How to make Capacitors

(12/24/2016)

One can build a Capacitor out of any conducting material as long as one also has an insulator between the conductors. For example aluminum foil sandwiched between glass plates, plastic, paper, stretch food wrap, plastic bag material, wax paper, paper soaked in oil, etc. will all work. It can be rolled into a tube or not.

The formula for determining capacitance is: **C=(0.224KA/d)(n-1)**

Where **C** is the capacitance in picofarads, **K** is a constant that depends on the insulator (or dielectric) between the plates (called the dielectric constant), **A** is the area of one conductive plate in square inches, **d** is the separation between adjacent plates in inches, and **n** is the number of plates. As you may know, different insulators have different dielectric constants. The tables below show the values of K for some common materials and the peak voltage they can withstand per 1/1000th inch (called a mil) of thickness. This rating is called the puncture or breakdown voltage.

One doesn't even need the formula or tables to build capacitors; one could make a small version based on what one has at hand and test to see when the voltage breaks down the insulation between the plates. Increase or decrease insulator thickness accordingly. One is striving for the thinnest insulator that will work for the intended voltage without much leakage. This will lower the amount of plate area needed in the end result. Then once a good sample is made, using a good digital meter that measures directly capacitance determine how much more plate area bigger the final version needs to be to get the capacitance desired. Capacitance is directly proportional to plate area.

Insulator breakdown voltage

Units:

The unit of dielectric strength is volts per meter (V/m). It is also common to see related units such as volts per centimeter (V/cm), megavolts per meter (MV/m), and so on.

In United States customary units, dielectric strength is often specified in volts per mil (a mil is 1/1000 inch). The conversion is:

$$1\ \mathrm{V/m} = 2.54 \times 10^{-5}\ \mathrm{V/mil}$$
$$1\ \mathrm{V/mil} = 3.94 \times 10^{4}\ \mathrm{V/m}$$

Dielectric strength (in MV/m, or 10^6 Volt/meter) of various common materials:

Substance	Dielectric Strength (MV/m)
Helium (relative to nitrogen)	0.15
Air	3.0
Alumina	13.4
Window glass	9.8 - 13.8
Borosilicate glass	20 - 40
Silicone oil, mineral oil	10 - 15
Benzene	163
Polystyrene	19.7
Polyethylene	19 - 160
Neoprene rubber	15.7 - 26.7
Distilled water	65 - 70
High vacuum (field emission limited)	20 - 40 (depends on electrode shape)
Fused silica	25–40 at 20 °C
Waxed paper	40 - 60
PTFE (Teflon, extruded)	19.7
PTFE (Teflon, insulating film)	60 - 173
Mica	118
Diamond	2000
PZT	10–25
Vacuum	10^{12}

Table 1 -- Dielectric Constants and Breakdown Voltages

Insulator	Dielectric Constant	Puncture Voltage per 0.001 Inch	Notes
Air	1.0	30	1
Window glass	7.8	200	
Polyethelene	2.3	450	
Paper (bond)	3.0	200	
Polycarbonate (Lexan)	2.96	400	
Teflon	2.1	1000	
Polystyrene	2.6	500	
Epoxy circuit board	5.2	700	2, 3
Pyrex	4.8	335	
Plexiglass	2.8	450	
PVC (rigid type)	2.95	725	
Silicone RTV	3.6	550	
Polyethelene Terphtalate (Mylar)	3.0	7500	
Nylon	3.2	407	4
Mineral Oil, Squibb	2.7	200	2, 5
Shellac	3.3	200	

Notes: All measurements at 1 MHz unless otherwise noted.
1 Tested with dry air
2 Tested at 300Hz using a Heathkit IM-2320 multimeter and homemade capacitor.
3 Estimate, based no experiences.
4 Lowest value of 3 types.
5 Estimate. Probably higher. A 0.040" gap withstood over 10,000 volts DC before breakdown in one test.

Substance	Dielectric Strength (KV/mil) (<0.06mm or 0.002" films)	Dielectric Strength (KV/mil) (>1.0 mm or 0.040")
Teflon NXT	2.2 –4.0 KV/.001"	0.4 – 0.5 KV/.001"
Polyimide (Kapton)	7.4 KV/.001"	--
Parylene (N, C, D, HT)	4.2 – 7.0 KV/.001"	--
Dyneon TFM	2.5- 3.0 KV/.001"	0.4 – 0.5 KV/.001"
CYTOP perfluoropolymer	2.3 – 2.8 KV/0.001"	--
Sapphire (Single-Crystal)	1.3 –1.4 KV/0.001"	1.2 KV/0.001"
Mica	2.0 –4.5 KV/0.001"	1.4-1.9 KV/0.001"
Boron Nitride	1.6 KV/0.001"	1.4 KV/0.001"
PEEK	3.0 - 3.8 KV/0.001"	0.3 – 0.5 KV/0.001"
Polyethersulfone	4.0 –4.2 KV/0.001"	0.3 - 0.5 KV/0.001"
Silica Quartz	1.1-1.4 KV/0.001"	1.1-1.4 KV/0.001"

TABLE 17–3 Dielectric constants (at 20°C)

Material	Dielectric constant K	Dielectric strength (V/m)
Vacuum	1.0000	
Air (1 atm)	1.0006	3×10^6
Paraffin	2.2	10×10^6
Polystyrene	2.6	24×10^6
Vinyl (plastic)	2–4	50×10^6
Paper	3.7	15×10^6
Quartz	4.3	8×10^6
Oil	4	12×10^6
Glass, Pyrex	5	14×10^6
Rubber, neoprene	6.7	12×10^6
Porcelain	6–8	5×10^6
Mica	7	150×10^6
Water (liquid)	80	
Strontium titanate	300	8×10^6

TABLE 26.1 Dielectric Constants and Dielectric Strengths of Various Materials at Room Temperature

Material	Dielectric Constant κ	Dielectric Strength[a] (V/m)
Air (dry)	1.000 59	3×10^6
Bakelite	4.9	24×10^6
Fused quartz	3.78	8×10^6
Neoprene rubber	6.7	12×10^6
Nylon	3.4	14×10^6
Paper	3.7	16×10^6
Polystyrene	2.56	24×10^6
Polyvinyl chloride	3.4	40×10^6
Porcelain	6	12×10^6
Pyrex glass	5.6	14×10^6
Silicone oil	2.5	15×10^6
Strontium titanate	233	8×10^6
Teflon	2.1	60×10^6
Vacuum	1.000 00	—
Water	80	—

[a] The dielectric strength equals the maximum electric field that can exist in a dielectric without electrical breakdown. Note that these values depend strongly on the presence of impurities and flaws in the materials.

PUNCTURING VOLTAGES
(KILOVOLTS PER INCH)

AIR	19.8
CASTOR OIL	380
EBONITE	725
FLINT GLASS	2280
GLASS, COMMON	200
" , LEAD	140
GUTTA PERCHA	450
HARD RUBBER	250-950
INDIA "	160-500
MANILLA PAPER	125
MICA	430-700
OLIVE OIL	185-425
PARAFFIN	
MELTED	185
SOLID	875-1000
PARAFFINED PAPER	1250
PORCELAIN	230
SPERM OIL	200-450
TURPENTINE	280-400

Table 1. Typical properties of some common types of capacitors.

Capacitor Types	K	Voltge Brkdn (V/ml)	DF (%)	Insulation Resistance @ 25°C (Ohms)	Max Oper. Temp (°C)	Enrg Dens (J/cc)
Plastic Film						
Polycarbonate (PC)	2.8	13,400	<1	$2x10^{11}$	125	0.5-1
Polypropylene (PP)	2.2	16,250	<0.1	$8x10^{11}$	105	1-1.5
Polyester (PET)	3.3	14,500	<1.5	$5x10^{10}$	125	1-1.5
Polyvinylidene-fluoride (PVDF)	12	15,000	1-5	$1x10^{9}$	125	2.4
Polyethylene-napthlate (PEN)	3.2	14,000	<1	$5x10^{10}$	125	1-1.5
Polyphenylene-sulfide (PPS)	3.0	14,000	<0.2	$5x10^{10}$	200	1-1.5
Teflon™ (PTFE)	2.1	7,000	<1	$5x10^{10}$	200	0.5-1

Material	Permittivity (ε_r)	Breakdown voltage (V/mm) (approx.)
Air	1	1,180
Glass (standard)	7.6 – 8.0	7,800
Plexiglass	~2.8	17,700
Rubber	2 – 7	-
ABS (plastic)	2.0 – 3.5	32,000
FR4	4.7	27,500
Polyimide (PI)	3.5	200,000
Polyester (PET)	~3.4	17,000

Dielectric Constants

Table 1. Dielectric constants of different materials.

Material	Dielectric Constant (K)
Air	1
Alumina	10
Ta_2O_5	27
Nb_2O_5	42
Potassium niobate (KN)	700
Barium titanate (BT)	4000
Modified barium titanate	≈ 10000
Lead magnesium niobate (PMN)	≈ 20000

MATERIAL	K	σ (mS/m)	v (m/ns)	a (dB/m)
Air	1	0	0.30	0
Distilled Water	80	0.01	0.033	2x10-3
Fresh Water	80	0.5	0.033	0.1
Sea Water	80	3x103	.01	103
Dry Sand	3-5	0.01	0.15	0.01
Saturated Sand	20-30	0.1-1.0	0.06	0.03-0.3
Limestone	4-8	0.5-2	0.12	0.4-1
Shales	5-15	1-100	0.09	1-100
Silts	5-30	1-100	0.07	1-100
Clays	5-40	2-1000	0.06	1-300
Granite	4-6	0.01-1	0.13	0.01-1
Dry Salt	5-6	0.01-1	0.13	0.01-1
Ice	3-4	0.01	0.16	0.01

Dielectric constants of some materials
(at room temperature)

material	dielectric constant
vacuum	1 .0
air	1 .0006
oil	2 .2
polyethylene	2 .26
beeswax	2 .8
fused quartz	3 .78
water	80
calcium titanate	168
barium titanate	1,250

Dielectric Constant of Materials

Air	1.00	Paper	3.00
Alsimag 196	5.70	Plexiglass	2.80
Bakelite	4.90	Polyethylene	2.30
Cellulose	3.70	Polystyrene	2.60
Fiber	6.00	Porcelain	5.57
Formica	4.75	Pyrex	4.80
Glass	7.75	Quartz	3.80
Mica	5.40	Steatite	5.80
Mycalex	7.40	Teflon	2.10

DIELECTRIC CONSTANT OF MATERIALS

Air	1.00	Paper	3.00
Alsimag 196	5.70	Plexiglass	2.80
Bakelite	4.90	Polyethylene	2.30
Cellulose	3.70	Polystyrene	2.60
Fiber	6.00	Porcelain	5.57
Formica	4.75	Pyrex	4.80
Glass	7.75	Quartz	3.80
Mica	5.40	Steatite	5.80
Mycalex	7.40	Teflon	2.10

Material	Dielectric	Material	Dielectric
Acrylic (Plexiglass)	2.7 - 4.5	Polyamide	2.5-2.6
Acrylonitrile Butadiene Styrene (ABS)	2.87	Polycarbonate (Lexan®)	2.9-3.0
Acetal resin (Delrin)	3.6	Polyester film (Mylar)	2.83-4.5
Air	1.000585	Polyethylene	2.27-2.5
Alumina	9.3 - 11.5	Polypropylene	2.25
Asbestos	3.0 - 4.8	Polystyrene	2.4-2.6
Bakelite	3.5-5.0	Polyvinyl Chloride (PVC)	2.8-3.4
Beeswax	2.6- 3.0	Porcelain	5.1-6.0
Celluloid	3.3-11	Pyrex Glass	4.3 - 5.0
Epoxy Resin (Cast)	3.6	Quartz	4.2
Formica	3.6 - 6	Rubber Cement	2.7-2.9
FR-4	4.3 - 5.0	Silicon	11.0 - 12.0
Mica	5.4	Silicone Oil	2.2-2.9
Micarta	3.2 - 5.5	Silicone Rubber	3.2-9.8
Neoprene	6-9	Silk	2.5-3.5
Nylon	4.0 - 5.0	Styrene (ABS)	2.8
Paper (clean)	3.0	Teflon (PTFE)	2.1
Paraffin Wax	2.1-2.5	Teflon (glass weave)	2.2-2.8
Phenol resin	4.9	Water (Distilled)	76.5 - 80
		Wax	2.4-6.5

How to make Capacitors

(12/24/2016)

Material	Dielectric constant (Approx.)	Material	Dielectric constant (Approx.)
Air	1.0	Lucite	2.5
Amber	2.6-2.7	Mica (electrical)	4.0-9.0
Asbestos Fiber	3.1-4.8	Mica (clear India)	7.5
Bakelite (asbestos base)	5.0-22	Mica (filled phenolic)	4.2-5.2
Bakelite (mica filled)	4.5-4.8	Micaglass (titanium dioxide)	9.0-9.3
Barium Titanate	100-1250	Micanta	3.2-5.5
Beeswax	2.4-2.8	Mycalex	7.3-9.3
Cambric (varnished)	4.0	Neoprene	4.0-6.7
Carbon Tetrachloride	2.17	Nylon	3.4-22.4
Celluloid	4.0	Paper (dry)	1.5-3.0
Cellulose Acetate	2.9-4.5	Paper (coated)	2.5-4.0
Durite	4.7-5.1	Paraffin (solid)	2.0-3.0
Ebonite	2.7	Plexiglas	2.6-3.5
Epoxy Resin	3.4-3.7	Polycarbonate	2.9-3.2
Ethyl Alcohol (absolute)	6.5-25	Polyethylene	2.5
Fiber	5.0	Polyimide	3.4-3.5
Formica	3.6-6.0	Polystyrene	2.4-3.0
Glass (electrical)	3.8-14.5	Porcelain (dry process)	5.0-6.5
Glass (photographic)	7.5	Porcelain (wet process)	5.8-6.5
Glass (Pyrex)	4.6-5.0	Quartz	5.0
Glass (window)	7.6	Quartz (fused)	3.78
Gutta Percha	2.4-2.6	Rubber (hard)	2.0-4.0
Isolantite	6.1	Ruby Mica	5.4
Selenium (amorphous)	6.0	Styrofoam	1.03
Shellac (natural)	2.9-3.9	Teflon	2.1
Silicone (glass) (molding)	3.2-4.7	Titanium Dioxide	100
Silicone (glass) (laminate)	3.7-4.3	Vaseline	2.16
Slate	7.0	Vinylite	2.7-7.5
Soil (dry)	2.4-2.9	Water (distilled)	34-78
Steatite (ceramic)	5.2-6.3	Waxes, mineral	2.2-2.3
Stearite (low loss)	4.4	Wood (dry)	1.4-2.9

Polymer	**Dielectric Constant (low frequency, 50 Hz)**
Polystyrene	2.5
Poly(1-vinyl naphthalene)	2.6
Poly(1-methyl styrene)	2.6
Poly(o-chlorostyrene)	2.6
Poly(vinyl chloride)	2.8
Poly(methyl methacrylate)	2.6
Poly(ethyl methacrylate)	2.7
Poly(2,6-dimethylphenylene oxide)	2.6
Poly(bisphenol carbonate)	2.6
Poly(cis-butadiene)	2.0
Poly(cyclohexyl methacrylate)	2.5
Parylene	2.6

Material	Deposition Method	k	Reporting Companies (Sample Listing)
Fluorinated Silicon Oxide (SiOF)	PE and HDP-CVD	3.3-3.5	AMT, Anelva, Hitachi, Motorola, NEC, Novellus, TI, Toshiba
Hydrogen Silsesquioxane (HSQ)	SOD	3.0	Dow Corning, Hitachi , IBM, Samsung, TI, TSMC, United Semiconductor
Methyl Silsesquioxane (MSQ)	SOD	3.0-3.2	Honeywell, IMEC, Sanyo , UMC United Semiconductor
Black Diamond™	PE-CVD	3.0	Applied Materials
SILK™	SOD	2.7	Dow Chemical
Fluorinated Amorphous Carbon (a-C:F)	HDP-CVD	2.2	AMT, NEC
Benzocyclobutene (BCB)	SOD	2.4-2.7	Lucent , NEC
Polyarylene Ether (PAE)	SOD	2.5-3.0	Honeywell (FLARE™), Schumacher (Velox™), TSMC
Parylene (N and F)	Vapor deposition	2.3 (AF4)	Alpha Metals, RPI, TI
Nanoporous Silica	SOD	1.3-over 2.5	Nanoglass, TI

PE = plasma enhanced, HDP = high-density plasma, SOD = spin-on-dielectric
Source: Dataquest (January 1998)

Product	Dielectric Constant, Dk ε_r @ 10 GHz (Typical)		Dissipation[1] Factor TAN δ @ 10 GHz (Typical)	Thermal[2] Coefficient of ε_r -50°C to 150°C ppm/°C (Typical)	Volume Resistivity Mohm • cm (Typical)	Surface Resistivity Mohm (Typical)	Moisture[4] Absorption D48/50 % (Typical)	Thermal[8] Conductivity W/m/°K (Typical) 80°C ASTM C518
	Process[1]	Design[12]						
RO3003™ PTFE Ceramic	[7] 3.00 ± 0.04	3.00	0.0013	11	10^{12}	10^{11}	0.05	0.50
RO3006™ PTFE Ceramic	6.15 ± 0.15	6.50	0.0020	-160	10^{3}	10^{3}	0.02	0.79
RO3010™ PTFE Ceramic	10.20 ± 0.30	11.20	0.0022	-280	10^{12}	10^{11}	0.05	0.95
RO3035™ PTFE Ceramic	3.50± 0.05	3.60	0.0018	-50° to 10°C: -34 10°C to 150°C: -11	10^{7}	10^{7}	0.08	0.50
RO3203™ PTFE Ceramic Woven Glass Reinforced	[7] 3.02 ± 0.04	3.02	0.0016	-75	10^{7}	10^{7}	0.06	0.48
RO3206™ PTFE Ceramic Woven Glass Reinforced	6.15 ± 0.15	6.60	0.0027	-212	10^{7}	10^{7}	0.05	0.67
RO3210™ PTFE Ceramic Woven Glass Reinforced	10.20 ± 0.50	10.80	0.0027	-459	10^{4}	10^{4}	0.13	0.81
RO4003C™ Hydrocarbon Ceramic	[8] 3.38 ± 0.05	3.55	0.0029	+40	1.7×10^{10}	4.2×10^{9}	0.04	0.71
RO4350B™ Hydrocarbon Ceramic	3.48 ± 0.05	3.66	0.0037	+50	1.2×10^{9}	5.7×10^{9}	0.05	0.69

Material	Constant	Material	Constant
ABS resin pellet	1.5-2.5	hexane	1.9
acetone	19.5	hydrogen cyanide	95.4
acetyl bromide	16.5	hydrogen peroxide	84.2
acrylic resin	2.7-4.5	isobutylamine	4.5
air	1.0	lime, shell	1.2
alcohol, industrial	16-31	marble	8.0-8.5
alcohol, isopropyl	18.3	melamine resin	4.7-10.2
ammonia	15-25	methane liquid	1.7
aniline	5.5-7.8	methanol	33.6
aqueous solutions	50-80	mica, white	4.5-9.6
ash (fly)	1.7	milk, powdered	3.5-4
bakelite	3.6	nitrobenzene	36
barley powder	3.0-4.0	neoprene	6-9
benzene	2.3	nylon	4-5
benzyl acetate	5	oil, for transformer	2.2-2.4
butane	1.4	oil, paraffin	2.2-4.8
cable sealing compound	2.5	oil, peanut	3.0
calcium carbonate	9.1	oil, petroleum	2.1
carbon tetrachloride	2.2	oil, soybean	2.9-3.5
celluloid	3.0	oil, turpentine	2.2
cellulose	3.2-7.5	paint	5-8
cement	1.5-2.1	paraffin	1.9-2.5
cement powder	5-10	paper	1.6-2.6
cereal	3-5	paper, hard	4.5
charcoal	1.2-1.8	paper, oil saturated	4.0
chlorine, liquid	2.0	perspex	3.2-3.5
coke	1.1-2.2	petroleum	2.0-2.2
corn	5-10	phenol	9.9-15
ebonite	2.7-2.9	phenol resin	4.9
epoxy resin	2.5-6	polyacetal (Delrin TM)	3.6
ethanol	24	polyamide (nylon)	2.5
ethyl bromide	4.9	polycarbonate	2.9
ethylene glycol	38.7	polyester resin	2.8-8.1
flour	2.5-3.0	polyethylene	2.3
FreonTM R22,R502 liq.	6.1	polypropylene	2.0-2.3
gasoline	2.2	polystyrene	3.0
glass	3.1-10	polyvinyl chloride resin	2.8-3.1
glass, raw material	2.0-2.5	porcelain	4.4-7
glycerine	47	press board	2-5

TABLE 7-1. Dielectric Constants for Common Materials.

MATERIAL	CONSTANT
Vacuum	1.0000
Air	1.0006
Paraffin paper	2.5 - 3.5
Transformer oil	4
Glass	5 - 10
Mica	3 - 6
Rubber	2.5 - 35
Wood	2.5 - 8
Porcelain	6
Glycerine (15 C)	56
Petroleum	2
Pure water	81

CAPACITOR RATING

Material	Constant	Material	Constant
quartz glass	3.7	Teflon (TM), PCTFE	2.3-2.8
rubber	2.5-35	Teflon (TM), PTFE	2.0
salt	6.0	toluene	2.3
sand	3-5	trichloroethylene	3.4
shellac	2.0-3.8	urea resin	6.2-9.5
silicon dioxide	4.5	urethane	3.2
silicone rubber	3.2-9.8	vaseline	2.2-2.9
silicone varnish	2.8-3.3	water	48-88
styrene resin	2.3-3.4	wax	2.4-6.5
sugar	3.0	wood, dry	2-7
sugar, granulated	1.5-2.2	wood, pressed board	2.0-2.6
sulfur	3.4	wood, wet	10-30
sulfuric acid	84	xylene	2.4

Table 7: Dielectric Constants

SOLIDS

	DIELECTRIC CONSTANT		DIELECTRIC CONSTANT
Acetic Acid	4.1	Phenol	4.3
Asbestos	4.8	Polyethylene	4.5
Asphalt	2.7	Polypropylene	1.5
Bakelite	5.0	Porcelain	5.7
Calcium Carbonate	9.1	Quartz	4.3
Cellulose	3.9	Rubber (Hard)	3.0
Ferrous Oxide	14.2	Sand	3.5
Glass	3.7	Sulphur	3.4
Lead Oxide	25.9	Sugar	3.0
Magnesium Oxide	9.7	Urea	3.5
Naphthalene	2.5	Zinc Sulfide	8.2
Nylon	45.0	Teflon®	2.0
Paper	2.0		

LIQUIDS

	TEMP °F/°C	DIELECTRIC CONSTANT		TEMP °F/°C	DIELECTRIC CONSTANT
Acetone	71/22	21.4	Heptane	68/20	1.9
Ammonia	-27/-33	22.4	Hexane	68/20	1.9
Aniline	32/0	7.8	Hydrogen Chloride	87/28	4.6
Benzene	68/20	2.3	Iodine	224/107	118.0
Benzil	202/94	13.0	Kerosene	70/21	1.8
Bromine	68/20	3.1	Methanol	77/25	33.6
Butane	30/-1	1.4	Methyl Alcohol	68/20	33.1
Carbon Tetrachloride	68/20	2.2	Methyl Ether	78/26	5.0
Castor Oil	60/16	4.7	Mineral Oil	80/27	2.1
Chlorine	32/0	2.0	Naphthalene	68/20	2.5
Chloroform	32/0	5.5	Octane	68/20	2.0
Cumene	68/20	2.4	Pentane	68/20	1.8
Cyclohexane	68/20	2.0	Phenol	118/47	9.9
Dimethylheptane	68/20	1.9	Phosgene	32/0	4.7
Dimethylpentane	68/20	1.9	Propane	32/0	1.6
Dowtherm	70/21	3.3	Pyridine	68/20	12.5
Ethanol	77/25	24.3	Styrene	77/25	2.4
Ethyl Acetate	68/20	6.4	Sulphur	752/400	3.4
Ethyl Benzene	68/20	2.5	Toluene	68/20	2.4
Ethyl Benzene	76/24	3.0	Urethane	74/23	3.2
Ethyl Ether	68/20	4.3	Vinyl Ether	68/20	3.9
Ethylene Chloride	68/20	10.5	Water	32/0	88.0
Formic Acid	60/16	58.5	Water	68/20	80.0
Freon 12	70/21	2.4	Water	212/100	48.0
Glycol	68/20	41.2	Xylene	68/20	2.4

Other usefully tables:

Table 12.3 Table of relative dielectric constants and radiowave velocities for a range of geological and man-made materials

Material	ε_r	V(mm/ns)
Air	1	300
Water (fresh)	81	33
Water (sea)	81	33
Polar snow	1.4–3	194–252
Polar ice	3–3.15	168
Temperate ice	3.2	167
Pure ice	3.2	167
Freshwater lake ice	4	150
Sea ice	2.5–8	78–157
Permafrost	1–8	106–300
Coastal sand (dry)	10	95
Sand (dry)	3–6	120–170
Sand (wet)	25–30	55–60
Silt (wet)	10	95
Clay (wet)	8–15	86–110
Clay soil (dry)	3	173
Marsh	12	86
Agricultural land	15	77
Pastoral land	13	83
Average 'soil'	16	75
Granite	5–8	106–120
Limestone	7–9	100–113
Dolomite	6.8–8	106–115
Basalt (wet)	8	106
Shale (wet)	7	113
Sandstone (wet)	6	112
Coal	4–5	134–150
Quartz	4.3	145
Concrete	6–30	55–112
Asphalt	3–5	134–173
PVC, Epoxy, Polyesters	3	173

Data from Johnson *et al.* (1979), McCann *et al.* (1988), Morey (1974), Reynolds (1990b, 1991b)