

10 Properties of the Elements

The following table lists the elements with atomic number up to 92 alphabetically by name. Columns 1-4 and 13-16 are self-explanatory. Column 5 gives the crystal structures of the elements in their solid state. Where a change in structure occurs, the transition temperature is indicated (in K) under the crystal structures. The following abbreviations are used:

bcc = body-centred cubic
 cubic (diam) = diamond structure
 fcc = face-centred cubic
 bcp = hexagonal close-packed
 hex = hexagonal
 mono = monoclinic
 ortho = orthorhombic
 tetra = tetragonal

Column 6 lists the atomic radii of the elements in pm (10^{-12} m). These radii are calculated as half the distance of closest approach of atomic centres in the crystalline state. Column 7 gives the principal oxidation numbers and column 8, the corresponding ionic radii. Column 9 and 10 give the energies (eV) required to remove the first and second electrons from the atom—multiply by 96.49 to convert to kJ mol^{-1} . Column 11 gives the energy required to remove an electron from the negative ion formed by the atom with an extra electron. These 'electron affinities' are difficult to measure and there are few reliable results. Column 12 gives the electronegativities assigned to the elements by Pauling. These are numbers between 0 and 4 which may be used in determining the contribution of the ionic and covalent components of the bonds between different atoms.

Symbol	Name	Atomic Number Z	Atomic Weight $M/g \text{ mol}^{-1}$	Crystal Structure	Atomic radius r_a/pm	Principal Oxidation Numbers	Ionic Radii r_i/pm	Ionization Energies E_i/eV	Electron Affinities E_e/eV	Electronegativity	Density $\rho/\text{kg m}^{-3}$	Melting Point T_m/K	Boiling Point T_b/K	Symbol
Ac	Actinium	89	227	fcc	188	3+	118	6.5 12.1	—	1.1	10 100	1 320	3 470	Ac
Al	Aluminium	13	26.98	fcc	143	3+	51	5.985 18.828	0.5	1.5	2 700	933.2	2 740	Al
Sb	Antimony	51	121.75	rhombic	145	{ 3+ 5+ }	{ 76 62 }	8.641 16.53	> 2.0	1.8	6 700	903.7	1 650	Sb
Ar	Argon	18	39.95	fcc	174	0(1+)	154	15.759 27.629	-1.0	—	1.66	83.7	87.4	Ar
As	Arsenic	33	74.92	rhombic	125	{ 3+ 5+ }	{ 58 46 }	9.81 18.633	—	2.0	5 730	1 090 (28 atm)	886 (sub)	As
At	Astatine	85	210	—	—	7+	62	9.5	—	2.2	—	520	623	At
Ba	Barium	56	137.34	bcc	217	2+	134	5.212 10.004	—	0.9	3 600	1 000	1 910	Ba
Be	Beryllium	4	9.01	bcp/cubic 1527	112	2+	35	9.322 18.211	0.50	1.5	1 800	1 550	3 243	Be
Bi	Bismuth	83	208.98	rhombic	155	{ 3+ 5+ }	{ 96 74 }	7.289 16.69	> 0.7	1.9	9 800	544.4	1 930	Bi
B	Boron	5	10.81	ortho (7)	88	3+	23	8.298 25.154	0.33	2.0	2 500	2 600	2 820 (sub)	B
Br	Bromine	35	79.90	ortho	114	{ 1- 3+ }	{ 196 47 }	11.814 21.8	3.363	2.8	3 100 (298 K)	265.9	331.9	Br
Cd	Cadmium	48	112.40	bcp	148	2+	97	8.993 16.908	—	1.7	8 650	594.2	1 038	Cd
Ce	Ceesium	55	132.90	bcc	262	1+	167	3.894 25.1	> 0.19	0.7	1 870	301.6	960	Ce
Ca	Calcium	20	40.08	fcc/bcc 737	196	2+	99	6.113 11.871	—	1.0	1 540	1 120	1 760	Ca
C	Carbon	6	12.01	hex/cubic graph/diam	71/77 g/d	{ 4+ 4- }	{ 16 260 }	11.260 24.383	1.25	2.5	2 300	> 3 800	5 100	C

Ce	Lanthanum	58	140.12	fcc/bcc/fcc	181	3+	103	5.47	10.85	—	1-1	6 800	1 670	3 740	Ce
Cl	Chlorine	17	35.45	95 203 998 tetra	91	4+	92	—	—	—	—	—	—	—	Cl
Cr	Chromium	24	52.00	bcc	125	1-	181	12.967	23.81	3-615	3.0	3.21	172.1	238.5	Cr
Co	Cobalt	27	58.93	bcc/fcc	125	3+	34	6.766	16.50	0.98	1-6	(273 K) 7 200	2 160	2 755	Co
Cu	Copper	29	63.55	fcc	125	6+	52	7.86	17.06	0.9	1-8	8 900	1 765	3 170	Cu
Dy	Dysprosium	66	162.50	rhombic/bcc 86	175	2+	72	7.726	20.292	1-8	1-9	8 930	1 356	2 868	Dy
Er	Erbium	68	167.26	bcc	173	3+	91	5.93	11.67	—	1-2	8 500	1 680	2 900	Er
Eu	Europium	63	151.96	bcc	198	3+	88	6.10	11.93	—	1-2	9 000	1 770	3 260	Eu
F	Fluorine	9	19.00	—	60	3+	95	5.67	11.25	—	1-1	5 200	1 100	1 712	F
Fr	Francium	87	223	—	—	2+	109	—	—	—	—	—	—	—	Fr
Gd	Gadolinium	64	157.25	bcc/fcc 1537	178	1-	133	17.422	34.97	3-448	4-0	1.7	53.5	85.01	Gd
Ga	Gallium	31	69.72	fcc or ortho	121	7+	8	4.0	—	—	0-7	(273 K)	302	920	Ga
Ge	Germanium	32	72.64	trigonal (diam)	132	1+	187	6.14	12.1	—	1-2	7 900	1 585	3 000	Ge
Au	Gold	79	196.97	fcc	141	3+	94	5.999	20.51	—	1-6	5 950	302.9	2 676	Au
Hf	Hafnium	72	178.49	bcc/bcc 2050	158	1+	81	7.890	15.934	—	1-8	5 400	1 210.5	3 100	Hf
He	Helium	2	4.003	bcc/cubic	176	1+	62	9.225	20.5	2-1	2-4	12 300	1 336.1	3 239	He
Ho	Holmium	67	164.93	bcc	176	3+	53	7.0	14.9	—	1-5	13 300	2 425	5 700	Ho
H	Hydrogen	1	1.00797	bcc/cubic	46	0	—	24.587	54.416	-0.53	—	0.166	0.95	4.21	H
In	Indium	49	114.82	bcc tetra	162	—	—	6.02	11.80	—	1-2	8 800	1 734	2 900	In
I	Iodine	53	126.90	ortho	135	1+	154	13.598	—	0.76	2-1	0.08987	14.01	20.4	I
Ir	Iridium	77	192.2	fcc	135	3+	81	5.786	18.869	—	1-7	7 310	429.8	2 300	Ir
Fe	Iron	26	55.85	bcc/fcc/fcc	123	1-	216	10.451	19.131	3.070	2-5	4 940	386.6	457.4	Fe
Kr	Krypton	36	83.80	fcc	201	4+	68	9.1	—	—	2-2	22 420	2 716	4 800	Kr
La	Lanthanum	57	138.91	bcc/fcc/fcc	187	2+	74	7.87	16.18	0.6	1-8	7 870	1 808	3 300	La
Pb	Lead	82	207.19	fcc	174	3+	64	13.999	24.359	—	—	3.49	116.5	120.8	Pb
Li	Lithium	3	6.94	bcc/fcc	152	0	—	5.577	11.06	—	1-1	6 150	1190	3 742	Li
						1+	139	7.416	15.032	—	1-8	11 340	600.4	2 017	
						4+	120	5.392	75.638	0.82	1-0	534	452	1 390	
						1+	68	—	—	—	—	—	—	—	

Symbol	Name	Atomic Number Z	Atomic Weight A _r /g mol ⁻¹	Crystal Structure	Atomic radius r _a /pm	Principal Oxidation Numbers	Ionic Radii r _i /pm	Ionization Energies E _i /eV	Electron Affinities E _a /eV	Electronegativities	Density ρ/kg m ⁻³	Melting Point T _m /K	Boiling Point T _b /K	Symbol
Lu	Lutetium	71	174.97	hcp	173	3+	85	5.426 13.9	—	1.2	9 800	1 925	3 600	Lu
Mg	Magnesium	12	24.31	hcp	160	1+	82	7.646 14.7	-0.32	1.2	1 741	924	1 380	Mg
Mn	Manganese	25	54.94	cubic	112	2+	66	7.435 15.640	—	1.5	7 440	1 517	2 370	Mn
Hg	Mercury	80	200.59	rhombic	156	2+	80	10.437 18.756	1.54	1.9	13 590 (273 K)	234.3	629.7	Hg
Mo	Molybdenum	42	95.94	bcc	136	3+	66	7.099 16.15	1.0	1.8	10 200	2 880	5 830	Mo
Nd	Neodymium	60	144.24	hcp/bcc 1135	181	4+	70	5.49 10.72	—	1.1	6 960	1 297	3 300	Nd
Ne	Neon	10	20.18	fcc	160	0	—	21.564 40.562	-0.57	—	0.839	24.5	27.2	Ne
Ni	Nickel	28	58.71	fcc	124	2+	69	7.635 18.168	1.3	1.8	8 900	1 725	3 005	Ni
Nb	Niobium	41	92.91	bcc	143	3+	62	6.88 14.32	—	1.6	8.570	2 741	5 200	Nb
N	Nitrogen	7	14.01	cubic/hcp 35-4	71	3+	100	14.534 29.601	0.05	3.0	1.165	63.3	77.3	N
Os	Osmium	76	190.2	hcp	135	5+	69	8.7 17.0	—	2.2	22 480	3 300	4 900	Os
O	Oxygen	8	16.00	rhombic	60	4+	132	13.618 35.116	1.471	3.5	1.33	54.7	90.2	O
Pd	Palladium	46	106.4	fcc	137	2+	80	8.34 19.43	—	2.2	12 000	1 825	3 200	Pd
P	Phosphorus	15	30.97	cubic	—	4+	65	10.486 19.725	0.8	2.1	2 200 (r) 1 800 (y)	317.2	552	P
Pt	Platinum	78	195.09	fcc	138	5+	35	9.0 18.563	—	2.2	21 450	2 042	4 100	Pt
Po	Polonium	84	209	monoclinic	168	2+	80	8.42 19.4	—	2.0	9 400	527	1 235	Po
K	Potassium	19	39.10	bcc	231	6+	67	4.341 31.625	0.82	0.8	860	336.8	1 047	K
Pr	Praseodymium	59	140.91	hcp/bcc 1065	182	1+	133	5.42 10.55	—	1.1	6 800	1 208	3 400	Pr
Pm	Promethium	61	145	—	—	3+	101	5.55 10.90	—	1.1	—	1 308	3 000	Pm
Pa	Protactinium	91	231	tetra	160	4+	98	—	—	1.5	15 400	1 500	4 500	Pa

Ra	Radium	88	226	—	—	2+	143	5.279	10.147	—	0.9	5 000	970	1 419	Ra
Rn	Radon	86	222	—	—	0	—	10.748	—	—	—	9.73	202	217.3	Rn
												(273 K)			
Re	Rhenium	75	186.2	hcp	137	4+	72	7.88	16.6	0.15	1.9	20 500	3 450	5 900	Re
Rh	Rhodium	45	102.91	fcc	134	3+	68	7.46	18.08	—	2.2	12 440	2 230	4 000	Rh
Rb	Rubidium	37	85.47	bcc	246	1+	147	4.177	27.28	0.4	0.8	1530	312.0	961	Rb
Ru	Ruthenium	44	101.07	hcp	133	4+	67	7.374	16.76	—	2.2	12 400	2 520	4 200	Ru
Sm	Samarium	62	150.35	Rhomb/bcc	179	3+	96	5.63	11.07	—	1.1	7 500	1 345	2 200	Sm
				1190											
Sc	Scandium	21	44.96	hcp/fcc 1223	160	3+	73	6.54	12.80	—	1.3	3 000	1 812	3 000	Sc
Se	Selenium	34	78.96	hcp	116	2-	191	9.752	21.19	3.7	2.4	4 810	490	958	Se
Si	Silicon	14	28.09	cubic	118	4+	42	8.151	16.345	1.5	1.8	2 300	1 680	2 628	Si
						4-	38								
Ag	Silver	47	107.87	fcc/hcp 5	144	1+	126	7.576	21.49	2.5	1.9	10 500	1 234	2 485	Ag
Na	Sodium	11	22.99	bcc	185	1+	97	5.139	47.286	0.84	0.9	970	371	1 165	Na
Sr	Strontium	38	87.62	fcc/hcp/bcc	215	2+	112	5.695	11.030	—	1.0	2 600	1042	1 657	Sr
				506 813											
S	Sulphur	16	32.06	fc ortho.	106	2-	184	10.360	23.33	2.07	2.5	2 070	386	717.7	S
						4+	37								
Ta	Tantalum	73	180.95	bcc	143	5+	68	7.89	16.2	—	1.5	16 600	3 269	5 698	Ta
Tc	Technetium	43	98.91	hcp	135	7+	98	7.28	15.26	—	1.9	11 400	2 500	4 900	Tc
Te	Tellurium	52	127.60	hcp	143	2-	211	9.009	18.6	3.6	2.1	6 240	722.6	1 260	Te
Tb	Terbium	65	158.92	hcp/rhomb	177	3+	92	5.85	11.52	—	1.2	8 300	1 629	3 100	Tb
				1590											
Tl	Thallium	81	204.37	hcp/fcc 503	171	1+	147	6.108	20.428	—	1.8	11 860	576.6	1 730	Tl
Th	Thorium	90	232.04	fcc/bcc 1673	180	4+	102	6.95	11.5	—	1.3	11 500	2 000	4 500	Th
Tm	Thulium	69	168.93	hcp/bcc 1158	174	3+	87	6.18	12.05	—	1.2	9 300	1 818	2 000	Tm
Sn	Tin	50	118.69	cub(diam)/bcc	140	2+	93	7.344	14.632	—	1.8	7 300	505.1	2 540	Sn
						4+	71								
Ti	Titanium	22	47.90	hcp/bcc 1158	146	4+	68	6.82	13.58	0.39	1.5	4 540	1 948	3 530	Ti
W	Tungsten	74	183.85	bcc	137	6+	62	7.98	17.7	0.5	1.7	19 320	3 650	6 200	W
U	Uranium	92	238.03	rhomb/tetr 941	138	4+	97	6.08	—	0.94	1.7	19 050	1 405.4	4 091	U
						6+	80								
V	Vanadium	23	50.94	bcc	131	3+	74	6.74	14.65	—	1.6	6 100	2 160	3 300	V
						5+	59								
Xe	Xenon	54	131.30	fcc	221	0	—	12.130	21.21	—	—	5.50	161.2	166.0	Xe
Yb	Ytterbium	70	173.04	fcc/bcc 1071	193	3+	86	6.254	12.17	—	1.2	7 000	1 097	1 700	Yb
Y	Yttrium	39	88.91	hcp/bcc 1763	181	3+	89	6.38	12.24	—	1.2	4 600	1 768	3 200	Y
Zn	Zinc	30	65.37	hcp	133	2+	74	9.394	17.964	—	1.6	7 140	692.6	1 180	Zn
Zr	Zirconium	40	91.22	hcp/bcc 1100	160	4+	70	6.84	13.13	—	1.4	6 500	2 125	3 851	Zr