (8)
- f_{7/2}** → Sc (21), Ti (22), V (23), Cr (24), Mn (25)
- pfg -shell** → Cu (29), Zn (30), Ga (31), Ge (32), As (33), Se (34), Br (35), Kr (36), Rb (37), Sr (38), Y (39), Zr (40), Sn (50)
- g_{9/2}** → Nb (41), Mo (42), Tc (43), Ru (44), Rh (45), Pd (46), Ag (47), Cd (48), In (49), Pb (82)
- h_{11/2}** → Ir (77), Pt (78), Au (79), Hg (80), Tl (81), Pb (82)

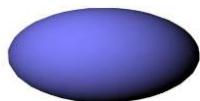
Key features of the periodic table:

- Proton magic numbers** (red arrow): He (2), O (8), Ca (20), Ni (28), Sn (50), Pb (82).
- (semi) magic numbers** (red bar): H (1), Be (4), S (16), Cl (17), Ar (18), K (19), Fe (26), Co (27), Y (39), In (49), Nh (113).

Nuclear Periodic Table

Shape and stability	
	Stable Unstable
Spherical	Nb 41 Nh 113
Deformed	Mo 42 Tc 43

- ✓ deformed nuclei : round square



- ✓ unstable nuclei : white letters

proton
magic

↓

(semi) magic numbers

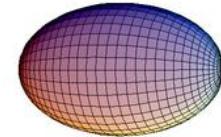
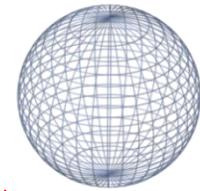
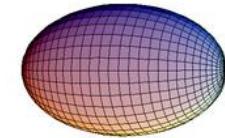
H	He
1	2
O	8
Ca	20
Ni	28
Zr	40
Sn	50
Pb	82
Tl	81
Fl	114
Fr	113
Cn	112
Nh	113
Ds	110
Rg	111
Au	79
Hg	80
Tl	81
Pt	78
Ir	77
Os	76
Re	75
W	74
Ta	73
Hf	72
Lu	71
Yb	70
Tm	69
Er	68
Fm	100
Md	101
No	102
Lr	103
Rf	104
Db	105
Sg	106
Bh	107
Hs	108
Mt	109
Ds	110
Rg	111
Cn	112
Nh	113

Nuclear Periodic Table

a version with proton magic nuclei
at the center

a pedagogical significance
: to familiarize nuclear phsyics

H	He	Li	Be	B									
1	2	3	4	5									
C	N	O	F	Ne	Na	Mg	Al	Si					
6	7	8	9	10	11	12	13	14					
P	S	Cl	Ar	K	Ca	Sc	Ti	V	Cr				
15	16	17	18	19	20	21	22	23	24				
			Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	
			25	26	27	28	29	30	31	32	33	34	
Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh			
35	36	37	38	39	40	41	42	43	44	45			
	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	La	Ce
	46	47	48	49	50	51	52	53	54	55	56	57	58
Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At
72	73	74	75	76	77	78	79	80	81	82	83	84	85
Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts
104	105	106	107	108	109	110	111	112	113	114	115	116	117
Og													



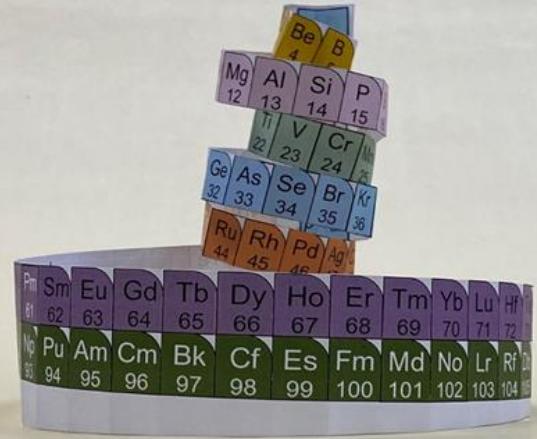
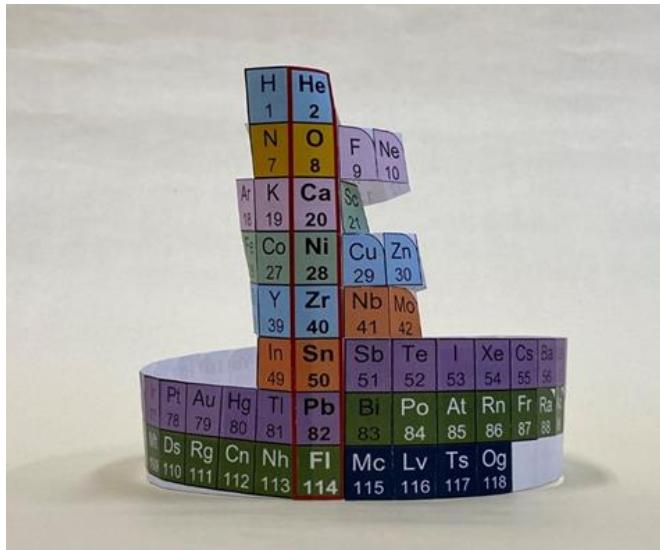
deformed

spherical

deformed

Nuclear Periodic Table

a 3D nuclear periodic table
“Nucletouch”



Nuclear Periodic Table

a 3D nuclear periodic table
“Nucletouch”

日本物理学会誌 第75巻 第12号
サブルメンタルマテリアル

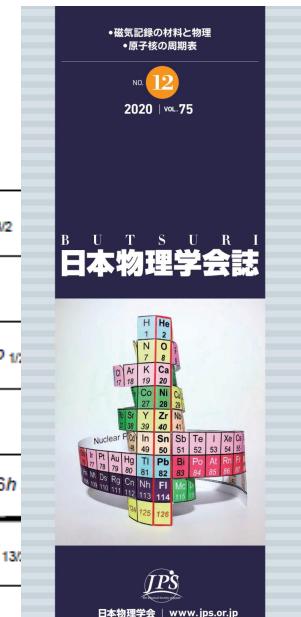
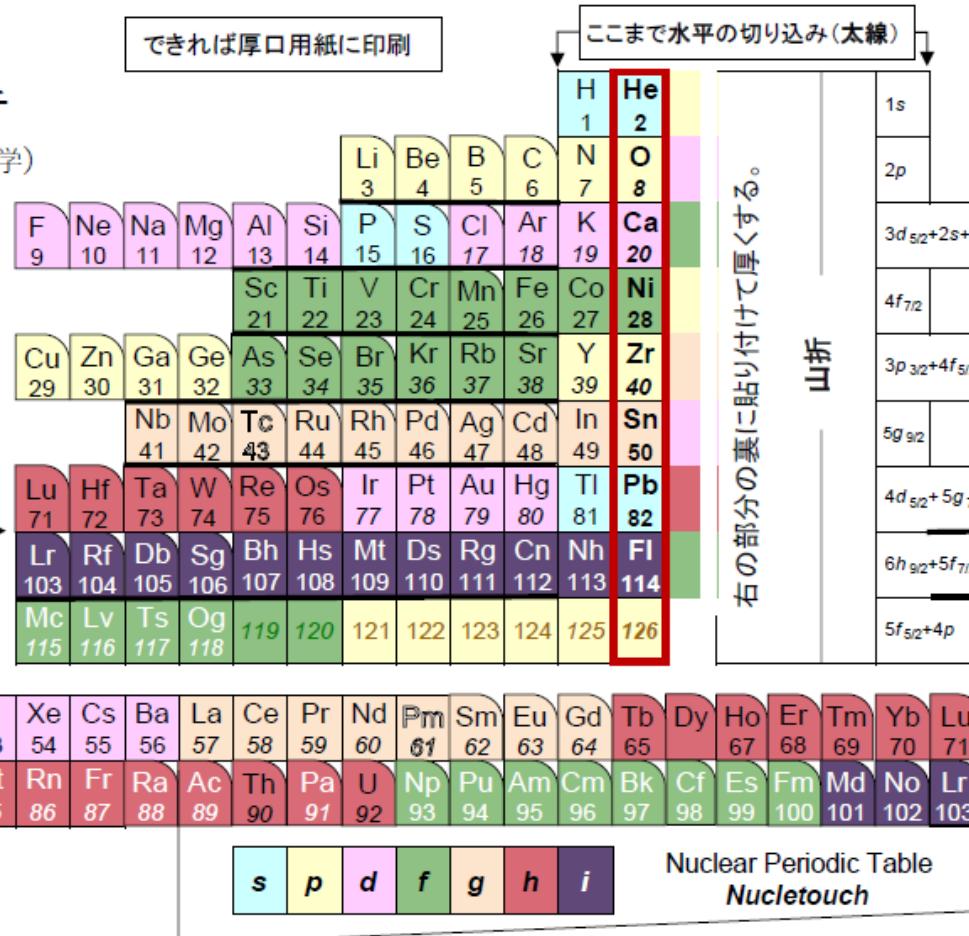
原子核の周期表

ニュークリタッチ

前野悦輝・萩野浩一（京都大学）

	安定	不安定
球形	Nb 41	Nh 113
変形	Mo 42	Tc 43

この行には切り込みいれない



a paper pattern (型紙) available at a Supplemental Material page in the JPS web site

Nuclear Periodic Table

a 3D nuclear periodic table
“Nucletouch”

購読はこちら [1週間無料]

讀賣新聞

オンライン

ログイン

新規登録

ニュース > 科学・IT

「すいへーりーべ」でおなじみの元素周期表、新パターン提案…京大が原子核の状態着目

2020/04/22 23:41

日本経済新聞

朝刊



ストーリー



Myニュース

日経

トップ 速報 マネー 経済・金融 政治 ビジネス マーケット テクノロジー

新しい周期表を考案 京大、原子核の性質を表現

2020/5/3付 | 日本経済新聞 朝刊

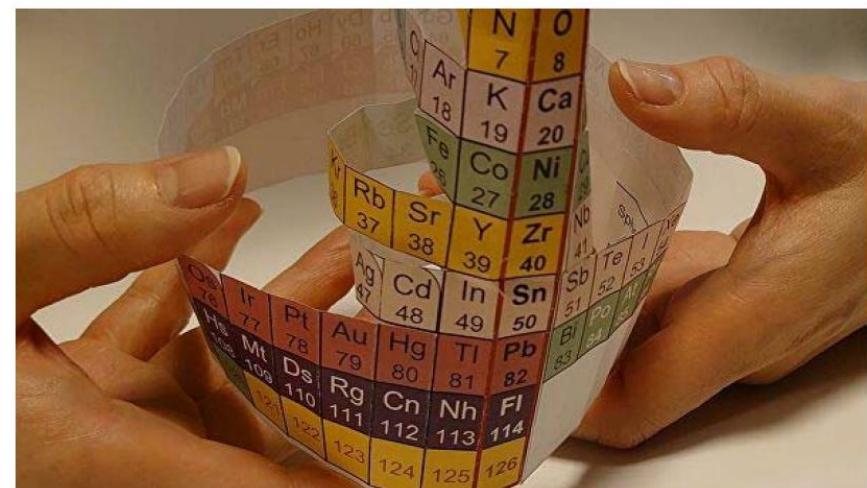
保存 共有



京都大学の前野悦輝教授と萩野浩一教授は、原子核の性質をわかりやすく表す新しい周期表を考案した。従来の周期表が元素の化学的な性質を知るために役立つ一方で、新しい周期表は元素の原子核の性質を知るために使える。

Японские физики представили новую периодическую таблицу элементов

19:34 27.05.2020 58122



© Foto : Kyoto University/Yoshiteru Maeno/Kouichi Hagino

МОСКВА, 27 мая — РИА Новости. Ученые из Киотского университета представили периодическую таблицу элементов, которая в отличие от таблицы Менделеева, где за основу взяты электроны в атоме, основана на

a magical coincidence

Y. Maeno, K. Hagino, and T. Ishiguro,
Found. of Chem. 23, 201 (2021)

periodic table of elements

					2 He
5 B	6 C	7 N	8 O	9 F	10 Ne
13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As
46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb
78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi
110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc
64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm
96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md
				70 Yb	71 Lu
				102 No	103 Lr

the nuclear magic numbers are there
in the same column!
(the same elements around them)

nuclear periodic table

H 1	He 2		Li 3	Be 4	B 5
C 6	N 7	O 8	F 9	Ne 10	Na 11
S 16	Cl 17	Ar 18	K 19	Ca 20	Sc 21
Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30
Kr 36	Rb 37	Sr 38	Y 39	Zr 40	Nb 41
Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51
Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Te 84
Ds 110	Rg 111	Cn 112	Nh 113	Fl 114	I 115
					Xe 118

a magical coincidence which
can be recognized only after
making a nuclear periodic table

Summary

Nucleotouch: a 3D nuclear periodic table

- a convenient tool to familiarize nuclear physics
 - ✓ magic numbers
 - ✓ nuclear deformation
 - ✓ nuclear stability
 - ✓ similarities and differences between atoms and nuclei

good for 1st year students at universities



原子核の周期表——Magicな関係

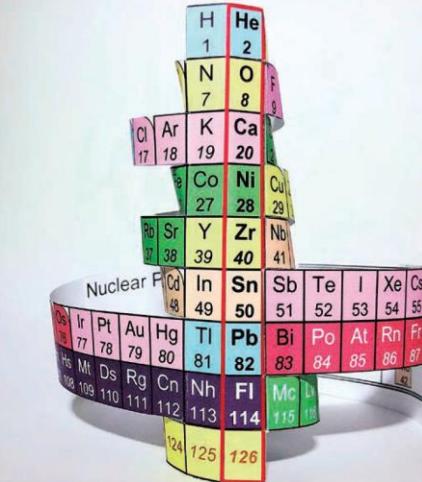
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- 磁気記録の材料と物理
- 原子核の周期表

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