

DUPONT™ NOMEX® PAPER TYPE 410

DuPont™ Nomex® paper Type 410 is an insulation paper which offers high inherent dielectric strength, mechanical toughness, flexibility and resilience. Nomex® paper Type 410 is the original form of Nomex® paper, and is widely used in a majority of electrical equipment applications. Available in 11 thicknesses (0.05 to 0.76 mm) (2 to 30 mil), Nomex® paper Type 410 is used in almost every known electrical sheet insulation application.

Electrical Properties

The typical electrical property values for Nomex® paper Type 410 are shown in Table 1. The AC Rapid Rise dielectric strength data of Table 1, representing voltage stress levels, withstood 10 to 20 seconds at a frequency of 60 Hz. These

values differ from long-term strength potential. DuPont recommends that continuous stresses in transformers not exceed 1.6 kV/mm (40 V/mil) to help minimize the risk of partial discharges (corona). The full wave impulse dielectric strength data shown in Table 1 are based on multiple sheets. These values are appropriate for the applications which employ these materials in such configurations. Data based on single sheets of material are available upon request.

The geometry of the system has an effect on the actual impulse strength values of the material. The dielectric strength data are typical values and not recommended for design purposes. Design values can be supplied upon request.

Table 1— Typical Electrical Properties

Nominal Thickness (mil) (mm)	2 0.05	3 0.08	4 0.10	5 0.13	7 0.18	10 0.25	12 0.30	15 0.38	20 0.51	24 0.61	29 0.73	30 0.76
Dielectric strength AC rapid rise ¹ (V/mil) (kV/mm)	460 18	565 22	527 21	715 28	865 34	845 33	870 34	850 33	810 32	810 32	760 30	680 27
Full wave impulse ² (V/mil) (kV/mm)	1000 39	1000 39	864 34	1400 55	1400 55	1600 63	N/A N/A	1400 55	1400 55	N/A N/A	N/A N/A	1250 49
Dielectric Constant ³ at 60 Hz	1.6	1.6	1.8	2.4	2.7	2.7	2.9	3.2	3.4	3.7	3.7	3.7
Dissipation Factor ³ at 60 Hz (x 10 ⁻³)	4	5	6	6	6	6	7	7	7	7	7	7

¹ ASTM D-149 using 50 mm (2 inches) electrodes, rapid rise; corresponds with IEC 60243-1 subclause 9.1 except for electrode set-up of 50 mm (2 inches)

² ASTM D-3426

³ ASTM D-150

Please note:

The properties in this data sheet are typical or average values and should not be used as specification limits. Unless otherwise noted, all properties were measured in air under "standard" conditions (in equilibrium at 23 °C, 50% relative humidity). Note that, like other products of papermaking technology, Nomex® papers have somewhat different properties in the papermaking machine direction (MD) compared to the cross direction (XD). In some applications it may be necessary to orient the paper in the optimum direction to obtain its maximum potential performance.



Nomex.

Temperature has a minor effect on dielectric strength and dielectric constant, as shown in Figure 1.

Variations in frequency up to 10^4 Hz have essentially no effect on the dielectric constant of DuPont™ Nomex® paper Type 410. The effects of temperature and frequency on dissipation factor of dry Nomex® paper Type 410 — 0.25 mm (10 mil) paper are shown in Figure 2. The 60 Hz dissipation factors of thinner papers are essentially the same as those for 0.25 mm (10 mil) at temperatures up to 200 °C. At higher temperatures and frequencies, the thicker papers have somewhat higher dissipation factors than those shown for the 0.25 mm (10 mil).

Surface and Volume Resistivities of dry Nomex® paper Type 410 — 0.25 mm (10 mil) paper are shown in Figure 3 as functions of temperature. The corresponding values for other thicknesses of Nomex® paper Type 410 are very similar.

Figure 1. Effect of Temperature on Electrical Properties — Nomex® Paper Type 410 — 0.25 mm (10 mil)

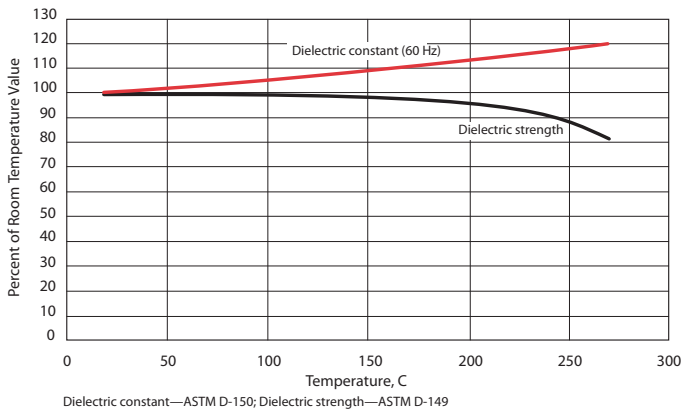
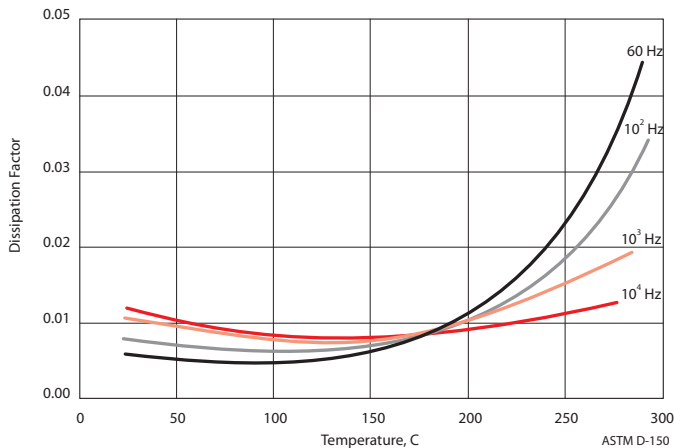


Figure 2. Dissipation Factor versus Temperature and Frequency — Nomex® Paper Type 410 — 0.25 mm (10 mil)



The relatively minor effects of moisture (humidity) on the electrical properties of Nomex® paper Type 410 — 0.25 mm (10 mil) are shown in Table 2.

Like other organic insulating materials, Nomex® paper is gradually eroded under attack by corona discharges. Corona intensity is a function of voltage stress, which, in turn, depends almost entirely on design parameters such as spacing between circuit elements, smooth vs. sharp contours, etc. Although corona does not occur during normal operation of properly designed electrical equipment, any device may be subject to occasional overvoltages which produce brief corona discharges; and it is important that the insulation not fail prematurely under these conditions. The voltage endurance (time to failure under corona attack) of Nomex® paper Type 410 is superior to other commonly used organic insulations and even compares favorably with some inorganic compositions, as shown in Figure 4. These data were obtained in all cases on single layers of 0.25 mm (10 mil) materials at room temperature, 50% relative humidity, and 360 Hz frequency. Times to failure at 50–60 Hz are approximately 6–7 times as long as indicated.

Figure 3. Resistivity versus Temperature — Nomex® Paper Type 410 — 0.25 mm (10 mil)

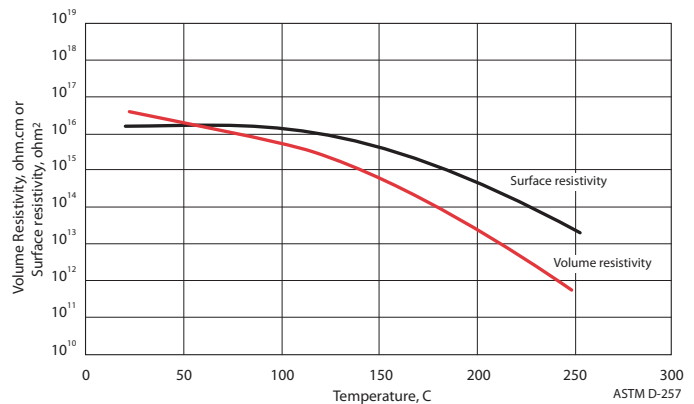


Table 2— Humidity Effects on Electrical Properties — Nomex® Paper Type 410 — 0.25 mm (10 mil)

Relative Humidity, %	Oven Dry	50	96
Dielectric Strength ¹ (V/mil) (kV/mm)	850	815	780
	33.5	32.1	30.7
Dielectric Constant ² at 60 Hz at 1 kHz	2.5	2.7	3.2
	2.3	2.6	3.1
Dissipation Factor ³ at 60 Hz (x 10 ⁻³) at 1 Hz (x 10 ⁻³)	6	6	11
	13	14	25
Volume Resistivity, (ohm.cm)	6 x 10 ¹⁶	2 x 10 ¹⁶	2 x 10 ¹⁴

¹ ASTM D-149 using 50 mm (2 inches) electrodes, rapid rise; corresponds with IEC 60243-1 subclause 9.1 except for electrode set-up of 50 mm (2 inches)

² ASTM D-3426

³ ASTM D-150

Mechanical Properties

The typical mechanical property values for DuPont™ Nomex® paper Type 410 are shown in Table 3. The effects of high temperatures on tensile strength and elongation are illustrated in Figure 5. Nomex® sheet structures also retain good mechanical properties at very low temperatures. At the boiling point of liquid nitrogen (minus 196 °C or 77 K) the tensile strength of Nomex® paper Type 410 — 0.25 mm (10 mil) paper exceeds its room temperature value by 30 to 60% (depending on direction), while elongation to break is still greater than 3% (better than most inorganic materials at room temperature). This allows Nomex® paper Type 410 to work well in cryogenic applications.

The effects of moisture (humidity) on tensile strength and elongation are shown in Figure 6. Like elongation, the tear strength and toughness of Nomex® paper Type 410 are also improved at higher moisture contents.

The dimensions of bone-dry DuPont™ Nomex® paper Type 410 exposed to 95% relative humidity conditions will increase at most 1% in the machine direction and 2% in the cross direction (due to moisture absorption). This swelling is largely reversible when the paper is redried. The rate of change in dimensions will depend, of course, on paper thickness and configuration (for example, individual sheets versus tightly wound rolls). Variations in environmental humidity will usually produce dimensional changes which will be less than 1%.

Figure 4. Voltage Endurance of Various Insulating Materials — Single Layer Nomex® Paper Type 410 — 0.25 mm (10 mil)

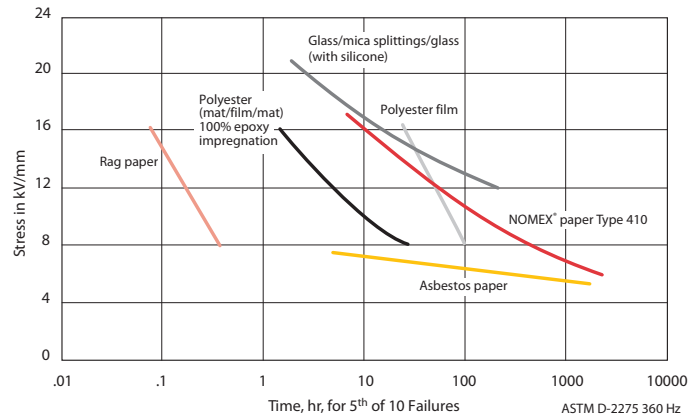


Figure 5. Effect of Temperature on Mechanical Properties — Nomex® Paper Type 410 — 0.25 mm (10 mil)

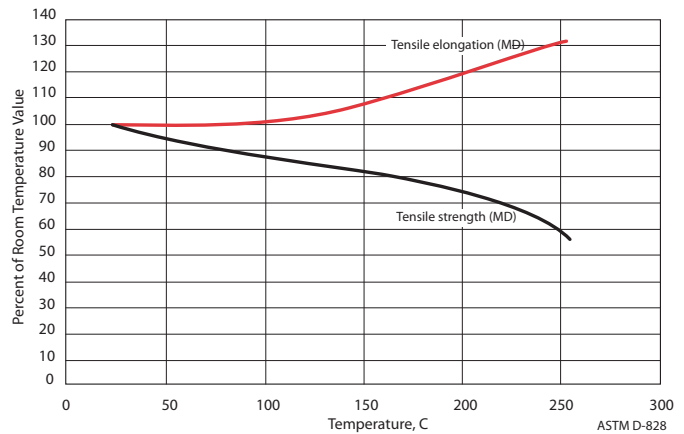


Table 3— Typical Mechanical Properties

Nominal Thickness (mil) (mm)	2	3	4	5	7	10	12	15	20	24	29	30	Test Method
Typical Thickness ¹ (mil) (mm)	2.2 0.06	3.1 0.08	4.2 0.11	5.2 0.13	7.2 0.18	10.2 0.26	12.2 0.31	15.3 0.39	20.4 0.52	24.2 0.61	28.7 0.73	30.6 0.78	ASTM D374
Basis Weight, g/m ²	41	64	88	115	174	249	310	395	549	692	846	839	ASTM D646
Density, g/cc	0.72	0.81	0.83	0.88	0.95	0.96	1.00	1.02	1.06	1.13	1.16	1.08	
Tensile Strength, N/cm													
MD	43	68	93	141	227	296	380	462	610	728	832	816	ASTM D828
XD	19	34	49	71	116	161	208	252	374	500	623	592	
Elongation, %													ASTM D828
MD	9	12	12	16	20	22	23	20	21	18	16	18	
XD	7	9	9	13	15	18	18	16	17	14	13	14	
Elmendorf Tear, N													TAPPI414
MD	0.7	1.2	1.9	2.3	3.7	5.6	7.1	9.0	14.3	N/A	N/A	N/A	
XD	1.5	2.4	4.4	4.8	7.2	10.6	13.7	16.7	24.8	N/A	N/A	N/A	
Initial Tear Strength ² , N													ASTM D1004
MD	11	16	24	31	48	69	88	110	158	191	233	233	
XD	6	9	14	17	27	42	55	71	114	153	193	193	
Shrinkage at 300 °C, %													
MD	1.8	1.1	0.8	0.7	0.6	0.3	0.3	0.2	0.0	0.0	0.0	0.0	
XD	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	

¹ Method D; 17 N/cm²

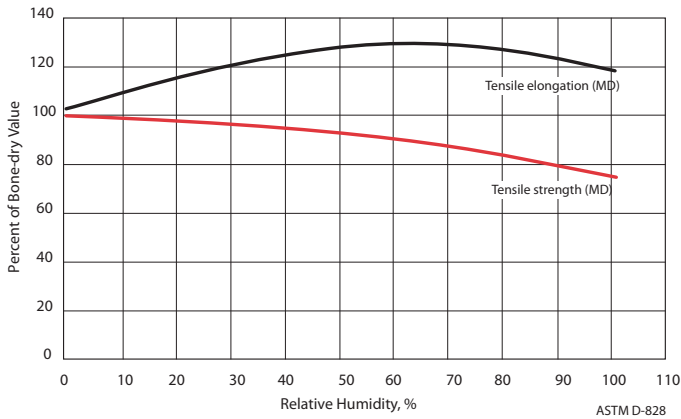
² Data presented for Initial Tear Strength is listed in the direction of the sample per ASTM D-1004.

The tear is 90 degrees to sample direction — hence for papers with a higher reported MD ITR, the paper will be tougher to tear in the cross direction.

MD = machine direction of paper

XD = cross direction of paper

Figure 6. Effect of Moisture on Mechanical Properties — Nomex® Paper Type 410 — 0.25 mm (10 mil)



However, even small dimensional changes, especially if they are non-uniform, can cause or accentuate non-flatness (sag, puckers, etc.) in the sheet, which can cause problems in critical operations like laminating or creping. Therefore, DuPont™ Nomex® paper intended for these applications should be kept sealed in its protective polyethylene wrapper, to maintain uniform moisture content, until just before use.

Thermal Properties

The effects of long-time exposure of DuPont™ Nomex® paper Type 410 — 0.25 mm (10 mil) to high temperature on important electrical and mechanical properties are shown in figures 7, 8 and 9. These Arrhenius plots of aging behavior are the basis for the recognition of Nomex® paper as a 220 °C insulation by Underwriters Laboratories, the U.S. Navy, and others, and are confirmed by more than 40 years' commercial experience. These curves can also be extrapolated to higher temperatures. Measurements show, for example, that Nomex® paper Type 410 will maintain 12 kV/mm (300 V/mil) dielectric strength for several hours at 400 °C, which is the performance predicted by the Arrhenius plot.

The thermal conductivity of DuPont™ Nomex® paper Type 410 — 0.25 mm (10 mil) paper is shown in Figure 10. These values are similar to those for cellulosic papers, and, as with most materials, are primarily determined by specific gravity (density). Therefore, thinner grades of Nomex® paper Type 410 will have slightly lower conductivity, and thicker grades will have higher conductivities, as is seen in Table 4. The total system construction may affect the overall thermal conductivity, therefore, care should be taken in applying individual sheet data to actual situations. For example, two sheet insulations with identical thermal conductivities may have quite different effects on heat transfer from a coil, due to the differences in stiffness or winding tension which affect the spacing between the insulation layers.

Figure 7. Useful Life versus Temperature — Nomex® Paper Type 410 — 0.25 mm (10 mil)

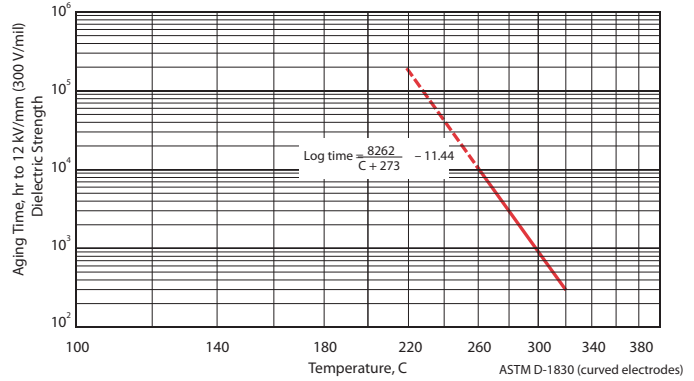


Figure 8. Useful Life versus Temperature — Nomex® Paper Type 410 — 0.25 mm (10 mil)

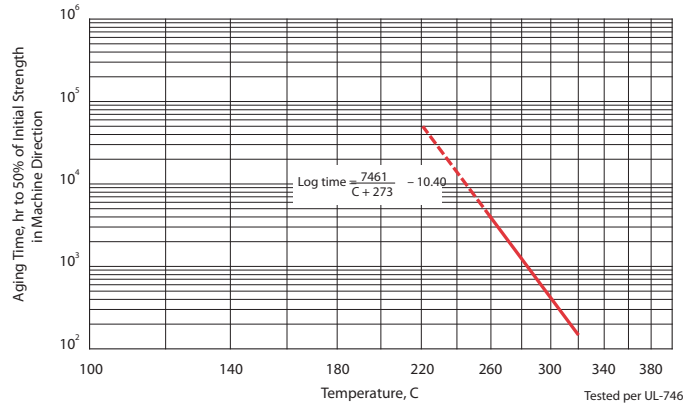
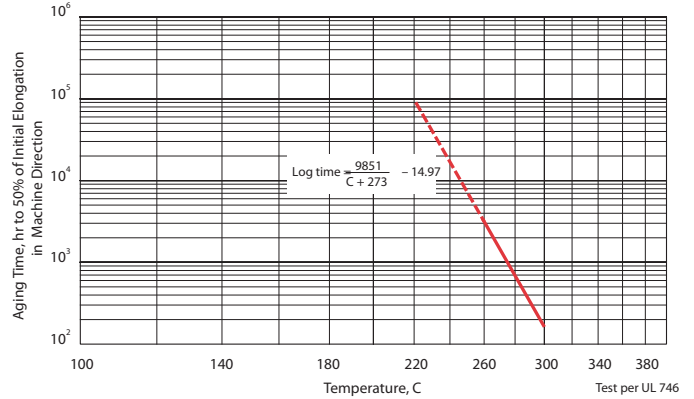


Figure 9. Useful Life versus Temperature — Nomex® Paper Type 410 — 0.25 mm (10 mil)



Chemical Stability

The compatibility of DuPont™ Nomex® paper and pressboard with virtually all classes of electrical varnishes and adhesives (polyimides, silicones, epoxies, polyesters, acrylics, phenolics, synthetic rubbers, etc.), as well as other components of electrical equipment, is demonstrated by the many UL-recognized systems comprising Nomex® as well as longstanding commercial experience. Nomex® papers are also fully compatible (and in commercial use) with transformer fluids (mineral and silicone oils and other synthetics) and with lubricating oils and refrigerants used in hermetic systems. Common industrial solvents (alcohols, ketones, acetone, toluene, xylene) have a slight softening and swelling effect on Nomex® paper Type 410, similar to that of water. These effects are mainly reversible when the solvent is removed.

The Limiting Oxygen Index (LOI) of Nomex® paper Type 410 at room temperature ranges between 27 and 32% (depending on thickness and density), and at 220 °C, from 22 to 25%. Materials with LOI above 20.8% (ambient air) will not support combustion. Nomex® paper Type 410 must be heated between 240 °C and 350 °C (again depending on thickness) before its LOI declines below the flammability threshold. The LOI data for Type 410 — 0.13 mm (5 mil) is shown in Figure 11.

The effect of 6400 megarads (64 Mgy) of 2 MeV beta radiation on the mechanical and electrical properties of Nomex® paper Type 410 is shown in Table 5. (By comparison, a laminate of polyester film and polyester mat of the same thickness, 100% epoxy-impregnated, crumbled after 800 megarads, or 8 Mgy). Similar results were obtained on exposure to gamma radiation. The outstanding radiation resistance of Nomex® paper has led to its use in critical control equipment for nuclear power installations.

Figure 10. Therma; Conductivity versus Temperature — Nomex® Paper Type 410 — 0.25 mm (10 mil)

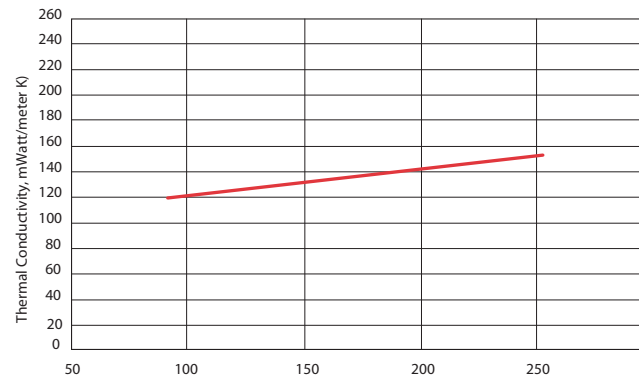


Table 4— Thermal Conductivity

Nominal Thickness (mil) (mm)	2	3	4	5	7	10	15	20	30
	0.05	0.08	0.10	0.13	0.18	0.25	0.38	0.51	0.76
Density, g/cc	0.72	0.81	0.83	0.88	0.95	0.96	1.02	1.06	1.08
Thermal Conductivity, ¹ mWatt/meter K	103	114	117	123	143	139	149	157	175

¹ All data taken at 150 °C

Figure 11. Limiting Oxygen Index (LOI) — Nomex® Paper Type 410 — 0.25 mm (10 mil)

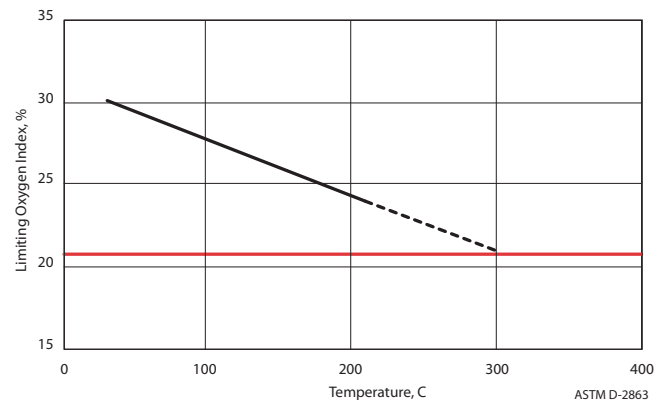


Table 5— Radiation Resistance to 2 MEV Electrons (Beta Rays) — Nomex® Paper Type 410 — 0.25 mm (10 mil)

(Mgy) Dose	0	1	2	4	8	16	32	64
Tensile Strength ¹ , % of original								
MD	100	96	100	100	94	87	81	65
XD	100	100	99	99	97	86	81	69
Elongation ¹ , % of original								
MD	100	89	92	96	76	60	36	18
XD	100	92	91	88	82	47	27	16
Dielectric Strength ² , kV/mm	34	34	33	33	33	34	35	31
Dielectric Constant ³								
60 Hz	3.1	3.0	3.0	3.0	3.0	3.1	2.3	2.5
1 kHz	3.0	3.0	2.9	3.0	2.9	3.1	2.3	2.5
10 kHz	2.9	2.9	2.9	2.9	2.8	3.0	2.2	2.4
Dielectric Factor ³ (x 10 ⁻³)								
60 Hz	8	14	10	12	9	14	7	10
1 kHz	13	16	15	16	13	16	11	13
10 kHz	18	21	20	20	19	20	15	17

¹ ASTM D-828

² ASTM D-149 with a 6.4 mm (1.4 inches) diameter electrode

³ ASTM D-150

UL ratings

Table 6 shows the UL ratings for the Type 410 papers. Descriptions of the numerical values for each of the UL ratings are detailed in the DuPont brochure entitled "The UL Yellow Card," available from DuPont.

Table 6— UL Ratings

ASTM D374 Thickness (mils)	ASTM D374 Thickness (mm)	UL94 Flame Class	UL746A HWI Rating	UL746A HAI Rating	UL746B RTI Electrical	UL746B RTI Mechanical	UL746A HVTR Rating	UL746A CTI Rating
2	0.05	—	0	3	220	220	3	3
3	0.08	—	0	3	220	220	3	3
4	0.10	V-0	0	3	220	220	3	3
5	0.13	V-0	0	1	220	220	3	3
7	0.18	V-0	0	1	220	220	3	3
10	0.25	V-0	0	0	220	220	3	3
12	0.30	V-0	0	0	220	220	3	3
15	0.38	V-0	0	0	220	220	3	3
20	0.51	V-0	0	0	220	220	3	3
24	0.61	V-0	0	0	220	220	3	3
29	0.74	V-0	0	0	220	220	3	3
30	0.76	V-0	0	0	220	220	3	3

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