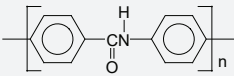
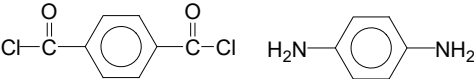


PPTA poly(p-phenylene terephthalamide)

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	poly(p-phenylene terephthalamide), aramid, Kevlar	
IUPAC name	-	poly(imino-1,4-phenyleneiminocarbonyl-1,4-phenylenecarbonyl)	
CAS name	-	poly(imino-1,4-phenyleneiminocarbonyl-1,4-phenylenecarbonyl)	
Acronym	-	PPTA	
CAS number	-	24938-64-5; 26125-61-1	
Formula			
RTECS number	-	TQ9875000	
HISTORY			
Person to discover	-	Stephanie Kwolek	
Date	-	1965; 1971	
Details	-	discovery in 1965 in DuPont laboratories, production of aramid fiber in 1971	
SYNTHESIS			
Monomer(s) structure	-		
Monomer(s) CAS number(s)	-	100-20-9; 106-50-3	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	203.02; 108.1	
Monomer ratio	-	1.87:1	
Method of synthesis	-	condensation reaction yielding hydrochloric acid as a byproduct	
Number average molecular weight, M_n	dalton, g/mol, amu	10,300-19,800	
Mass average molecular weight, M_w	dalton, g/mol, amu	31,400-48,350	
Polydispersity, M_w/M_n	-	2.4-5.3	
Molar volume at 298K	cm ³ mol ⁻¹	160 (crystalline)	
Van der Waals volume	cm ³ mol ⁻¹	112.6 (crystalline)	
Chain-end groups	mequiv kg	0.42 (amine)	Horta, A; Coca, J; Diez, F V, Adv. Polym. Technol., 22, 1, 15-21, 2003.
STRUCTURE			
Crystallinity	%	72.2-91.0	Mooney, D A; Don McElroy, J M, Chem. Eng. Sci., 59, 2159-70, 2004.
Cell type (lattice)	-	monoclinic; orthorhombic	Chatzi, E G; Koenig, J L, Polym. Plast. Technol. Eng., 26, 229, 1987.

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PARAMETER	UNIT	VALUE	REFERENCES
Cell dimensions	nm	a:b:c=0.78:0.519:1.29; unit cell dimensional changes at low temp. in ref.	Chatzi, E G; Koenig, J L, Polym. Plast. Technol. Eng., 26, 229, 1987; Iyer, R V; Sooryanarayana, K; Guru Row, T N; Vijayan, K, J. Mater. Sci., 38, 133-39, 2003.
Unit cell angles	degree	α : β : γ =90:90:90	Chatzi, E G; Koenig, J L, Polym. Plast. Technol. Eng., 26, 229, 1987.
Number of chains per unit cell	-	2	Chatzi, E G; Koenig, J L, Polym. Plast. Technol. Eng., 26, 229, 1987.
Crystallite size	nm	5 x 5 x 20; 52-55; 60	Pauw, B R; Vigild, M E; Mortensen, K; Andreasen, J W; Klop, E A, J. Appl. Cryst. 43, 837-49, 2010; Knijnenberg, A; Bos, J; Dingemans, T J, Polymer, 1887-97, 2010; Mooney, D A; Don McElroy, J M, Chem. Eng. Sci., 59, 2159-70, 2004.
Chain conformation	-	TTTT	
COMMERCIAL POLYMERS			
Some manufacturers	-	DuPont	
Trade names	-	Kevlar	
PHYSICAL PROPERTIES			
Density at 20°C	g cm ⁻³	1.44-1.47, 1.48 (crystalline)	
Bulk density at 20°C	g cm ⁻³	0.56	
Refractive index, 20°C	-	2.12 and 1.61	
Birefringence	-	2.0499, 1.5886	
Melting temperature, DSC	°C	551-554	
Decomposition temperature	°C	427-482 (air)	
Thermal expansion coefficient, 23-80°C	°C ⁻¹	-2-5.7E-6	Jain, A; Polym. Eng. Sci., 48, 211-15, 2008.
Thermal conductivity, melt	W m ⁻¹ K ⁻¹	5.03 -5.07e(-0.00487) @ 7-290K	Ventura, G; Martelli, V, Cryogenics, 49, 735-37, 2009.
Glass transition temperature	°C	425	
Specific heat capacity	J K ⁻¹ kg ⁻¹	1,420 (25°C); 2,515 (180°C)	
Maximum service temperature	°C	300-350	
Long term service temperature	°C	149-177	De Groh, K K; Banks, B A; Mc-Carthy, C E; Rucker, R N; Roberts, L M; Berger, L A, High Performance Polym., 20, 388-409, 2008.
Contact angle of water, 20°C	degree	63.7-64.6	
Surface free energy	mJ m ⁻²	45.7	
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	2,920-3,600 (yarns); 3,600 (strands impregnated with resin)	
Tensile modulus	MPa	70,500-138,000 (yarns); 83,000-124,000 (strands impregnated with resin); 200,000 (fully crystalline)	Deng, L; Young, R J; van der Zwaag, S; Picken, S, Polymer, 51, 2033-39, 2010.
Elongation	%	2.4-3.6	
Compressive strength	MPa	650	Knijnenberg, A; Bos, J; Dingemans, T J, Polymer, 1887-97, 2010.

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PARAMETER	UNIT	VALUE	REFERENCES
Young's modulus	MPa	40,000-78,000	Rao, Y; Waddon, A J; Farris, R J, Polymer, 5925-35, 2001.
Tenacity (fiber) (standard atmosphere)	cN tex ⁻¹ (daN mm ⁻²)	44-270 (60-400)	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Tenacity (wet fiber, as % of dry strength)	%	75-100	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Fineness of fiber (titer)	dtex	1.1-12	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Length (elemental fiber)	mm	38-120	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Poisson's ratio	-	0.63	Nakamae, K; Nishino, T; Airu, X, Polymer, 33, 23, 4898-4900, 1992.
Shrinkage	%	<0.1	
Intrinsic viscosity, 25°C	dl g ⁻¹	3-7	Allen, S R; Roche, E J; Bennett, B; Molaison, R, Polymer, 33, 9, 1849-54, 1992.
Water absorption, equilibrium in water at 23°C	%	3.5-7.0 (as shipped); 3.5-4.5 (regained from dried)	
Moisture absorption, equilibrium 23°C/50% RH	%	0.96-3.9	Mooney, D A; Don McElroy, J M, Chem. Eng. Sci., 59, 2159-70, 2004.
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	good-poor	
Alcohols	-	resistant	
Alkalis	-	good-fair	
Aliphatic hydrocarbons	-	resistant	
Aromatic hydrocarbons	-	resistant	
Esters	-	resistant	
Good solvent	-	H ₂ SO ₄ , polar aprotic solvents	
Non-solvent	-	aliphatic and aromatic hydrocarbons, alcohols, ethers, esters	
FLAMMABILITY			
Ignition temperature	°C	>550	
Limiting oxygen index	% O ₂	28-29	
Char at 500°C	%	36.1	Lyon, R E; Walters, R N, J. Anal. Appl. Pyrolysis, 71, 27-46, 2004.
Heat of combustion	J g ⁻¹	26,450; 35,000	Walters, R N; Hacket, S M; Lyon, R E, Fire Mater., 24, 5, 245-52, 2000.
Volatile products of combustion	-	H ₂ , CO, CO ₂ , HCN, H ₂ O, NH ₃ , benzene, benzonitrile, toluene	
WEATHER STABILITY			
Spectral sensitivity	nm	300-450	
Activation wavelengths	nm	310	
Effect of exposure	Fadeometer	50% tensile strength lost in 900 h	

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PARAMETER	UNIT	VALUE	REFERENCES
TOXICITY			
NFPA: Health, Flammability, Reactivity rating	-	0/1/0	
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP	
Mutagenic effect	-	no known effect	
Teratogenic effect	-	animal testing showed effects on embryo-faetal development at levels below those causing maternal toxicity	
Oral rat, LD₅₀	mg kg ⁻¹	7,500	
Skin rabbit, LD₅₀	mg kg ⁻¹	no skin irritation	
PROCESSING			
Additives used in final products	-	UV stabilizer: nano-titanate	Xing, Y; Ding, X, J. Appl. Polym. Sci., 103, 3113-19, 2007.
Applications	-	fibers, papers, yarns; some examples: body armor, protection vests, military helmets, heat resistant gloves, vehicle armor, automotive components, fiber optics, adhesives, sealants, composites, oil, gas, and many more	
Outstanding properties	-	structural rigidity, flame resistance, chemical resistance	
BLENDS			
Suitable polymers	-	PPy	
ANALYSIS			
x-ray diffraction peaks	degree	20.5, 23.4	Nakamae, K; Nishino, T; Airu, X, Polymer, 33, 23, 4898-4900, 1992.