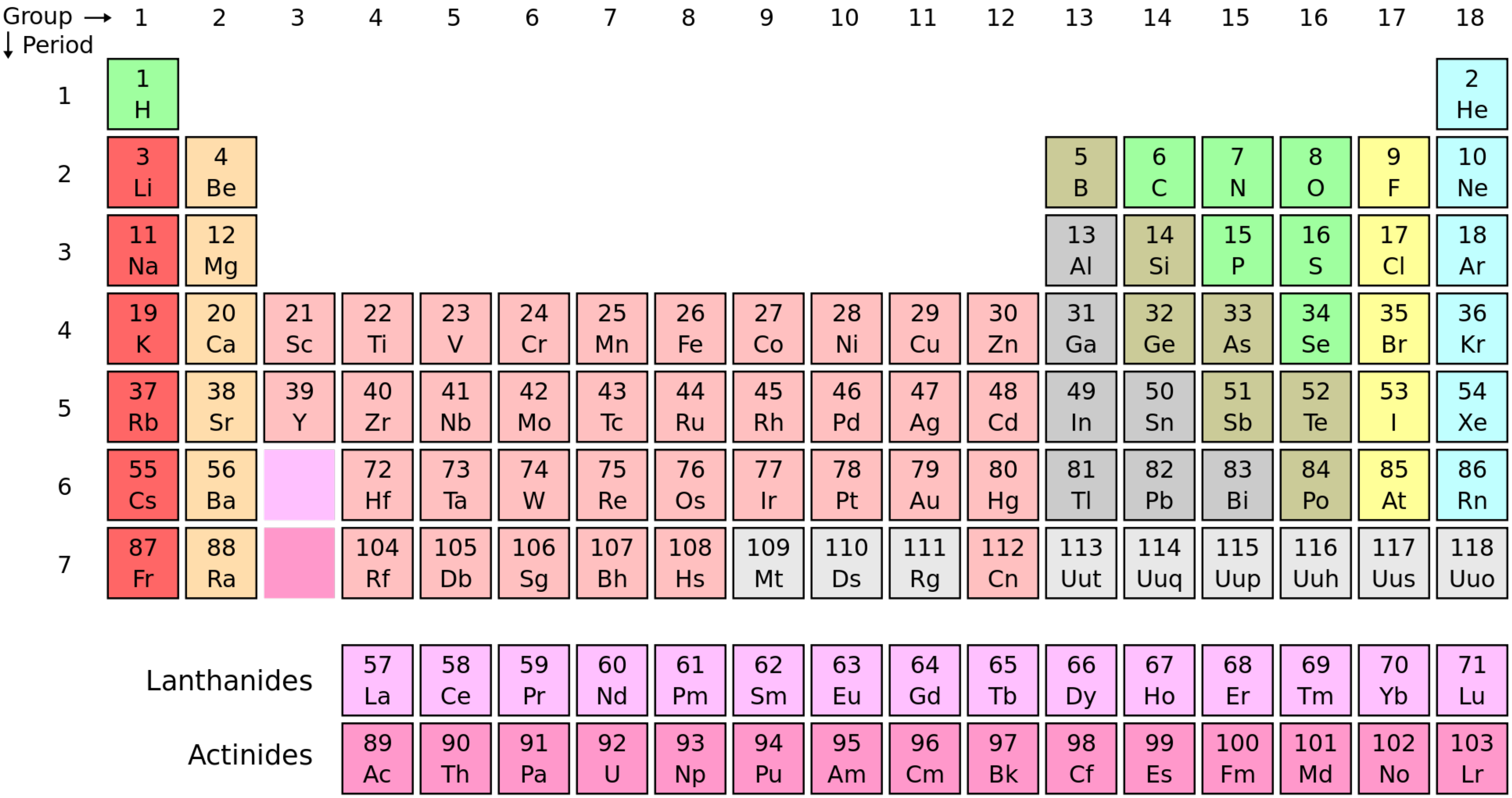


Group → ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
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	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		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	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
Lanthanides				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
Actinides				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

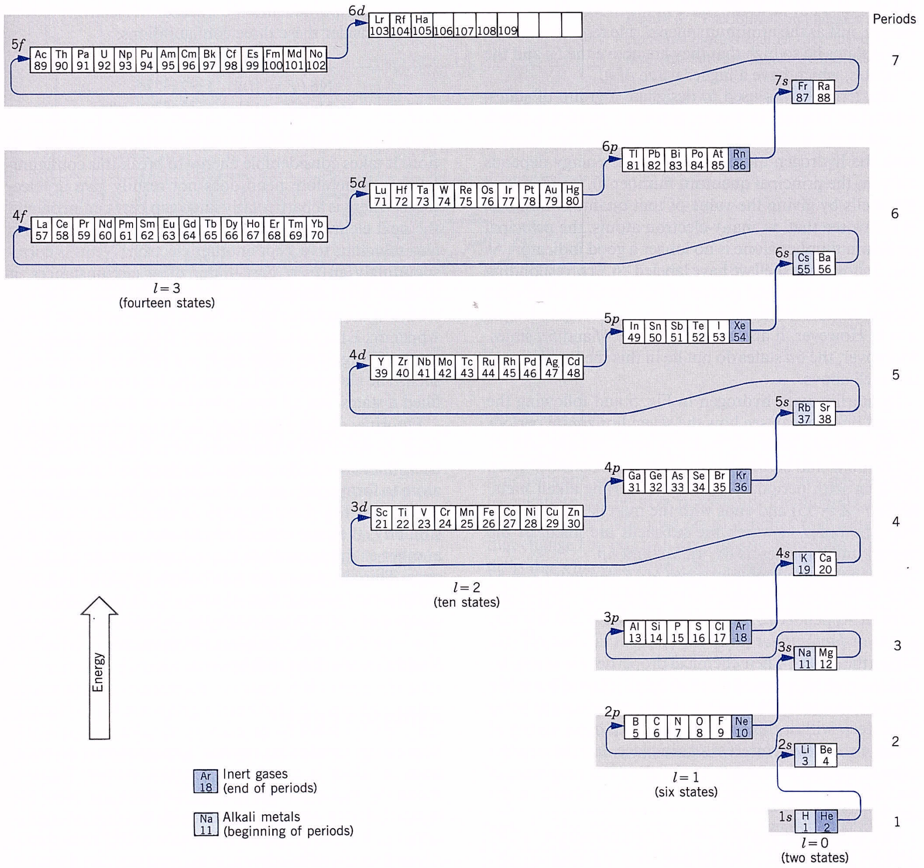


Figure 5 Starting with hydrogen at the bottom, the curved line shows the sequence of the seven horizontal periods of the periodic table. Each period starts with an alkali metal and ends with an inert gas.

in this figure. States with the same value of l have been displaced to the left for clarity and grouped into columns according to their l value.

Before we look more closely at this table, we introduce a new notation for the angular momentum quantum number l. For historical reasons* the values of l have been given letter equivalents, according to this scheme:

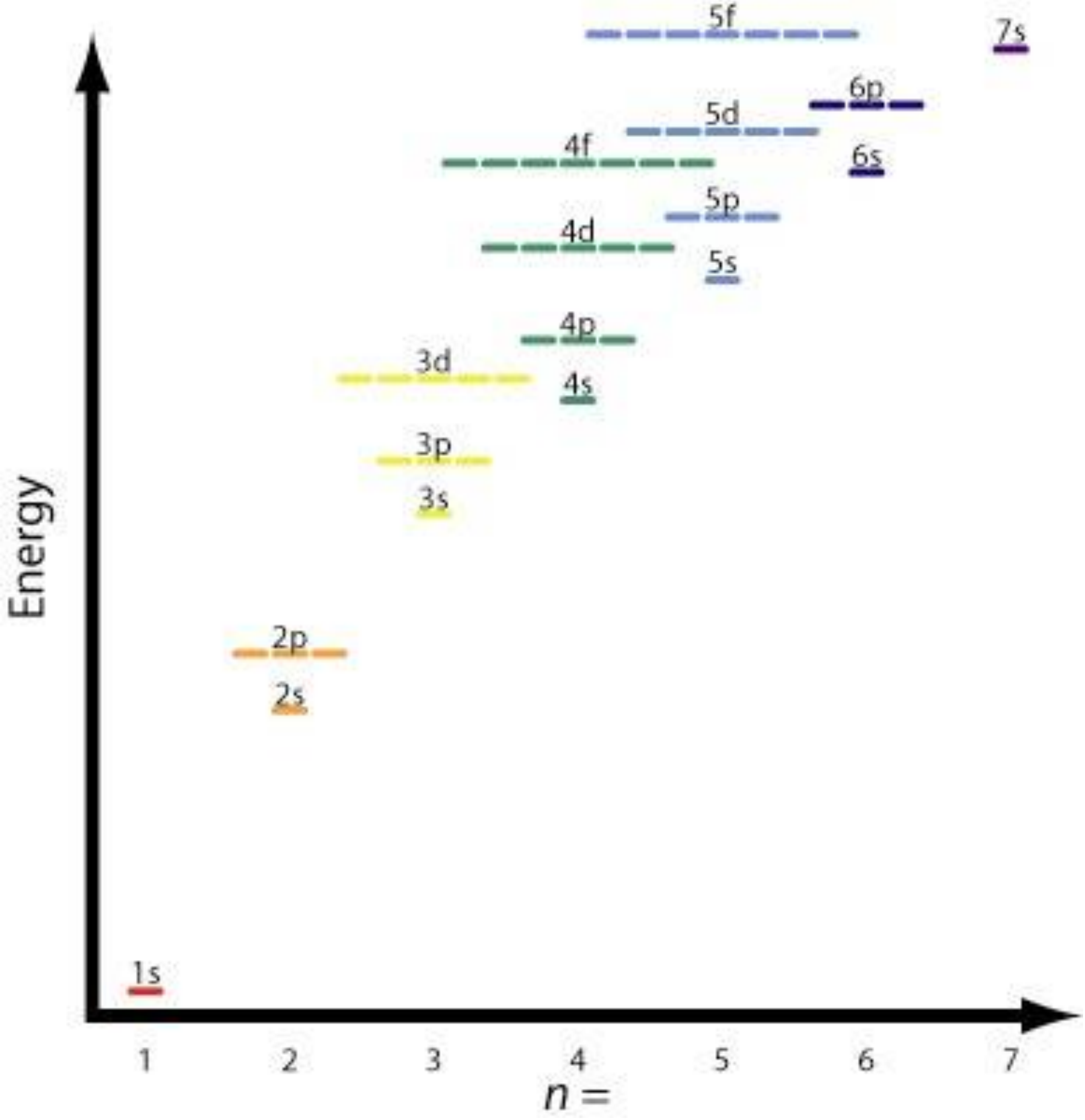
l	0	1	2	3	4	5	. . .
Symbol	s	p	d	f	g	h	. . .

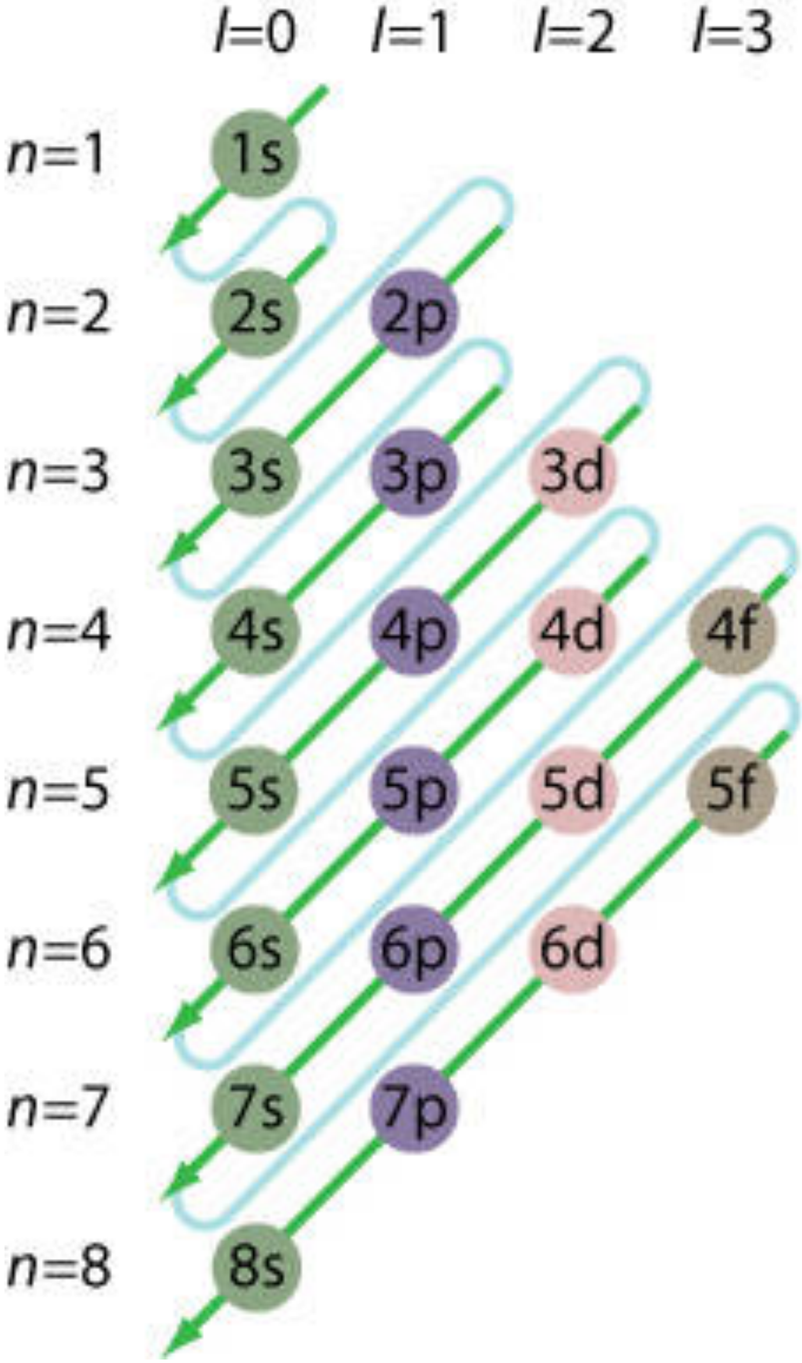
In this notation, a state with $n = 1$ and $l = 0$ is called a "1s" state. Similarly, a state with $n = 4$ and $l = 3$ is called a "4f" state, and so on. These states are also known as *subshells*.

The dependence of energy on l is a dominant feature of Fig. 5. Look, for example, at the sequence of states 4s, 4p,

---

* The letters s, p, d, f stand for *sharp, principal, diffuse,* and *fundamental,* which were early spectroscopic designations of spectral lines. Beyond f, the states are labeled in alphabetic order.


5f
7s
6p
5d
4f
6s
5p
4d
5s
4p
3d
4s
3p
3s
Energy
2p
2s
1s
1
2
3
4
5
6
7
n =



l=0
l=1
l=2
l=3
n=1
1s
n=2
2s
2p
n=3
3s
3p
3d
n=4
4s
4p
4d
4f
n=5
5s
5p
5d
5f
n=6
6s
6p
6d
n=7
7s
7p
n=8
8s

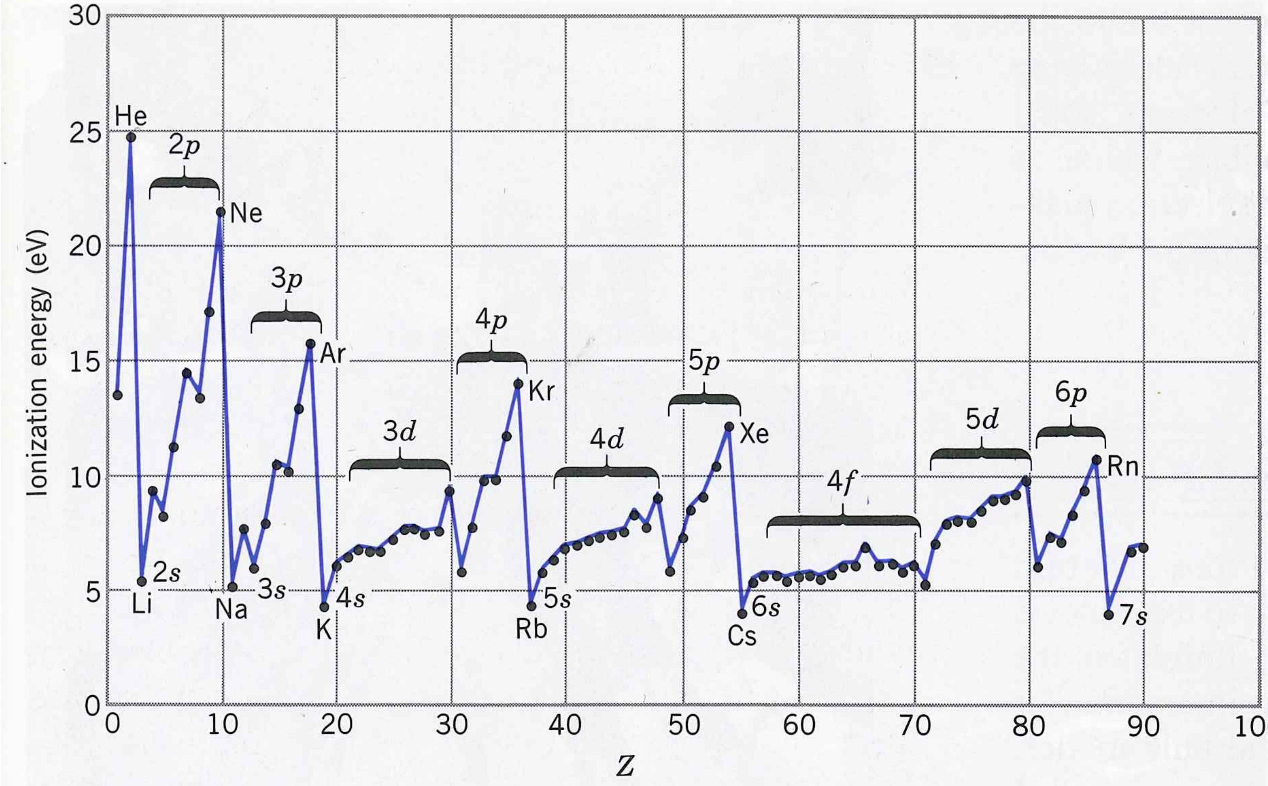
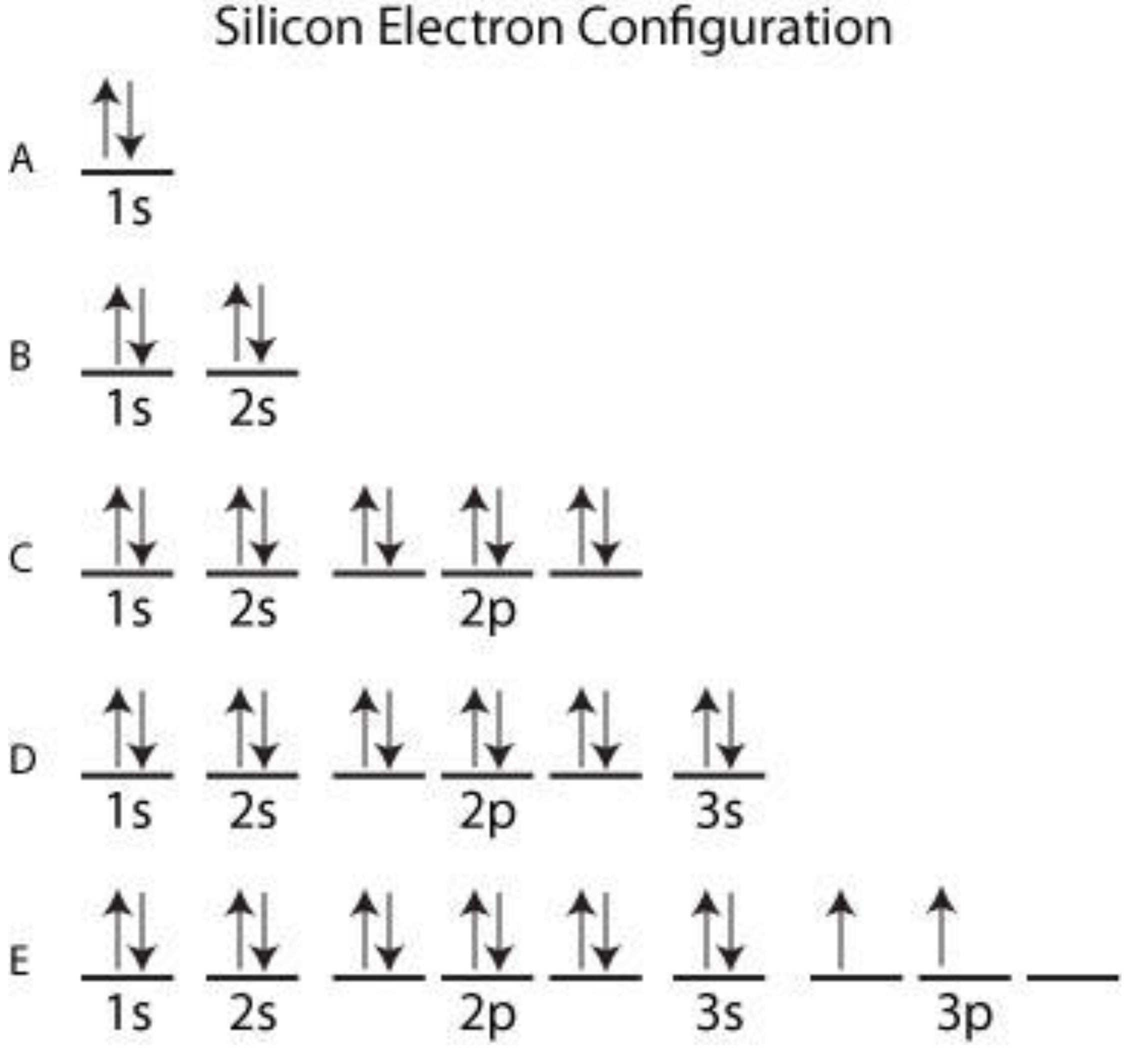


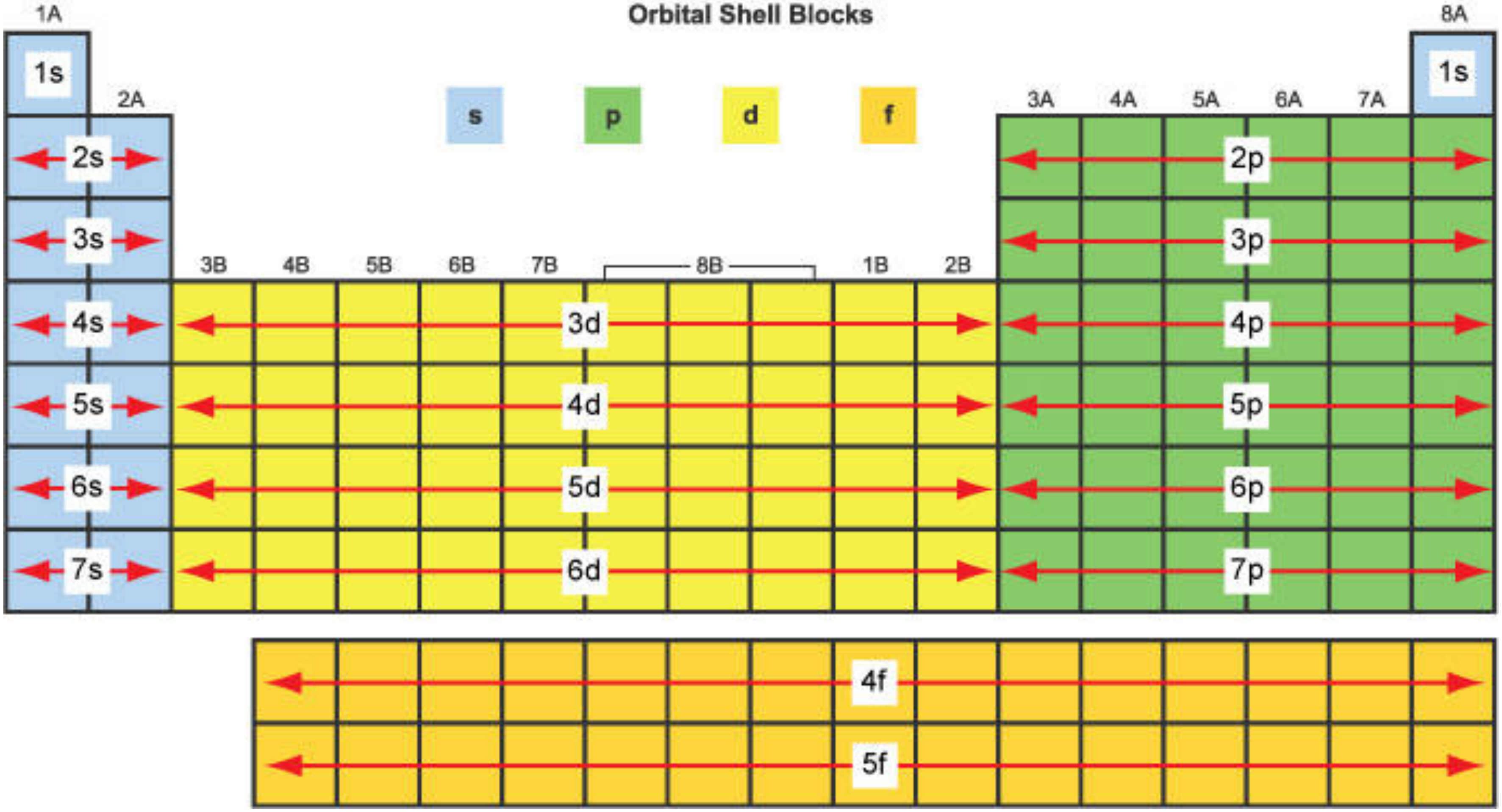
Figure 6 The ionization energies of the elements plotted against their atomic number. Subshell labels are indicated.

Hund’s Rule (He/Be/Ne/Mg/Si)

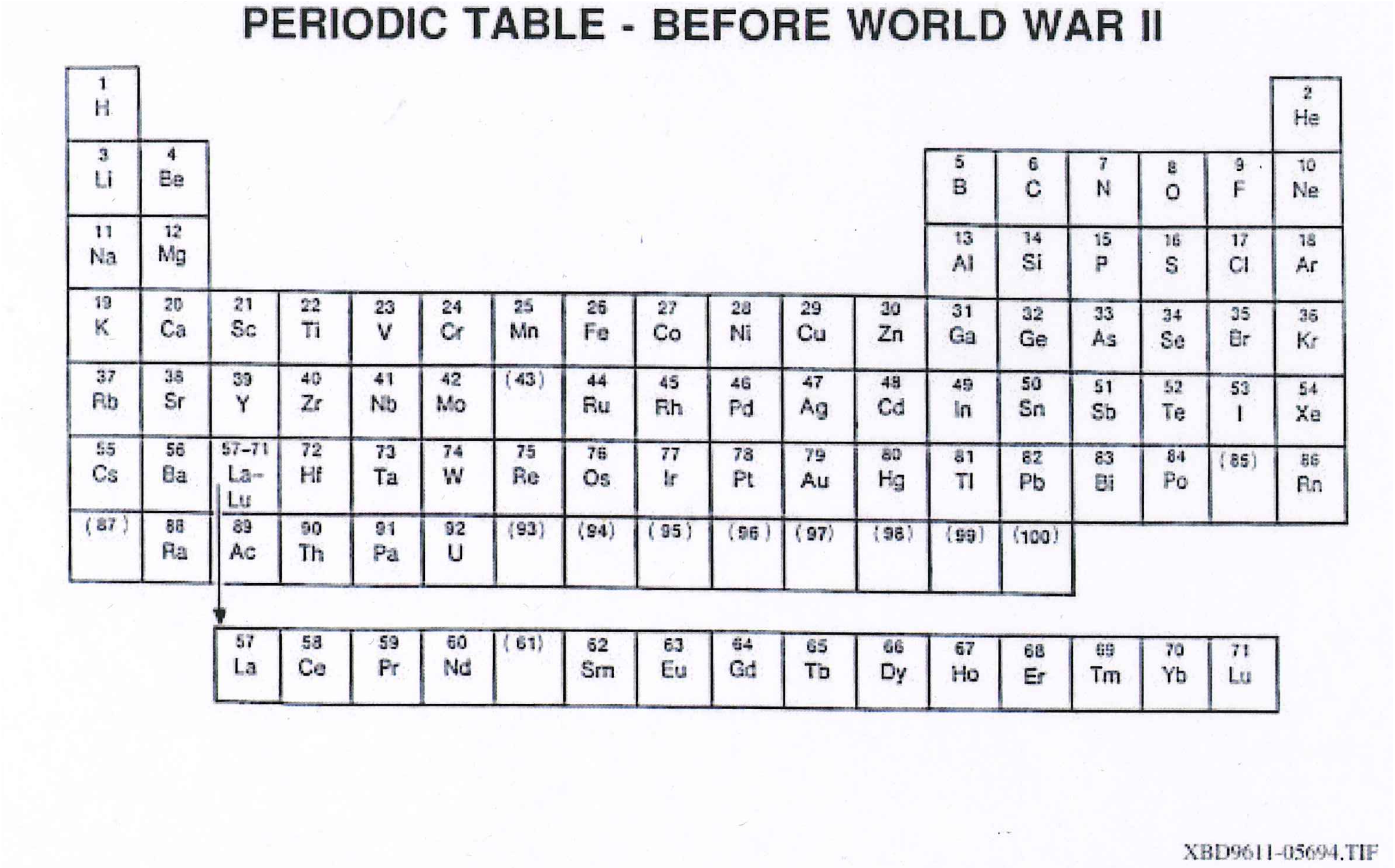


Periodic Table of the Elements

Orbital Shell Blocks



Pre-1941 Whoops!



PERIODIC TABLE - BEFORE WORLD WAR II

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
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
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	(43)	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57–71 La–Lu	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)	86 Rn
(87)	88 Ra	89 Ac	90 Th	91 Pa	92 U	(93)	(94)	(95)	(96)	(97)	(98)	(99)	(100)				

57 La	58 Ce	59 Pr	60 Nd	(61)	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu

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Figure 1: Periodic table before World War II. Fermi irradiated U with neutrons and found products which are chemically similar to Mn and Re; he thought he had found element 93. Before Meitner proposed the theory of nuclear fission, she called the speculated elements 93, 94, 95 and 96 eka-rhenium, eka-osmium, eka-iridium and eka-platinum, respectively. Segre was convinced that element 93 would be chemically similar to Re and Mn, and missed the discovery of element 93, which is actually chemically similar to U.

The Heroes of the Story

Electron shells filled in violation of Madelung's rule[21] (red)

Period 4			Period 5			Period 6			Period 7		
Element	**Z**	**Electron Configuration**	**Element**	**Z**	**Electron Configuration**	**Element**	**Z**	**Electron Configuration**	**Element**	**Z**	**Electron Configuration**
						Lanthanum	57	[Xe] $6s^2$ $5d^1$	Actinium	89	[Rn] $7s^2$ $6d^1$
						Cerium	58	[Xe] $6s^2$ $4f^1$ $5d^1$	Thorium	90	[Rn] $7s^2$ $6d^2$
						Praseodymium	59	[Xe] $6s^2$ $4f^3$	Protactinium	91	[Rn] $7s^2$ $5f^2$ $6d^1$
						Neodymium	60	[Xe] $6s^2$ $4f^4$	Uranium	92	[Rn] $7s^2$ $5f^3$ $6d^1$
						Promethium	61	[Xe] $6s^2$ $4f^5$	Neptunium	93	[Rn] $7s^2$ $5f^4$ $6d^1$
						Samarium	62	[Xe] $6s^2$ $4f^6$	Plutonium	94	[Rn] $7s^2$ $5f^6$
						Europium	63	[Xe] $6s^2$ $4f^7$	Americium	95	[Rn] $7s^2$ $5f^7$
						Gadolinium	64	[Xe] $6s^2$ $4f^7$ $5d^1$	Curium	96	[Rn] $7s^2$ $5f^7$ $6d^1$
						Terbium	65	[Xe] $6s^2$ $4f^9$	Berkelium	97	[Rn] $7s^2$ $5f^9$
Scandium	21	[Ar] $4s^2$ $3d^1$	Yttrium	39	[Kr] $5s^2$ $4d^1$	Lutetium	71	[Xe] $6s^2$ $4f^{14}$ $5d^1$	Lawrencium	103	[Rn] $7s^2$ $5f^{14}$ $7p^1$
Titanium	22	[Ar] $4s^2$ $3d^2$	Zirconium	40	[Kr] $5s^2$ $4d^2$	Hafnium	72	[Xe] $6s^2$ $4f^{14}$ $5d^2$	Rutherfordium	104	[Rn] $7s^2$ $5f^{14}$ $6d^2$
Vanadium	23	[Ar] $4s^2$ $3d^3$	Niobium	41	[Kr] $5s^1$ $4d^4$	Tantalum	73	[Xe] $6s^2$ $4f^{14}$ $5d^3$			
Chromium	24	[Ar] $4s^1$ $3d^5$	Molybdenum	42	[Kr] $5s^1$ $4d^5$	Tungsten	74	[Xe] $6s^2$ $4f^{14}$ $5d^4$			
Manganese	25	[Ar] $4s^2$ $3d^5$	Technetium	43	[Kr] $5s^2$ $4d^5$	Rhenium	75	[Xe] $6s^2$ $4f^{14}$ $5d^5$			
Iron	26	[Ar] $4s^2$ $3d^6$	Ruthenium	44	[Kr] $5s^1$ $4d^7$	Osmium	76	[Xe] $6s^2$ $4f^{14}$ $5d^6$			
Cobalt	27	[Ar] $4s^2$ $3d^7$	Rhodium	45	[Kr] $5s^1$ $4d^8$	Iridium	77	[Xe] $6s^2$ $4f^{14}$ $5d^7$			
Nickel	28	[Ar] $4s^2$ $3d^8$ or [Ar] $4s^1$ $3d^9$ (disputed)[22]	Palladium	46	[Kr] $4d^{10}$	Platinum	78	[Xe] $6s^1$ $4f^{14}$ $5d^9$			
Copper	29	[Ar] $4s^1$ $3d^{10}$	Silver	47	[Kr] $5s^1$ $4d^{10}$	Gold	79	[Xe] $6s^1$ $4f^{14}$ $5d^{10}$			
Zinc	30	[Ar] $4s^2$ $3d^{10}$	Cadmium	48	[Kr] $5s^2$ $4d^{10}$	Mercury	80	[Xe] $6s^2$ $4f^{14}$ $5d^{10}$			

The electron-shell configuration of elements beyond rutherfordium is not yet known.

P E R I O D I C T A B L E

Atomic Properties of the Elements

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

Physics Laboratory
physics.nist.gov

Standard Reference Data
www.nist.gov/srd

Frequently used fundamental physical constants

For the most accurate values of these and other constants, visit physics.nist.gov/constants

1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of ^{133}Cs

speed of light in vacuum	c	299 792 458 m s^{-1}	(exact)
Planck constant	h	6.6261 x 10^{-34} J s	($\hbar = h/2\pi$)
elementary charge	e	1.6022 x 10^{-19} C	
electron mass	m_e	9.1094 x 10^{-31} kg	
	m_ec^2	0.5110 MeV	
proton mass	m_p	1.6726 x 10^{-27} kg	
fine-structure constant	α	1/137.036	
Rydberg constant	R_∞	10 973 732 m^{-1}	
	$R_\infty c$	3.289 842 x 10^{15} Hz	
	$R_\infty hc$	13.6057 eV	
Boltzmann constant	k	1.3807 x 10^{-23} J K^{-1}	

☐ Solids
🟦 Liquids
🟪 Gases
🟨 Artificially Prepared

Period	Group 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 $^{2}S_{1/2}$ **H** Hydrogen 1.00794 $1s$ 13.5984																	2 $^{1}S_{0}$ **He** Helium 4.002602 $1s^2$ 24.5874
2	3 $^{2}S_{1/2}$ **Li** Lithium 6.941 $1s^22s$ 5.3917	4 $^{1}S_{0}$ **Be** Beryllium 9.012182 $1s^22s^2$ 9.3227											5 $^{2}P^{\circ}_{1/2}$ **B** Boron 10.811 $1s^22s^22p$ 8.2980	6 $^{3}P_{0}$ **C** Carbon 12.0107 $1s^22s^22p^2$ 11.2603	7 $^{4}S^{\circ}_{3/2}$ **N** Nitrogen 14.0067 $1s^22s^22p^3$ 14.5341	8 $^{3}P_{2}$ **O** Oxygen 15.9994 $1s^22s^22p^4$ 13.6181	9 $^{2}P^{\circ}_{3/2}$ **F** Fluorine 18.9984032 $1s^22s^22p^5$ 17.4228	10 $^{1}S_{0}$ **Ne** Neon 20.1797 $1s^22s^22p^6$ 21.5645
3	11 $^{2}S_{1/2}$ **Na** Sodium 22.98976928 [Ne]$3s$ 5.1391	12 $^{1}S_{0}$ **Mg** Magnesium 24.3050 [Ne]$3s^2$ 7.6462											13 $^{2}P^{\circ}_{1/2}$ **Al** Aluminum 26.9815386 [Ne]$3s^23p$ 5.9858	14 $^{3}P_{0}$ **Si** Silicon 28.0855 [Ne]$3s^23p^2$ 8.1517	15 $^{4}S^{\circ}_{3/2}$ **P** Phosphorus 30.973762 [Ne]$3s^23p^3$ 10.4867	16 $^{3}P_{2}$ **S** Sulfur 32.065 [Ne]$3s^23p^4$ 10.3600	17 $^{2}P^{\circ}_{3/2}$ **Cl** Chlorine 35.453 [Ne]$3s^23p^5$ 12.9676	18 $^{1}S_{0}$ **Ar** Argon 39.948 [Ne]$3s^23p^6$ 15.7596
4	19 $^{2}S_{1/2}$ **K** Potassium 39.0983 [Ar]$4s$ 4.3407	20 $^{1}S_{0}$ **Ca** Calcium 40.078 [Ar]$4s^2$ 6.1132	21 $^{2}D_{3/2}$ **Sc** Scandium 44.955912 [Ar]$3d4s^2$ 6.5615	22 $^{3}F_{2}$ **Ti** Titanium 47.867 [Ar]$3d^24s^2$ 6.8281	23 $^{4}F_{3/2}$ **V** Vanadium 50.9415 [Ar]$3d^34s^2$ 6.7462	24 $^{7}S_{3}$ **Cr** Chromium 51.9961 [Ar]$3d^54s$ 6.7665	25 $^{6}S_{5/2}$ **Mn** Manganese 54.938045 [Ar]$3d^54s^2$ 7.4340	26 $^{5}D_{4}$ **Fe** Iron 55.845 [Ar]$3d^64s^2$ 7.9024	27 $^{4}F_{9/2}$ **Co** Cobalt 58.933195 [Ar]$3d^74s^2$ 7.8810	28 $^{3}F_{4}$ **Ni** Nickel 58.6934 [Ar]$3d^84s^2$ 7.6399	29 $^{2}S_{1/2}$ **Cu** Copper 63.546 [Ar]$3d^{10}4s$ 7.7264	30 $^{1}S_{0}$ **Zn** Zinc 65.38 [Ar]$3d^{10}4s^2$ 9.3942	31 $^{2}P^{\circ}_{1/2}$ **Ga** Gallium 69.723 [Ar]$3d^{10}4s^24p$ 5.9993	32 $^{3}P_{0}$ **Ge** Germanium 72.64 [Ar]$3d^{10}4s^24p^2$ 7.8994	33 $^{4}S^{\circ}_{3/2}$ **As** Arsenic 74.92160 [Ar]$3d^{10}4s^24p^3$ 9.7886	34 $^{3}P_{2}$ **Se** Selenium 78.96 [Ar]$3d^{10}4s^24p^4$ 9.7524	35 $^{2}P^{\circ}_{3/2}$ **Br** Bromine 79.904 [Ar]$3d^{10}4s^24p^5$ 11.8138	36 $^{1}S_{0}$ **Kr** Krypton 83.798 [Ar]$3d^{10}4s^24p^6$ 13.9996
5	37 $^{2}S_{1/2}$ **Rb** Rubidium 85.4678 [Kr]$5s$ 4.1771	38 $^{1}S_{0}$ **Sr** Strontium 87.62 [Kr]$5s^2$ 5.6949	39 $^{2}D_{3/2}$ **Y** Yttrium 88.90585 [Kr]$4d5s^2$ 6.2173	40 $^{3}F_{2}$ **Zr** Zirconium 91.224 [Kr]$4d^25s^2$ 6.6339	41 $^{6}D_{1/2}$ **Nb** Niobium 92.90638 [Kr]$4d^45s$ 6.7589	42 $^{7}S_{3}$ **Mo** Molybdenum 95.96 [Kr]$4d^55s$ 7.0924	43 $^{6}S_{5/2}$ **Tc** Technetium (98) [Kr]$4d^55s^2$ 7.28	44 $^{5}F_{5}$ **Ru** Ruthenium 101.07 [Kr]$4d^75s$ 7.3605	45 $^{4}F_{9/2}$ **Rh** Rhodium 102.90550 [Kr]$4d^85s$ 7.4589	46 $^{1}S_{0}$ **Pd** Palladium 106.42 [Kr]$4d^{10}$ 8.3369	47 $^{2}S_{1/2}$ **Ag** Silver 107.8682 [Kr]$4d^{10}5s$ 7.5762	48 $^{1}S_{0}$ **Cd** Cadmium 112.411 [Kr]$4d^{10}5s^2$ 8.9938	49 $^{2}P^{\circ}_{1/2}$ **In** Indium 114.818 [Kr]$4d^{10}5s^25p$ 5.7864	50 $^{3}P_{0}$ **Sn** Tin 118.710 [Kr]$4d^{10}5s^25p^2$ 7.3439	51 $^{4}S^{\circ}_{3/2}$ **Sb** Antimony 121.760 [Kr]$4d^{10}5s^25p^3$ 8.6084	52 $^{3}P_{2}$ **Te** Tellurium 127.60 [Kr]$4d^{10}5s^25p^4$ 9.0096	53 $^{2}P^{\circ}_{3/2}$ **I** Iodine 126.90447 [Kr]$4d^{10}5s^25p^5$ 10.4513	54 $^{1}S_{0}$ **Xe** Xenon 131.293 [Kr]$4d^{10}5s^25p^6$ 12.1298
6	55 $^{2}S_{1/2}$ **Cs** Cesium 132.9054519 [Xe]$6s$ 3.8939	56 $^{1}S_{0}$ **Ba** Barium 137.327 [Xe]$6s^2$ 5.2117		72 $^{3}F_{2}$ **Hf** Hafnium 178.49 [Xe]$4f^{14}5d^26s^2$ 6.8251	73 $^{4}F_{3/2}$ **Ta** Tantalum 180.94788 [Xe]$4f^{14}5d^36s^2$ 7.5496	74 $^{5}D_{0}$ **W** Tungsten 183.84 [Xe]$4f^{14}5d^46s^2$ 7.8640	75 $^{6}S_{5/2}$ **Re** Rhenium 186.207 [Xe]$4f^{14}5d^56s^2$ 7.8335	76 $^{5}D_{4}$ **Os** Osmium 190.23 [Xe]$4f^{14}5d^66s^2$ 8.4382	77 $^{4}F_{9/2}$ **Ir** Iridium 192.217 [Xe]$4f^{14}5d^76s^2$ 8.9670	78 $^{3}D_{3}$ **Pt** Platinum 195.084 [Xe]$4f^{14}5d^96s$ 8.9588	79 $^{2}S_{1/2}$ **Au** Gold 196.966569 [Xe]$4f^{14}5d^{10}6s$ 9.2255	80 $^{1}S_{0}$ **Hg** Mercury 200.59 [Xe]$4f^{14}5d^{10}6s^2$ 10.4375	81 $^{2}P^{\circ}_{1/2}$ **Tl** Thallium 204.3833 [Hg]$6p$ 6.1082	82 $^{3}P_{0}$ **Pb** Lead 207.2 [Hg]$6p^2$ 7.4167	83 $^{4}S^{\circ}_{3/2}$ **Bi** Bismuth 208.98040 [Hg]$6p^3$ 7.2855	84 $^{3}P_{2}$ **Po** Polonium (209) [Hg]$6p^4$ 8.414	85 $^{2}P^{\circ}_{3/2}$ **At** Astatine (210) [Hg]$6p^5$	86 $^{1}S_{0}$ **Rn** Radon (222) [Hg]$6p^6$ 10.7485
7	87 $^{2}S_{1/2}$ **Fr** Francium (223) [Rn]$7s$ 4.0727	88 $^{1}S_{0}$ **Ra** Radium (226) [Rn]$7s^2$ 5.2784		104 $^{3}F_{2}$? **Rf** Rutherfordium (265) [Rn]$5f^{14}6d^27s^2$? 6.0?	105 **Db** Dubnium (268)	106 **Sg** Seaborgium (271)	107 **Bh** Bohrium (272)	108 **Hs** Hassium (277)	109 **Mt** Meitnerium (276)	110 **Ds** Darmstadtium (281)	111 **Rg** Roentgenium (280)	112 **Cn** Copernicium (285)	113 **Uut** Ununtrium (284)	114 **Uuq** Ununquadium (289)	115 **Uup** Ununpentium (288)	116 **Uuh** Ununhexium (293)	117 **Uus** Ununseptium (294)	118 **Uuo** Ununoctium (294)

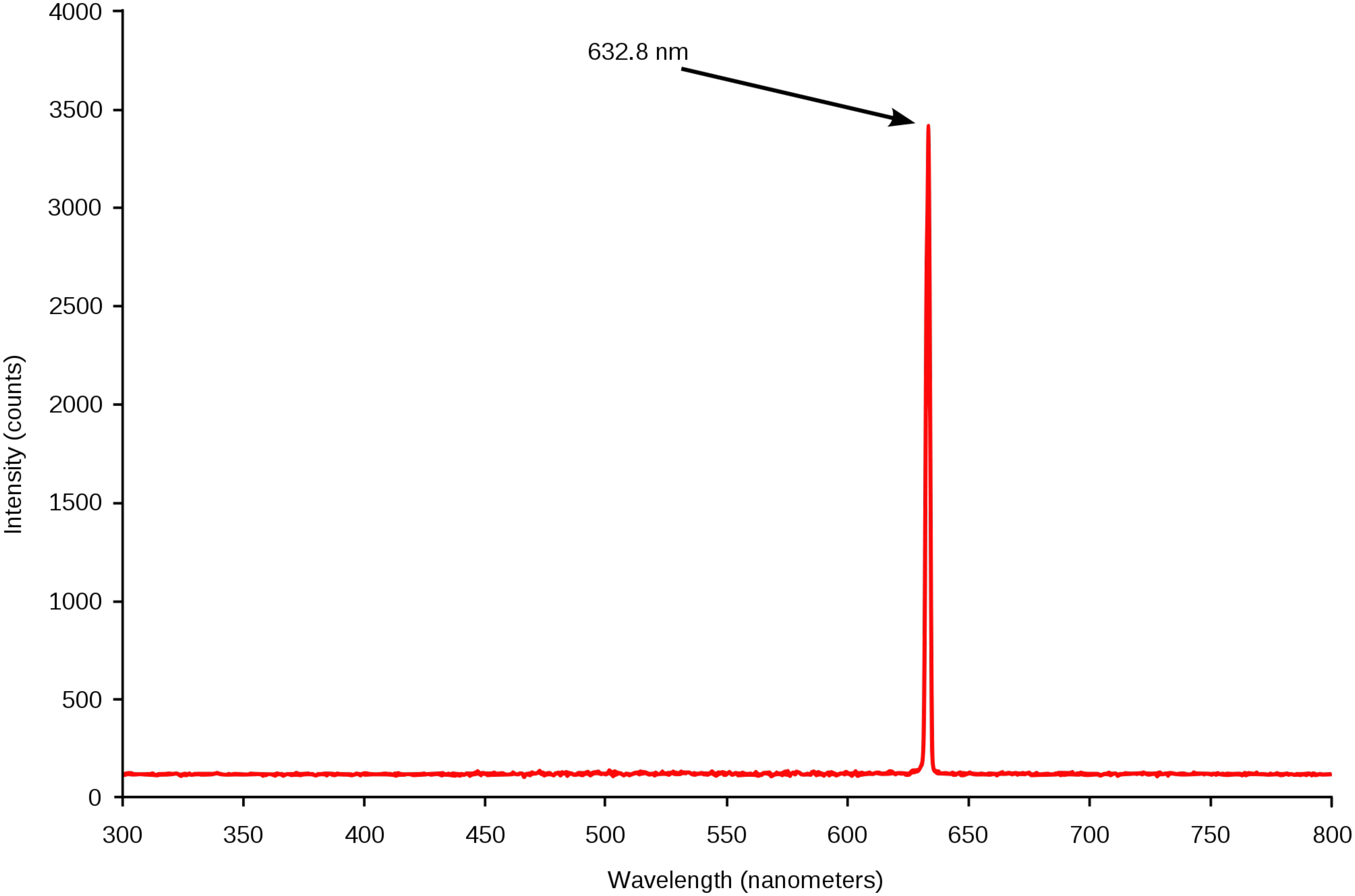
Lanthanides	57 $^{2}D_{3/2}$ **La** Lanthanum 138.90547 [Xe]$5d6s^2$ 5.5769	58 $^{1}G^{\circ}_{4}$ **Ce** Cerium 140.116 [Xe]$4f5d6s^2$ 5.5387	59 $^{4}I^{\circ}_{9/2}$ **Pr** Praseodymium 140.90765 [Xe]$4f^36s^2$ 5.473	60 $^{5}I_{4}$ **Nd** Neodymium 144.242 [Xe]$4f^46s^2$ 5.5250	61 $^{6}H^{\circ}_{5/2}$ **Pm** Promethium (145) [Xe]$4f^56s^2$ 5.582	62 $^{7}F_{0}$ **Sm** Samarium 150.36 [Xe]$4f^66s^2$ 5.6437	63 $^{8}S^{\circ}_{7/2}$ **Eu** Europium 151.964 [Xe]$4f^76s^2$ 5.6704	64 $^{9}D^{\circ}_{2}$ **Gd** Gadolinium 157.25 [Xe]$4f^75d6s^2$ 6.1498	65 $^{6}H^{\circ}_{15/2}$ **Tb** Terbium 158.92535 [Xe]$4f^96s^2$ 5.8638	66 $^{5}I_{8}$ **Dy** Dysprosium 162.500 [Xe]$4f^{10}6s^2$ 5.9389	67 $^{4}I^{\circ}_{15/2}$ **Ho** Holmium 164.93032 [Xe]$4f^{11}6s^2$ 6.0215	68 $^{3}H_{6}$ **Er** Erbium 167.259 [Xe]$4f^{12}6s^2$ 6.1077	69 $^{2}F^{\circ}_{7/2}$ **Tm** Thulium 168.93421 [Xe]$4f^{13}6s^2$ 6.1843	70 $^{1}S_{0}$ **Yb** Ytterbium 173.054 [Xe]$4f^{14}6s^2$ 6.2542	71 $^{2}D_{3/2}$ **Lu** Lutetium 174.9668 [Xe]$4f^{14}5d6s^2$ 5.4259
Actinides	89 $^{2}D_{3/2}$ **Ac** Actinium (227) [Rn]$6d7s^2$ 5.3807	90 $^{3}F_{2}$ **Th** Thorium 232.03806 [Rn]$6d^27s^2$ 6.3067	91 $^{4}K_{11/2}$ **Pa** Protactinium 231.03588 [Rn]$5f^26d7s^2$ 5.89	92 $^{5}L^{\circ}_{6}$ **U** Uranium 238.02891 [Rn]$5f^36d7s^2$ 6.1939	93 $^{6}L_{11/2}$ **Np** Neptunium (237) [Rn]$5f^46d7s^2$ 6.2657	94 $^{7}F_{0}$ **Pu** Plutonium (244) [Rn]$5f^67s^2$ 6.0260	95 $^{8}S^{\circ}_{7/2}$ **Am** Americium (243) [Rn]$5f^77s^2$ 5.9738	96 $^{9}D^{\circ}_{2}$ **Cm** Curium (247) [Rn]$5f^76d7s^2$ 5.9914	97 $^{6}H^{\circ}_{15/2}$ **Bk** Berkelium (247) [Rn]$5f^97s^2$ 6.1979	98 $^{5}I_{8}$ **Cf** Californium (251) [Rn]$5f^{10}7s^2$ 6.2817	99 $^{4}I^{\circ}_{15/2}$ **Es** Einsteinium (252) [Rn]$5f^{11}7s^2$ 6.3676	100 $^{3}H_{6}$ **Fm** Fermium (257) [Rn]$5f^{12}7s^2$ 6.50	101 $^{2}F^{\circ}_{7/2}$ **Md** Mendelevium (258) [Rn]$5f^{13}7s^2$ 6.58	102 $^{1}S_{0}$ **No** Nobelium (259) [Rn]$5f^{14}7s^2$ 6.65	103 $^{2}P^{\circ}_{1/2}$? **Lr** Lawrencium (262) [Rn]$5f^{14}7s^27p$? 4.9 ?

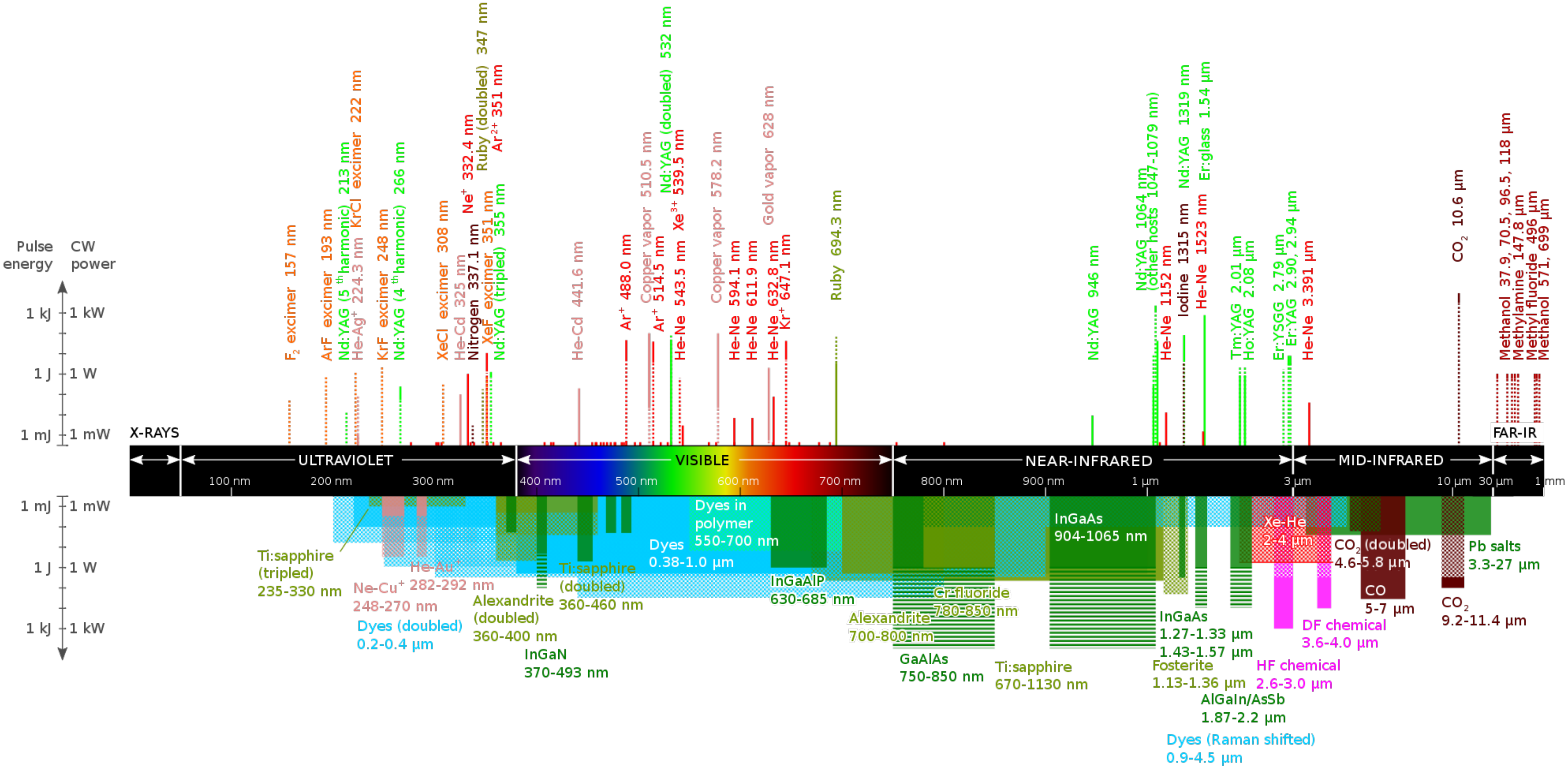
Atomic Number	58
Ground-state Level	$^{1}G^{\circ}_{4}$
Symbol	**Ce**
Name	Cerium
Atomic Weight†	140.116
Ground-state Configuration	[Xe]$4f5d6s^2$
Ionization Energy (eV)	5.5387

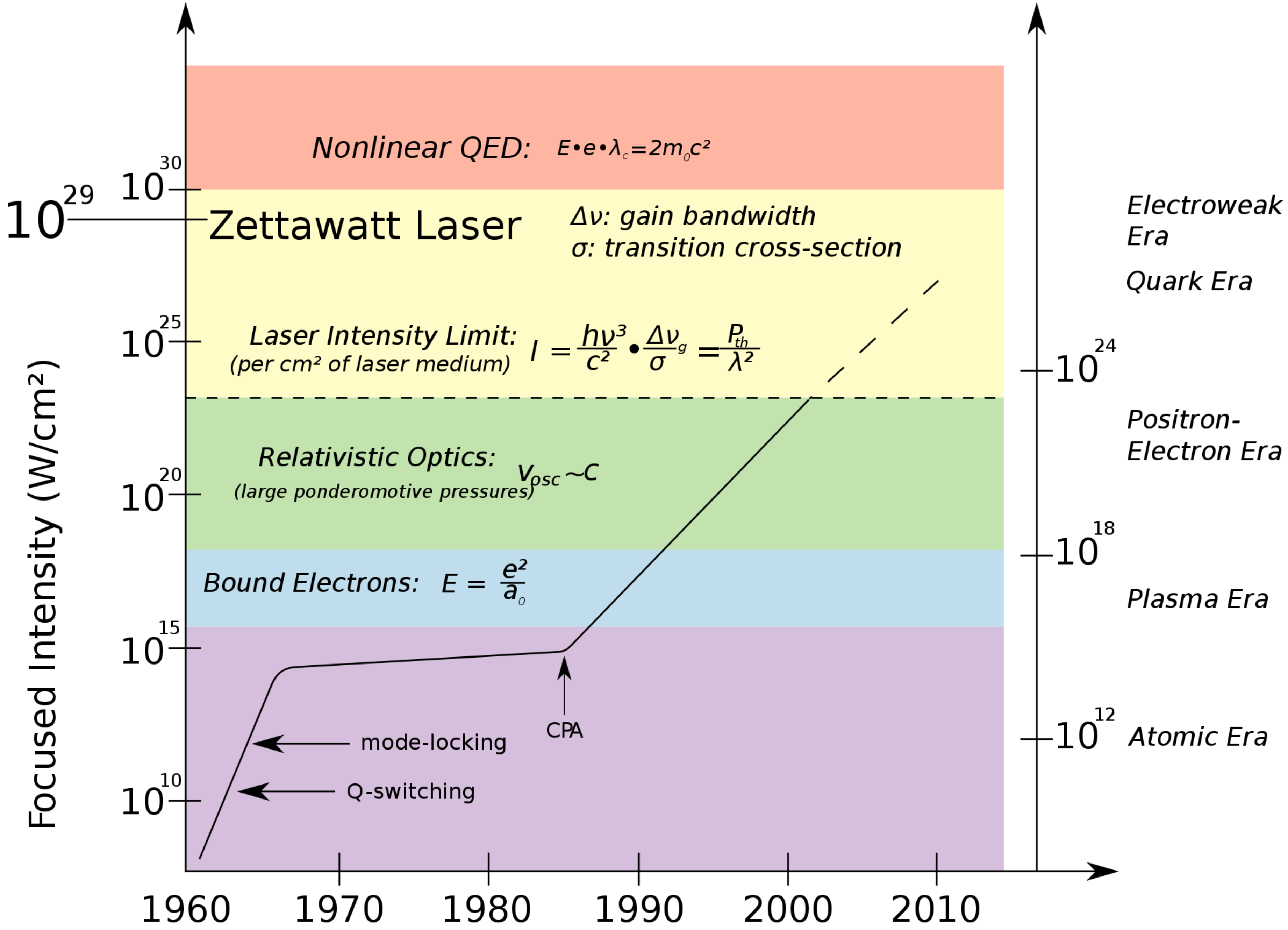
†Based upon ^{12}C. () indicates the mass number of the longest-lived isotope.

For a description of the data, visit physics.nist.gov/data

NIST SP 966 (September 2010)


632.8 nm
Intensity (counts)
4000
3500
3000
2500
2000
1500
1000
500
0
300
350
400
450
500
550
600
650
700
750
800
Wavelength (nanometers)


Pulse energy
CW power
1 kJ
1 kW
1 J
1 W
1 mJ
1 mW
X-RAYS
ULTRAVIOLET
VISIBLE
NEAR-INFRARED
MID-INFRARED
FAR-IR
100 nm
200 nm
300 nm
400 nm
500 nm
600 nm
700 nm
800 nm
900 nm
1 µm
3 µm
10 µm
30 µm
1 mm
F_2 excimer 157 nm
ArF excimer 193 nm
Nd:YAG (5th harmonic) 213 nm
$He-Ag^+$ 224.3 nm
KrCl excimer 222 nm
KrF excimer 248 nm
Nd:YAG (4th harmonic) 266 nm
XeCl excimer 308 nm
He-Cd 325 nm
Ne^+ 332.4 nm
Nitrogen 337.1 nm
Ruby (doubled) 347 nm
XeF excimer 351 nm
Ar^{2+} 351 nm
Nd:YAG (tripled) 355 nm
He-Cd 441.6 nm
Ar^+ 488.0 nm
Copper vapor 510.5 nm
Ar^+ 514.5 nm
Nd:YAG (doubled) 532 nm
Xe^{3+} 539.5 nm
He-Ne 543.5 nm
Copper vapor 578.2 nm
He-Ne 594.1 nm
He-Ne 611.9 nm
Gold vapor 628 nm
He-Ne 632.8 nm
Kr^+ 647.1 nm
Ruby 694.3 nm
Nd:YAG 946 nm
Nd:YAG 1064 nm (other hosts 1047-1079 nm)
He-Ne 1152 nm
Iodine 1315 nm
Nd:YAG 1319 nm
He-Ne 1523 nm
Er:glass 1.54 µm
Tm:YAG 2.01 µm
Ho:YAG 2.08 µm
Er:YSGG 2.79 µm
Er:YAG 2.90, 2.94 µm
He-Ne 3.391 µm
CO_2 10.6 µm
Methanol 37.9, 70.5, 96.5, 118 µm
Methylamine 147.8 µm
Methyl fluoride 496 µm
Methanol 571, 699 µm
Ti:sapphire (tripled) 235-330 nm
$Ne-Cu^+$ 248-270 nm
$He-Au^+$ 282-292 nm
Dyes (doubled) 0.2-0.4 µm
Alexandrite (doubled) 360-400 nm
InGaN 370-493 nm
Ti:sapphire (doubled) 360-460 nm
Dyes 0.38-1.0 µm
Dyes in polymer 550-700 nm
InGaAlP 630-685 nm
Alexandrite 700-800 nm
Cr-fluoride 780-850 nm
GaAlAs 750-850 nm
Ti:sapphire 670-1130 nm
InGaAs 904-1065 nm
InGaAs 1.27-1.33 µm 1.43-1.57 µm
Fosterite 1.13-1.36 µm
AlGaIn/AsSb 1.87-2.2 µm
Dyes (Raman shifted) 0.9-4.5 µm
Xe-He 2-4 µm
HF chemical 2.6-3.0 µm
DF chemical 3.6-4.0 µm
CO_2 (doubled) 4.6-5.8 µm
CO 5-7 µm
CO_2 9.2-11.4 µm
Pb salts 3.3-27 µm


Nonlinear QED: $E \bullet e \bullet \lambda_c = 2m_0c^2$
10^{29}
Zettawatt Laser
Δν: gain bandwidth
σ: transition cross-section
Laser Intensity Limit:
(per cm² of laser medium)
$I = \frac{h\nu^3}{c^2} \bullet \frac{\Delta\nu_g}{\sigma} = \frac{P_{th}}{\lambda^2}$
Relativistic Optics:
(large ponderomotive pressures)
$v_{osc} \sim c$
Bound Electrons: $E = \frac{e^2}{a_0}$
mode-locking
Q-switching
CPA
Focused Intensity (W/cm²)
10^{30}
10^{25}
10^{20}
10^{15}
10^{10}
1960
1970
1980
1990
2000
2010
Electroweak Era
Quark Era
10^{24}
Positron-Electron Era
10^{18}
Plasma Era
10^{12}
Atomic Era

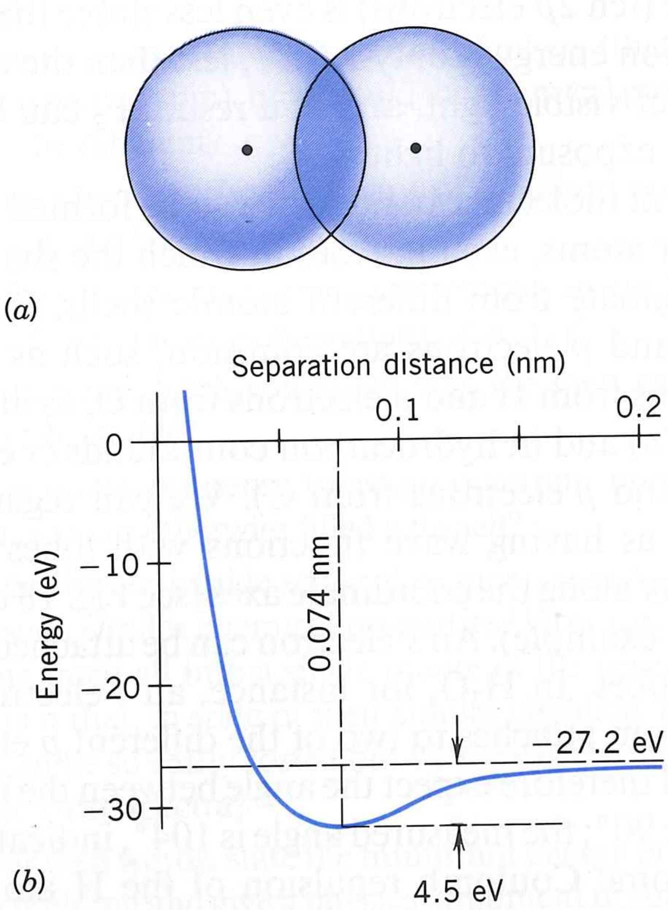


Figure 16 (*a*) The overlap of the *s* electrons in H is responsible for the formation of the H_2 molecule. (*b*) The total energy of the two electrons in the bound state of the H_2 molecule, as a function of the atomic separation distance. When the separation is large, the energy is −27.2 eV (twice the energy of the single electron in atomic hydrogen, −13.6 eV). The minimum energy of the bound molecule is −31.7 eV when the separation is 0.074 nm.

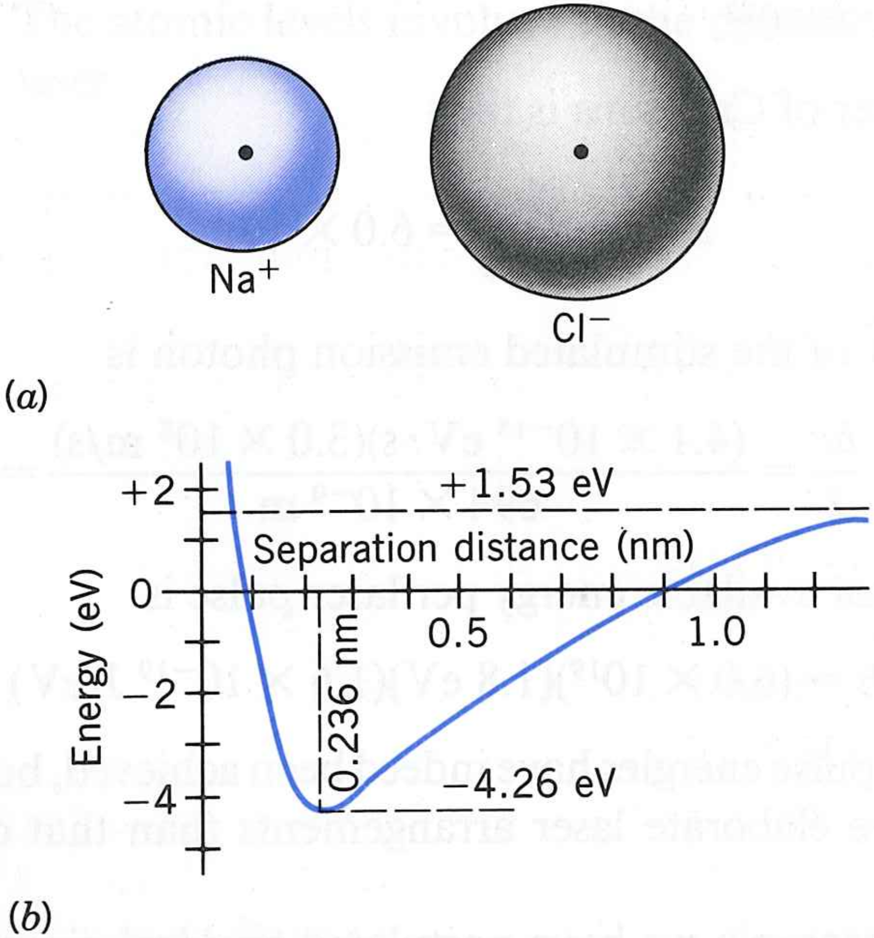


Figure 18 (*a*) Ionic bonding in NaCl. Note that there is no appreciable overlap of the electron distributions. (*b*) Binding energy in NaCl. The zero of energy corresponds to Na and Cl *atoms* separated by a large distance. The dashed line represents the energy of Na$^+$ and Cl$^-$ *ions* separated by a large dis-

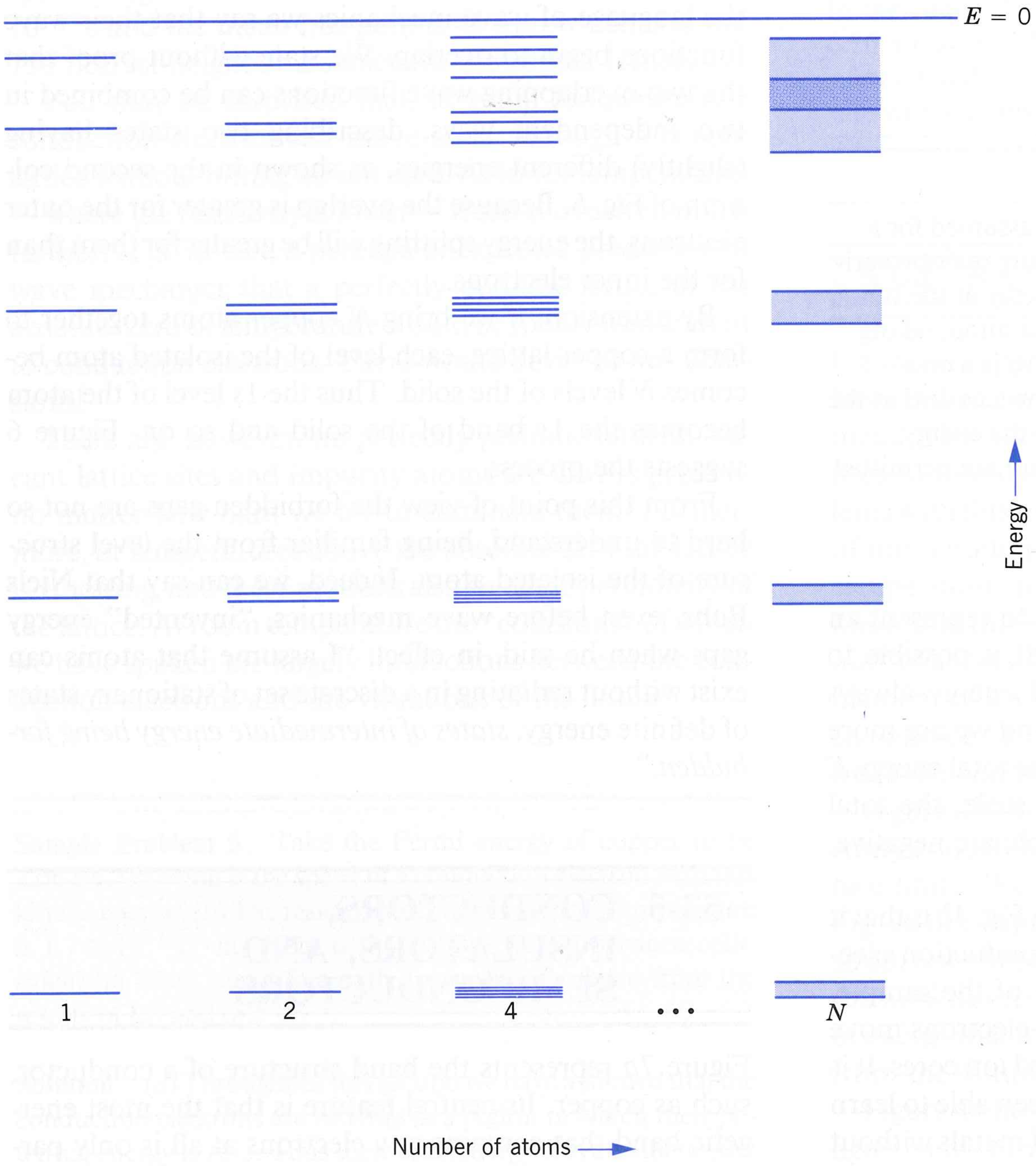


Figure 6 As atoms are brought together to form a lattice, the levels of the isolated atoms split, eventually forming bands of closely lying levels. For the case shown, the upper bands overlap in energy.

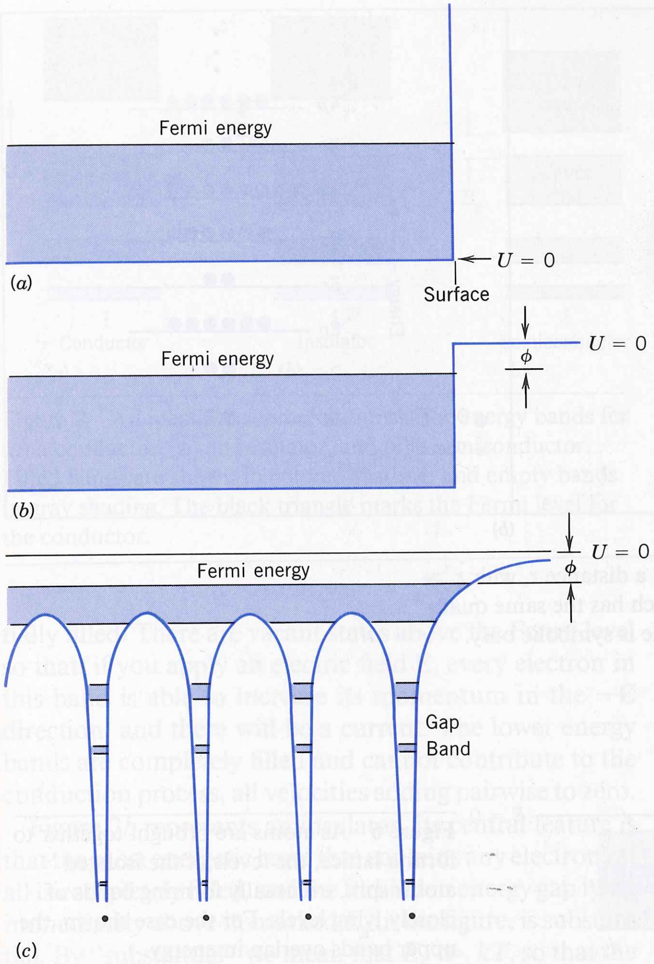
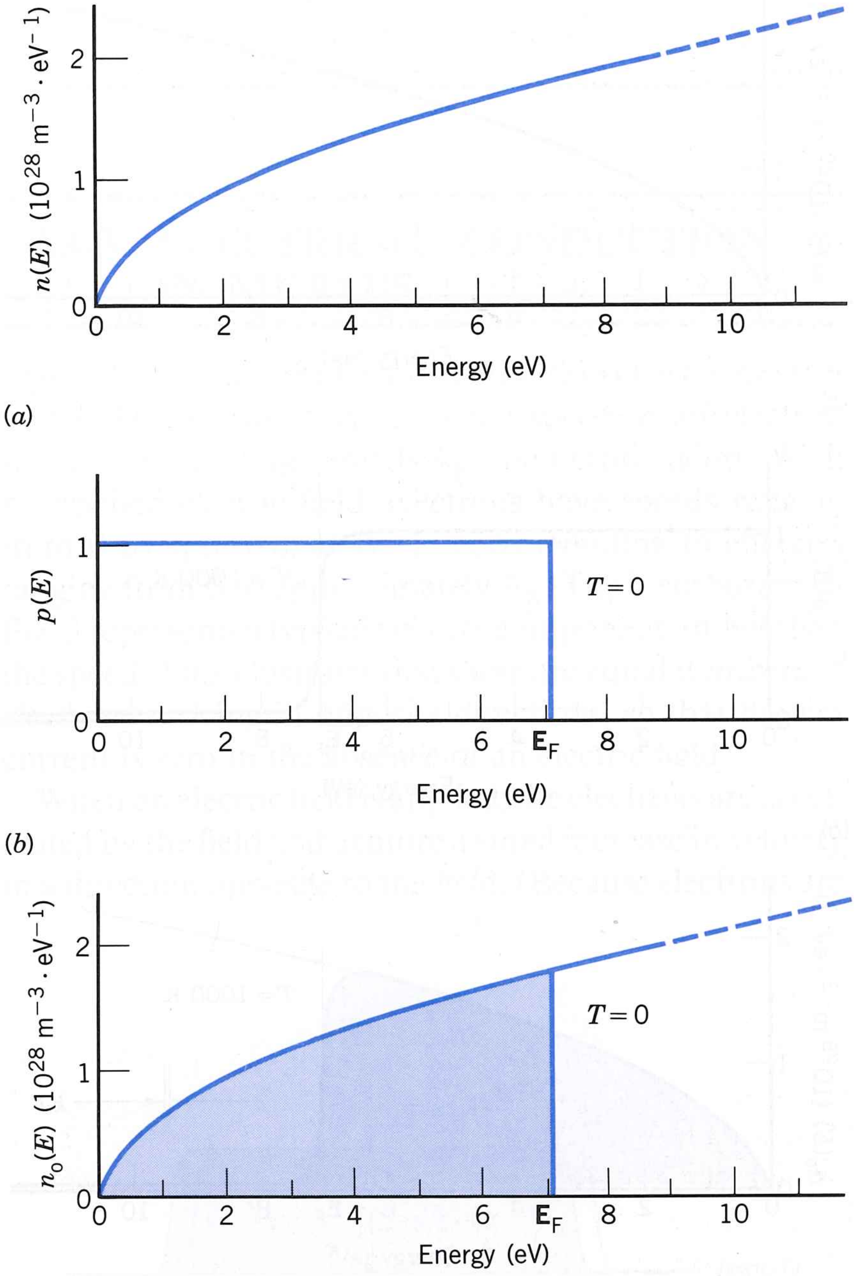


Figure 4 (*a*) The potential energy variation assumed for a metal in the free electron gas model. (*b*) A more realistic variation, showing a finite change in potential energy at the surface of the sample. (*c*) A still more realistic variation, taking the lattice of ion cores into account. This curve is a one-dimensional cut along a line of ion cores (shown as dots at the bottom of the figure). The shaded regions are the energy bands permitted for the electrons. Electrons are not permitted to have energies corresponding to the gaps.


n(E) (10^28 m^-3 · eV^-1)
0
1
2
0
2
4
6
8
10
Energy (eV)
(a)
p(E)
0
1
T = 0
0
2
4
6
E_F
8
10
Energy (eV)
(b)
n_0(E) (10^28 m^-3 · eV^-1)
0
1
2
T = 0
0
2
4
6
E_F
8
10
Energy (eV)

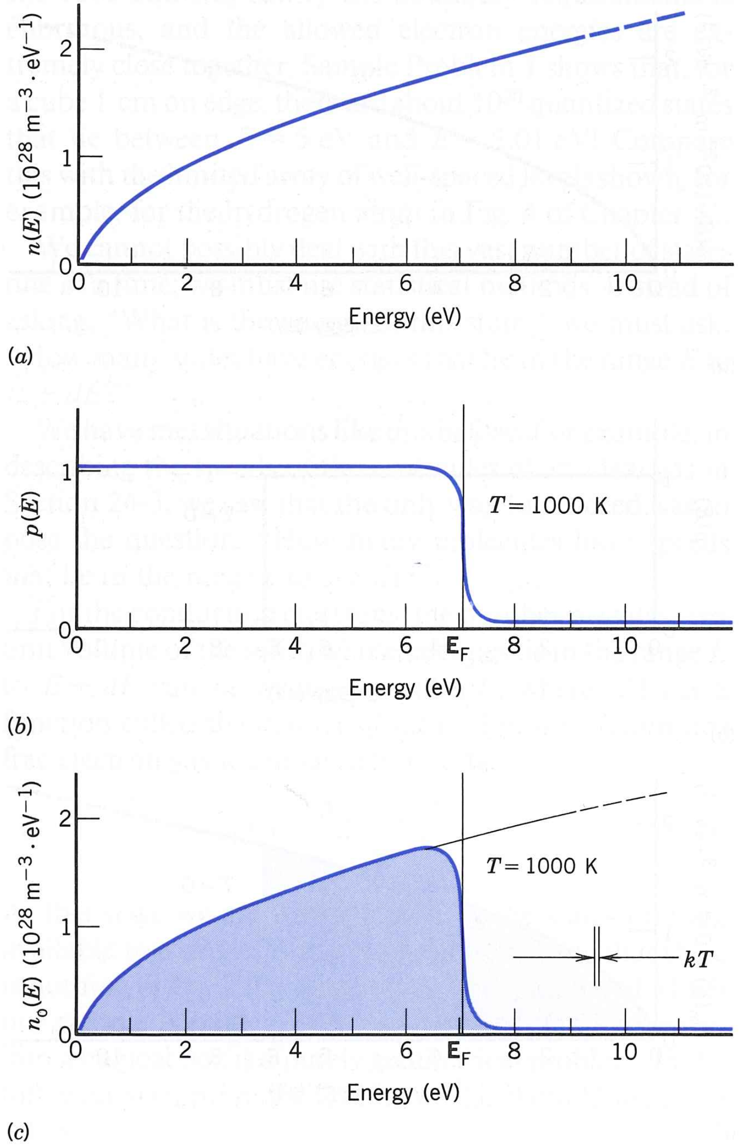


Figure 2 Same as Fig. 1, but for $T = 1000$ K. Note how little the plots differ from those of Fig. 1. (These plots are somewhat idealized in that they assume the electrons move in a region of uniform potential. Measured density of states plots in real metals do not have this simple shape.)

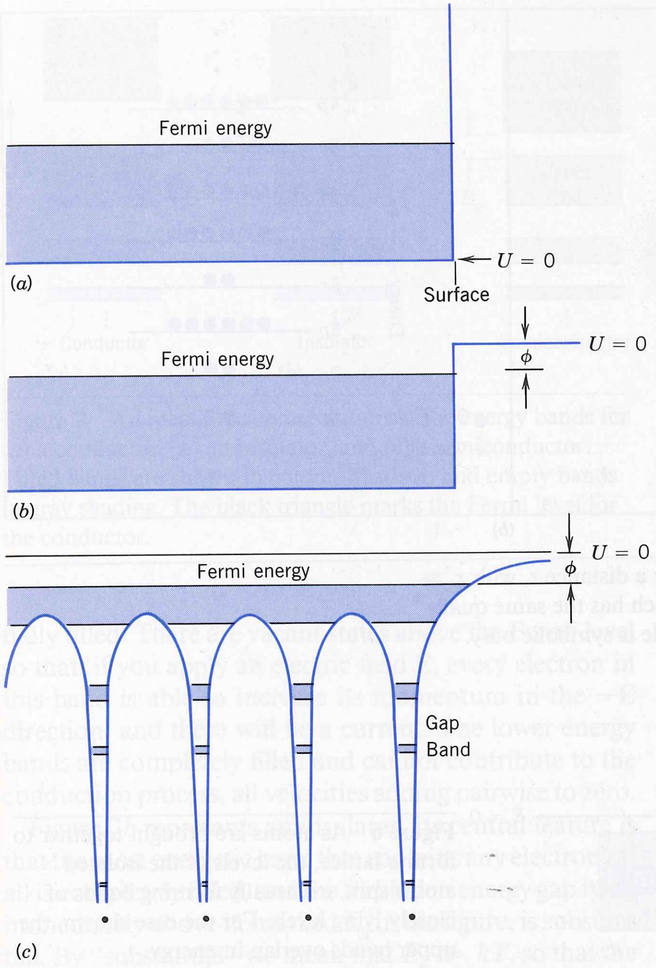


Figure 4 (*a*) The potential energy variation assumed for a metal in the free electron gas model. (*b*) A more realistic variation, showing a finite change in potential energy at the surface of the sample. (*c*) A still more realistic variation, taking the lattice of ion cores into account. This curve is a one-dimensional cut along a line of ion cores (shown as dots at the bottom of the figure). The shaded regions are the energy bands permitted for the electrons. Electrons are not permitted to have energies corresponding to the gaps.

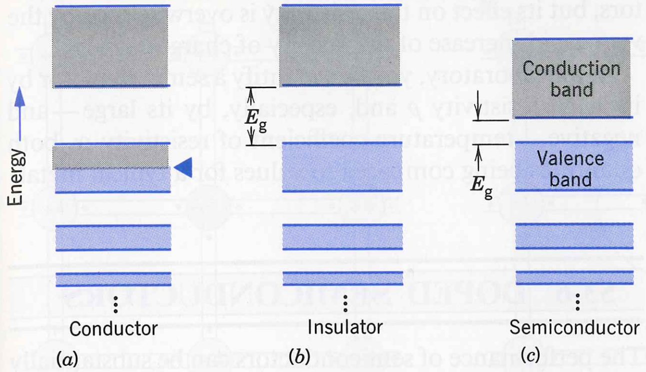


Figure 7 An idealized representation of the energy bands for (*a*) a conductor, (*b*) an insulator, and (*c*) a semiconductor. Filled bands are shown in colored shading, and empty bands in gray shading. The black triangle marks the Fermi level for the conductor.