Física dos Materiais – 4300502

1º Semestre de 2014

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As propriedades de materiais sólidos podem ser grupadas em 6 diferentes categorias:

(a) mecânica;
(b) elétrica;
(c) térmica;
(d) magnética;
(e) ótica, e
(f) deteriorativa.

Para cada uma existe um tipo característico de estímulo capaz de provocar diferentes respostas.

• Propriedades mecânicas relacionam deformação a uma carga ou força aplicada; exemplos incluem elástico e resistência mecânica. Para propriedades elétricas, tais como condutividade elétrica e constante dielétrica, o estímulo é um campo elétrico.

- O comportamento térmico de sólidos pode ser representado em termos de capacidade calorífica e condutividade térmica.

- Propriedades magnéticas demonstram a resposta de um material à aplicação de um campo magnético.

- Para propriedades óticas, o estímulo é eletromagnético ou radiação de luz, índice de refração e refletividade são representativas propriedades óticas.

- Finalmente, características deteriorativas indicam a reatividade química de materiais.

Por que nós estudamos materiais?

Muitos dos cientistas aplicados ou engenheiros, sejam eles mecânicos, civis, químicos, ou elétricos, estarão uma vez ou outra expostos a um problema de projeto envolvendo materiais.

CLASSIFICAÇÃO DE MATERIAIS

Materiais sólidos têm sido convenientemente agrupados em 3 classificações básicas:

(a) metais;
(b) cerâmicas, e
(c) Polímeros

Este esquema é baseado principalmente na constituição química e estrutura atômica, e muitos materiais caem num distinto grupamento ou num outro, embora existam alguns intermediários.

Em adição, existem 2 outros grupos de importantes materiais de engenharia:
(d) compósitos, e
(e) semicondutores.

(a) METAIS

• Materiais metálicos são normalmente combinações de elementos metálicos. Eles têm grande número de elétrons não localizados, isto é, estes elétrons não estão amarrados a particulares átomos. Muitas propriedades de metais são diretamente atribuíveis a estes elétrons.

• Metais são extremamente bons condutores de eletricidade e de calor e não são transparentes à luz visível: a superfície de um metal polido tem aparência lustrosa. Além disso, metais são bastante resistentes, ainda que deformáveis, que respondem pelo seu extensivo uso em aplicações estruturais.

(b) CERÂMICAS

• Cerâmicas são compostos formados entre elementos metálicos e não metálicos: eles são muito frequentemente óxidos, nitretos e carbetos. A larga faixa de materiais que caem dentro desta classificação inclui cerâmicas que são compostas de minerais de argilas, cimento e vidro.

• Estes materiais são tipicamente isolantes à passagem de eletricidade e de calor, e são mais resistentes a altas temperaturas e ambientes rudes do que metais e polímeros. Com relação ao comportamento mecânico, cerâmicas são duras mas muito frágeis.

(c) POLÍMEROS

• Polímeros incluem os materiais familiares plástico e borracha. Muitos deles são compostos orgânicos que são quimicamente baseados em carbono, hidrogênio, e outros elementos não metálicos; além disto, eles têm muito grandes estruturas moleculares.

• Estes materiais têm tipicamente baixas densidades e podem ser extremamente flexíveis.

(d) COMPÓSITOS

• Têm sido fabricados um número de materiais compósitos que consistem mais do que um tipo de material. Fiberglass é um exemplo familiar, no qual fibras de vidro são embutidas dentro de um material polimérico.

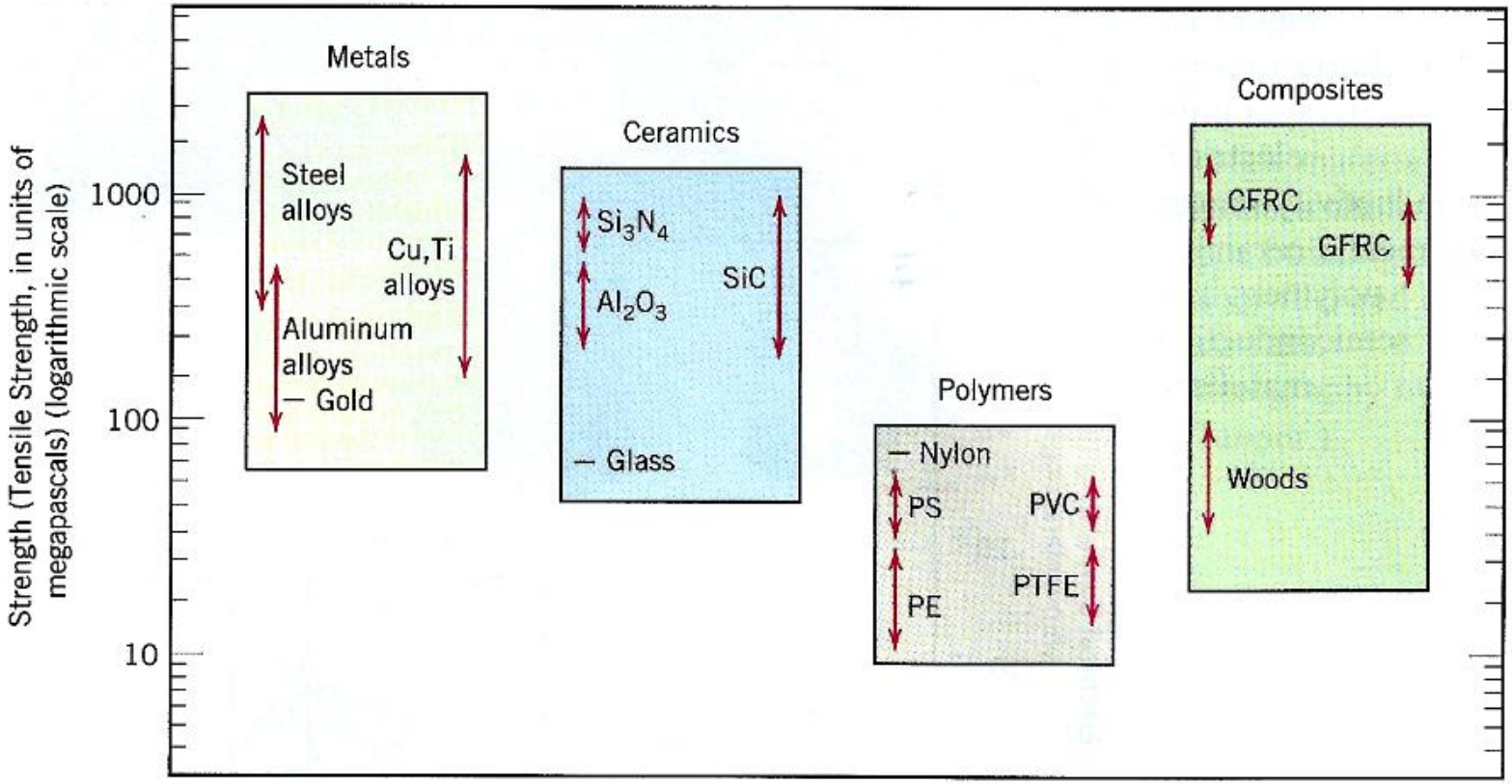
• Um compósito é projetado para exibir uma combinação das melhores características de cada um dos materiais componentes. "Fiberglass" adquire resistência mecânica das fibras de vidro e flexibilidade do polímero. Muitos dos recentes desenvolvimentos de material têm envolvido materiais compósitos.

(e) SEMICONDUTORES

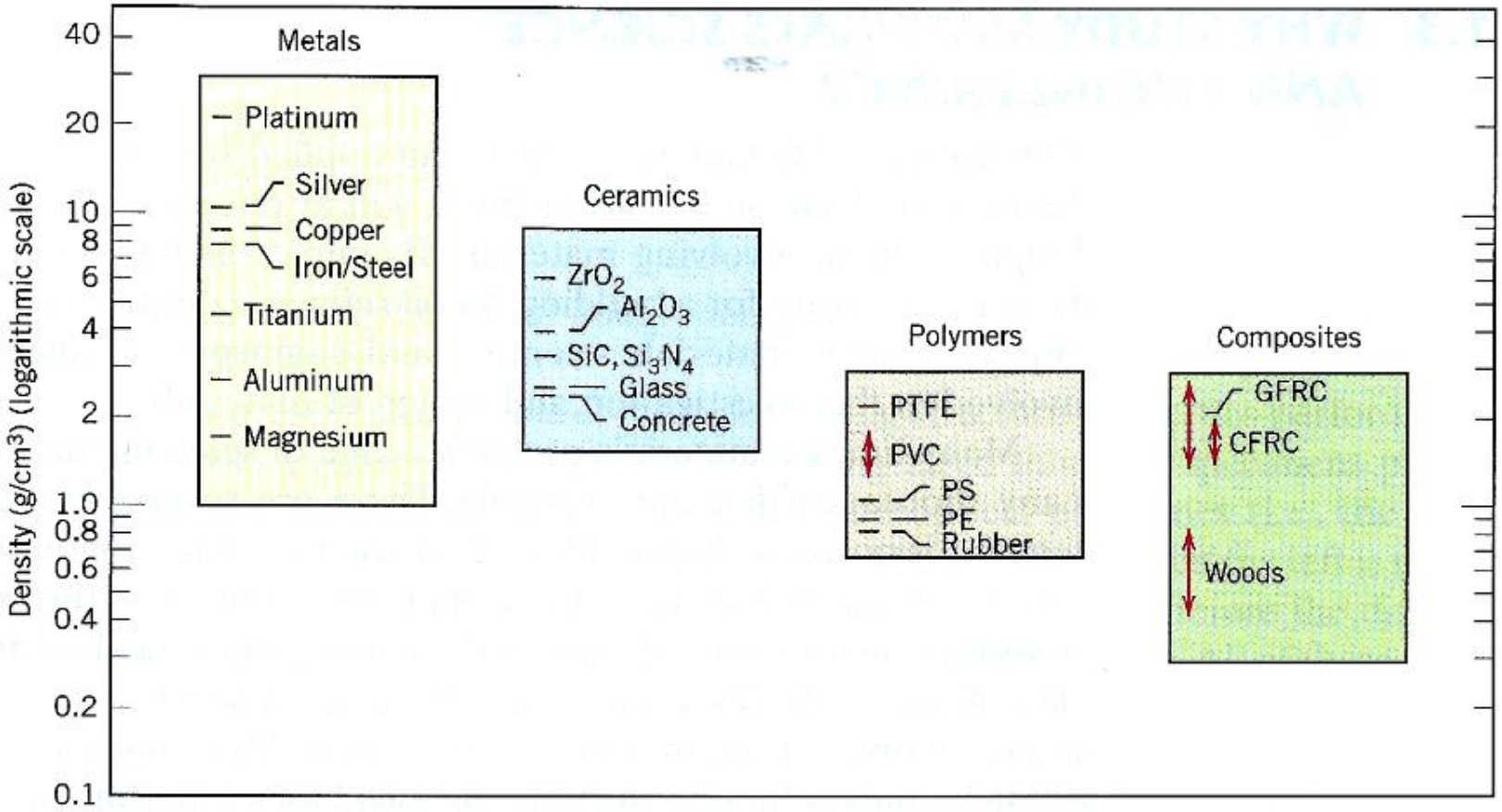
• Semicondutores têm propriedades elétricas que são intermediárias entre os condutores elétricos e os isolantes. Além disso, as características elétricas destes materiais são extremamente sensíveis à presença de diminutas concentrações de átomos impurezas, cujas concentrações podem ser controladas ao longo de muito pequenas regiões espaciais.

• Os semicondutores tornou possível o advento do circuito integrado que revolucionou totalmente a eletrônica e as indústrias de computadores, celulares e produtos eletrônicos.

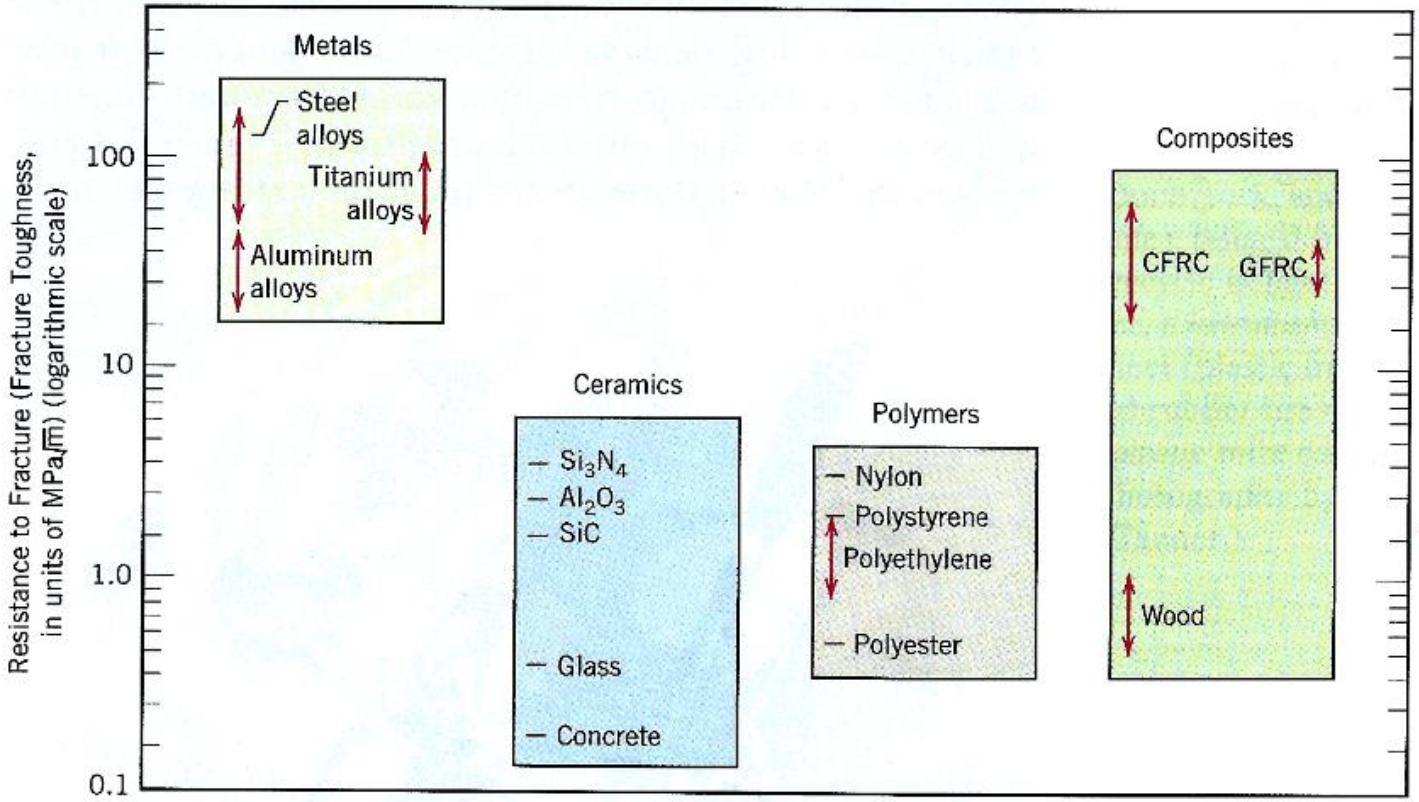
Resistência à tração à T_{amb}



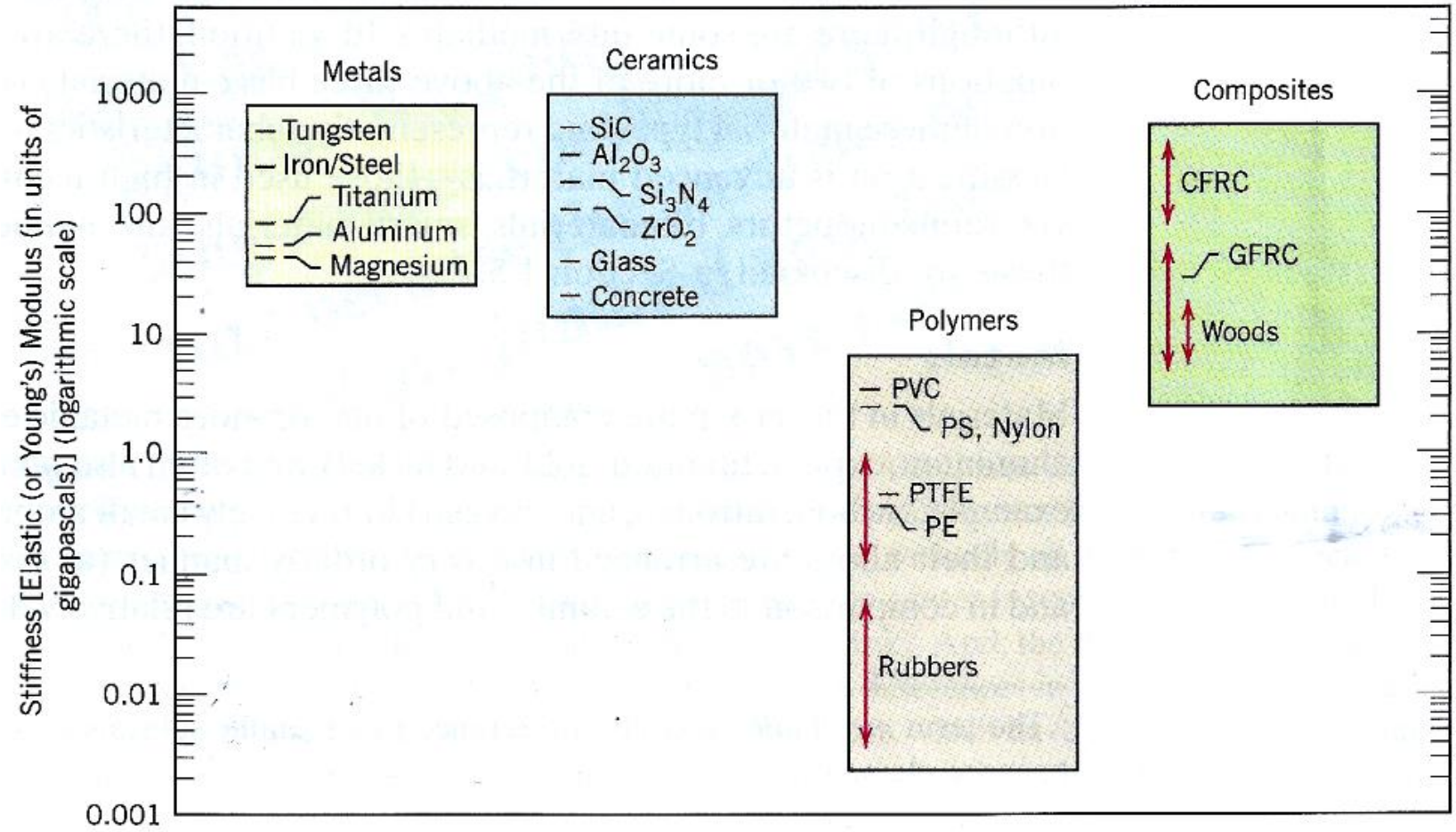
Densidade à temperatura ambiente



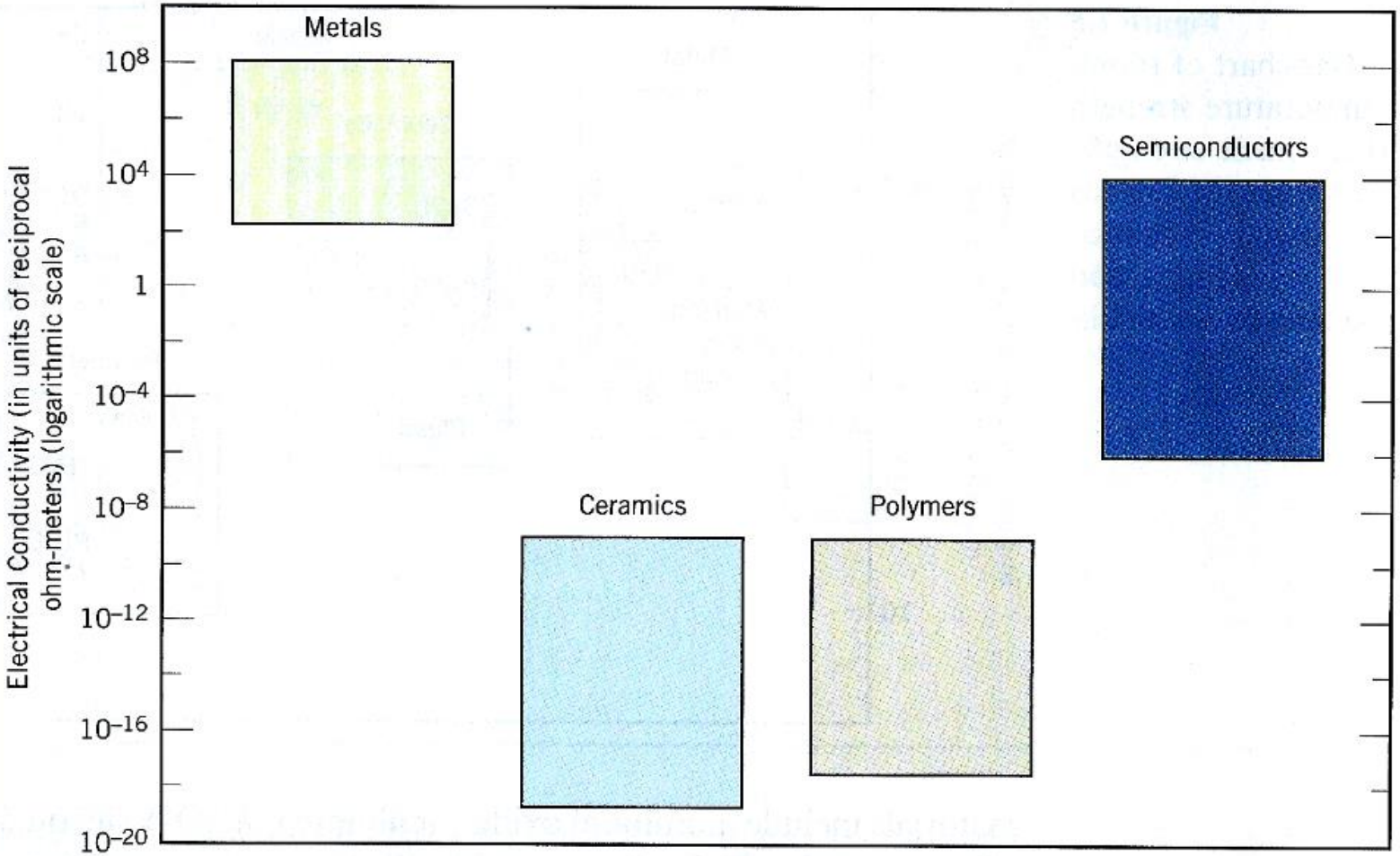
Resistência a fratura à T_{amb}



Rigidez (módulo da elasticidade) à temperatura ambiente



Condutibilidade elétrica à temperatura ambiente



Algumas das importantes propriedades de materiais sólidos depende dos arranjos geométricos dos átomos, e também das interações que existem entre os átomos ou moléculas constituintes.

Vários conceitos fundamentais e importantes, isto é:
(a) estrutura,

(b) configurações eletrônicas em átomos e na tabela periódica,

(c) os vários tipos de ligações interatômicas primárias e secundárias que mantém juntos os átomos que compõem um sólido.

Física dos Materiais

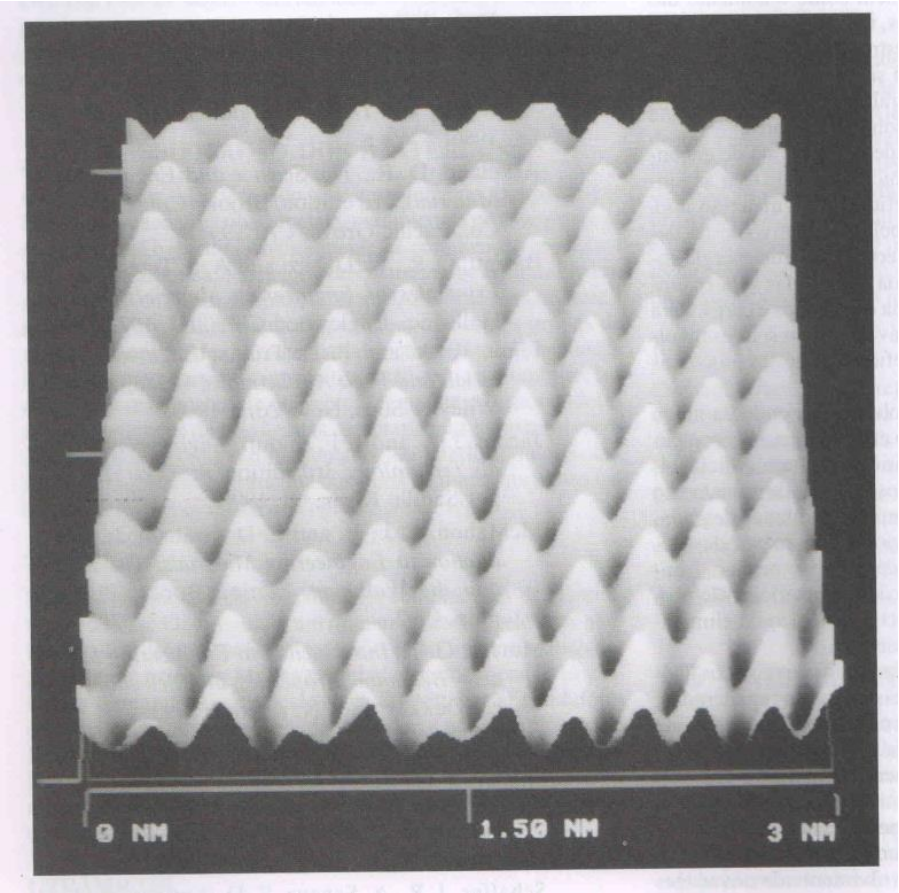


Imagem obtida por microscopia de força atômica (AFM) de uma superfície de Au, no plano (111)

PERIODIC TABLE OF THE ELEMENTS

Table of Selected Radioactive Isotopes

n	1	(15.3 min) β^-	67	(4.88 h) β^-	124	(60.20 d) β^-	181	(1.6 d) EC	231	(3.28x10⁴ y) α
H	3	(12.26 y) β^-	Zn	65 (244.1 d) β^+, EC	125	(2.7 y) β^-	182	(23.1 d) β^-	U	232 (1.39x10⁹ y) α
Be	7	(53.3 d) EC	Ge	67 (18.7 h) EC	Te	121 m(154 d) IT	188	(69 d) β^-		234 (2.44x10⁵ y) α
	10	(1.6x10⁶ y) β^-		72 (14.10 h) β^-		123 m(119.7 d) IT	Re	187 (5x10¹⁰ y) β^-		235 (7.04x10⁸ y) α
C	11	(20.40 min) β^+	Ge	68 (275 d) EC		127 m(109 d) IT	Os	194 (6.0 y) β^-		236 (2.34x10⁷ y) α
	14	(5730 y) β^-	As	73 (80.3 d) EC	I	129 (1.6x10⁷ y) β^-	Ir	192 (74.0 d) β^-, β^+, EC		238 (4.47x10⁹ y) α
F	18	(109.8 min) β^+		74 (17.9 d) β^-, β^+, EC		131 (8.040 d) β^-	Au	195 (183 d) EC	Np	236 (1.1x10⁵ y) EC, β^-
Na	22	(2.602 y) β^+, EC	Se	75 (118.5 d) β^-	Xe	133 (5.25 d) β^-		196 (6.18 d) β^+, EC, β^-		237 (2.1x10⁶ y) α
	24	(15.02 h) β^-		79 (6.5x10⁴ y) β^-		135 (9.10 h) β^-		198 (2.696 d) β^-		239 (2.346 d) β^-
Mg	28	(20.9 h) β^-	Br	82 (35.34 h) β^-	Cs	134 (2.06 y) β^-		199 (3.15 d) β^-	Pu	238 (87.75 y) α
Al	26	(7.2x10⁵ y) β^+, EC	Kr	81 (2.1x10⁵ y) EC		135 (2.9x10⁶ y) β^-	Hg	203 (46.8 d) β^-		239 (2.41x10⁴ y) α
P	32	(14.26 d) β^-		85 (10.72 y) β^-		137 (30.17 y) β^-	Tl	204 (3.77 y) β^-		240 (6.54x10³ y) α
S	35	(87.2 d) β^-	Rb	86 (18.7 d) β^-	Ba	140 (12.8 d) β^-	Pb	202 (3x10⁴ y) EC		242 (3.8x10⁵ y) α
Cl	36	(3.01x10⁵ y) β^-		87 (4.8x10¹⁰ y) β^-	La	137 (6x10⁴ y) EC		205 (3x10⁷ y) EC		244 (8.3x10⁷ y) α
	38	(37.2 min) β^-	Sr	90 (28.8 y) β^-		140 (40.3 h) β^-		210 (22.3 y) β^-, α	Am	241 (432 y) α
Ar	37	(35.02 d) EC	Y	88 (106.6 d) β^+, EC	Ce	144 (284 d) β^-	Bi	207 (38 y) EC		243 (7.37x10³ y) α
	39	(265 y) β^-	Zr	93 (1.5x10⁶ y) β^-	Pr	142 (19.1 h) β^-		208 (3.7x10⁵ y) EC	Cm	242 (163.2 d) α
K	40	(1.28x10⁹ y) EC		95 (64.0 d) β^-	Nd	147 (11.1 d) β^-		210 (3.01 d) β^-, α		244 (18.12 y) α
	42	(12.36 h) β^-	Nb	94 (2.0x10⁴ y) β^-	Pm	145 (18 y) EC		210 m(3x10⁶ y) α		247 (1.55x10⁷ y) α
Ca	45	(165 d) β^-		95 (35.15 d) β^-		147 (2.62 y) β^-	Po	208 (2.90 y) α		248 (3.5x10⁵ y) α, SF
Sc	46	(83.80 d) β^-	Mo	99 (66.02 h) β^-	Sm	146 (2x10⁷ y) α		209 (102 y) α	Bk	247 (1.4x10³ y) α
Cr	51	(27.70 d) EC	Tc	97 (2.6x10⁶ y) EC		151 (93 y) β^-		210 (138.38 d) α	Cf	249 (351 y) α
Mn	53	(2x10⁶ y) EC		98 (4.2x10⁶ y) β^-	Eu	152 (13 y) β^+, EC, β^-	At	211 (5.4 h) EC, α		251 (900 y) α
	54	(313.0 d) EC		99 (2.13x10⁵ y) β^-		154 (8.5 y) β^-	Fr	212 (6.1 h) EC	Es	252 (472 d) α
Fe	56	(2.578 h) β^-	Ru	106 (367 d) β^-	Gd	150 (1.1x10⁶ y) α		213 (19.3 min) EC, α		253 (20.47 d) α
	59	(44.6 d) β^-	Rh	101 (3.3 y) EC	Tb	158 (1.2x10⁵ y) EC, β^-	Ra	222 (3.824 d) α		254 (276 d) α
Co	56	(78.8d) β^+,EC	Pd	103 (17.0 d) EC		160 (72.3 d) β^-		224 (11.4 d) α	Fm	255 (20.1 h) α
	57	(270 d) EC		107 (7x10⁶ y) β^-	Ho	166 m(1.2x10³ y) β^-	Rn	220 (55.6 s) α		257 (100.5 d) α
	58	(71.3 d) β^+, EC	Ag	108 (127 y) EC	Tm	170 (128.6 d) β^-		222 (3.823 d) α	Md	258 (55 d) α
	60	(5.272 y) β^-		110 (252 d) β^-		171 (1.92 y) β^-	Ra	226 (1.60x10³ y) α	No	259 (58 min) α
Ni	57	(36.0 h) β^+, EC		111 (7.45 d) β^-	Yb	169 (32.0 d) EC	Ac	227 (21.77 y) β^-	Lr	260 (3.0 min) α
	59	(8x10⁴ y) EC	Cd	109 (453 d) EC		175 (4.19 d) β^-	Th	228 (1.913 y) α	104	261 (65 s) α
	63	(92 y) β^-	In	114 (49.51 d) IT	Lu	176 (3.7x10¹⁰ y) β^-		230 (7.7x10⁴ y) α	105	262 (40 s) α
Cu	64	(12.70 h) β^-, β^+, EC	Sn	121 (76 y) β^-	Ta	182 (115.0 d) β^-		232 (1.40x10¹⁰ y) α	106	263 (0.9 s) α

Selected Radioactive Isotopes

Naturally occurring radioactive isotopes are designated by a mass number in blue (although some are also manufactured). Letter m indicates an isomer of another isotope of the same mass number. Half-lives follow in parentheses, where s, min, h, d, and y stand respectively for seconds, minutes, hours, days, and years. The table includes mainly the longer-lived radioactive isotopes; many others have been prepared. Isotopes known to be radioactive but with half-lives exceeding 10¹⁰ y have not been included. Symbols describing the principal mode (or modes) of decay are as follows (these processes are generally accompanied by gamma radiation):

α alpha particle emission
β^- beta particle (electron) emission
β^+ positive emission
EC orbital electron capture
IT isomeric transition from upper to lower isomeric state
SF spontaneous fission

GROUP IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA	IB	IIB	IIIB	IVB	VB	VIB	VIIB	VIII
1 1.0079 H Hydrogen															2 4.00260 He Helium
3 6.941 Li Lithium	4 9.01218 Be Beryllium									5 10.81 B Boron	6 12.011 C Carbon	7 14.0067 N Nitrogen	8 15.9994 O Oxygen	9 18.998403 F Fluorine	10 20.179 Ne Neon
11 22.98977 Na Sodium	12 24.305 Mg Magnesium									13 26.98154 Al Aluminum	14 28.0855 Si Silicon	15 30.97376 P Phosphorus	16 32.06 S Sulfur	17 35.453 Cl Chlorine	18 39.948 Ar Argon
19 39.0983 K Potassium	20 40.08 Ca Calcium	21 44.9559 Sc Scandium	22 47.90 Ti Titanium	23 50.9415 V Vanadium	24 51.996 Cr Chromium	25 54.9380 Mn Manganese	26 55.847 Fe Iron	27 58.9332 Co Cobalt	28 58.70 Ni Nickel	29 63.546 Cu Copper	30 65.38 Zn Zinc	31 69.72 Ga Gallium	32 72.59 Ge Germanium	33 74.9216 As Arsenic	34 78.96 Se Selenium
37 85.4678 Rb Rubidium	38 87.62 Sr Strontium	39 88.9059 Y Yttrium	40 91.22 Zr Zirconium	41 92.9064 Nb Niobium	42 95.94 Mo Molybdenum	43 (98) Tc Technetium	44 101.07 Ru Ruthenium	45 102.9055 Rh Rhodium	46 106.4 Pd Palladium	47 107.868 Ag Silver	48 112.41 Cd Cadmium	49 114.82 In Indium	50 118.69 Sn Tin	51 121.75 Sb Antimony	52 127.60 Te Tellurium
55 132.9054 Cs Cesium	56 137.33 Ba Barium	57 138.9055 La Lanthanum	72 178.49 Hf Hafnium	73 180.9479 Ta Tantalum	74 183.85 W Tungsten	75 186.207 Re Rhenium	76 190.2 Os Osmium	77 192.22 Ir Iridium	78 195.09 Pt Platinum	79 196.9665 Au Gold	80 200.59 Hg Mercury	81 204.37 Tl Thallium	82 207.2 Pb Lead	83 208.9804 Bi Bismuth	84 (209) Po Polonium
87 (223) Fr Francium	88 226.0254 Ra Radium	89 227.0278 Ac Actinium	104 (261) Unq (Unniquadium)	105 (262) Unp (Unnilpentium)	106 (263) Unh (Unnilhexium)										

GROUP IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA	IB	IIB	IIIB	IVB	VB	VIB	VIIB	VIII
															85 (210) At Astatine
															86 (222) Rn Radon

† The names and symbols of elements 104 - 106 are those recommended by IUPAC as systematic alternatives to those suggested by the purported discoverers. Berkeley (USA) researchers have proposed Rutherfordium, Rf, for element 104 and Hahnium, Ha, for element 105. Dubna (USSR) researchers, who also claim the discovery of these elements have proposed different names (and symbols).

The A & B subgroup designations, applicable to elements in rows 4, 5, 6, and 7, are those recommended by the International Union of Pure and Applied Chemistry. It should be noted that some authors and organizations use the opposite convention in distinguishing these subgroups.

* Estimated Values

★ 58 140.12 Ce Cerium	59 140.9077 Pr Praseodymium	60 144.24 Nd Neodymium	61 (145) Pm Promethium	62 150.4 Sm Samarium	63 151.96 Eu Europium	64 157.25 Gd Gadolinium	65 158.9254 Tb Terbium	66 162.50 Dy Dysprosium	67 164.9304 Ho Holmium	68 167.26 Er Erbium	69 168.9342 Tm Thulium	70 173.04 Yb Ytterbium	71 174.967 Lu Lutetium	
★★ 90 232.0381 Th Thorium	91 231.0359 Pa Protactinium	92 238.029 U Uranium	93 237.0482 Np Neptunium	94 (244) Pu Plutonium	95 (243) Am Americium	96 (247) Cm Curium	97 (247) Bk Berkelium	98 (251) Cf Californium	99 (252) Es Einsteinium	100 (257) Fm Fermium	101 (258) Md Mendelevium	102 (259) No Nobelium	103 (260) Lr Lawrencium	

KEY

ATOMIC NUMBER — ATOMIC WEIGHT (2) — BOILING POINT, K — OXIDATION STATES (Bold most stable) — MELTING POINT, K — SYMBOL (1) — DENSITY at 300 K (3) (g/cm³) — ELECTRON CONFIGURATION — NAME

30 65.38 Zn [Ar]3d¹⁰4s² Zinc

NOTES:
(1) Black — solid. Red — gas. Blue — liquid. Outline — synthetically prepared.
(2) Based upon carbon-12. ( ) indicates most stable or best known isotope.
(3) Entries marked with asterisks refer to the gaseous state at 273 K and 1 atm and are given in units of g/l.

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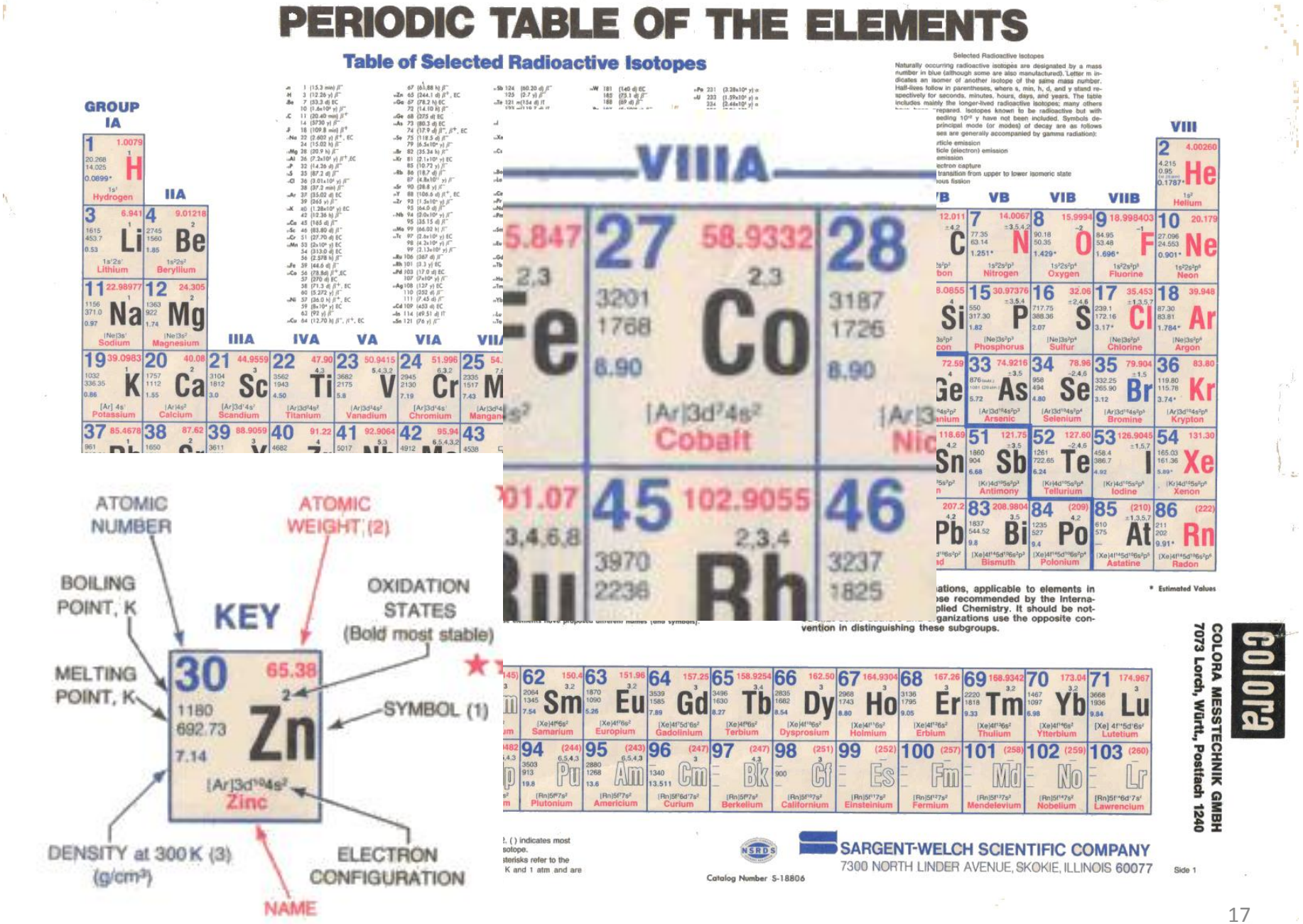
NSRDS
Catalog Number S-18806
SARGENT-WELCH SCIENTIFIC COMPANY
7300 NORTH LINDER AVENUE, SKOKIE, ILLINOIS 60077
Side 1

COLORA MESSTECHNIK GMBH
7073 Lorch, Württ., Postfach 1240
colora


PERIODIC TABLE OF THE ELEMENTS
Table of Selected Radioactive Isotopes
GROUP IA
IIA
IIIA
IVA
VA
VIA
VIIA
VIIIA
VIB
VIIB
VIII
Selected Radioactive Isotopes
Naturally occurring radioactive isotopes are designated by a mass number in blue (although some are also manufactured). Letter m indicates an isomer of another isotope of the same mass number. Half-lives follow in parentheses, where s, min, h, d, and y stand respectively for seconds, minutes, hours, days, and years. The table includes mainly the longer-lived radioactive isotopes; many others have been prepared. Isotopes known to be radioactive but with exceeding 10^24 y have not been included. Symbols denote principal mode (or modes) of decay are as follows (modes are generally accompanied by gamma radiation):
article emission
ticle (electron) emission
emission
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transition from upper to lower isomeric state
ous fission
ations, applicable to elements in
se recommended by the Interna-
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ganizations use the opposite con-
vention in distinguishing these subgroups.
* Estimated Values
ATOMIC NUMBER
ATOMIC WEIGHT (2)
BOILING POINT, K
OXIDATION STATES (Bold most stable)
KEY
MELTING POINT, K
SYMBOL (1)
DENSITY at 300 K (3) (g/cm³)
ELECTRON CONFIGURATION
NAME
30 65.38 2 1180 692.73 7.14 Zn [Ar]3d¹⁰4s² Zinc
27 58.9332 2,3 3201 1768 8.90 Co [Ar]3d⁷4s² Cobalt
28 3187 1726
45 102.9055 2,3,4 3970 2236 Rh
46 3237 1825
62 150.4 Sm Samarium
63 151.96 Eu Europium
64 157.25 Gd Gadolinium
65 158.9254 Tb Terbium
66 162.50 Dy Dysprosium
67 164.9304 Ho Holmium
68 167.26 Er Erbium
69 168.9342 Tm Thulium
70 173.04 Yb Ytterbium
71 174.967 Lu Lutetium
94 (244) Pu Plutonium
95 (243) Am Americium
96 (247) Cm Curium
97 (247) Bk Berkelium
98 (251) Cf Californium
99 (252) Es Einsteinium
100 (257) Fm Fermium
101 (258) Md Mendelevium
102 (259) No Nobelium
103 (260) Lr Lawrencium
NSRDS
Catalog Number S-18806
SARGENT-WELCH SCIENTIFIC COMPANY
7300 NORTH LINDER AVENUE, SKOKIE, ILLINOIS 60077
Side 1
colora
COLORA MESSTECHNIK GMBH
7073 Lorch, Württ., Postfach 1240

TABLE OF PERIODIC PROPERTIES OF THE ELEMENTS

Percent Ionic Character of a Single Chemical Bond

Difference in electronegativity	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2
Percent ionic character %	0.5	1	2	4	6	9	12	15	19	22	26	30	34	39	43	47	51	55	59	63	67	70	74	76	79	82	84	86	88	89	91	92

DATA CONCERNING THE MORE STABLE ELEMENTARY (SUBATOMIC) PARTICLES

	Neutron	Proton	Electron*	Neutrino*	Photon
Symbol	n	p	e (e^-)	ν	γ
Rest mass (kg)	1.67495×10^{-27}	1.67265×10^{-27}	9.1095×10^{-31}	~0	0
Relative atomic mass (^{12}C = 12)	1.008665	1.007276	5.48580×10^{-4}	~0	0
Charge (C)	0	1.60219×10^{-19}	-1.60219×10^{-19}	0	0
Radius (m)	8×10^{-16}	8×10^{-16}	$<1\times10^{-16}$	~0	0
Spin quantum number	1/2	1/2	1/2	1/2	1
Magnetic Moment†	$-1.913\ \mu_N$	$2.793\ \mu_N$	$1.001\ \mu_B$	0	0

* The positron (e^+) has properties similar to those of the (negative) electron or beta particle except that its charge has opposite sign (+). The antineutrino ($\bar{\nu}$) has properties similar to those of the neutrino except that its spin (or rotation) is opposite in relation to its direction of propagation.

An antineutrino accompanies release of an electron in radioactive β^- (particle) decay, whereas a neutrino accompanies the release of a positron in β^+ decay.

†μ_B=Bohr magneton and μ_N=Nuclear magneton.

GROUP IA, IIA, IIIA, IVA, VA, VIA, VIIA, VIIIA, IB, IIB, IIIB, IVB, VB, VIB, VIIB, VIII

Z	Symbol	Name	Atomic mass	Density	Melting point	Boiling point	Specific heat	Atomic volume	Ionization potential	Electronegativity	Covalent radius	Atomic radius	Heat of vaporization	Heat of fusion	Electrical conductivity	Thermal conductivity
1	H	Hydrogen	1.008	0.0899	14.4	20.28	14.304	11.42	13.598	2.20	0.32	0.79	0.449	0.058	—	0.001815
2	He	Helium	4.003	0.1785	0.95	4.216	5.193	21.0	24.587	—	0.93	0.49	0.084	0.005	—	0.00152
3	Li	Lithium	6.941	0.534	453.7	1615	3.582	13.1	5.392	0.98	1.23	2.05	145.92	3.00	13.10	0.847
4	Be	Beryllium	9.012182	1.848	1560	2742	1.825	4.9	9.322	1.57	0.90	1.40	292.40	5.0	12.20	2.00
5	B	Boron	10.811	2.34	2300	2550	1.026	4.6	8.298	2.04	0.82	1.17	489.70	50.20	0.071	0.270
6	C	Carbon	12.0107	2.267	3823	4300	0.709	5.3	11.260	2.55	0.77	0.91	355.80	—	4.58	1.29
7	N	Nitrogen	14.0067	0.0012506	63.15	77.35	1.042	17.3	14.534	3.04	0.75	0.75	2.7928	0.3604	0.71	0.0002598
8	O	Oxygen	15.9994	0.001429	54.75	90.188	0.918	14.0	13.618	3.44	0.73	0.65	3.4099	0.22259	0.267	0.0002674
9	F	Fluorine	18.9984032	0.001696	53.53	85.03	0.824	17.1	17.422	3.98	0.72	0.57	3.2698	0.2552	0.279	0.000279
10	Ne	Neon	20.1797	0.9002	24.56	27.102	1.030	16.7	21.564	—	0.71	0.51	1.7326	0.3317	0.494	0.000493
11	Na	Sodium	22.989769	0.971	370.95	1156	1.228	23.7	5.139	0.93	1.54	2.23	96.960	2.598	7.846	1.41
12	Mg	Magnesium	24.3050	1.738	923	1363	1.024	14.0	7.646	1.31	1.36	1.72	127.40	8.954	1.02	1.56
13	Al	Aluminum	26.981539	2.7	933.47	2793	0.900	10.0	5.986	1.61	1.18	1.82	293.40	10.790	0.90	2.37
14	Si	Silicon	28.0855	2.33	1687	3538	0.703	12.1	8.151	1.90	1.11	1.46	384.220	50.550	0.71	1.48
15	P	Phosphorus	30.973761	1.823	317.30	553	0.769	17.0	10.486	2.19	1.06	1.23	12.129	0.657	0.77	0.00235
16	S	Sulfur	32.066	2.07	388.36	717.824	0.732	15.5	10.360	2.58	1.02	1.09	—	1.7175	0.71	0.00269
17	Cl	Chlorine	35.4527	0.0032166	172.2	239.18	0.479	22.7	12.967	3.16	0.99	0.97	10.20	3.203	0.48	0.000089
18	Ar	Argon	39.948	1.7837	83.81	87.29	0.520	28.5	15.759	1.188	0.98	0.88	6.447	—	0.320	0.0001772
19	K	Potassium	39.0983	0.862	336.8	1032	0.757	45.46	4.341	0.82	2.03	2.77	79.870	2.334	4.341	1.024
20	Ca	Calcium	40.078	1.55	1112	1757	0.647	29.9	6.113	1.00	1.74	2.23	153.60	8.540	0.63	2.00*
21	Sc	Scandium	44.955910	2.989	1814	3109	0.568	15.0	6.54	1.36	1.44	2.09	314.20	14.10	0.6	0.158
22	Ti	Titanium	47.867	4.54	1933	3560	0.523	10.64	6.82	1.54	1.32	2.00	421.00	15.450	0.52	0.219
23	V	Vanadium	50.9415	6.11	2183	3680	0.489	8.78	6.74	1.63	1.22	1.92	0.452	20.90	0.49	0.307
24	Cr	Chromium	51.9961	7.19	2180	2944	0.449	7.23	6.766	1.66	1.18	1.85	344.30	16.90	0.45	0.937
25	Mn	Manganese	54.938049	7.3	1519.5	2334	0.479	7.39	7.435	1.55	1.17	1.79	226.0	12.050	0.48	0.0782
26	Fe	Iron	55.845	7.87	1808	3023	0.449	7.1	7.870	1.83	1.17	1.72	349.60	13.80	0.44	0.802
27	Co	Cobalt	58.933200	8.9	1768	3143	0.421	6.7	7.86	1.88	1.16	1.67	376.50	16.190	0.42	1.00
28	Ni	Nickel	58.6934	8.9	1728	3186	0.444	6.59	7.635	1.91	1.15	1.62	370.40	17.470	0.44	0.907
29	Cu	Copper	63.546	8.96	1357.77	2835	0.385	7.1	7.726	1.90	1.17	1.57	300.30	13.050	0.38	4.01
30	Zn	Zinc	65.409	7.133	692.73	1180	0.388	9.2	9.394	1.65	1.25	1.53	115.30	7.322	0.39	1.16
31	Ga	Gallium	69.723	5.904	302.9146	2403	0.371	11.8	5.999	1.81	1.26	1.81	258.70	5.590	0.37	0.406
32	Ge	Germanium	72.64	5.323	1211.40	3106	0.320	13.6	7.899	2.01	1.22	1.52	330.90	36.940	0.32	0.599
33	As	Arsenic	74.921596	5.73	1090	887	0.329	13.1	9.81	2.18	1.20	1.33	34.760	—	0.33	0.500
34	Se	Selenium	78.96	4.81	494	958.1	0.321	16.45	9.752	2.55	1.16	1.22	37.70	6.694	0.32	0.0204
35	Br	Bromine	79.904	3.12	265.8	332.0	0.473	23.5	11.814	2.96	1.14	1.12	15.438	5.286	0.473	0.00122
36	Kr	Krypton	83.798	3.749	115.79	119.93	0.248	38.9	13.999	1.638	1.12	1.03	9.029	0.0000949		
37	Rb	Rubidium	85.4678	1.532	312.46	961	0.363	55.9	4.177	0.82	2.16	2.98	72.216	2.192	0.363	0.582
38	Sr	Strontium	87.62	2.54	1050	1384	0.301	33.7	5.695	0.95	1.91	2.45	144.0	8.30	0.30	0.353
39	Y	Yttrium	88.905850	4.469	1799	3609	0.298	19.8	6.38	1.22	1.62	2.27	363.0	11.40	0.30	0.172
40	Zr	Zirconium	91.224	6.506	2128	4682	0.278	14.1	6.84	1.33	1.45	2.16	58.20	16.90	0.27	0.227
41	Nb	Niobium	92.906378	8.57	2468	5015	0.265	10.87	6.88	1.6	1.34	2.08	682.0	26.40	0.26	0.537*
42	Mo	Molybdenum	95.94	10.22	2896	4912	0.251	9.4	7.099	2.16	1.30	2.01	598.0	32.0	0.25	1.38
43	Tc	Technetium	[98]	11.5	2430	4538	0.243	8.5	7.28	1.9	1.27	1.95	660.0	24.0	0.21	0.506
44	Ru	Ruthenium	101.07	12.41	2607	4423	0.238	8.3	7.37	2.2	1.25	1.89	595.0	24.0	0.238	1.17
45	Rh	Rhodium	102.905500	12.41	2237	4538	0.243	8.3	7.46	2.28	1.25	1.83	493.0	21.50	0.242	1.50
46	Pd	Palladium	106.42	12.02	1828.05	3236	0.246	8.9	8.34	2.20	1.28	1.79	357.0	17.60	0.24	0.718
47	Ag	Silver	107.8682	10.501	1234.93	2436	0.235	10.3	7.576	1.93	1.34	1.75	250.580	11.30	0.235	4.29
48	Cd	Cadmium	112.411	8.65	594.22	1040	0.232	13.1	8.993	1.69	1.48	1.71	99.570	6.192	0.23	0.968
49	In	Indium	114.818	7.31	429.75	2353	0.233	15.7	5.786	1.78	1.44	2.00	231.50	3.263	0.23	0.816
50	Sn	Tin	118.710	7.287	505.08	2875	0.228	16.3	7.344	2.05	1.41	1.72	295.80	7.029	0.227	0.666
51	Sb	Antimony	121.760	6.691	903.78	1908	0.205	18.23	8.641	2.05	1.40	1.53	77.140	19.870	0.21	0.243
52	Te	Tellurium	127.60	6.24	722.66	1261	0.202	20.5	9.009	2.1	1.36	1.42	52.550	17.490	0.20	0.0235
53	I	Iodine	126.904473	4.93	386.85	457.4	0.214	25.74	10.451	2.66	1.33	1.32	20.752	7.824	0.214	0.00449
54	Xe	Xenon	131.293	5.887	161.4	165.051	0.158	37.3	12.130	2.297	1.31	1.24	12.636	2.297	0.158	0.0000569
55	Cs	Cesium	132.905451	1.873	301.59	944	0.242	70.0	3.894	0.79	2.35	3.34	67.740	2.092	0.24	0.359
56	Ba	Barium	137.327	3.594	1000	2171	0.204	39.24	5.212	0.89	1.98	2.78	142.0	7.750	0.204	0.184*
57	La	Lanthanum	138.90547	6.145	1193	3737	0.195	22.5	5.58	1.10	1.69	2.74	414.0	8.368	0.19	0.135
72	Hf	Hafnium	178.49	13.31	2506	4602	0.144	13.6	6.65	1.3	1.44	2.16	575.0	24.060	0.14	0.230
73	Ta	Tantalum	180.94788	16.654	3269	5458	0.140	10.90	7.89	1.5	1.34	2.09	743.0	31.60	0.14	0.575
74	W	Tungsten	183.84	19.3	3422	5555	0.134	9.53	7.98	2.36	1.30	2.02	824.0	35.40	0.13	1.74
75	Re	Rhenium	186.207	21.02	3186	5596	0.137	8.85	7.88	1.9	1.28	1.97	713.0	33.20	0.13	0.479
76	Os	Osmium	190.23	22.57	3033	5012	0.130	8.49	8.7	2.2	1.26	1.92	746.0	31.80	0.13	0.876
77	Ir	Iridium	192.217	22.42	2447	4428	0.131	8.54	9.1	2.20	1.27	1.87	604.0	26.10	0.130	1.47
78	Pt	Platinum	195.078	21.45	2041.4	4098	0.133	9.10	9.0	2.28	1.30	1.83	510.0	19.60	0.13	0.716
79	Au	Gold	196.966569	19.32	1064.43	3129	0.129	10.2	9.225	2.54	1.34	1.79	324.40	12.550	0.128	3.17
80	Hg	Mercury	200.59	13.546	234.31	629.88	0.139	14.82	10.437	2.00	1.49	1.76	59.229	2.295	0.139	0.0834
81	Tl	Thallium	204.383	11.85	577	1746	0.130	17.2	6.108	2.04	1.48	2.08	164.10	4.142	0.13	0.461
82	Pb	Lead	207.2	11.342	600.61	2022	0.129	18.17	7.416	2.33	1.47	1.81	177.70	4.799	0.13	0.353
83	Bi	Bismuth	208.980378	9.808	544.592	1837	0.122	21.3	7.289	2.02	1.46	1.63	104.80	11.30	0.12	0.0787
84	Po	Polonium	[209]	9.32	527	1235	—	—	8.42	2.0	1.46	1.53	—	—	—	0.20*
85	At	Astatine	[210]	—	575	610	—	—	—	2.2	(1.45)	1.43	—	—	—	0.017*
86	Rn	Radon	[222]	9.73	202	211.4	0.094	50.5	10.748	2.890	—	1.34	16.40	—	0.09*	0.0000364*
87	Fr	Francium	[223]	—	300	950	—	—	—	0.7	—	—	—	—	—	0.15*
88	Ra	Radium	[226]	5.0	973	1413	0.094	45.20	5.279	0.9	—	—	—	—	—	0.186*
89	Ac	Actinium	[227]	10.07	1323	3471	0.120	22.54	5.17	1.1	—	—	—	—	—	0.12*
90	Th	Thorium	232.038100	11.72	2023	5061	0.113	19.9	6.08	1.3	1.65	1.80	514.40	16.10	0.12	0.540
91	Pa	Protactinium	231.035880	15.37	1841	4300	—	—	—	1.5	—	—	—	—	—	0.47*
92	U	Uranium	238.028913	18.95	1405.5	4404	0.116	12.59	6.05	1.38	1.42	1.86	477.0	8.520	0.12	0.276
93	Np	Neptunium	[237]	20.25	917	4273	—	11.62	6.19	1.36	—	—	—	5.190	0.12	0.063
94	Pu	Plutonium	[244]	19.84	913	3505	0.128	12.32	6.06	1.28	—	—	344.0	2.840	0.12*	0.0674
95	Am	Americium	[243]	13.67	1449	2880	—	17.86	5.993	1.3	—	—	—	14.40	0.11*	0.1*
96	Cm	Curium	[247]	13.51	1340	3383	—	18.28	6.02	1.3	—	—	—	15.0	—	0.1*
97	Bk	Berkelium	[247]	14.78	1050	2627	—	—	—	1.3	—	—	—	—	6.23	—
98	Cf	Californium	[251]	15.1	900	1173	—	—	—	1.3	—	—	—	—	6.30	—
99	Es	Einsteinium	[252]	8.84	1133	1773	—	—	—	1.3	—	—	—	—	6.42	—
100	Fm	Fermium	[257]	—	1800	—	—	—	—	1.3	—	—	—	—	6.50	—
101	Md	Mendelevium	[258]	—	1100	—	—	—	—	1.3	—	—	—	—	6.58	—
102	No	Nobelium	[259]	—	1100	—	—	—	—	1.3	—	—	—	—	6.65	—
103	Lr	Lawrencium	[262]	—	1900	—	—	—	—	—	—	—	—	—	—	—
104	Unq	Unnilquadium	[261]	—	—	—	—	—	—	—	—	—	—	—	—	—
105	UnP	Unnilpentium	[262]	—	—	—	—	—	—	—	—	—	—	—	—	—
106	Unh	Unnilhexium	[263]	—	—	—	—	—	—	—	—	—	—	—	—	—

The names and symbols of elements 104 - 106 are those recommended by IUPAC as systematic alternatives to those suggested by the purported discoverers. Berkeley (USA) researchers have proposed Rutherfordium, Rf, for element 104 and Hahnium, Ha, for element 105. Dubna (USSR) researchers, who also claim the discovery of these elements have proposed different names (and symbols).

Z	Symbol	Name	Atomic mass	Density	Melting point	Boiling point	Specific heat	Atomic volume	Ionization potential	Electronegativity	Covalent radius	Atomic radius	Heat of vaporization	Heat of fusion	Electrical conductivity	Thermal conductivity
58	Ce	Cerium	140.116	6.689	1068	3443	0.192	20.67	5.54	1.12	1.65	2.70	414.0	5.460	0.19	0.114
59	Pr	Praseodymium	140.907653	6.773	1208	3793	0.193	20.8	5.46	1.13	1.65	2.67	296.80	6.890	0.19	0.125
60	Nd	Neodymium	144.242	7.01	1297	3347	0.190	20.6	5.53	1.14	1.64	2.64	273.0	7.140	0.19	0.165
61	Pm	Promethium	[145]	7.26	1315	3273	—	22.39	5.554	—	1.63	2.62	—	—	—	0.179*
62	Sm	Samarium	150.36	7.52	1345	2067	0.197	19.95	5.64	1.17	1.62	2.59	166.40	8.630	0.20	0.133
63	Eu	Europium	151.964	5.244	1099	1802	0.182	28.9	5.67	1.2	1.85	2.56	162.50	9.210	0.18	0.139*
64	Gd	Gadolinium	157.25	7.901	1585	3273	0.236	19.9	6.15	1.20	1.61	2.54	359.40	10.050	0.23	0.106
65	Tb	Terbium	158.925354	8.229	1629	3123	0.182	19.2	5.86	1.2	1.59	2.51	330.90	10.80	0.18	0.111
66	Dy	Dysprosium	162.500	8.551	1412	2567	0.173	19.0	5.94	1.22	1.59	2.49	230.0	11.060	0.17	0.107
67	Ho	Holmium	164.930328	8.795	1474	2700	0.165	18.7	6.018	1.23	1.58	2.47	241.0	17.20	0.16	0.162
68	Er	Erbium	167.259	9.066	1529	2868	0.168	18.4	6.101	1.24	1.57	2.45	261.0	19.90	0.17	0.143
69	Tm	Thulium	168.934213	9.321	1545	1950	0.160	18.1	6.184	1.25	1.56	2.42	191.0	16.840	0.16	0.168
70	Yb	Ytterbium	173.054	6.966	819	1196	0.155	24.79	6.254	1.1	1.74	2.40	128.90	7.660	0.15	0.349
71	Lu	Lutetium	174.967	9.841	1663	3402	0.154	17.78	5.43	1.27	1.56	2.25	355.90	18.60	0.15	0.164
90	Th	Thorium	232.038100	11.72	2023	5061	0.113	19.9	6.08	1.3	1.65	1.80	514.40	16.10	0.12	0.540
91	Pa	Protactinium	231.035880	15.37	1841	4300	—	—	—	1.5	—	—	—	—	—	0.47*
92	U	Uranium	238.028913	18.95	1405.5	4404	0.116	12.59	6.05	1.38	1.42	1.86	477.0	8.520	0.12	0.276
93	Np	Neptunium	[237]	20.25	917	4273	—	11.62	6.19	1.36	—	—	—	5.190	0.12	0.063
94	Pu	Plutonium	[244]	19.84	913	3505	0.128	12.32	6.06	1.28	—	—	344.0	2.840	0.12*	0.0674
95	Am	Americium	[243]	13.67	1449	2880	—	17.86	5.993	1.3	—	—	—	14.40	0.11*	0.1*
96	Cm	Curium	[247]	13.51	1340	3383	—	18.28	6.02	1.3	—	—	—	15.0	—	0.1*
97	Bk	Berkelium	[247]	14.78	1050	2627	—	—	—	1.3	—	—	—	—	6.23	—
98	Cf	Californium	[251]	15.1	900	1173	—	—	—	1.3	—	—	—	—	6.30	—
99	Es	Einsteinium	[252]	8.84	1133	1773	—	—	—	1.3	—	—	—	—	6.42	—
100	Fm	Fermium	[257]	—	1800	—	—	—	—	1.3	—	—	—	—	6.50	—
101	Md	Mendelevium	[258]	—	1100	—	—	—	—	1.3	—	—	—	—	6.58	—
102	No	Nobelium	[259]	—	1100	—	—	—	—	1.3	—	—	—	—	6.65	—
103	Lr	Lawrencium	[262]	—	1900	—	—	—	—	—	—	—	—	—	—	—

KEY

Zn
COVALENT RADIUS, Å — 1.25
ATOMIC RADIUS, Å (7) — 1.65
ATOMIC VOLUME, cm³/mol (8) — 9.2
FIRST IONIZATION POTENTIAL, V — 9.394
SYMBOL — Zn
CRYSTAL STRUCTURE (2) — hexagonal
ACID-BASE PROPERTIES (1) — 0.39
ELECTRONEGATIVITY (Pauling's) — 1.65
HEAT OF VAPORIZATION, kJ/mol (4) — 115.30
HEAT OF FUSION, kJ/mol (5) — 7.322
ELECTRICAL CONDUCTIVITY, $10^4\ \Omega^{-1}\ cm^{-1}$ (6) — 1.16
SPECIFIC HEAT CAPACITY, $J\ g^{-1}\ K^{-1}$ (3) — 0.540
THERMAL CONDUCTIVITY, $W\ cm^{-1}\ K^{-1}$ (3) — 0.12

NOTES: (1) For representative oxides (higher valence) of group. Oxide is acidic if color is red, basic if color is blue and amphoteric if both colors are shown. Intensity of color indicates relative strength.

(2) Cubic, face centered; cubic, body centered; cubic; hexagonal; rhombohedral; tetragonal; orthorhombic; monoclinic.

(3) At 300 K (27°C)

(4) At boiling point

(5) At melting point

(6) Generally at 293 K (20°C)

(7) Quantum mechanical value for free atom

(8) From density at 300 K (27°C) for liquid and solid elements; values for gaseous elements refer to liquid state at boiling point

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Catalog Number S-18806
SIDE 2

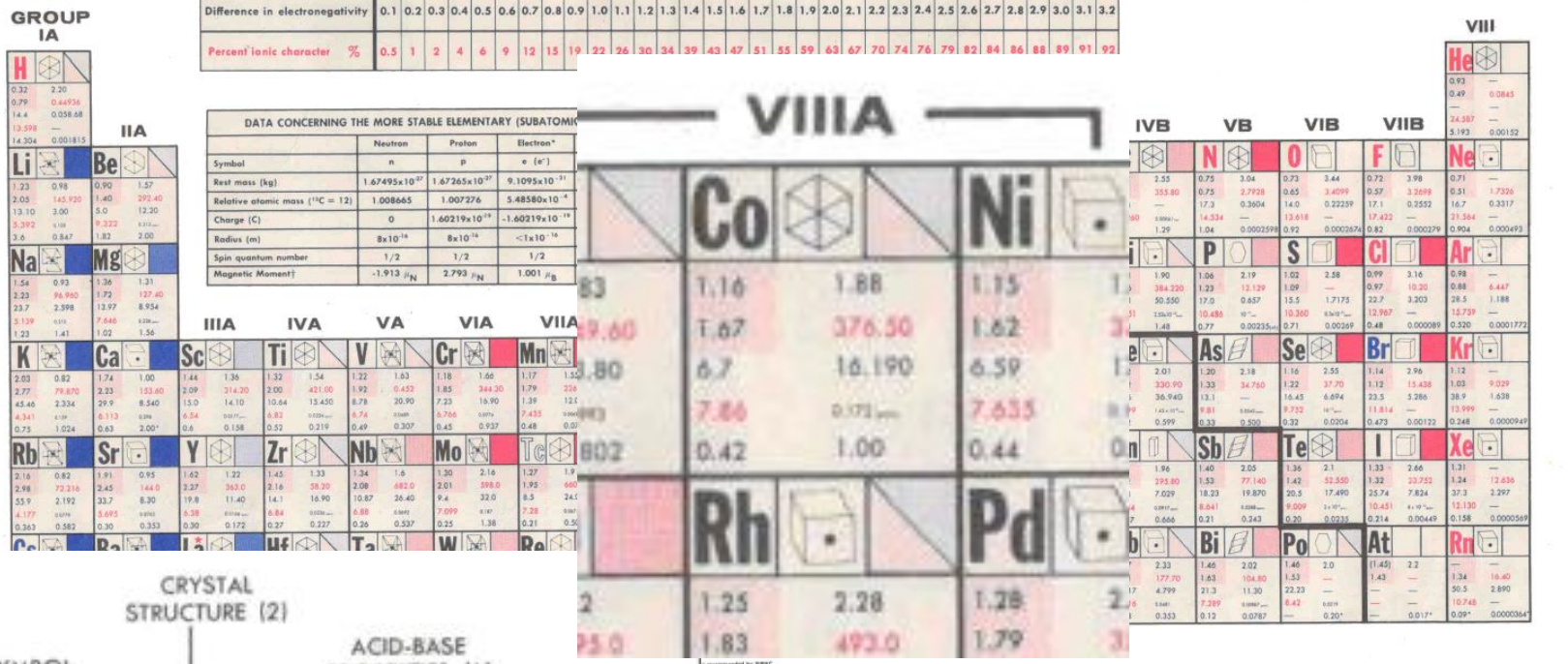
TABLE OF PERIODIC PROPERTIES OF THE ELEMENTS

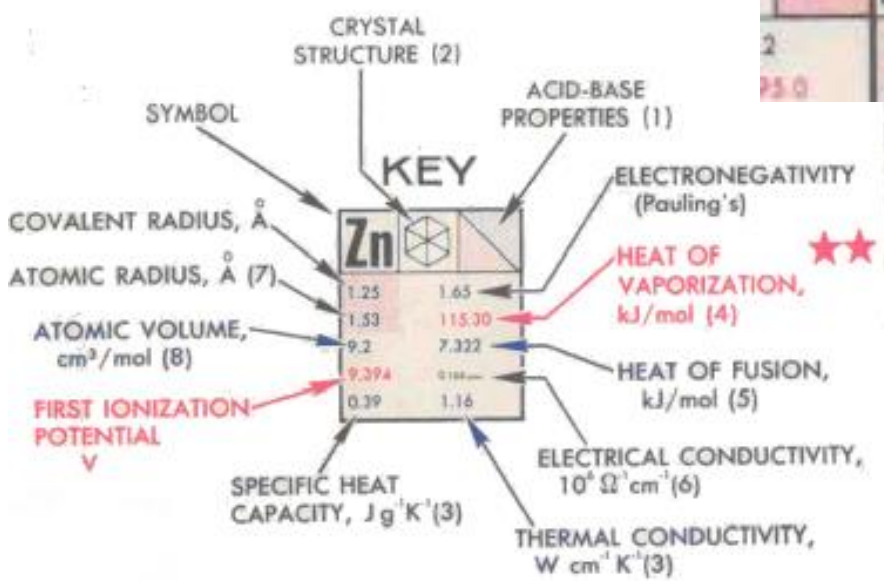
Percent Ionic Character of a Single Chemical Bond

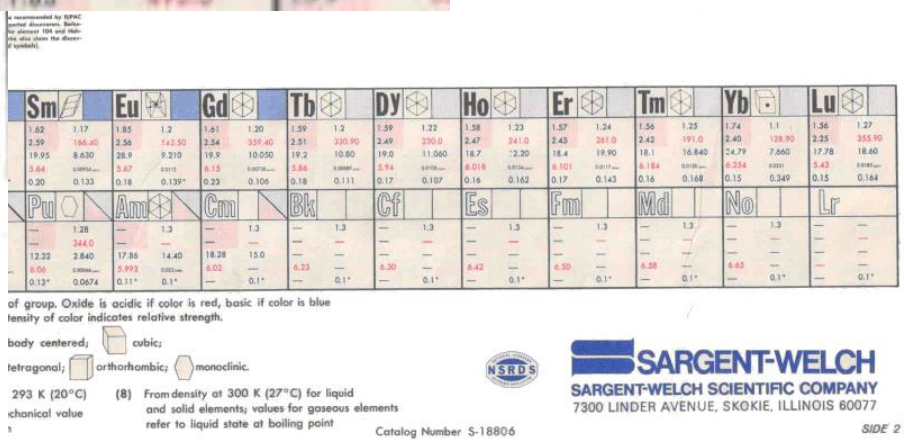
Difference in electronegativity	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2
Percent ionic character %	0.5	1	2	4	6	9	12	15	19	22	26	30	34	39	43	47	51	55	59	63	67	70	74	76	79	82	84	86	88	89	91	92

DATA CONCERNING THE MORE STABLE ELEMENTARY (SUBATOMIC

	Neutron	Proton	Electron*
Symbol	n	p	e (e^-)
Rest mass (kg)	1.67495×10^{-27}	1.67265×10^{-27}	9.1095×10^{-31}
Relative atomic mass ($^{12}C = 12$)	1.008665	1.007276	5.48580×10^{-4}
Charge (C)	0	1.60219×10^{-19}	-1.60219×10^{-19}
Radius (m)	8×10^{-16}	8×10^{-16}	$<1\times10^{-16}$
Spin quantum number	1/2	1/2	1/2
Magnetic Moment†	-1.913 μ_N	2.793 μ_N	1.001 μ_B

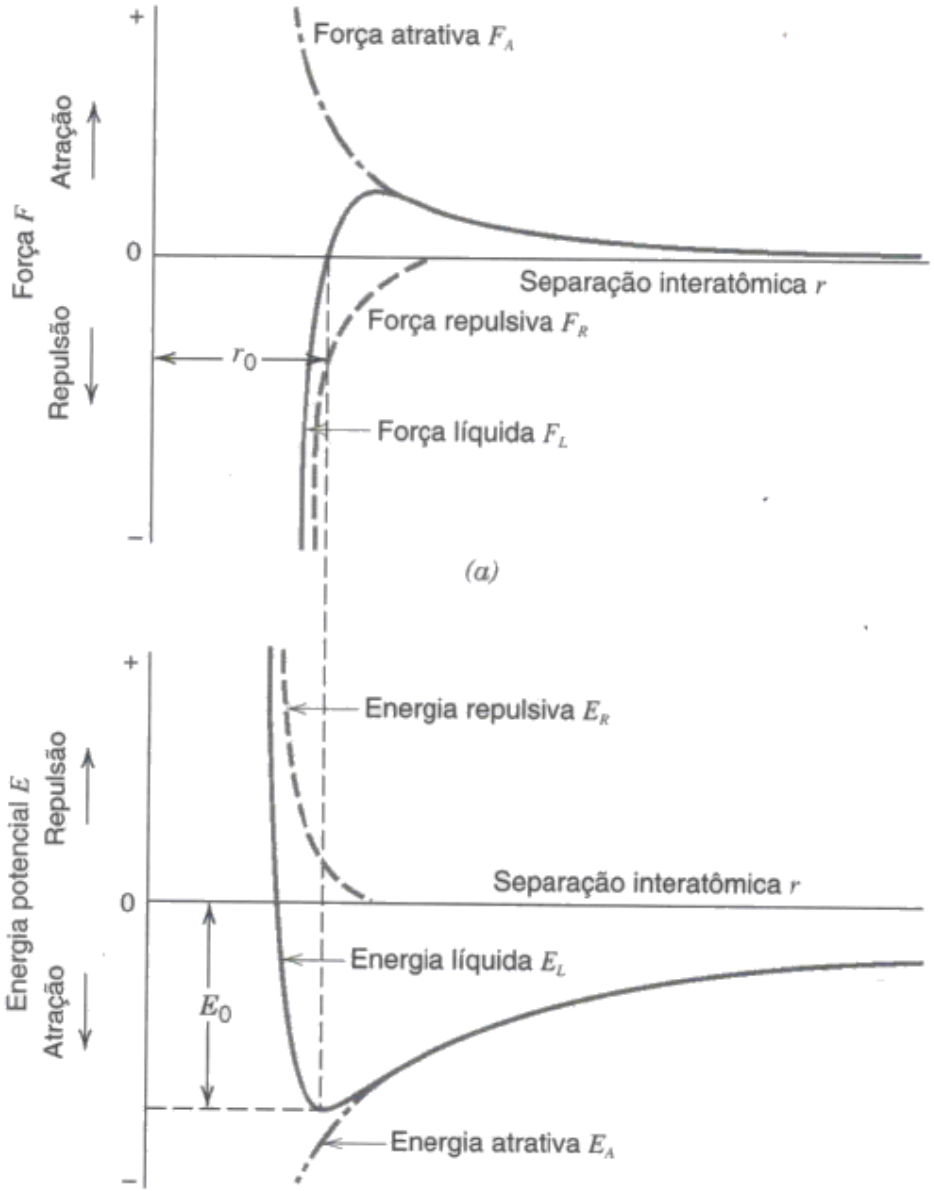






Física dos Materiais

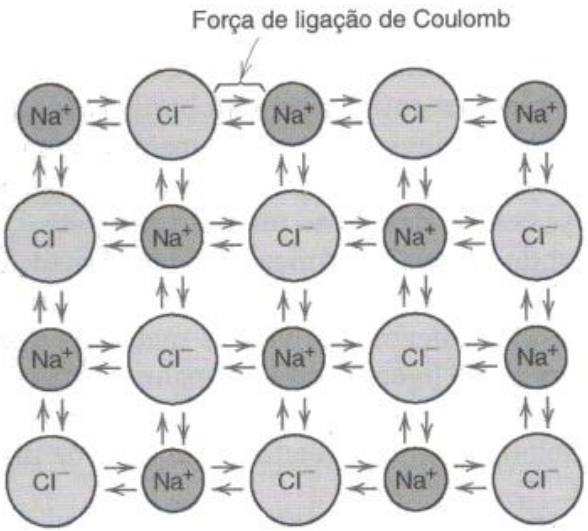
Ligações químicas



Força e Energia Potencial entre dois átomos vizinhos.

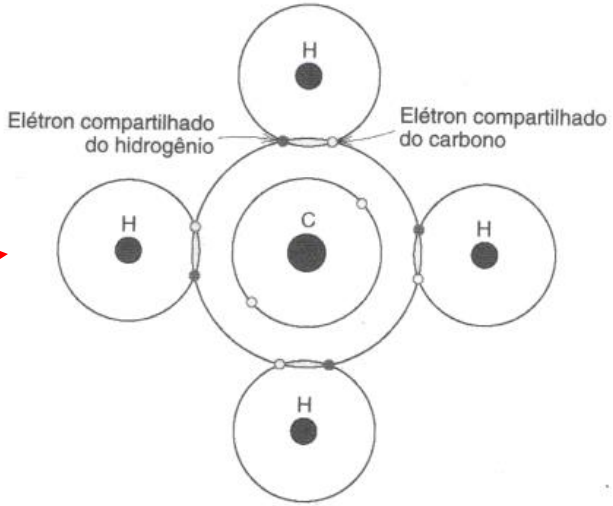
Física dos Materiais

Ligações químicas



Representação esquemática da ligação iônica no (NaCl).

Ligações iônica, covalente e metálica



Representação esquemática da ligação covalente em molécula de metano (CH_4).

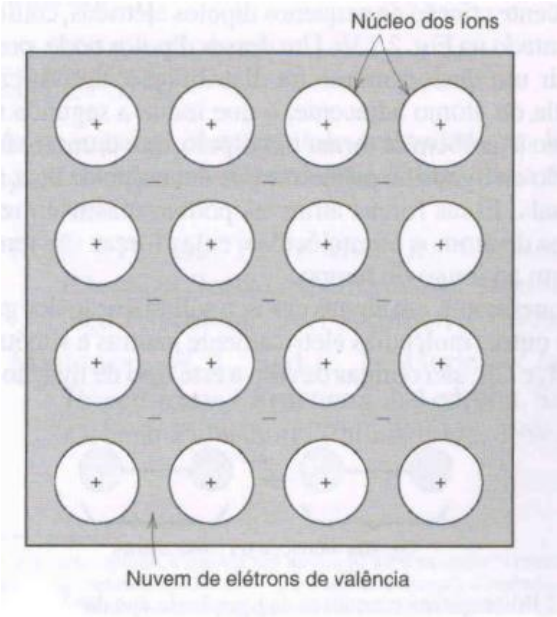


Ilustração esquemática da ligação metálica.

Física dos Materiais

Ligações químicas

Tabela 2.3 Energias de Ligação e Temperaturas de Fusão para Várias Substâncias

Tipo de Ligação	*Substância*	*Energia de Ligação* *kJ/mol (kcal/mol)*	*Energia de Ligação* *eV/Átomo, Íon, Molécula*	*Temperatura de Fusão (°C)*
Iônica	NaCl	640 (153)	3,3	801
	MgO	1000 (239)	5,2	2800
Covalente	Si	450 (108)	4,7	1410
	C (diamante)	713 (170)	7,4	>3550
Metálica	Hg	68 (16)	0,7	−39
	Al	324 (77)	3,4	660
	Fe	406 (97)	4,2	1538
	W	849 (203)	8,8	3410
van der Waals	Ar	7,7 (1,8)	0,08	−189
	Cl_2	31 (7,4)	0,32	−101
Hidrogênio	NH_3	35 (8,4)	0,36	−78
	H_2O	51 (12,2)	0,52	0

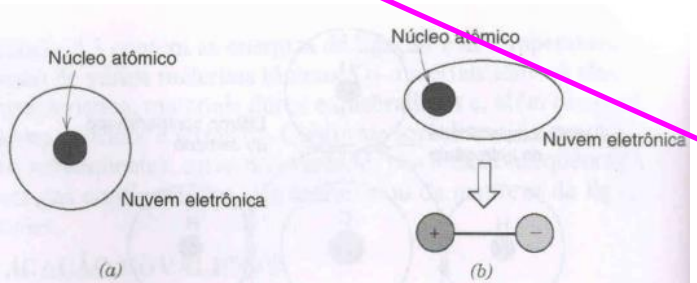


Fig. 2.13 Representações esquemáticas de (*a*) um átomo eletricamente simétrico e (*b*) um dipolo atômico induzido.

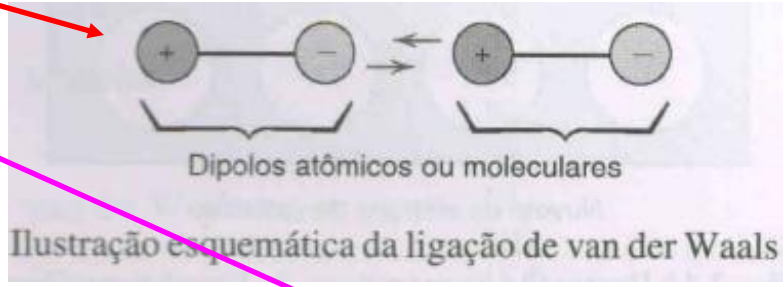
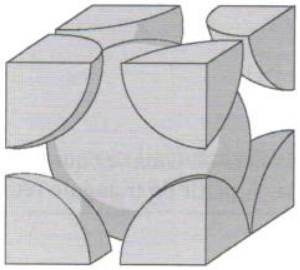
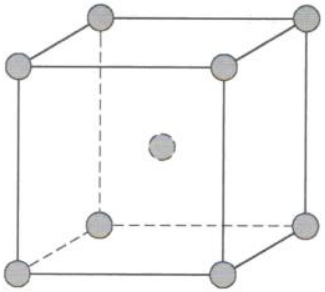
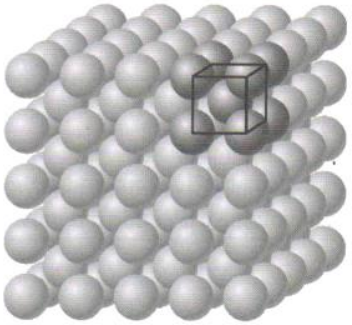
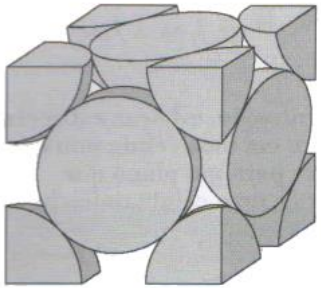
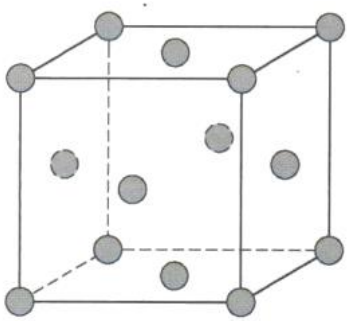
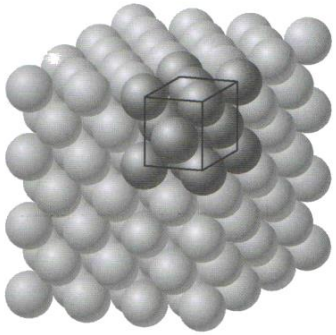
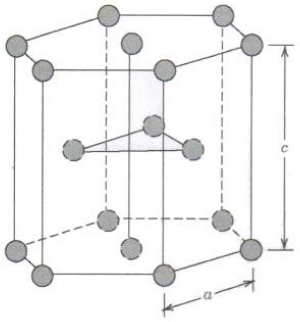
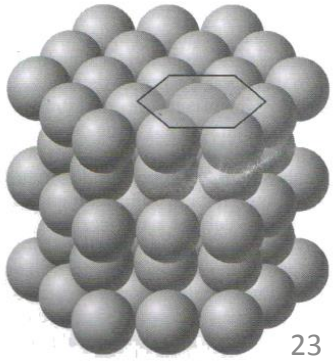


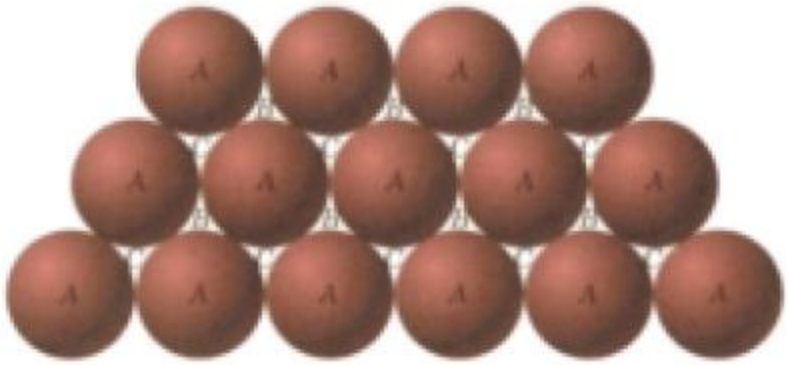
Ilustração esquemática da ligação de van der Waals

Representação esquemática da ligação de hidrogênio

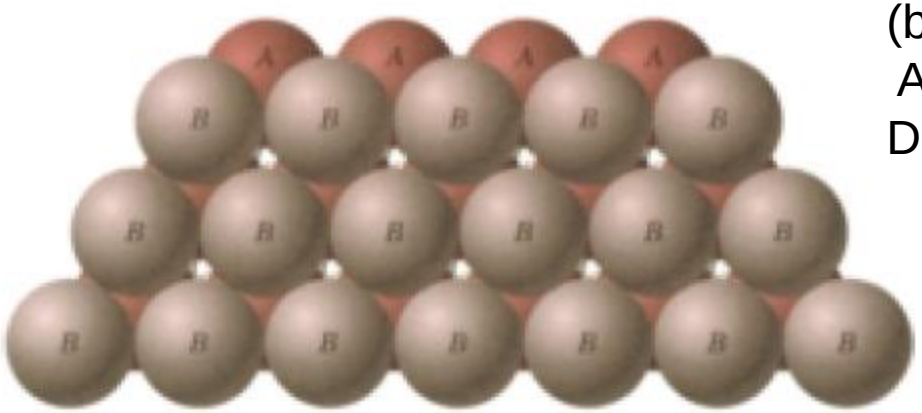
Física dos Materiais

Estrutura cristalina

	Célula unitária com esferas rígidas	Célula unitária com esferas reduzidas	Agregado com muitos átomos
Rede cúbica de corpo centrado			
Rede cúbica de face centrada			
Rede hexagonal compacta			



(a)

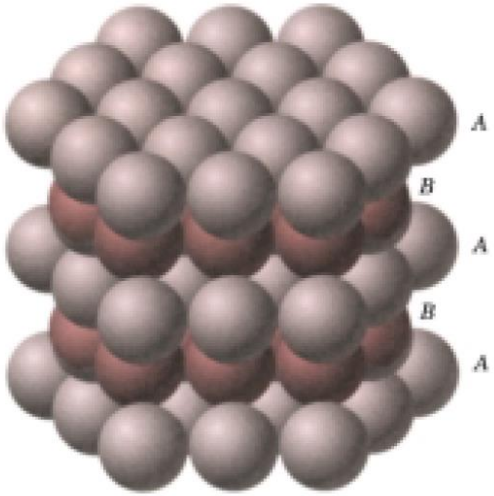


(a) Plano de átomos: posições A, B e C para um plano compacto de átomos
(b) Sequência de empilhamento AB para planos compactos De átomos

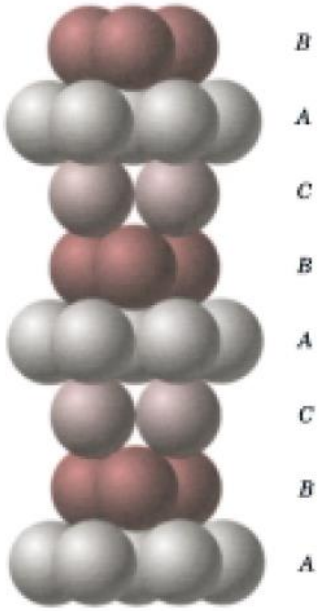
Física dos Materiais

Estrutura cristalina

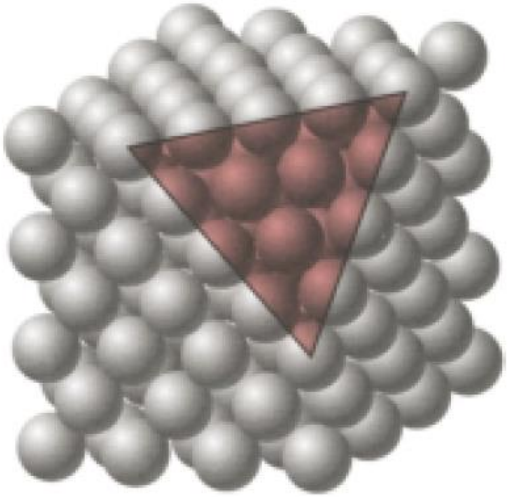
Sequência de empilhamento de planos para a rede hexagonal compacta (HC)



Sequência de empilhamento de planos para a rede cúbica de face centrada



(a)

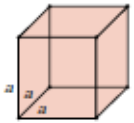
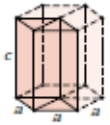
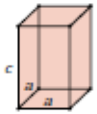
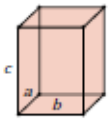
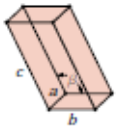
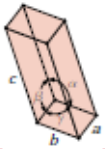


(b)

Física dos Materiais

Estrutura cristalina

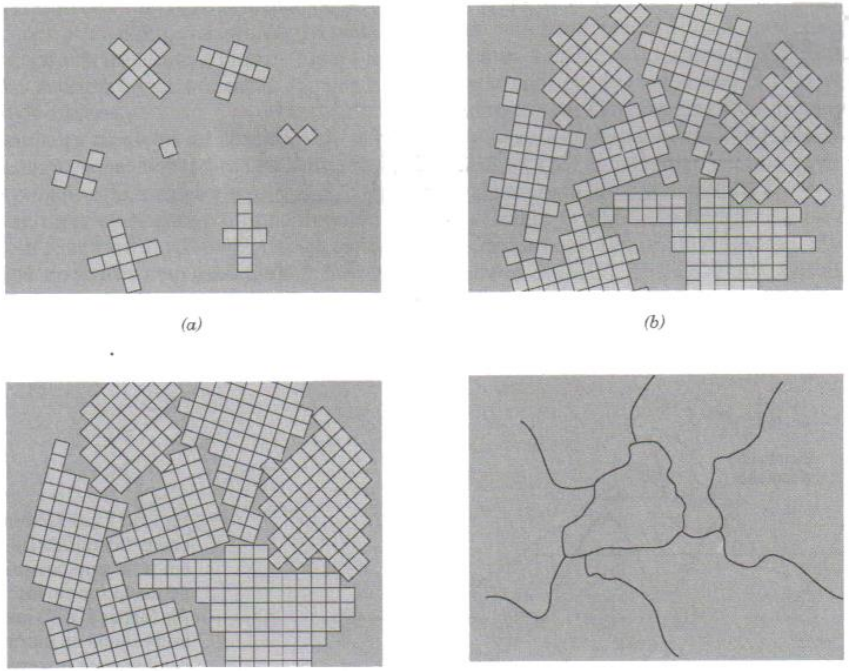
Table 3.6 Lattice Parameter Relationships and Figures Showing Unit Cell Geometries for the Seven Crystal Systems

Crystal System	*Axial Relationships*	*Interaxial Angles*	*Unit Cell Geometry*
Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90°$	
Hexagonal	$a = b \neq c$	$\alpha = \beta = 90°, \gamma = 120°$	
Tetragonal	$a = b \neq c$	$\alpha = \beta = \gamma = 90°$	
Rhombohedral	$a = b = c$	$\alpha = \beta = \gamma \neq 90°$	
Orthorhombic	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90°$	
Monoclinic	$a \neq b \neq c$	$\alpha = \gamma = 90° \neq \beta$	
Triclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90°$	

Física dos Materiais

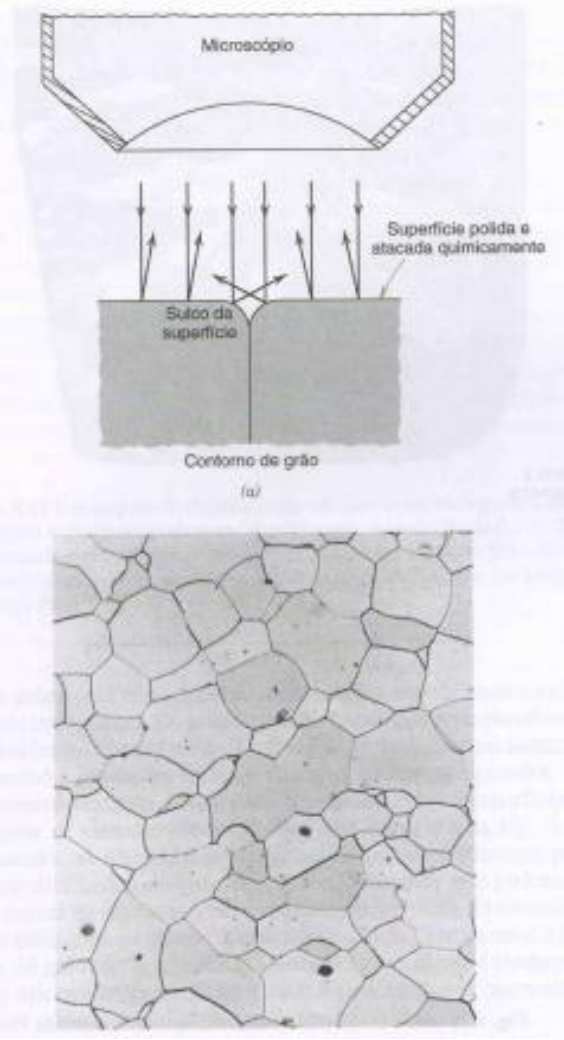
Estrutura cristalina

Estágios de solidificação de um material policristalino



Um lingote de chumbo policristalino de elevada pureza.

Técnica de observação de contornos de grãos

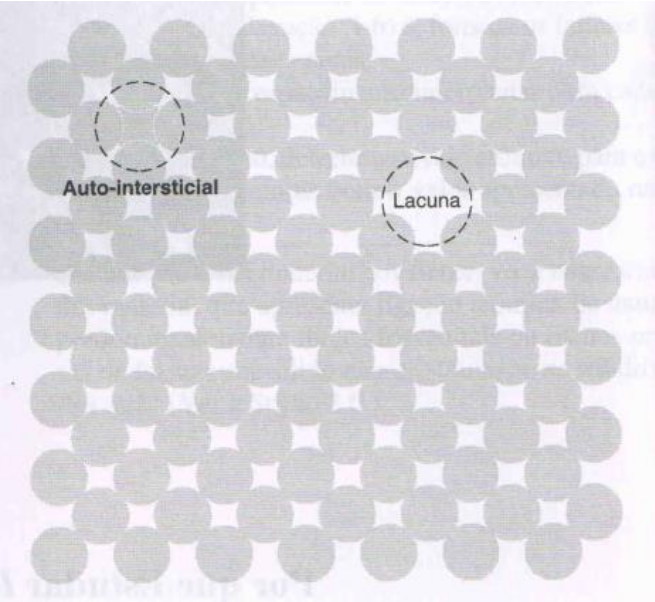


Física dos Materiais

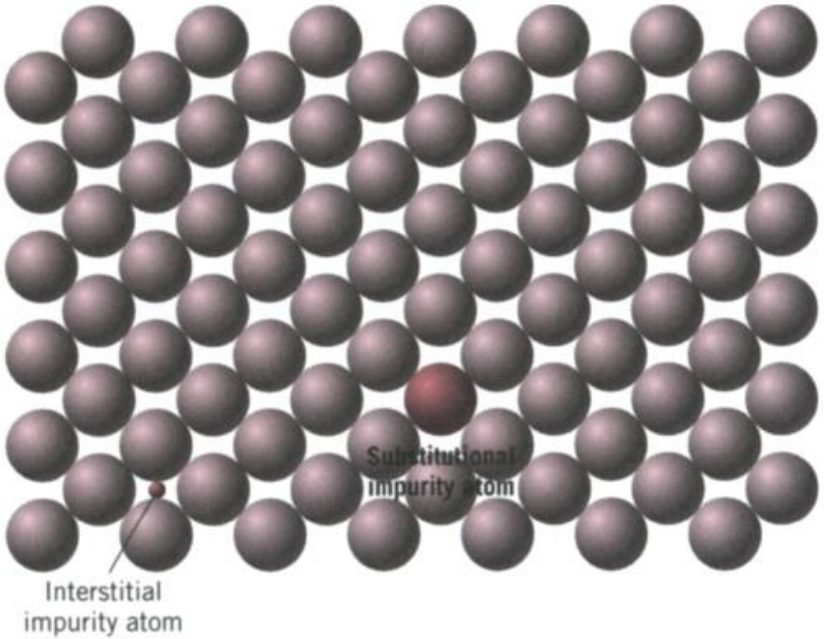
Defeitos em cristais

Pontuais

Defeitos de mesmo elemento

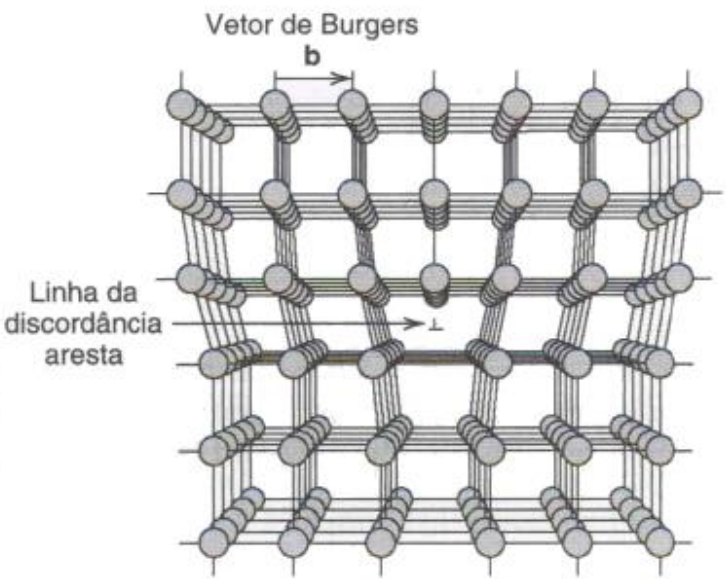


Impurezas

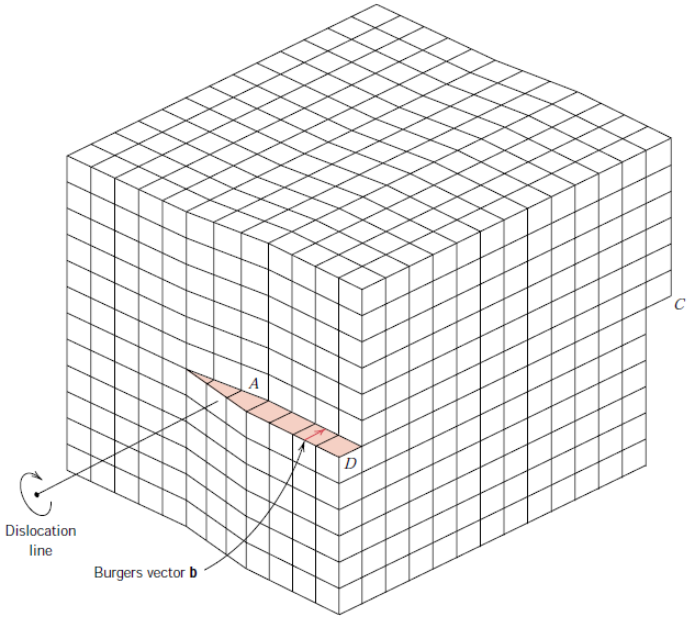


Física dos Materiais

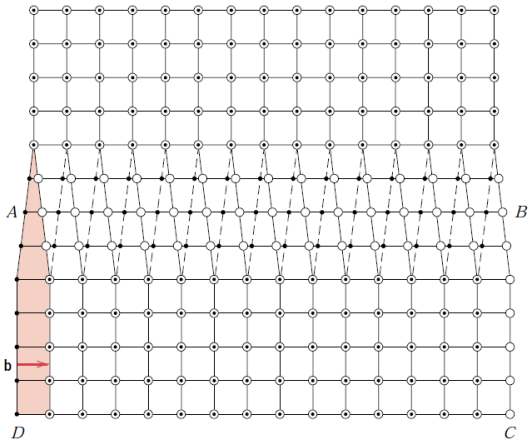
Linha de discordância aresta



Linha de discordância espiral no interior de um cristal

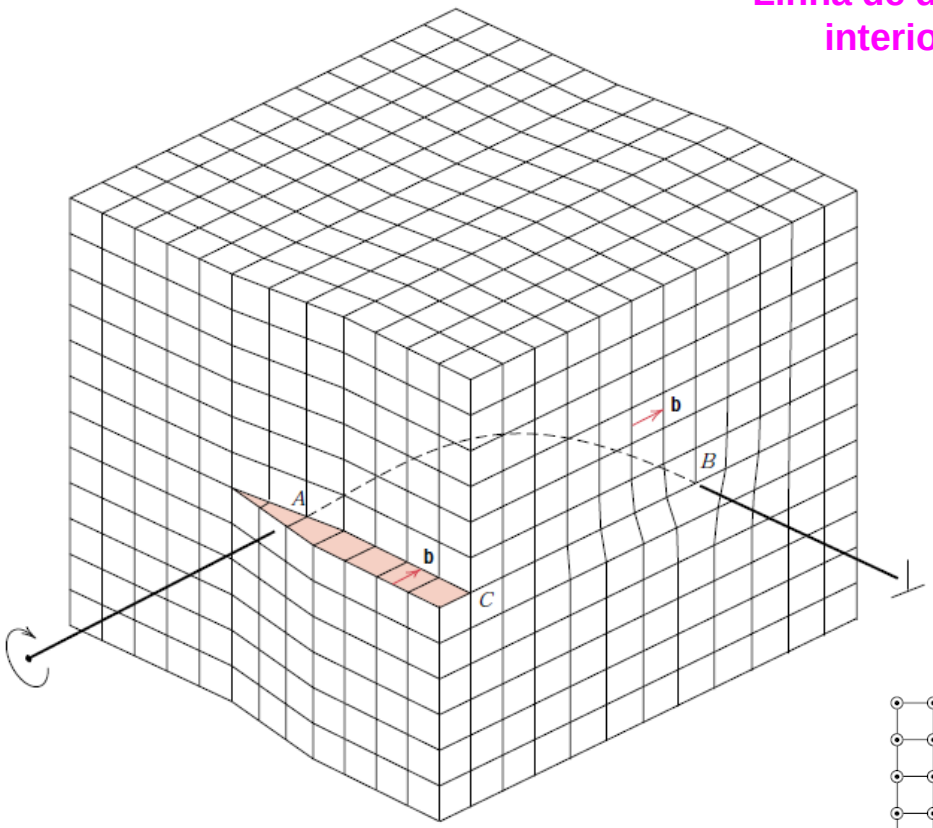


(a)



(b)

Linha de discordância mista no interior de um cristal



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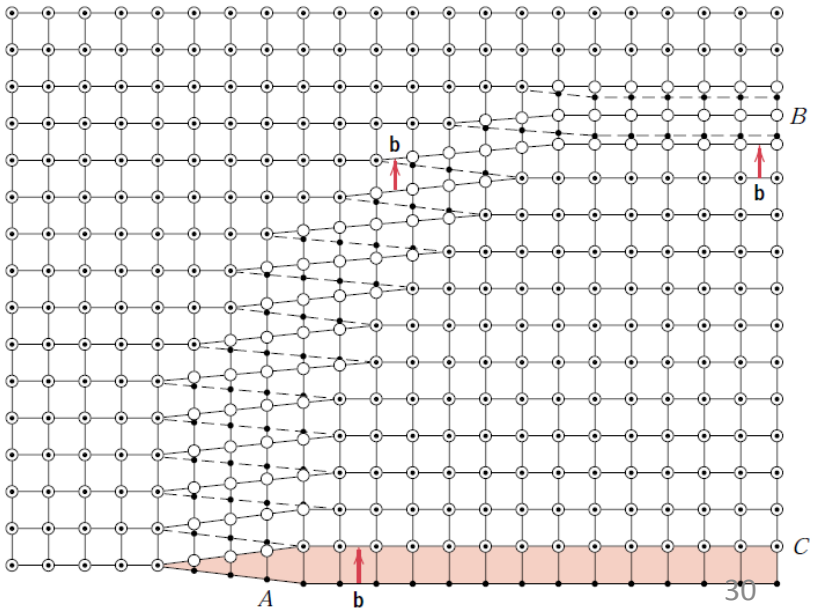

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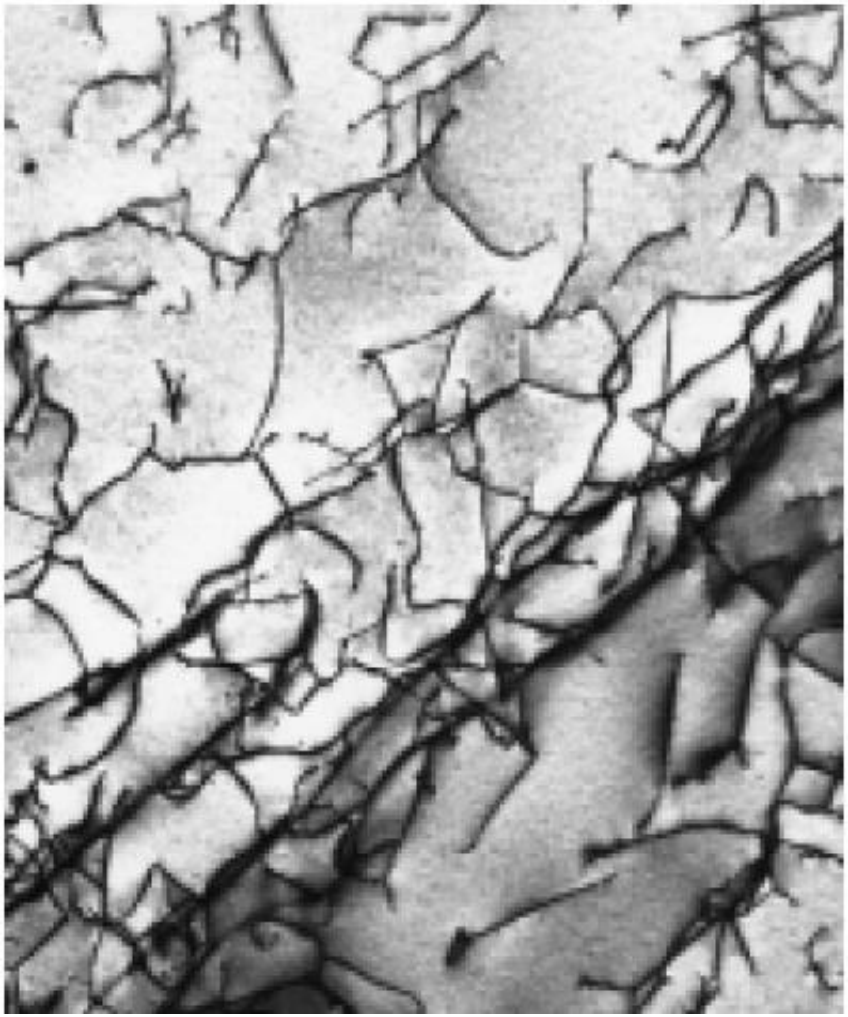
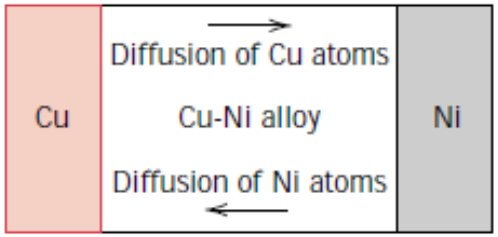


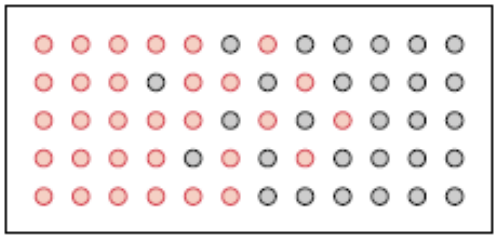
MET de uma liga de Titânio em que as linhas
Escuras são as discordâncias

Física dos Materiais

Difusão em cristais



(a)



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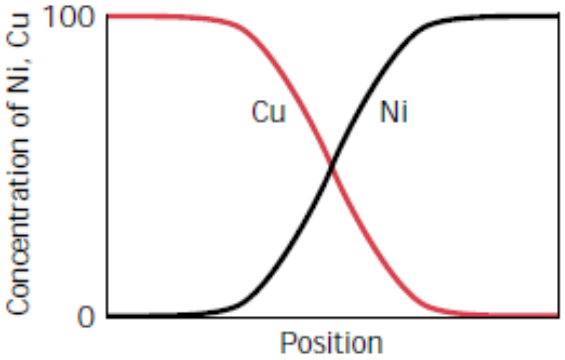


(c)

Física dos Materiais

Difusão em cristais

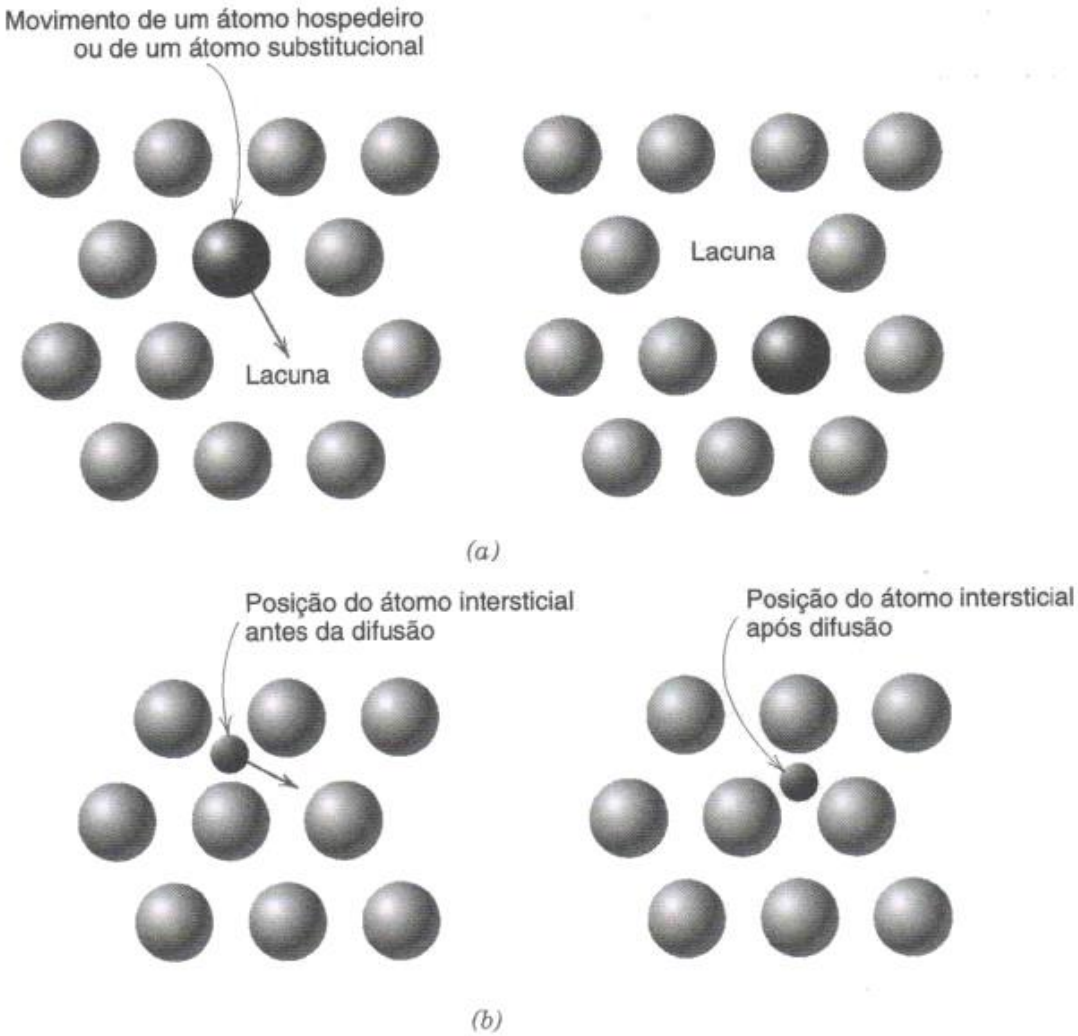


Fig. 5.3 Representações esquemáticas da (*a*) difusão por lacuna e (*b*) difusão intersticial.

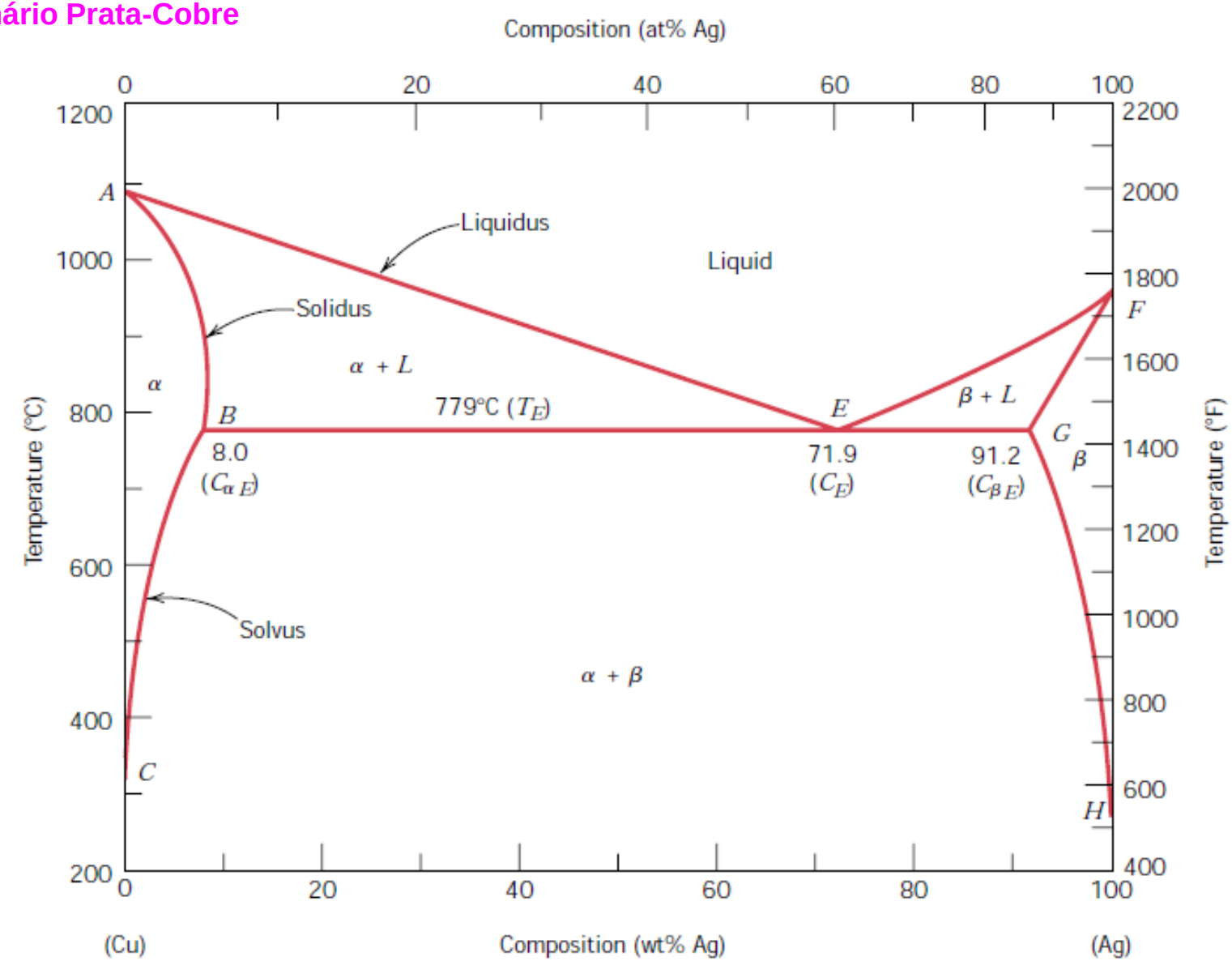
Difusão de lacuna

Difusão intersticial

Física dos Materiais

Ligas metálicas

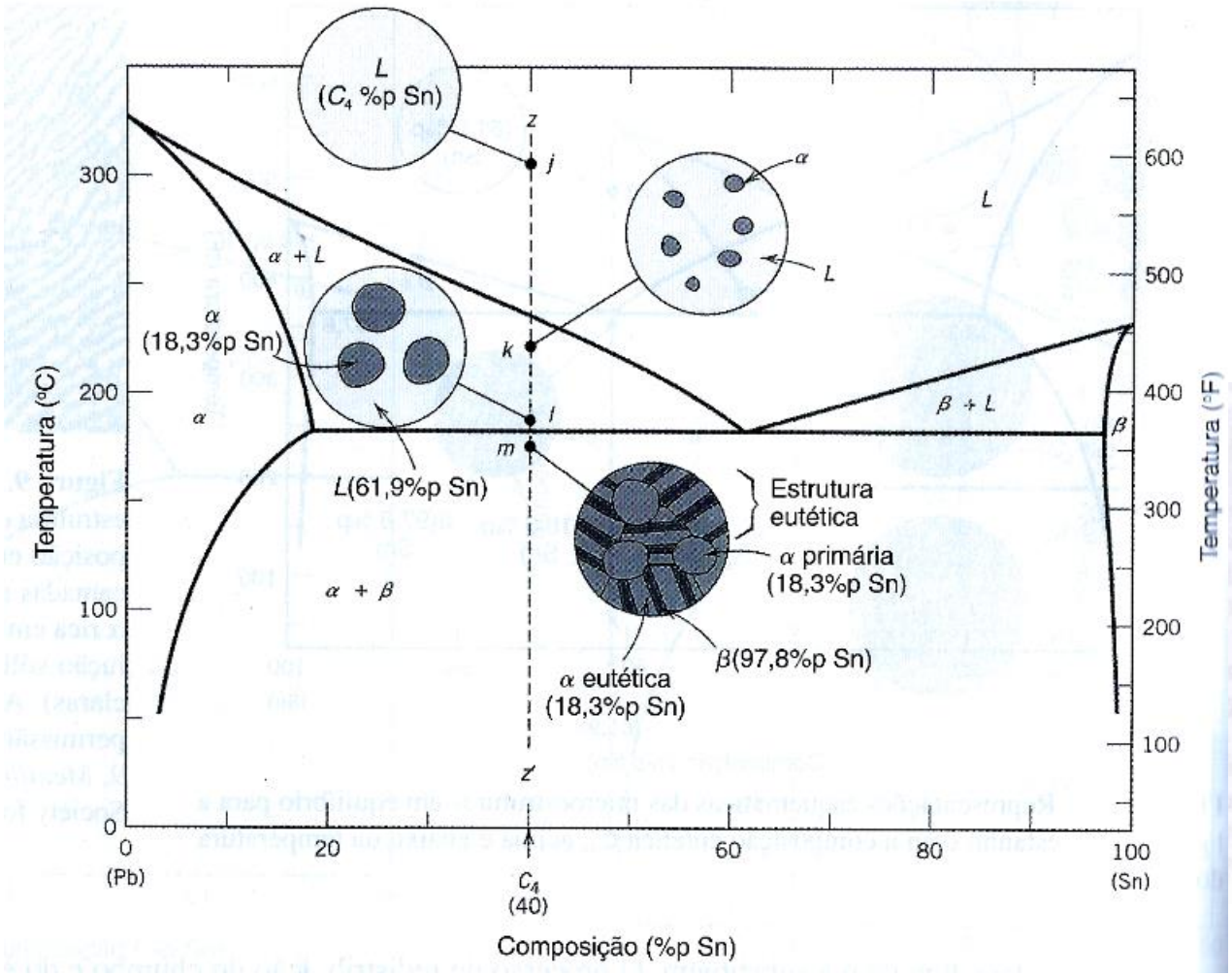
Diagrama de fases do sistema binário Prata-Cobre



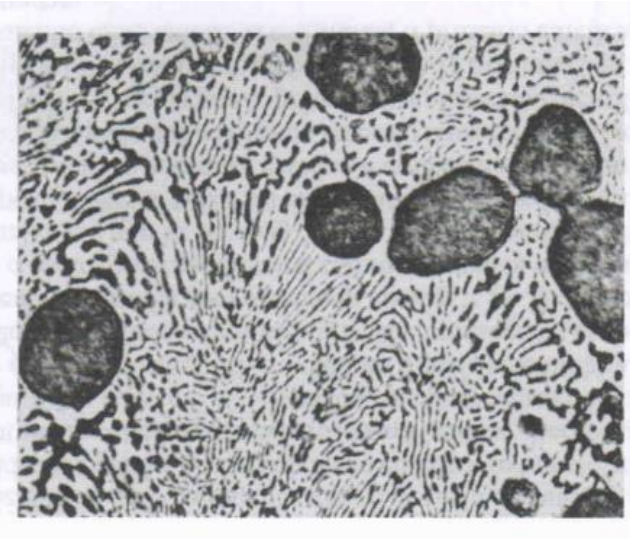
Física dos Materiais

Ligas metálicas

Diagrama de fases do sistema binário Chumbo-Estanho



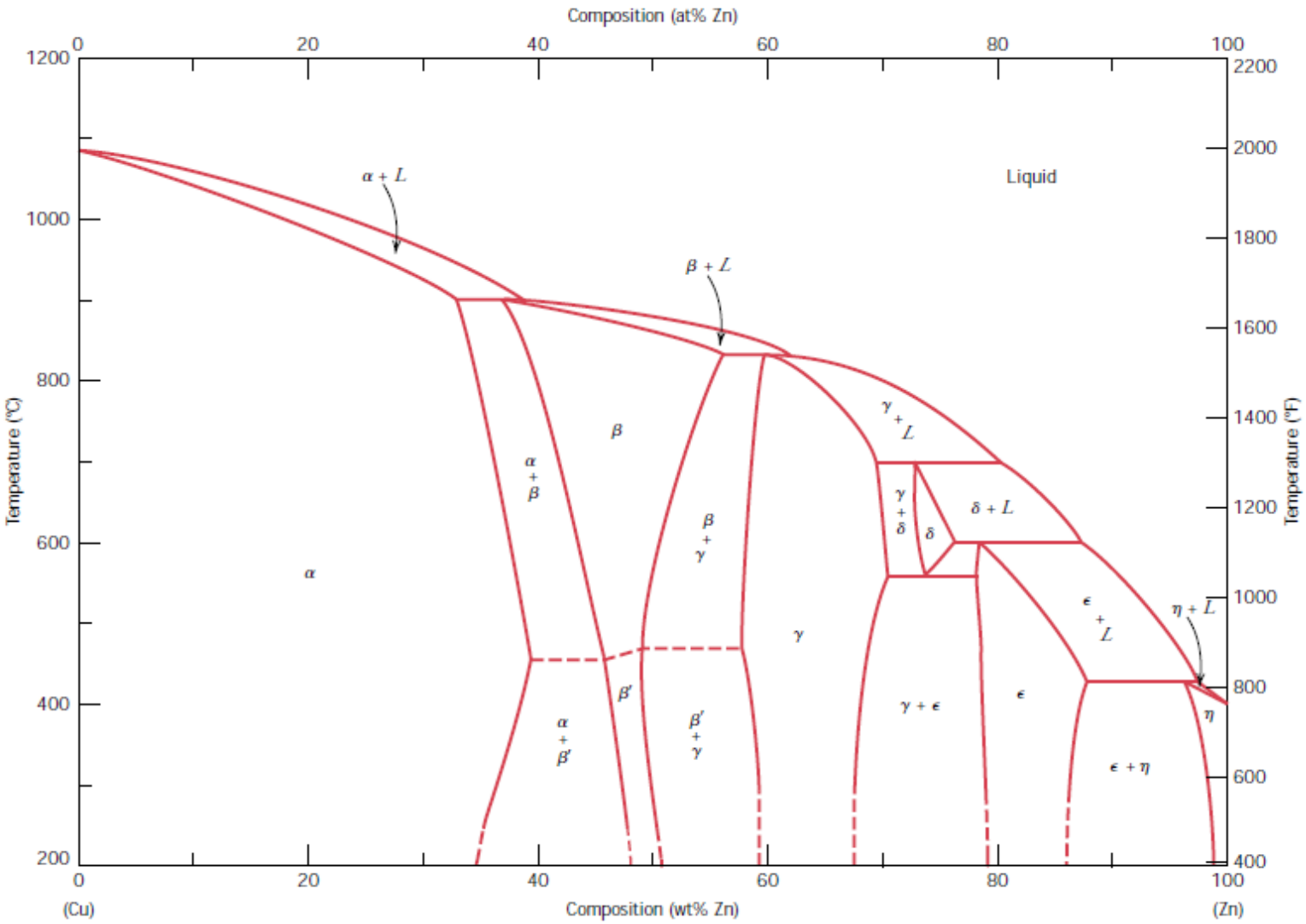
Fotomicrografia de amostra de Chumbo-Estanho (50% em massa)



Física dos Materiais

Ligas metálicas

Diagrama de fases do sistema binário Cobre-Zinco



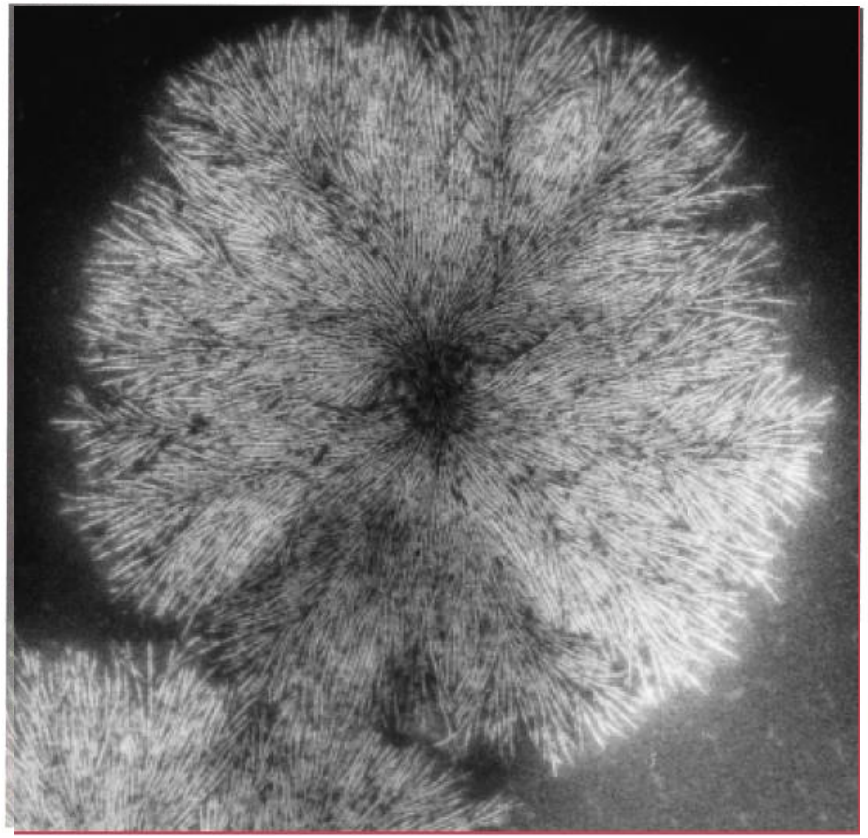
Física dos Materiais

Polímeros ou macromoléculas

Por que Estudar as *Estruturas Poliméricas*?

Um número relativamente grande de características químicas e estruturais afeta as propriedades e os comportamentos dos materiais poliméricos. Algumas dessas influências são:

1. Grau de cristalinidade dos polímeros semicristalinos — em relação à sua densidade, rigidez, resistência e dutilidade (Seções 15.10 e 16.4).
2. Grau de ligações cruzadas — em relação à rigidez dos materiais com características de borracha (Seção 16.8).
3. Química dos polímeros — em relação às temperaturas de fusão e de transição vítrea (Seção 16.5).



Micrografia eletrônica de transmissão mostrando a estrutura de esferulite em uma amostra de borracha natural. Cristalitos lamelares com cadeia dobrada com aproximadamente 10 nm de espessura se estendem em direções radiais a partir do centro; eles aparecem na forma de linhas brancas nesta micrografia. Ampliação de 30.000×. (Fotografia fornecida por P. J. Phillips. Publicada inicialmente em R. Bartnikas e R. M. Eichhorn, *Engineering Dielectrics*, Vol. IIA, *Electrical Properties of Solid Insulating Materials: Molecular Structure and Electrical Behavior*. Copyright ASTM, 1916 Race Street, Philadelphia, PA 19103, Reimpresso sob permissão.)

Polímeros naturais:

Madeira, borracha, algodão, lã, couro, seda, ...

Polímeros biológicos:

Proteínas, enzimas, amidos, celulose, ...

Polímeros sintéticos:

. . .

Física dos Materiais

Polímeros

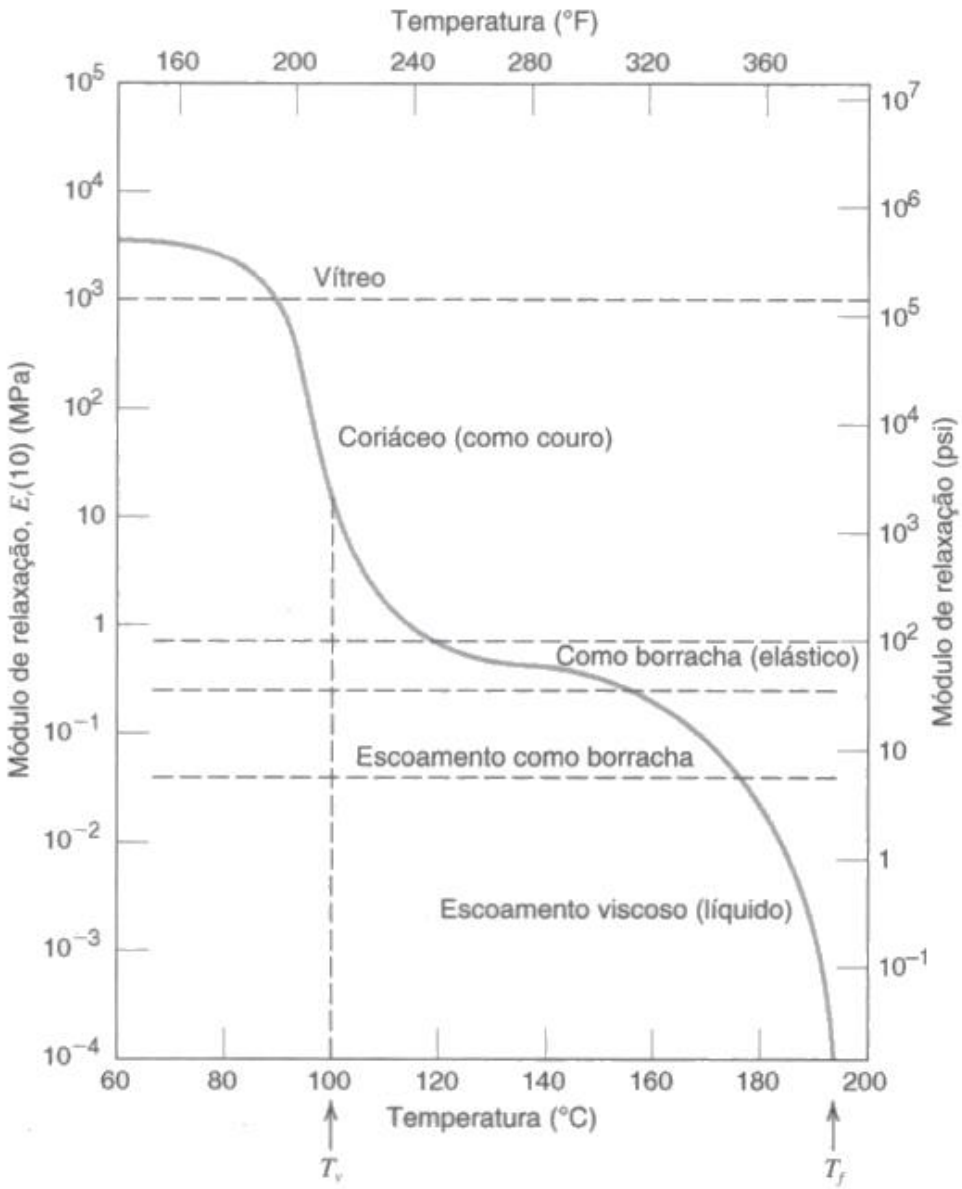
Tabela 16.1 Características Mecânicas à Temperatura Ambiente de Alguns dos Polímeros Mais Comuns

Material	*Densidade Relativa*	*Módulo de Tração [GPa (ksi)]*	*Limite de Resistência à Tração [MPa (ksi)]*	*Limite de Escoamento [MPa (ksi)]*	*Alongamento na Fratura (%)*
Polietileno (baixa densidade)	0,917-0,932	0,17-0,28 (25-41)	8,3-31,4 (1,2-4,55)	9,0-14,5 (1,3-2,1)	100-650
Polietileno (alta densidade)	0,952-0,965	1,06-1,09 (155-158)	22,1-31,0 (3,2-4,5)	26,2-33,1 (3,8-4,8)	10-1200
Cloreto de polivinila	1,30-1,58	2,4-4,1 (350-600)	40,7-51,7 (5,9-7,5)	40,7-44,8 (5,9-6,5)	40-80
Politetrafluoroetileno	2,14-2,20	0,40-0,55 (58-80)	20,7-34,5 (3,0-5,0)	—	200-400
Polipropileno	0,90-0,91	1,14-1,55 (165-225)	31-41,4 (4,5-6,0)	31,0-37,2 (4,5-5,4)	100-600
Poliestireno	1,04-1,05	2,28-3,28 (330-475)	35,9-51,7 (5,2-7,5)	—	1,2-2,5
Polimetil metacrilato	1,17-1,20	2,24-3,24 (325-470)	48,3-72,4 (7,0-10,5)	53,8-73,1 (7,8-10,6)	2,0-5,5
Fenol-formaldeído	1,24-1,32	2,76-4,83 (400-700)	34,5-62,1 (5,0-9,0)	—	1,5-2,0
Náilon 6,6	1,13-1,15	1,58-3,80 (230-550)	75,9-94,5 (11,0-13,7)	44,8-82,8 (6,5-12)	15-300
Poliéster (PET)	1,29-1,40	2,8-4,1 (400-600)	48,3-72,4 (7,0-10,5)	59,3 (8,6)	30-300
Policarbonato	1,20	2,38 (345)	62,8-72,4 (9,1-10,5)	62,1 (9,0)	110-150

Fonte: *Modern Plastics Encyclopedia '96*. Copyright 1995, The McGraw-Hill Companies. Reimpresso com permissão.

Física dos Materiais

Polímeros



Comportamento visco-elástico do Poliestireno amorfo

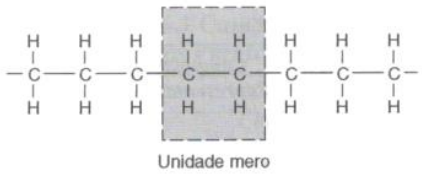
• Um polímero amorfo pode se comportar como um vidro a baixas temperaturas, um sólido tipo borracha (elastomérico) em temperaturas intermediárias (acima da temperatura de transição vítrea) e um líquido viscoso quando a temperatura é elevada mais ainda.

• Para deformações relativamente pequenas, o comportamento mecânico a baixas temperaturas pode ser elástico; isto é, em conformidade com a lei de Hooke, $\sigma = E\varepsilon$. (sigma é a tensão e epson é a deformação)

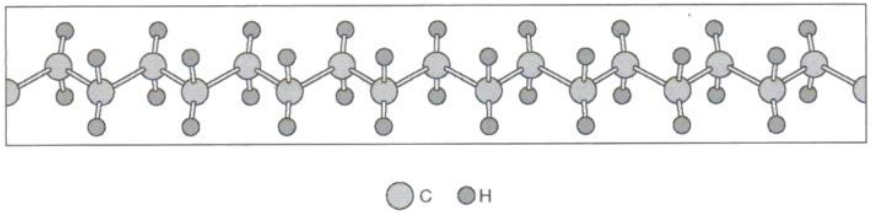
• Na mais alta temperatura, prevalece o comportamento viscoso ou tipo líquido. Para temperaturas intermediárias, o polímero é um sólido com as características de uma borracha, que exibe características mecânicas que são uma combinação desses dois extremos.

Física dos Materiais

Polímeros

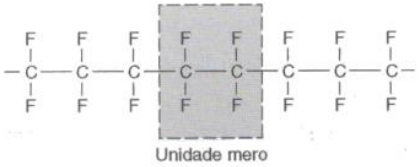


(a)



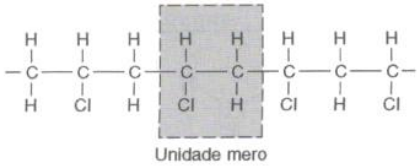
(b)

Polietileno (PE)



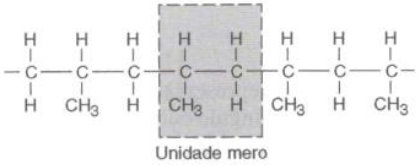
(a)

Politetrafluoroetileno (PTFE)



(b)

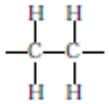
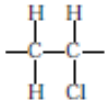
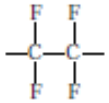
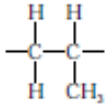
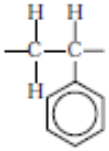
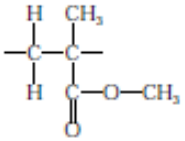
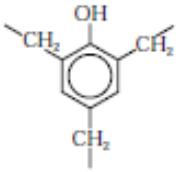
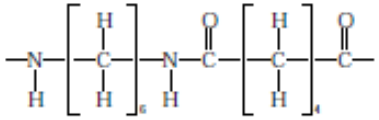
Cloreto de Polivinila (PVC)

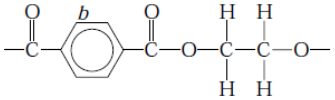
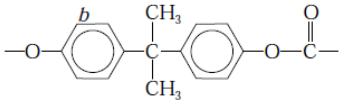


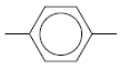
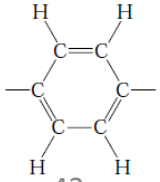
(c)

Polipropileno (PP)

Lista dos Polímeros mais comuns

Polymer	*Repeating (Mer) Structure*
Polyethylene (PE)	
Polyvinyl chloride (PVC)	
Polytetrafluoroethylene (PTFE)	
Polypropylene (PP)	
Polystyrene (PS)	
Polymethyl methacrylate (PMMA)	
Phenol-formaldehyde (Bakelite)	
Polyhexamethylene adipamide (nylon 6,6)	

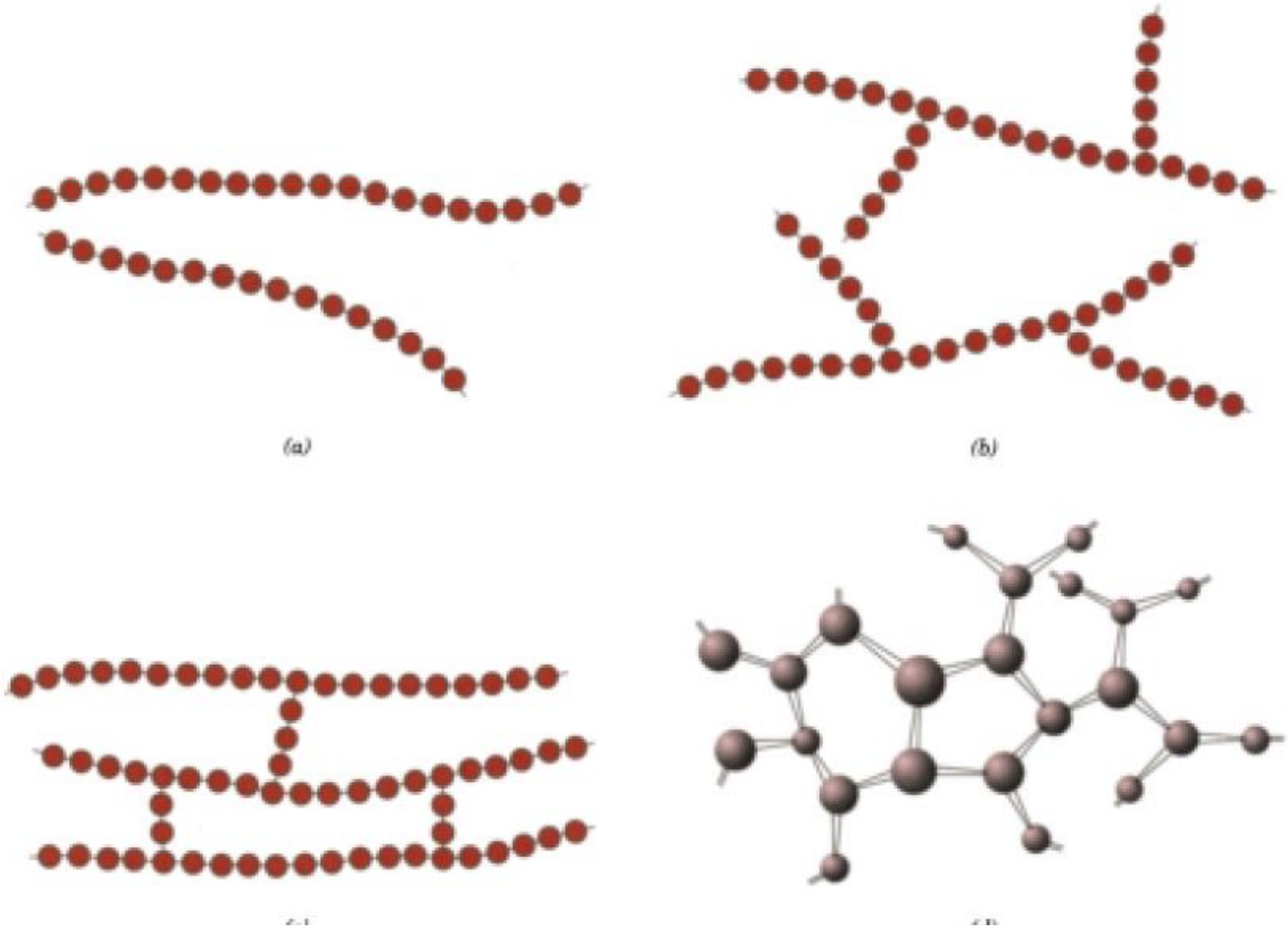
Polymer	*Repeating (Mer) Structure*
Polyethylene terephthalate (PET, a polyester)	
Polycarbonate	

[b] The  symbol in the backbone chain denotes an aromatic ring as 

Física dos Materiais

Polímeros

Possíveis estruturas

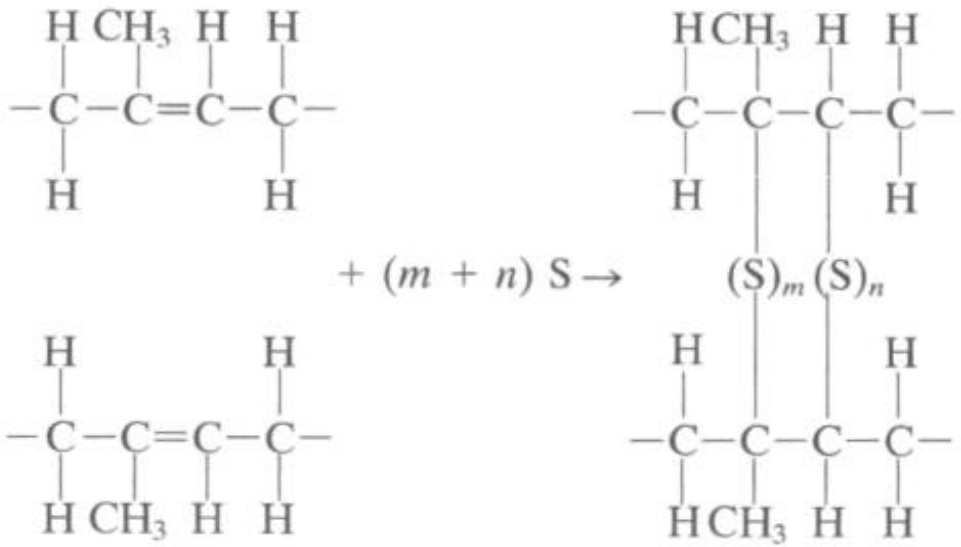


Física dos Materiais

Polímeros

VULCANIZAÇÃO

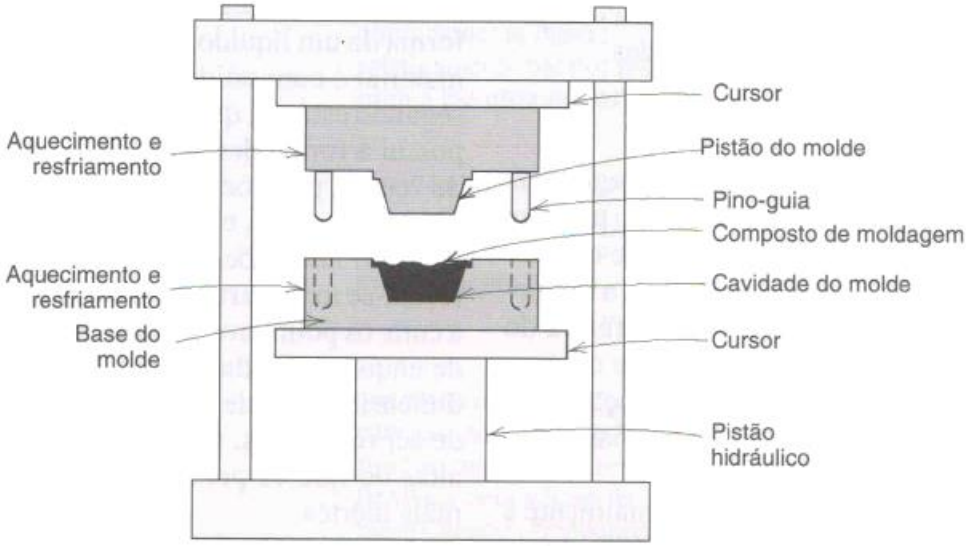
Uma característica obrigatória para um comportamento elastomérico é que a estrutura molecular seja levemente provida de ligações cruzadas. O processo de formação de ligações cruzadas nos elastômeros é conhecido por **vulcanização**, o qual é realizado através de uma reação química irreversível, normalmente conduzida a uma temperatura elevada. Na maioria das reações de vulcanização, compostos de enxofre são adicionados ao elastômero aquecido; cadeias de átomos de enxofre se ligam com as cadeias principais do polímero que se encontram adjacentes, formando ligações cruzadas entre elas, o que é obtido de acordo com a seguinte reação:



Física dos Materiais

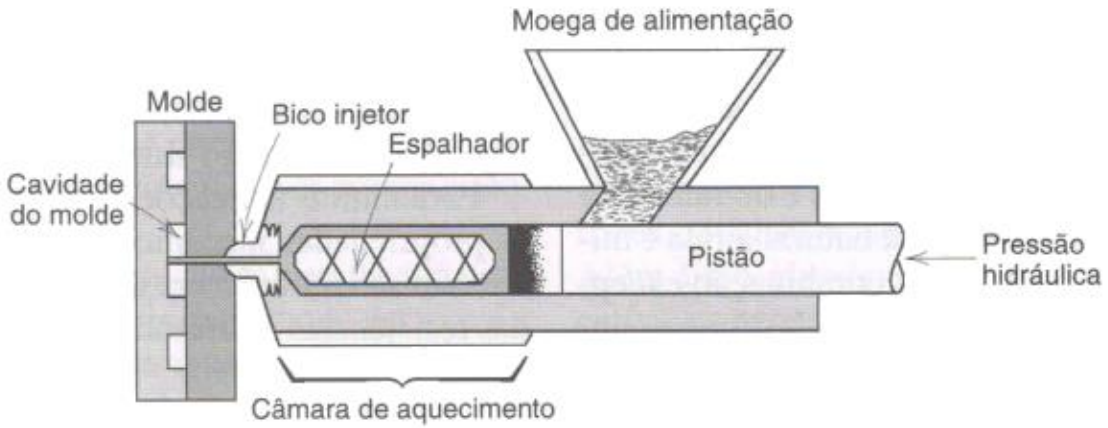
Polímeros

Moldagem por Compressão



equipamento para moldagem por compres

Moldagem por injeção



equipamento para moldagem por injeção.

Física dos Materiais

Cerâmicas

Cerâmicas são materiais inorgânicos e não-metálicos.

São formadas por elementos químicos metálicos e não-metálicos, onde as ligações são iônicas ou preponderantemente iônicas.

Cerâmicas tradicionais (à base de argila): louça, porcelana, tijolos, telhas, azulejos, vidros e cerâmicas de altas temperaturas.

Hoje, . . .

. . . Óxidos, nitretos, carbetos e muito mais !

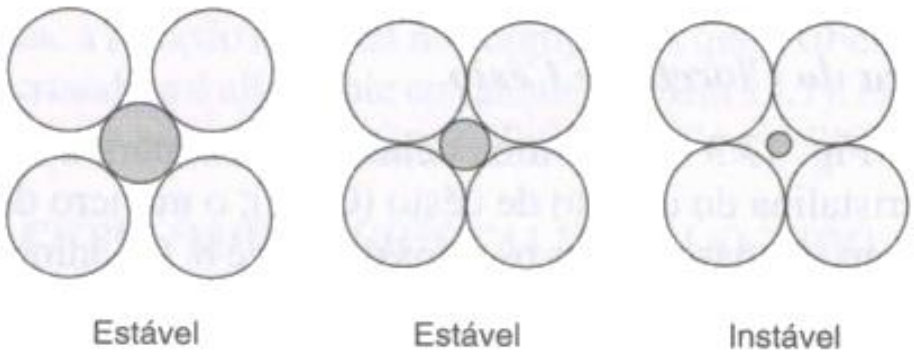


Fig. 13.1 Configurações de coordenação ânion-cátion estáveis e instáveis. Os círculos abertos representam os ânions; os círculos coloridos representam os cátions.

Física dos Materiais

Cerâmicas

Table 3.4 Ionic Radii for Several Cations and Anions (for a Coordination Number of 6)

Cation	*Ionic Radius (nm)*	*Anion*	*Ionic Radius (nm)*
Al^{3+}	0.053	Br^{-}	0.196
Ba^{2+}	0.136	Cl^{-}	0.181
Ca^{2+}	0.100	F^{-}	0.133
Cs^{+}	0.170	I^{-}	0.220
Fe^{2+}	0.077	O^{2-}	0.140
Fe^{3+}	0.069	S^{2-}	0.184
K^{+}	0.138		
Mg^{2+}	0.072		
Mn^{2+}	0.067		
Na^{+}	0.102		
Ni^{2+}	0.069		
Si^{4+}	0.040		
Ti^{4+}	0.061		

Table 3.3 Coordination Numbers and Geometries for Various Cation–Anion Radius Ratios (r_C/r_A)

Coordination Number	*Cation–Anion Radius Ratio*	*Coordination Geometry*
2	<0.155	
3	0.155–0.225	
4	0.225–0.414	
6	0.414–0.732	
8	0.732–1.0	

Física dos Materiais

Cerâmicas

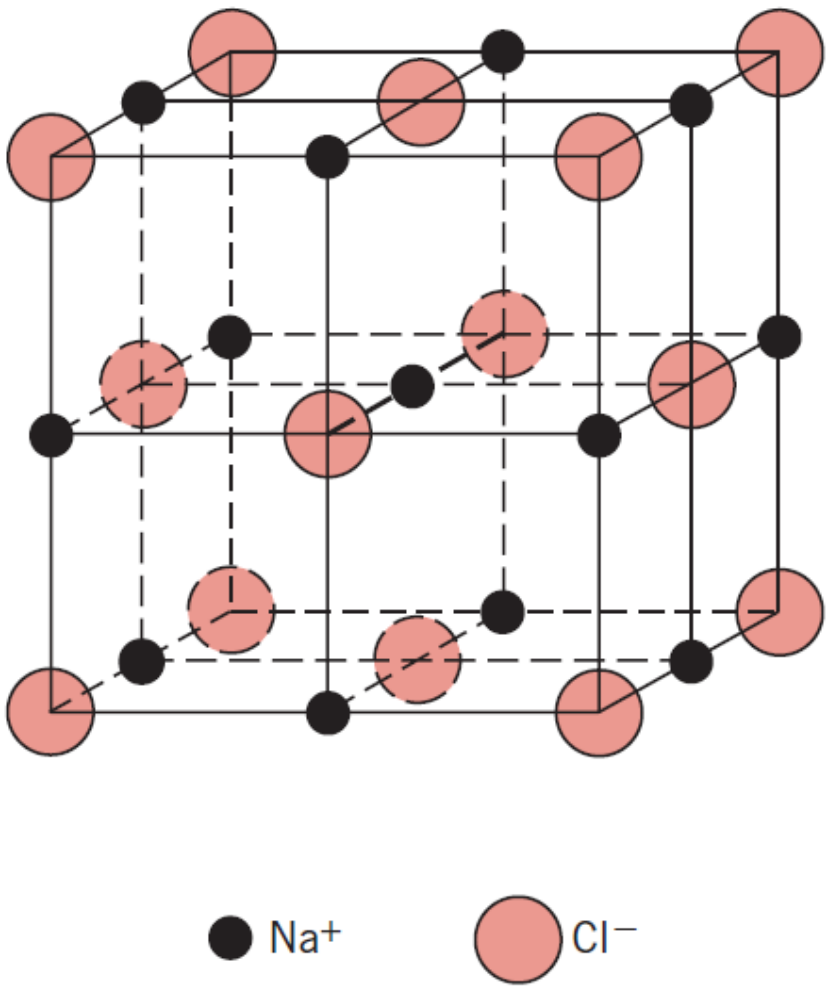


FIGURE 3.5 A unit cell for the rock salt, or sodium chloride (NaCl), crystal structure.

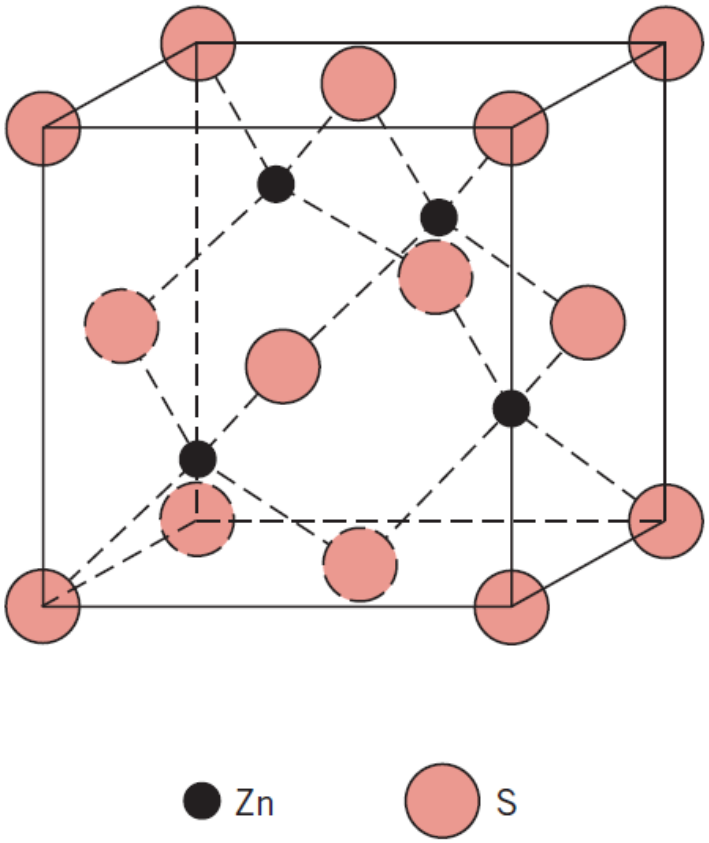


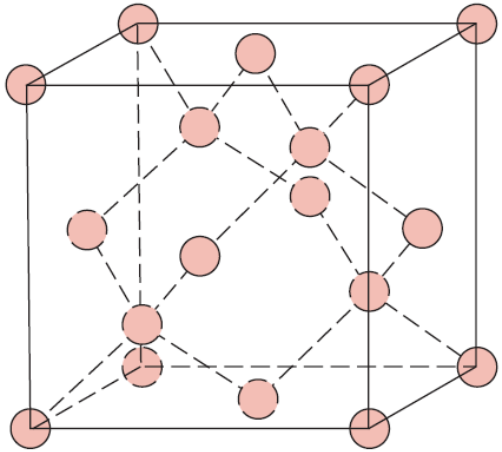
FIGURE 3.7 A unit cell for the zinc blende (ZnS) crystal structure.

Mesmas estruturas cristalinas dos metais

Física dos Materiais

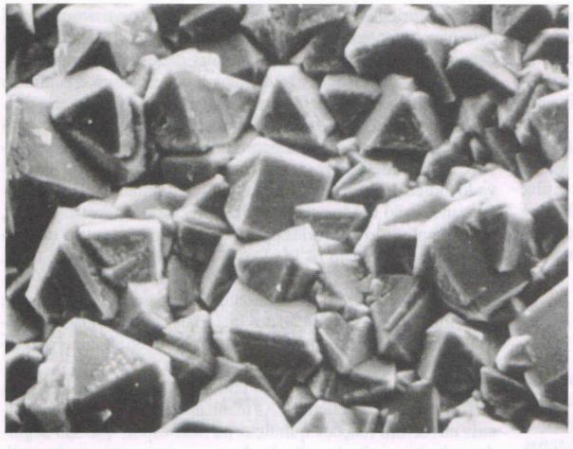
Cerâmicas

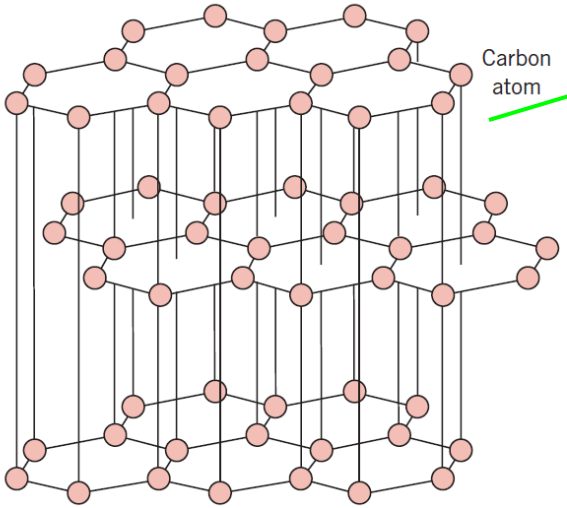
Materiais baseados no carbono



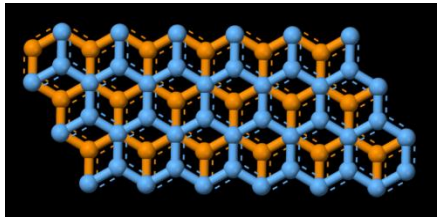
C

Uma célula unitária para a estrutura cristalina

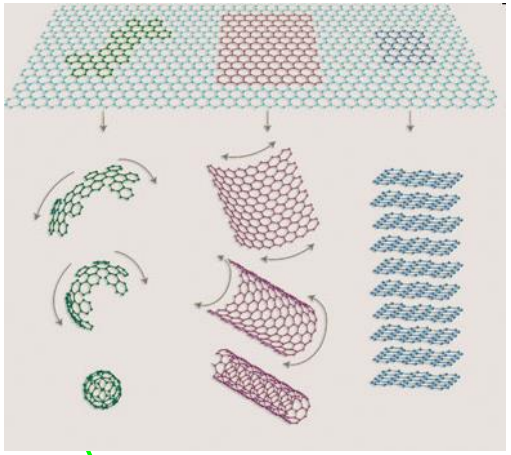




Grafite



Grafeno



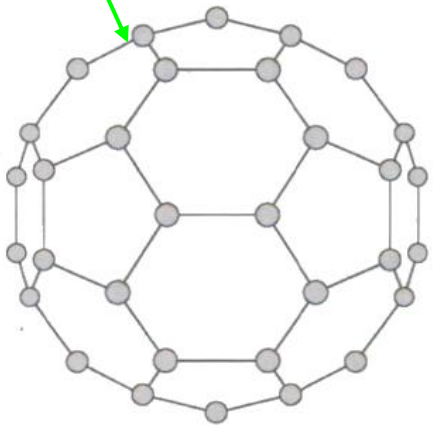


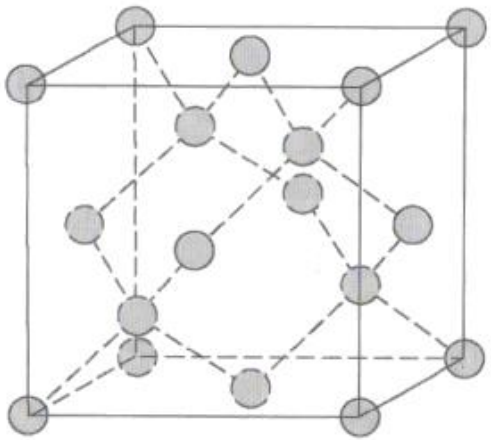
Fig. 13.18 A estrutura de uma molécula de C_{60}.

Fulereno

Física dos Materiais

Cerâmicas

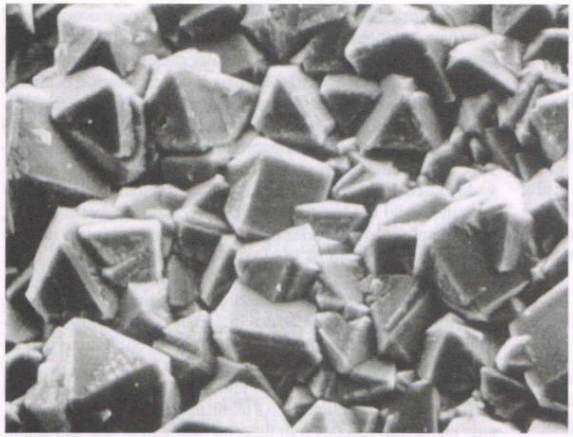
Materiais baseados no carbono



Diamante

C

Uma célula unitária para a estrutura cristalina



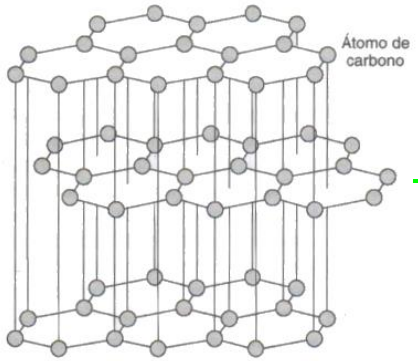
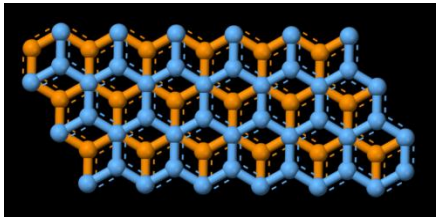
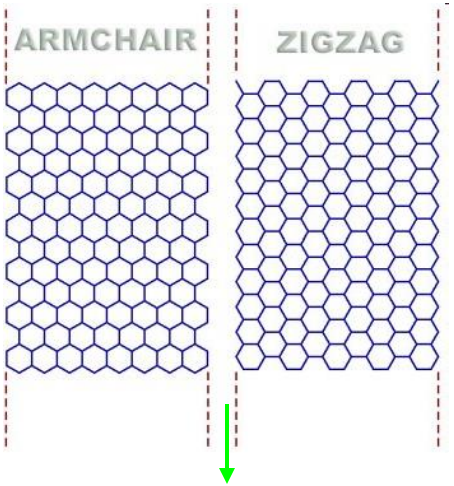


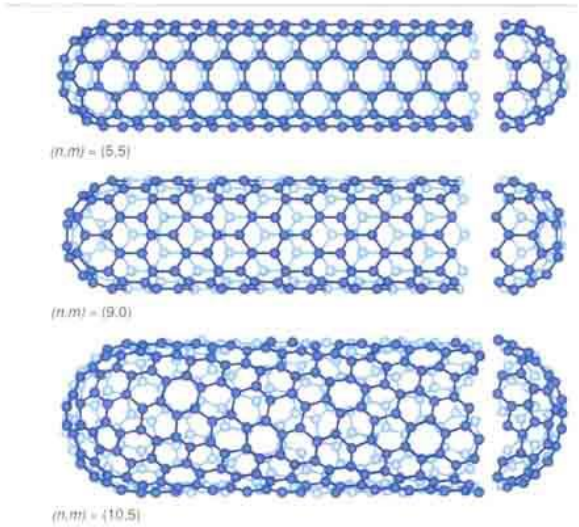
Fig. 13.17 A estrutura da grafita.

Grafite

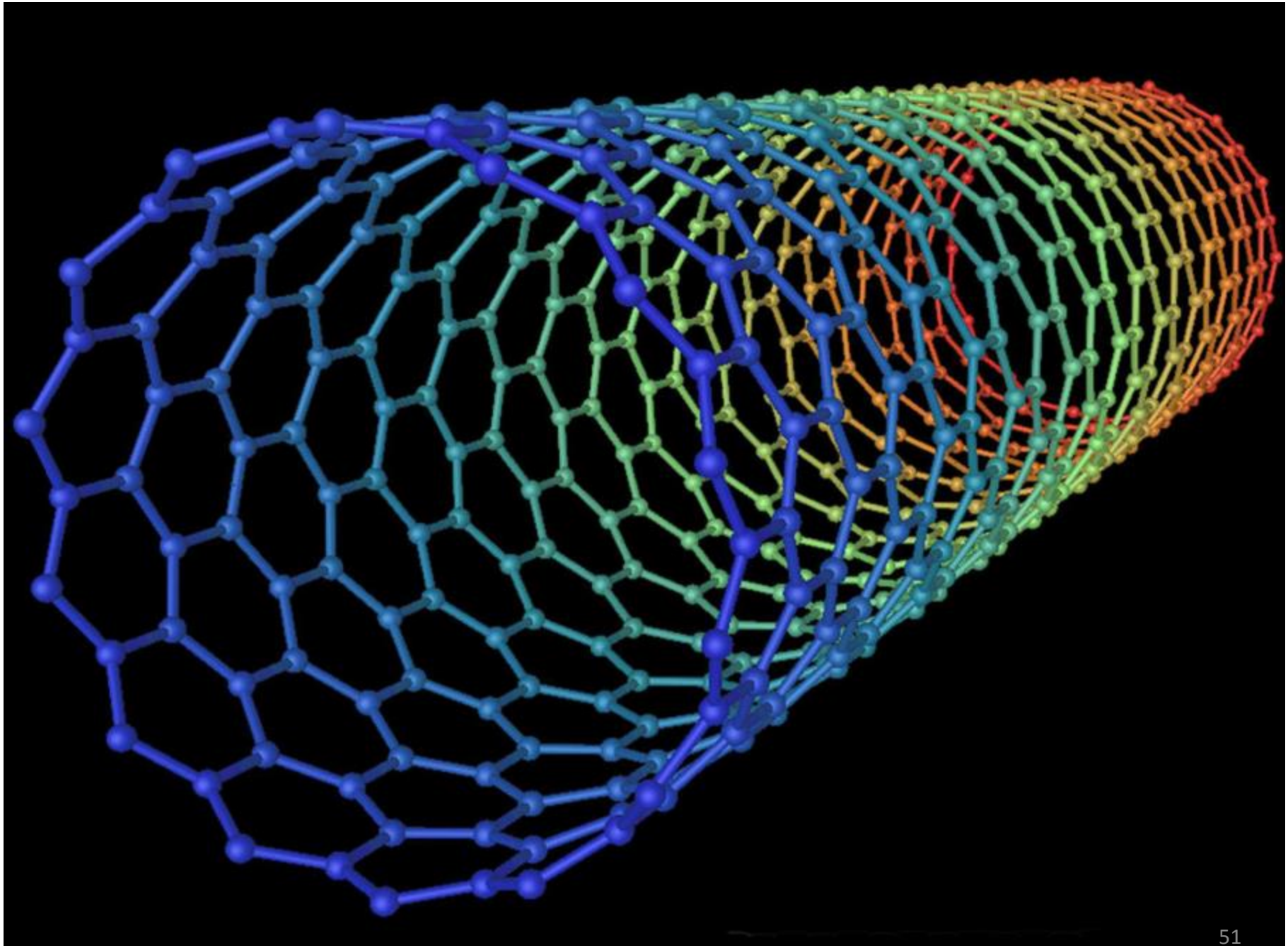


Grafeno





Nanotubos



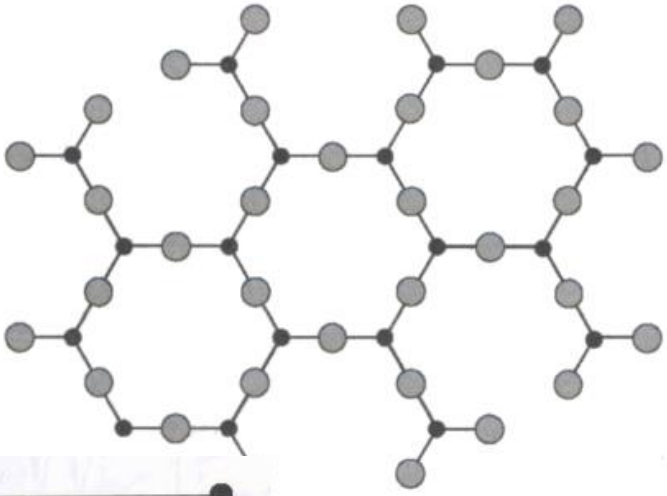
Física dos Materiais

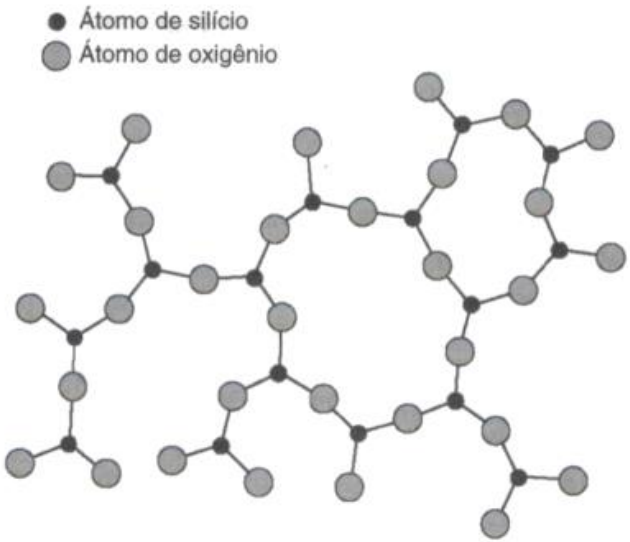
Cerâmicas

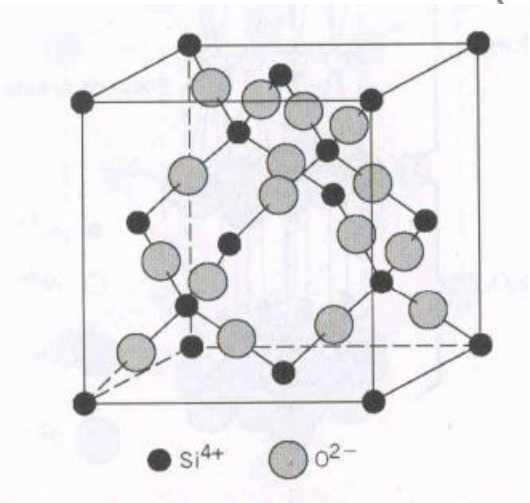
Vidros

SiO_2 cristalino (quartzo)

SiO_2 não cristalino (amorfo) (vidro)







Cristobalita

Física dos Materiais

Cerâmicas

Vidros

Tabela 14.1 Composições e Características de Alguns Vidros Comerciais Típicos

Tipo de Vidro	*Composição (%p)*						*Características e Aplicações*
	SiO_2	*Na_2O*	*CaO*	*Al_2O_3*	*B_2O_3*	*Outros*	
Sílica fundida	>99,5						
96% Sílica (Vycor)	96				4		
Borossilicato (Pyrex)	81	3,5		2,5	13		
Recipientes (cal de soda)	74	16	5	1			
Fibra de vidro	55		16	15	10		
Sílex ótico	54	1					
Vitrocerâmica (Piroceram)	43,5	14		30	5,5		

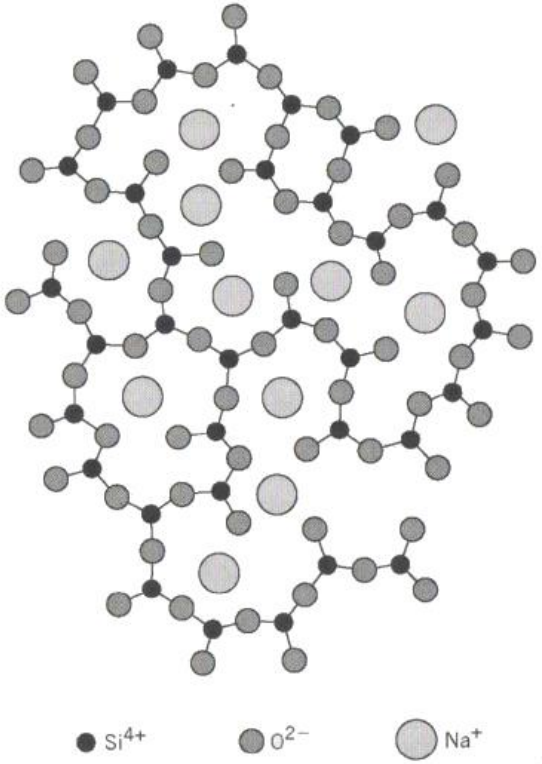
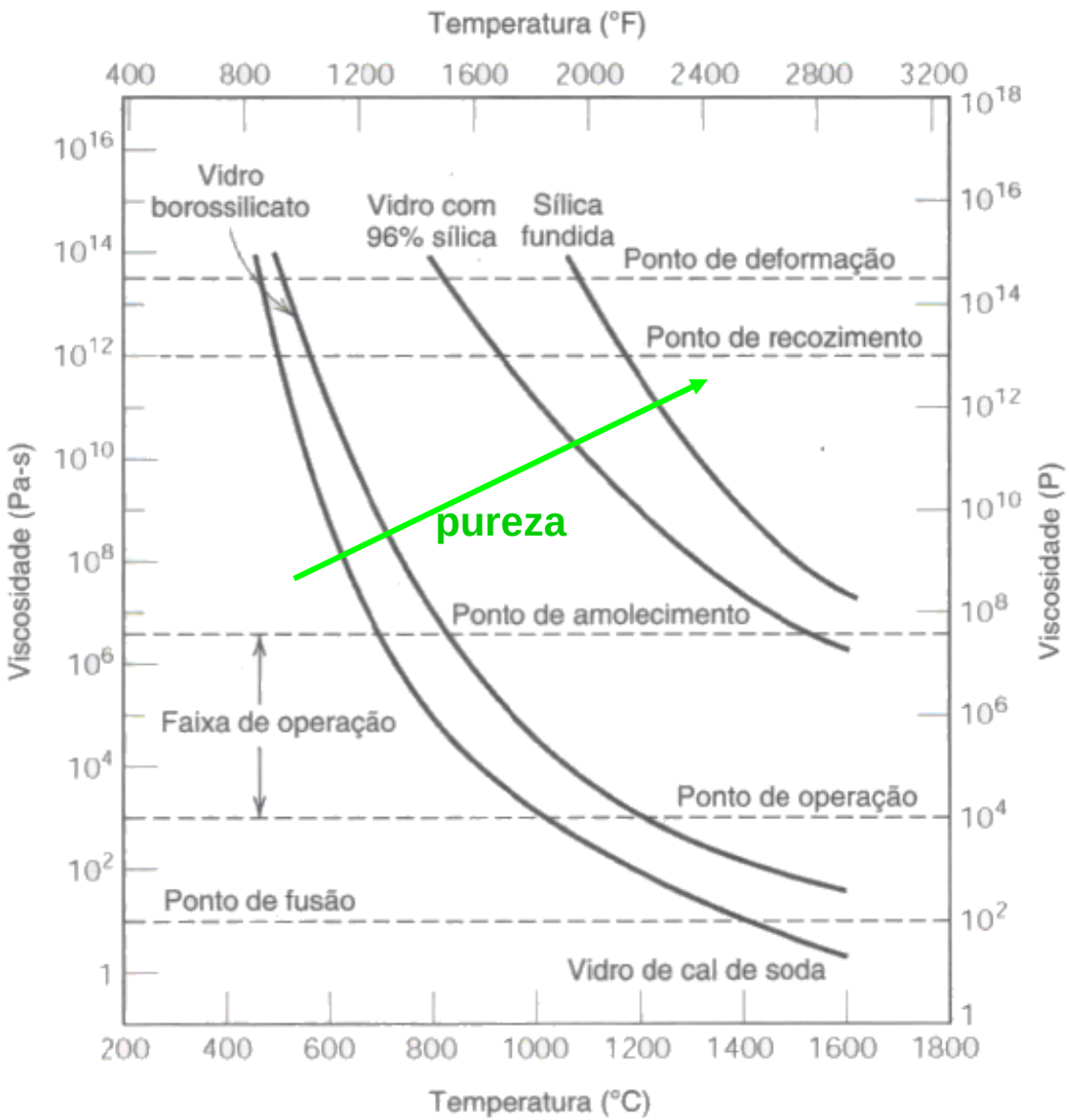


Fig. 13.11 Representação esquemática das posições dos íons em um vidro sódio-silicato.

Física dos Materiais

Cerâmicas

Vidros



Física dos Materiais

Cerâmicas

Compostas

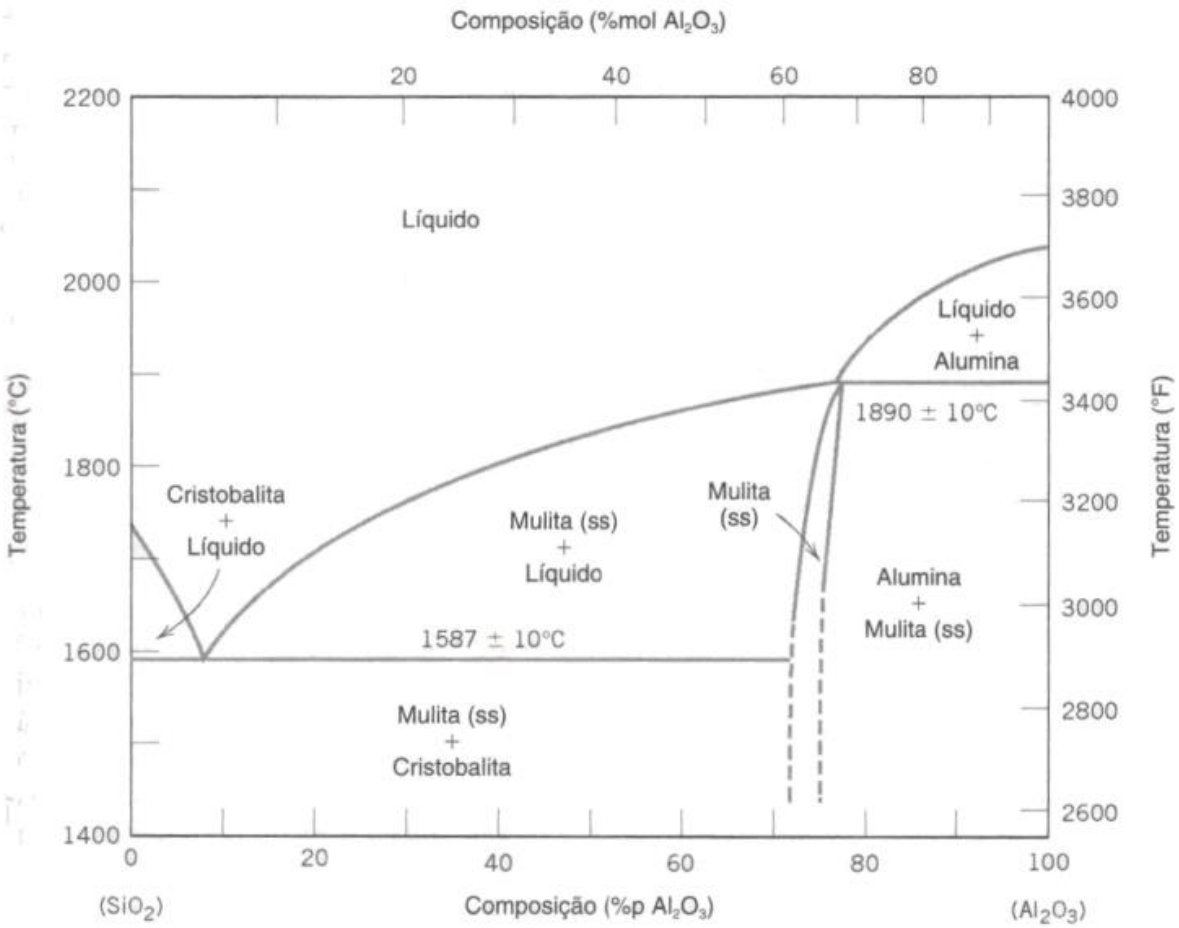
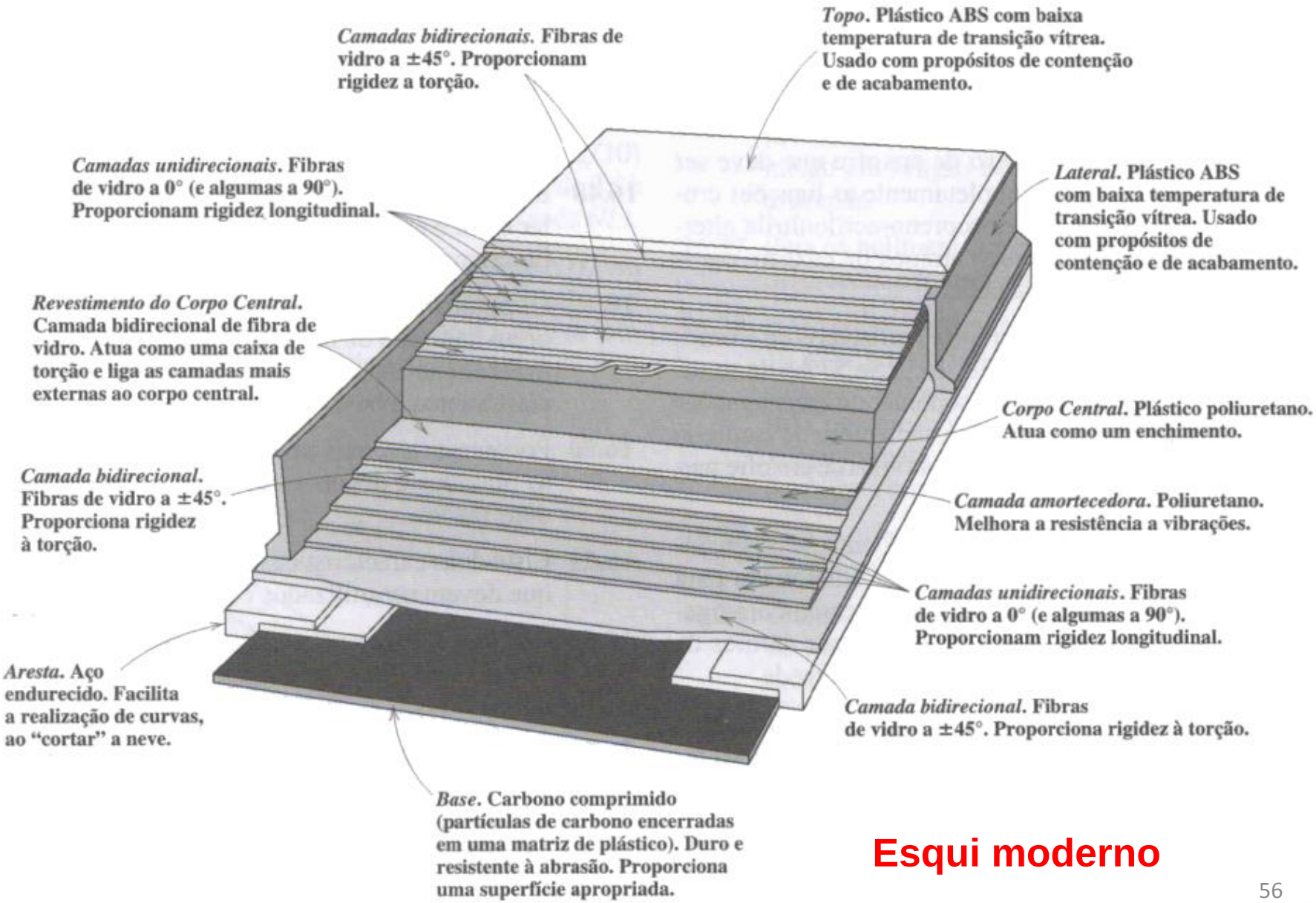


Fig. 13.26 O diagrama de fases para o sistema sílica-alumina. (Adaptado de F. J. Klug, S. Prochazka e R. H. Doremus, "Alumina-Silica Phase Diagram in the Mullite Region", *J. Am. Ceram. Soc.*, **70** [10] 758 (1987). Reimpresso sob permissão da American Ceramic Society.)

Vitrocerâmica

Física dos Materiais

Compósitos



Esqui moderno