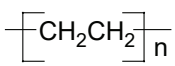
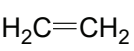
LDPE low density polyethylene

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	low density polyethylene	
IUPAC name	-	polyethylene	
Acronym	-	LDPE	
CAS number	-	9002-88-4 (homopolymer)	
Formula			
HISTORY			
Person to discover	-	Fawcett, E; Perrin, M, both of ICI	
Date	-	1933; 1935; 1939	
Details	-	Fawcett produced PE by accident; Perrin developed sound technology; ICI begun production	
SYNTHESIS			
Monomer(s) structure	-		
Monomer(s) CAS number(s)	-	74-85-1	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	28.05	
Monomer(s) expected purity(ies)	%	99.9	
Monomer ratio	-	100% ethylene or less	
Vinyl acetate content (only some grades)	wt%	3-6	
Formulation example	-	oxygen or an organic peroxide such as dibutyl, benzoyl, or diethyl peroxide used as initiator; benzene or chlorobenzene are used as solvents; tubular and autoclave reactors are used for synthesis	
Temperature of polymerization	°C	132-332	
Time of polymerization	h	100-300	
Pressure of polymerization	MPa	150-300	
Number average molecular weight, M_n	dalton, g/mol, amu	13,000-18,000	
Mass average molecular weight, M_w	dalton, g/mol, amu	69,000-411,000	
Polydispersity, M_w/M_n	-	4-30	
Degree of branching	methyl/1000 C	7.8-33	
Type of branching	-	methyl, ethyl, butyl, amyl, and longer	Zhu, H; Wang, Y; Zhang, X; Su, Y; Dong, X; Chen, Q; Zhao, Y; Geng, C; Zhu, S; Han, C C; Wang, D, Polymer, 48, 5098-106, 2007.
Unsaturations	% total	80 (vinylidene), 10 (vinyl), 10 (trans)	
STRUCTURE			
Crystallinity	%	28.8-60	
Cell type (lattice)	-	orthorhombic	
Cell dimensions	nm	a:b:c=0.738:0.493:0.253	
Crystallite thickness	nm	6.5-10.5	
Rapid crystallization temperature	°C	96-100	

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Avrami constants, k/n	-	n=1.5-3	Grady, B P; Genetti, W B, Conductive Polymers and Plastics, Rupprecht, L, Ed., WilliamAndrew, Norwich, 1999.
COMMERCIAL POLYMERS			
Some manufacturers	-	DOW; ExxonMobil	
Trade names	-	LDPE; LDPE	
PHYSICAL PROPERTIES			
Density at 20°C	g cm^{-3}	0.915-0.929; 0.855 (amorphous); 1.0-1.014 (crystalline)	
Refractive index, 20°C	-	1.517-1.526	
Transmittance	%	90-91	
Haze	%	2.2-27	
Gloss, 60°, Gardner (ASTM D523)	%	33-87	
Melting temperature, DSC	°C	105-115; 102 (copolymer with VAc)	
Thermal expansion coefficient, 23-80°C	$°C^{-1}$	1-5.1E-4	
Thermal conductivity, melt	W m^{-1} K^{-1}	0.55	
Glass transition temperature	°C	-103 to -133	
Heat of fusion	kJ mol^{-1}	1.37-2.18	
Long term service temperature	°C	70	
Heat deflection temperature at 0.45 MPa	°C	37-48	
Heat deflection temperature at 1.8 MPa	°C	36-40	
Vicat temperature VST/A/50	°C	76-109	
Dielectric constant at 100 Hz/1 MHz	-	2.25-2.31	
Dissipation factor at 1000 Hz	E-4	2	
Volume resistivity	ohm-m	1E13	
Electric strength K20/P50, d=0.60.8 mm	kV mm^{-1}	16-28	
Arc resistance	s	135-160	
Power factor	-	0.0003	
Percolation threshold for MWCNT	wt%	0.85 (DC conductivity = 3.47E-07 S/cm)	Han, S H; Yeom, Y S; Ko, J G; Kang, H C; Yoon, H G, Compos. Sci. Technol., 117, 351-6, 2015.
Coefficient of friction	-	0.6 (itself, dynamic)	
Permeability to nitrogen, 25°C	cm^3 cm cm^{-2} s^{-1} Pa^{-1} x 10^{12}	0.073	
Permeability to oxygen, 25°C	cm^3 cm cm^{-2} s^{-1} Pa^{-1} x 10^{12}	0.22	

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Permeability to water vapor, 25°C	cm^3 cm cm^{-2} s^{-1} Pa^{-1} x 10^{12}	6.8	
Diffusion coefficient of nitrogen	cm^2 s^{-1} $x10^6$	0.32	
Diffusion coefficient of oxygen	cm^2 s^{-1} $x10^6$	0.46	
Speed of sound	m s^{-1}	32.5	
Acoustic impedance		1.79	
Attenuation	dB cm^{-1}, 5 MHz	2.4	
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	10-20; 25.4-27.0 (MD) and 14.5-17.3 (TD) for 0.025 mm thick film; 21.6-31.8 (MD) and 16.9-28.9 (TD) for 0.051 mm thick film; 22.1-26.7 (copolymer with VAc)	
Tensile modulus	MPa	130-348	
Tensile stress at yield	MPa	10.8-14.1 (MD) and 10.0-12.3 (TD) for 0.025 mm thick film; 11.8-13.6 (MD) and -11.6-13.7 (TD) for 0.051 mm thick film	
Elongation	%	130-270 (MD) and 490-570 (TD) for 0.025 mm thick film; 180-580 (MD) and 560-780 (TD) for 0.051 mm thick film; 600 (copolymer VAc)	
Flexural strength	MPa	7.5	Yildirir, E; Miskolczi, N; Onwudili, J A; Nemeth, K E; Williams, P T; Soja, J, Composites: Part B, 78, 393-400, 2015.
Flexural modulus	MPa	230-495	
Charpy impact strength, unnotched, 23°C	kJ m^{-2}	18.2	Yildirir, E; Miskolczi, N; Onwudili, J A; Nemeth, K E; Williams, P T; Soja, J, Composites: Part B, 78, 393-400, 2015.
Izod impact strength, notched, 23°C	J m^{-1}	420 to NB	
Film puncture resistance	J cm^{-3}	2.8-5.7	
Film toughness	J cm^{-3}	55.1-82.5 (MD) and 63.7-109 (TD) for 0.025 mm thick fim; 64.5-216 (MD) and 66.9-211 (TD) for film thickness of 0.051 mm	
Dart drop impact	g	72-250; 120-1,200 (copolymer with VAc)	
Elmendorf tear strength	g	140-510 (MD) and 110-180 (TD) for 0.025 mm thick film; 300-560 (MD) and 180-470 (TD) for 0.051 mm thick film	
Puncture force	N	37	
Shore D hardness	-	41-50	
Shrinkage	%	2.4	
Brittleness temperature (ASTM D746)	°C	-34 to -60	
Melt viscosity, shear rate=0 s^{-1} at 150°C	Pa s	54,500	Hertel, D; Valette, R; Muenstedt, H, J. Non-Newtonian Fluid Mech., 153, 82-94, 2008.
Pressure coefficient of melt viscosity, b	G Pa^{-1}	17.6	Aho, J; Syrjala, S, J. Appl. Polym. Sci., 117, 1076–84, 2010.
Melt index, 230°C/3.8 kg	g/10 min	0.25-55	
Water absorption, equilibrium in water at 23°C	%	0.005-0.015	

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CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	very good	
Alcohols	-	good	
Alkalis	-	very good	
Aliphatic hydrocarbons	-	poor	
Aromatic hydrocarbons	-	poor	
Esters	-	poor	
Greases & oils	-	good to poor	
Halogenated hydrocarbons	-	poor	
Ketones	-	poor	
Θ solvent, Θ-temp.=141-170	-	di-(2-ethylhexyl) adipate	
Good solvent	-	1,2,4-trichlorobenzene, decalin, halogenated hydrocarbons, aliphatic ketones, xylene (all above 80°C)	
Non-solvent	-	most common solvents	
FLAMMABILITY			
Ignition temperature	°C	340-343	
Autoignition temperature	°C	350	
Limiting oxygen index	% O_2	<20	
Char at 500°C	%	0	Lyon, R E; Walters, R N, J. Anal. Appl. Pyrolysis, 71, 27-46, 2004.
Heat of combustion	J g^{-1}	47,740	
Volatile products of combustion	-	CO, CO_2, aldehydes, benzene	
UL 94 rating	-	HB	
WEATHER STABILITY			
Spectral sensitivity	nm	<300	
Activation wavelengths	nm	300, 330-360	
Excitation wavelengths	nm	230, 254, 265, 273, 278, 280, 300, 331	
Emission wavelengths	nm	275, 295, 335, 350, 378, 381, 391, 405, 416, 420, 435, 455, 470	
Depth of UV penetration	μm	<1500	
Important initiators and accelerators	-	unsaturations, aromatic carbonyl compounds (deoxyanisoin, dibenzocycloheptadienone, flavone, 4-methoxybenzophenone, 10-thioxanthone), hydrogen bound to tertiary carbon at branching points, aromatic amines, groups formed on oxidation (hydroperoxides, carbonyl, carboxyl, hydroxyl) substituted benzophenones, complexes with ground-state oxygen, quinones (anthraquinone, 2-chloroanthraquinone, 2-tert-butylathraquinone, 1-methoxyanthraquinone, 2-ethylanthraquinone, 2-methylanthraquinone), transition metal compounds (Ni < Zn < Fe < Co), ferrocene derivatives, titanium dioxide (anatase), ferric stearate, polynuclear aromatic compounds (anthracene, phenanthrene, pyrene, naphthalene	
Products of degradation	-	free radicals, hydroperoxides, carbonyl groups, chain scission, crosslinking	

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Stabilizers	-	UVA: 2-hydroxy-4-octyloxybenzophenone; phenol, 2-(5-chloro-2H-benzotriazole-2-yl)-6-(1,1-dimethylethyl)-4-methyl-; 2,2'-methylenebis(6-(2H-benzotriazol-2-yl)-4-1,1,3,3-tetramethylbutyl)phenol; 2,4-di-tert-butyl-6-(5-chloro-2H-benzotriazole-2-yl)-phenol; reaction product of methyl 3(3-(2H-benzotriazole-2-yl)-5-t-butyl-4-hydroxyphenyl propionate/ PEG 300; 2-[4,6-bis(2,4-dimethylphenyl)-1,3,5-triazin-2-yl]-5-(octyloxy) phenol; Screener: titanium dioxide; zinc oxide; carbon black; Acid scavenger: hydrotalcite; Fiber: carbon nanotube; HAS: 1,3,5-triazine-2,4,6-triamine, N,N'''[1,2-ethane-diyl-bis[[[4,6-bis[butyl(1,2,6,6-pentamethyl-4-piperidinyl)amino]-1,3,5-triazine-2-yl]imino]-3,1-propanediyl] bis[N',N''-dibutyl-N',N''-bis(1,2,2,6,6-pentamethyl-4-piperidinyl)-; bis(1,2,2,6,6-pentamethyl-4-piperidyl)sebacate + methyl-1,2,2,6,6-pentamethyl-4-piperidyl sebacate; 2,2,6,6-tetramethyl-4-piperidinyl stearate; reaction products of N,N'-ethane-1,2-diylbis(1,3-propanediamine), cyclohexane, peroxidized 4-butylamino-2,2,6,6-tetramethylpiperidine and trichloro-1,3,5-triazine; poly[[(6-[1,1,3,3-tetramethylbutyl) amino]-1,3,5-triazine-2,4-diyl][2,2,6,6-tetramethyl-4-piperidinyl) imino]-1,6-hexanediyl[2,2,6,6-tetramethyl-4-piperidinyl)imino]]; 1,6-hexanediamine- N,N'-bis(2,2,6,6-tetramethyl-4-piperidinyl)-polymer with 2,4,6-trichloro-1,3,5-triazine, reaction products with N-butyl-1-butanamine an N-butyl-2,2,6,6-tetramethyl-4-piperidinamine; butanedioic acid, dimethylester, polymer with 4-hydroxy-2,2,6,6-tetramethyl-1-piperidine ethanol; alkenes, C20-24-.alpha.-, polymers with maleic anhydride, reaction products with 2,2,6,6-tetramethyl-4-piperidinamine; 1,6-hexanediamine, N,N'-bis(2,2,6,6-tetramethyl-4-piperidinyl)-, polymers with morpholine-2,4,6-trichloro-1,3,5-triazine reaction products, methylated; Phenolic antioxidant: 2,6,-di-tert-butyl-4-(4,6-bis(octylthio)-1,3,5,-triazine-2-ylamino) phenol; pentaerythritol tetrakis(3-(3,5-di-tert-butyl-4-hydroxyphenyl) propionate); octadecyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl)-propionate; 3,3',3',5,5',5'-hexa-tert-butyl-a,a',a'-(mesitylene-2,4,6-triyl)tri-p-cresol; 2-(1,1-dimethylethyl)-6-[[3-(1,1-dimethylethyl)-2-hydroxy-5-methylphenyl] methyl-4-methylphenyl acrylate; 1,3,5-tris(3,5-di-tert-butyl-4-hydroxybenzyl)-1,3,5-triazine-2,4,6(1H,3H,5H)-trione; 3,4-dihydro-2,5,7,8-tetramethyl-2-(4,8,12-trimethyltridecyl)-2H-1-benzopyran-6-ol; 2',3-bis[[3-[3,5-di-tert-butyl-4-hydroxyphenyl]propionyl]]propionohydrazide; isotridecyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl) propionate; 2,2'-ethylidenebis (4,6-di-tert-butylphenol); ethylene bis[3,3-bis[3-(1,1-dimethylethyl)-4-hydroxyphenyl]butanoate];1,3,5-tris(4-tert-butyl-3-hydroxy-2,6-dimethylbenzyl)-1,3,5-triazine-2,4,6-(1H,3H,5H)-trione; 2,2'-methylenebis(4-methyl-6-tertbutylphenol); 3,5-bis(1,1-dimethyethyl)-4-hydroxy-benzenepropanoic acid, C13-15 alkyl esters; 2,2'-isobutylidenebis(2,4-dimethylphenol); 1,1,3-tris(2'methyl-4'-hydroxy-5'tert-butylphenyl)butane; Phosphite: bis-(2,4-di-t-butylphenol) pentaerythritol diphosphite; tris (2,4-di-tert-butylphenyl)phosphite; trinonylphenol phosphite; distearyl pentaerythritol diphosphite; trilauryl trithiophosphite; Thiosynergist: didodecyl-3,3'-thiodipropionate; dioctadecyl 3,3'-thiodipropionate; 2,2'-thiodiethylene bis[3-(3,5-ditert-butyl-4-hydroxyphenyl)propionate]; 4,4'-thiobis(2-t-butyl-5-methylphenol); 2,2'-thiobis(6-tert-butyl-4-methylphenol); pentaerythritol tetrakis(b-laurylthiopropionate); Quencher: (2,2'-thiobis(4-tert-octyl-phenolato))-N-butylamine-nickel(II); Optical brightener: 2,2'-(2,5-thiophenediyl)bis(5-tert-butylbenzoxazole)	

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PARAMETER	UNIT	VALUE	REFERENCES
BIODEGRADATION			
Typical biodegradants	-	fungi, bacteria, Actinomycetes (10% mass loss per year)	Sudhakar, M; Doble, M; Sriyutha Murthy, P; Venkatesan, R, Int. Biodet. Biodeg., 61, 203-13, 2008.
TOXICITY			
NFPA: Health, Flammability, Reactivity rating	-	1/0/1	
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP	
Mutagenic effect	-	not known	
Teratogenic effect	-	not known	
Reproductive toxicity	-	not known	
Oral rat, LD_{50}	mg kg^{-1}	>5,000	
Skin rabbit, LD_{50}	mg kg^{-1}	>2,000	
ENVIRONMENTAL IMPACT			
Biological oxygen demand, BOD_5	-	3.08	Psomiadou, E; Arvanitoyannis, I; Biliaderis, C G; Ogawa, H; Kawasaki, N, Carbohydrate Polym., 33, 227-42, 1997.
Cradle to grave non-renewable energy use	MJ/kg	81.8	Harding, K G; Dennis, J S; von Blottnitz, H; Harrison, S T L, J. Biotechnol., 130, 57-66, 2007.
Cradle to pellet greenhouse gasses	kg CO_2 kg^{-1} resin	2.0-2.2	
PROCESSING			
Typical processing methods	-	blown film extrusion, cast film extrusion, coating, coextrusion, extrusion, injection molding, molding, lamination, rotational molding	
Processing temperature	°C	199-232 (extrusion); 212 (blown film); 316-332 (coating)	
Additives used in final products	-	Fillers: aluminum, barium sulfate, calcium carbonate, calcium sulfate whiskers, carbon black, diatomaceous earth, ferromagnetic powder, glass fiber, glass spheres, ground tire rubber, hollow silicates, hydrotalcite, kaolin, lignin, magnesium hydroxide, marble, mica, nickel fibers, red mud, sand, silica, soot, starch, superconductor ($YBa_2Cu_3O_{7-x}$), talc, wollastonite, wood flour, zirconium silicate; Plasticizers: dioctyl phthalate, EPDM, EVA, glycerin, glyceryl tribenzoate, mineral oil, paraffin oil, polyethylene glycol, sunflower oil; Antistatics: carbon black, copper complex of polyacrylic acid, ethoxylated amines, fatty diethanol amines, glycerol monostearate, graphite, ionomer, lauric diethanolamide, polyethylene glycol, quaternary ammonium compound, trineoalkoxy zirconate; Antiblocking: diatomaceous earth, natural silica, siloxane spheres, synthetic silica, talc, zeolite; Release: stearyl erucamide; Slip: erucamide, ethylene bisoleamide, oleamide	
Applications	-	car covers, cling wrap, moisture barriers in construction, liners for tanks and ponds, sandwich bags, squeeze bottles	
BLENDS			
Suitable polymers	-	chitosan, EEA, EPDM, EVA, HDPE, HIPS, LLDPE, NBR, NR, PA6, PET, iPP, PP, PS, PVDF, SBR, starch	

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Compatibilizers	-	LDPE-g-MA	Telen, L; Jansens, K J A; Verpoest, I; Delcour, J A; Van Puyvelde, P; Goderis, B, Ind. Crops Prod., 74, 824-38, 2015.