

## 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( $\alpha$ -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( <i>p</i> -phenylene benzobisthiazole)
PPP	poly( <i>p</i> -phenylene)
PPS	poly( <i>p</i> -phenylene sulfide)
PPSU	poly(phenylene sulfone)

PPV	poly( <i>p</i> -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( <i>N</i> -vinylcarbazole)
PVP	poly( <i>N</i> -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

*This page intentionally left blank*

## Representative Properties of Some Important Commercial Polymers

**Table B-1 Physical and Thermal Properties\***

Polymer	$\rho$ (g cm <sup>-3</sup> ) <sup>a</sup>	$T_g$ (°C)	$T_m$ (°C) <sup>b</sup>
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

<sup>a</sup> 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.

<sup>b</sup> 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)	$\sigma_b$ ( $\sigma_y$ ) <sup>b</sup> (MPa)	$\varepsilon_b$ ( $\varepsilon_y$ ) <sup>c</sup> %	Izod Impact <sup>d</sup> 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	—

<sup>a</sup> Tensile modulus; to convert GPa to psi, multiply by  $1.45 \times 10^5$ .<sup>b</sup> Stress at break (yield); to convert MPa to psi, multiply by 145.<sup>c</sup> Elongation at break (yield).<sup>d</sup> To convert J m<sup>-1</sup> to ft-lbf in.<sup>-1</sup>, divide by 53.38.

## 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)**

<b>ASTM</b>	<b>Standard</b>
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)**

<b>ASTM</b>	<b>Standard</b>
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)**

<b>ASTM</b>	<b>Standard</b>
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

---

A P P E N D I X      **D**

---

## SI Units and Physical Constants

**Table D-1 Units and Symbols**

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

**Table D-2 Conversion Factors**

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

**Table D-3 SI Prefixes**

Prefix	Symbol	Equivalent
pico	p	$10^{-12}$
nano	n	$10^{-9}$
micro	$\mu$	$10^{-6}$
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	$N_A$	$\text{mol}^{-1}$	$6.0220 \times 10^{23}$
Boltzmann constant, $R/N_A$	k	$\text{J K}^{-1}$	$1.3807 \times 10^{-23}$
Gas law constant	R	$\text{J (mol K)}^{-1}$	8.3144
		$\text{bar cm}^3 (\text{mol K})^{-1}$	83.144
		$\text{psia ft}^2 (\text{lb mol } {}^\circ\text{R})$	10.732
		$\text{atm cm}^3 (\text{mol K})^{-1}$	82.057
Gravitational acceleration	g	$\text{m s}^{-2}$	9.80665
Planck constant	h	$\text{J s}$	$6.6262 \times 10^{-34}$
Permeability of vacuum	$\mu_0$	$\text{N A}^{-2}$	$12.566 \times 10^{-7}$
Permittivity of vacuum, $1/\mu_0 c^2$	$\epsilon_0$	$\text{F m}^{-1}$	$8.85419 \times 10^{-12}$
Speed of light in vacuum	c	$\text{m s}^{-1}$	$2.9979 \times 10^8$

## 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

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

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

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

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

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

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

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

## 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

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

## Geometric Series

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

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

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

## Taylor Series

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

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

$$\ln(1-x) = -x - \frac{x^2}{2} - \frac{x^3}{3} - \dots$$

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

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

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

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

## The Gamma Function

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

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

## Fourier Sine Transforms

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

**Table E-2 Fourier Sine Transforms**

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

## Fourier Cosine Transforms

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

**Table E-3 Fourier Cosine Transforms**

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

## Laplace Transforms

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

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

**Table E-1 Table of Useful Laplace Transforms**

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

*This page intentionally left blank*

## 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

---

# Index

---

## A

- Ab initio methods, 581, 584  
ABA block copolymers, SBS elastomers, 385  
ABA-triblock copolymers, 9  
AB-block copolymers, 9  
Abbreviations, polymer, 14–15, 621–623  
ABS, 401–402  
Acetal, 405–406  
Acrylics  
  medical applications, 526  
  non-cellulosic synthetic fibers of, 353  
  synthetic fibers of, 348  
Acrylonitrile  
  in ABS, 401  
  ABS formulated from, 401  
  acrylic fibers as copolymers of, 353  
  with butadiene for nitrile rubber, 377  
  copolymerization of styrene with, 369  
  free-radical copolymerization, 44–46  
  polymerized in SCFs, 72  
  polymerizing with ATRP, 60  
Activation energies  
  dissociation rate constant, 32  
  dynamic-mechanical analysis, 220–221  
Activity coefficients, predicting, 566–574  
Addition polymers, 4–5, 7  
Additives  
  antiplasticization, 286–287  
  antistatic agents, 292  
  biocides, 291  
  biodegradability and, 278  
  blowing agents, 292–293  
  compatibilizers, 293  
  determining composition of polymer mixture, 284  
  external and internal plasticization, 284–286  
  fillers and reinforcers, 287–288  
  flame retardants, 290–291  
  heat distortion and impact modifiers, 292  
  list of PVC plasticizers, 286  
  lubricants, curing agents, and colorants, 291–292  
  overview of, 281–282  
  plasticizers, 282–284  
  for potable water, 288–289  
  in prevention of degradation, 288  
  references, 293  
  stabilizers, 289–290  
Adenine (A), 337  
Adhesion, improving polymers with, 74  
Advanced technologies  
  biomedical engineering. *See* Biomedical engineering and drug delivery  
  electronics/energy. *See* Electronics and energy applications  
  membranes. *See* Membrane science and technology  
  overview of, 493–494  
  photonic polymers, 541–544  
  references, 550–551  
  review problems, 550  
  sensor applications, 544–546  
  suggested reading, 547–549  
Affine deformation, rubber elasticity, 254  
AFM (atomic force microscopy), 200–201  
Aliphatic polyamides. *See* Nylons (aliphatic polyamides)  
American Chemical Society (ACS), nomenclature, 14  
American Society of Testing Methods (ASTM)  
  D-4000, 14  
  heat-distortion temperature, 176–177  
  standards for plastics and rubber, 627–629  
Amidation, 26  
Amino acids, naturally occurring, 332–335  
Aminoplasts (UF or MF) resins, 389–393, 524  
Amorphous state  
  of atactic polymers, 11  
  critical molecular weight, 154–155  
  defined, 20  
  density measures, 166

- Amorphous state (*continued*)  
 glass-transition temperature and, 156–158  
 overview of, 154  
 reptation, 155–156  
 secondary-relaxation processes, 158–159
- Amorphous Teflon (TEFLON-AF), 411
- Anion-exchange resins, 75
- Anionic polymerization  
 electron-withdrawing monomers in, 31  
 overview of, 49–51  
 preparing dienes, 375
- Anions, polymerization in ionic liquids, 73
- ANNs (artificial neural networks), 554, 578–581
- Antimicrobial polymers, 532
- Antioxidants, 268, 288–289
- Antiplasticization, 286–287
- Antistatic agents, as additives, 292
- Antithixotropic fluid, 452
- Apparent shear rate, capillary-rheometry, 470
- Apparent viscosity, 448–451, 470
- $\alpha$ -PS (atactic PS), 368
- Argon gas, plasma polymerization, 70
- Aromatic polyamides (aramids)  
 as engineering plastics, 400–401  
 as step-growth polymers, 26
- Arrhenius dependence on temperature  
 apparent viscosity, 451  
 dissociation rate constant, 32  
 propagation/termination rate constants, 36–37
- Artificial neural networks (ANNs), 554, 578–581
- Artificial organs, biomedical engineering, 533
- Association step, free-radical polymerization, 33
- ASTM. *See American Society of Testing Methods (ASTM)*
- Asymmetric-membrane formation, 518–523
- Atactic polymers  
 example of amorphous polymer, 154  
 geometric isomers as, 12–13  
 overview of, 10–12  
 producing atactic polypropylene, 367
- Atactic PS ( $\alpha$ -PS), 368
- Atom transfer radical polymerization (ATRP), 51, 59–61
- Atomic force microscopy (AFM), 200–201
- Atomic indices, topological calculations polymer properties, 575–577
- Atomistic simulations, MD applications, 581–583
- ATRP (atom transfer radical polymerization), 51, 59–61
- Average degree of polymerization, 29
- Averages, molecular-weight, 16–20
- Avrami equation, 164
- Axial annular Couette flow, 467–468
- Azeotropic copolymerization, 47
- Azide-alkyne coupling reaction., click chemistry, 79–80
- Azo (R-N=N-R) compounds, free-radical initiators, 33
- B**
- Backbone bonds, 575
- Bacterial growth, biocides for, 291
- Baekeland, Leo Hendrik, 2, 438
- Bagley plot of pressure drop, capillary rheometer, 472–473
- Bakelite, 2, 390
- Ball-and-stick representation, PVT simulation, 592
- Band gaps, electrically conductive polymers, 535
- Barostats  
 NPT ensembles, 591  
 PVT simulation, 591–593
- Barrier polymers, 494–495
- Batteries, polymeric, 535–537
- Becquerel, Edmund, 537
- Benzene, 109–110, 131–132
- Benzoyl peroxide, free-radical polymerizations, 32–34
- $\text{BF}_3$  counterion (gegen ion), isobutylene polymerization, 51
- BHJ (bulk-heterojunction) solar cells, 538–539
- Bicerano's method  
 artificial neural network, 578–581  
 topological indices and, 574–578
- Bingham fluids, 461–462
- Binodal curve, phase equilibria, 123–125
- Biocidal polymers, 532
- Biocides, additives, 291
- Biocompatibility  
 controlled drug delivery and, 526–527  
 improving polymer by adding, 74  
 protein adsorption and, 526
- Biodegradation  
 managing plastics, 275–278  
 stability of polymers, 262
- Biomedical engineering and drug delivery  
 antimicrobial polymers, 532  
 artificial organs, 533  
 controlled drug delivery, 527–530  
 gene therapy, 530–531  
 kidney dialysis, 533  
 overview of, 526–527  
 review problems, 547–549  
 suggested reading, 547–549  
 tissue engineering, 532
- Biopolymers  
 cellulose as, 76  
 naturally occurring elastomers, 344–346  
 overview of, 331–332

- polynucleotides, 336–341  
polysaccharides, 341–344  
proteins, 332–336  
references, 359–360  
suggested reading, 358–359
- Bischloroformates, 381–382
- Bisphenol-A  
nomenclature, 14–15  
polymerization of, 6  
synthesizing polycarbonate, 402–403  
synthesizing polysulfones, 407
- Blade coating operation, 446
- Blends. *See* Polymer blends
- Block copolymers  
overview of, 306–307  
self-assembly, 307–309  
suggested reading, 327
- Blow molding, 443–444
- Blowing agents, additives, 292–293
- BMC (bulk-molding compound), 316
- Boltzmann superposition principle  
Flory–Huggins theory, 111  
methods of dielectric analysis, 245–246  
transient and dynamic properties, 247–248
- Bond indices, topological calculations for properties, 575–576
- Bonded terms, molecular mechanics force fields, 583–584
- Bond-rotation angle, polymer chain bonds, 105, 107–108
- Bound electrons, OPV solar cells, 538
- Bragg equation, 201, 598–599
- Bragg peaks, 167–168
- Branching, low-density polyethylene, 364–365
- Bromination, fire retardancy with, 74
- Buckyballs, nanocomposites, 322–323
- Bulk modulus, mechanical properties, 601–602
- Bulk polymerization, 64–65
- Bulk-heterojunction (BHJ) solar cells, 538–539
- Bulk-molding compound (BMC), 316
- Butadiene, 12–13, 401
- Butadiene-based elastomers, 376–377
- C**
- CA. *See* Cellulose diacetate (CA)
- Calendering, 436, 445
- Calorimetry  
dynamic, 239–242  
measuring thermal transitions, 170, 174–176
- Canonical ensemble, molecular simulations, 590–591
- Capillary, flow through a, 464–466
- Capillary modules, UF/MF applications, 524
- Capillary rheometry, 469–473
- Capillary viscometers, 142
- Carbon dioxide, supercritical fluid in polymerization, 71
- Carbon nanofiber (CNF), 319
- Carbon nanotubes (CNTs), 319, 323–324
- Carbonium ion, isobutylene polymerization, 51
- Carothers, Wallace, 4, 331
- Cartesian coordinates  
equations for, 486  
incompressible fluids, 462–463  
polymer conformation/chain dimensions, 102–103
- Cast polymerization, 65
- Catalysts  
atom transfer radical polymerization, 60  
cationic polymerization, 51  
chloromethylation of polystyrene, 74  
metallocene, 55–56  
olefin metathesis, 82  
polyethylene with reduced branching, 364–365  
RAFT polymerization, 61–63  
using green chemistry for, 86  
Ziegler-Natta, 55–56
- Cation-exchange resins, 75
- Cationic polymerization, 31–32, 51–52
- Cationic ring-opening polymerization (CROP), 51–52
- Cations, polymerization in ionic liquids, 73
- Caustic production, 504–505
- CBAAs (chemical blowing agents), 292–293
- CED (Cohesive energy density), solubility parameter, 127–129, 593–594
- Ceiling temperatures ( $T_c$ ), free-radical polymerization, 41–43
- Cellophane, 76
- Celluloid, 2, 440
- Cellulose  
chemical structure of, 343  
graft copolymerization using ATRP of, 61  
as natural and abundant biopolymer, 76  
polysaccharides, 342  
preparing cellulose acetate from, 76
- Cellulose diacetate (CA)  
intrinsic viscosity measurements, 140–143  
low-angle laser light scattering of, 139–140  
preparing from cellulose, 76  
properties of, 347
- Cellulose nitrate development, 2
- Cellulose triacetate (CTA), 349–350
- Cellulosics, 347, 349–350
- CG (coarse-grained) simulations, 582–583, 587–588
- Chain dimensions, polymer conformation, 102–109
- Chain entanglements, 154–156, 202
- Chain expansion factor, 108
- Chain flexibility, 177

- Chain scission reactions, polymer degradation, 263–265
- Chain transfer, cationic polymerization, 52
- Chain-growth polymerization
- chain-extension reaction in, 25
  - controlled radical polymerizations, 57–64
  - coordination polymerization, 53–57
  - free-radical copolymerization, 43–49
  - free-radical polymerization, 32–43
  - free-radical polymerization kinetics, 28
  - ionic copolymerization, 53
  - ionic polymerization, 49–52
  - overview of, 31–32
- Chain-transfer agent
- bulk polymerization, 64–65
  - free-radical polymerization kinetics, 40–41
  - suspension polymerization, 66
- Chain-transfer coefficient, 40
- Characteristic pressure for mixture, Flory equation of state theory, 121
- Characteristic ratios, 108
- Characteristic temperature for mixture, Flory equation of state theory, 121
- Charpy tests, 185, 198
- Chemical blowing agents (CBAs), 292–293
- Chemical modification, reactions of polymers, 74–75
- Chemical structure determination
- nuclear magnetic resonance spectroscopy, 89–92
  - overview of, 86
  - structure–property relationships, 177–179
  - and thermal transitions, 20–22
  - vibrational spectroscopy, 86–89
- Chitin, 343–344
- Chitosan, 343
- Chlor-alkali cell, caustic production, 504–505
- Chlorination, commercial PVC, 370
- Chloromethylation, polystyrene, 74
- 4-chlorostyrene, 44–49
- Cholesteric state, liquid-crystal structures, 425
- cis*-polyacetylene, 427
- Classification of polymers
- mechanism of polymerization, 4–7
  - polymer structure, 7–8
  - thermoplastics and thermosets, 3–4
- Click chemistry, 74, 79–80
- Clot (thrombus) formation, artificial organs, 533
- Cloud-point curve, polymer blends, 295–296
- Clusters, ionic polymers, 421
- CNF (carbon nanofiber), 319
- CNTs (carbon nanotubes), 319, 323–324
- Coarse-grained (CG) simulations, 582–583, 587–588
- Coated asymmetric membranes, 521–523
- Coating, 445–446
- Cohesive energy density (CED), solubility parameter, 127–129, 593–594
- Cold drawing, stress/strain testing, 192
- Colorants, as additives, 291–292
- Combinatorial (entropy) term, UNIFAC-FV, 566–568
- Commercial blends, 300–301
- Commodity thermoplastics
- as largest share of market, 361
  - overview of, 362
  - polyolefins, 362–367
  - thermoplastic polyesters, 372–374
  - vinyl polymers, 367–372
- Common names, nomenclature for polymers, 14
- Comonomer distribution, 90
- COMPASS force field, 587, 592–593
- Compatibilizers, as additives, 293
- Composite membranes, 521–523
- Composites
- benefits of, 282
  - dynamic-mechanical properties, 314–316
  - fabrication of, 316–317
  - filament winding in fabrication of, 317–318
  - interfacial adhesion and coupling agents, 313–314
  - modulus of, 311–312
  - overview of, 310–311
  - pultrusion in fabrication of, 317–318
  - strength of, 312–313
  - suggested reading, 327
- Compressibility coefficient, Flory equation of state theory, 119
- Compression
- molding, 438
  - processing composites, 310
  - as section of extruders, 436–437
  - testing mechanical properties, 190–191
- Condensation polymers
- nomenclature rules, 13–14
  - overview of, 6–7
  - RIM suited only for, 442
  - step growth polymerization of, 7, 26–27
- Conductive polymers, 427–429, 533–535
- Cone-and-plate rheometer, 475
- Configuration
- of polymer chain, 102
  - stereochemical/geometrical arrangement of atoms, 9–11
- Conformation and chain dimensions
- overview of, 102–109
  - references, 150
  - review problems, 146–150
  - suggested reading, 146
- Connectivity indices, 575–576
- Consistency, power-law index and, 461–462
- Constitutive equations, 456–457, 461–468
- Continuity equations
- defined, 462

- for incompressible fluids, 463  
polymer processing, 486–487  
Controlled drug delivery (release), 527–530  
Controlled living radical polymerizations (CRP), 51, 58, 73  
Controlled radical polymerizations  
atom transfer radical polymerization, 59–61  
miniemulsion techniques of, 69  
nitroxide-mediated polymerization, 58–59  
overview of, 57–58  
RAFT polymerization, 61–64  
Conversion factors, 632  
Coordination polymerization  
metallocene polymerizations, 56–57  
overview of, 53–56  
for polyethylene with reduced branching, 364–365  
Copolyesters, thermoplastic, 386  
Copolymerization  
free-radical, 43–49  
ionic, 53  
Copolymers  
in low-density polyethylene production, 363–364  
overview of, 9  
possible structures of, 9–10  
scheme for naming, 15  
of vinyl chloride, 369–371  
Copper halide, 60  
Copper-catalyzed Huisgen Cu(I) 1,3-dipolar cyclo-addition, 79  
Correlations and simulations  
group-contribution. *See* Group-contribution methods  
molecular simulation applications. *See* Molecular simulation applications  
molecular simulations. *See* Molecular simulations  
overview of, 553–554  
references, 612–616  
review problems, 612  
suggested reading, 611–612  
topological indices and Bicerano's method, 574–581  
Cotton, 346–347  
Couette rheometer, 472–474  
Coulombic expression, 586–587  
Coupling agents, composites, 313–314  
Cox–Merz rule, 230  
 $Cp_2MX_2$  (cyclopentadienyl ligands), as metallocene catalysts, 57  
CPDB (2-cyanoprop-2-yl dithiobenzoate), 62–63  
CPK (space-filling) representation  
of PVC chain, 11–12  
of PVT simulation, 592  
CPK (space-filling) representation, PVT simulation, 592  
Cracking, solvent, 269–270  
Crankshaft rotation model, 158  
Crazing, 183–184, 269–270  
Creep resistance, acetal, 405  
Creep tests  
Maxwell model and, 222  
overview of, 185  
time-temperature superposition, 242–245  
transient tests of mechanical properties, 195–196  
Voigt model and, 225  
Critical concentration regions, solution viscosity, 452–455  
Critical micelle concentration, emulsions, 67  
Critical molecular weight ( $M_c$ ), 154–155  
Critical point, phase equilibria, 124  
CROP (cationic ring-opening polymerization), 51–52  
Cross coupling, molecular force fields, 585–586  
Cross talk, dielectrics, 541  
Crosslinks  
effect on glass-transition temperature, 182  
hydrogels, 80  
of polystyrene, 369  
rubber elasticity and, 254  
unsaturated polyesters, 387–388  
Cross-terms, molecular force fields, 585  
CRP (controlled living radical polymerizations), 51, 58, 73  
Cryogenic separation, 498  
Crystalline kinetics, 164–165  
Crystalline polyoxymethylene, 70  
Crystalline state  
crystalline kinetics, 164–165  
crystalline-melting temperature, 163–164  
ordering of polymer chains, 159–162  
overview of, 159  
techniques for determining crystallinity, 165–167  
Crystalline-melting temperature ( $T_m$ )  
crystalline state and, 160  
heat-distortion temperature, 176–177  
overview of, 163–164  
structure–property relationships, 177–179  
thermal transitions and, 21–22, 161  
Crystallinity  
isotactic polypropylene, 54  
low-density polyethylene, 53  
Raman spectroscopy studying, 89  
suggested reading, 202  
of tactic polymers, 11  
using FTIR to follow development of, 87–88  
Crystallites, thermal transitions and, 21  
CTA (cellulose triacetate), 349–350  
CTFE (polychlorotrifluoroethylene), 377, 411–412  
Cull, transfer molding process, 438–439  
Curing agents, as additives, 291–292  
CVFF force field, 587

Cyclic tests. *See* Fatigue tests  
 Cycloalkene, 82  
 Cyclohexane, 131–132  
 Cyclopentadienyl ligands ( $\text{Cp}_2\text{MX}_2$ ), as metallocene catalysts, 57  
 Cyclopentene, ring-opening metathesis of, 82  
 Cylindrical coordinates  
   equations for, 487  
   expressing elastic response, 458  
   polymer rheology, 447  
   using Couette rheometer, 473–474

**D**

D (diffusion coefficient), estimating permeability, 605–610  
 de Gennes, Pierre-Gilles, 156  
 Debye, Peter, 237  
 Debye equation, 139–140  
 Definite integrals, 635  
 Deformation mechanisms  
   crazing, 183–185  
   dynamic, 212–213  
   elastic recovery of solutions after shear, 457–460  
   overview of, 183  
   shear banding, 184  
   testing compression or shear strain, 190–191  
   testing stress or strain, 186–190  
 Degradation of polymers  
   additives for preventing, 288  
   biodegradation, 275–278  
   chain scission reactions, 263–265  
   environmental strategies for managing plastics, 272–273  
   hydrolytic effects, 269–271  
   incineration of plastics, 274  
   mechanodegradation, 272  
   non-chain scission reactions, 265–266  
   overview of, 261  
   oxidative and UV stability, 267–269  
   radiation effects, 271–272  
   recycling plastics, 273–274  
   references, 279–280  
   solvent crazing and cracking, 269–270  
   stability and, 262  
   strategies for thermal stability, 266–267  
   suggested reading, 279  
   thermal degradation, 262–263  
 Degree of polymerization, as molecular weight, 29  
 Dehydrohalogenation, in degradation, 265  
 Delaunay tessellation, free volume, 610–611  
 Dendrimers  
   defined, 430  
   in polymeric nanomedicines, 527–528  
   as specialty plastics, 430–431

Density  
   crystallinity measures, 165–166  
   polymerization in ionic liquids and, 73  
 Density functional theory (DFT), 581, 584  
 Deoxyribonucleic acid (DNA), 336–339  
 Depolymerization  
   chain scission reactions in degradation, 263–264  
   thermodynamics of free-radical polymerization, 41–42  
 Derivatives  
   mathematical functions of, 634  
   preparing polymer, 76–77  
 Detector, gel-permeation chromatography, 144  
 Determination of interaction, 125–126  
 Devolatilization process, extrusion, 437  
 DFT (density functional theory), 581, 584  
 Dialysis, 505, 533  
 Die  
   extrusion operations, 436–437  
   flow through capillary, 465  
   injection molding process, 440–441  
   modeling extrusion process, 477–479  
   modeling wire coating process, 482–485  
 Die swell, elastic response, 457–460  
 Dielectrics  
   analysis, 237–239  
   overview of, 541  
   relaxational strength, 235  
   suggested reading, 255  
 Diels-Alder diene + olefin cycloaddition reaction, 79  
 Diene elastomers  
   butadiene-based elastomers, 376–377  
   metathesis elastomers, 377  
   polychloroprene, 377  
   polyisoprene, 377  
   polymerization of, 374–376  
   vulcanization, 377–379  
 Differential refractometer, gel-permeation chromatography, 144  
 Differential scanning calorimetry (DSC), 170, 174–176  
 Diffusion coefficient ( $D$ ), estimating permeability, 605–610  
 Diffusion control, of drug release, 529  
 Diffusivity, solution-diffusion transport, 509–515  
 Diisocyanates, 381–383  
 Dilatometry, 169, 172–174  
 Dilute polymer solution, Flory-Krigbaum theory, 116–117  
 Dimethyl terephthalate (DMT), 273  
 Dipolar correlation function, 598–599  
 Dissociation of initiator, 32, 37–39  
 Dissociation rate constants, free-radical polymerization, 32–33  
 Dissolving power, supercritical fluids, 71

- Dissymmetry method, molecular weight, 138–139  
Distribution, molecular weight, 15–16  
DMT (dimethyl terephthalate), 273  
DNA  
  in conjugated polymeric nanomedicines, 527–528  
  in gene therapy, 530–531  
  using genetically engineered protein-like polymers, 85  
Double extrapolation, Zimm plot, 137–138  
Drag flow  
  axial annular Couette flow, 467–468  
  extrusion process, 477–482  
  plane Couette flow, 467  
  wire coating process, 484–485  
Drag reduction, polymer rheology, 460–461  
Draw stress, 192  
DREIDING force field, 587  
Drug conjugates, polymeric nanomedicines, 527–528  
Drug delivery, controlled, 527–530  
Dry process, asymmetric-membrane formation, 520  
Dry spinning, fibers, 355  
DSC (differential scanning calorimetry), 170, 174–176  
Dual-mode model, solution-diffusion transport, 510–511, 513  
Dynamic calorimetry, 239–242  
Dynamic deformation, 212–213  
Dynamic equations  
  defined, 462  
  flow through capillary, 464–465  
  plane Couette flow, 467  
  polymer processing, 486–487  
  solution to flow problems, 462–464  
  wire coating, 485  
Dynamic viscosity, 230  
Dynamic-mechanical analysis, viscoelasticity  
  activation energies, 220–221  
  experimental techniques, 213–214  
  forced-vibration methods, 218–220  
  free-vibration methods, 214–218  
  theory, 208–212  
  work in dynamic deformation, 212–213  
Dynamic-mechanical properties, composites, 314–316  
Dynamic-mechanical spectroscopy, 255
- E**
- Eccentric rotating-disk (ERD), 231–232  
Ehrenfest second-order transition, 169  
Einstein coefficient, viscosity of suspensions, 455  
Ejector pin, transfer molding, 438–439  
Elastic properties of polymeric fluids, 457–460  
Elastin, 344–345  
Elastomers. *See also* Rubber elasticity  
  birth of polymer science, 2  
from copolymers of TFE/perfluoroalkyl vinyl ethers, 412  
diene, 375–379  
graft copolymers as, 9  
naturally occurring, 344–346  
nondiene, 379–384  
obtained from metathesis, 81–82  
overview of, 374–375  
principle feature of, 361–362  
references, 395  
review problems, 394  
RIM-produced polyurethane used for, 442  
suggested reading, 394  
suitable polymers for, 1  
thermoplastic, 384–386  
Electrically conductive polymers, 533–535  
Electrodialysis, 504–505  
Electromagnetic interference (EMI) shielding, 540  
Electron acceptors, OPV solar cells, 538–539  
Electron beams, radiation effects on polymers, 271–272  
Electron spectroscopy for chemical analysis (ESCA), 70  
Electron-donating monomers, polymerizing by cationic pathway, 31–32  
Electronic encapsulation, 541  
Electronic shielding, 540  
Electronics and energy applications  
  dielectrics, 541  
  electrically conductive polymers, 533–535  
  electronic encapsulation, 541  
  electronic shielding, 540  
  organic photovoltaic polymers, 537–540  
  overview of, 533  
  polymeric batteries, 535–537  
  review problems, 550  
  suggested reading, 547–549  
Electron-withdrawing monomers, 31  
Electro-osmosis, 505  
Electrospinning, fibers, 357–358  
EMI (electromagnetic interference) shielding, 540  
Emissions, burning plastic, 274  
Emulsion polymerizations, 67–69  
Encapsulation, electronic, 541  
Endurance limits, fatigue tests, 199  
Energy, laws of thermodynamics and, 248–251  
Energy equations, 462  
Engineering plastics  
  ABS, 401–402  
  acetal, 405–406  
  engineering polyesters, 409–410  
  fluoropolymers, 411–412  
  modified poly(phenylene oxide), 404–405  
  polyamides, 399–401  
  polycarbonates, 402–403

- Engineering plastics (*continued*)  
 poly(*p*-phenylene sulfide) (PPS), 408–409  
 polysulfones, 406–408  
 properties of important, 398  
 references, 433–434  
 review problems, 433  
 specialty plastics vs., 397–398  
 suggested reading, 431–432
- Engineering polyesters, 409–410
- Engineering shear stress, 190
- Engineering strain, 186
- Engineering stress, 186
- Ensembles, molecular simulations, 590–591
- Entanglements  
 effect of shear on, 449–450  
 solution viscosity, 454–455
- Enthalpy of mixing, Flory–Huggins theory, 114–115
- Entropy, laws of thermodynamics and, 248–251
- Entropy of mixing, 111–115
- Environment  
 agents impacting polymers, 262  
 biodegradation, 275–278  
 green chemistry and hazards of, 86  
 incineration of plastics, 274  
 recycling plastics, 273–274  
 strategies for managing plastics, 272–273
- EOS. *See* Equation of state (EOS), Flory
- Epoxies  
 cure of, 387–388  
 overview of, 386–387  
 producing using RIM, 442  
 as thermosets, 4
- EPS (expandable PS), 367
- Equation of state (EOS), Flory  
 Flory–Huggins theory, 297–298  
 interaction parameter determination, 125–126  
 overview of, 118–122  
 predicting activity coefficients, 566, 570  
 thermodynamics of polymer solutions, 117–118
- ERD (eccentric rotating-disk), 231–232
- ESCA (electron spectroscopy for chemical analysis), 70
- Ester interchange, step-growth polymers, 26
- Esterification, step-growth polymers, 26
- Ethylene  
 addition polymers derived from, 4–5  
 free-radical polymerization of, 53  
 gas-phase polymerization of, 69  
 in low-density polyethylene production, 363–364  
 polymerizing. *See* Polyethylene (PE)  
 and propylene (EPM/EPDM) rubber, 384  
 Unipol process for, 366
- Euler's identity, 210–211, 633
- EVA (vinyl acetate), 363, 370–371
- Evapomeation process, membranes, 502–503
- EVOH (vinyl alcohol), 363
- Exchange interaction parameter, Flory, 121
- Excitons, OPV solar cells, 538
- Excluded volume, real polymer chain bonds, 106–108
- Expandable PS (EPS), 367
- Explosives detection, chemical sensors, 546
- External degrees of freedom, Flory EOS theory, 118–119
- External plasticization, 284–286
- Extruder  
 extrusion blow-molding process, 443–444  
 extrusion operations, 436–437
- Extrusion  
 blow-molding process, 443–444  
 defined, 436  
 modeling of, 476–482  
 process, 436–437
- F**
- Fabrication of composites, 316–318
- Facilitated and coupled transport, 515–516
- Failure envelope, testing stress or strain, 193
- Fast-scanning calorimetry (FSC), 176
- Fatigue life, 199
- Fatigue tests, 186, 199–200
- Feed section, extruders, 436–437
- FEP (fluorinated ethylene–propylene copolymer), 412
- Fiberglass, 4, 310
- Fibers  
 cellulosics, 349–350  
 in composite materials, 310  
 fiber-reinforced composites, 313  
 filler and reinforcer additives, 287–288  
 naturally occurring, 346–347  
 non-cellulosic, 350–354  
 overview of, 331–332, 346  
 references, 359–360  
 spinning, 354–358  
 suggested reading, 359  
 synthetic, 1–2, 347–348  
 U.S. production of synthetic, 2–3
- Fiber-spinning operations  
 dry spinning, 355  
 electrospinning, 357–358  
 melt spinning, 354  
 wet spinning, 356–357
- Fibroin, 347
- Fick's first law, 512–513
- Filament winding, 310, 317–318
- Fillers, as additives, 287–288
- Filtration membranes, 495–498
- Finite (van der Waals) volume, 106
- First (or primary) normal-stress difference, 459
- First-order transitions, thermodynamic relationships, 167–169

- Flame retardants  
as additives, 288, 290–291  
improving polymer by adding, 74  
strategies for thermal stability, 266
- Flash  
compression molding process, 438  
rotational molding producing little/no, 444
- Flexibility, chains, 177
- Flory, Paul  
equation of state theory. *See* Equation of state (EOS), Flory  
Flory–Huggins theory. *See* Flory–Huggins theory
- Fox–Flory parameters, 179–180  
liquid-crystalline polymers and, 424
- Flory constant, 143
- Flory–Huggins theory  
estimating activity of solvents, 566  
membrane osmometry, 130  
modified, 117  
predicting activity coefficients, 567–568  
predicting blend behavior, 296–298  
solution-diffusion transport, 509–510  
thermodynamics of polymer solutions, 110–115  
weaknesses of, 116–118
- Flory–Krigbaum theory, 116–117
- Flowing afterglow plasma reactor, 70
- Fluids  
drag flow, 467–468  
drag reduction, 460–461  
elastic properties of polymeric, 457–460  
generalized Newtonian fluid model, 448–450  
melt instabilities, 460  
modeling polymer-processing operations, 476–485  
rheometry. *See* Rheometry  
supercritical, 71  
thixotropic vs. antithixotropic, 452
- Fluorinated ethylene–propylene copolymer (FEP), 412
- Fluoroelastomers, 380–381
- Fluoropolymers, 411–412
- Flux, asymmetric-membrane formation, 518–519
- Force field parameterization, CG systems, 582, 587–588
- Force fields, molecular, 583–588
- Forced-vibration methods, dynamic-mechanical analysis, 218–220
- Formaldehyde resins  
acetal, 405–406  
aminoplasts, 391–393  
overview of, 389–390  
phenoplasts, 390–391
- Fourier transform infrared (FTIR) spectroscopy, 86–88
- Fox equation, 181–182
- Fox–Flory parameters, 179–180
- Fractional monomer conversion, 29
- Free radical polymerization, with step growth, 28
- Free radicals, oxidative and UV stability, 268
- Free volume, molecular simulation applications, 610–611
- Freely jointed chains, 102–105
- Freely rotating chain models, 107–108
- Free-radical copolymerization, 43–49
- Free-radical polymerization  
of commercial-grade PVC, 370  
controlled. *See* Controlled radical polymerizations  
of ethylene and polyethylene, 53–54  
initiation step, 32–33  
kinetics, 37–41  
of low-density polyethylene, 364–365  
overview of, 32  
propagation step, 34  
termination step, 34–37  
thermodynamics of, 41–43  
using bulk polymerization, 65
- Free-vibration methods, dynamic-mechanical analysis, 214–218
- Free-volume contribution, predicting activity coefficients, 570, 573–574
- FSC (fast-scanning calorimetry), 176
- FTIR (Fourier transform infrared) spectroscopy, 86–88
- Fuel cell membranes, 506–507
- Functional group, macromers, 84
- G**
- G (guanine), 337
- Gage length ( $L_o$ ), static testing, 186
- Gamma function, 635
- Gas permeability, predicting, 559–560
- Gas sensors, conjugated polymers as, 546
- Gas separations, polymeric membranes in, 498–501
- Gas-phase polymerization, 69
- Gaussian distribution, 102–103
- Gauss's flux theorem, 233
- GCMC (Grand Canonical Monte Carlo) simulations, 602–605
- Gel effect, 65
- Gel-permeation chromatography (GPC), 129–130, 143–146
- Gene therapy, 530–531
- Generalized Newtonian fluid (GNF) model, 448–450
- General-purpose styrenic polymers (GP-PS), 367–369
- Genetic engineering, 85–86
- Geometric isomerism, 12–13
- Geometric series, 635
- Geometrical arrangement of atoms, conformation, 9
- Gibbs free energy ( $G$ )  
first derivative applied to thermal properties, 167–168

Gibbs free energy ( $G$ ) (*continued*)  
 of mixing, 112, 122–125  
 polymer blends and, 294  
 second derivative applied to thermal properties, 169–170

Glass-transition temperature ( $T_g$ )  
 crystalline state and, 160  
 defined, 154  
 heat-distortion temperature, 176–177  
 molecular simulation applications, 594–595  
 molecular weight, composition, pressure and, 179–182  
 overview of, 20–21  
 predicting by group contributions, 558–559  
 of sample amorphous polymers, 158  
 structure–property relationships and, 157, 177–179  
 suggested reading, 202  
 thermal transitions of semicrystalline polymers, 161  
 views of, 156–157

Glassy domains, SBS elastomers, 385–386

Glycogen, 341–342

Glyptal, 2

GNF (generalized Newtonian fluid) model, 448–450

Goodyear, Charles, 2

Gordon–Taylor equation, 283–284

*Gossamer Albatross* aircraft, 26

Gough–Joule effect, 248

GPC (gel-permeation chromatography), 129–130, 143–146

GP-PS (general-purpose styrenic polymers), 367–369

$\gamma$ -radiation, 271–272

Gradient IPNs, 306

Graft copolymers, 9, 61, 70

Graft polymerization, 84

Graham, Thomas, 498

Grand Canonical Monte Carlo (GCMC) simulations, 602–605

Grand canonical ( $\mu VT$ ) ensemble, molecular simulations, 591

Graphene, 324–325

Green chemistry, 86

Group-contribution methods  
 activity coefficients, 566–574  
 glass-transition temperature, 558–559  
 overview of, 554  
 permeability, 559–562  
 predicting polymer properties with, 553–554  
 solubility parameter, 562–565  
 volumetric properties, 554–558

Group-interaction parameters, UNIFAC, 569–570

Group-transfer polymerization (GTP), 83–84

GTP (group-transfer polymerization), 83–84

Guanine (G), 337

Guar, as drag-reducing agent, 461  
 Guth–Smallwood equation, 253

## H

Hagen–Poiseuille *equation*, 465

Halogen atom transfer promoter, 60

Halpin–Tsai equation, 311–312

HALS (hindered-amine light stabilizers), 405

HDPE. *See* High-density polyethylene (HDPE)

HDT. *See* Heat-distortion temperature (HDT)

Head-to-head monomer placement, 34, 90

Head-to-tail monomer placement, 34, 90

Heat capacity, thermal conductivity, 65

Heat dissipation, in bulk polymerization, 65

Heat distortion modifiers, as additives, 292

Heat of polymerization ( $\Delta H_p$ ), 42–43

Heat-distortion temperature (HDT)  
 heat distortion modifiers, 292  
 measuring thermal transitions, 176–177  
 polymerizing polycarbonates, 403  
 PPO, 404  
 properties of blends, 303

Heating rate, effect on  $T_g$ , 182

Helium–neon (He–Ne) lasers, light scattering instruments, 139–140

Helmholtz free energy, 252

Henry's law, solution–diffusion transport, 509–511, 513

Heterochain polymers, backbone structure of, 8

Heteropolymers, proteins as, 332

Hevea rubber  
 as natural elastomer, 346  
 as natural occurring polymer, 1  
 synthetic rubber and short supply of, 2  
 vulcanization of, 377–379

High-impact polymers, 9

High monomer conversion, 29–30

High monomer purity, 30

High reaction yield, 29–30

High yield, of bulk polymerization, 64–65

High-density polyethylene (HDPE)  
 commercial applications, 366  
 development of, 54–55  
 polypropylene vs., 367  
 properties, 362–363

High-impact polystyrene (HIPS)  
 overview of, 302–303  
 production of, 369  
 properties of, 367

High-molecular-weight polymers, 25

High-performance fibers, 429–430

Hindered-amine light stabilizers (HALS), 405

HIPS (high-impact polystyrene), 302–303, 369

Hollow-fiber modules, 524

Homochain polymers, 7–8

- Hooke's law  
    applied to strain rate of elastic spring, 221  
    determining mechanical properties, 600–602  
    dynamic-mechanical analysis and, 210  
    shear deformation, 190  
    stress and strain in tensile deformation, 188
- Huggins equation, 141
- Huggins, Maurice. *See* Flory-Huggins theory
- Hyatt, John Wesley, 440, 443
- Hydrogels, controlled drug release, 529
- Hydrolysis, 262, 269–271
- Hydroxyl groups, 76
- Hyper-filtration membranes, 497–498
- I**
- IGC (inverse gas chromatography), 125–126
- Immiscibility, polymer blends and, 296–297
- Impact modifiers, as additives, 292
- Impact tests, 186, 198–199
- Incineration of plastics, 274
- Indefinite integrals, 634
- Infrared spectroscopy, 86–89
- Iniferters, 58
- Initiation step  
    anionic polymerization, 49–50  
    free-radical polymerization, 32–33  
    free-radical polymerization kinetics, 37–39
- Initiators  
    anionic polymerization, 49–50  
    bulk polymerization, 64–65  
    controlled “living” radical polymerization, 58  
    emulsion polymerization water-soluble, 67–69  
    free-radical, 32–33  
    group-transfer polymerization, 83  
    RAFT polymerization, 63  
    solution polymerization, 66  
    suspension polymerization, 66
- Injection blow-molding process, 443
- Injection molding, 438, 440–441, 452
- Inorganic photovoltaic (IPV) solar cells, 537–538
- Instantaneous copolymerization equation, 44
- Instrumentation  
    gel-permeation chromatography, 143–144  
    He-Ne lasers in light scattering, 139–140  
    light-scattering, 136–137
- Interaction parameter  
    determination of, 125–126  
    Flory, 115–116  
    Flory exchange, 121
- Interfacial adhesion, composites, 313–314
- Internal degrees of freedom, Flory EOS theory, 118–119
- Internal plasticization, 284
- Internal rotational angle, real polymer chain bonds, 105–106
- International Union of Pure and Applied Chemistry (IUPAC), 14–15
- Interpenetrating polymer networks (IPNs), 304–306, 326–327
- Intrinsic viscosity measurements, molecular-weight determination, 140–143
- Inverse emulsion polymerization, 69
- Inverse gas chromatography (IGC), 125–126
- Inverse rule of mixtures, 181
- Ion-exchange resins, 75
- Ionic addition, 28
- Ionic copolymerization, 53
- Ionic liquids, 72–73
- Ionic polymerization  
    anionic polymerization, 49–51  
    cationic polymerization, 51–52  
    overview of, 49
- Ionic polymers, as specialty plastics, 421–422
- Ionization, radiation effects on polymers, 271–272
- Ionomers, 421–422
- IPNs (interpenetrating polymer networks), 304–306, 326–327
- i*-PP (isotactic polypropylene), 54–55, 367–368
- i*-PS (isotactic PS), 368
- IPV (inorganic photovoltaic) solar cells, 537–538
- IR analysis, FTIR spectroscopy, 87
- Isobutylene polymerization, 51
- Isocyanates, elastomeric polyurethane, 381
- Isoentropic state, glass transition, 157
- Isofree volume, glass transition, 157
- Isomeric forms, 12–13
- Isotactic polymers, 10–13
- Isotactic polypropylene (*i*-PP), 54–55, 367–368
- Isotactic PS (*i*-PS), 368
- Isothermal compressibility coefficient ( $\beta$ ), 170–172
- Isothermal flow, wire coating, 484–485
- Isothermal-isobaric (NPT) dynamics  
    defined, 591  
    glass-transition temperature, 594–595  
    PVT simulation, 591–593
- Isoviscous state, glass transition, 156–157
- Italicized connective terms, naming copolymers, 15
- IUPAC (International Union of Pure and Applied Chemistry), 14–15
- Izod tests, 185, 198–199
- K**
- $K_2SO_4$  (persulfate-ferrous) redox initiator, 67
- Kapton (DuPont), 413–414
- Kel (or CTFE), 377, 411–412
- Kelley-Bueche equation, 180–181
- Keratin, in naturally occurring fibers, 347
- Kidney dialysis, 533
- Kinetics  
    crystalline, 164–165

Kinetics (*continued*)

- free-radical emulsion polymerization, 68–69
- free-radical polymerization, 28, 37–41
- step-growth polymerization, 30–31

Knudsen flow, 508–509

Knudsen number, 508

**L**

Ladder polymers, 418

LALLS (low-angle laser light scattering), 139–140

Lamé constants, 601–602

Lamellae, 159, 164

L-amino acids, 332–335

Langmuir-type hole-filling, solution-diffusion transport, 510–513

Laplace transforms, 247, 636

Latex, 455

Lattice model

Flory–Huggins theory, 110–116

modified Flory–Huggins, 117

weaknesses of, 117–118

LCP (liquid-crystalline polymers), 424–426

LCST (lower critical solution temperature), 125, 294–297

LDPE. *See* Low-density polyethylene (LDPE)

LEDs (light-emitting diodes), 543–544

Lennard-Jones model, 506–508, 511

Letters, nomenclature system, 13–15

Lewis acid, 51, 55

Lewis–Randall law, 112

Light-emitting diodes (LEDs), 543–544

Light-scattering measurements

determining molecular-weight with, 17, 134–147

dissymmetry method of, 138–139

low-angle laser light scattering method of, 139–140

Zimm plot for, 137–138

Limiting-property relationships, 179–180

Liquid separation membranes, 502–504

Liquid-crystalline polymers (LCP), 424–426

Liquid–liquid equilibrium (LLE), predicting, 566

Lithium-polymer batteries, 535–537

Living cationic polymerization, 52

Living polymerization, 49–51

LLDPE (low-pressure, low-density PE), 366

LLE (liquid–liquid equilibrium), predicting, 566

Log decrement, dynamic-mechanical analysis, 215–216

Logarithmic rule of mixtures, 182

Low-angle laser light scattering (LALLS), 139–140

Low-density polyethylene (LDPE)

commercial applications, 363

development of, 53

LLDPE advantages over, 366

production of, 363–366

properties of, 362–363

Lower critical solution temperature (LCST), 125, 294–297

Low-pressure, low-density PE (LLDPE), 366

Low-pressure, low-density polyethylene (LLDPE), 366

Lubricants, as additives, 291–292

Lyotropic polymers, 424

**M**

Macromers, 84

Magic-angle spinning (MAS) NMR, 91

MAO (methylaluminoxane), 55–56

Market forecasting, using ANNs, 579

Mark–Houwink constants, GPC universal calibration, 145–146

Mark–Houwink–Sakurada equation, 140

MARTINI force field, 587–588

MAS (magic-angle spinning) NMR, 91

Mastication, mechanodegradation, 272

Mathematical relationships

definite integrals, 635

derivatives, 634

Euler's identity, 633

gamma function, 635

geometric series, 635

indefinite integrals, 634

Laplace transforms, 636

quadratic equation, 633

Taylor series, 635

trigonometric functions, 633

Maxwell elements

limitations of simple Maxwell model, 225–226

Maxwell–Wiechert multielement modeling, 226–228

modeling viscoelastic behavior, 221–224

relaxation and retardation spectra, 228–229

MC. *See* Monte Carlo (MC) simulations

MCMC (Monte Carlo Markov chain) method, 582

MD. *See* Molecular dynamics (MD)

MD.REACT force field, 587

MDMO-PPV/fullerene BHV, 538–539

Mean free path, through porous media, 508

Mean-square end-to-end distance

calculating for polymer chain, 103–104

light-scattering measurements, 136

in real polymer chain bonds, 104–105

Mean-square radius of gyration, light-scattering, 136

Measurement techniques, thermal transitions

calorimetry, 174–176

dilatometry, 172–174

heat-distortion temperature, 176–177

overview of, 172

Mechanical models, viscoelastic behavior

Maxwell model, 221–224

- multi-element models, 226–228  
overview of, 221  
relaxation and retardation spectra, 228–230  
simple models, 225–226  
Voigt model, 225
- Mechanical properties  
commercial polymers, 626  
composites, 311–312  
creep tests, 195–196  
fatigue testing, 199–200  
impact testing, 198–199  
mechanisms of deformation, 183–185  
molecular simulation applications, 600–602  
static testing, 186  
stress-relaxation measurement, 196–198  
stress-strain behavior curves, 191–194  
suggested reading, 202–203  
testing compression or shear strain, 190–191  
testing methods overview, 185  
testing stress or strain, 186–190  
transient testing, 194–197
- Mechanodegradation, 272
- Mediating nitroxides, 59
- Medical applications. *See* Biomedical engineering and drug delivery
- Melamine-formaldehyde (MF) resins, 389–393
- Melt fracture, 460
- Melt index, LDPE, 364
- Melt instabilities, polymer rheology, 460
- Melt spinning, fibers, 354
- Melts, rheometry of polymer, 475–476
- Membrane osmometry, 17, 130–133
- Membrane preparation  
asymmetric-membrane formation, 518–521  
coated asymmetric and composite membranes, 521–523  
microporous membranes, 517–518  
module fabrication, 523–526  
overview of, 517
- Membrane science and technology  
mechanisms of transport. *See* Transport mechanisms  
membrane preparation. *See* Membrane preparation  
membrane separations. *See* Membrane separations  
overview of, 494  
review problems, 550  
suggested reading, 547–549
- Membrane separations  
barrier polymers, 494–495  
filtration, 495–498  
fuel cells, 506–507  
gas separations, 498–501  
liquid separations, 502–504
- mechanisms of transport. *See* Transport mechanisms  
other separations, 504–505
- Merrifield synthesis of proteins, 74
- Mesogens, liquid-crystalline polymers, 424–425
- Metallocene polymerizations  
coordination polymerization using, 56–57  
of ethylene, 365–366  
syndiotactic polypropylene (*s*-PP), 367
- Metals, conductivity of polymers and, 534
- Metastable region, phase equilibria, 123
- Metathesis elastomers, 377
- Metathesis polymerization, 427
- Metathesis reactions, 81–82
- Metering section, extruders, 436–437, 476–482
- (Meth)acrylates, 59–61
- Methacrylic acid, 363–364, 421–422
- Methanol crossover, fuel cell membranes, 506
- Methyl methacrylate  
as chain-transfer constant, 41  
group-transfer polymerization of, 83–84  
heat of polymerization and ceiling temperatures, 43  
pathways of, 32
- Methylaluminoxane (MAO), 55–56
- Metropolis algorithm, 582, 602–605
- MF (melamine-formaldehyde) resins, 389–393, 524
- Micelles, 67–69, 527–528
- Microcanonical ensemble, molecular simulations, 590–591
- Microfiltration membranes, 496–498
- Microporous membranes  
for composite membranes, 522–523  
overview of, 517–518  
thermally induced phase separation of, 521
- Microscopy, 200–201
- Miniemulsion polymerization, 69
- Miscibility  
and phase equilibria, 122–125  
of polymer blends, 300–301
- Mixtures, Flory EOS theory for, 120–121
- MMT (Montmorillonite), 319–322
- Modeling of polymer-processing operations  
extrusion, 476–482  
wire coating, 482–485
- Models. *See* Mechanical models, viscoelastic behavior
- Modified Flory-Huggins, 117
- Modified poly(phenylene oxide), 404–405
- Module fabrication, 523–526
- Modulus, 301, 311–312
- Moisture. *See* Hydrolysis
- Molar attraction constants, solubility parameters, 562–564

Molar energy of vaporization of pure liquid (DE<sub>v</sub>), 127–129

Molar Gibbs free energy, 112

Molar volume of liquid ( $V_i$ ), 127–128

Molar-mass dispersity ( $D_M$ ), 17–20

Molding

blow, 443–444

compression, 438

defined, 436

grades of PET, 373–374

injection, 440–441

reaction injection molding (RIM), 441–443

rotational, 444

thermoforming, 443

transfer, 438–439

Mole fraction of monomer, free-radical copolymerization, 46–48

Molecular dynamics (MD)

cohesive energy density from, 593–594

early applications of, 581–582

molecular mechanics force fields in, 583–588

Monte Carlo methods of, 588–591

obtaining permeability coefficient, 605–610

overview of, 581

velocity autocorrelation function in, 597

Molecular mechanics force fields, 583–588

Molecular sieving, through porous media, 508–509

Molecular simulation applications

cohesive energy density and solubility parameter, 593–594

free volume, 610–611

glass-transition temperature, 594–595

mechanical properties, 600–602

overview of, 591

pair correlations, 595–597

permeability, 605–610

PVT simulation, 591–593

scattering functions, 599–600

sorption isotherms, 602–605

time-correlation coefficients, 597–599

Molecular simulations

CG force fields, 587–588

molecular dynamics and Monte Carlo methods, 588–591

molecular mechanics force fields, 583–588

Monte Carlo simulations, 582–583

overview of, 581–582

predicting polymer properties, 554

reactive force fields, 587

Molecular weight

in anionic polymerization, 50

critical, 154–155

determining, 15–20

effect on  $T_g$ , 179–180

of epoxies, 386–387

of isotactic polypropylene, 367–368

of low-density polyethylene, 364

polymer viscosity and increasing, 450

RAFT polymerization and, 63–64

references, 150

in step-growth polymerization, 28–29

ultrahigh-molecular-weight PE, 366

Molecular weight, measurement

gel-permeation chromatography, 143–146

intrinsic viscosity, 140–143

light-scattering, 134–140

osmometry, 130–133

overview of, 129–130

review problems, 146–150

suggested reading, 146

vapor-pressure osmometry, 133–134

Monoethylophenol, phenolic resins, 390

Monomers

of copolymers, 9–10

macromers as macromolecular, 84

in polymer synthesis. *See* Polymer synthesis

Monte Carlo Markov chain (MCMC) method, 582

Monte Carlo (MC) simulations

introduction to, 581

molecular dynamics and, 588–591

molecular dynamics vs., 597

molecular mechanics force fields in, 583–588

obtaining permeability coefficient, 605

obtaining sorption isotherms, 602–605

overview of, 582

Montmorillonite (MMT), 319–322

Mooney–Rivlin equation, rubber elasticity, 253–255

Multi-element models, viscoelastic behavior,

226–228

Multi-impression molds, 440–441

Multiplets, ionic polymers, 421

## N

Nafion perfluorinated ionomer, 422, 516–517

Nanocomposites

buckyballs, 322–323

carbon nanotubes, 323–324

graphene, 324–325

montmorillonite, 319–320

overview of, 318–319

polyhedral oligomeric silsesquioxane (POSS), 325–326

processing, 321

properties of, 321–322

suggested reading, 327

Nanofiltration (NF) membranes, 497–498

Nanomedicines, polymeric, 527–528

Naphthalene dicarboxylate (NDC), 410

Natta, Giulio, 2, 54–55

Natural polymers, 331–332

- Natural rubber (NR)  
development of elastomer for, 2  
as electrical insulator, 533  
as natural elastomer, 346  
as natural occurring polymer, 1  
polyisoprene in, 377  
synthetic rubber and short supply of, 2  
vulcanization of, 377–379
- Naturally occurring polymers, 1
- Navier-Stokes equations, 463–464
- NBR (nitrile rubber), 377
- Nematic state, liquid-crystal structures, 425
- Neutron scattering, 598–599
- Newton's law of motion, 589
- Newton's law of viscosity, 221, 231, 446–450
- NF (nanofiltration) membranes, 497–498
- Nitrile rubber (NBR), 377
- Nitroaromatic explosives, detecting, 546
- Nitroxide-mediated polymerization (NMP), 51, 58–59
- NLO (nonlinear optical) polymers, 542–543
- NMP (nitroxide-mediated polymerization), 51, 58–59
- NMR (nuclear magnetic resonance) spectroscopy, 89–92
- Nodes, artificial neural networks, 578–581
- Nomenclature system, polymers, 13–15
- Nomex (poly(*m*-phenylene isophthalamide)), 21, 26, 400
- Non-bonded terms, force fields, 583–584, 586–587
- Non-cellulosics, 350–354
- Non-chain scission reactions, polymer degradation, 265–266
- Non-condensation-type, step-growth polymers, 27–28
- Nondiene elastomers  
fluoroelastomers, 380–381  
overview of, 379  
polyisobutylene or butyl rubber, 379–380  
from polyolefins, 384  
polysiloxanes, 380  
polyurethanes, 381–384  
properties of, 375
- Nonlinear optical (NLO) polymers, 542–543
- Non-Newtonian flow or apparent viscosity  
analysis of simple flow, 461–468  
constitutive equations, 461–462  
overview of, 448–450  
solution viscosity and, 454–455
- Non-Newtonian fluid, capillary rheometry data for, 469–470
- Non-vinyl polymers, nomenclature rules for, 13–14
- Normal stresses, elastic response, 458–460
- Norrish-Smith effect, 65
- Novolac formation, phenolic resins, 390–391
- NR. *See* Natural rubber (NR)
- Nuclear magnetic resonance (NMR) spectroscopy, 89–92
- Nucleation track etching, microporous membranes, 518
- Nuclei, in polymer NMR, 89–92
- Number-average molecular weight ( $M_n$ ), 129  
determining, 16–20  
membrane osmometry, 133  
vapor-pressure osmometry, 133–134
- Number-average ( $X_n$ ) degree of polymerization  
free-radical polymerization, 39–40  
RAFT polymerization, 63  
step-growth polymerization, 29
- Numbers, nomenclature system for polymers, 13–15
- NVE ensemble, molecular simulations, 590–591
- Nylons (aliphatic polyamides)  
development of, 331  
improving with aromatic polyamides, 400–401  
nomenclature rules for, 13–14  
non-cellulosic synthetic fibers, 351  
polyamidation of, 6  
as step-growth polymers, 26  
synthetic fibers, 348
- O**
- Olefins  
olefinic elastoerms, 386  
olefinic fibers, 353–354  
undergoing metathesis to yield elastomers, 81–82
- Open discharge condition, modeling extrusion, 477
- Optical storage of computer data, photonic polymers, 541–544
- Order-disorder transition, 307
- Organic halide, 60
- Organic light-emitting diodes (OLEDs), 543–544
- Organic photovoltaic (OPV) polymers, 537–540
- Orientation hardening, testing stress or strain, 192
- Osmometry  
membrane, 130–133  
molecular-weight determination, 130  
vapor-pressure, 133–134
- Osmotic pumps, controlled drug release, 529–530
- Ostwald-de Waele-Nutting (power-law index) model, 461–462
- Ostwald-Fenske capillary viscometers, 142–143
- Oxidation, stability of polymers and, 267–269
- Oxidative pyrolysis, 290
- Ozone, 261–262, 268
- Ozonolysis, 268
- P**
- P* (permeability coefficient), 605–610
- PAEK (polyaryletherketones), 419–420
- PAI (poly(amide-imide)), 414, 416–417
- Pair correlation functions (PCFs), 595–597
- PAN (polyacrylonitrile), 265–266, 494

- PANI (polyaniline), 427–428  
 PAR (polyarylate), 409  
 Parison, blow molding process, 443–444  
 Partial immobilization theory, solution-diffusion transport, 513  
 Partial-molar Gibbs free energy, 112, 114  
 Particle-scattering function, light-scattering, 135–136  
 Partition functions, Flory EOS theory, 118–119  
 Pattern recognition, using ANNs, 579  
 PBD. *See* Polybutadiene (PBD)  
 PBI (poly[2,2'-(*m*-phenylene)-5,5'-bibenzimidazole]), 20  
 PBI (polybenzimidazole), 417–418, 429–430  
 PBO (polybenzobisoxazole), 430  
 PBT (polybenzobisthiazole), 430  
 PBT (poly(butylene terephthalate)), 373, 409  
 PCFF force field, 587  
 PCFs (pair correlation functions), 595–597  
 PCL (polycaprolactone), 21, 277  
 PCT (poly(dimethylene cyclohexane terephthalate)), 409–410  
 PE. *See* Polyethylene (PE)  
 PEEK (polyimidazopyrrolones), 419–420  
 PEG (poly(ethylene glycol)), 527, 530  
 PEI (polyetherimide), 414, 416–417  
 PEN (poly(ethylene naphthalate)), 410  
 PEN (poly(ethylene oxide)), 461  
 Perfluorosulfonate ionomers (PFSI)  
     commercial applications, 422  
     fuel-cell applications, 506  
     transport through, 516–517  
 Periodic boundary conditions, molecular simulations, 589–590  
 Permachor method, predicting permeability, 494, 560–562  
 Permeability  
     barrier polymers and, 494–495  
     molecular simulation applications, 605–610  
     polymers for gas-separation applications, 499–500  
     predicting by group contributions, 559–562  
 Permeability coefficient (P), 605–610  
 Permeate, liquid separations, 502–503  
 Permselectivity, 499–500  
 Persulfate-ferrous ( $K_2SO_4$ ) redox initiator, 67  
 Pertraction, liquid separations, 502  
 Pervaporation process, membranes, 502–504  
 PES (polyethersulfone), 406–407  
 PET. *See* Poly(ethylene terephthalate) (PET)  
 PFSI. *See* Perfluorosulfonate ionomers (PFSI)  
 PGA, in controlled drug delivery, 527  
 Phantom chain approximation, rubber elasticity, 254  
 Phase equilibria, thermodynamics of solutions, 122–125  
 Phase inversion, asymmetric-membrane formation, 519  
 Phase-separated blends, 302–304  
 PHEMA (poly(2-hydroxyethyl methacrylate)), 529  
 Phenol-formaldehyde resins, as thermosets, 4  
 Phenomenological model, rubber elasticity, 253–254  
 Phenoplasts or (phenolic) PF resins, 389–391  
 Philips-type catalysts, PE with reduced branching, 364–365  
 Photoconductive polymers, 428–429  
 Photooxidative degradation, of polystyrene, 368  
 Photovoltaic polymers, organic, 537–540  
 Physical constants, symbols and units, 632  
 Physical properties, of commercial polymers, 625  
 PIB (polyisobutylene), 379–380, 461  
 PLA (poly(lactic acid)), 276–277  
 PLA, controlled drug delivery using, 527  
 Plane Couette flow, 467–468  
 Plant oils, polymer synthesis, 86  
 Plasma polymerization, 70–71  
 Plasticizer efficiency, 284  
 Plasticizers  
     antiplasticization and, 286–287  
     determining composition of polymer mixture, 284  
     external and internal plasticization, 284–286  
     list of common PVC, 286  
     overview of, 282–284  
 Plastics  
     ASTM standards for, 627–629  
     high-performance engineering, 2  
     U.S. production of, 2–3  
 Plastisol, 455  
 PLF. *See* Power-law fluid (PLF) model  
 PLGA (poly(lactide-*co*-glycolide)), 277, 529  
 Plunger, transfer molding process, 438–439  
 PMAN structure 1 (polymethacrylonitrile), 494  
 PMMA. *See* Poly(methyl methacrylate) (PMMA)  
 PMP (poly(4-methylpentene-1)), 420  
 Poiseuille (pressure) flow, 464–466  
 Poisson's ratio, 187–188, 601–602  
 Poly (prefix), nomenclature for vinyl polymers, 13  
 Poly[1-(trimethylsilyl)-1-propyne] (PTMSP), 500–501  
 Poly[2,2'-(*m*-phenylene)-5,5'-bibenzimidazole]  
     (PBI), 20  
 Poly(2,6-dimethyl-1,4-phenylene oxide) (PPO), 404–405  
 Poly(2-hydroxyethyl methacrylate) (PHEMA), 529  
 Poly(4-methylpentene-1) (PMP), 420  
 Polyacetal, as engineering plastic, 405–406  
 Polyacetylene, 8, 534–535  
     *cis*-polyacetylene, 427  
 Polyacrylamide, 461  
 Polyacrylonitrile (PAN), 265–266, 494  
 Polyalkenylenes, 8  
 Polyalkylenes (or polyalkylidenes), 7–8  
 Polyallomers, 386

- Poly(amide-imide) (PAI), 414, 416–417  
Polyamides  
aromatic, 400–401  
chemical structures of, 399–400  
non-cellulosic synthetic fibers, 351–353  
producing using RIM, 442  
Polyaniline (PANI), 427–428  
Polyarylate (PAR), 409  
Polyaryletherketones (PAEK), 419–420  
Polybenzimidazole (PBI), 417–418, 429–430  
Polybenzobisoxazole (PBO), 430  
Polybenzobisthiazole (PBT), 430  
Polybismaleimides, 417  
Polybutadiene (PBD)  
ABS polystyrene developed from, 401  
effects of ozone on, 262  
GPC calibration curve, 145  
improving impact strength of brittle plastics, 302–303  
obtaining polystyrene using, 369  
polymerization of, 374, 376  
Poly(butylene terephthalate) (PBT), 373, 409  
Polycaprolactone (PCL), 21, 277  
Polycarbonates, 26, 402–403  
Polychlorotrifluoroethylene (CTFE), 377, 411–412  
Polycondensations, step-growth, 26–27  
Poly(dichlorophosphazene), 78  
Poly(diethyleneglycol adipate), 382  
Poly(dimethylene cyclohexane terephthalate) (PCT), 409–410  
Polydimethylsiloxane, 20  
Polyelectrolytes, 421  
Polyesters  
engineering, 409–410  
non-cellulosic synthetic fibers, 350–351  
polyurethanes based on, 382–383  
as step-growth polymers, 26  
synthetic fibers, 348  
thermoplastic, 372–374  
unsaturated, 387–389  
Polyetherimide (PEI), 414, 416–417  
Polyethersulfone (PES), 406–407  
Polyethylene (PE)  
as barrier polymer, 494–495  
as commercial thermoplastic, 3  
conformation of small chain, 106–107  
free-radical polymerization of, 53–54  
high-density (HDPE), 54–55  
isotactic polypropylene (*i*-PP), 54  
low-density (LDPE), 53  
overview of, 363–366  
as polyalkylene, 7  
UHMWPE, 420  
Unipol process for, 69–70  
U.S. production of, 2–3  
Poly(ethylene glycol) (PEG), 527, 530  
Poly(ethylene naphthalate) (PEN), 410  
Poly(ethylene oxide) (PEO), 461  
Poly(ethylene terephthalate) (PET)  
as barrier polymer, 494  
commercial production of, 372–374  
crystalline kinetics, 164–165  
improving with PEN, 410  
liquid-crystal polyester properties vs., 426  
modified grades of, 409  
recycling plastics, 273–274  
Polyfluorenes, 429  
Polyformaldehyde, 405–406  
Polyfuran, 70  
Polyhedral oligomeric silsesquioxane (POSS), 319, 325–326  
Polyimidazopyrrolones (PEEK), 419–420  
Polyimides  
poly(amide-imide) and polyetherimide, 416–417  
polybenzimidazole, 417–418  
polybismaleimides, 417  
properties of, 414  
synthesis of, 413–416  
Polyisobutylene (PIB), 379–380, 461  
Polyisoprene, 345–346, 377  
Poly(lactic acid) (PLA), 276–277  
Poly(lactide-*co*-glycolide) (PLGA), 277, 529  
Polymer  
abbreviations, 621–623  
derivation of term, 1  
solubility parameters, 129  
Polymer blends  
benefits of, 281–282  
commercial blends, 300–301  
Flory–Huggins theory predicting behavior of, 296–298  
free-energy considerations in, 294  
immiscibility and, 296–297  
interpenetrating networks, 304–306  
LCST and UCST phase behavior, 294–297  
overview of, 293  
properties of, 301–302  
references, 293  
suggested reading, 326  
ternary, 299–300  
thermodynamics and, 293–294  
toughened plastics and phase-separated, 302–304  
Polymer processing  
analysis of simple flow, 461–466  
basic operations, 436  
calendering, 445  
coating, 445–446  
dynamic and continuity equations, 486–487  
extrusion, 436–437  
extrusion, modeling, 476–482

- Polymer processing (*continued*)  
 molding. *See* Molding  
 references, 491  
 relationship between WLF parameters and free volume, 485–486  
 review problems, 488–491  
 rheology. *See* Polymer rheology  
 rheometry. *See* Rheometry  
 suggested reading, 487–488  
 wire coating, modeling, 482–485
- Polymer rheology  
 constitutive equations, 456–457  
 drag reduction, 460–461  
 elastic properties of polymeric fluids, 457–460  
 introduction to, 446–448  
 melt instabilities, 460  
 non-Newtonian flow, 448–452  
 references, 491  
 review problems, 488–491  
 suggested reading, 487–488  
 viscosity of polymer solutions/suspensions, 452–456
- Polymer science, introduction to  
 birth of, 2  
 chemical structure/thermal transitions, 20–22  
 classifications, 3–8  
 copolymers, 9  
 geometric isomerism, 12–13  
 introduction to, 1–3  
 molecular weight, 15–20  
 nomenclature, 13–15  
 references, 24  
 review problems, 22–24  
 structure, 8–15  
 suggested reading, 22  
 tacticity, 9–12
- Polymer structure  
 classification based on, 7–8  
 copolymers, 9  
 geometric isomerism, 12–13  
 nomenclature, 13–15  
 properties, 8–9  
 tacticity, 9–12
- Polymer synthesis  
 chain-growth polymerization. *See* Chain-growth polymerization  
 chemical structure determination, 86–92  
 genetic engineering in, 85  
 green chemistry in, 86  
 group-transfer polymerization in, 83–84  
 macromers in, 84  
 metathesis reactions in, 81–82  
 overview of, 25  
 polymerization techniques. *See* Polymerization techniques
- reactions of polymers, 74–80  
 references, 98–100  
 review problems, 95–98  
 step-growth polymerization, 26–31  
 suggested reading, 92–95
- Polymer-assisted membrane formation, 521
- Polymeric batteries, 535–537
- Polymeric solar cells (PSCs), 538
- Polymerization  
 classifying polymers by, 4–7  
 determining tactic or atactic polymers, 11  
 in ionic liquids, 72–73  
 molecular-weight determination, 15–16  
 in supercritical fluids, 71–72
- Polymerization rate ( $R_p$ )  
 free-radical polymerization kinetics, 37–41  
 step-growth polymerization kinetics, 30–31
- Polymerization techniques  
 bulk polymerization, 64–65  
 emulsion polymerizations, 67–69  
 gas-phase polymerization, 69  
 plasma polymerization, 70–71  
 polymerization in ionic liquids, 72–73  
 polymerization in supercritical fluids, 71–72  
 solid-state polymerization, 69–70  
 solution polymerization, 66  
 suspension polymerization, 66–67
- Polymer-sensitive detector, gel-permeation chromatography, 144
- Polymethacrylonitrile (PMAN, structure 1), 494
- Poly(methyl methacrylate) (PMMA)  
 amorphous in solid state, 20  
 commercial-grade, 371  
 properties of, 14  
 universal GPC calibration curve, 145  
 using NMR to study tacticity of, 91–92
- Poly(*m*-phenylene isophthalamide) (Nomex), 21, 26, 400
- Polynorbornene, 377
- Polynucleotides  
 heterocyclic bases, 337  
 molecular weight/structure of DNA, 338–340  
 protein synthesis and, 340–341  
 types of, 336
- Poly(*N*-vinyl-2-pyrrolidinone) (PVP), 372
- Poly(*N*-vinylcarbazole) (PVK), 428–429
- Polyoctenamer, 377
- Polyolefins  
 as barrier polymers, 494–495  
 as commercial thermoplastic, 3  
 elastomers from, 384  
 medical applications of, 526  
 metallocene polymers, 55–56  
 as nondiene elastomers, 384  
 overview of, 362–363

- polyethylene, 363–366  
polypropylene, 366–367  
specialty, 420  
synthetic fibers of, 348
- Poly(organophosphazenes), 78, 422–423
- Polyoxymethylene (POM), 405–406
- Polyphenylsulfone, 406
- Poly(*p*-phenylene) (PPP), 428
- Poly(*p*-phenylene sulfide) (PPS), 408–409
- Poly(*p*-phenylene terephthalamide) (PPT) (Kevlar), 401
- Polypropylene (PP)
- atactic, 11
  - as barrier polymer, 494–495
  - as commercial thermoplastic, 3
  - development of, 2
  - isotactic polypropylene, 54
  - medical applications of, 526
  - overview of, 366–367
  - as polyalkylene, 7
  - U.S. production of, 2–3
- Poly(propylene glycol), 382
- Polypyrrole (PPy), 428
- Polysaccharides
- cellulose, 342
  - chitin, 343–344
  - overview of, 341–342
  - reactions of, 344
  - starch, 342–343
- Polysilanes or polysilylenes, 423
- Polysilastrene, 423–424
- Polysiloxanes, 8, 380
- Polystyrene (PS)
- abbreviation for, 14
  - ABS as high-HDT grade of, 401–402
  - as addition polymer, 4
  - amorphous in solid state, 20
  - chloromethylation of, 74
  - commercial applications, 367
  - as commercial thermoplastic, 3
  - GPC chromatogram of, 144–145
  - HIPS as high impact, 302–303, 367, 369
  - medical applications, 526–527
  - as polyalkylene, 7
  - syndiotactic, 11
  - topological calculations for properties, 574–578
  - universal GPC calibration curve, 145
  - U.S. production of, 2–3
- Polysulfones (PSF), 26, 406–408
- Polysulfurnitride (SN), 534
- Polytetrafluoroethylene (PTFE or Teflon)
- dielectric constants of, 541
  - engineering plastic, 411
  - as good electrical insulator, 533
- Polythiophene (PT), 70, 428
- Polyurethane (PUR)
- producing using RIM, 442
  - as step-growth polymer, 26
  - synthesizing elastomeric, 381–384
- Poly(vinyl acetate) (PVAC), 76, 371
- Poly(vinyl alcohol) (PVAL), 76, 371
- Poly(vinyl butyral) (PVB), 76, 371
- Poly(vinyl chloride) (PVC)
- calendering process for, 445
  - commercial grades of, 369–370
  - commercial production/properties of, 370–371
  - as commercial thermoplastic, 3
  - dehydrohalogenation, 265–266
  - development of crystallinity, 87–88
  - electronic shielding applications, 540
  - imperfect tactic structure of, 11–12
  - list of common plasticizers, 286
  - medical applications of, 526
  - plasticizers for, 282
  - recycling plastics, 273
  - softening temperature/blending properties, 74
  - universal GPC calibration curve, 145
  - U.S. production of, 2–3
- Poly(vinyl fluoride) (PVF), 412
- Poly(vinylidene chloride) (Saran), 494
- Poly(vinylidene fluoride) (PVDF), 412
- POM (polyoxymethylene), 405–406
- Pore structure, microporous membranes, 518
- Porous media transport, 508–509
- POSS (polyhedral oligomeric silsesquioxane), 319, 325–326
- Potable water, 288–289
- Power-law fluid (PLF) model
- analysis of simple flow, 462
  - axial annular Couette flow, 467–468
  - constitutive equations and, 456–457
  - extrusion process, 482
  - flow through capillary, 464–466
  - wire coating process, 483
- Power-law index (Ostwald-de Waele-Nutting) model, 461–462
- PP. *See* Polypropylene (PP)
- PPO (poly(2,6-dimethyl-1,4-phenylene oxide)), 404–405
- PPP (Poly(*p*-phenylene)), 428
- PPS (Poly(*p*-phenylene sulfide)), 408–409
- PPT (Poly(*p*-phenylene terephthalamide)) (Kevlar), 401
- PPy (polypyrrole), 428
- Precipitation threshold, supercritical fluids, 71
- Predictions of solubilities, thermodynamics of polymer solutions, 126–129
- Pressure, effect on  $T_g$ , 182
- Pressure dependence, and viscosity, 452

- Pressure flow  
 capillary rheometer determining, 469–473  
 drag flow, 467–468  
 modeling extrusion process, 477–482  
 modeling wire coating process, 484–485  
 through capillary, 464–466
- Pressure-swing adsorption (PSA), 498
- Primary (first) normal-stress difference, 459
- Process modeling, using ANNs, 579
- Processing. *See* Polymer processing
- Processing agents, as additives, 291
- Propagation step  
 free-radical copolymerization, 43–44  
 free-radical polymerization, 34, 36–37  
 free-radical polymerization thermodynamics, 41–43
- Properties  
 atomistic modeling determining mechanical, 600–602  
 of blends, 301–302  
 of important commercial polymers, 625–626  
 predicting polymer. *See* Correlations and simulations  
 of supercritical fluids, 71
- Proportional limit, stress-strain relations, 188
- Protein synthesis  
 overview of, 336  
 polynucleotides and, 340–341
- Proteins  
 biocompatibility depending on adsorption of, 526  
 biological functions of, 334  
 cell structure and, 334–335  
 in conjugated polymeric nanomedicines, 527–528  
 fibrous and globular, 335  
 naturally occurring amino acids, 332–336  
 proteomics, 335–336  
 synthesizing, 336
- PSA (pressure-swing adsorption), 498
- PSCs (polymeric solar cells), 538
- PSF (polysulfones), 26, 406–408
- PT (polythiophene), 70, 428
- PTFE or Teflon (polytetrafluoroethylene)  
 dielectric constants of, 541  
 engineering plastic, 411  
 as good electrical insulator, 533
- PTMSP (poly[1-(trimethylsilyl)-1-propyne]), 500–501
- Pultrusion, 310, 317–318
- PUR. *See* Polyurethane (PUR)
- Purines, in nucleic acids, 337
- PVAC (poly(vinyl acetate)), 76, 371
- PVAL (poly(vinyl alcohol)), 76, 371
- PVB (poly(vinyl butyral)), 76, 371
- PVC. *See* Poly(vinyl chloride) (PVC)
- PVDF (poly(vinylidene fluoride)), 412
- PVK (poly(*N*-vinylcarbazole)), 428–429
- PVP (poly(*N*-vinyl-2-pyrrolidinone)), 372
- PVT simulation, 591–593
- Pyrimidines, nucleic acids, 337–339
- Pyrolysis, flame retardant, 290
- Q**
- Q-e* values, 45–46
- Quadratic equation, 633
- Quality of polymer–solvent interactions, membrane osmometry, 131
- Quartic expression, modern force fields, 584
- R**
- Radial distribution function (RDF), 103–104, 594–595
- Radiation, degradation of polymers, 271–272
- Radiation stabilizers, as additives, 290
- Radio frequency (RF)  
 energy, 70  
 shielding, 540
- Radiolysis, 271–272
- RAFT (reversible addition-fragmentation chain transfer) polymerization, 51, 61–64
- Raleigh ratio, light-scattering measurements, 135
- Raman spectroscopy, 89
- Random degradation, 263
- Random flight chain, conformation, 102
- Random reactions, step-growth polymerization, 25
- Raoult's ideal solution law, 109–110
- RATTLE algorithm, MD simulations, 589
- Rayleigh scattering, 89
- Rayon (as cellulose fiber)  
 processes in making, 344  
 synthetic fibers, 347–348  
 viscose process of obtaining, 76
- RDF (radial distribution function), 103–104, 594–595
- RDRP (reversible deactivation radical polymerization), 58
- Reaction injection molding (RIM), 381, 441–443
- Reaction-controlled systems, drug release, 529
- Reactions of polymers  
 chemical modification, 74–75  
 click chemistry, 79–80  
 overview of, 74  
 preparation of polymer derivatives, 76–78  
 in step-growth vs. chain-growth polymerization, 25
- Reactive force fields, 587
- Reactivity ratios, free-radical copolymerization, 44–45
- ReaxFF force field, 587
- Receptor sites, sensor applications, 545
- Reciprocating-screw injection-molding machine, 440–441
- Recycled PET, 373–374

- Recycled plastics, 273–274  
Reduced viscosity, 141  
Reinforcers, as additives, 287–288  
Relative viscosity increment, 141  
Relaxation-time distribution function, viscoelastic behavior, 228–230  
Repeating units of identical structure, polymers, 1  
Reptation, theory of, 155–156  
Residual (enthalpic) term, UNIFAC-FV, 568–569  
Resins  
    ABS, 401–402  
    epoxy, 386–388  
    formaldehyde, 389–393  
    molding. *See* Molding  
    unsaturated polyester, 387–389  
Resin-transfer molding, composites, 310  
Resole formation, phenolic resins, 390–391  
Retardation spectrum function, 229–230  
Retentate, liquid separations, 502  
Reverse osmosis membranes, 497–498  
Reversible addition-fragmentation chain transfer (RAFT) polymerization, 51, 61–64  
Reversible deactivation radical polymerization (RDRP), 58  
RF (radio frequency)  
    energy, 70  
    shielding, 540  
Rheology. *See* Polymer rheology  
Rheometry  
    capillary rheometer, 469–473  
    cone-and-plate rheometer, 475  
    Couette rheometer, 473–474  
    overview of, 468–469  
    of polymer solutions and melts, 475–476  
Ribonucleic acid (RNA), 336–339  
RIM (reaction injection molding), 381, 441–443  
Ring-opening metathesis polymerization (ROMP), 81–82  
Ring-opening polymerization of trioxane, 4  
RNA (ribonucleic acid), 336–339  
Roll coating operation, 445–446  
ROMP (ring-opening metathesis polymerization), 81–82  
Root-mean-square end-to-end distance, polymer chains, 104, 107–108  
Rotatable side-group bonds, polymer properties, 575  
Rotational molding (rotomolding), 444  
Rotations of polymer chains, steric interference with, 105  
Rubber. *See also* Natural rubber (NR)  
    ASTM standards for, 629  
    development of synthetic, 2  
    ethylene and propylene (EPM/EPDM), 384  
    slush molding of, 444  
    thermodynamics of polymer solutions, 109–110  
Rubber elasticity. *See also* Elastomers  
    development of elastomer, 2  
    introduction to, 248  
    phenomenological model, 253–254  
    recent developments in, 254–255  
    references, 259  
    review problems, 256–259  
    statistical theory, 252–253  
    suggested reading, 255–256  
    thermodynamics and, 248–251  
Rubbery plateau, stress-strain relation, 189–190  
Rule of mixtures, 180–182  
Runners, injection molding, 441
- ## S
- S. *See* Solubility coefficient (S)  
Salts  
    ionic liquids as, 72–73  
    in polymeric batteries, 535–536  
SAN (styrene–acrylonitrile copolymer), developing  
    ABS, 401–402  
Saran (Poly(vinylidene chloride)), 494  
SAXS (small-angle X-ray scattering), 167  
SBR (styrene–butadiene rubber). *See* Styrene–butadiene rubber (SBR)  
SBS elastomers  
    commercial applications/properties, 385–386  
    glassy domains in, 385  
    introduction to, 385–386  
    overview of, 375  
SBS triblock copolymer, 53–54  
Scaffold structure, tissue engineering, 532  
Scanning electron microscopy (SEM), 200  
Scanning tunneling microscopy (STM), 200  
Scatchard–Hildebrand equation, 128  
Scattered light. *See* Light-scattering measurements  
Scattering functions, molecular simulation, 599–600  
SCFs (supercritical fluids), polymerization in, 71–72  
Schering impedance bridge, dielectric analysis, 237–238  
Schönbein, Christian F., 2  
Screw characteristic, flow through capillaries, 466  
Screw pot, injection molding, 441  
Screw-driven extruders, 436–437, 477–482  
SEC (size-exclusion chromatography), 129–130, 143  
Secant modulus, stress-strain relations, 188  
Second normal-stress difference, 459  
Secondary methods, molecular-weight determination, 129–130  
Secondary-relaxation processes  
    amorphous glassy state, 158–159  
    defined, 154  
    thermal transitions, 20–22

- Second-order transitions, thermodynamic relationships, 169–172
- SEM (scanning electron microscopy), 200
- Semi-IPNs, 306
- Sensor applications, 544–546
- Separations. *See* Membrane separations
- SHAKE algorithm, MD simulations, 589
- Sharkskin, melt fracture, 460
- Shear**
- Boltzmann superposition principle, 245–246
  - mechanodegradation due to, 262, 272
  - testing mechanical properties, 190–191
- Shear banding, 184–185
- Shear flow**
- analysis of simple, 461–468
  - apparent viscosity, 448–450
  - melt instabilities, 460
  - modeling extrusion process, 477
  - Newton's law of viscosity for, 446–448
- Shear strain rate (or shear rate)
- analysis of simple flow, 461–468
  - apparent viscosity, 448–450
  - determining with rheometry. *See* Rheometry
  - Newton's law of viscosity, 447–448
  - solution viscosity and, 454–455
- Shear-thickening behavior, 449, 452
- Shear-thinning behavior
- apparent viscosity, 449
  - molecular-weight dependence and, 450
  - solution viscosity and, 454–455
  - time dependence and, 452
- Sheet-molding compound (SMC), composites, 316–317
- Shielding, electronic, 540
- Shinoda force field, 587–588
- SI units, 631–632
- Silicon dioxide ( $\text{SiO}_2$ ), dielectrics, 541
- Simple flows
- analysis of, 461–464
  - constitutive equations for modeling, 456–457
  - drag flow, 467–468
  - Newton's law of viscosity, 447–448
  - pressure (Poiseuille) flow, 464–466
- SIMS (static secondary ion mass spectroscopy), 70
- Simultaneous interpenetrating networks (SINs), 306
- SINs (simultaneous interpenetrating networks), 306
- $\text{SiO}_2$  (silicon dioxide), dielectrics, 541
- Site fraction, Flory EOS theory, 121
- Site-directed drug delivery, 527, 530
- Size exclusion, transport mode in membrane separations, 506
- Size-exclusion chromatography (SEC), 129–130, 143
- Slush molding, 444
- Small-angle X-ray scattering (SAXS), 167
- Small's method, 562–565
- SMC (sheet-molding compound), composites, 316–317
- Smectic state, liquid-crystal structures, 425
- SN (polysulfurnitride), 534
- Sodium naphthalene, ionic copolymerization, 53–54
- SOG concept, UNIFAC, 569
- Solar cells, 537–540
- Solid-state NMR, 91
- Solid-state polymerization, 69–70
- Solid-state properties
- amorphous state, 154
  - calorimetry measurements, 174–176
  - creep tests, 195–196
  - critical molecular weight, 154–155
  - crystalline kinetics, 164–165
  - crystalline state, 159
  - crystalline-melting temperature, 163–164
  - determining crystallinity, 165–167
  - dilatometry, 172–174
  - fatigue tests, 199–200
  - first-order transitions in thermodynamics, 167–169
  - glass-transition temperature, 156–158
  - heat-distortion temperature, 176–177
  - impact tests, 198–199
  - measurement techniques, 172
  - mechanisms of deformation, 183–185
  - microscopy characterizing, 200–201
  - molecular weight, composition, pressure on  $T_g$ , 179–182
  - ordering of polymer chains, 159–162
  - overview of, 153–154
  - reptation, 155–156
  - review problems, 203–204
  - scattering methods in characterizing, 201
  - secondary-relaxation processes, 158–159
  - second-order transitions in thermodynamics, 169–172
  - static tests, 186
  - stress-relaxation measurement, 196–198
  - stress-strain behavior curves, 191–194
  - structure–property relationships, 177–179
  - suggested reading, 202–203
  - testing compression or shear strain, 190–191
  - testing mechanical performance, 185
  - testing stress or strain, 186–190
  - transient tests, 194
- Solubility**
- predictions of, 126–129
  - solution-diffusion transport, 509–515
- Solubility coefficient ( $S$ )**
- estimating permeability coefficient, 605, 609–610
  - obtaining sorption isotherms, 602–603
- Solubility parameter ( $\delta$ )**
- cohesive energy density and, 593–594

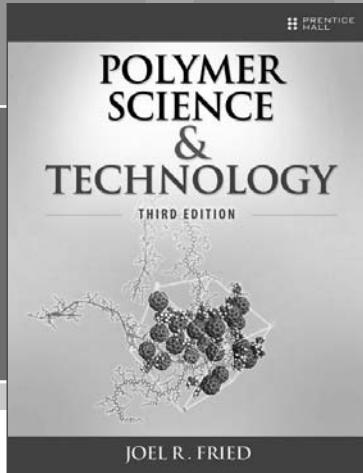
- predicting by group contributions, 562–565  
predictions of solubilities, 127–129  
Solution polymerization, 66  
Solution–diffusion transport, 509–515  
Solutions  
    analysis of simple flow, 461–468  
    drag flow, 467–468  
    drag reduction, 460–461  
    elastic properties of polymeric, 457–460  
    melt instabilities, 460  
    references, 150  
    rheometry of polymer, 475–476  
    thermodynamics of. *See* Thermodynamics of polymer solutions  
    viscosity of, 452–455  
Solvent-controlled delivery, drug release, 529  
Solvents  
    cationic polymerizations, 52  
    gel-permeation chromatography, 143–144  
    group-transfer polymerization, 84  
    ionic liquid as, for polymerization, 73  
    membrane osmometry, 130–133  
    solubility parameters of, 129, 564  
    in solution polymerization, 66  
    vapor-pressure osmometry, 133–134  
Sorption  
    isotherms, 602–605  
    solution–diffusion transport, 510  
Space-filling (CPK) representation  
    of PVC chain, 11–12  
    of PVT simulation, 592  
Spatial arrangement, determining properties, 9  
Specialty plastics  
    conductive polymers, 427–429  
    dendritic polymers, 430–431  
    engineering plastics vs., 397–398  
    high-performance fibers, 429–430  
    inorganic polymers, 422–424  
    ionic polymers, 421–422  
    ladder polymers, 418  
    liquid-crystalline polymers, 424–426  
    poly(amide-imide) and polyetherimide, 416–417  
    polyaryletherketones, 419–420  
    polybenzimidazoles, 417–418  
    polybismaleimides, 417  
    polyimides, 413–416  
    polyolefins, 420  
    references, 433–434  
    review problems, 433  
    suggested reading, 432  
Spectroscopic methods  
    of chemical structure determination, 86  
    nuclear magnetic resonance spectroscopy, 89–92  
    suggested reading, 255  
    vibrational spectroscopy, 86–89  
Speech recognition, using ANNs, 579  
Spherulites, 160–161, 164–165  
Spinneret, fibers, 354  
Spinning, fibers, 354–358  
Spinodal curve, phase equilibria, 124–125  
Spinodal decomposition, asymmetric-membranes, 520–521  
Spiral-wound membranes, 525  
Sprue, injection molding process, 441  
*s*-PS (stereospecific polystyrene), 368  
Stability  
    degradation of polymers and, 262  
    oxidative and UV, 267–269  
    thermal, 266–267  
Stabilizers, as additives, 289–290  
Standards. *See* American Society of Testing Methods (ASTM)  
Starch, 278, 342–343  
Static secondary ion mass spectroscopy (SIMS), 70  
Static tests, 186  
Statistical theory, rubber elasticity, 252–253  
Steady-shear viscosity, 230  
Steady-state concentration, free-radical polymerization kinetics, 37–39  
Step-growth polymerization  
    with bulk polymerization, 65  
    kinetics, 30–31  
    molecular weight in, 28–29  
    overview of, 26–28  
    random reaction in, 25  
Stereochemistry  
    arrangement of atoms, 9  
    controlling in metathesis, 82  
Stereospecific polystyrene (*s*-PS), 368  
Stereo-styrene-butadiene copolymers (stereo SBR), 377  
Steric interference, rotations of polymer chains, 105  
Stirling approximation, Flory–Huggins theory, 111  
STM (scanning tunneling microscopy), 200  
Strain  
    analysis of simple flow, 461–468  
    Boltzmann superposition principle, 245–246  
    crazing, cracking and, 269–270  
    determining mechanical properties, 600–601  
    dynamic-mechanical analysis, 208–209  
    stress-strain behavior curves, 191–194  
    testing mechanical properties, 186–190  
    work expressed as stress and, 212–213  
Strain softening, 192  
Strength  
    properties of blends, 301  
    properties of composites, 312–313  
Stress  
    analysis of simple flow, 461–468  
    Boltzmann superposition principle, 245–246

- Stress (*continued*)  
 crazing, cracking and, 269–270  
 determining for polymer solutions and melts, 231–232  
 determining mechanical properties, 600–601  
 determining with rheometry. *See* Rheometry  
 dynamic-mechanical analysis, 208–209  
 elastic response of polymeric fluids, 457–460  
 mechanodegradation, 272  
 stress-strain behavior curves, 191–194  
 testing mechanical properties, 186–190  
 tests, 187–190  
 work expressed as strain and, 212–213
- Stress-at-break ( $\sigma_b$ ), 192
- Stress-relaxation measurement  
 experiment in, 223  
 overview of, 185  
 time-temperature superposition, 242–245  
 transient tests of mechanical properties, 196–198
- Structure factor, PCF, 596
- Structure–property relationships, 157, 177–179
- Styrene  
 atom transfer radical polymerization of, 59–61  
 in controlled drug delivery, 527–528  
 in free-radical copolymerization, 44–49  
 in free-radical polymerization. *See* Free-radical polymerization  
 nitroxide-mediated polymerization of, 58–59  
 pathways of, 32  
 polymerization of, 4  
 Styrene copolymers, 368–369
- Styrene–acrylonitrile copolymer (SAN), developing ABS, 401–402
- Styrene–butadiene rubber (SBR)  
 commercial applications/properties, 376–377  
 producing high-impact PS, 369  
 YSBR vs., 385–386
- Sulfonyl chlorides, 407
- Sulfur, 377–378
- Sunlight, stability of polymers and, 262
- Supercritical fluids (SCFs), polymerization in, 71–72
- Surface area, Flory EOS theory, 121
- Surface modification, 70–71, 74
- Surface properties, in plasma polymerization, 70
- Surlyn, 421–422
- Suspension polymerization, 66–67
- Suspensions, viscosity of, 455
- Symbols, units and, 631
- Syndiotactic polymers, 10–13
- Synthetic fibers, 347–348
- Synthetic polymers, 1
- Synthetic rubbers  
 development of, 2  
 types of, 374
- U.S. production of, 3
- Synthia software program, 574
- T**
- Tacticity, 9–12, 90–91
- Taylor series, 635
- TBA (torsional-braid analysis), 216–218
- Technologies. *See* Advanced technologies
- Teflon or PFTE (polytetrafluoroethylene), 411, 533, 541
- TEFLON-AF (amorphous Teflon), 411
- TEM (transmission electron microscopy), 200
- Temperature dependence. *See* Arrhenius dependence on temperature
- Temperature-modulated DSC (TMDSC)  
 dynamic calorimetry, 239–242  
 measuring thermal transitions, 176  
 suggested reading, 256
- Termination step  
 cationic polymerizations, 52  
 free-radical polymerization, 34–37  
 “living” polymerization, 49–50  
 rate of termination, 38–41  
 termination by chain transfer, 36  
 termination by combination, 34–35  
 termination by disproportionation, 35–36
- Ternary blends, polymer blends, 299–300
- Terpolymer, 9
- Tertiary recycling, 273
- Testing methods, mechanical properties  
 creep tests, 195–196  
 fatigue tests, 199–200  
 impact tests, 198–199  
 overview of, 185  
 static tests, 186  
 stress-relaxation measurement, 196–198  
 stress-strain behavior curves, 191–194  
 testing compression or shear strain, 190–191  
 testing stress or strain, 186–190  
 transient tests, 194
- Tetrabromobisphenol-A polycarbonate (TMBPC), 403
- Tetrafluoroethylene (TFE), in PFTE, 411
- Tetramethylbisphenol-A polycarbonate (TMPC), 403
- Textiles, polymers suitable for, 1
- TFE (tetrafluoroethylene), in PFTE, 411
- $T_g$ . *See* Glass-transition temperature ( $T_g$ )
- Thermal conductivity  
 heat capacity and, 65  
 in solution polymerization, 66  
 in suspension polymerization, 66–67
- Thermal degradation  
 chain scission reactions, 263–265  
 non-chain scission reactions, 265–266  
 overview of, 262–263

- Thermal process, asymmetric-membrane formation, 520
- Thermal properties, of commercial polymers, 625
- Thermal stability, 266–267
- Thermal stabilizers, as additives, 288
- Thermal transitions, and chemical structure, 20–22
- Thermal transitions and properties
- calorimetry measurement, 174–176
  - dilatometry measurement, 172–174
  - first-order transitions, 167–169
  - heat-distortion temperature measurement, 176–177
  - measurement techniques, 172
  - molecular weight, composition, pressure and  $T_g$ , 179–182
  - second-order transitions, 169–172
  - of semicrystalline polymers, 161
  - structure–property relationships, 177–179
- Thermal-expansion coefficient, 119, 170–172
- Thermally induced phase separation (TIPS), asymmetric-membrane formation, 520
- Thermally stimulated current (TSC) analysis, dielectrics, 238–239
- Thermal-oxidative degradation, flame retardants, 290
- Thermal-pressure coefficient, Flory EOS theory, 119
- Thermid resin, 415
- Thermistors
- calorimetry measurements, 174
  - vapor-pressure osmometry, 133–134
- Thermodynamic relationships, 167–172
- Thermodynamics
- of crystalline polymers, 161
  - free-radical polymerization, 41–43
  - polymer blends and, 293–294
  - rubber elasticity and, 248–251
- Thermodynamics of polymer solutions
- determination of interaction parameter, 125–126
  - equation of state theories, 117–122
  - Flory–Huggins theory, 110–116
  - Flory–Krigbaum theory, 116–117
  - modified Flory–Huggins, 117
  - overview of, 109–110
  - phase equilibria, 122–125
  - predictions of solubilities, 126–129
- Thermoforming process, 443
- Thermoplastic copolymers, 386
- Thermoplastic elastomers
- copolyesters, 386
  - olefinic elastoerms, 386
  - overview of, 384–385
  - properties of, 375
  - SBS elastomers, 385–386
- Thermoplastic polyesters, 372–374
- Thermoplastics. *See also* Commodity thermoplastics
- condensation, 6–7
  - overview of, 362
  - polyolefins, 53
  - references, 395
  - review problems, 394
  - suggested reading, 393–394
  - thermosets vs., 3–4
- Thermoset PIs, 415
- Thermosets
- composites and, 310
  - epoxies, 386–387
  - formaldehyde resins, 389–393
  - molding resins, 439
  - principle feature of, 361–362
  - references, 395
  - thermoplastics vs., 3–4
  - unsaturated polyesters, 387–389
- Thermostats
- for ensembles, 591
  - PVT simulation, 591–593
- Thermotropic polymers, 424
- Thiol-ene reaction, click chemistry, 79
- Thixotropic fluid, 452
- Thomson formula, crystallinity, 166
- Thrombus (clot) formation, artificial organs, 533
- Time dependence, and viscosity, 452
- Time-correlation coefficients, 597–599
- Time-temperature superposition, 197, 242–245
- TIPS (thermally induced phase separation), asymmetric-membrane formation, 520
- Tissue engineering, 532
- TMBPC (tetrabromobisphenol-A polycarbonate), 403
- TMDSC. *See* Temperature-modulated DSC (TMDSC)
- TMPC (tetramethylbisphenol-A polycarbonate), 403
- TNT (trinitrotoluene), detection of, 546
- Topological indices and Bicerano's method
- artificial neural network, 578–581
  - overview of, 574–578
  - predicting polymer properties with, 554
- Torsion pendulum, 214–216
- Torsional-braid analysis (TBA), 216–218
- Tortoise shells, thermoforming, 443
- Toughened plastics, 302–304
- Transfer (or plunger) molding, 438–439
- Transient tests
- creep tests, 195–196
  - overview of, 186
  - stress-relaxation, 196–198
  - testing mechanical properties, 194
- Transition State Theory (TST) method, 607, 610
- Transition-metal catalyst, 60
- Transmission electron microscopy (TEM), 200
- Transport mechanisms
- facilitated and coupled, 515–516

- Transport mechanisms (*continued*)  
 in membrane separations, 506–508  
 solution-diffusion, 509–515  
 through perfluorosulfonate ionomers, 516–517  
 through porous media, 508–509
- Trinitrotoluene (TNT), detection of, 546
- Trommsdorff effect, 65
- True strain, 187
- True stress, 187
- TSC (thermally stimulated current) analysis, dielectrics, 238–239
- TST (Transition State Theory) method, 607, 610
- Tubular-membrane modules, 525–526
- Twin-screw extruders, 436–437
- Two-stage screw, injection molding, 441
- U**
- Ubbelohde capillary viscometers, 142–143
- UDEL polysulfone, 408
- UF (Urea-formaldehyde) resins, 389–393, 524
- Ultimate stress, 192
- Ultrafiltration membranes, 496–498
- Ultrahigh-molecular-weight PE (UHMWPE), 366, 420
- Ultraporous membranes, preparation of, 517–518
- Ultraviolet (UV) light, 261–262, 267–269
- UNIFAC-FV method, 566–574
- Unipol process, ethylene, 366
- UNIQUAC Functional-group Activity Coefficients, 566
- United-atom (UA) simulations, MD applications, 581–582
- Units, and symbols, 631
- Universal calibration curve, GPC, 144–146
- Unsaturated polyesters, 387–389
- Upper critical solution temperature (UCST)  
 phase equilibria, 123, 125  
 polymer blends and, 294–297
- Urea-formaldehyde (UF) resins, 389–393, 524
- UV degradation, stabilizing acetal against, 405–406
- UV stabilizers, as additives, 288, 290
- V**
- VACF (velocity autocorrelation function), 597
- Vacuum-forming operation, 443
- Valence angles, chain bonds, 104–105
- Valence atomic indices, topological calculations, 575–577
- van der Waals volume  
 calculating properties of molecule, 556–558  
 as finite in real chain bonds, 106  
 free volume, 610–611  
 predicting activity coefficients, 566–567
- van Krevelen
- glass-transition temperature, 558–559  
 predicting volumetric properties, 553–556  
 values for van der Waals volume increments, 557–558
- van't Hoff equation  
 membrane osmometry, 130  
 sorption isotherms, 603
- Vapor-liquid equilibrium (VLE), 566
- Vapor-pressure osmometry, 133–134
- Vectorial or orientational autocorrelation function, 597–598
- Vectors, in gene therapy, 530–531
- Velocity  
 analysis of simple flow, 463–464  
 drag flow, 467–468  
 flow through capillary, 464–466
- Velocity autocorrelation function (VACF), 597
- Vibrational spectroscopy, 86–89
- Vinyl acetate (EVA), 363, 370–371
- Vinyl alcohol (EVOH), 363
- Vinyl monomers, polymerization of, 31
- Vinyl polymers  
 nomenclature rules for, 13  
 poly(methyl methacrylate), 371  
 poly(*N*-vinyl-2-pyrrolidinone), 372  
 polystyrene, 367–368  
 poly(vinyl acetate), 371  
 poly(vinyl chloride), 369–371  
 stereospecific polystyrene, 368  
 styrene copolymers, 368–369
- Viral coefficients, membrane osmometry, 131
- Viruses, as vectors in gene therapy, 530
- Viscoelasticity  
 activation energies, 220–221  
 Boltzmann superposition principle, 245–246  
 dynamic calorimetry, 239–242  
 experimental methods of dielectric analysis, 237–238  
 experimental techniques, 213–214, 231–232  
 forced-vibration methods, 218–220  
 free-vibration methods, 214–218  
 introduction to, 208  
 Maxwell model, 221–224  
 mechanical models, 221  
 multi-element models, 226–228  
 of polymer solutions and melts, 230  
 references, 259  
 relaxation and retardation spectra, 228–230  
 review problems, 256–259  
 simple models, 225–226  
 suggested reading, 256  
 theory of dielectric analysis, 233–237  
 theory of dynamic-mechanical analysis, 208–212  
 thermally stimulated current analysis, 238–239

- time-temperature superposition, 242–245  
transient and dynamic properties, 247–248  
viscoelastic properties of polymer solutions and melts, 230  
Voigt model, 225  
work in dynamic deformation, 212–213
- Viscometric flow, 467–468  
Viscose process, 76
- Viscosity  
capillary rheometer determining, 471  
cone-and-plate rheometer determining, 475  
Couette rheometer determining, 473–474  
of dilute suspensions in Newtonian liquid, 455  
dynamic viscosity, 230  
increasing molecular weight and polymer, 450  
measuring intrinsic, 140–143  
modeling wire coating process, 482–485  
Newton's law of, 221, 231, 446–448  
non-Newtonian flow or apparent, 448–450  
of polymer solutions/suspensions, 452–456  
polymerization in ionic liquids and, 73  
pressure dependence and, 452  
temperature dependence and, 451–452  
time dependence and, 452  
viscous flow region, 189
- Viscosity-average molecular weight ( $M_v$ ), 17, 130
- Viscous flow, 189, 508–509
- VLE (vapor-liquid equilibrium), 566
- Voigt elements  
limitations of simple Voigt model, 225–226  
modeling viscoelastic behavior, 225  
relaxation and retardation spectra, 229–230
- Voigt–Kelvin approach to multielement modeling, 228
- Volume  
finite (van der Waals), 106  
Flory–Huggins theory, 113, 117–118  
thermodynamics of polymer solutions, 109–110
- Volumeless chain, conformation, 102
- Volumetric properties, group contributions, 554–558
- Voorinrholt method, 610–611
- Voronoi tessellation, 610–611
- Vulcanization process, 377–379, 384–386
- W**
- Waste thermoplastics, refabricating, 3
- Water-soluble initiator, emulsion polymerization, 67
- WAXS (wide-angle X-ray scattering), 167–168, 201
- Weak-link degradation, 263
- Weathering, 262
- Webster, Owen, 83
- Weight-average molecular weight ( $M_w$ ), 129  
determining, 16–20  
light-scattering measurements, 134–140
- Weight-average degree of polymerization ( $X_w$ ), 29
- Weighting, artificial neural networks, 579
- Wet process, asymmetric-membrane formation, 520
- Wet spinning, fibers, 356–357
- Wheatstone bridge, 237–238
- Wide-angle X-ray scattering (WAXS), 167–168, 201
- Wire coating, 482–485
- WLF equation  
free volume and, 485–486  
temperature dependence of melt viscosity, 451–452  
time-temperature superposition, 242–245
- Work ( $W$ )  
expressed in terms of stress and strain, 212–213  
laws of thermodynamics and, 248–251  
naturally occurring fibers, 346–347
- X**
- Xanthan, as drag-reducing agent, 461
- X-ray  
diffraction, 166–167, 598–599  
radiation effects on polymers, 271–272  
scattering in polymer characterization, 201
- Y**
- Yield stress, 192
- Young's modulus  
determining mechanical properties, 601–602  
of layered silicate-elastomer nanocomposites, 321, 323  
time-temperature superposition, 244–245
- YSBR, and SBS elastomers, 385–386
- Z**
- z-average, 16–20, 129
- Ziegler, Karl, 2, 54
- Ziegler–Natta (Z-N) catalysts, 55–56
- Ziegler-type catalysts, 364–365, 367
- Zimm plot, 137–138



# FREE Online Edition

Your purchase of ***Polymer Science and Technology, Third Edition*** includes access to a free online edition for 45 days through the Safari Books Online subscription service. Nearly every Prentice Hall book is available online through Safari Books Online, along with thousands of books and videos from publishers such as Addison-Wesley Professional, Cisco Press, Exam Cram, IBM Press, O'Reilly Media, Que, Sams, and VMware Press.

Safari Books Online is a digital library providing searchable, on-demand access to thousands of technology, digital media, and professional development books and videos from leading publishers. With one monthly or yearly subscription price, you get unlimited access to learning tools and information on topics including mobile app and software development, tips and tricks on using your favorite gadgets, networking, project management, graphic design, and much more.

**Activate your FREE Online Edition at  
[informat.com/safarifree](http://informat.com/safarifree)**

**STEP 1:** Enter the coupon code: YYFPFDB.

**STEP 2:** New Safari users, complete the brief registration form.  
Safari subscribers, just log in.

If you have difficulty registering on Safari or accessing the online edition,  
please e-mail [customer-service@safaribooksonline.com](mailto:customer-service@safaribooksonline.com)



Adobe Press



Cisco Press



Microsoft  
Press



O'REILLY



SAMS



vmware PRESS

