

Welcome to 3.091

Lecture 7

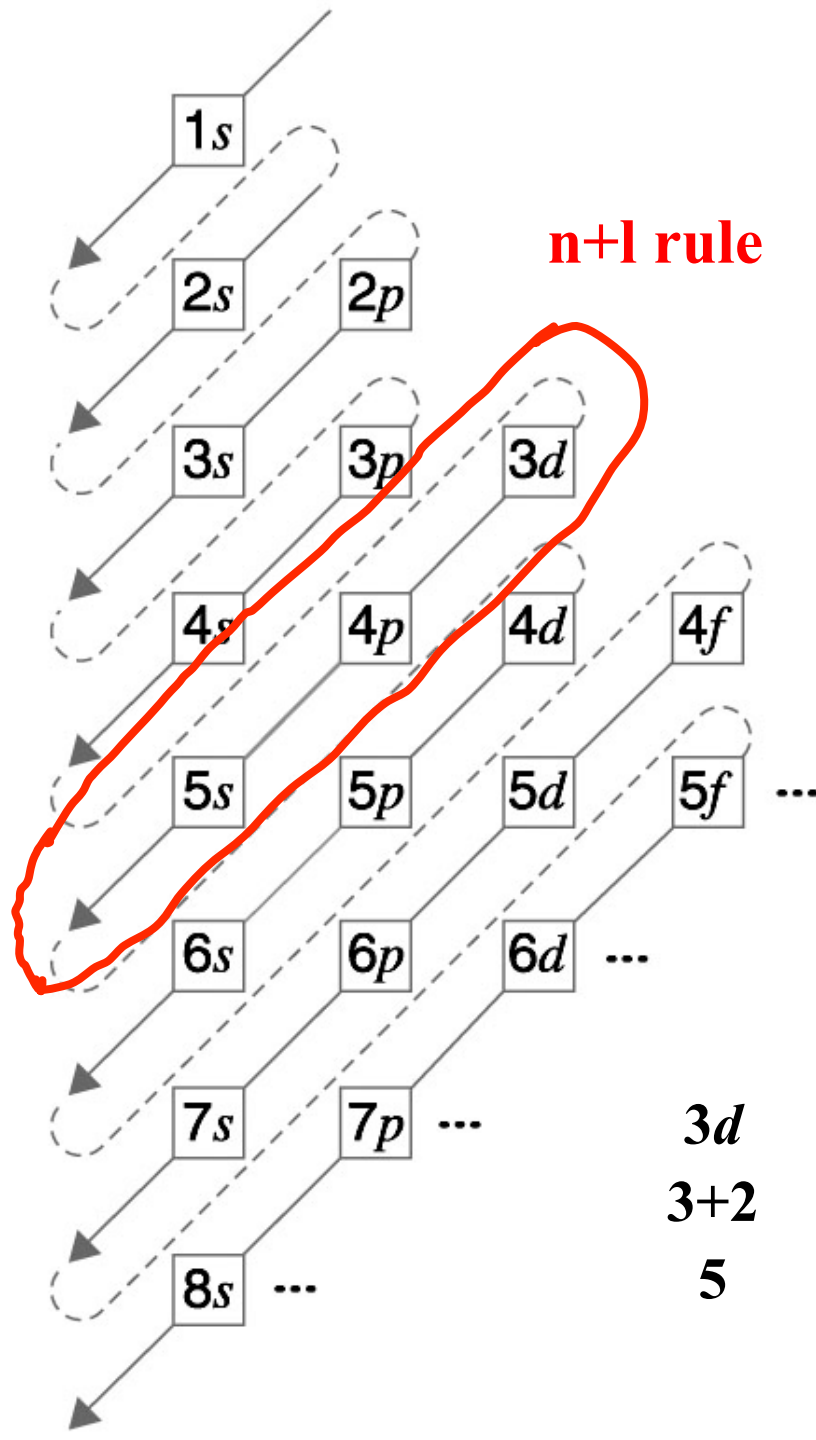
September 23, 2009

The Aufbau Principle; Photoelectron Spectroscopy

																		13 IIIB IIIA		14 IVB IVA		15 VB VA		16 VIB VIA		17 VIIB VIIA		18 VIII 0												
1.00794 -259.34 -252.87 0.0899 2.20 13.598 5.392	1 IA IA																	2 He																						
6.941 180.5 1342 0.534 0.98 5.392	3 Li		4 Be																	10 Ne																				
[He]2s ¹ Lithium	[He]2s ² Beryllium																	[He]2s ² p ⁶ Neon																						
22.989768 97.72 883 0.97 0.93 5.139	11 Na		12 Mg																	18 Ar																				
[Ne]3s ¹ Sodium	[Ne]3s ² Magnesium																	[Ne]3s ² p ⁶ Argon																						
39.0983 65.38 759 0.86 0.82 4.341	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					
[Ar]4s ¹ Potassium	[Ar]4s ² Calcium		[Ar]3d ¹ 4s ² Titanium		[Ar]3d ² 4s ² Vanadium		[Ar]3d ³ 4s ² Chromium		[Ar]3d ⁴ 4s ² Manganese		[Ar]3d ⁵ 4s ² Iron		[Ar]3d ⁶ 4s ² Cobalt		[Ar]3d ⁷ 4s ² Nickel		[Ar]3d ⁸ 4s ² Copper		[Ar]3d ⁹ 4s ² Zinc		[Ar]3d ¹⁰ 4s ² Gallium		[Ar]3d ¹⁰ 4s ² Germanium		[Ar]3d ¹⁰ 4s ² Arsenic		[Ar]3d ¹⁰ 4s ² Selenium		[Ar]3d ¹⁰ 4s ² Bromine		[Ar]3d ¹⁰ 4s ² Krypton									
85.4678 39.31 688 1.532 0.82 4.177	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					
[Kr]5s ¹ Rubidium	[Kr]5s ² Strontium		[Kr]4d ¹ 5s ² Yttrium		[Kr]4d ² 5s ² Zirconium		[Kr]4d ³ 5s ² Niobium		[Kr]4d ⁴ 5s ² Molybdenum		[Kr]4d ⁵ 5s ² Technetium		[Kr]4d ⁶ 5s ² Ruthenium		[Kr]4d ⁷ 5s ² Rhodium		[Kr]4d ⁸ 5s ² Palladium		[Kr]4d ⁹ 5s ² Silver		[Kr]4d ¹⁰ 5s ² Cadmium		[Kr]4d ¹⁰ 5s ² Indium		[Kr]4d ¹⁰ 5s ² Tin		[Kr]4d ¹⁰ 5s ² Antimony		[Kr]4d ¹⁰ 5s ² Tellurium		[Kr]4d ¹⁰ 5s ² Iodine		[Kr]4d ¹⁰ 5s ² Xenon							
132.90543 28.44 671 1.879 0.79 3.894	55 Cs		56 Ba		57 La		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							
[Xe]6s ¹ Cesium	[Xe]6s ² Barium		[Xe]4f ¹ 5d ¹ 6s ² Lanthanum		[Xe]4f ¹ 5d ¹ 6s ² Cerium		[Xe]4f ² 6s ² Praseodymium		[Xe]4f ³ 6s ² Neodymium		[Xe]4f ⁴ 6s ² Promethium		[Xe]4f ⁵ 6s ² Samarium		[Xe]4f ⁶ 6s ² Europium		[Xe]4f ⁷ 6s ² Gadolinium		[Xe]4f ⁸ 6s ² Terbium		[Xe]4f ⁹ 6s ² Dysprosium		[Xe]4f ¹⁰ 6s ² Holmium		[Xe]4f ¹¹ 6s ² Erbium		[Xe]4f ¹² 6s ² Thulium		[Xe]4f ¹³ 6s ² Ytterbium		[Xe]4f ¹⁴ 6s ² Lutetium									
(223.0197) 707 677 5.8 0.7	87 Fr		(226.0254) 700 3198		88 Ra		(227.0278) 1051 3198		89 Ac		(261) 104		(262) 105		(263) 106		(262) 107		(265) 108		(266) 109		(269) 110		(272) 111		(277) 112		113		(285) 114		115		(289) 116		117		(293) 118	
[Rn]7s ¹ Francium	[Rn]7s ² Radium		[Rn]5f ¹ 6d ¹ 7s ² Actinium		[Rn]5f ¹ 6d ¹ 7s ² Rutherfordium**		[Rn]5f ¹ 6d ¹ 7s ² Dubnium**		[Rn]5f ¹ 6d ¹ 7s ² Seaborgium**		[Rn]5f ¹ 6d ¹ 7s ² Bohrium**		[Rn]5f ¹ 6d ¹ 7s ² Hassium**		[Rn]5f ¹ 6d ¹ 7s ² Meitnerium**		[Rn]5f ¹ 6d ¹ 7s ² Ununnilium		[Rn]5f ¹ 6d ¹ 7s ² Ununnilium		[Rn]5f ¹ 6d ¹ 7s ² Ununnilium		[Rn]5f ¹ 6d ¹ 7s ² Ununnilium		[Rn]5f ¹ 6d ¹ 7s ² Ununnilium		[Rn]5f ¹ 6d ¹ 7s ² Ununnilium		[Rn]5f ¹ 6d ¹ 7s ² Ununnilium		[Rn]5f ¹ 6d ¹ 7s ² Ununnilium		[Rn]5f ¹ 6d ¹ 7s ² Ununnilium		[Rn]5f ¹ 6d ¹ 7s ² Ununnilium					

* 140.115 799 3424 6.770	58 Ce		140.90765 931 3000 6.773		59 Pr		144.24 1016 3066 7.00		60 Nd		(144.9127) 1042 3000 7.254		61 Pm		150.36 1072 3000 7.536		62 Sm		151.965 822 1596 5.244		63 Eu		157.25 1314 3224 7.901		64 Gd		158.92534 1359 3221 8.230		65 Tb		162.50 1411 2561 8.80		66 Dy		164.93032 1472 2694 9.066		67 Ho		167.26 1529 2862 9.066		68 Er		168.93421 1545 1946 9.321		69 Tm		173.04 824 1194 9.696		70 Yb		174.967 1663 3393 9.84		71 Lu	
5.466 1.12 1.3 6.08	[Xe]4f ¹ 5d ¹ 6s ² Cerium		[Xe]4f ² 6s ² Praseodymium		[Xe]4f ³ 6s ² Neodymium		[Xe]4f ⁴ 6s ² Promethium		[Xe]4f ⁵ 6s ² Samarium		[Xe]4f ⁶ 6s ² Europium		[Xe]4f ⁷ 6s ² Gadolinium		[Xe]4f ⁸ 6s ² Terbium		[Xe]4f ⁹ 6s ² Dysprosium		[Xe]4f ¹⁰ 6s ² Holmium		[Xe]4f ¹¹ 6s ² Erbium		[Xe]4f ¹² 6s ² Thulium		[Xe]4f ¹³ 6s ² Ytterbium		[Xe]4f ¹⁴ 6s ² Lutetium		[Xe]4f ¹⁴ 6s ² Lutetium		[Xe]4f ¹⁴ 6s ² Lutetium		[Xe]4f ¹⁴ 6s ² Lutetium		[Xe]4f ¹⁴ 6s ² Lutetium		[Xe]4f ¹⁴ 6s ² Lutetium		[Xe]4f ¹⁴ 6s ² Lutetium		[Xe]4f ¹⁴ 6s ² Lutetium		[Xe]4f ¹⁴ 6s ² Lutetium											
** 232.0381 1750 4788 11.72 1.3 6.08	90 Th		231.03588 1572 4131 15.37 1.5 5.89		91 Pa		238.0289 1135 1905+02 4131 1.38 6.05		92 U		(237.0482) 644 3228 19.816 1.38 6.19		93 Np		(244.0642) 644 3228 19.816 1.28 5.8		94 Pu		(242.0614) 640 2507 13.45 1.3 6.02		95 Am		(247.0703) 1345 3151 14.78 1.3 6.27		96 Cm		(247.0703) 1050 3221 14.78 1.3 6.27		97 Bk		(251.0796) 900 3221 14.78 1.3 6.27		98 Cf		(252.083) 860 3221 14.78 1.3 6.27		99 Es		(257.0951) 1327 3221 14.78 1.3 6.27		100 Fm		(258.10) 827 3221 14.78 1.3 6.27		101 Md		(259.1009) 827 3221 14.78 1.3 6.27		102 No		(252.11) 827 3221 14.78 1.3 6.27		103 Lr	
[Rn]6d ² 7s ² Thorium	[Rn]5f ¹ 6d ¹ 7s ² Protactinium		[Rn]5f ¹ 6d ¹ 7s ² Uranium		[Rn]5f ¹ 6d ¹ 7s ² Neptunium		[Rn]5f ¹ 6d ¹ 7s ² Plutonium		[Rn]5f ¹ 6d ¹ 7s ² Americium		[Rn]5f ¹ 6d ¹ 7s ² Curium		[Rn]5f ¹ 6d ¹ 7s ² Berkelium		[Rn]5f ¹ 6d ¹ 7s ² Californium		[Rn]5f ¹ 6d ¹ 7s ² Einsteinium		[Rn]5f ¹ 6d ¹ 7s ² Fermium		[Rn]5f ¹ 6d ¹ 7s ² Mendelevium		[Rn]5f ¹ 6d ¹ 7s ² Nobelium		[Rn]5f ¹ 6d ¹ 7s ² Lawrencium		[Rn]5f ¹ 6d ¹ 7s ² Lawrencium		[Rn]5f ¹ 6d ¹ 7s ² Lawrencium		[Rn]5f ¹ 6d ¹ 7s ² Lawrencium		[Rn]5f ¹ 6d ¹ 7s ² Lawrencium		[Rn]5f ¹ 6d ¹ 7s ² Lawrencium		[Rn]5f ¹ 6d ¹ 7s ² Lawrencium		[Rn]5f ¹ 6d ¹ 7s ² Lawrencium															

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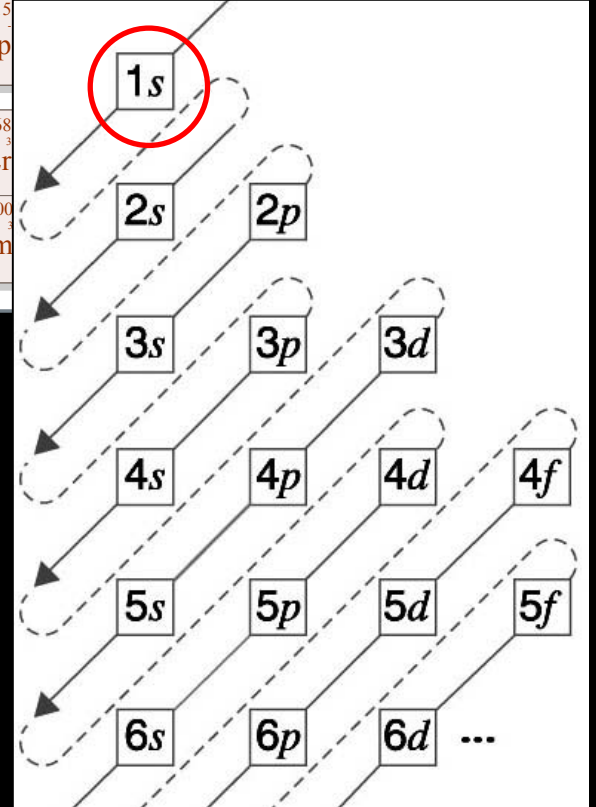


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1 IA IA	← 1s →																18 VIII 0
1 1 H																	2 He
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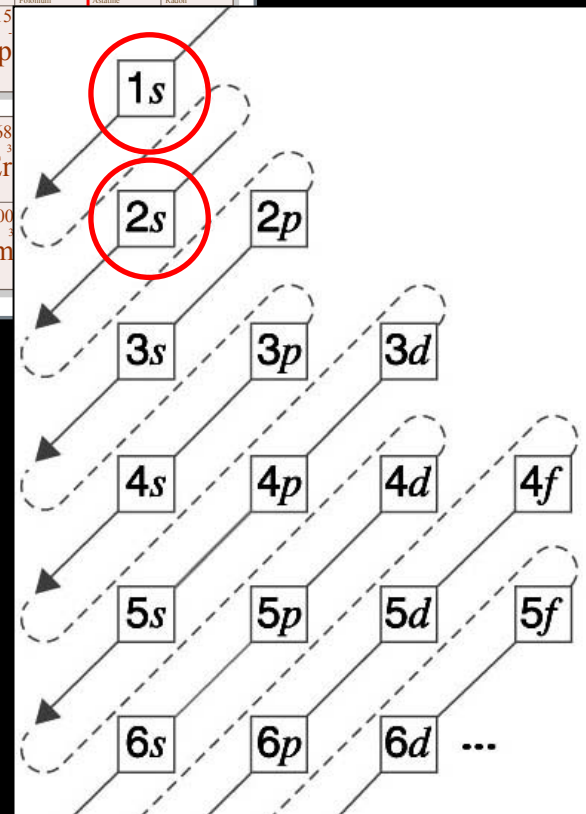


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1 IA IA	← 1s →																18 VIII 0
1 1 H																	2 He
2 IIA IIA																	10 Ne
3 IIIA IIIA	← 2s →																18 Ar
4 IIA IIA																	18 Ar
5 VA VB																	18 Ar
6 VIA VIB																	18 Ar
7 VIIA VIIA																	18 Ar
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2p

140.115	58	140.90765	59	144.24	60	(144.9127)	61	150.36	62	151.965	63	158.92534	64	165.50	65	167.26	66	164.93032	67	167.26	68
424	Ce	424	Pr	424	Nd	424	Pm	424	Sm	424	Eu	424	Gd	424	Tb	424	Dy	424	Ho	424	Er
232.0381	90	231.03588	91	238.0289	92	(237.0482)	93	244.0642	94	(243.0614)	95	(247.0703)	96	(247.0703)	97	(251.0796)	98	(252.0832)	99	(257.0951)	100
1750	Th	1750	Pa	1750	U	1750	Np	1750	Pu	1750	Am	1750	Cm	1750	Bk	1750	Cf	1750	Es	1750	Fm

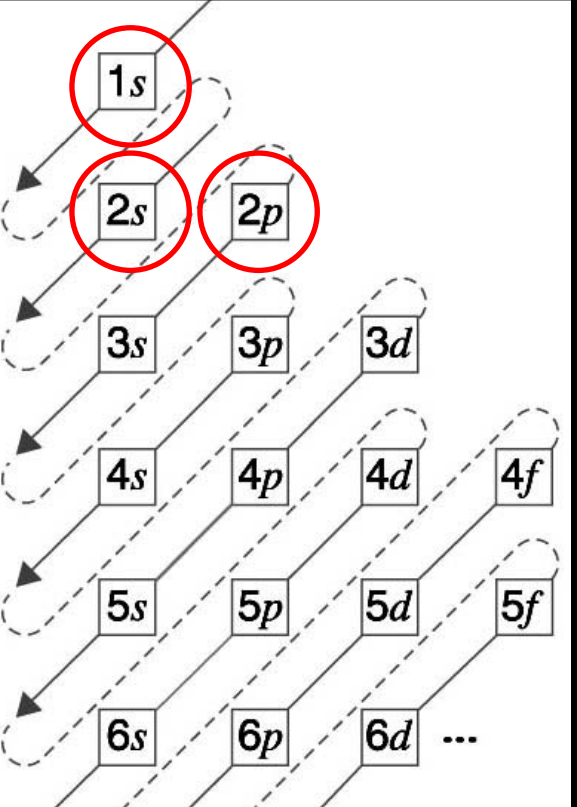


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1 IA 1A																	18 VIII 0
1 1 H																	2 He
2 2 Li Be																	10 Ne
3 3 Na Mg																	18 Ar
4 4 K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr																	36 Kr
5 5 Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe																	54 Xe
6 6 Cs Ba La Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn																	86 Rn
7 7 Fr Ra Ac Rf Db Sg Bh Hs Mt Uun Uuu Uub Uut Uuq Uup																	118 Og

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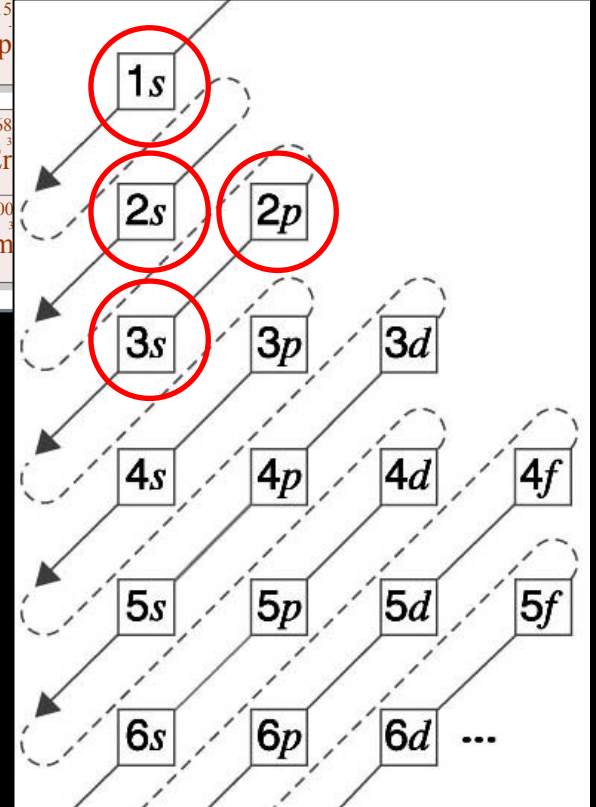


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1.00794 201.12 238.02891 0.00018089 2.016 14.003094 Hydrogen																		4.002602 272.26 268.93 0.1782 24.987 He									
6.941 180.5 132 0.534 0.98 5.992 [He] ²⁺ Lithium																		15.9994 238.02891 182.95 1.679 3.996 18.9984032 23.999 201.797 238.02891 24.985 Ne									
22.989768 97.72 803 1.74 0.97 0.93 5.139 [He] ²⁺ Sodium																		32.066 115.21 444.60 3.214 2.07 1.784 15.759 [Ne] ³⁺ Argon									
39.0983 63.38 79 0.86 0.82 4.341 [Ar] ⁴⁺ Potassium																		36.46 72.61 93.92 230.04 6.941 1.82 3.996 18.9984032 23.999 201.797 238.02891 24.985 Ne									
85.4678 39.31 688 1.522 0.82 4.177 [Kr] ⁵⁺ Rubidium																		36.46 72.61 93.92 230.04 6.941 1.82 3.996 18.9984032 23.999 201.797 238.02891 24.985 Ne									
132.90543 28.44 671 1.879 0.79 3.894 [Xe] ⁶⁺ Cesium																		36.46 72.61 93.92 230.04 6.941 1.82 3.996 18.9984032 23.999 201.797 238.02891 24.985 Ne									
(223.0197) 27 677 0.7 Fr																		36.46 72.61 93.92 230.04 6.941 1.82 3.996 18.9984032 23.999 201.797 238.02891 24.985 Ne									
[Ra] ⁷⁺ Francium																		36.46 72.61 93.92 230.04 6.941 1.82 3.996 18.9984032 23.999 201.797 238.02891 24.985 Ne									

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140.115 59 6.770 1.12 8.466 [Xe] ⁶⁺ Cesium																		36.46 72.61 93.92 230.04 6.941 1.82 3.996 18.9984032 23.999 201.797 238.02891 24.985 Ne									
232.0381 1750 4788 11.72 1.3 6.08 [Ra] ⁷⁺ Thorium																		36.46 72.61 93.92 230.04 6.941 1.82 3.996 18.9984032 23.999 201.797 238.02891 24.985 Ne									

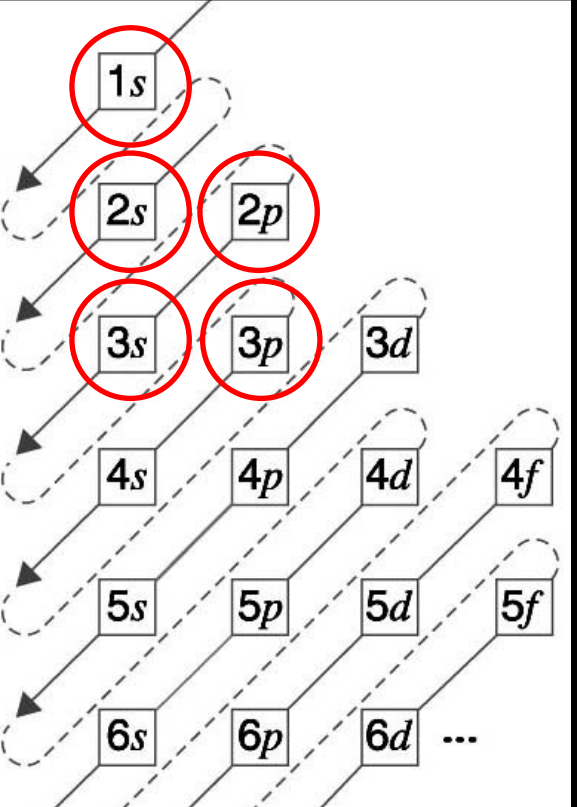


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223.0381 90 Th Thorium	231.03588 91 Pa Protactinium	238.02891 92 U Uranium	(237.0482) 93 Np Neptunium	(244.0642) 94 Pu Plutonium	(243.0614) 95 Am Americium	(247.0703) 96 Cm Curium	(247.0703) 97 Bk Berkelium	(251.0766) 98 Cf Californium	(252.0832) 99 Es Einsteinium	(257.0951) 100 Fm Fermium

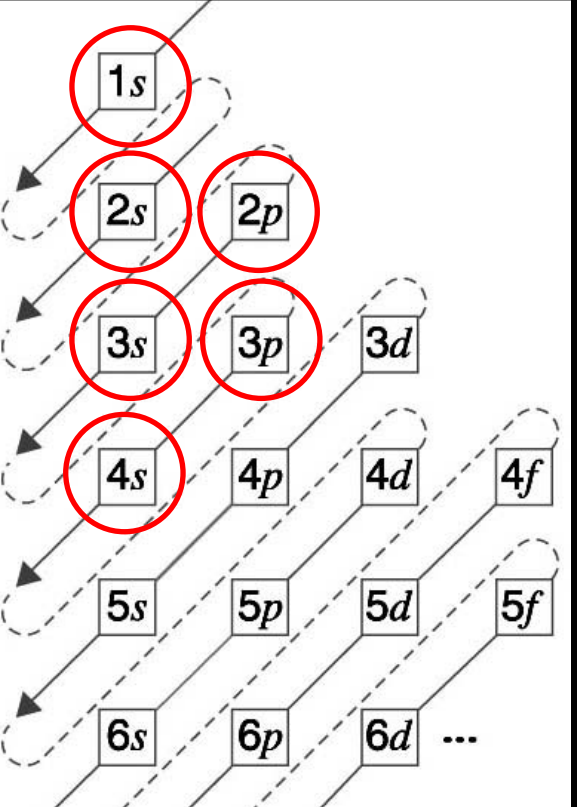


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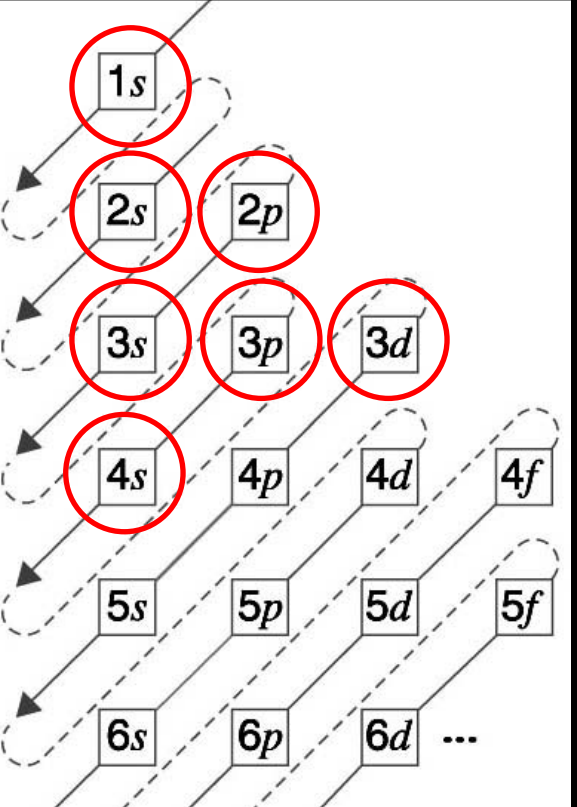
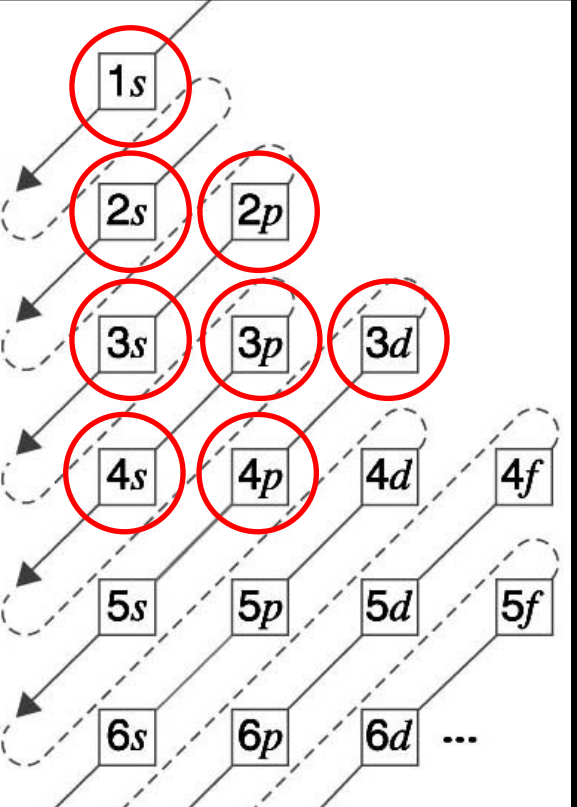


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87 Fr Francium	88 Ra Radium	89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Uun Ununium	111 Uuu Ununium	112 Uub Unbium	113 Uut Ununtrium	114 Uuq Unquadium	115 Uup Unpentium	116 Uuq Unquadium	117 Uup Unpentium	118 Uuo Ununoctium

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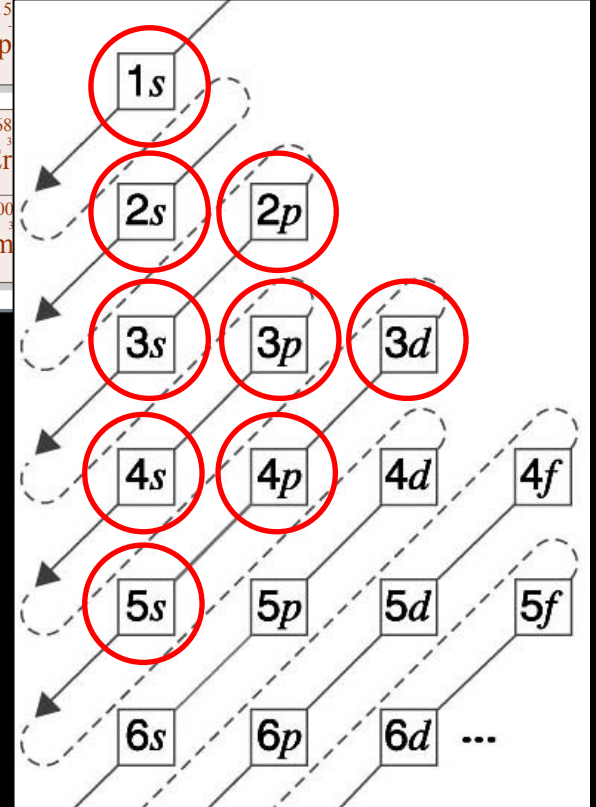


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87 Fr	88 Ra	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuq	117 Uup	118 Uuq

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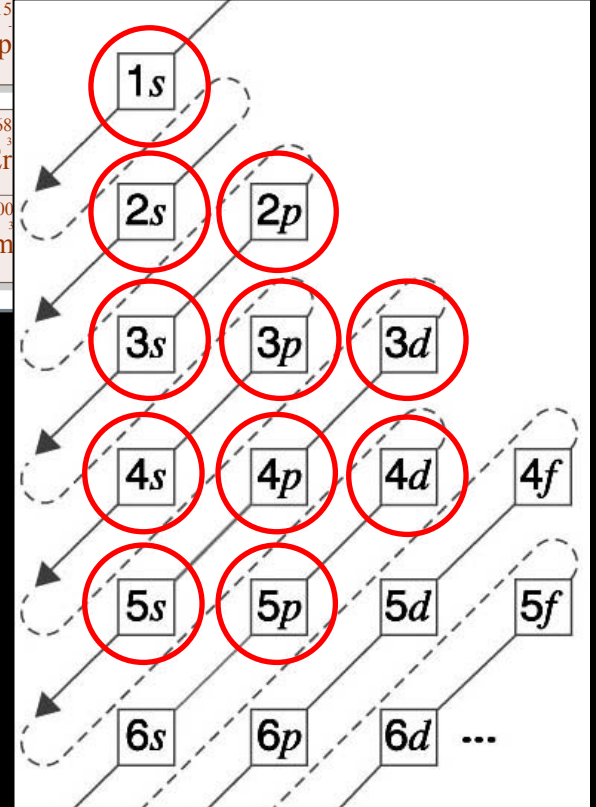


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Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er
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90	91	92	93	94	95	96	97	98	99	
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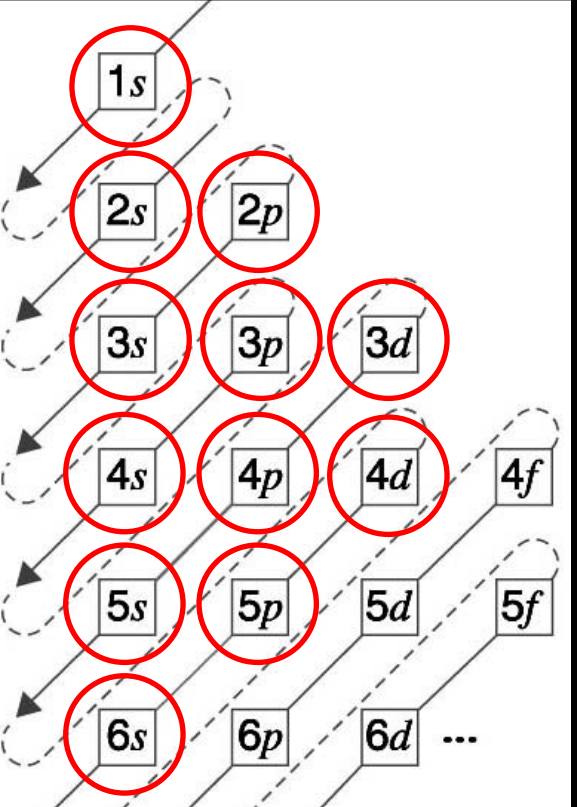
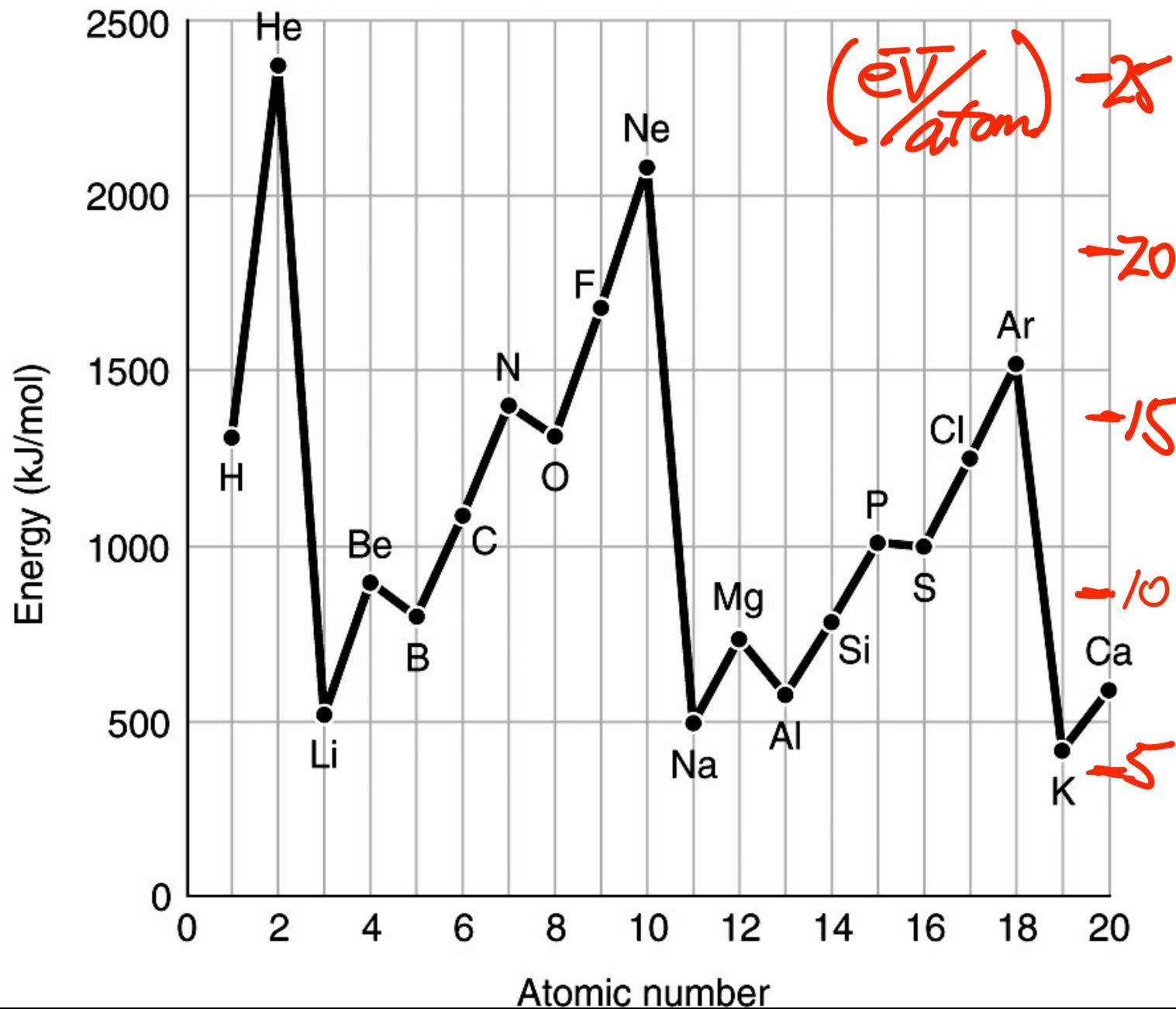


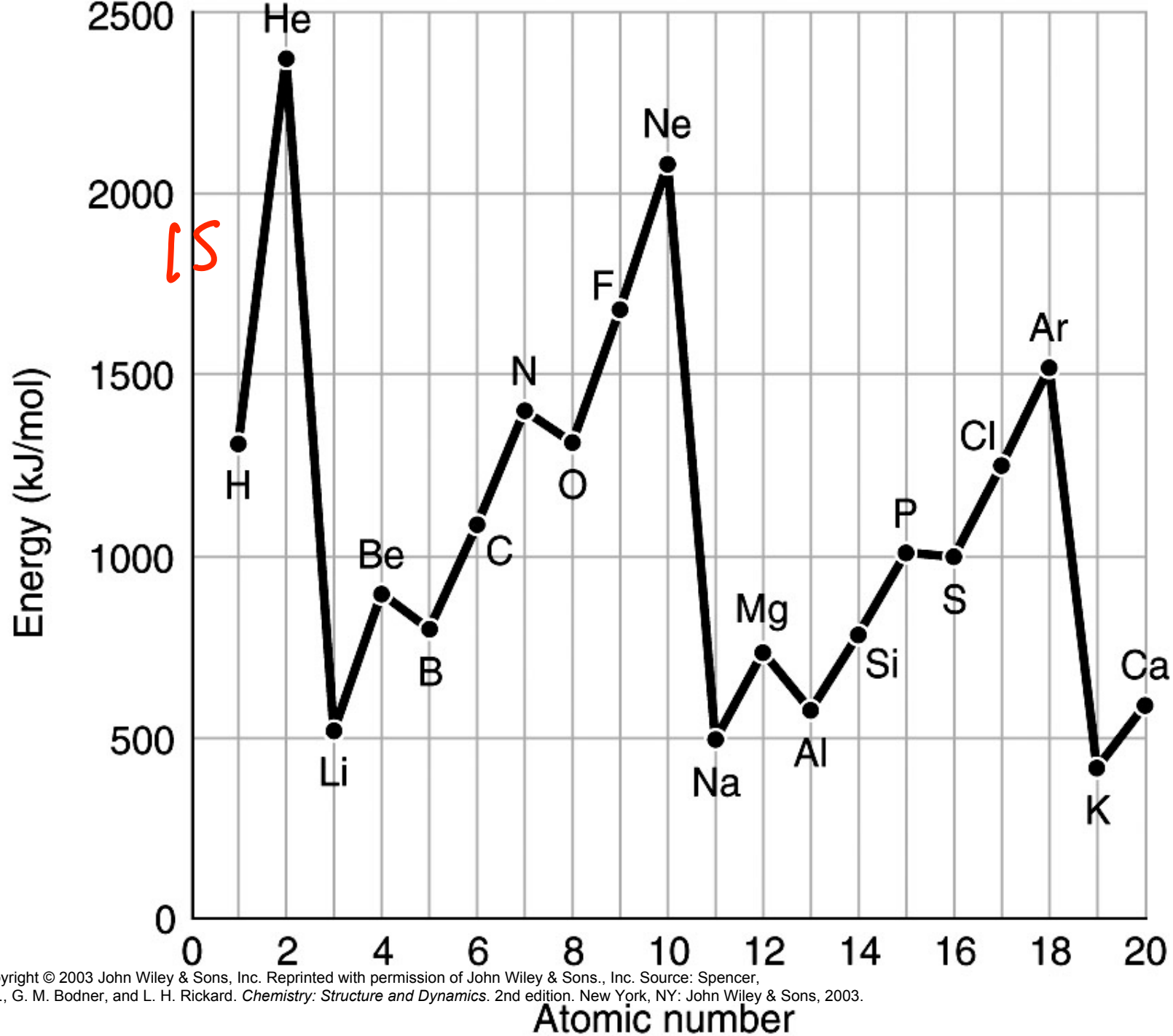
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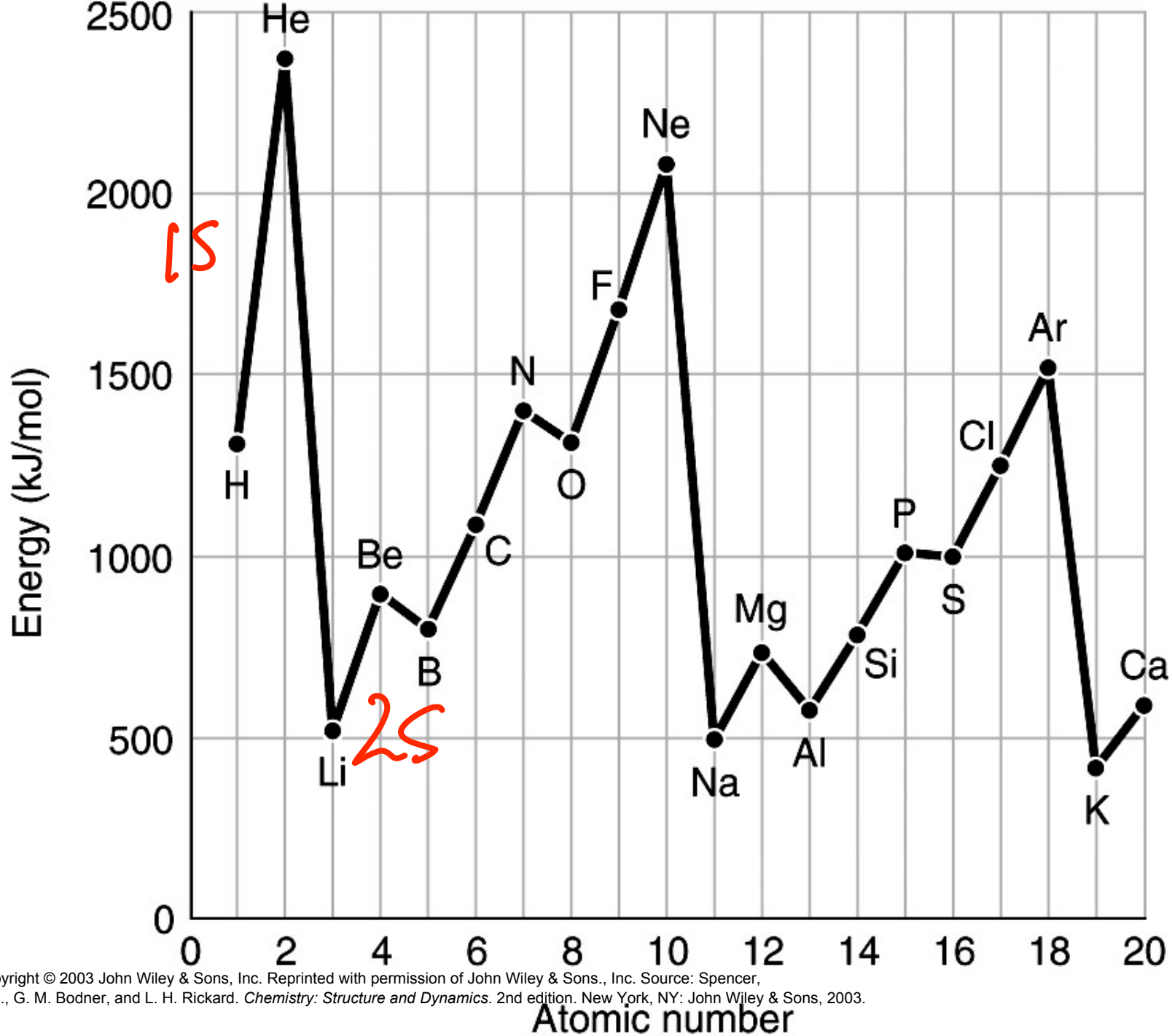
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Variation of 1st Ionization Energy with Atomic Number

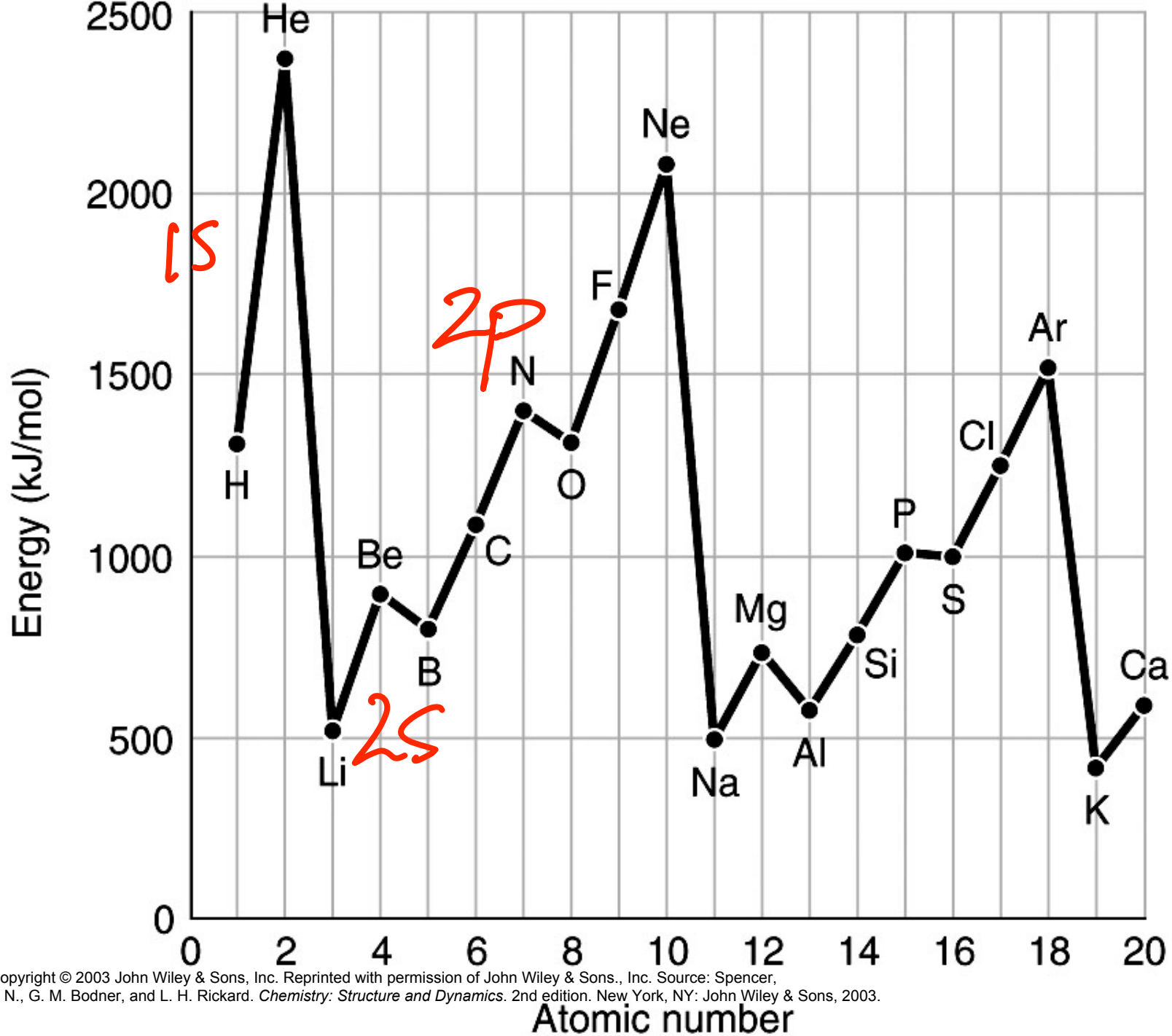




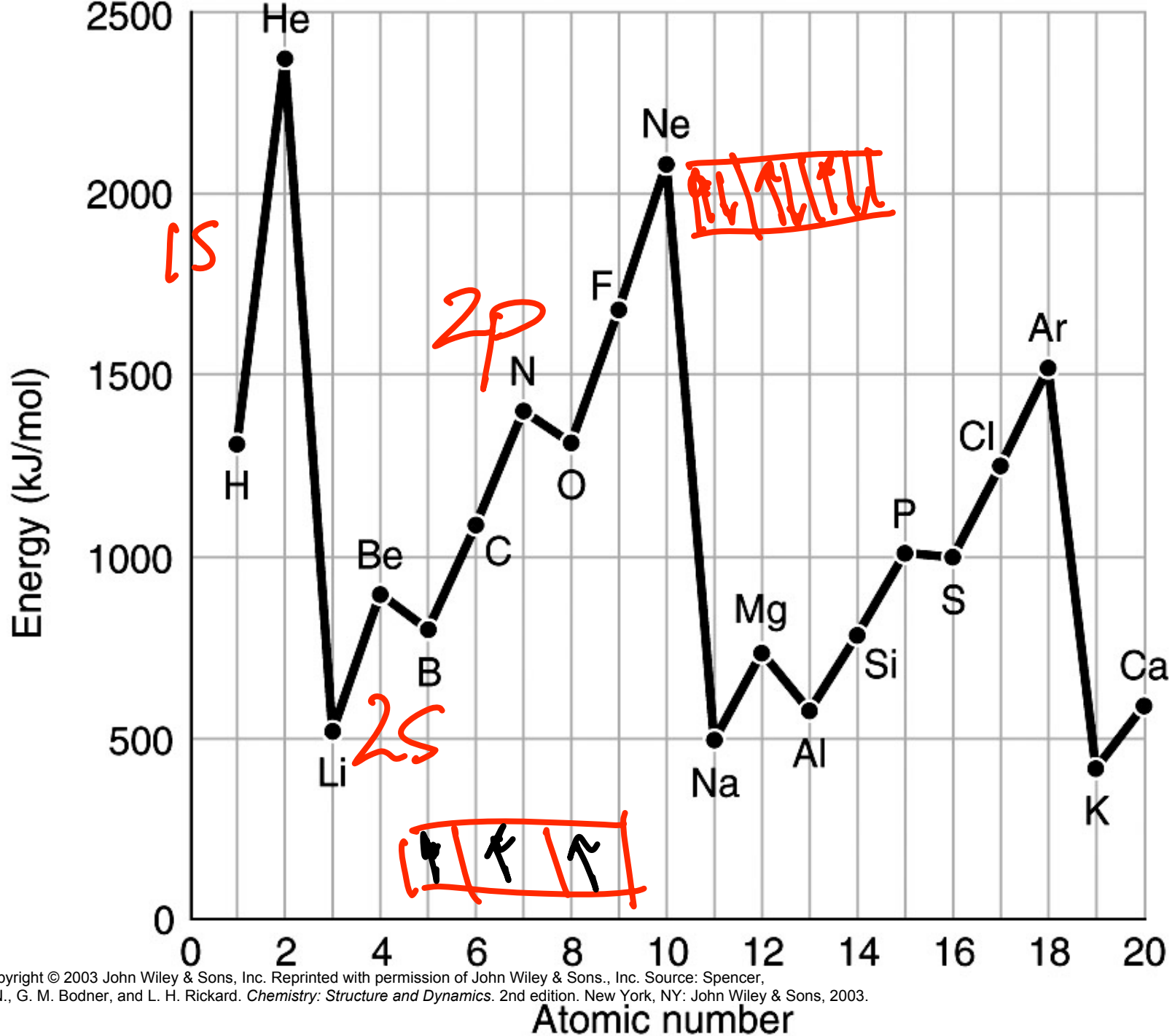
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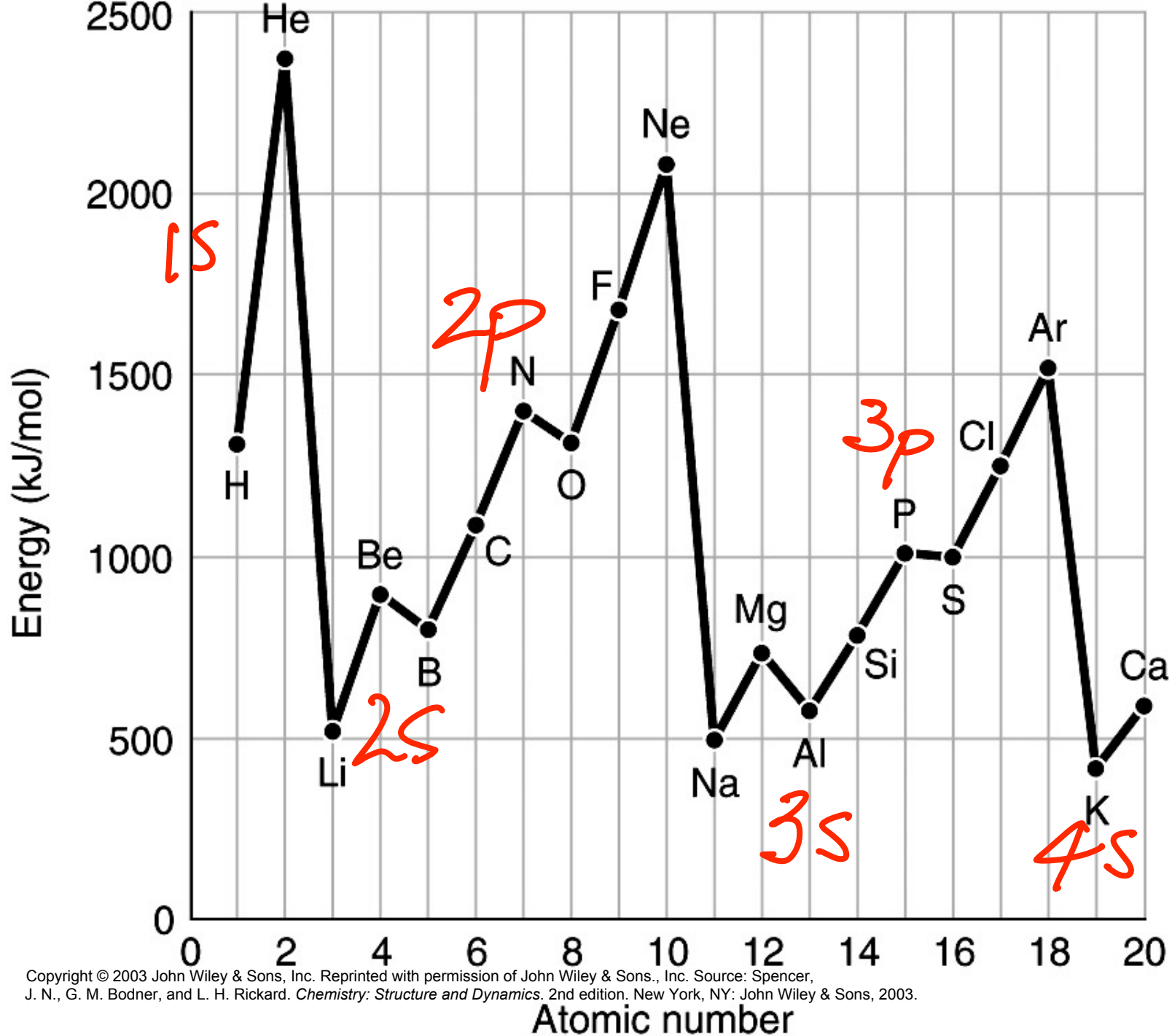


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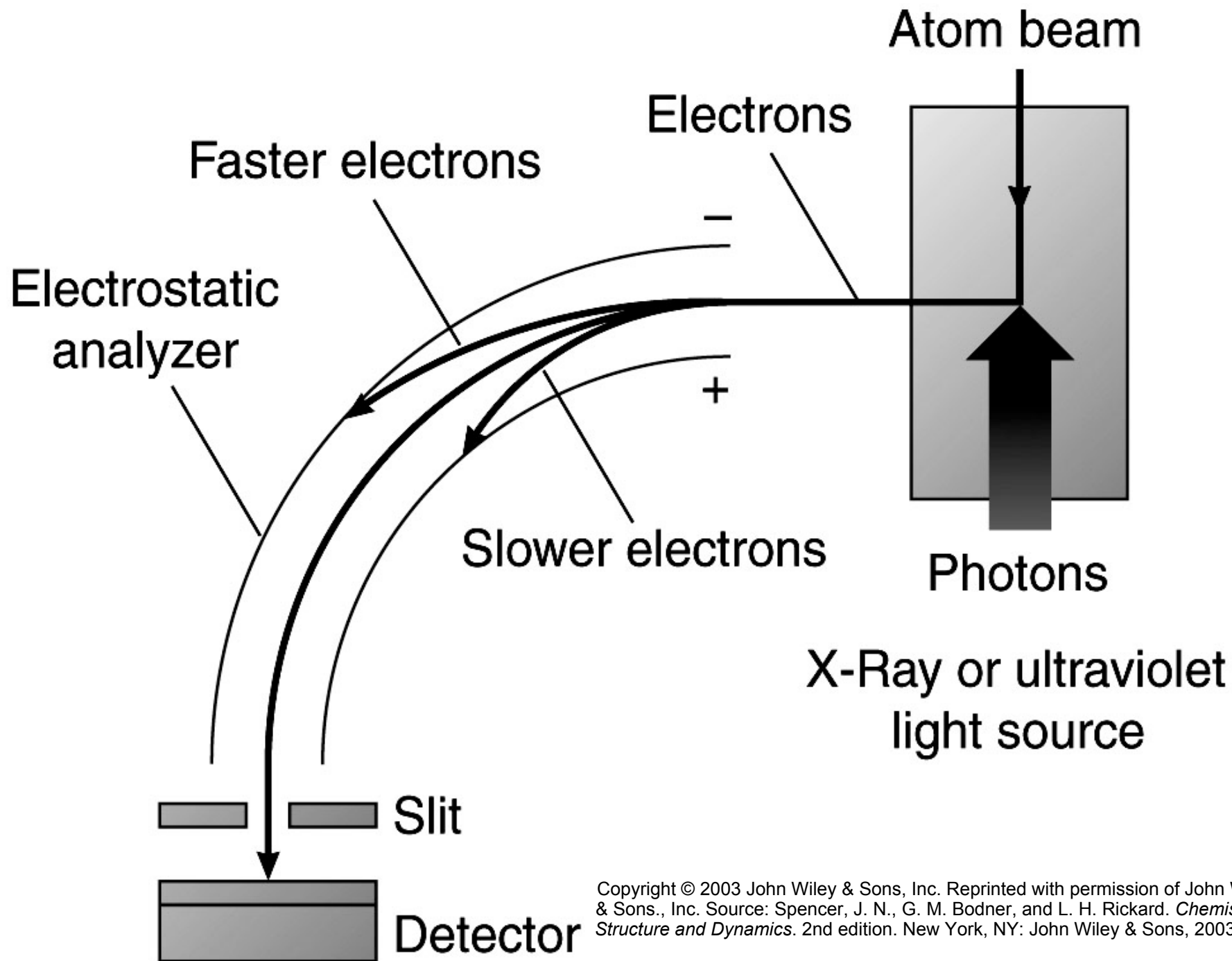


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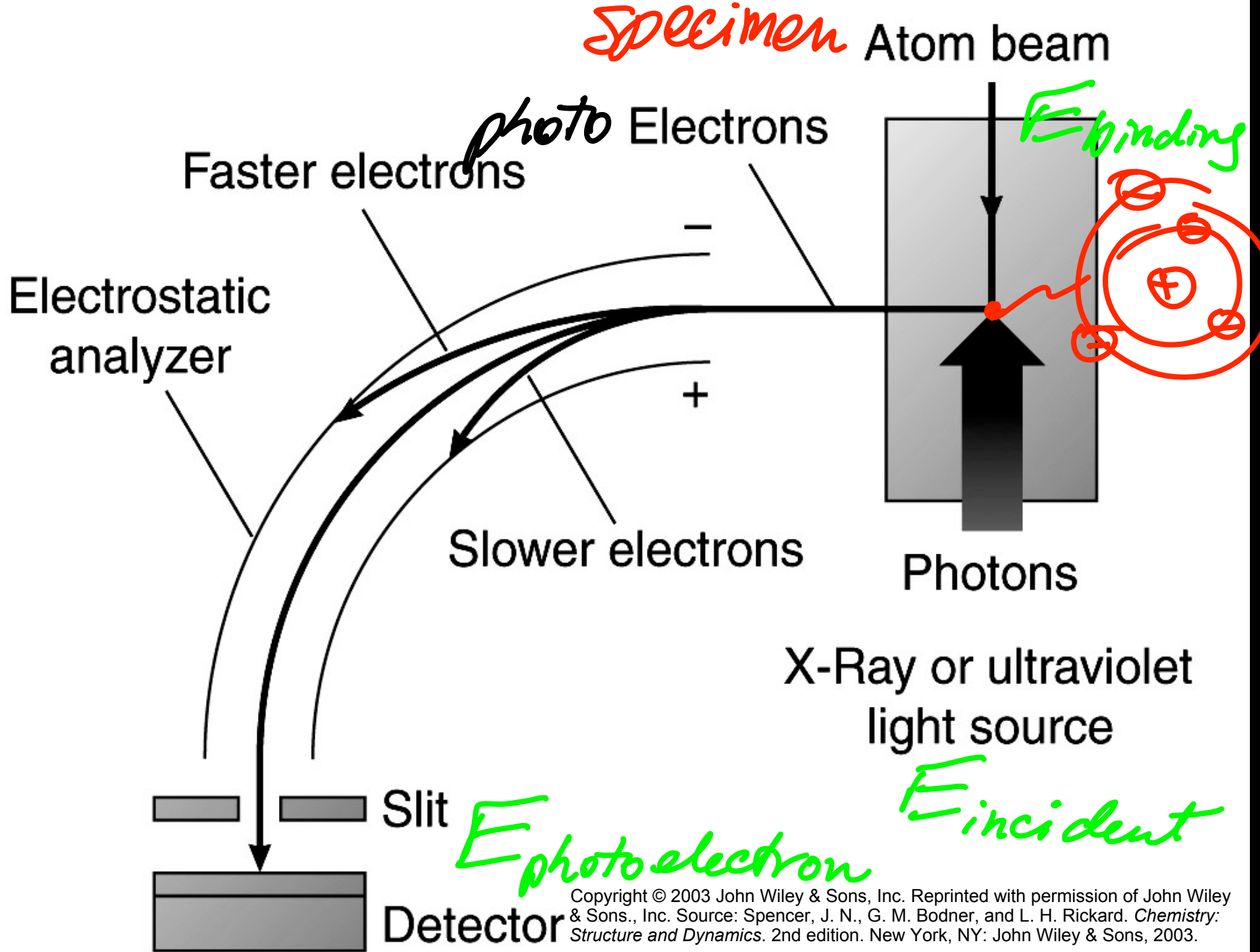




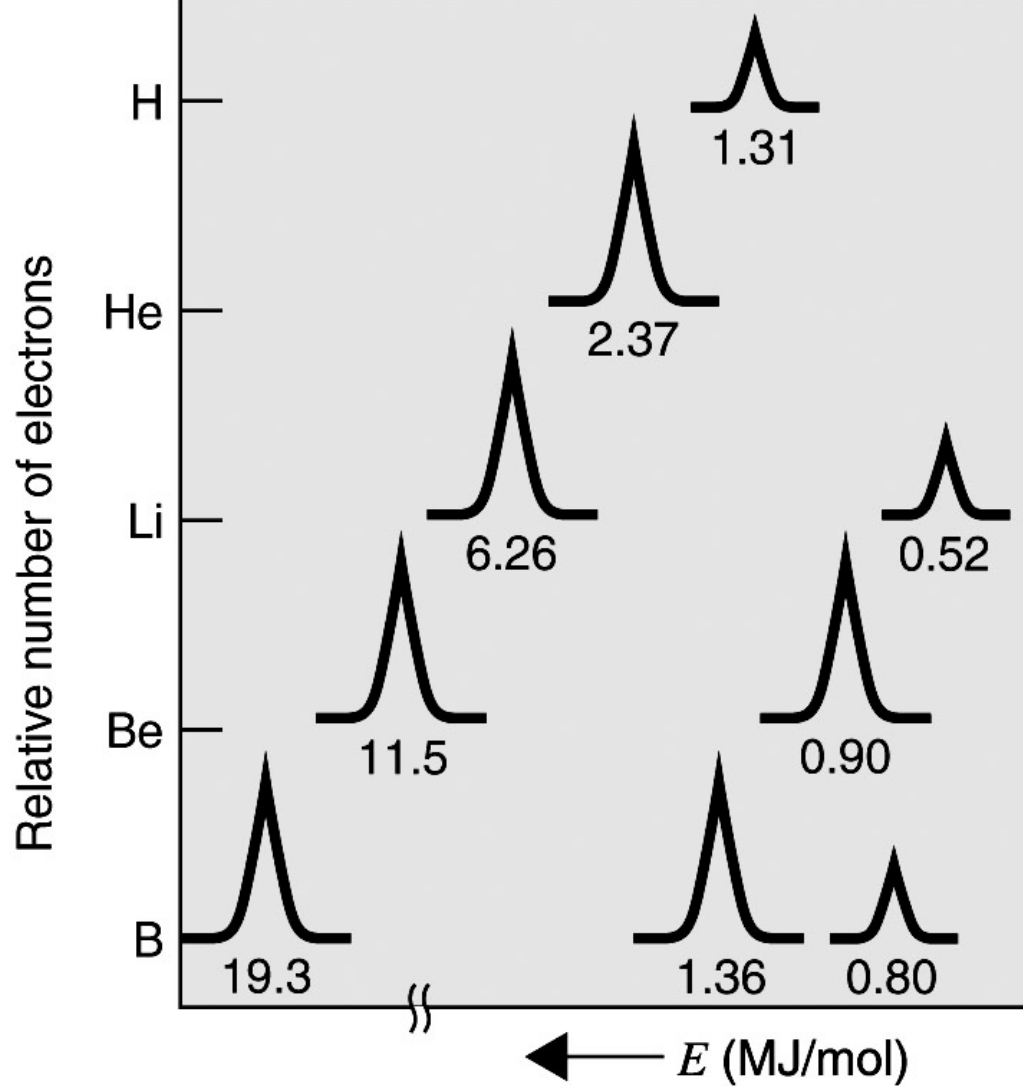
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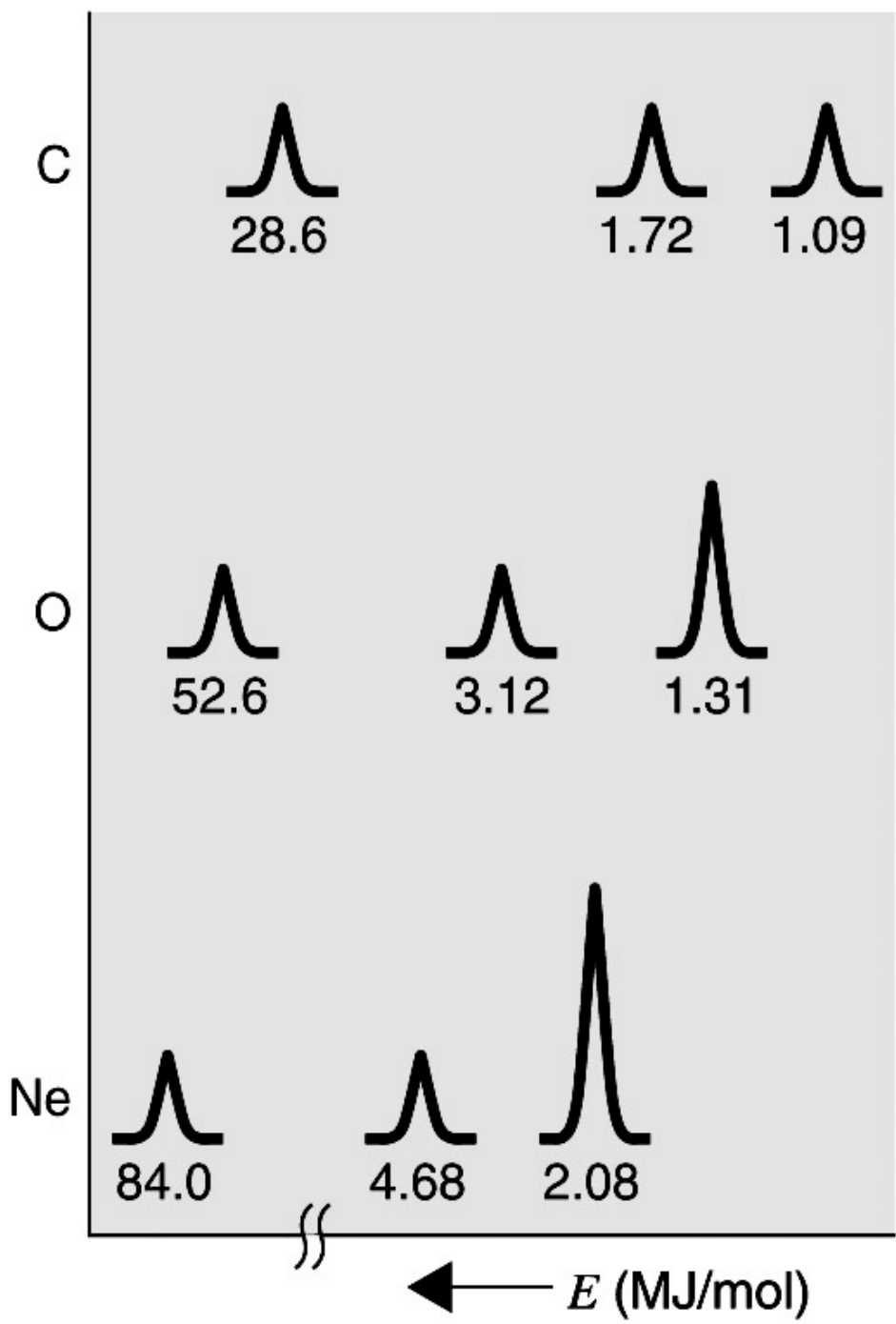


intensity
population

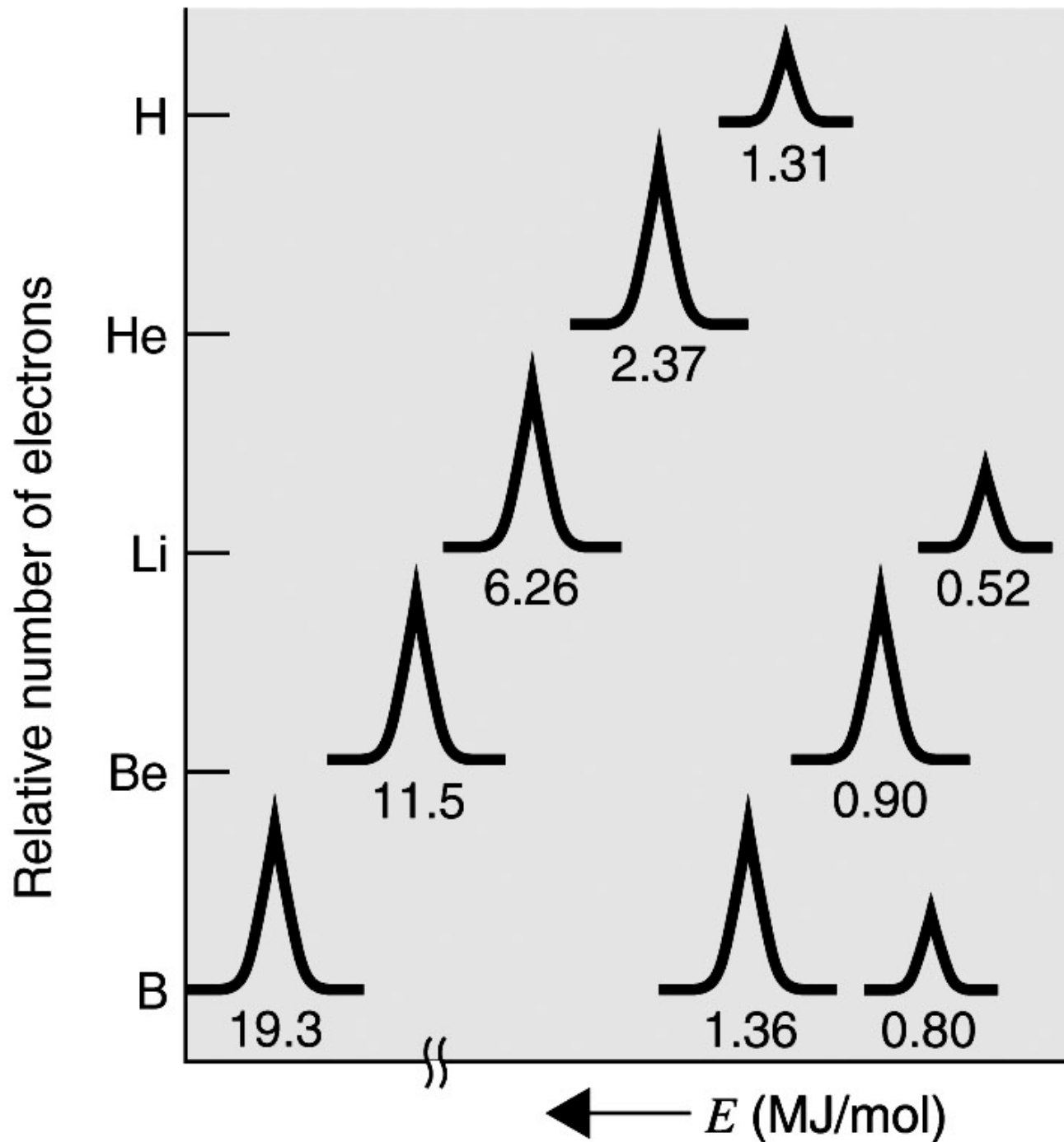


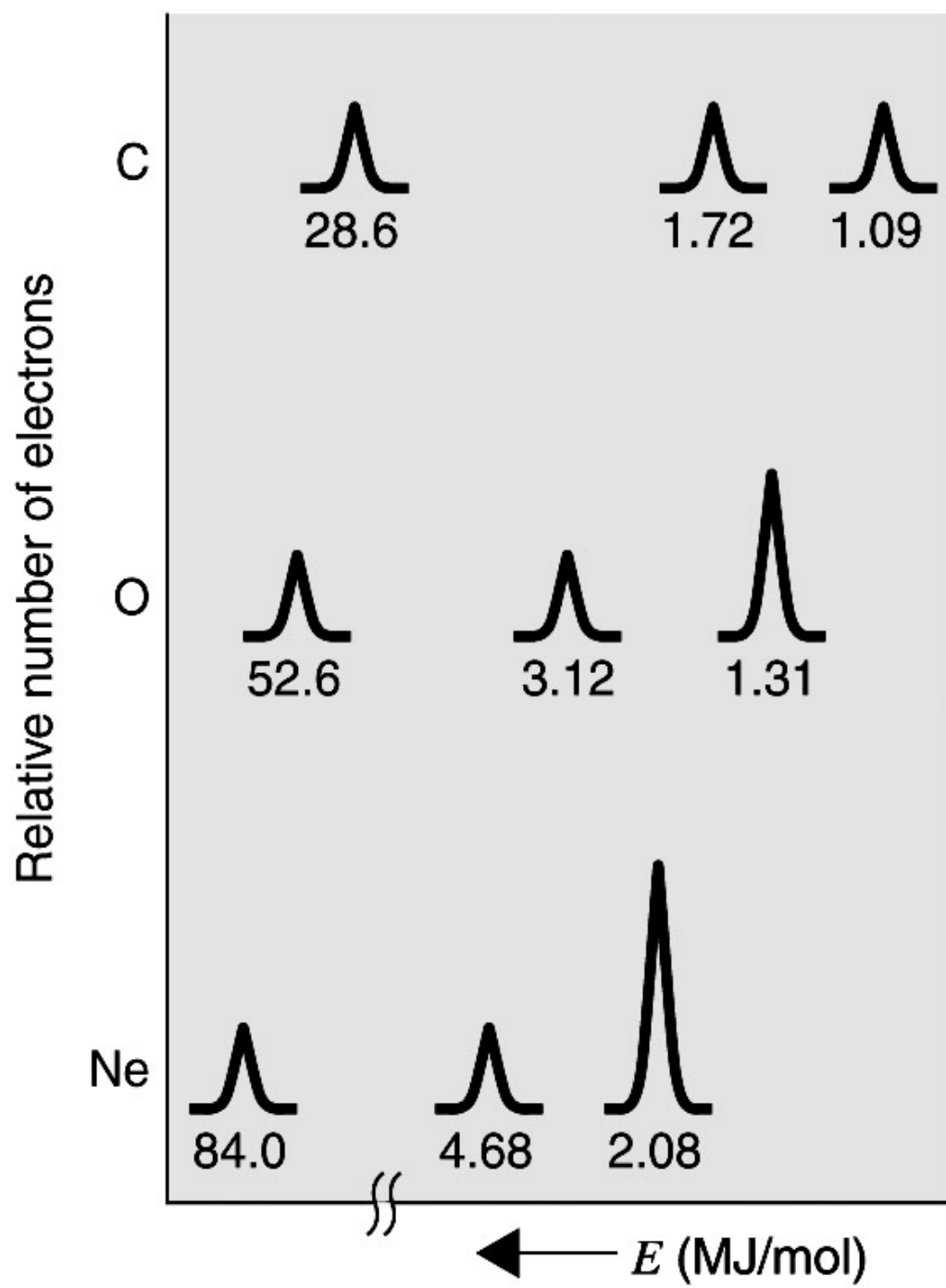
energy \Rightarrow identity
"characteristic"

Relative number of electrons

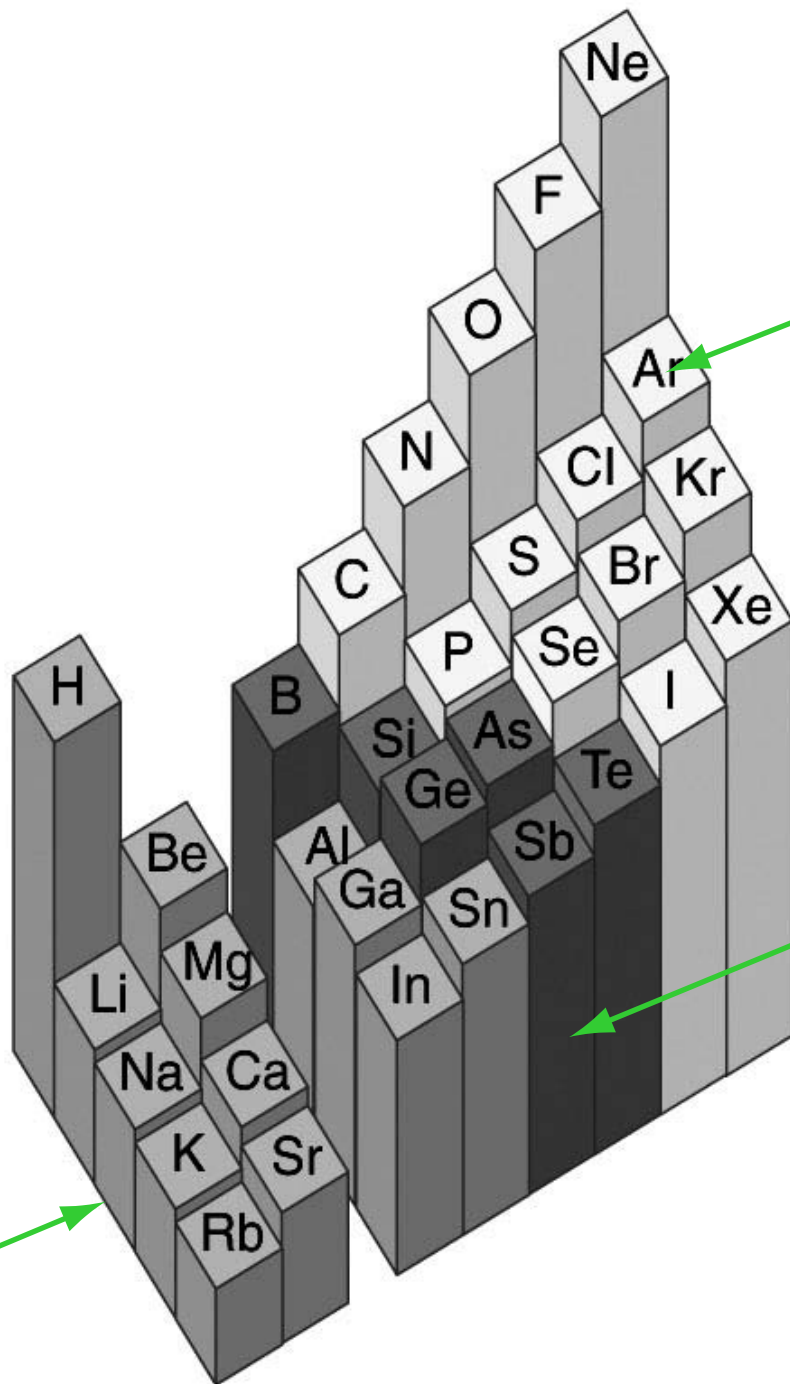


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metals
 $AVEE < 11\text{eV}$

nonmetals
 $AVEE > 13\text{eV}$

$11\text{ eV} < AVEE < 13\text{eV}$
 Semimetals

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Spontaneous Reaction

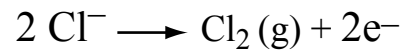
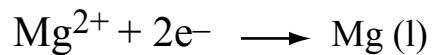
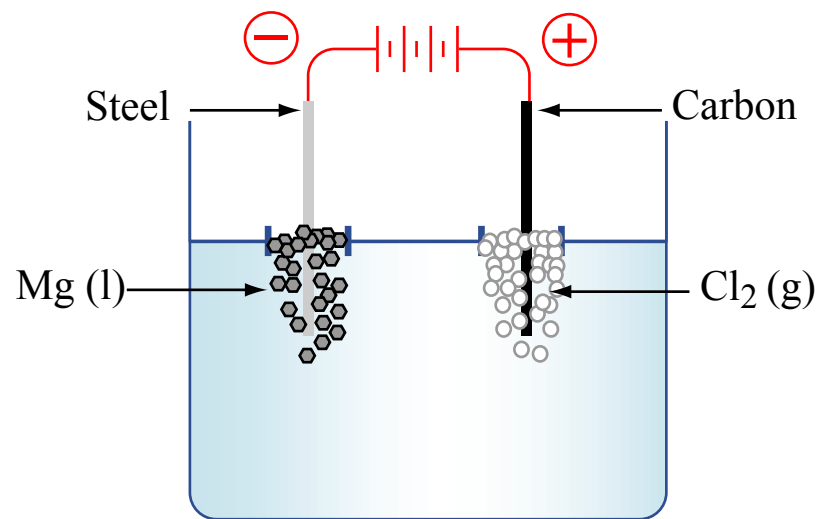
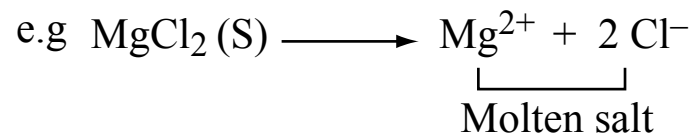
Spontaneous RXN:



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Impact of Electrolysis

Ionic Solids $\xrightarrow{\text{high T}}$ Ionic Liquids



Electrolysis undoes spontaneous e⁻ transfer of ion formation

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Mamantov, G., Mamantov, C. B., and Braunstein, J.

Advances in Molten Salt Chemistry. New York,

NY: Elsevier Science Ltd., 1987. ISBN: 9780444428226.□□

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Kipouros, Georges J. and Sadoway, Donald R.

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Production" In *Advances in Molten Salt Chemistry*.

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Fall 2009

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