



University of  
South Australia

# ENR116 Engineering Materials

## Module 1 Introduction to Materials

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University of  
South Australia

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# Chemical bonding

unisa



## Intended Learning Outcomes

**At the end of this section, students will be able to:-**

- Plot the **attractive**, **repulsive** and **net forces** between two atoms or ions.
- Describe **primary** and **secondary bonding** types.
- Note which materials exhibit which types of bonding

The intended learning outcomes from this presentation are for students to understand the types of forces between atoms and ions; describe primary and secondary bonding and identify which materials exhibit these.



# The Periodic Table

Group VIIA and VIA elements are, respectively, *one and two electrons deficient* from having stable structures.

IA		IIA																III										IVA										VA										VIA										VIIA										VIII										IX										X										XI										XII										O																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
1 H 1.0080		3 Li 6.941		4 Be 9.0122		11 Na 22.990		12 Mg 24.305		19 K 39.098		20 Ca 40.08		21 Sc 44.956		22 Ti 47.87		23 V 50.942		24 Cr 51.996		25 Mn 54.938		26 Fe 55.845		27 Co 58.933		28 Ni 58.69		29 Cu 63.54		30 Zn 65.41		31 Ga 69.72		32 Ge 72.64		33 As 74.922		34 Se 78.96		35 Br 79.904		36 Kr 83.80		37 Rb 85.47		38 Sr 87.62		39 Y 88.91		40 Zr 91.22		41 Nb 92.91		42 Mo 95.94		43 Tc (98)		44 Ru 101.07		45 Rh 102.91		46 Pd 106.4		47 Ag 107.87		48 Cd 112.41		49 In 114.82		50 Sn 118.71		51 Sb 121.76		52 Te 127.60		53 I 126.90		54 Xe 131.30		55 Cs 132.91		56 Ba 137.34		57 La 138.91		58 Ce 140.12		59 Pr 140.91		60 Nd 144.24		61 Pm (145)		62 Sm 150.36		63 Eu 151.96		64 Gd 157.25		65 Tb 158.93		66 Dy 162.50		67 Ho 164.93		68 Er 167.26		69 Tm 168.93		70 Yb 173.05		71 Lu 174.967		72 Hf 178.49		73 Ta 180.948		74 W 183.84		75 Re 186.207		76 Os 190.23		77 Ir 192.225		78 Pt 195.084		79 Au 196.967		80 Hg 200.59		81 Tl 204.38		82 Pb 207.19		83 Bi 208.980		84 Po (209)		85 At (210)		86 Rn (222)		87 Fr (223)		88 Ra (226)		89 Ac (227)		90 Th (232)		91 Pa (231)		92 U (238)		93 Np (237)		94 Pu (244)		95 Am (243)		96 Cm (247)		97 Bk (247)		98 Cf (251)		99 Es (252)		100 Fm (257)		101 Md (258)		102 Ds (261)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
Atomic number		Symbol		Atomic weight		Nonmetal		Intermediate		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII		VIII		IX		X		XI		XII	

Adapted from Fig. 2.06, Callister & Rethwisch 8e.

In the previous presentation I introduced the concepts of atomic structure, electron orbitals and valence electrons. I would like to begin this lecture summary by looking at the periodic table which was developed by the Russian scientist Dmitri Mendeleev. The periodic table is composed of periods and groups, so the elements are placed in order of increasing atomic number from left to right and top to bottom. What is common to the elements is the groups, columns of elements, which have similar electron configurations and so similar chemical properties. So the VIIA and VIA groups outlined here are respectively one and two electrons in the outer electronic orbital short of a stable filled shell.



# The Periodic Table

The **Group VIIA** elements (F, Cl, Br, I, and At) are sometimes termed the **halogens**.

Periodic Table																		0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
IA		IIA		Transition Metals														IIIA		IVA		VA		VIA		VIIA		0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
1 H 1.0080		3 Li 6.941	4 Be 9.0122	5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180	11 Na 22.990	12 Mg 24.305	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948	19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.87	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.69	29 Cu 63.54	30 Zn 65.41	31 Ga 69.72	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.30	55 Cs 132.91	56 Ba 137.34	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)	87 Fr (223)	88 Ra (226)	89 Ac (227)	90 Th (232)	91 Pa (231)	92 U (238)	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (281)	111 Nh (286)	112 Fl (289)	113 Mc (290)	114 Lv (293)	115 Ts (294)	116 Og (294)	117 Tennessine (294)	118 Oganesson (294)	119 Ununennium (295)	120 Unbinilium (296)	121 Untrium (297)	122 Unquadrium (298)	123 Unquadium (299)	124 Unpentium (300)	125 Unsextium (301)	126 Unseptium (302)	127 Unoctium (303)	128 Unnonium (304)	129 Undecium (305)	130 Undecium (306)	131 Untridecium (307)	132 Unquadecium (308)	133 Unpentecium (309)	134 Unhexium (310)	135 Unseptium (311)	136 Unoctium (312)	137 Unnonium (313)	138 Undecium (314)	139 Undecium (315)	140 Untridecium (316)	141 Unquadecium (317)	142 Unpentecium (318)	143 Unhexium (319)	144 Unseptium (320)	145 Unoctium (321)	146 Unnonium (322)	147 Undecium (323)	148 Undecium (324)	149 Untridecium (325)	150 Unquadecium (326)	151 Unpentecium (327)	152 Unhexium (328)	153 Unseptium (329)	154 Unoctium (330)	155 Unnonium (331)	156 Undecium (332)	157 Undecium (333)	158 Untridecium (334)	159 Unquadecium (335)	160 Unpentecium (336)	161 Unhexium (337)	162 Unseptium (338)	163 Unoctium (339)	164 Unnonium (340)	165 Undecium (341)	166 Undecium (342)	167 Untridecium (343)	168 Unquadecium (344)	169 Unpentecium (345)	170 Unhexium (346)	171 Unseptium (347)	172 Unoctium (348)	173 Unnonium (349)	174 Undecium (350)	175 Undecium (351)	176 Untridecium (352)	177 Unquadecium (353)	178 Unpentecium (354)	179 Unhexium (355)	180 Unseptium (356)	181 Unoctium (357)	182 Unnonium (358)	183 Undecium (359)	184 Undecium (360)	185 Untridecium (361)	186 Unquadecium (362)	187 Unpentecium (363)	188 Unhexium (364)	189 Unseptium (365)	190 Unoctium (366)	191 Unnonium (367)	192 Undecium (368)	193 Undecium (369)	194 Untridecium (370)	195 Unquadecium (371)	196 Unpentecium (372)	197 Unhexium (373)	198 Unseptium (374)	199 Unoctium (375)	200 Unnonium (376)	201 Undecium (377)	202 Undecium (378)	203 Untridecium (379)	204 Unquadecium (380)	205 Unpentecium (381)	206 Unhexium (382)	207 Unseptium (383)	208 Unoctium (384)	209 Unnonium (385)	210 Undecium (386)	211 Undecium (387)	212 Untridecium (388)	213 Unquadecium (389)	214 Unpentecium (390)	215 Unhexium (391)	216 Unseptium (392)	217 Unoctium (393)	218 Unnonium (394)	219 Undecium (395)	220 Undecium (396)	221 Untridecium (397)	222 Unquadecium (398)	223 Unpentecium (399)	224 Unhexium (400)	225 Unseptium (401)	226 Unoctium (402)	227 Unnonium (403)	228 Undecium (404)	229 Undecium (405)	230 Untridecium (406)	231 Unquadecium (407)	232 Unpentecium (408)	233 Unhexium (409)	234 Unseptium (410)	235 Unoctium (411)	236 Unnonium (412)	237 Undecium (413)	238 Undecium (414)	239 Untridecium (415)	240 Unquadecium (416)	241 Unpentecium (417)	242 Unhexium (418)	243 Unseptium (419)	244 Unoctium (420)	245 Unnonium (421)	246 Undecium (422)	247 Undecium (423)	248 Untridecium (424)	249 Unquadecium (425)	250 Unpentecium (426)	251 Unhexium (427)	252 Unseptium (428)	253 Unoctium (429)	254 Unnonium (430)	255 Undecium (431)	256 Undecium (432)	257 Untridecium (433)	258 Unquadecium (434)	259 Unpentecium (435)	260 Unhexium (436)	261 Unseptium (437)	262 Unoctium (438)	263 Unnonium (439)	264 Undecium (440)	265 Undecium (441)	266 Untridecium (442)	267 Unquadecium (443)	268 Unpentecium (444)	269 Unhexium (445)	270 Unseptium (446)	271 Unoctium (447)	272 Unnonium (448)	273 Undecium (449)	274 Undecium (450)	275 Untridecium (451)	276 Unquadecium (452)	277 Unpentecium (453)	278 Unhexium (454)	279 Unseptium (455)	280 Unoctium (456)	281 Unnonium (457)	282 Undecium (458)	283 Undecium (459)	284 Untridecium (460)	285 Unquadecium (461)	286 Unpentecium (462)	287 Unhexium (463)	288 Unseptium (464)	289 Unoctium (465)	290 Unnonium (466)	291 Undecium (467)	292 Undecium (468)	293 Untridecium (469)	294 Unquadecium (470)	295 Unpentecium (471)	296 Unhexium (472)	297 Unseptium (473)	298 Unoctium (474)	299 Unnonium (475)	300 Undecium (476)	301 Undecium (477)	302 Untridecium (478)	303 Unquadecium (479)	304 Unpentecium (480)	305 Unhexium (481)	306 Unseptium (482)	307 Unoctium (483)	308 Unnonium (484)	309 Undecium (485)	310 Undecium (486)	311 Untridecium (487)	312 Unquadecium (488)	313 Unpentecium (489)	314 Unhexium (490)	315 Unseptium (491)	316 Unoctium (492)	317 Unnonium (493)	318 Undecium (494)	319 Undecium (495)	320 Untridecium (496)	321 Unquadecium (497)	322 Unpentecium (498)	323 Unhexium (499)	324 Unseptium (500)	325 Unoctium (501)	326 Unnonium (502)	327 Undecium (503)	328 Undecium (504)	329 Untridecium (505)	330 Unquadecium (506)	331 Unpentecium (507)	332 Unhexium (508)	333 Unseptium (509)	334 Unoctium (510)	335 Unnonium (511)	336 Undecium (512)	337 Undecium (513)	338 Untridecium (514)	339 Unquadecium (515)	340 Unpentecium (516)	341 Unhexium (517)	342 Unseptium (518)	343 Unoctium (519)	344 Unnonium (520)	345 Undecium (521)	346 Undecium (522)	347 Untridecium (523)	348 Unquadecium (524)	349 Unpentecium (525)	350 Unhexium (526)	351 Unseptium (527)	352 Unoctium (528)	353 Unnonium (529)	354 Undecium (530)	355 Undecium (531)	356 Untridecium (532)	357 Unquadecium (533)	358 Unpentecium (534)	359 Unhexium (535)	360 Unseptium (536)	361 Unoctium (537)	362 Unnonium (538)	363 Undecium (539)	364 Undecium (540)	365 Untridecium (541)	366 Unquadecium (542)	367 Unpentecium (543)	368 Unhexium (544)	369 Unseptium (545)	370 Unoctium (546)	371 Unnonium (547)	372 Undecium (548)	373 Undecium (549)	374 Untridecium (550)	375 Unquadecium (551)	376 Unpentecium (552)	377 Unhexium (553)	378 Unseptium (554)	379 Unoctium (555)	380 Unnonium (556)	381 Undecium (557)	382 Undecium (558)	383 Untridecium (559)	384 Unquadecium (560)	385 Unpentecium (561)	386 Unhexium (562)	387 Unseptium (563)	388 Unoctium (564)	389 Unnonium (565)	390 Undecium (566)	391 Undecium (567)	392 Untridecium (568)	393 Unquadecium (569)	394 Unpentecium (570)	395 Unhexium (571)	396 Unseptium (572)	397 Unoctium (573)	398 Unnonium (574)	399 Undecium (575)	400 Undecium (576)	401 Untridecium (577)	402 Unquadecium (578)	403 Unpentecium (579)	404 Unhexium (580)	405 Unseptium (581)	406 Unoctium (582)	407 Unnonium (583)	408 Undecium (584)	409 Undecium (585)	410 Untridecium (586)	411 Unquadecium (587)	412 Unpentecium (588)	413 Unhexium (589)	414 Unseptium (590)	415 Unoctium (591)	416 Unnonium (592)	417 Undecium (593)	418 Undecium (594)	419 Untridecium (595)	420 Unquadecium (596)	421 Unpentecium (597)	422 Unhexium (598)	423 Unseptium (599)	424 Unoctium (600)	425 Unnonium (601)	426 Undecium (602)	427 Undecium (603)	428 Untridecium (604)	429 Unquadecium (605)	430 Unpentecium (606)	431 Unhexium (607)	432 Unseptium (608)	433 Unoctium (609)	434 Unnonium (610)	435 Undecium (611)	436 Undecium (612)	437 Untridecium (613)	438 Unquadecium (614)	439 Unpentecium (615)	440 Unhexium (616)	441 Unseptium (617)	442 Unoctium (618)	443 Unnonium (619)	444 Undecium (620)	445 Undecium (621)	446 Untridecium (622)	447 Unquadecium (623)	448 Unpentecium (624)	449 Unhexium (625)	450 Unseptium (626)	451 Unoctium (627)	452 Unnonium (628)	453 Undecium (629)	454 Undecium (630)	455 Untridecium (631)	456 Unquadecium (632)	457 Unpentecium (633)	458 Unhexium (634)	459 Unseptium (635)	460 Unoctium (636)	461 Unnonium (637)	462 Undecium (638)	463 Undecium (639)	464 Untridecium (640)	465 Unquadecium (641)	466 Unpentecium (642)	467 Unhexium (643)	468 Unseptium (644)	469 Unoctium (645)	470 Unnonium (646)	471 Undecium (647)	472 Undecium (648)	473 Untridecium (649)	474 Unquadecium (650)	475 Unpentecium (651)	476 Unhexium (652)	477 Unseptium (653)	478 Unoctium (654)	479 Unnonium (655)	480 Undecium (656)	481 Undecium (657)	482 Untridecium (658)	483 Unquadecium (659)	484 Unpentecium (660)	485 Unhexium (661)	486 Unseptium (662)	487 Unoctium (663)	488 Unnonium (664)	489 Undecium (665)	490 Undecium (666)	491 Untridecium (667)	492 Unquadecium (668)	493 Unpentecium (669)	494 Unhexium (670)	495 Unseptium (671)	496 Unoctium (672)	497 Unnonium (673)	498 Undecium (674)	499 Undecium (675)	500 Untridecium (676)	501 Unquadecium (677)	502 Unpentecium (678)	503 Unhexium (679)	504 Unseptium (680)	505 Unoctium (681)	506 Unnonium (682)	507 Undecium (683)	508 Undecium (684)	509 Untridecium (685)	510 Unquadecium (686)	511 Unpentecium (687)	512 Unhexium (688)	513 Unseptium (689)	514 Unoctium (690)	515 Unnonium (691)	516 Undecium (692)	517 Undecium (693)	518 Untridecium (694)	519 Unquadecium (695)	520 Unpentecium (696)	521 Unhexium (697)	522 Unseptium (698)	523 Unoctium (699)	524 Unnonium (700)	525 Undecium (701)	526 Undecium (702)	527 Untridecium (703)	528 Unquadecium (704)	529 Unpentecium (705)	530 Unhexium (706)	531 Unseptium (707)	532 Unoctium (708)	533 Unnonium (709)	534 Undecium (710)	535 Undecium (711)	536 Untridecium (712)	537 Unquadecium (713)	538 Unpentecium (714)	539 Unhexium (715)	540 Unseptium (716)	541 Unoctium (717)	542 Unnonium (718)	543 Undecium (719)	544 Undecium (720)	545 Untridecium (721)	546 Unquadecium (722)	547 Unpentecium (723)	548 Unhexium (724)	549 Unseptium (725)	550 Unoctium (726)	551 Unnonium (727)	552 Undecium (728)	553 Undecium (729)	554 Untridecium (730)	555 Unquadecium (731)	556 Unpentecium (732)	557 Unhexium (733)	558 Unseptium (734)	559 Unoctium (735)	560 Unnonium (736)	561 Undecium (737)	562 Undecium (738)	563 Untridecium (739)	564 Unquadecium (740)	565 Unpentecium (741)	566 Unhexium (742)	567 Unseptium (743)	568 Unoctium (744)	569 Unnonium (745)	570 Undecium (746)	571 Undecium (747)	572 Untridecium (748)	573 Unquadecium (749)	574 Unpentecium (750)	575 Unhexium (751)	576 Unseptium (752)	577 Unoctium (753)	578 Unnonium (754)	579 Undecium (755)	580 Undecium (756)	581 Untridecium (757)	582 Unquadecium (758)	583 Unpentecium (759)	584 Unhexium (760)	585 Unseptium (761)	586 Unoctium (762)	587 Unnonium (763)	588 Undecium (764)	589 Undecium (765)	590 Untridecium (766)	591 Unquadecium (767)	592 Unpentecium (768)	593 Unhexium (769)	594 Unseptium (770)	595 Unoctium (771)	596 Unnonium (772)	597 Undecium (773)	598 Undecium (774)	599 Untridecium (775)	600 Unquadecium (776)	601 Unpentecium (777)	602 Unhexium (778)	603 Unseptium (779)	604 Unoctium (780)	605 Unnonium (781)	606 Undecium (782)	607 Undecium (783)	608 Untridecium (784)	609 Unquadecium (785)	610 Unpentecium (786)	611 Unhexium (787)	612 Unseptium (788)	613 Unoctium (789)	614 Unnonium (790)	615 Undecium (791)	616 Undecium (792)	617 Untridecium (793)	618 Unquadecium (794)	619 Unpentecium (795)	620 Unhexium (796)	621 Unseptium (797)	622 Unoctium (798)	623 Unnonium (799)	624 Undecium (800)	625 Undecium (801)	626 Untridecium (802)	627 Unquadecium (803)	628 Unpentecium (804)	629 Unhexium (805)	630 Unseptium (806)	631 Unoctium (807)	632 Unnonium (808)	633 Undecium (809)	634 Undecium (810)	635 Untridecium (811)	636 Unquadecium (812)	637 Unpentecium (813)	638 Unhexium (814)	639 Unseptium (815)	640 Unoctium (816)	641 Unnonium (817)	642 Undecium (818)	643 Undecium (819)</

Adapted from Fig. 2.06, Callister & Rethwisch 8e.

The group VIIA elements are sometimes referred to as the halogens and they are all relatively reactive non-metals.



# The Periodic Table

The *alkali* and the *alkaline earth metals* (Li, Na, K, Be, Mg, Ca, etc.) are labelled as **Groups IA and IIA**, having, respectively, one and two electrons in excess of stable structures.

Key

- Atomic number
- Symbol
- Atomic weight
- Nonmetal
- Intermediate

1 H 1.0080	2 He 4.0026																
3 Li 6.941	4 Be 9.0122																
11 Na 22.990	12 Mg 24.305	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948										
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.87	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.69	29 Cu 63.54	30 Zn 65.41	31 Ga 69.72	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.30
55 Cs 132.91	56 Ba 137.34	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97	72 Hf 178.49
73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.19	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)				
87 Fr (223)	88 Ra (226)	89 Ac (227)	90 Th (232)	91 Pa (231)	92 U (238)	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)	104 Rf (261)
105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (281)												

Adapted from Fig. 2.06, Callister & Rethwisch 8e.

At the other side of the periodic table we have the groups labelled IA and IIA and these are characterised by having just 1 or 2 electrons in the outermost shell.



# The Periodic Table

The elements in the three long periods, **Groups IIIB through IIB**, are termed the **transition metals**, which have partially filled **d electron states** and in some cases one or two electrons in the next higher energy shell.

IA		IIA		VIII										IB		IIB		0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
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Adapted from Fig. 2.06, Callister & Rethwisch 8e.

This section of the periodic table are known as the transition metals. They are characterised by their partially filled d electron states.







# Electronegativity

Ranges from 0.7 to 4.0

Large values: tendency to acquire electrons.

IA																	0				
H 2.1																	He -				
Li 1.0	Be 1.5															B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne -
Na 0.9	Mg 1.2															Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	Ar -
		IIIB	IVB	VB	VIB	VII B	VIII			IB	IIB										
K 0.8	Ca 1.0	Sc 1.3	Ti 1.5	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr -				
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe -				
Cs 0.7	Ba 0.9	La-Lu 1.1-1.2	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.0	At 2.2	Rn -				
Fr 0.7	Ra 0.9	Ac-No 1.1-1.7																			



Smaller electronegativity



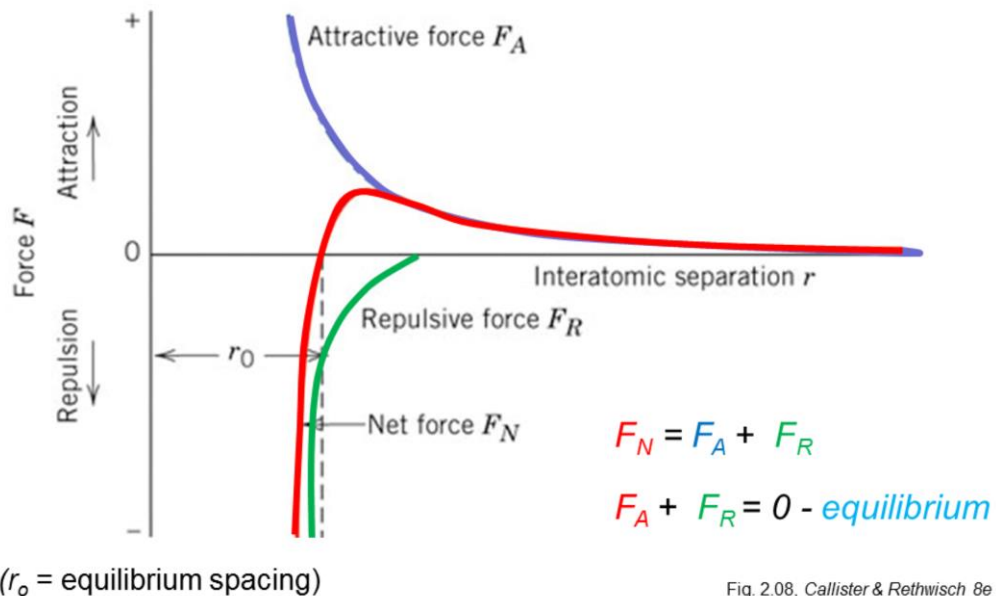
Larger electronegativity

Adapted from Fig. 2.07, Callister & Rethwisch 8e. (Fig. 2.07 is adapted from Linus Pauling, *The Nature of the Chemical Bond*, 3rd edition, Copyright 1939 and 1940, 3rd edition. Copyright 1960 by Cornell University.

Another important property of elements is that of electronegativity. This is the ability of one specific element to acquire electrons. In considering the periodic table the electronegativity increases from the bottom left corner to the top left corner. On the left are elements with low electronegativity and on the right are elements with high electronegativity, so the alkali earth metals and the alkali metals have low electronegativities and the non-metals such as oxygen and fluorine have high electronegativities. The exception is the inert gas group which, because of their filled outer shells, do not have any electronegativity.



## Bonding forces and energies

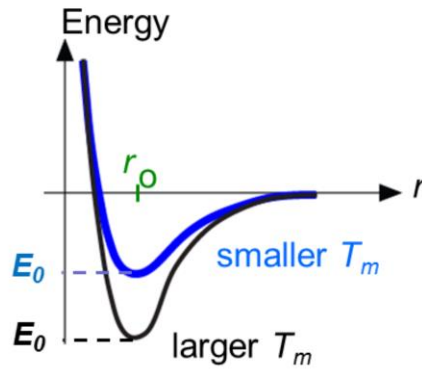


The forces and energies binding the atoms of a material dictate many of its properties and this can be seen schematically. The overall force between two atoms, the red line, is the sum of the attractive force seen as the blue line and the repulsive force, the green line. In a similar manner we can plot the potential energies between the atoms from which we can determine the bonding energy.



## Properties From Bonding: $T_m$

### Melting Temperature, $T_m$



$T_m$  is larger if  $E_0$  is larger.

Whilst these plots of energy against the separation between two atoms can be considered as the ideal situation they can tell us a great deal about the material as a whole. As seen here the greater the value for bonding energy the higher the materials melting temperature and in later lectures the influence of this interatomic bonding on a materials mechanical properties will be explored.



# Interatomic Bonding

## Primary bonds:

The bonding necessarily involves the valence electrons. The nature of the bond depends on the electron structures of the constituent atoms.

Bonding arises from the tendency of the atoms to assume stable electron structures, like those of the inert gases, by completely filling the outermost electron shell.

Ionic

Covalent

Metallic

## Secondary (Physical) bonds:

These bonds are weaker than the primary ones, but nonetheless influence the physical properties of some materials.

The final part of this week's lectures will discuss bonds and atomic bonding. These are generally described as primary bonds and secondary bonds. The primary bonds will involve the valence electrons; the nature of the bond depends on the electron structure of the constituent atoms, and the bonding will arise from the tendency of the atoms to assume stable electron structures - which we have already discussed like the inert gases, by completely filling the outermost electron shell. The primary bonds are the ionic bond, the covalent bond and the metallic bond. There are also secondary bonds and these are much weaker bonds than primary bonds but they are still very important in defining the properties of materials.



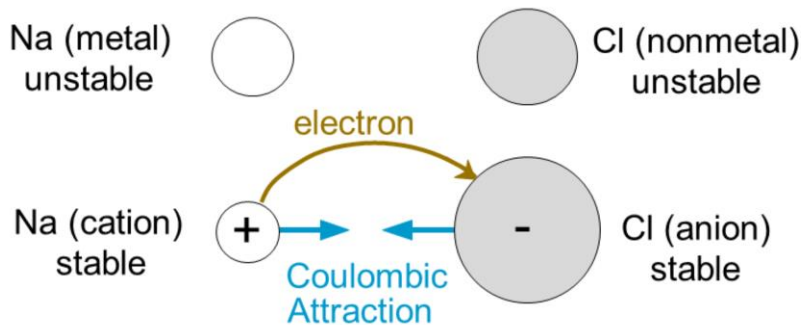
# Ionic Bonding

Occurs between (+) and (–) ions

Requires **electron transfer**

Large difference in electronegativity required

Example: NaCl



Ionic bonding occurs between ions. If you have two atoms with very different electro-negativities, such as sodium, which is on the left of the periodic table, and chlorine, which is on the right - they have very different electronic activities and they will form sodium chloride, table salt. So how does this happen? Chlorine is very much electronegative and so it has a strong tendency to acquire electrons, so pulling away the valence electrons of the sodium. Thus the sodium atom will become deficient of one electron and so become an ion of one positive charge. Chlorine on the other side will acquire one electron, so it become an ion of one negative charge. Then the plus and minus charged ions will attract each other forming an ionic bond.



# Ionic Bonding

Ionic bond – metal + nonmetal

↑  
donates  
electrons

↑  
accepts  
electrons

Dissimilar electronegativities

Ex: MgO

Mg

$1s^2 2s^2 2p^6$

$3s^2$

O

$1s^2 2s^2 2p^4$

$Mg^{2+}$

$1s^2 2s^2 2p^6$

[Ne]

$O^{2-}$

$1s^2 2s^2 2p^6$

[Ne]

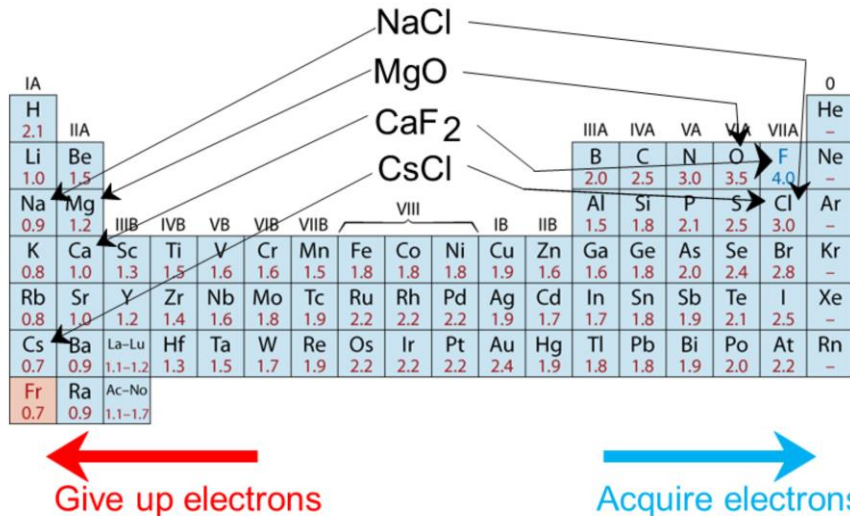
So again, ionic bonding will happen between metals and non-metals, involving elements of lower and higher electronegativities; between elements with very different electronegativities. The metal will tend to donate electrons and is so known as the electron donor, and the non-metal, accepting the donated electrons, will be electron acceptors.

Another example of ionic bond will be magnesium oxide. Magnesium has two extra electrons compared to the stable configuration of neon whilst oxygen has two electrons less. The magnesium donates its extra two electrons and the oxygen accepts them to form the ionic bonds present in magnesium oxide.



# Ionic Bonding

## Predominant bonding in Ceramics



Adapted from Fig. 2.07, Callister & Rethwisch 8e. (Fig. 2.07 is adapted from Linus Pauling, *The Nature of the Chemical Bond*, 3rd edition, Copyright 1939 and 1940, 3rd edition. Copyright 1960 by Cornell University.

Ionic bonds will occur between elements of very different electronic activities, such as the sodium on the left and chlorine on the right, the magnesium on the left and oxygen on the right. Another example would be calcium fluoride or caesium chloride and there are many other combinations which we will see throughout the unit.





# Ionic Bonding

## Sodium chloride (NaCl)

The bond is generally non-directional.

Bonding energies generally range between 600 and 1500 kJ/mol.

Ionic compounds have high melting temperatures.

They are hard and brittle and, furthermore, electrically and thermally insulative.

Predominant bonding in ceramic materials.

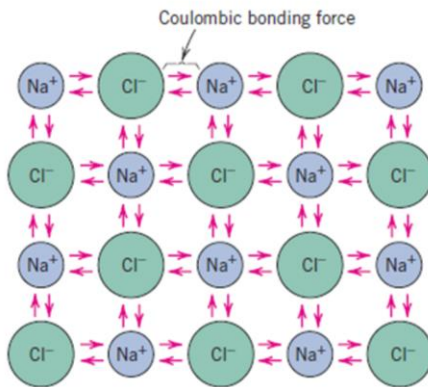


Fig. 2.09, Callister & Rethwisch 8e.

This is an example of the ionic bonding. This is the structure of the sodium chloride. You will see that each atom, either negative or positive, is surrounded by oppositely charged ions, so each sodium atom has four neighbours. These bonds are generally non-directional, the bonding energies will be between 600 and 1500 kJ/mol which means that they are strong bonds. The ionic compounds, because of these strong bonds, in general will have high melting temperatures.

They are hard and brittle and will be electrically and thermally insulated because of the alternation of positive-negative, positive-negative, and this is the predominant bonding in ceramic materials.

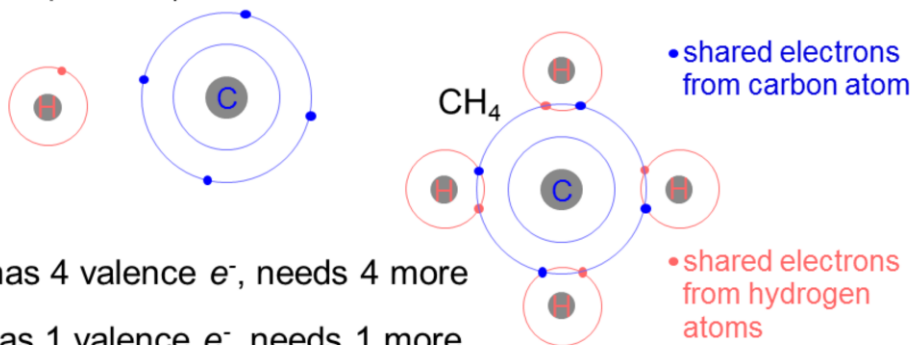


## Covalent Bonding

similar **electronegativity** - share electrons

bonds determined by valence – *s* & *p* orbitals dominate bonding

Example: CH<sub>4</sub>



C: has 4 valence e<sup>-</sup>, needs 4 more

H: has 1 valence e<sup>-</sup>, needs 1 more

Electronegativities are comparable

The next type of bonding is covalent bonding. Here again the atoms will acquire stable electron configurations but in another manner. This bonding usually happens between elements of similar electronegativity and typically between the non-metals.

Let's see an example here with methane which is formed with one carbon and four hydrogen atoms. Carbon, has four valence electrons, four electrons in one shell. Hydrogen has one electron, so it's one electron deficient of a filled shell and carbon is four electrons deficient. Both want extra electrons and so they share their electrons.

The four hydrogen's each share their four single electrons with the four electrons in the outer orbital of the carbon; each hydrogen will have two electrons and become like helium whilst the carbon will have eight electrons in the outer shell.



## Covalent Bonding

Many nonmetallic elemental molecules ( $\text{H}_2$ ,  $\text{Cl}_2$ ,  $\text{F}_2$ , etc).

Molecules containing dissimilar atoms ( $\text{CH}_4$ ,  $\text{H}_2\text{O}$ ,  $\text{HNO}_3$ ,  $\text{HF}$ ).

Solids such as diamond, silicon, germanium and other solid compounds of elements located on the right-hand side of the periodic table, such as gallium arsenide ( $\text{GaAs}$ ), and silicon carbide ( $\text{SiC}$ ).

The covalent bond is typical for many non-metallic elements such as hydrogen, chlorine, fluorine etcetera. They can be molecules that contain dissimilar atoms such as water, nitric acid and hydrogen fluoride; they can be solids such as diamond or silicon.



# Covalent Bonding

## Polymeric materials:

Bonding energies and melting points are variable.

$T_m$  diamond  $> 3550^\circ\text{C}$

$T_m$  bismuth  $= 270^\circ\text{C}$

Number of covalent bonds for a particular compound  $= 8 - N'$

$N'$  – number of valence electrons

*Examples: Cl – 7 valence electrons – one covalent bond*

*C – 4 valence electron – 4 covalent bonds*

Covalent bonding is also present in polymeric materials.

The bonding energies of covalent bonds can be very different; they can be very strong such as in diamond, the hardest material with a very high melting temperature. Alternatively they can be very weak such as those in bismuth which is seen by its low melting temperature.

We can determine the number of covalent bonds which an element can form using a simple expression  $8 - N'$  where  $N'$  is the number of the valence electrons.

An example would be chlorine which has 7 valence electrons - 8 minus 7 is 1 so it can form one covalent bond. Carbon has 4 valence electrons, and so can form 4 covalent bonds.



## Mixed covalent and ionic bonds

Very few compounds exhibit pure ionic or covalent bonding.

For a compound, the degree of either bond type depends on the relative positions of the constituent atoms in the periodic table.

The greater the difference in electronegativity – the more ionic character.

The **percentage ionic character** of a bond between elements A and B (A being the more electronegative) may be approximated by the expression:

$$\% \text{ ionic character} = \{1 - \exp[-(0.25)(X_A - X_B)^2]\} \times 100$$

where  $X_A$  and  $X_B$  are the electronegativities for the respective elements.

However, very few compounds are formed with purely covalent or purely ionic bonds. In most of the cases the bond type will be a mixture of both covalent and ionic bonds. The greater the difference in the electronegativities of the constituent elements the more ionic character.

The percentage ionic character may be determined by this simple expression: where  $X_{\text{subscript A}}$  and  $X_{\text{subscript B}}$  are the electronegativities of the respective elements. We will look more closely at this calculation in the first tutorial session.



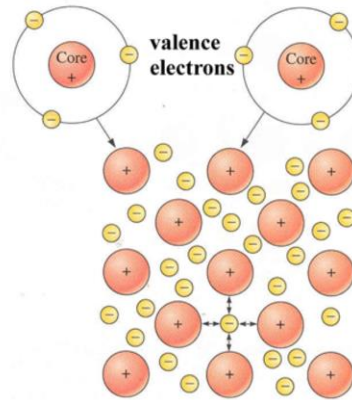
# Metallic Bonding

This bond is found in metals and their alloys.

The valence electrons are **not shared between any specific or particular atoms** in the solid.

The electrons are **free to move** throughout the entire metal.

Electrons may be thought of as belonging to the metal as a whole forming a “sea of electrons” or an **“electron cloud.”**



The metallic bond is a bond found in metals and their alloys. What is different in metallic bonding is the fact that the electrons are not shared between any specific or particular atoms; they are shared between all the atoms in the metallic material. As such the valence electrons are free to travel across the material and thus they form an electron cloud and this will determine the properties of the material. It is this aspect of metals which makes them good conductors of electricity.

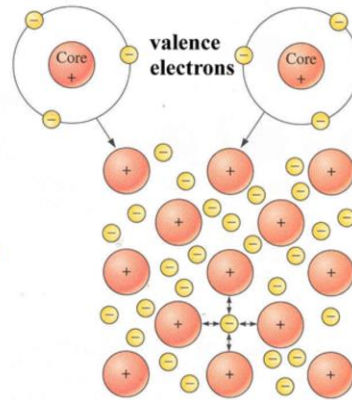


# Metallic Bonding

The remaining non-valence electrons and atomic nuclei form **ion cores**, which possess a net positive charge equal in magnitude to the total valence electron charge per atom.

The **free electrons** shield the ion cores from mutually repulsive electrostatic forces, which they would otherwise exert upon one another.

The free electrons act as a “glue” to hold the ion cores together.



The non-valence electrons are not free to move and will stay around the nucleus. But, since the valence electrons are moving the ion cores assume a net positive charge. The atoms are closely packed together and the free electrons do not belong to any particular number of atoms but to the whole material.



## Metallic Bonding

Bonding energies may be weak or strong

$E_o$  W (tungsten) = 850 kJ/mol;  $T_m$  = 3410°C

$E_o$  Hg (mercury) = 68 kJ/mol;  $T_m$  = -39°C

Metals are good conductors of both electricity and heat, as a consequence of their free electrons.

Metals and their alloys are usually ductile (capacity for plastic deformation), opaque, shiny and lustrous.

The majority of metals have higher densities than the majority of non-metals, except the alkali and alkaline earth metals.

The metallic bond can be very strong such as in tungsten with its very high melting temperature, or they can be very weak such as in mercury.

Metals, because of the free electron cloud are good conductors of electricity and heat; they are usually ductile because of the electron structure, opaque and the majority, excepting the alkali or alkali earth metals, have higher densities than most of the other elements.

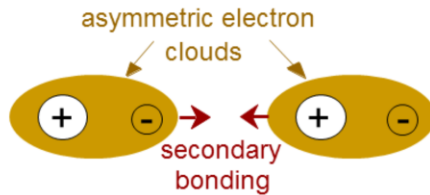




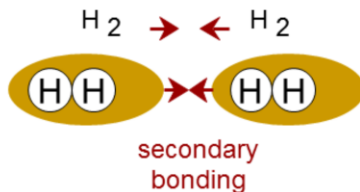
# Secondary Bonding

Arises from interactions **between dipoles**

## Fluctuating dipoles



ex: liquid  $H_2$

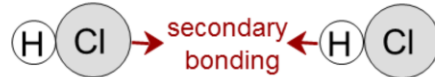


## Permanent dipoles

- general case:



- ex: liquid HCl



- ex: polymer



Adapted from Fig. 2.13, Callister & Rethwisch 8e.

There is another class of bonding known as secondary bonding or van der Waals bonding. Secondary bonding is much weaker than primary bonding but it's still very important. It has a value of about 10 kJ/mol and occurs between dipoles.

A dipole can be considered as the attraction between unlike charges in a similar manner to opposite poles of a magnet. Wherever there is an atom or molecule with a positively charged region and a negatively charged region then the possibility of secondary bonding between adjacent atoms and molecules will exist. The strength of these bonds will depend on the atoms involved and their relative electronegativities.

This slide illustrates some of the instances where secondary bonding occurs; for example between simple molecules and polymer chains.



# Hydrogen bond

It is **strongest of the secondary bonds** (as high as 51 kJ/mol).

It occurs between molecules in which **hydrogen is covalently bonded to fluorine** (as in **HF**), **oxygen** (as in **H<sub>2</sub>O**) and **nitrogen** (as in **NH<sub>3</sub>**).

For each H—F, H—O, or H—N bond, the single hydrogen electron is shared with the other atom.

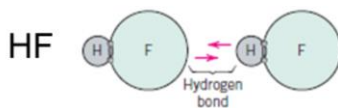


Fig. 2.15, Callister & Rethwisch 8e.

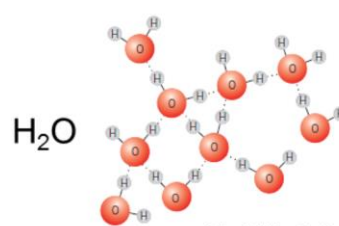


Fig. 2.16b, Callister & Rethwisch 8e.

The hydrogen bond is another example of secondary bonding however it has a strength of 51 kJ/mol and is typical found between molecules in which hydrogen is covalently bound to fluorine, oxygen or nitrogen.

With hydrogen bonding the electron of the hydrogen is strongly attracted towards the other element such that the hydrogen atom is left with a bare nucleus and so has a much stronger positive charge than normal. The result is a dipole forming a strong attraction between the hydrogen of the one molecule and the corresponding element of an adjacent molecule.



# Hydrogen bond

Melting and boiling temperatures for hydrogen fluoride and water are **abnormally high** in light of their low molecular weights, as a consequence of hydrogen bonding.

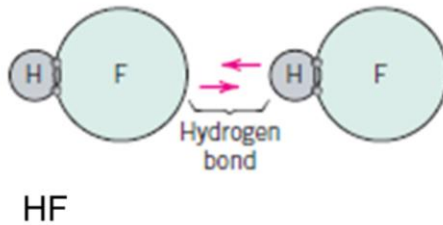


Fig. 2.15, Callister & Rethwisch 8e.

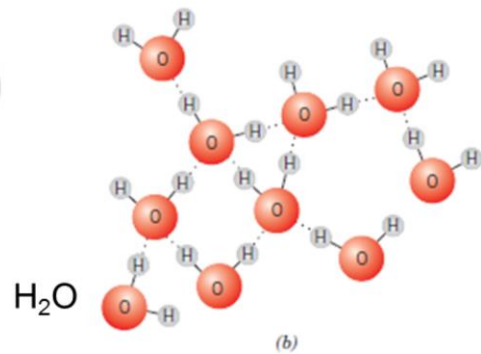


Fig. 2.16b, Callister & Rethwisch 8e.

The abnormally high melting point and boiling point of water, relative to its molecular weight, is due to the hydrogen bonds that occur between the water molecules.



## Bonding: Examples

What are the **bonding types** associated with the following **compounds**?



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**Salt**

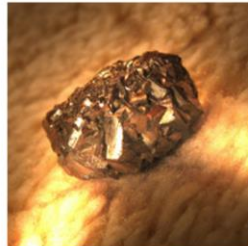
**$\text{Na}^+\text{Cl}^-$**

**Ionic**

**Gold**

**Au**

**Metallic**



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**Water**

**$\text{H}_2\text{O}$**

**Covalent  
Hydrogen  
bonding**

So materials are formed with a range of bonds between the constituent atoms and molecules. For example common salt comprises of ionic bonds between the sodium and chlorine atoms. Another example is gold whose atoms form dense metallic bonds between each other and finally water; covalent bonds between the two hydrogen atoms and one oxygen atom are accompanied by hydrogen bonds between the adjacent water molecules.



## Summary

- The forces between two atoms or ions depend on their **interatomic** spacing.
- The primary bonding types are **covalent**, **ionic** and **metallic**.
- Secondary bonding types include **van der Waals** and **hydrogen** bonding.

In summary, there are a number of primary and secondary bonding types between elements forming compounds. The primary bonds are stronger than the secondary however the secondary bonds can still be an influence on a compound and its material properties.



**Thank you**

If you have any questions or desire further clarification please post a question or comment on the Engineering Materials Discussion Forum.