APPENDIX A

Polymer Abbreviations

ABS	acrylonitrile–butadiene–styrene resin
CA	cellulose acetate
CAB	cellulose acetate butyrate
CAP	cellulose acetate propionate
CF	cresol–formaldehyde
CMC	carboxymethylcellulose
CN	cellulose nitrate
CP	cellulose propionate
CPE	chlorinated polyethylene
CTA	cellulose triacetate
CTFE	poly(chlorotrifluoroethylene)
EC	ethylcellulose
EP	epoxy resin
E/P	ethylene–propylene copolymer
EPDM	elastomeric terpolymer of ethylene, propylene, and a nonconjugated diene
EPS	expanded polystyrene (foam)
ETFE	ethylene–tetrafluoroethylene copolymer
EVA	ethylene–vinyl acetate copolymer
FEP	elastomeric copolymer of tetrafluoroethylene and hexafluoroethylene
FF	furan–formaldehyde resin
GP	gutta percha
HDPE	high-density polyethylene
HEC	hydroxyethylcellulose
HIPS	high-impact polystyrene
HMWPE	high-molecular-weight polyethylene
LDPE	low-density polyethylene

LLDPE	linear low-density polyethylene
MBS	methyl methacrylate-butadiene-styrene copolymer
MC	methylcellulose
MDPE	medium-density polyethylene
MF	melamine–formaldehyde resin
MPF	melamine/phenol–formaldehyde resin
NBR	nitrile rubber (elastomeric copolymer of butadiene and acrylonitrile)
NR	natural rubber
PA	polyamide, polyacetylene
PAA	poly(acrylic acid)
PAI	poly(amide-imide)
PAMS	poly(α-methylstyrene)
PAN	polyacrylonitrile
PANI	polyaniline
PAR	polyarylate
PB	polybutene-1
PBA	poly(butyl acrylate)
PBI	polybenzimidazole
PBO	polybenzoxazole
PBT	poly(butylene terephthalate)
PC	polycarbonate
PCTFE	poly(chlorotrifluoroethylene)
PDAP	poly(diallyl phthalate)
PDMS	polydimethylsiloxane
PE	polyethylene
PEEK	poly(aryl ether ether ketone)
PEN	poly(ethylene-2,6-naphthalate)
PEO	poly(ethylene oxide)
PES	polyethersulfone
PET	poly(ethylene terephthalate)
PF	phenol–formaldehyde resin
PHEMA	poly(2-hydroxyethyl methacrylate)
PI	polyimide
PIB	polyisobutylene
PMMA	poly(methyl methacrylate)
PMP	poly(4-methyl-1-pentene)
POM	poly(oxymethylene); polyformaldehyde
POP	poly(phenylene oxide)
PP	polypropylene
PPBT	poly(*p*-phenylene benzobisthiazole)
PPP	poly(*p*-phenylene)
PPS	poly(*p*-phenylene sulfide)
PPSU	poly(phenylene sulfone)

PPV	poly(*p*-phenylene vinylene)
PPy	polypyrrole
PS	polystyrene
PSF	polysulfone
PT	polythiophene
PTFE	polytetrafluoroethylene
PUR	polyurethane
PVAC	poly(vinyl acetate)
PVAL	poly(vinyl alcohol)
PVB	poly(vinyl butyral)
PVC	poly(vinyl chloride)
PVF	poly(vinyl fluoride)
PVDC	poly(vinylidene dichloride)
PVDF	poly(vinylidene difluoride)
PVFM	poly(vinyl formal)
PVK	poly(*N*-vinylcarbazole)
PVP	poly(*N*-vinylpyrrolidone)
S/B	styrene–butadiene copolymer
SIN	simultaneous interpenetrating network
SMC	sheet molding compound
UF	urea–formaldehyde resin
UHMW-PE	ultrahigh-molecular-weight polyethylene
UP	unsaturated polyester

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APPENDIX B

Representative Properties of Some Important Commercial Polymers

Table B-1 Physical and Thermal Properties*

Polymer	ρ (g cm^{-3})[a]	T_g (°C)	T_m (°C)[b]
Cellulose acetate	1.27–1.34	(49)	—
Nylon-6	1.08–1.23	46–60	223
Nylon-6,6	1.07–1.24	45–57	265
Polycarbonate	1.20–1.31	141–150	227
Polyethylene (all grades)	0.91–1.00	(-120)	98–135
Poly(ethylene terephthalate)	1.33–1.48	69–77	267
Poly(methyl methacrylate)	1.17–1.23	105–126	160
Polyoxymethylene	1.43–1.54	-85 to -30	187
Polypropylene	0.9–0.95	-10 to -18	177
Polysulfone	1.24	190	—
Polystyrene	1.05–1.13	100	240
Polytetrafluoroethylene	2.1–2.35	-73	327–332
Poly(vinyl acetate)	1.19–1.34	28–31	—
Poly(vinyl chloride)	1.39–1.52	81	273
Silicone rubber	1.07	-123	-43

[a] Numbers typically indicate a range of reported values for samples with different crystallinity, water content, molecular weight, and thermal histories. Uncertain or controversial values are given within parentheses.

[b] In most cases, values indicate the range of densities between that of the glassy amorphous state to that of the fully crystalline polymer as calculated from X-ray data of crystalline domains.

Table B-2 Mechanical Properties

Polymer	E^a (GPa)	σ_b (σ_y)[b] (MPa)	ε_b (ε_y)[c] %	Izod Impact[d] Strength (J/m)
Cellulose acetate	2	30 (60)	30 (6)	6–133
Nylon-6	1.9	75 (50)	300 (30)	(25)
Nylon-6,6	2.0	80 (57)	200 (25)	110
Polycarbonate	2.5	60 (65)	125 (30)	800
Polyethylene (all grades)	0.2–1	10–30 (8–30)	600–800 (9–20)	130–700
Poly(ethylene terephthalate)	3.0	54	275 (6)	70
Poly(methyl methacrylate)	3.2	65	10	27
Polyoxymethylene	2.7	65	40	80
Polypropylene	1.4	33 (32)	400 (12)	80
Polysulfone	3.4	50	2.5	28
Polystyrene	2.5	65	75	85
Polytetrafluoroethylene	0.5	25 (13)	200 (63)	160
Poly(vinyl acetate)	0.6	29–49	10–20	160
Poly(vinyl chloride)	2.6	50 (48)	30 (3)	43
Silicone rubber	—	4.8–7.0	100–400	—

[a] Tensile modulus; to convert GPa to psi, multiply by 1.45×10^5.
[b] Stress at break (yield); to convert MPa to psi, multiply by 145.
[c] Elongation at break (yield).
[d] To convert J m^{-1} to ft-lb_f $in.^{-1}$, divide by 53.38.

APPENDIX C

ASTM Standards for Plastics and Rubber

Table C-1 Plastics (Vols. 8.01, 8.02, 8.03)

ASTM	Standards
D 256	Impact resistance of plastics and electrical insulating materials
D 412	Rubber properties in tension
D 542	Index of refraction of transparent organic plastics
D 543	Resistance of plastics to chemical reagents
D 568	Rate of burning and/or extent and time of burning of flexible plastics in a vertical position
D 569	Measuring the flow properties of thermoplastic molding materials
D 570	Water absorption of plastics
D 618	Conditioning plastics and electrical insulating materials for testing
D 621	Deformation of plastics under load
D 635	Rate of burning and/or extent and time of burning of self-supporting plastics in a horizontal position
D 638	Tensile properties of plastics
D 647	Design of molds for test specimens of plastics under flexural load
D 648	Deflection temperature of plastics under flexural load
D 671	Flexural fatigue of plastics under flexural load
D 695	Compressive properties of rigid plastics
D 696	Coefficient of linear thermal expansion of plastics
D 746	Brittleness temperature of linear thermal expansion of plastics
D 785	Rockwell hardness of plastics and electrical insulating materials
D 790	Flexural properties of unreinforced and reinforced plastics and electrical insulating materials
D 792	Specific gravity and density of plastics by displacement
D 882	Tensile properties of thin plastic sheeting

(*Continues*)

Table C-1 Plastics (Vols. 8.01, 8.02, 8.03) (*Continued*)

ASTM	Standard
D 1238	Flow rates of thermoplastics by extrusion plastometer
D 1434	Determining gas permeability characteristics of plastic film and sheeting
D 1435	Outdoor weathering of plastics
D 1505	Density of plastics by the density-gradient technique
D 1525	Vicat softening temperature of plastics
D 1637	Tensile heat-distortion temperature of plastic sheeting
D 1708	Tensile properties of plastics by use of microtensile specimens
D 1746	Transparency of plastic sheeting
D 1790	Brittleness temperature of plastic sheeting by impact
D 1822	Tensile-impact energy to break plastics and electrical insulating materials
D 1870	Elevated temperature aging using a tubular oven
D 1894	Static and kinetic coefficients of friction of plastic film and sheeting
D 1895	Apparent density, bulk factor, and pourability of plastic materials
D 1896	Transfer-molding test specimens of thermosetting compounds
D 1897	Injection-molding test specimens of thermoplastic molding and extrusion materials
D 1898	Sampling of plastics
D 1925	Yellowness index of plastics
D 1929	Ignition properties of plastics
D 1938	Tear propagation resistance of plastic film and thin sheeting by a single-tear method
D 2117	Melting point of semicrystalline polymers by the hot stage microscopy method
D 2126	Response of rigid cellular plastics to thermal and humid aging
D 2134	Softening of organic coatings by plastic compositions
D 2236	Dynamic mechanical properties of plastics by means of a torsional pendulum
D 2240	Rubber property—durometer hardness
D 2288	Weight loss of plasticizers on heating
D 2471	Gel time and peak exothermic temperature of reacting thermosetting resins
D 2566	Linear shrinkage of cured thermosetting casting resins during cure
D 2582	Puncture–propagation tear resistance of plastic film and thin sheeting
D 2684	Determining permeability of thermoplastic containers
D 2732	Unrestrained linear thermal shrinkage of plastic film and sheeting
D 2734	Density of smoke from the burning or decomposition of plastics
D 2857	Dilute solution viscosity of polymers
D 2863	Measuring the minimum oxygen concentration to support candle-like combustion of plastics (oxygen index)
D 2990	Tensile, compressive, and flexural creep and creep rupture of plastics
D 3029	Impact resistance of rigid plastic sheeting or parts by means of a tub (falling weight)
D 2856	Open cell content of rigid cellular plastics by the air pycnometer
D 3420	Test method for dynamic ball burst (pendulum) impact resistance of plastic films

(*Continues*)

Table C-1 Plastics (Vols. 8.01, 8.02, 8.03) (*Continued*)

ASTM	Standard
D 3593	Test method for molecular-weight averages and molecular weight distribution of certain polymers by liquid size-exclusion chromatography (gel permeation chromatography, GPC) using universal calibration
D 3750	Practice for determination of number-average molecular weight of polymers by membrane osmometry
D 3763	Test method for high-speed puncture properties of plastics using load and displacement sensors
D 3795	Test method for thermal flow and cure properties of thermosetting resins by torque rheometer
D 3845	Test method for the rheological properties of thermoplastics with a capillary rheometer
D 3846	Test method for in-plane shear strength of reinforced plastics
D 4000	Specifying plastic material
D 4001	Practice for determination of weight-average molecular weight of polymers by light scattering
D 4065	Practice for determining and reporting dynamic mechanical properties of plastics
D 4093	Test method for photoelastic measurements of birefringence and residual strains in transparent or translucent plastic materials
D 4272	Test method for impact resistance of plastic film by instrumented dart drop
D 4440	Practice for rheological measurement of polymer melts using dynamic mechanical procedures
D 4473	Practice for measuring the cure behavior of thermosetting resins using dynamic mechanical procedures
D 4526	Determination of volatiles in polymers by headspace chromatography
D 6108	Standard test method for compressive properties of plastic lumber and shapes
D 6109	Standard test method for flexural properties of unreinforced and reinforced plastic lumber
D 6111	Standard test method for bulk density and specific gravity of plastic lumber and shapes by displacement
D 6662	Standard specification for polyolefin-based plastic lumber decking boards

Table C-2 Rubber (Vols. 9.01 and 9.02)

ASTM	Standard
D 297	Methods for rubber products—chemical analysis
D 395	Test methods for rubber property—compression set
D 412	Test methods for rubber properties in tension
D 471	Test methods for rubber property—effect of liquids
D 624	Test methods for rubber property—tear resistance
D 797	Test methods for rubber property—Young's modulus at normal and subnormal temperatures
D 814	Test methods for rubber property—vapor transmission of volatile liquids
D 1349	Recommended practice for rubber—standard temperatures and atmospheres for testing and conditioning
D 1630	Test method for rubber property—abrasion resistance (NBS abrader)

(*Continues*)

Table C-2 Rubber (Vols. 9.01 and 9.02) (*Continued*)

ASTM	Standard
D 2084	Test method for rubber property—vulcanization characteristics using oscillating disk cure meter
D 2228	Test method for rubber property—abrasion resistance (Pico abrader)
D 2240	Test method for rubber property—Durometer hardness
D 3137	Test method for rubber property—hydrolytic stability
D 3452	Practice for rubber—identification by pyrolysis-gas chromatography
D 3677	Test methods for rubber—identification by infrared spectrophotometry

APPENDIX D

SI Units and Physical Constants

Table D-1 Units and Symbols

Quantity	Name	Symbol	CGS Equiv.
Capacity	liter	L	10^{-3} m^3
Electric capacitance	farad	F	A s V^{-1}
Electric current	ampere	A	ampere
Energy, work, heat	joule	J	N m
Force	newton	N	m kg s^{-2}
Frequency	hertz	Hz	s^{-1}
Mass	kilogram	kg	kg
Plane angle	radian	rad	rad
Power	watt	W	J s^{-1}
Pressure, stress	pascal	Pa	N m^{-2}
Viscosity (dynamic)	pascal second	Pa s	N s m^{-2}

Table D-2 Conversion Factors

	Conversion
Density	1 g cm^{-3} = 0.0361 lb $in.^{-3}$
Energy	1 J = 0.2387 cal
Force	1 N = 10^5 dynes = 0.102 kg_f = 0.2248 lb_f
Pressure, stress	1 Pa = 10 dyne cm^{-2} = 7.5×10^{-3} mm Hg = 7.5×10^{-4} cm Hg = 10^{-5} bar = 1 kg m^{-1} s^{-2} = 1.45×10^{-4} psi = 9.869×10^{-6} atm
Solubility parameter	1 $(MPa)^{1/2}$ = 0.489 $(cal\ cm^{-3})^{1/2}$
Temperature	°R = (9/5)K °C = (5/9)(°F - 32) = K + 273.15
Thermal conductivity	J s^{-1} cm^{-1} K^{-1} = 1×10^{-2} W m^{-1} K^{-1}
Viscosity	1 Pa s = 10 poise

Table D-3 SI Prefixes

Prefix	Symbol	Equivalent
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}

Table D-4 Fundamental Physical Constants

Physical Constant	Symbol	Unit	Value
Avogadro's number	N_A	mol^{-1}	6.0220×10^{23}
Boltzmann constant, R/N_A	k	J K^{-1}	1.3807×10^{-23}
Gas law constant	R	J $(mol\ K)^{-1}$	8.3144
		bar cm^3 $(mol\ K)^{-1}$	83.144
		psia ft^2 (lb mol °R)	10.732
		atm cm^3 $(mol\ K)^{-1}$	82.057
Gravitational acceleration	g	m s^{-2}	9.80665
Planck constant	h	J s	6.6262×10^{-34}
Permeability of vacuum	μ_o	N A^{-2}	12.566×10^{-7}
Permittivity of vacuum, $1/\mu_o c^2$	ε_o	F m^{-1}	8.85419×10^{-12}
Speed of light in vacuum	c	m s^{-1}	2.9979×10^{8}

APPENDIX E

Mathematical Relationships

Trigonometric Functions

$$\sin^2\theta = \frac{1}{2} - \frac{1}{2}\cos 2\theta$$
$$\sin^2\theta + \cos^2\theta = 1$$
$$\sin(\theta \pm \phi) = \sin\theta\cos\phi \pm \cos\theta\sin\phi$$
$$\sin 2\theta = 2\sin\theta\cos\theta$$
$$\cos 2\theta = \cos^2\theta - \sin^2\theta$$

Euler's Identities

$$e^{i\theta} = \cos\theta + i\sin\theta$$
$$e^{-i\theta} = \cos\theta - i\sin\theta$$

Quadratic Equation

$$ax^2 + bx + c = 0$$
$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Derivatives

$$\frac{d}{dx}\left(u^n\right) = nu^{n-1}\frac{du}{dx}$$

$$\frac{d}{dx}(uv) = u\frac{dv}{dx} + v\frac{du}{dx}$$

$$\frac{d}{dx}\left(\frac{u}{v}\right) = \frac{v(du/dx) - u(dv/dx)}{v^2}$$

$$\frac{d}{dx}\sin\theta = \cos\theta\frac{d\theta}{dx}$$

$$\frac{d}{dx}\cos\theta = -\sin\theta\frac{d\theta}{dx}$$

$$\frac{d}{dx}\ln u = \frac{1}{u}\frac{du}{dx}$$

$$\frac{d}{dx}e^u = e^u\frac{du}{dx}$$

Indefinite Integrals

$$\int u^n du = \frac{u^{n+1}}{n+1} \quad (n \neq -1)$$

$$\int a^u du = \frac{a^u}{\ln a}$$

$$\int u dv = uv - \int v du \quad (\text{integration by parts})$$

$$\int e^u du = e^u$$

$$\int \frac{du}{u} = \ln u$$

$$\int \ln x dx = x\ln x - x$$

$$\int \sin u du = -\cos u$$

$$\int \cos u du = \sin u$$

$$\int \sin ax \cos ax dx = \frac{\sin^2 ax}{2a}$$

$$\int \sin ax \cos ax dx = \frac{\sin^2 ax}{2a}$$

$$\int \cos^2 u du = \frac{u}{2} + \frac{\sin 2u}{4} = \frac{1}{2}(u + \sin u \cos u)$$

Definite Integrals

$$\int_0^{\pi} \sin mx \cos nx dx = \begin{Bmatrix} 0 & m \text{ and } n, \text{ integers} & m+n, \text{ odd} \\ 2m/\left(m^2-n^2\right) & m \text{ and } n, \text{ integers} & m+n, \text{ even} \end{Bmatrix}$$

Geometric Series

$$a + ar + ar^2 + ar^3 \cdots + ar^{n-1} = \frac{a\left(1-rn\right)}{1-r} \frac{a-rl}{1-r}$$

where $l = ar^{n-1}$ is the last term and $r \neq 1$

$$a + ar + ar^2 + ar^3 + \cdots = \frac{a}{1-r} \quad \left(-1 < r < 1\right)$$

Taylor Series

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots \quad \left(-\infty < x < \infty\right)$$

$$\ln\left(1+x\right) = x - \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots \quad \left(-1 < r \leq 1\right)$$

$$\ln\left(1-x\right) = -x - \frac{x^2}{2} - \frac{x^3}{3} - \cdots$$

$$\ln x = 2\left\{\left(\frac{x-1}{x+1}\right) + \frac{1}{3}\left(\frac{x-1}{x+1}\right)^3 + \frac{1}{5}\left(\frac{x-1}{x+1}\right)^5 + \cdots\right\} \quad \left(x > 0\right)$$

$$\ln x = \left(\frac{x-1}{x}\right) + \frac{1}{2}\left(\frac{x-1}{x}\right)^2 + \frac{1}{3}\left(\frac{x-1}{x}\right)^3 + \cdots \quad \left(x \geq \frac{1}{2}\right)$$

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \cdots \quad \left(-\infty < x < \infty\right)$$

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^4}{6!} + \cdots \quad \left(-\infty < x < \infty\right)$$

The Gamma Function

$$\Gamma\left(n\right) = \int_0^{\infty} t^{n-1} e^{-t} dt \quad n>0$$

$$\Gamma\left(n+1\right) = \int_0^{\infty} t^n e^{-t} dt = n\Gamma\left(n\right) = n! \quad \left(n \text{ is a positive integer}\right)$$

Fourier Sine Transforms

$$F_S(\alpha) = \int_0^\infty f(x) \sin \alpha x dx$$

Table E-2 Fourier Sine Transforms

$f(x)$	$F_S(\alpha)$
$\begin{cases} 1, & 0 < x < b \\ 0, & x > b \end{cases}$	$\dfrac{1 - \cos b\alpha}{\alpha}$
x^{-1}	$\pi/2$
$\dfrac{x}{x^2 + b^2}$	$(\pi/2) e^{-b\alpha}$
e^{-bx}	$\dfrac{\alpha}{\alpha^2 + b^2}$

Fourier Cosine Transforms

$$F_C(\alpha) = \int_0^\infty f(x) \cos \alpha x dx$$

Table E-3 Fourier Cosine Transforms

$f(x)$	$F_c(\alpha)$
$\begin{cases} 1, & 0 < x < b \\ 0, & x > b \end{cases}$	$\dfrac{\sin b\alpha}{\alpha}$
$\dfrac{1}{x^2 + b^2}$	$\dfrac{\pi e^{-b\alpha}}{2b}$
e^{-bx}	$\dfrac{b}{\alpha^2 + b^2}$

Laplace Transforms

$$L\left[F(t)\right] = \int_0^\infty e^{-pt} F(t) dt = f(p)$$

$$F(t) = L^{-1}\left\{f(p)\right\}$$

Table E-1 Table of Useful Laplace Transforms

***F*(*t*)**	***f*(*p*)**
a	$\frac{a}{p}$
t	$\frac{1}{p^2}$
at	$\frac{a}{p^2}$
$e^{\mathrm{a}t}$	$\frac{1}{p-\mathrm{a}}$
$e^{-\mathrm{a}t}$	$\frac{1}{p+\mathrm{a}}$
$\cos \mathrm{a}t$	$\frac{p}{p^2+\mathrm{a}^2}$
$\frac{\sin \mathrm{a}t}{\mathrm{a}}$	$\frac{1}{s^2+\mathrm{a}^2}$
$F(t-\mathrm{a})$	$e^{-\mathrm{a}p}L[F(t)]$
$F'(t)$	$pf(p)-F(0)$
$F''(t)$	$p^2 f(p)-pF(0)-F'(0)$
$\int_0^t F(u)G(t-u)du$	$f(p)g(p)$

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APPENDIX F

The Major Elements

Table F-1 The Elements

Element	Symbol	Atomic Number	Atomic Weight
Aluminum	Al	13	26.98154
Argon	Ar	18	39.948
Arsenic	As	33	74.9216
Barium	Bs	56	137.33
Boron	B	5	10.81
Bromine	Br	35	79.904
Calcium	Ca	20	40.08
Carbon	C	6	12.011
Chlorine	Cl	17	35.453
Chromium	Cr	24	51.996
Cobalt	Co	27	51.9332
Copper	Cu	29	63.546
Fluorine	F	9	18.998404
Germanium	Ge	32	72.59
Gold	Au	79	196.9665
Helium	He	2	4.00260
Hydrogen	H	1	1.00794
Iodine	I	53	126.9045
Iron	Fe	26	55.847
Lead	Pb	82	207.2
Lithium	Li	3	6.941
Magnesium	Mg	12	24.305
Mercury	Hg	80	200.59

(*continues*)

Table F-1 The Elements (*continued*)

Element	Symbol	Atomic Number	Atomic Weight
Neon	Ne	10	20.1179
Nickel	Ni	28	58.69
Nitrogen	N	7	14.0067
Osmium	Os	76	190.2
Oxygen	O	8	15.9994
Palladium	Pd	46	106.42
Phosphorus	P	15	30.97376
Platinum	Pt	78	195.08
Potassium	K	19	39.0983
Radon	Rn	86	(222)
Rhodium	Rh	45	102.9055
Silicon	Si	14	28.0855
Silver	Ag	47	107.8682
Sodium	Na	11	22.98977
Sulfur	S	16	32.06
Tin	Sn	50	118.69
Titanium	Ti	22	47.88
Tungsten	W	74	183.85
Vanadium	V	23	50.9415
Zinc	Zn	30	65.38

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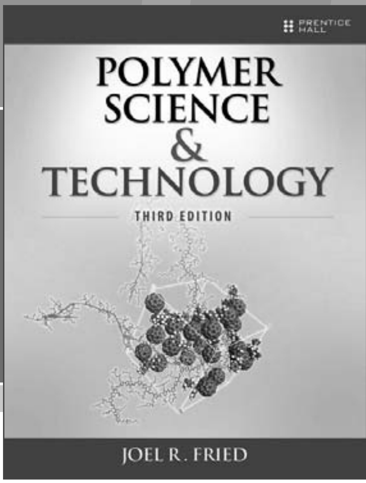
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