

# Encyclopedia of Electrical Insulating Materials

Classification, Synoptic Tables, and Descriptive Sheets

**Revised Edition 1958**

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# Encyclopedia of Electrical Insulating Materials

## Classification, Synoptic Tables, and Descriptive Sheets

Revised Edition 1958

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# Introduction to the Encyclopedia of Insulating Materials

**T**HE CORRECT selection of an insulation material plays a predominant role in the performance and life of an electric machine or apparatus. However, this selection is becoming more and more difficult because of the increasing number of available insulating materials. The technical information available on them is often insufficient for a special application and, all too often, does not allow comparison between different types. Their unfavorable characteristics are usually only hinted at. Quite often, insulating materials which belong to the same class but which differ in their properties, are designated by the same trade name. Further, the engineer who designs and builds an electric machine rarely has the chemical knowledge to predict the behavior of the insulating materials under variable service conditions. He must, in order to make his choice, consult a great number of specialized references.

The object of this encyclopedia is to supply the designer of electric machines and apparatus with a handbook in which he can rapidly find the physical and chemical properties of all the insulating materials suitable for a particular job. He will also find information on the conditions under which they may be used, their behavior in service, and the precautions which must be observed during use.

The encyclopedia includes:

A classification of insulating materials.

Comparative tables and description sheets of insulation groups.

Monographs describing the properties of insulating materials.

## Classification

Different classification methods were considered:

1. A classification based on the chemical constitution of the insulating material. This method was discarded because insulating materials are rarely made of only one constituent and because the chemical terminology is not well known to the manufacturers.
2. A classification based on the main constituent, such as mica, a synthetic resin, a varnish, etc. This type of classification, the most widely accepted today, was not retained because it would force the design engineer to search for the product suitable for his application in different classes.
3. A classification based on the end use of the insulating material, such as slot insulation, insulation between the plates of capacitors, impregnating varnishes, etc. This system was discarded because the same insulation can be used for several applications.
4. A classification based on one predetermined property, e.g. thermal stability. However, this method has the inconvenience of requiring a classification within each group of insulating materials presenting the same property.

The classification which was adopted in this encyclopedia is based on practical considerations, namely:

1. The final state of the insulation in the machine (gaseous, liquid, solid).
2. The end use of the insulation (coating, varnishing, etc.).
3. The transformation which the insulation undergoes during application.
4. Certain characteristics which influence its use such as the auxiliary compounds contained in the insulation (solvents, pigments).
5. The state and the form of the insulation at the moment of its application.




Table 1 shows schematically the main factors on which the classification is based. Table 2 presents this classification in a simplified form and indicates the numbering of the insulation groups.

The insulating materials in the same group have this in common: They have the same final state and final form, they are used in the same way, and they undergo the same transformation during application. Two compounds of identical chemical structure, one solid and the other liquid, are in two different groups, since they are not used in the same manner. On the other hand, two insulating materials with greatly different chemical structures are in the same group if they can be used in the same manner for the same purpose.

## Comparative Tables and Descriptive Sheets of Groups

The groups contain a score of insulating materials, sometimes more. It has been judged advantageous to present their general properties and the characteristics which distinguish them in such a way as to allow a first choice in a very short time. This is the purpose of the *comparative tables*. They provide data on the general properties of the insulating materials of the group, on their manner of use, on the precautions to be observed, and on their manufacture to the extent that this influences their properties. Moreover they present, in the majority of cases with the aid of graphic symbols, the specific characteristics of each insulating material of the group.

The following symbols have been adopted:

-  means poor or unfavorable (some exceptions are indicated in the table)\*
-  means excellent or very favorable
-  the black segment indicates the minimum characteristics attained for all the insulating materials sold under the same name, and the grey segment those obtained with special qualities, generally to the detriment of other properties. The grey segment thus gives, for a product of ordinary quality, the variation of the characteristics attributable to the choice of the raw material, to the mixture chosen, and to the manufacturing process. It gives also the variation due to the application and to the type of use.

\* In the case of temperature coefficient, "poor" means a high coefficient and "good" means a low coefficient.

The symbols enable a *comparison* to be made between the behavior in service of the insulating materials in the same group or of two different groups. They do not aim at giving in a graphic form exact numerical values and cannot be used as the basis for design calculations in manufacturing. However, in order to supply an order of magnitude and to allow a comparison between tables, the limiting values corresponding to the symbols ○ and ● have been indicated at the bottom of each table; and intermediate values are represented by full or shaded sectors. Logarithmic scales and standard numbers have been adopted. Appendix 1 gives the numerical values corresponding to each of the different sectors.

In many cases, especially for resilience, arc resistance or resistance to electric discharge, chemical agents, etc., no limiting numerical values have been indicated, because conventional measurement methods do not provide a certain basis for the behavior of the insulation in service, and thus could give rise to false interpretation.

Not all the comparative tables are drawn up in the same way. Above all, an effort was made to give to each of them a practical value. Only the properties which really characterize the insulating materials of the group have been described. Certain properties must be interpreted cautiously, because they depend on the method of measurement. Electric strength, for example, varies greatly with the shape and the size of the test piece, the position and the size of the electrodes, the duration of the test, the ambient conditions, etc. Therefore the symbols adopted do not allow prediction of the behavior of the insulating material in the electric machine.

In some cases it has not been possible to present the characteristics of the insulating materials of a group in a comparative table. Then a "Descriptive Sheet" is provided, which describes the insulating materials of a group in the form of a text.

The comparative tables and the descriptive sheets give data needed for making a first choice. However, they do not contain all the facts about an insulating compound that would be of use in applying it to best advantage. This information will be included in the monographs.

### Monographs

The purpose of the monographs, which are at present in preparation, is to supply detailed data necessary for correct use of the different insulating

compounds. The monographs will contain four distinct parts:

1. General data on the constitution, manufacture, commercial form, properties, and applications of the insulating materials.
2. Physical and chemical characteristics.
3. Service experience with the insulation.
4. Bibliographical source.

It is premature to say what their exact form will be. The preparation of the monographs will take several years.

The comparative tables and the descriptive sheets cover those insulating materials which have already found extensive application in electric apparatus; Appendix 2 lists them alphabetically. The list will be revised periodically, in order to introduce new insulation materials and to incorporate the results of the latest experience.

The commercial names of insulating materials have not been given in the tables and descriptive sheets, and they probably will not be in the monographs, in order not to favor any manufacturer. An exception has been made when the commercial name has practically replaced all other designations in the current language; for example, Nylon and Thiokol. It is possible that, in order to facilitate the use of the Encyclopedia, it will be necessary to establish in each country an alphabetical list of commercial names of the main insulating materials. It would have to be constantly revised and kept up to date.

**Note:** The comparative tables presented in this first part of the Encyclopedia have been prepared on the basis of data on file with Technical Committee 15, Insulating Materials, of the Swiss Electrotechnical Committee (CES). Very complete in some areas, much less so in others, they contain some important contradictions, due in part to different methods of investigation.

It is possible that some graphical symbols or numerical values given in the tables do not correspond with the reader's experience. He may also have successfully used insulating materials which are not mentioned in the Encyclopedia.

Technical Committee 15 of CES would be particularly happy to be informed of all errors found in the tables and will gratefully accept all suggestions tending to make the Encyclopedia an indispensable manual for the designer of electric equipment. Suggestions should be addressed to:

Comité Technique 15, Comité Electrotechnique Suisse, 301 Seefeldstrasse, Zurich 8, Switzerland

or to:

Subcommittee on Technical Information, Electrical Insulation Committee, American Institute of Electrical Engineers, 345 East 47th Street, New York 17, N. Y., U. S. A.

**Table No. 1**  
**Classification of Electrical Insulation**

Final State of the Insulation	Transformation Undergone by the Insulation During Application		Auxiliary Substance Contained in the Insulation	State or Form of the Insulation When Applied	Description of the Insulation Group
Gases					Gases and vapors
Liquids					Liquid insulation
Solids	No physical or chemical transformation during their application			Without definite form	Formable substances, powders, flocs, fibers
				Filiform	Threads (filaments) and cords, impregnated or not
				Sheet	Films, sheets, papers, fabrics, laminated sheets, etc.
				—	Ceramics, molded objects, elastomers, laminates
	Insulation for winding or stacking, followed by bonding of the layers with a physical or chemical transformation during application	Bonding with a cold adhesive	Without solvent	Sheet	Adhesive tapes and sheets
		Bonding with a heated adhesive	Without solvent	Sheet	Heat bonding tapes and sheets
			With solvent	Sheet	Micaceous products containing a solvent
		Bonding by fusion	Without solvent	Sheet	Weldable fibers and sheets
	Insulation for filling, varnishing, coating or bonding, solidified by a physical or chemical transformation during application	Solidified by physical transformation (congealing, evaporation of a solvent or gellation)	Without solvent	Liquid when hot	Fusible insulating substances
			With solvent	Liquid when cold	Insulating varnishes drying by solvent evaporation
			Without solvent	Liquid when cold	Plastisols
		Solidified by chemical reaction (polymerization, polycondensation or polyaddition)	Without solvent	Liquid, cold or hot	Thermosetting resins for casting or impregnation
				Solid without definite form	Thermosetting mastics without solvent
		Solidified by physical and chemical transformation (evaporation of a solvent, oxidation, polymerization, polycondensation or polyaddition)	With solvent	Liquid when cold	Varnish insulation drying by physical and chemical transformation
Solid without definite form	Thermosetting mastics with a solvent				

**Table No. 2**  
**Classification of Electrical Insulation and Numerical Notation of the Groups**

1 Gaseous Insulation		111 Gases and vapors
2 Liquid Insulation		211 Liquid insulating materials
3 Solid insulation of all forms not undergoing a transformation during their application	31 Insulation without definite form	311 Formable soft masses 312 Powders, flakes, fibers
	32 Solid filiform insulation	321 Threads and twines 322 Impregnated threads and twines
	33 Solid insulation—sheet form	331 Inorganic sheet insulation (micas) 332 Films and sheets 333 Papers, cardboards, and similar products 334 Fabrics and similar products 335 Papers and cloths, impregnated or coated (largely in the form of tapes) 336 Laminated sheet insulation (slot insulation, etc.)
	34 Solid insulation—nonlaminated bodies	341 Inorganic insulation (ceramics, glasses, quartz, etc.) 342 Thermosetting molded insulation 343 Thermoplastic molded insulation 344 Elastomers (vulcanized rubber, etc.) 345 Other nonlaminated insulating materials
	35 Solid insulation—laminated bodies	351 Laminates
	4 Solid sheet insulation for winding or stacking followed by a bonding of superimposed layers. (The insulations of Groups 411–431 are, for this purpose, covered with a binder)	41 Solid sheet insulation bonded when cold (with a pressure sensitive adhesive)
42 Solid insulation bonded with heat		421 Films bonded with heat 422 Papers and fabrics bonded with heat 423 Laminated sheets bonded with heat (principally mica products)
43 Solid sheet insulation bonded with heat, the adhesive containing a solvent		431 Sheet laminates containing solvents (principally mica products)
44 Solid sheet insulation bonded by simple fusion		441 Films and sheets bonded by simple fusion
45 Sheet insulation bonded by fusion and chemical reaction		451 Films and sheets bonded by fusion and chemical reaction
5 Insulation which is solid in the final state but applied in the form of a liquid or paste, for filling, varnishing, coating or bonding	51 Insulation solidified by physical transformation (congealing, evaporation of a solvent or gellation)	511 Fusible insulating materials, without filler, liquefiable by heating 512 Fusible insulating materials, with filler, liquefiable by heating 513 Nonpigmented insulating varnishes dried by evaporation of a solvent 514 Pigmented insulating lacquers, dried by solvent evaporation 515 Plastisols and organosols 516 Adhesives and mastics, dried by evaporation of a solvent
	52 Insulation solidified by chemical reaction (polymerization, polycondensation or polyaddition)	521 Thermosetting resins, without solvent, nonpigmented, for casting or impregnation 522 Thermosetting resins, without solvent, pigmented, for casting or impregnation 523 Paste materials, hardenable, without solvent (mastics and cements)
	53 Insulation solidified by physical and chemical change (evaporation of a solvent, followed by oxidation, polymerization, polycondensation or polyaddition)	531 Insulating varnishes for the impregnation of coils and protection of apparatus, nonpigmented, dried by solvent evaporation and chemical processes 532 Pigmented insulating varnishes dried by solvent evaporation and chemical processes 533 Insulating varnishes for the coating of electrical conductors 534 Adhesives and mastics dried by evaporation of a solvent and chemical processes

## Group 111: Gases and Vapors

Gases and vapors occupy a special place among insulating materials because of their low dielectric constant, the practically complete absence of dielectric losses, and their ability to regain their insulating capability rapidly and completely after a discharge. Because the elementary processes in a gas discharge have been thoroughly investigated, the phenomena occurring therein can, to a certain extent, be analyzed and predicted mathematically.

In general, the following statements apply:

1. For all technical applications the relative dielectric constant of all gases may be assumed with sufficient accuracy to be 1.

2. Volume insulation resistance and dielectric losses are negligible for all frequencies provided that neither in the gas, nor at the electrodes, nor at localized spots electric charge carriers are created in significant numbers (e.g., by corona discharges at points of high field concentration, high temperature, heavy radioactivity, or radiation of short wavelength).

3. Because of the comparatively rapid establishment of changes in the electrical condition the initiation of the discharge depends not only on the peak value of the voltage applied, but also on the rate of voltage rise.

4. Only in a nearly uniform field (such as between parallel plates with rounded edges or between two spheres close to each other) does the spark develop without preliminary discharges. In a highly distorted field, the spark is preceded by a preliminary discharge which sometimes develops in several steps. According to its appearance and the electrode configuration, glow, corona, and brush-, spraybrush-, or stem-discharge are to be distinguished.

5. Even when all external influences are maintained constant, the voltage required for setting up a discharge is not always the same but is subject to fluctuations because of the statistical nature of the elementary processes on which the discharge depends. For most of the arrangements the corona and the breakdown voltage are quite reproducible. As a rule, the standard deviation is less than 5%. Sometimes it will be desirable not to refer to a breakdown voltage, but instead, for instance, to a value 10% less or, synonymously, to a 90% proof-voltage.

6. The mean voltage, for the initiation of a discharge, depends mainly on the chemical constitution of the gas, on its pressure, on its temperature, and on the shape of the electrodes, and, at certain gas pressures, also on the electrode material. In a nearly uniform field, for example between plates with well-rounded edges or spheres spaced at less than one third the radius, the breakdown voltage is directly proportional to the pressure and the electrode spacing. This holds good for small variations of the pressure close to atmospheric pressure when the other conditions remain unchanged. These relations are more exactly expressed by "Paschen's Law" which states that the breakdown voltage in geometrically

similar arrangements is a function of the product: gas density times electrode spacing. The curves in Fig. 1 give the peak values of the breakdown voltage  $U_d$  in a homogeneous field as a function of electrode spacing times relative gas density.

The relative gas density  $d/d_0$  can be calculated from the known gas laws. For ideal gases, i.e., sufficiently distanced from the condensation point or the critical point, the following equation holds good to a sufficient approximation:

$$\frac{d}{d_0} = \frac{p}{P_0} \frac{273}{273 + t}$$

$$d_0 = \frac{M}{22.4} \left[ \frac{g}{l} \right]$$

(For the symbols, units, and numerical values see the comparative table of group 111.) The following formula can give an approximation in the vicinity of the condensation limit, i.e., for

$$\frac{p}{p_k} \gtrsim 1,000 e^{-6.9 \frac{t+273}{t_k+273}}$$

$$\frac{d^3}{d_k^3} - \frac{3d^2}{d_k^2} + \frac{1}{3} \frac{d}{d_k} \left( \frac{p}{p_k} + 8 \frac{t}{t_k} + \frac{273}{273} \right) - \frac{p}{p_k} = 0$$

7. The calculation of the breakdown field strength, on the basis of the values given in Fig. 1, is subject to some restrictions, mainly at the extreme limits: at very small electrode spacings, very low or very high pressures, high local temperature, very steep voltage gradient, floating impurities, or with certain gas mixtures.

8. A magnetic field does not influence the breakdown voltage except at a very low gas pressure, with great average free-path lengths of molecules.

9. When electric discharges occur, there exists the risk of decomposition of the gas molecules. Under the continuous influence of glow discharge in air, ozone and nitric oxides are formed. In a heavy arc column with very high temperatures the chemical reactions are still more violent. The products formed can have a strongly corrosive effect on adjacent insulation or metal parts.

10. The time required for the re-establishment of the insulation strength following a discharge depends, at high pressure and heavy current, primarily on the dissipation of heat. At low gas pressures, it is mainly dependent on the rate at which the charge carriers recombine, as well as on the decomposition of the metastable products.

11. The heat conductivity,  $\lambda$ , can be considered as independent of the pressure and it varies very little with temperature. A sufficient approximation for the temperature variation is given by:

$$\lambda_t = \lambda_0 (1 + 0.0018t)$$

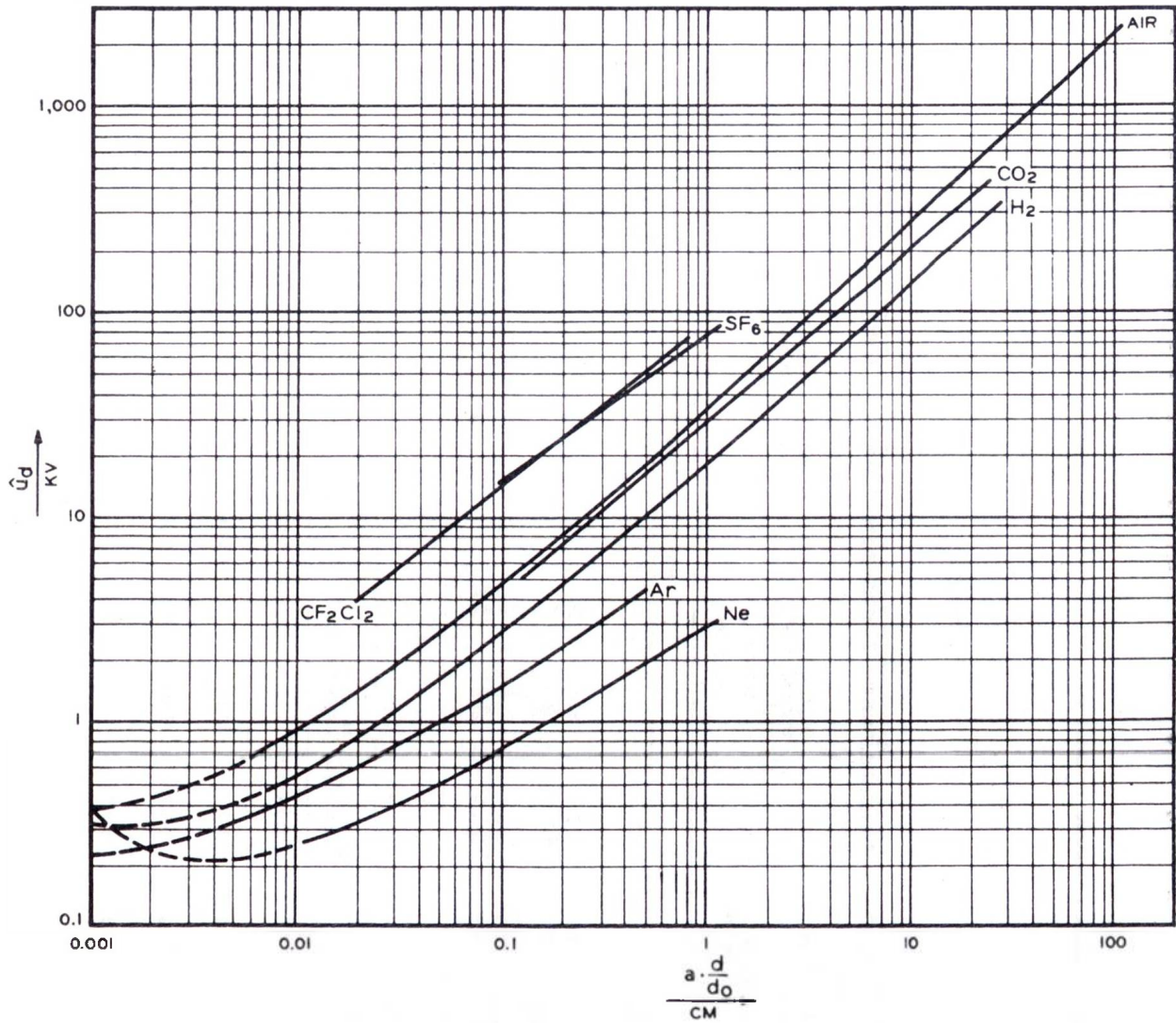
This law is valid if the electrode spacing,  $d$ , is a large multiple of the molecular free path, i.e., if  $(d/d_0) a \gg 0.001$  cm.



12. The specific heat of a perfect gas is practically independent of the pressure and temperature; but it increases as the gas approaches the condensation point.

## Bibliography

1. DER ELEKTRISCHE DURCHSCHLAG VON GASEN, B. Ganger. Julius Springer, Berlin, Germany.
2. ELECTRICAL BREAKDOWN OF GASES, Meek, Craggs. Clarendon Press, London, England, 1953.



Value of the crest breakdown voltage  $\hat{U}_d$  as a function of the product of the electrode spacing  $a$  and the relative density (g per liter) of the gas

SEC/TC 15

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## Electrical Insulating Materials

### Synoptic Table for Group 111 Gases and Vapors

The general properties of the gaseous insulation of this group are given in the attached descriptive sheet for Group 111.

Symbols:

$d$  gas density  
 $p$  pressure  
 $V$  volume  
 $\theta$  temperature  
 $c$  specific heat

Subscripts:

$\lambda$  heat conductivity  
 $A_i$  energy of ionization  
 $U_d$  breakdown voltage  
 $a$  electrode spacing  
 $E_d = \frac{U_d}{a}$  electric strength

without subscript arbitrary conditions  
0 standard conditions, 0 C, 1 atm.  
K value at the critical point

Designation	Formula	General Characteristics													Precautions in use	Number of the monograph	
		Molecular weight	Normal gas density (1) 0 C, 1 atm.	Density relative to air = 1	Specific heat at constant pressure $10^3 \frac{J}{kg \times deg C}$	Specific heat at constant volume $10^3 \frac{J}{kg \times deg C}$	Ratio of specific heats	Heat conductivity (1) 0 C, 1 atm. $\frac{W}{m \times deg C}$	Critical temperature deg C	Critical pressure at (1)	Gas density at the critical point $\frac{g}{liter}$	Energy of ionization ev	Electric strength 0 C, 1 atm, 1 cm spacing kv cm	Toxicity (8)			Danger of corrosion after discharge (8)
Symbol		$M$	$d_0$	$\rho$	$c_p$	$c_v$	$\frac{c_p}{c_v}$	$\lambda$	$\theta_c$	$p_c$	$d_c$	$A_i$	$E_{40}$	(8)	(8)		
Unit		$\frac{g}{mole}$	$\frac{g}{liter}$	...	$10^3 \frac{J}{kg \times deg C}$	$10^3 \frac{J}{kg \times deg C}$	..	$\frac{W}{m \times deg C}$	deg C	at (1)	$\frac{g}{liter}$	ev	kv cm				
Air		(28.96)	1.251	1	1.005	0.717	1.401	0.0236	(-140.7)	38.4	(310)		32	●	●	●	●
Hydrogen	H <sub>2</sub>	2.016	0.0869	0.06952	14.22	10.10	1.408	0.165	-239.9	13.2	31.02	15.43	19	○	○	○	○
Nitrogen	N <sub>2</sub>	28.02	1.210	0.9672	1.042	0.740	1.405	0.02425	-147.2	34.6	311.0	14.48	33	●	●	●	●
Oxygen	O <sub>2</sub>	32.00	1.381	1.103	0.907	0.648	1.402	0.023	-118.8	51.35	430		29	●	●	●	●
Carbon dioxide	CO <sub>2</sub>	44.01	1.912	1.529	0.832	0.639	1.301	0.01435	31.0	75.3	460	13.73	29	●	●	●	●
Helium	He	4.003	0.1727	0.1380	5.265	3.215	1.66	0.1415	-267.9	2.337	69.3	34.48	10	●	●	●	●
Neon	Ne	20.18	0.871	0.6964	1.028	0.627	1.64	0.0455	-228.7	27.77	483.5	21.47	2.9	●	●	○	○

Argon	Ar	39.94	1.726	1.380	0.524	0.314	1.668	0.0163	-122.4	49.6	530.8	15.68	6.5						
Krypton	Kr	83.80	3.59	2.868	0.251 <sup>(6)</sup>	0.150 <sup>(6)</sup>	1.689	0.00873	-62.6	56.1	909	13.94	8						
Water vapor	H <sub>2</sub> O	18.016	0.779 <sup>(6)</sup>	0.622 <sup>(6)</sup>	2.005 <sup>(7)</sup>	1.503 <sup>(7)</sup>	1.324 <sup>(7)</sup>		374.0	226	400		~30						
Sulfur hexafluoride	SF <sub>6</sub>	146.1	5.39	5.106	0.618	0.560	1.104		45.55	38.35	751.7	19.3	~80						
Tetrafluoromethane	CF <sub>4</sub>	88.01	3.812	3.047	0.652	0.531	1.228		-45.50	38.15		17.8	~40						
Trifluorochloromethane	CF <sub>3</sub> Cl	104.5	4.15 <sup>(4)</sup> 4.515 <sup>(6)</sup>	3.318 <sup>(4)</sup>	0.617	0.533	1.158		28.78	39.5	581								
Difluorodichloromethane	CF <sub>2</sub> Cl <sub>2</sub>	12.9	5.33 <sup>(6)</sup> 5.225	4.262	0.588	0.512	1.149	0.00835	111.5	40.85	557.6	11.7	68						
Trifluoromethane	CHF <sub>3</sub>	70.02	3.465 <sup>(4)</sup> 3.032 <sup>(6)</sup>	2.769 <sup>(4)</sup>	0.726				32.3	52.2	492.6								
Difluorochloromethane	CHF <sub>2</sub> Cl	86.48	3.745 <sup>(6)</sup>	2.993	0.595	0.4925	1.178 <sup>(5)</sup>		96.0	50.3	525								
Hexafluoroethane	C <sub>2</sub> F <sub>6</sub>	138.00	5.982	4.781					19.7			14.3							
Trichloromethane	CHCl <sub>3</sub>	119.39	5.17	4.12 <sup>(6)</sup>	0.605	0.525 <sup>(6)</sup>	1.15		263		516		~120(?)						
Tetrachloromethane	CCl <sub>4</sub>	153.84	6.65 <sup>(6)</sup>	5.31 <sup>(6)</sup>	0.58	0.514 <sup>(6)</sup>	1.13		283.1	46.5	558		~180(?)						
(Trifluoromethyl) sulfur pentafluoride	CF <sub>3</sub> SF <sub>5</sub>	196.1	8.48 <sup>(6)</sup>	6.76 <sup>(6)</sup>									~120(?)						

poor

excellent

dispersion between inferior and better qualities

(5) 47.3 C

(6) theory

(7) 110 C, 1 atm.

(8) The expressions 'poor' and 'excellent' are not applicable to all characteristics of insulations of this group, particularly toxicity and danger of corrosion after discharge.

(1) 1 atm. = 1 kg/cm<sup>2</sup> = 735.5 mm Hg

(2)  $10^3 \frac{\text{J}}{\text{kg} \times \text{deg C}} = 0.2395 \frac{\text{kcal}}{\text{kg} \times \text{deg C}}$

(3)  $1 \frac{\text{W}}{\text{m} \times \text{deg C}} = 0.863 \frac{\text{kcal}}{\text{m} \times \text{h} \times \text{deg C}}$

(4) Conditions uncertain.

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## Electrical Insulating Materials

### Synoptic Table for Group 211

### Liquid Insulating Materials

Type of material	General Characteristics														Precautions in use	Number of the monograph			
	Specific weight (20 C) g/cm <sup>3</sup>	Coefficient of volume expansion (0-100 C) 10 <sup>-4</sup> /deg C	Viscosity (20 C) CP	Variation of viscosity as a function of temperature	Conventional freezing point, deg C	Conventional flash point, deg C	Specific heat (20 C) J/(g deg C)	Heat conductivity (20 C) W/(m deg C)	Volatility	Dielectric constant, $\epsilon'$ (20-100 C)	Resistivity (20-100 C) ohm-cm (2)	Dissipation factor, tan $\delta$ , at 50 cps (20-100 C)	Constancy of the dielectric properties as a function of frequency (2)	Resistance to decomposition in the presence of oxygen (1) (2)			Principal thermal decomposition products	Gas absorption (2)	Action upon solid insulating materials
Mineral oil with low viscosity (for example, transformer oil) (4)	0.85 to 0.90	6.5	15 to 50		< -30	130 to 180	~1.9	~0.16		2.0 to 2.3	10 <sup>10</sup> to 10 <sup>16</sup>	0.01 to 0.000			hydrogen, acetylene, carbon				
Mineral oil with high viscosity (for example, oil for high-voltage terminals)	~0.90	~6.5	1000 to 20000		~0	180 to 250	~1.9	~0.14		2.0 to 2.3	10 <sup>12</sup> to 10 <sup>16</sup>	0.01 to 0.000			hydrogen, acetylene, carbon				
Mineral oil with resins (for example, oil for cables)	0.90 to 0.95	~6.5	200 to 30000			150 to 220	~2.0	~0.14		2.1 to 2.5	10 <sup>12</sup> to 10 <sup>16</sup>	0.01 to 0.000			hydrogen, acetylene, carbon				
Synthetic aliphatic hydrocarbons (for example, polyisobutylene)	~0.90	~6.5	10 to 10000			<130	~2.0	~0.15		2.0 to 2.3	10 <sup>10</sup> to 10 <sup>16</sup>	0.01 to 0.000			hydrogen, acetylene, carbon				
Synthetic aromatic hydrocarbons (for example, alkylated naphthalene or diphenyl)	~0.95	~7	10 to 1000		0 to -30	<130	~1.8	~0.15		2.2 to 2.6	10 <sup>10</sup> to 10 <sup>16</sup>	0.02 to 0.000			hydrogen, acetylene, much carbon				slightly toxic (3)

Chlorinated aromatic hydrocarbons (commercial "askarel's")	~1.5	~7	30 to 30000		-30 to +15	none	~1.2	~0.10		4.5 to 7.0	10 <sup>10</sup> to 10 <sup>15</sup>	0.05 to 0.00		hydrochloric acid			highly corrosive and slightly toxic decomposition products (3)
Fluorinated aliphatic hydrocarbons	~1.8	~7	100 to 30000		-20 to +15	none	~1.1	~0.10		3 to 3.5	10 <sup>10</sup> to 10 <sup>14</sup>	0.05 to 0.00		hydrofluoric acid, fluorine			highly corrosive and slightly toxic decomposition products (3)
Liquid silicones	~0.95	~6.5	10 to 30000		-70 to -30	150 to 300	~1.5	~0.15		2.3 to 2.8	10 <sup>10</sup> to 10 <sup>16</sup>	0.01 to 0.000		hydrogen, colloidal, silica			tendency to gelatinize
Esters with high molecular weight (for example, sebacic and phthalic diesters)	0.95 to 1.3	~6.5	50		-35 to +10	100 to 300	~2.1	~0.15		3.5 to 12	10 <sup>10</sup> to 10 <sup>14</sup>	0.1 to 0.00		hydrogen, water, carbon oxide			impurities in solution very hard to eliminate, sometimes toxic

Numerical values used in the editing of the table (logarithmic scales)  
(should not be used as basis of construction)

	Test method and units	%/deg C	mm Hg at 100 C (5)	Days (7)	(6)	(8)	(9)	(10)
poor		>25	>3	<1	>3000	all	>100	<4
excellent		<1	<0.001	>3000	>3000	none	<4	>3000
dispersion between inferior and better qualities		>25	>3	<1	>3000	all	>100	<4

(1) These properties are unimportant in the case of hermetically sealed installations.

(2) New products of "commercial" purity.

(3) May cause eczema upon prolonged contact with human skin.

(4) Similar oils having high fluidity and somewhat more volatility (viscosity 10 cp at 20 C, flash point about 90 C) are used in circuit breakers operating at low temperature.

(5) Volatility is measured by steam pressure in mm Hg at 100 C on the residue after evaporation of the first 10%.

(6) The behavior of the dielectric properties as a function of the frequency is characterized by resonance frequencies with change in the dielectric constant and maximum dielectric losses.

(7) The aging resistance is determined by the time necessary until the insulating material, heated at 100 C in an open receptacle where the surface of the liquid is ventilated, is chemically transformed so that it can no longer be used for simple insulation.

(8) Measured through the solution or softening of solid organic insulating materials.

(9) No gas absorption and high hydrogen output.

(10) No gas formed.

## Group 211: Liquid Insulating Materials

The expression "liquid insulation" as used here refers to all insulating materials which, at normal service temperatures, form a plane horizontal surface due to their own weight, and do not undergo any significant physical or chemical transformation while being applied. Liquid insulating materials are particularly useful when interstices are to be filled and large amounts of heat are to be transferred through small channels. If solid insulating materials are impregnated with insulating liquids their effectiveness is considerably increased (see also comparative table for group 511). The physical properties of liquid insulating materials, such as density, coefficient of expansion, heat conductivity, specific heat, viscosity, and dielectric constant, are primarily a function of their molecular structure, i.e., of their chemical composition. The dielectric properties, however, are primarily a function of the impurities in suspension or in solution in the liquid introduced during the manufacturing process, in application, or while in service. The electric strength is considerably reduced by minuscule amounts of foreign bodies which are not soluble in the insulating material, e.g., small water droplets or fibers. This applies also if gas bubbles are present, which may form as a result of the electric stress. Therefore, this table does not show a numerical value for electric strength. The electric strength is approximately the same for all liquid insulating materials, and varies between 50 and 300 kv per cm (117 and 760 volts per mil), depending on the degree of purity and the test method. Impurities whose molecules dissociate (such as highly polar decomposition products and acids, and even traces thereof) increase the conductivity and the dielectric losses, especially at low frequency. Another important property affecting the behavior of a liquid as a dielectric for high voltage is its absorption capacity for the gases, principally hydrogen, formed at its surface due to electric discharges. This absorption capacity for gases depends, to a large degree, upon the aromatic groups (benzene nucleus) present in the liquid. The dielectric losses and conductivity generally increase with temperature and, in the case of liquids with an analogous chemical composition, with their fluidity, which itself is a function of the temperature. The insulating materials listed in this

table are sufficiently stable that they can be stored at a temperature below 50 C in closed containers without undergoing significant changes in their properties, even over a storage period of many years. The decomposition of certain liquid insulating materials is due primarily to the influence of the air. Air leads to an oxidation process which is considerably accelerated by traces of dissolved metals, particularly copper. However, this oxidation may be inhibited by the addition of certain chemical substances. All liquid insulating materials decompose rapidly if considerably overheated or if under the influence of the electric arc. The decomposition products are indicated in the table. The liquid insulating materials can soften or swell certain insulating materials, particularly some organic thermoplastic materials. In this respect, chlorinated or fluorinated liquids are considerably more active than are aliphatic hydrocarbons or silicones. Insulating materials of this group are generally not toxic and do not require special safety measures. The decomposition products of the chlorinated or fluorinated liquids are the exception. The commercially available liquid insulating materials are arranged according to their chemical composition:

*Pure hydrocarbons:* Petroleum and coal-refining products consisting exclusively of carbon and hydrogen. They sometimes contain small amounts of oxidation inhibitors and substances to modify the viscosity, reduce the solidification temperature, or to increase the absorption capacity for gases.

*Chlorinated aromatic hydrocarbons:* Mixture of synthetic products such as trichlorobenzene and pentachlorodiphenyl. They frequently contain stabilizers to act on the hydrochloric acid which may be formed by thermal decomposition.

*Fluorinated aliphatic hydrocarbons:* Polymers of the  $\begin{matrix} \text{R} \\ | \\ \text{—C—} \\ | \\ \text{F} \end{matrix}$  structure, where the radical R is hydrogen, a hydrocarbon, or halogen.

*Silicones:* Polymers of the group  $\begin{matrix} \text{R} \\ | \\ \text{—SiO—} \\ | \\ \text{R} \end{matrix}$ , where the radicals are hydrocarbons.

*Other liquid insulation materials:* Esters and others applicable for special cases. In view of the great number of such materials, the table gives only the extreme values.

## Group 311: Formable Soft Masses

The insulating materials of this group possess no definite shape. They can be easily formed at ordinary temperatures and they maintain the shape into which they have been molded. They generally consist of synthetic resins of suitable consistency or of elastomers devoid of vulcanizing agents. Often fillers (preferably fiber-like, see comparative table of group 312) are added to improve the stability of shape. They also consist of nonvolatile, viscous liquids to which thickening agents have been added. When superimposed layers of soft, moldable materials are compressed, or when they are kneaded together, a homogeneous and compact insulation is obtained from which the distinct layers have disappeared. The insulating materials of this group maintain their consistency during application and use, except for possible modifications due to aging. They contain no volatile materials and cannot change into a rigid mass by solidification, as in the case of the insulating materials of groups 513 and 534. These moldable materials are more or less thermoplastic; that is, they often soften on heating, without becoming liquid as do the insulating compounds of groups 511 and 512. They regain their initial state on cooling.

### Commercial Shapes

These soft, moldable materials are sold in the form of tapes, extruded sections, or in bulk.

### Uses

1. To insulate electric conductors and to protect them against water and certain corrosive agents, especially at connecting terminals and cable splices, etc.
2. To fill interstices.

### Examples of Moldable Materials

1. *Polyisobutylene*. This is often used with fillers such as asbestos in fibers, flakes, or powder, or with mineral fillers such as talc or kaolin. The polymer is characterized by excellent dielectric properties and good resistance to moisture, aqueous solutions, and many solvents. However, the materials based on polyisobutylene dissolve or swell in hot mineral oils.
2. *Elastomers*. These often consist of natural or synthetic rubber with fillers, devoid of vulcanizing agents, sometimes with the addition of phenolic or other types of resins. Their properties depend greatly upon the elastomer used (see comparative table of group 344). Silicone elastomers are characterized by excellent heat resistance.
3. *Mixtures of Mineral Oils or of Other Viscous, Nonvolatile Liquids with Fillers*. These materials generally possess less geometrical stability when heated than do the preceding ones. They are more rigid when cold and more sensitive to solvents.

## Group 312: Powders, Flakes, Fibers

### Definitions

The insulating materials of this group are solid, nonvolatile, and nonadhesive products obtained by pulverizing organic or inorganic materials. Depending on the materials used and the method of pulverizing them, they are in the form of fine or coarse powders, flakes, or fibers. They are called "fillers" if they are finely dispersed in liquid or solid insulating materials.

### Uses

Powders, flakes, and fibers are rarely used as independent insulating materials, that is, in their natural state and "impregnated" with a gaseous insulating material, because they can only detract from the insulating properties of the gas. However, certain powders which have a high thermal capacity, good thermal resistance, and a high vaporization point, may be used as arc extinguishers, for example, in fuses or as fillers in heating tubes.

The light and porous flakes are definitely bad heat conductors because they prevent convection currents.

The powders, flakes, and fibers are sometimes used after impregnation with a liquid insulating material. Their thermal conductivity is increased by the impregnation and very often exceeds that of the liquid impregnating agent when used alone. The dielectric properties of the mixture are the result of complex phenomena which must be studied for each particular case.

Their main application is in the form of an additive to solid insulating materials, in which they are incorporated during manufacture. During application particular attention should be paid to the moisture absorbed by the powders, flakes, and fibers. The moisture is generally not eliminated from the organic medium in which the materials are dispersed and, therefore, reduces considerably the mechanical and dielectric properties of the whole. The moisture has a tendency to cause agglomeration of the particles which makes application difficult.

Combinations of insulating materials of group 312 with insulating materials of other groups are described in the comparative tables and in the description sheets for groups 343, 344, 512, 514, 522, 523, 534, and partially 342. A comparison of these groups shows that the admixture of powders, flakes, and fibers affects not only the application of the insulating material in the liquid state, but also the final properties of the solid insulation.

### Influence on Insulating Material of Other Groups

#### IN APPLICATION

They increase the viscosity of insulating materials which are liquid when applied and solid in their final stage. In sufficient amounts, they form a paste which is sometimes thixotropic and which is then used as a mastic (groups 523 and 534). The coarse, dense, spherical grains with a smooth surface have the least effect on the viscosity. The fine, porous grains with irregular surfaces and the fibers which can intermingle with each other, have the greatest effect.

Fillers reduce *shrinkage* at the moment of solidification, especially if the particles are irregular and if the filler content is high. They reduce the *cost* because the insulating materials of group 312 cost considerably less than the medium in which they are dispersed.

#### IN THE FINAL STATE

They modify the mechanical properties. Hardness and compression resistance are generally higher, whereas resistance to bending and tension are lower, when the fillers are in powder form. They are higher when the fillers consist of fibers.

They change the *dielectric properties* but there is no rule applicable to this case. Those fillers which are fire-resistant and decompose at high temperatures without production of conductive residue increase the resistance to arcing and surface tracking.

Generally they increase the *resistance to chemical agents*, if exposed for a short time. If exposure is prolonged and the surface of the insulation is affected, the deterioration of the insulating material tends to occur rather rapidly.

They modify the thermal properties, particularly the specific heat and the thermal conductivity. Dense and compact fillers, such as quartz powder, improve the properties.

They change the *appearance* by making the insulation material opaque. Some of them have a coloring effect.

The above-mentioned comparative tables and descriptive sheets give all details regarding the effect of the insulating materials of group 312 upon the insulating materials of other groups.

(See page 16 for Group 312 table)



## Group 321: Threads and Twines

This group comprises insulating materials in the form of mono-filaments or threads, twisted threads, twines, etc. They may consist of vegetable, animal, or mineral textile fibers, or of organic or inorganic artificial fibers.

Certain artificial fibers, such as glass or polyanide, are made by starting with a molten material, a filament of which extruded through a die is then solidified. With other fibers such as cellulose acetate, one starts with colloidal solutions from which the solvent is evaporated and which are then solidified after passing through a die.

The molecules of natural and synthetic fibers are more or less oriented in the direction of the fibers. This orientation improves the mechanical resistance of the synthetic fibers. When drawing the filament, it is thus possible to vary considerably the degree

of orientation of the molecules and therewith the mechanical properties of the fibers. The threads can consist of practically continuous filaments (multi-filaments), e.g., silk thread; or of fibers with limited length (staple), e.g., cotton yarn. Continuous filaments give the best mechanical strength. Insulating materials of this group are used to cover electric conductors (winding, braiding), to insulate coils, and for typing. As they are usually not used alone but are combined with impregnating agents, the dielectric properties of the insulation depend primarily on the agent. When multifilaments such as thread, twisted threads, twine, etc., are used alone however, their dielectric properties are important and the fact that they are strongly influenced by lubricants and by other textile products used in their manufacture must be taken into consideration.

*(See page 18 for Group 321 table)*

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**Electrical Insulating Materials**  
**Synoptic Table for Group 312**  
**Powders, Flakes, Fibers**

The general properties of the insulating materials  
of this group are given in description sheet 312.

Type of material	Symbol or chemical composition	General Characteristics										Use additives for groups No.	Precautions in use	Number of the monograph
		Specific weight of the particles in g/cm <sup>3</sup>	Apparent specific weight after packing, g/cm <sup>3</sup>	Heat resistance	Resistance to Chemical Agents		Water absorption	Minimum quantity in dispersing agent	Price comparison					
					Acids	Alkalis								
Quartz powder	SiO <sub>2</sub>	2.6	1.25 to 1.35	●	●	●	●	●	●	100	●	522, 532	may cause silicosis	
Mica powder	Potassium or magnesium silico-aluminate	2.7 to 3.0	0.64 to 0.70	●	●	●	●	●	●	50	●	341, 522, 532		
Kaolin (pure clay)	Aluminum silicate	2.6	0.60 to 0.68	●	●	●	●	●	●	70	●	532, 537		
Talc (1)	Magnesium, aluminum silicate, etc.	2.8	1.50 to 1.55	●	●	●	●	●	●	50	●	341, 522, 532, 537		
Corundum	Al <sub>2</sub> O <sub>3</sub>	4.0	1.10 to 1.20	●	●	●	●	●	●	70	●	532		
Carborundum	SiC	3.1	1.30 to 1.40	●	●	●	●	●	●	60	●	532	degrades the dielectric properties	
Calcium carbonate (chalk)	CaCO <sub>3</sub>	2.6 to 2.9	0.80 to 1.10	●	○	○	○	○	○	70	●	317, 522, 537, 547		
Lithopone	ZnS + BaSO <sub>4</sub>	4.1	1.15 to 1.20	●	○	○	○	○	○	50	●	522, 542		
Zinc white	ZnO	5.5	0.75 to 0.80	●	○	○	○	○	○	60	●	542		
Titanium white	TiO <sub>2</sub>	3.8 to 4.2	0.95 to 0.98	●	○	○	○	○	○	40	●	522, 542		

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Barite (barium sulfate)	BaSO <sub>4</sub>	4.3 to 4.6	2.0	●	●	●	●	●	●	100	522, 537, 542	
Kieselguhr (diatomaceous earth)	SiO <sub>2</sub>	2.6	0.91 to 1.0	●	●	●	●	●	●	20	522, 542	may cause silicosis
Asbestos	Calcium and magnesium silicate	2.6	1.0	●	●	●	●	●	●	20	341, 522	
Lamp black	C	1.9	0.18 to 0.45	●	●	●	●	●	●	5	341	strongly degrades the dielectric properties
Nutshell powder		1.4	0.25 to 0.30	●	●	●	●	●	●	10	341	
Sawdust	Cellulose plus lignin	1.5	0.17 to 0.25	●	●	●	●	●	●	10	341, 532	
Wood cellulose	Cellulose	1.56		●	●	●	●	●	●	10	341	
Cotton linters	Cellulose	1.56		●	●	●	●	●	●	5	341	
Artificial fibers	Organic fibers	1.0 to 1.4		●	●	●	●	●	●	20	341	
Asbestos fibers or flakes	Calcium and magnesium silicate	2.6		●	●	●	●	●	●	15	341, 522, 537, 547	
Glass fibers	Silicates	2.6		●	●	●	●	●	●	20	341, 522	may cause silicosis

		Numerical values used in the editing of the table (logarithmic scales) (should not be used as basis of construction)					
	Test method and units	deg C	Ab-sorption, %				
○ poor	○	<100	>25			>10	
● excellent	●	>1000	<0.2			<0.4	
◐ dispersion between the inferior and better qualities							

- (1) Powdered slate has analogous properties.
- (2) The quantity of water absorbed by the powders, flakes, and fibers considerably affects the properties of the organic insulation materials to which they are added.

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### Electrical Insulating Materials Synoptic Table for Group 321 Threads and Twines

Type of material	General Characteristics													Precautions in use	Number of the monograph						
	Form of the product (1)		Dielectric Properties (2)								Mechanical Properties					Resistance to Chemical Agents					
	Form of the product (1)	Specific weight, g/cm <sup>3</sup>	Volume resistivity	Dissipation factor, tan δ, from 50 to 10 <sup>6</sup> cps	Dielectric constant, ε'	Resistance to electric discharges (effect of corona)	Constancy of the dielectric properties as a function of temperature	Constancy of the dielectric properties as a function of humidity	Tensile strength	Elongation at rupture	Elastic deformation	Modulus of elasticity	Constancy of the mechanical properties as a function of temperature			Maximum operating temperature, deg C (3)	Water	Solvents for impregnation	Mineral oils	Chlorinated dielectrics	Price comparison
Cotton	c	1.5		50 to 10 <sup>6</sup> cps	6									90	☐	☐	☐	☐	☐	Sensitive to fungi	
Acetylated cotton	c	1.3 to 1.44	☐	50 to 10 <sup>6</sup> cps	4 to 5									90 to 105	☐	☐	☐	☐	☐		
Viscose	b, c	1.5			7									90	☐	☐	☐	☐	☐	Sensitive to fungi	
Cellulose acetate	b, c	1.3	☐	50 to 10 <sup>6</sup> cps	3.5 to 6									60 to 105	☐	☐	☐	☐	☐		
Polyethylene	a, b	0.9	☐	50 to 10 <sup>6</sup> cps	2.3									60 to 90	☐	☐	☐	☐	☐		
Polyvinyl chloride	a, b, c	1.4	☐	50 to 10 <sup>6</sup> cps	3 to 6									75 to 90	☐	☐	☐	☐	☐		
Polyvinyl chloroacetate	a, b, c	1.3 to 1.4	☐	50 to 10 <sup>6</sup> cps	3 to 6									60 to 75	☐	☐	☐	☐	☐		
Polyvinylidene chloride	a, b, c	1.7	☐	50 to 10 <sup>6</sup> cps	3 to 5									75 to 90	☐	☐	☐	☐	☐		

Polyacrylnitrile	b, c	1.1 to 1.2	4 to 5									90 to 105										Sensitive to fungi
Polytetrafluoroethylene	a, b	2.2	2									180 to 250										Sensitive to ultra-violet rays
Natural silk	b	1.3	4 to 5									90										Sensitive to ultra-violet rays
Polyamide	a, b, c	1.1	4 to 6									90 to 105										Sensitive to ultra-violet rays
Polyethylene terephthalate	b, c	1.4	3 to 4									90 to 120										
Polyurethane	b, c	1.2	3 to 5									90 to 120										
Glass	b, c	2.4 to 2.6	5 to 6									180 to 300										
Asbestos	c	2.0 to 2.6										200 to 450										

Numerical values used in the editing of the table (logarithmic scale)  
(should not be used as basis of construction)

	Test method and units	ohm-cm	(5) g/den	(6)(7) %	(5)(7) g/den	Absorption, %
poor		$<10^8$	$<0.63$	$<4$	$<10$	$>25$
excellent		$>10^{16}$	$>16$	$>500$	$>90$	$<0.2$
dispersion between inferior and better qualities						

(1) a—monofilaments.

b—multifilaments formed from continuous fibers (for example, silk thread).

c—thread of fibers with limited lengths (for example, cotton yarn).

(2) The statements given in the table with regard to the dielectric properties refer to the fibers as such and not to an insulating material made from those fibers.

(3) The lowest temperature refers to the untreated insulating material, the highest to an insulating material protected against the oxygen of the air by impregnation or immersion.

(4) The losses at high frequencies are higher than at 50 cps.

(5) The unit "denier" in the numerical system for textile filaments represents the weight in grams for 9,000 meters of the filament.

(6) The elastic deformation corresponds to the elastic elongation in percent to the total elongation. The statements in the table refer to elongation of 25% of the rupture elongation of the fiber under consideration. With other elongations, different comparative values are obtained.

(7) The comparative values are based upon tests at 20 C and 65% relative humidity. Rate of increase of the stress 10 g/den/min. Time of stress application 30 sec. Recovery time 60 sec.

(8) For certain types of glass, the resistivity is scarcely over  $10^8$  ohm-cm above 120 C.

## Group 322: Impregnated Threads and Twine

This group comprises the insulating materials of group 321 which have been impregnated with liquid insulating materials (group 211), varnishes (group 513 or 531), or with fusible insulating materials (group 511), which penetrate between the fibers or the fiber groups, fill, or partly fill the interstices, and more or less cover the surface. Impregnated threads and twines are rarely used as primary insulating materials, but are used for lacing, typing, etc.

The properties of the insulating materials of this group are dependent upon the properties of the threads and twines (group 321), and on those of the impregnating agents (groups 513, 531, 511). Com-

pared with the corresponding nonimpregnated insulating materials, they show the following characteristics:

1. The tensile strength is increased because the cohesion between the fibers is increased. Elongation at rupture may be less.
2. Resistance to water and water vapor is generally increased. The impregnating agents do not prevent absorption, but retard it.
3. Resistance to gaseous or liquid chemical substances is increased, as well as the resistance to biological influences (fungi, etc.).
4. Application is easier because flexibility, friction, and abrasion resistance are better.

## Group 331: Inorganic Sheet Insulation (Micas)

This group includes completely inorganic insulating materials in the form of thin, flexible, colorless or colored sheets or flakes, whose thickness ranges from 0.01 mm (0.4 mil) to 0.8 mm (3.2 mils) and whose surface area does not usually exceed 650 square centimeters. These materials are known as micas. Although chemically different, the natural micas, which are practically the only ones used, are all aluminum and potassium silicates, which may contain very appreciable amounts of sodium, iron, magnesium, lithium, or other metals, and sometimes fluorine. Each crystal is composed of lamellar crystal layers. It is this lamellar arrangement which allows the cleavage of mica into the thin mica flakes or sheets constituting this group.

The value of mica depends especially upon its purity and the size of the sheets or flakes, which is standardized internationally in ISO: Recommendation R67, as follows:

As thin mica flakes of a size greater than 3 rarely present an even thickness, their use is limited to particular application, the more so because their price is very high. The principal types of natural micas are: *muscovites* or potassium micas; *phlogopites* or magnesium micas; *biotites* or magnesium-iron micas; *paragonites* or sodium micas; and *lepidolites* or lithium micas. Only the first two have significant use in the electrical industry. Multiple varieties

exist and can be recognized from their external characteristics. The muscovites, for example, comprise two main classes, the ruby and the green micas. The former are harder and have lower electrical losses, especially at high voltages. ISO/TC56 has proposed to divide them into 11 classes: class V-1, which is absolutely clear and possesses the best electrical properties; classes from V-2 to V-6, which are stained to a certain extent but are generally good insulating materials; classes V-7 to V-11, which are badly stained by extraneous substances and must be used with great caution, especially in thin layers and when heat is applied. Phlogopites are grouped into three classes: hard, semihard, and soft.

The general characteristics of the principal micas used in the electrical industry appear in the comparative table. If air is enclosed in the crystals, the dielectric properties, especially the heat losses, may decrease noticeably. Micas are not attacked by atmospheric agents, but water easily penetrates into the crystals. The same thing happens if micas are immersed in oils. The table also gives, for comparison, the characteristics of a synthetic mica which might be used commercially in the near future. Its flakes are generally no larger than the surface area of micas of class 5. Micas are used either in the natural state, as in capacitors, or combined with other insulating materials (groups 335, 423, 431).

ISO Size: Trade Grade:	630 OOEE Special	500 OEE Special	400 EE Special	315 E Special	250 Special	160 1
Surface area of usable rectangle cm <sup>2</sup>	645.2 and above	516.1-645.2	387.1-516.1	309.7-387.1	232.3-309.7	154.8-232.3
in <sup>2</sup>	100 and above	80-100	60-80	48-60	36-48	24-36
Min. length of shorter side cm	10.2	10.2	10.2	10.2	8.9	7.6
in	4	4	4	4	3 1/2	3

ISO Size: Trade Grade:	100	63	40	20	16	06	05
Surface area of usable rectangle cm <sup>2</sup>	96.8-154.8	64.5-96.8	38.7-64.5	19.4-38.7	14.5-19.4	6.4-14.5	4.8-6.4
in <sup>2</sup>	15-24	10-15	6-10	3-6	2.25-3	1-2.25	0.75-1
Min. length of shorter side cm	5.1	5.1	3.8	2.5	2.2	1.9	1.6
in	2	2	1 1/2	1	7/8	3/4	5/8

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Provisional Edition 1958**Electrical Insulating Materials****Synoptic Table for Group 331****Inorganic Sheet Insulation (Micas)**

Designation	Fundamental chemical composition	Appearance	Origin	Physical Properties						Dielectric Properties								Mechanical Properties							Comparative price	Precautions in use	Number of the monograph			
				Density, g/cm <sup>3</sup>	Coefficient of linear expansion, 10 <sup>-6</sup> deg C <sup>-1</sup>	Specific heat, J/kg × deg C × 10 <sup>3</sup>	Heat conductivity, W/m × deg C	(2)	Temperature of decomposition, deg C (1)	Electric strength	Volume resistivity	Dissipation factor, tan δ, at 50 cps	Dielectric constant, ε'	Arc resistance (3)	Constancy of the dielectric properties as a function of temperature (20-450 deg C)	Tensile strength	Compressive strength	Hardness, "Mohs"	Flexibility	Modulus of elasticity	Punchability	Resistance to concentrated acids								
Muscovite (ruby mica, green mica)	Si <sub>3</sub> AlO <sub>10</sub> (OH) <sub>2</sub> Al <sub>2</sub> K	Colorless brown, yellow or greenish transparent	India, USA, Argentina, Africa	2.6 to 3.2	3	0.85	0.4 to 0.6		600	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
Phlogopite (amber mica)	Si <sub>3</sub> AlO <sub>10</sub> (OH) <sub>2</sub> Mg <sub>3</sub> K	Amber white to copperish yellow and deep green, often opaque and rough	Canada, Madagascar	2.6 to 3.2	3	0.85	0.4 to 0.6		850 to 900	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
Fluorophlogopite	Si <sub>3</sub> AlO <sub>10</sub> F <sub>2</sub> Mg <sub>3</sub> K	Colorless, transparent	Chemically synthesized	2.9	2.5 to 3	0.85			1000	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○		

Numerical values used in the editing of the table (logarithmic scale)  
(should not be used as basis of construction)

Test method and units	kv/cm	ohm-cm	kg/cm <sup>2</sup>	kg/cm <sup>2</sup>	10 <sup>8</sup> kg/cm <sup>2</sup>	10 <sup>8</sup> kg/cm <sup>2</sup>
○	<25	<10 <sup>6</sup>	>0.3	<250	<3000	<360
●	>630	>10 <sup>10</sup>	<0.0001	>6300	>27000	>4000

(1) This temperature is characterized by the beginning of the separation of the water of crystallization.

(2) Inclusions of air reduce the heat conductivity greatly.

(3) The resistance to electric discharges is good.

○ poor

● excellent

○ dispersion between inferior and better qualities



## Group 332: Films and Sheets

This group comprises homogeneous, continuous plastic materials, not more than approximately 0.5 mm (20 mils) thick in the case of rigid sheets and about 1 mm (40 mils) in the case of flexible sheets. These sheets can be made: by *casting* (coagulation or evaporation of a thin layer of the solution); *rolling or calendering*; *extrusion* by means of a die plate or annular die, sometimes followed by drawing (for example, blowing); *compression molding*; or *slicing* from blocks. Casting produces sheets approximately 0.01 to 0.2 mm (0.4 to 8 mils) thick and slicing produces sheets approximately 0.01 to 0.2 mm (4 to 12 mils) while heavier sheets are obtained by calendering, extrusion, or compression molding. Subsequent drawing of the sheets leads to a molecular orientation, resulting in a modification of their mechanical properties, e.g., an increase in tensile strength. The drawn sheets are anisotropic, i.e., certain properties, such as tensile strength and rupture elongation, are not identical in all directions. Most thermoplastic products can be made more flexible by

the addition of plasticizers, but this generally has an unfavorable effect on certain mechanical, dielectric, and thermal properties.

The sheets are used as intermediary insulation in electric machines and as covering for conductors and coils. When submitted to electric stresses of short duration, most of the sheets show high electric strength. However, since the resistance of all the sheets to corona discharges is only medium or poor, the electric stress, if prolonged, must be maintained below the limit at which corona starts in the surrounding air. Only in insulations made free of air voids, by completely filling the interstices with solid or liquid insulating material, is it possible to make full use of the exceptional electric strength of insulation sheets. (For this reason it is not possible to give useful comparative values of electric strength in the tables.) Certain thermoplastic films and sheets, mostly applied in the form of tapes, can be fused into a compact mass. These can be found in group 441.

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## Electrical Insulating Materials

### Synoptic Table for Group 332 Films and Sheets

Type of Material	Manufacturing Processes	General Characteristics												Precautions in use	Number of the Monograph				
		Dielectric Properties			Mechanical Properties				Resistance to Chemical Agents			Steam permeability	Weldability (1)			Price comparisons			
		Volume resistivity	Loss index, $\tan \delta$ , from $50$ to $10^6$ cycles	Dielectric constant, $\epsilon'$	Resistance to corona effect	Stability of the dielectric properties as a function of temperature	Stability of the dielectric properties as a function of humidity	Tensile strength	Elongation at rupture	Tearing strength	Stability of the mechanical properties as a function of temperature			Maximum service temperature	Water		Solvents of impregnating varnishes	Mineral oils	Chlorinated dielectrics
Regenerated cellulose	Cast			6.5 to 8								60 to 105						Danger of electrolytic corrosion in the presence of humidity	
Cellulose acetate (primarily diacetate)	Cast, extruded			3 to 7								60 to 105							
Cellulose triacetate	Cast			3.5 to 6								60 to 120							
Cellulose acetobutyrate	Cast, extruded			3.5 to 6								60 to 120							
Ethylcellulose	Cast			3 to 4								55 to 90							
Polyethylene	Calendering, extrusion (blowing)			2.3								60 to 90						Sensitive to sunlight	
Polystyrene	Cast, extrusion			2.2 to 3								60 to 90							



## Group 333: Papers, Cardboards, and Similar Products

### Definition

Papers are thin sheets made of fibers, flock, or small plates of cellulose, artificial plastic materials, asphalt, glass, or mica. Cellulose is by far the most common of the raw materials.

We call papers those sheets whose thickness does not exceed 0.2 mm (0.008 inch) and whose fibers are no longer than about 1 mm (0.040 inch). We call *felts* and *mats* (see Table 334) those items whose fibers are coarser and, above all, longer, and we call *cardboard* the material whose weight is greater than about 200 g/sq m. All intermediate compositions are possible. Cardboards are obtained by pressing together moist thinner sheets, i.e., superimposing thoroughly soaked thin layers. The *electrical pressboards* (presspahn) are cardboards consisting of a very great number of very thin layers, which are pressed at high pressure while they still contain a large quantity of water and then are dried.

### Cellulose Papers

The manufacture of cellulose papers consists of two distinct stages: the transformation of the raw material into a pulp (in this stage cellulose must be separated from accompanying products), followed by the manufacture of a continuous sheet using this pulp. Cellulose constitutes the solid portion of plants; wood contains 40–60%. The accompanying products (lignin, etc.) must be eliminated by solution, and this solution process gives the name to the cellulose. Thus we can distinguish: *sulfite cellulose*, obtained by cooking wood in solutions based on bisulphite, and *sulfate cellulose*, obtained by cooking wood in solutions based on sodium sulfate. Kraft cellulose is a sulfate cellulose. This method of cooking aims at a greater degree of mechanical strength of the cellulose.

A widely spread opinion holds that sulfate celluloses are the best for electrical uses. However, the dielectric properties and the resistance to aging depend less upon the cooking process than upon the impurities contained in the cellulose. Modern washing processes yield insulating papers deriving from both types of cellulose.

Although celluloses can be bleached, only a most cautious treatment will avoid the presence of halogens or electrolytes in the papers and so, until now, non-bleached, or natural, cellulose has been preferred for electrical applications.

In order to transform the raw cellulose into a pulp, it is first ground (refined); that is, the small particles are pulverized and disintegrated in aqueous media. Thus the number of contact points between the now thin and flexible fibers increase. Cellulose swells in water. The attraction forces between the particles of swollen cellulose are very great and are maintained after drying. These are responsible for the strength of the paper, much more so than the mechanical interlacing of the fibers. Cotton waste, for example,

swells much less and so produces papers with a weaker mechanical strength. Paper sheets are fabricated by suspending cellulose fibers in a suitable medium, usually water, followed by deposition onto the screen of special machines. It is then possible to obtain sheets of weights up to 200 g/sq m. Other cellulosic raw materials may be used too.

Wood can be transformed into paper pulp by simple mechanical maceration (ground-wood pulp). The resulting paper, called "wood paper," is not generally used as insulating paper, but is used for newspapers.

Cotton, flax, hemp, and certain grasses can be used for the fabrication of special papers. Cotton is almost always used in the form of cloth waste, old or new, and transformed into rag paper. The quality depends greatly upon the available rags. Rope papers are essentially made from old ropes based on Manilla hemp or from wastes. Among the grasses, esparto grass is the most common (Alfa paper). It gives bulky paper with fine structure.

### Sizing

Sizing is added to papers to improve their physical properties. To do this an aqueous suspension of glue, most often a natural or artificial resin, is added to the pulp. The papers sized with natural resins are inferior electrically as the thermal resistance of these resins often does not exceed 100 C. The synthetic resin adhesives, especially melamine and urea resins, allow the fabrication of wet-strength papers which are, when suitably employed, almost equivalent to non-sized papers from the dielectric point of view. Their water absorption is similar; only tearing when in a moist state is rendered more difficult. The porosity of sized papers is less than that of unsized papers.

### Properties

The sheets which are deposited on the screens of paper or cardboard-making machines present, from the beginning, a certain anisotropy due to the relative motion of the screen and the suspension and to the effect of filtration. It is increased by the contraction and the longitudinal tensions which are the results of drying. The solidity of the sheet increases in the direction of the machine, while the elongation decreases. The contrary is true for the transverse direction. All papers manufactured by machine and many cardboards present this anisotropic character. The latter is noticeably smaller for electrical pressboards, because of the method of fabrication mentioned above.

All papers contain between the fibers a system of *pores*, whose volume ranges from 10 to 60% of the total volume. The pore percentage can be calculated approximately from the ratio between the weight of the paper per unit volume and the specific weight of the fibrous substance. The natural fibers, too, may

contain cavities so small that it is extremely difficult to fill them with impregnating material.

According to the degree of beating (refining) of the fibers, their origin, and the amount of compression of papers and cardboards, the pores between the fibers have a rather variable diameter. The air permeability and the capillarity of the papers may supply some indication as to the size and distribution of the pores.

When insulation consists of a great number of paper layers, it is possible, by avoiding severe compression of the layers, to leave voids between the layers, in addition to the pores of the paper. This is done practically by using crepe paper. The volume of the pores of such insulation is naturally much greater than the pore volume of the paper sheet. By judiciously choosing the nature of the impregnating compound, it is possible to influence strongly the electrical properties of the whole insulation.

The *dielectric properties* of papers and cardboards depend, as far as cellulose is concerned, only partially upon the nature of the raw materials. They are above all determined by the moisture content, the volume of the pores, the additives, and the impurities (electrolytes).

The *electric strength* can only be measured on thin sheets. In thick sheets leakage surface currents are formed which are a function of the geometrical form of the test piece. If the paper is not dry, conduction currents give rise to secondary reactions (vaporization of moisture, heating, and eventually decomposition) which vitiate the measurement.

The *dielectric constant* (permittivity) of cellulose is of the order of 6.6 at 60 cycles. That of cellulosic papers depends upon the fiber content, the voids, and the moisture.

The *dielectric losses and the insulation resistance* vary so greatly as a function of the humidity that they cannot be of any use as a criterion of comparison between papers unless they contain less than 0.01% water. Pure cellulosic papers have, when dry, low losses ( $\tan \delta$ : ca. 0.0009–0.004 at 40 C). The additives and the adhesives are often soluble in the liquid dielectrics whose losses they increase.

Impregnating agents do not prevent absorption of moisture by cellulose; they only retard it.

The *mechanical properties* attain their optimum values when the papers contain neither too much nor too little water. Water plays the role of a plasticizer. It decreases the tensile strength and increases the elongation and resistance to folding. The longitudinal strength is 1.5–5 times greater than the transverse strength, while the elongation is 2–3 times smaller. In applications which require flexing, it is then advantageous for the paper to contain much water and for the folding to be done perpendicularly to the direction of the paper machine.

*Aging* of cellulose is a complex process. It manifests itself in very variable ways, according to the temperature and the presence or absence of deleterious substances. The paper loses flexibility by the evaporation of water (this phenomenon is almost always reversible). With prolonged heating it becomes brittle and it shows a decrease in the average degree of polymerization of cellulose. The salts of

heavy metals with a catalytic effect have an unfavorable influence, especially in the presence of oxygen. Acids, which have been added in the course of the manufacture or which have formed in the liquid dielectric, and the halogens resulting from bleaching, all decrease the stability of the paper. The thermal resistance of cellulosic products allows them to withstand for 10's of years a temperature of about 110 C (when suitably impregnated they withstand 120–130 C). Toward 140 C rapid decomposition takes place, even in vacuo.

In air, the cellulosic products contain 2–12% moisture. Complete drying causes shrinking, which may reach 1% in the direction of the machine, 2% in the transverse direction, and 5% in thickness.

The general properties of cellulosic materials are mentioned in the comparative table of the group. It is incomplete because of the great number of products used as insulating materials.

## Chemical Transformation of Cellulose

In treating paper sheets with sulfuric acid zinc chloride, etc., cellulose is partially transformed into hydrocellulose. The sheets can then be pressed into plates and into sections. These products, known as "vulcanized fibers" (fish paper), have greater resistance to humidity and a much greater mechanical rigidity than does untreated cellulose. The chemical compounds used for the treatment cannot be completely eliminated by washing, so the vulcanized fiber is only useful for limited electrical requirements. Cellulosic fibers can also be esterified, while maintaining their texture unchanged. This method is used to make acetylated paper, in which the hydroxyl groups of the cellulose are partially replaced by acetyl groups. Great purity is obtained, provided the paper is washed with great care after acetylation. The operation becomes difficult when papers are thick and it cannot be done when the weight exceeds 180 g/sq m.

The electrical qualities of the dry fibers can be improved by replacing a portion of the very polar hydroxyl groups with the less polar acetyl groups. On the other hand, moisture absorption is noticeably reduced so that, under equal climatic conditions, partially acetylated fibers absorb less moisture from the air than do untreated cellulose fibers. Among the mechanical properties, only the resistance to tear and to flexing is decreased by esterification. Partially acetylated fibers swell in solvents such as acetone, chlorinated hydrocarbons, and phenol.

Moisture absorption by cellulose can be decreased by other chemical agents or by treatment with synthetic resins, both because they affix themselves to the cellulose where water would, and because they are not hygroscopic.

## Other Papers

As indicated previously, raw materials other than cellulose can be used for the manufacture of papers according to analogous processes. However, the properties are different.

Wholly synthetic organic fibers do not swell in the

same way and to the same degree as cellulose and thus these papers are much weaker, although this property can be improved by the addition of special adhesives (synthetic resins). The electrical properties are less sensitive to changes in moisture.

The papers based on glass or asbestos fibers or on mica flakes are fireproof and are much more thermally stable than are organic papers.

### Other Insulating Materials Based on Papers

Papers are not ordinarily used in electrical manufacturing as independent insulators. They serve, most often, as support for impregnating compounds, as mechanical reinforcement, and as separators.

*Impregnated papers* have properties which are very different from those of raw papers. They constitute insulator group 335. *Laminates* based on paper form insulator groups 336 and 351. *Paper filaments* and *twines* are in insulator groups 321 and 322. If they are *woven*, they appear in insulator group 334.

### Common Terminology

*Vulcanized fibers*: sheets prepared by treating rag paper with zinc chloride. The paper obtained is rolled around a cylinder, cut into plates, treated with a solution of caustic soda, and washed. The plates are then dried and polished. These sheets are often called "fish paper."

*Fish paper*: sheets having a thickness of 0.1–0.3 mm, obtained by treating with zinc chloride, paper, or cardboard rich in cellulose (see also vulcanized fibers).

*Linters*: short fibers found attached to cotton grains after the long fibers used for the fabrication of textiles have been removed. They are removed by means of special procedures and are sometimes used for making paper.

*Alfa paper*: it is also called esparto paper and, in English, "grass paper." The paper is made with the cellulose extract of alfa, Algeria grass, employed either alone or in combination with wood cellulose. The fibers are very fine and produce a regular and bulky paper.

*Sulfite paper*: all paper manufactured entirely or largely with a sulfite cellulose.

*Cable paper*: paper based on sulfate cellulose or Manila hemp. It must have good tensile strength in machine direction (longitudinal direction) and good resistance to tear perpendicularly to that direction (transversally). Other requirements are good thermal resistance, small loss factor, and good electric strength.

*Hemp paper*: paper manufactured mainly with rope waste or similar products (Manila hemp, or possibly jute).

*Linen paper*: paper composed entirely, or for the greater part, of fibers obtained from linen rags.

*Capacitor paper*: paper based on sulfate cellulose. The main properties are chemical purity, even thickness, uniform formation, very low porosity, and low dissipation factor.

*Oiled paper*: incorrect expression indicating "varnished paper." It designates a paper impregnated with varnishes based on drying oils and on resins (see table 335).

*Japan paper*: paper with long fibers, very strong mechanically and of irregular texture. Weight is 75–225 g/sq m. Japan papers are generally unsized (also see "Japan silk paper").

*Kraft paper*: paper entirely based on wood cellulose, manufactured according to a modified sulfate process. Kraft cellulose, without prolonged beating, gives a paper with relatively coarse fibers. The manufacturing procedure produces a paper with good mechanical properties.

*Manila paper*: a general expression to designate papers whose color and appearance are those belonging to papers formerly made with Manila hemp. The expression as used today has no relation to the fibers used.

*Parchment*: paper of pure cellulose, which has been immersed in sulfuric acid, washed, and dried. By this treatment the paper is made grease-proof. Its wet strength is much superior to that of ordinary papers.

*Sulfate papers*: papers manufactured wholly or for the major part with sulfate cellulose (see kraft).

*Japan silk paper*: very light paper manufactured with Kozu fibers (fibers from the bark of the mulberry tree).

*Electrical pressboard*: also called "pressboard," "Fullerboard," etc. Cardboard based on pure cellulose, manufactured by rolling a great number of thin paper layers around a cylinder, and then by pressing them in a moist condition under high pressure. The sheets, with a thickness of 0.5–7 mm (0.020–0.280 inch), are mechanically very strong, even perpendicularly to the layers.

*Rag paper*: more exactly "rag content paper," is a paper containing at least 25% rag fibers. Common contents are 25, 50, 75, and 100%.

*Rope paper*: paper based on Manila hemp.

*Yoshino*: paper of Japanese silk manufactured with mulberry fibers.

(See page 30 for Group 333 table)

## Group 334: Fabrics and Similar Products (Also in the Form of Wrappings)

The word fabric means, in general:

1. *Fabrics properly called*, that is, products obtained by the interweaving of threads, manufactured by the insertion of filling threads in the warp thread perpendicularly one to the other during the weaving.
2. *Knits (tricot)*, where the joining of the threads is achieved by interlacing by means of meshes. Tricot is very elastic, but is mechanically weaker than fabrics woven with identical threads.
3. *Mats and felts*. Mats are made of sheets of nonbraided fibers or of skeins of nontwisted parallel fibers (roving). The fibers of the sheets or of the skeins may be oriented according to their end use. Mats may be assembled either by cementing the sheets with the aid of a binder or by stitching. Felts consist of relatively dense layers of thin fibers held together by a purely mechanical means designed for felting.
4. *Glass bats*. A bat is a mat made of short glass fibers (about 5 cm), possessing a cohesion sufficient to allow easy manipulation. This cohesion is obtained either by the use of an organic binder or by glass threads, as is done for rugs.
5. *Braided wrappings*, which are made of polished cotton, rayon, and glass threads.

The mechanical, chemical, and dielectric properties of fabrics are a result of the corresponding properties of the threads or of the fibers used (see the comparative table of group 321). This applies especially to their mechanical properties, which derive from the nature of the threads (length, twist), and from the process of manufacture of the fabric (construction, thickness, weight per sq m, and subsequent treatments such as finishing and shrinkage). Sizing and finishing agents can exert an unfavorable effect on the dielectric properties, on the ability to absorb liquid dielectrics, and on the thermal resistance of the fabrics.

The fabrics, often used in the form of tapes, do not generally serve as insulating materials in electrical practice, but as support to the impregnating compound in order to reinforce the mechanical properties, or as a separating element. Impregnation or coating may be accomplished either on the assembled insulation in place on the object, or on the fabric before use. The latter, after its interstices are sealed by the impregnating compound, becomes in fact an insulating material itself (see comparative table 335).

The term "construction" designates the method of interweaving of the warp and fill. The fabrics used in electrical practice are of three fundamental constructions which are shown at the bottom of column 2.

Plain constructions are generally used for insulating fabrics. The serge and satin constructions are found in fabrics with reinforced warps, a weaker filling, and a warp count often higher than the filling. Oc-

asionally, mixed fabrics are used, such as cotton warps and silk filling. The fabrics woven with continuous fibers (or multifibers as of silk or glass filaments) are more solid and smooth than the corresponding fabrics made from discontinuous fibers (cotton threads, staple glass fibers), but they are not impregnated as easily because their power of absorption is lower. Laminates made with these fabrics are very easily delaminated.

The following are used in electrical practice:

*Cotton fabrics*, often in the form of tapes.

*Silk fabrics*, when great mechanical strength is desired together with low thickness.

*Fabrics based on synthetic or improved fibers*, especially cellulose/acetate fibers, acetylated cotton, and polyester fibers, because of their small sensitivity to moisture and their stability toward aging.

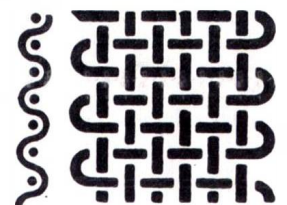
*Fiber-glass fabrics*, for service temperature higher than 120 C and for increased mechanical strength, when aging resistance and moisture resistance are required.

*Glass fiber mats and assemblages of glass fibers similar to felts*, for service temperatures higher than 120 C and requiring only slight mechanical strength, but good resistance to aging and moisture.

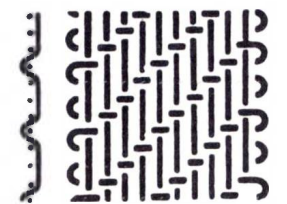
*Asbestos fabrics*, for service temperatures higher than 120 C, when relatively large insulating thicknesses are desired and when limited dielectric properties can be tolerated.

Wide fabrics are most frequently either impregnated or coated (see comparative table 335). Tapes, on the other hand, are often applied to the object to be insulated before impregnation. They are standardized according to country. The width, thickness, number of warp threads and fill, construction, weight per sq m, and the minimum tensile strength have been fixed. These standards vary greatly from country to country.

"Square woven" or "plain" construction: This is the simplest construction with the greatest number of linked points. A plain fabric is less pliable than a fabric with a different construction, the other characteristics being comparable.



"Twill" or "serge" construction: This is a looser construction. It presents salient ribs, separated by the oblique lines of the linked points, forming grooves.



"Satin" construction: This is a fabric with shiny surface obtained by distributing the linked points uniformly over the whole surface.



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## Electrical Insulating Materials

### Synoptic Table for Group 333 Papers, Cardboards, and Similar Products

Principal Constituents	Designation	General Characteristics										Precautions in use	Number of the monograph
		Thickness, mm	Weight per square meter, gm	Apparent density, gm/cm <sup>3</sup>	(3) Porosity	(4) Conductivity of water extract	(5) Tensile strength	(5) Elongation at rupture	Ash content, %	Maximum temperature admitted in service (8)	Comparative price		
Organic Cellulose of vegetable fibers	Jap tissue paper made from bark	0.02 to 0.1	5 to 50	0.5					1.5	90			
	capacitors	0.005 to 0.04	10 to 50	1.2					1.0	90			
	cables	0.01 to 0.05	10 to 50	1.0					1.5	90			
	Papers transformers for laminates	0.06 to 0.12	50 to 100	0.8					1.5	90			
Papers		0.10 to 0.25	60 to 150	0.6					1.5	90			
	Acetyl paper	0.06 to 0.3	30 to 200	0.5 to 0.9					1.0	90			
Transformed cellulose	Parchment paper	0.01 to 0.05	10 to 60	1.25						90			



		(1)									
Asbestos fibers	Asbestos paper	0.05 to 0.2	50 to 200	0.9			70 to 100	130 to 250			
		Mica flakes	Mica paper	0.02 to 0.2	20 to 200	0.9			250		
Inorganic	Glass	0.03 to 0.2	10 to 50	0.2 to 0.25			100	250			
		Cellulose of vegetable fibers	Electrical cardboard, pressboard	0.5 to 6	600 to 7500	1.2 to 1.35			1.5		90
Organic	Transformed cellulose	0.2 to 10	250 to 13000	1.2 to 1.4				90			
		Inorganic	Fibers of asbestos	Asbestos card-board	1 to 10	1000 to* 14000	1.0 to 1.5			70 to 100	130 to 250
Cardboards											

Numerical values used in the editing of the table (logarithmic scale)  
(should not be used as basis of construction)

Test method and units	%	10 <sup>6</sup> ohm-cm (7)	kg/cm <sup>2</sup>	%	%
	<~10	>200	<63	<0.4	>100
	>~75	<40	>16 0	>10	<4

poor

excellent

dispersion between inferior and better qualities

- (1) It may contain cellulose and, sometimes, some organic binders.
- (2) See also the descriptive table of group 336.
- (3) Since the porosity of papers and cardboards was not measured in the same way, the values indicated in this table do not allow comparison between these two groups.
- (4) Gives an indication of the electrolyte content.
- (5) Average of longitudinal and transversal measurements.
- (6) Absorption power of the insulators.
- (7) Measurement made after having boiled, in 100 g of distilled water, 5 g of paper for 1 hour.
- (8) Papers, cardboards and organic tissues, when suitably impregnated, withstand 110 deg C.

## Group 335: Papers and Cloths, Impregnated or Coated

The insulating materials of this group are papers (group 333) or cloths (group 334), often called supports in the text, impregnated or coated with a substance whose main purpose is to retard the absorption of water appreciably and, by filling the interstices, to improve the dielectric properties very considerably, especially the electric strength. They are used as sheets or tapes of all sizes. The impregnated cloths are supplied either with a straight weave or with a bias weave. The latter is characterized by high elongation at break, and permits the manufacture of more compact insulation. The properties of the insulation depend upon the support used (chemical constitution, nature of the fibers, type of threads, spinning, weaving, sizing, etc.), upon the impregnating materials, on the latter's percentage in the support, and on the method of fabrication (impregnation or coating). The properties of insulation prepared with this insulating material depend, moreover, upon the care exercised during the application, especially in the case of air occluded between the layers.\* The impregnating and coating compounds are numerous. They include the fusible compounds of group 511, the varnishes of group 531, the thermoplastic materials of groups 343 and 515, and the elastomers of group 344. By adding asphalt to varnishes, which is the practical procedure for black

impregnated papers and cloths, their flexibility in the cold and their resistance to hot oils is diminished, but their dielectric properties in the presence of humidity are improved.

These insulating assemblies are manufactured by dipping or by knife coating. In the first procedure the support is passed one or more times through a melted impregnant, a solvent solution, or, sometimes, an aqueous emulsion. The support is thoroughly impregnated and consequently its water resistance is good. In the second procedure the impregnant is spread on the surface of the support with the aid of a doctor blade. With this method the impregnant does not penetrate, or hardly penetrates, the support, with consequent lower water resistance. It is very advantageous to combine these two methods. Certain insulations of this group are covered with a lubricant to facilitate the slipping of the layers one over the other. The papers and the cloths are numerous, and so are the impregnants. This table, therefore, can supply only the characteristics of the more important combinations used in the electrical industry.†

\* This is the reason why the dielectric strength of insulation manufactured from several layers of impregnated cloth is not a multiple of that measured on the cloth before slitting into tape.

† Papers coated with plastisols and organosols, for example, are not mentioned because they are not used in the electrical industry. They are utilized for packaging.

(See page 34 for Group 335 table)

## Group 336: Laminated Sheet Insulation (Slot Insulation, etc.)

This group includes all the insulating materials in sheets or in tapes, made from superimposed layers, generally of different nature, and bonded by means of binders of all types. The layers most commonly used are the micas of group 331, the films of group 332, the papers and the pasteboards of group 333, the fabrics of group 334, and the impregnated papers and fabrics of group 335. Among the binders are the flexible adhesives of group 534.

A large variety of combinations is possible. The properties of the insulation which results depend upon those of each of the constituents. It is possible, for example, to combine the high electric strength of a film with the low elongation of a paper or of a fabric. If the thermal and electric stresses are high, suitably

impregnated mica paper or glass cloth can be used. If the electric strength must be high for small over-all dimensions, impregnated silk or mica would be utilized. This comparative table cannot give the properties of all possible combinations. They are too numerous. It has been considered preferable to supply some properties of the layers commonly used and, as an example, those of some compounded insulation. The properties of an insulating material under scrutiny can be estimated on the basis of the properties of the constituents, as given in this table and in the tables of the groups cited. The insulating materials should, however, be used with discrimination, because they do not maintain completely the properties of their constituents considered separately.

*(See page 36 for Group 336 table)*

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**Electrical Insulating Materials**  
**Synoptic Table for Group 335**  
**Papers and Cloths, Impregnated or Coated**  
**(largely in the form of tapes)**

Nature of support	Materials used for impregnation or coating	General Characteristics														Precautions in use	Comparative price	Number of the monograph		
		Dielectric Properties				Mechanical Properties				Resistance to Chemical Agents										
		Thickness, mm	Apparent density, g/cm <sup>3</sup>	(1) Electric strength	Volume resistivity	Dissipation factor, tan δ, at 50 to 10 <sup>4</sup> cps	Dielectric constant, ε'	Resistance to discharges (corona effect)	Constancy of the dielectric properties with temperature	Constancy of the dielectric properties with humidity	Tensile strength	Elongation at rupture, % (2)	Resistance to tearing	Constancy of the mechanical properties with temperature	Maximum temperature admitted in service, deg C				Water	Solvents of impregnating varnishes
Organic papers	Fusible substances (Group 511)	0.03 to 0.30	1.2	1 to 5	1 to 5	2.25 to 6	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	40 to 50	1/2	1/2	1/2	1/2	cast when hot	1/2
	Cellulose papers	0.02 to 0.30	1.2	1 to 5	1 to 5	5 to 7	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	90 to 120	1/2	1/2	1/2	1/2		1/2
Inorganic papers	Organic varnishes (Group 531)	0.12 to 0.45	0.95 to 1.2	1 to 5	1 to 5		1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	130 to 155	1/2	1/2	1/2	1/2		1/2
	Asbestos paper	0.12 to 0.45	0.95 to 1.2	1 to 5	1 to 5		1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	180 to 200	1/2	1/2	1/2	1/2		1/2
		0.15 to 0.50	0.98 to 1.25	1 to 5	1 to 5		1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	180 to 200	1/2	1/2	1/2	1/2		1/2
Organic fabrics	Fusible substances (Group 511)	0.10 to 0.60	1.2	3 to 6 20 to 25	3 to 6 20 to 25	2.85 to 6	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	40 to 50	1/2	1/2	1/2	1/2	cast when hot	1/2
	Organic varnishes (Group 531)	0.10 to 0.60	1.2	3 to 6 20 to 25	3 to 6 20 to 25	5 to 7	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	90 to 120	1/2	1/2	1/2	1/2		1/2
	Plastics (Groups 343 and 515) (3)	0.10 to 1.0	1.1 to 1.3	3 to 6 20 to 25	3 to 6 20 to 25		3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	40 to 60	1/2	1/2	1/2	1/2		1/2
	Cotton cloth usually sized, sometimes acetylated	0.10 to 1.0	1.2 to 1.7	3 to 6 20 to 25	3 to 6 20 to 25		3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	3 to 6 20 to 25	90 to 120	1/2	1/2	1/2	1/2		1/2

			0.05 to 0.20	1.1												8 to 14 20 to 30							90 to 120						
			0.05 to 0.20	1.1 to 1.2												8 to 14 20 to 30							(4) 90 to 120						
			0.05 to 0.45	1.3 to 1.45												3 to 7 30 to 40							130 to 155						
			0.06 to 0.70	1.38 to 1.44												3 to 7 30 to 40							180 to 200						
			0.12 to 0.80	1.40 to 1.47												3 to 7 30 to 40							180 to 200						
			0.08 to 0.45	2.80 to 3.30												3 to 7 30 to 40							250						
			0.75 to 1.30	1.3 to 1.45																			130 to 155						
			0.75 to 1.30	1.40 to 1.45																			180						

Numerical values used in the editing of the table (logarithmic scale)  
(should not be used as basis of construction)

			Test method and units	kv/cm	ohm-cm		kg/cm²		Einm-dorf, g	Ab-sorption, %
<p>○ poor</p> <p>● excellent</p> <p> dispersion between inferior and better qualities</p>	<p>○</p> <p>●</p>			<25	<10 <sup>9</sup>	>0.3	<250	<63	>25	
				>630	>10 <sup>16</sup>	<0.0001	>6300	>1600	<0.2	

(1) The dielectric strength of a cloth stretched 6% is from 20 to 50% lower, according to the thickness of the cloth.  
(2) The first figures are those for the square woven cloth, the second figures for the bias woven cloth.  
(3) Generally, plasticized polyvinylchloride.  
(4) Cloths suitably impregnated with terephthalic esters withstand 155 deg C. They are sensitive to the combined effect of heat and humidity.

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# Electrical Insulating Materials

Synoptic Table for Group 336

Laminated Sheet Insulation (Slot Insulation, Etc.)

Principal base material	General Characteristics											Precautions in use	Number of the monograph					
	Thickness, mm	Weight per square meter, gms	Apparent density, g/cm <sup>3</sup>	Dielectric Properties			Mechanical Properties			Maximum temperature in service, deg C	Resistance to Chemical Agents							
				Electric strength	Volumic resistivity	Resistance to discharges (corona effect)	Tensile strength	Elongation at rupture	Resistance to tearing		Water			Solvents of impregnating varnishes	Hot mineral oil	Chlorinated dielectrics	Comparative price	
Kraft paper (4)	0.10 to 0.30	60 to 180	0.6	1/2	1/2	0	1/2	1/2	1/2	1/2	90	0	1	1	1	0		
Rag paper	0.12 to 0.30	140 to 360	1.2 to 1.35	1/2	1/2	0	1/2	1/2	1/2	1/2	90	0	1	1	1	0		
Asbestos cloth	0.05 to 0.20	50 to 200	0.9	1/2	1/2	1/2	1/2	1/2	1/2	1/2	130 to 150	0	1	1	1	1/2		
Varnished cotton cloth	0.10 to 0.60	120 to 720	1.2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	90 to 120	1/2	1/2	1/2	1/2	1/2		
Varnished silk	0.05 to 0.20	55 to 220	1.1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	90 to 120	1/2	1/2	1/2	1/2	1/2		
Varnished glass cloth	0.05 to 0.45	65 to 650	1.3 to 1.45	1/2	1/2	1/2	1/2	1/2	1/2	1/2	130 to 180	1/2	1/2	1/2	1/2	1/2		
Cellulose triacetate films	0.022 to 0.06	26 to 28	1.2 to 1.3	1/2	1/2	1/2	1/2	1/2	1/2	1/2	60 to 105	1/2	1/2	1/2	1/2	1/2		
Polyethylene terephthalate films	0.025 to 0.05	35 to 70	1.4	1/2	1/2	1/2	1/2	1/2	1/2	1/2	90 to 130	1/2	1/2	1/2	1/2	1/2		
Muscovite mica	0.01 to 0.03		2.6 to 3.2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	500	1/2	1/2	1/2	1/2	1/2		

Rag paper Polyethylene terephthalate films	0.20 0.050	0.23	285	1.2								120 to 130				
Polyethylene terephthalate films Rag paper Polyethylene terephthalate films	0.050 0.20 0.050	0.30	370	1.2								120 to 130				
Kraft paper Polyethylene terephthalate films	0.2 0.05	0.22	230	1								105 to 120				
Examples of laminated insulation Kraft paper Cellulose triacetate Kraft paper	0.09 0.06 0.09	0.20	220	1.1								105 to 120				
Varnished cotton cloth Kraft paper Varnished cotton cloth	0.25 0.18 0.20	0.70	830	1.2								105 to 120				
Varnished silk Muscovite mica	0.05 0.05	0.10	150	1.5								120 to 130				
Varnished glass cloth Muscovite mica	0.1 0.1	0.21	350	1.6								130 to 180				

Numerical values used in the editing of the table (logarithmic scale)  
(should not be used as basis of construction)

Test method and units	kv/cm	ohm-cm	kg/cm²	%	Elmen-dorf g	Ab-sorp-tion, %
	<25	<10 <sup>8</sup>	<63	<0.4	<100	>25
	>630	>10 <sup>10</sup>	>1600	>10	>500	<0.2

poor  
 excellent  
 dispersion between inferior and better qualities

- (1) These bodies are porous and liquids penetrate them immediately. If the liquid is a good insulating material, the electrical properties are improved. The other properties may be modified in one direction or the other.
- (2) May split on contact with liquids.
- (3) When bonded to a support, the film presents a great resistance to tear.
- (4) In certain cases thinner papers are used.

## Group 341: Inorganic Insulation (Ceramics, Glasses, Quartz, etc.)

The insulating materials of this group are constituted exclusively of inorganic materials, which include the ceramics, glasses, and certain natural products. Ceramics are opaque or translucent masses composed of crystalline materials bonded by a vitrified amorphous substance. The physical, electrical, and mechanical properties depend essentially upon the ratio between the amorphous and the crystalline phases. Glasses, on the other hand, are amorphous transparent substances. When a melted glass is cooled, it proceeds from the liquid to the solid state without a sharp solidification point. Shaping is performed either by molding, casting, extrusion followed by high-temperature heat (for ceramics), or by casting or forming of the melted mass (glasses). These operations are accompanied by noticeable shrinking, which vitiates the precision of the dimensions.

Inorganic insulating materials are characterized

by great hardness at elevated temperatures and by excellent flame resistance. However, it must be noted that as most of these compounds lose a great part of their dielectric properties when the temperature increases, it is impossible to take full advantage of their dimensional stability toward heat. The nonporous compounds do not absorb water, but the weather affects the surface dielectric properties either temporarily or lastingly. This effect is more pronounced if their surface is rough and contaminated with dirt. This is why many ceramics are covered with an enamel (glazed) and at times with a product capable of facilitating run-off of water by lowering its surface tension (e.g. a silicone). The enamel likewise improves the mechanical properties of ceramics and the distribution of the electric field in the insulator. Dark-colored enamels absorb light rays; the insulator heats up and dries rapidly. Insulators in this group have good resistance to most chemicals.

*(See page 40 for Group 341 table)*



## Group 342: Thermosetting Molded Insulations

The insulations of this group are objects formed by compression molding. They are composed of a heat-hardening resin into which are incorporated inorganic or organic fillers in the form of powders, fibers, or clippings for the purpose of improving the mechanical properties. They are made by compressing the resin-filler mixture under high pressure in a heated mold. With the heat applied the resin liquifies, takes the shape of the mold, and undergoes a

chemical reaction to become hard and infusible. Hot molded insulations are characterized by good thermal stability, that is, their shape and mechanical properties change only slightly up to the decomposition temperature. Most can be considered to be isotropic; their properties are practically the same in all directions. They generally resist corrosion well. They are used when a large number of similar pieces is required.

*(See page 42 for Group 342 table)*

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### Electrical Insulating Materials

Synoptic Table for Group 341  
Inorganic Insulation (Ceramics, glasses, quartz, etc.)

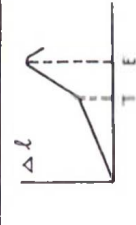
Designation	Structure	General Characteristics														Precautions in use	Number of the monograph							
		Physical Properties							Dielectric Properties									Mechanical Properties						
		Temperature of transformation, deg C (1)	Temperature of softening, deg C (2)	Coefficient of expansion, $\frac{1}{\text{deg C}} \times 10^{-6}$	Heat capacity, Joules $\times 10^3$ / kg deg C	Heat conductivity, Watts / Meter deg C	Electric strength	Volume resistivity	Dissipation factor, $\tan \delta$ , from 50 to 10 <sup>6</sup> cps	Dielectric constant, $\epsilon'$	Resistance to arcs	Constancy of the dielectric properties with temperature (20-350 C)	Tensile strength	Flexural strength	Resilience			Compressive strength	Hardness, Mohs	Elastic modulus	Resistance to humidity and water	Dimensional tolerances, $\pm\%$ (3)	Comparative price (4)	
Porcelain	nonporous		1300 to 1400	3.5 to 5.0	0.88	1.15 to 1.60		6 to 7											2 to 5					
Steatite	nonporous		1350 to 1400	6.8 to 10.0	0.84 to 1.0	1.72 to 2.75		5 to 6											1 to 5					
Refractory pastes (clays) for furnaces: Cordierite	fine-porous nonporous		1300 to 1400	1.0 to 6.0	0.84 to 1.0	2.1 to 2.3		4 to 5											1 to 3					
Pastes (clays) rich in Al <sub>2</sub> O <sub>3</sub>	fine-porous nonporous		1450 to 1700	6.0 to 8.0	0.90 to 1.05	2.3 to 11.5		8 to 9											2 to 5					
Oxides of titanium	nonporous		1250 to 1400	6.0 to 10.0	0.84 to 1.0	3.2 to 4.2		30 to 5000											3					
Metals oxides of (Be, Al, Mg, Zr)	fine-porous nonporous		1600 to 2000	5.0 to 12.0	0.73 to 1.05	2.3 to 16		7 to 10											2 to 5					
Ceramics of zirconium	nonporous		1320 to 4100	5.2 to 5.8	0.90 to 0.95	2.3		17											1 to 3					

Quartz	nonporous	2.0 to 2.2	1050	1400	0.54	0.75	1.1 to 1.2	●	●	●	●	●	●	●	●	●	●	●	●	0.2 to 2	○	Permeable to gas above 200 C
Simple silicates	nonporous	2.3 to 2.8	450 to 550	500 to 600	7.0 to 12.0	0.70 to 0.96	0.9 to 1.5	○	○	○	○	○	○	○	○	○	○	○	○	3 to 10	●	
Glasses	Alumino-silicates of lead	nonporous	400 to 600	450 to 700	7.0 to 12.0	0.70 to 0.96	0.9 to 1.5	○	○	○	○	○	○	○	○	○	○	○	○	3 to 10	●	
	Boro-silicates	nonporous	460 to 750	500 to 850	3.0 to 6.0	0.70 to 0.96	0.9 to 1.5	○	○	○	○	○	○	○	○	○	○	○	○	3 to 10	●	
Mica-glasses	nonporous	2.68 to 4.4	550		9	0.75 to 0.95	0.57	○	○	○	○	○	○	○	○	○	○	○	○	0.2 to 1.3	●	
Natural products	Marble	nonporous			10	0.9	2.1 to 3.5	○	○	○	○	○	○	○	○	○	○	○	○		●	Becomes brittle above 100 C
	Slate	nonporous			8	0.88	2	○	○	○	○	○	○	○	○	○	○	○	○		●	

Numerical values used in the editing of the table (logarithmic scale)  
(should not be used as basis of construction)

Test method and units	kv/cm	ohm cm	kg/cm <sup>3</sup>	kg/cm <sup>2</sup>	kg/cm <sup>2</sup>	kg/cm <sup>2</sup>	kg/cm <sup>2</sup>	kg/cm <sup>2</sup>	kg/cm <sup>2</sup>	kg/cm <sup>2</sup>	kg/cm <sup>2</sup>	Ab-sorp-tion, %
	○	<25	<10 <sup>8</sup>	<250	<250	<3000	<1	<360	>25	>100	>100	>4
●	>630	>10 <sup>8</sup>	>6300	>6300	>7000	>8	>4000	<0.2	<4	<4	<4	

- (1) Structural transformation, corresponding to the abrupt modification of the curves of expansion, of electrical conductivity, etc., at the same time that softening commences (T).
- (2) Temperature corresponding to a maximum expansion (E).



- (3) By grinding pieces are made with extreme precision.
- (4) The comparative values indicated in the column have no interest, because the price of the molded pieces depends upon the cost of the mold and the number of the pieces to be molded.
- (5) They are sensitive to hot water.

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# Electrical Insulating Materials

## Synoptic Table for Group 342

### Thermosetting Molded Insulation

Resin	Filler	General Characteristics															Precautions in use	Number of the monograph									
		Dielectric Properties										Mechanical Properties			Behavior to Heat				Resistance to Chemical Agents								
		(1)	Electric strength	Volume resistivity	Dissipation factor, tan δ, from 50 to 10 <sup>6</sup> cps	Resistance to tracking	Constancy of the dielectric properties as a function of temperature	Constancy of the dielectric properties as a function of humidity	Tensile and flexural strength	Flexibility	Constancy of the mechanical properties as a function of temperature	Maximum temperature admitted in service, deg C	Resistance to combustion	Stability of form under the influence of humidity, internal stresses or crystallization	Water	Solvents of impregnating varnishes (2)			Hot mineral oils	Chlorinated dielectrics	Comparative price						
																						Thermosetting Molded Insulation					
Phenol-formaldehyde	Without filler	1.3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Vegetable powder (wood flour, etc.)	1.4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Vegetable fibers	1.4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phenol-formaldehyde	Chopped fabric	1.4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Asbestos flock	1.8	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Mica powder	1.8	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Phenol-formaldehyde + rubber	Glass fiber	1.8	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Vegetable powder	1.3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Asbestos flock	1.8	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Urea-formaldehyde	Vegetable powder	1.5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Vegetable fiber	1.5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○



## Group 343: Thermoplastic Molded Insulations

Insulating materials of this group are thermoplastic, i.e., they become soft with increasing temperature and regain their original hardness on cooling. They are made in all forms: tubes, rods, sheets, etc. The first method of manufacture is by injecting the heated material into a cold mold whose form it takes on cooling. The second method is by extrusion, by forcing the hot material to pass through a die into a coolant. Sheets are formed by casting (see table of group 521), pressing, shaving, etc. The thermo-

plastic nature of these insulations permits their deformation by heat (molding, etc.) and generally permits heat sealing. They are mostly isotropic, i.e., their properties are practically the same in all directions. The properties are very dependent on the temperature. By addition of plasticizers, or copolymerization, one can give them almost any degree of hardness. Most of them are transparent or translucent and can be made in all colors or rendered opaque.

*(See page 46 for Group 343 table)*

## Group 344: Elastomers (Vulcanized Rubber, etc.)

This group comprises all the insulating materials of which the principal characteristic is the fact that they are predominantly elastic. For the majority of these materials, this property is obtained by thermal treatment in the presence of special ingredients, most frequently sulfur. This treatment, which transforms a plastic mass into an elastic mass, is termed "vulcanization" (curing). In addition to the elastomer and the sulfur necessary for the vulcanization, they contain fillers, plasticizers, accelerators, antioxidants, and possibly other curing agents which greatly influence their properties.

The properties of the vulcanized elastomers listed in the table correspond to the compounds described in the monographs, where certain particular properties are also given (a change in ingredients influences

all the properties more or less, especially the density and dielectric and mechanical properties). Hardness varies between 50 and 80 IKH.\* Resistance to alcohol, which is not considered in the table, is always good. Some elastomers in this group deteriorate slowly in contact with air: They age.\* Those which are little oxidizable such as the silicones, butyl rubber, polychloroprene (Neoprene), etc., behave more favorably in this respect. The aging depends also to a great extent on the amount of antioxidants contained in the mixture. Before vulcanization the mixtures can be milled, extruded, calendered, pressed, etc., so that they can be given any desired form.

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\* See table.

(See page 48 for Group 344 table)

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## Electrical Insulating Materials

Synoptic Table for Group 343

Thermoplastic Molded Insulation

Designation	General Characteristics														Precautions in use	Comparative price (4)	Number of the monograph	
	(1)	Dielectric Properties				Mechanical Properties			Behavior to Heat		Resistance to Chemical Agents							
	Specific gravity, g/cm <sup>3</sup>	Electric strength	Volume resistivity	Dissipation factor, tan δ, at 50 cps	Resistance to tracking	Constancy of the dielectric properties as a function of temperature	Constancy of the dielectric properties as a function of humidity	Tensile and flexural strength	Flexibility	Constancy of the mechanical properties as a function of temperature	Maximum service temperature, deg C	Resistance to combustion	Stability of shape under the influence of humidity, internal stresses or crystallization	Water	Solvents of impregnating varnishes	Cold mineral oil	Chlorinated dielectrics	
Acetate	1.2 to 1.3										60 to 105							
Cellulose	1.1 to 1.2										60 to 105							
Nitrate (celluloid)	1.3 to 1.4										60							
Ethylcellulose	1.1 to 1.2										55 to 85							
Benzylcellulose	1.2										55 to 85							
Hexamethylene diamine adipate	1.1										90 to 105							
Polyamides	1.1 to 1.2										90 to 105							
Caprolactame	1.1 to 1.2										60 to 80							
Polyurethane	1.2 to 1.3																	



Polyvinyl chloride (little or no plasticizer)	1.3 to 1.4																	75 to 90												
Plasticized polyvinyl chloride (containing 15-50% plasticizer)	1.2 to 1.7																	75 to 90												
Polyvinylidene chloride not plasticized	1.6 to 1.7																	75 to 90												
Polyvinylbutyral	1.0 to 1.2																	50												
Polyvinylcarbazole	1.2																	105 to 120												
Polymethylmethacrylate	1.1 to 1.2																	75 to 90												
Polystyrene	1.0 to 1.3																	60 to 90												Crazes in contact with solvents
Polyethylene	0.9																	60 to 90												Crazes in the presence of certain liquids (soaps, etc.)
Polymonochlorotrifluoroethylene	2.1 to 2.3																	130 to 155												
Polytetrafluoroethylene	2.1 to 2.3																	180 to 225												

Numerical values used in the editing of the table (logarithmic scale)  
(should not be used as basis of construction)

	Test method and units	kv/cm	ohm- cm	kg/ cm <sup>2</sup>	Ab- sorp- tion, %
poor		<25	<10 <sup>6</sup>	<250	>25
excellent		>630	>10 <sup>16</sup>	>6300	<0.2
dispersion between inferior and better qualities		>0.3	<0.0001		>100
					<4

- The plastic foams have not been considered in this table. They are included in the Group 345 table.
- Only the hydrocarbon solvents have been considered. A solid dark circle signifies that the insulation resists all hydrocarbons (aliphatic and aromatic), a half dark circle that the insulation resists only the aliphatic hydrocarbons (derivatives of petroleum), and an open circle indicates no resistance to any aliphatic hydrocarbons.
- The action of hot oil should be avoided with all thermoplastics.

- The comparative price indicated in this column is not of much interest. The price of molded objects is for the most part a function of the price of the mold and the number of pieces to be molded.
- The value of the flexibility depends on the method of test and the moisture content. It is much lower for polyamides if the measurement is made when dry.
- Tensile strength.
- The losses at high frequency are a little lower.
- The higher values are obtained with certain copolymers.

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## Electrical Insulating Materials

### Synoptic Table for Group 344 Elastomers

	General Characteristics													Precautions in use	Comparative price	Number of the monograph		
	Resistance to Chemical Agents																	
	Dielectric Properties			Mechanical Properties		Behavior to Heat		Resistance to Chemical Agents										
	Electric strength	Volume resistivity	Dissipation factor, tan $\delta$ , from 50 to 10 <sup>6</sup> cps	Constancy of the dielectric properties as a function of temperature	Constancy of the dielectric properties as a function of humidity	Tensile strength	Elongation at rupture	Temperature limit for use, deg C (5)	Resistance to burning	Water	Aliphatic hydrocarbons	Aromatic hydrocarbons	Mineral oil	Chlorinated dielectrics	Acids	Alkalies	Ozone	
Elastomers (3)	Density, g/cm <sup>3</sup>																	
Natural rubber	1.4 to 1.8							-45 to +70										
Butadiene-styrene	1.4 to 1.8							-45 to +70										
Butadiene-acrylonitrile (4)	1.3 to 1.6							-20 to +120										
Polychloroprene (neoprene)	1.5 to 1.7							-35 to +90										
Polyisobutylene-isoprene (butyl rubber)	1.4 to 1.7							-40 to +120										
Silicone	1.3 to 1.5							-60 to +180										
Chloro-sulfonated polyethylene	1.7 to 1.8							-20 to +110										
Organic polysulfide (Thiokol)	1.5 to 1.7																	

Numerical values used in the editing of the table (logarithmic scale)  
(should not be used as basis of construction)

Test method and units	kv/cm	ohm-cm	kg/cm <sup>2</sup>	Ab-sorp-tion, %	Ab-sorp-tion, %
○ poor	<25	<10 <sup>9</sup>	<40	>25	>100
● excellent	>630	>10 <sup>10</sup>	>200	<0.2	<4
◐ dispersion between inferior and better qualities					

- (1) International rubber hardness degrees. The scale is selected so that degree 0 represents the hardness of a substance having a zero modulus of elasticity, degree 100 the hardness of a substance having an infinite modulus of elasticity.
- (2) The artificial aging, which has the purpose of determining the change in properties of the elastomer in a relatively short time is done in a forced draft oven at 70 ± 1 deg C. The duration of the test is 3, 7, 10 days, or an integral multiple of 7 days.

- (3) The foam rubbers have not been considered in this table.
- (4) Usually employed as a sheath and not for primary insulation owing to its polarity and its electrolyte content.
- (5) According to the conditions of use, for example under mechanical stress the temperature of use would be below that indicated in this column.

## Group 345: Other Nonlaminated Insulating Materials

This group comprises insulating materials not covered by the definitions for groups 341-344. In this group are products which have quite different characteristics. They cannot be compared with each other and normally are not used for the same purposes. This comparative table will show only their general properties. Foamed materials which are primarily used for heat and sound insulation have been included in this group because they have recently also found application as electrical insulation. Included are plastic or elastomeric materials having fine gaseous inclusions or pores (diameter about 0.1 to 0.25 mm, 4 to  $10 \times 10^{-3}$  in), which gives them special properties, particularly very light weight and heat conductivity, which, in a given product, decreases with the decrease of the specific weight (0.03 to 0.04 watt/m deg C). The foams are soft or rigid, depending on whether the plastic material is soft or rigid. The individual cells within the material may be closed or open (interconnecting). In the latter case, the foams absorb liquids. They are manufactured, for example, by violently agitating or

expanding a fluid plastic material in the process of solidification, so as to introduce air, whether by decomposition of so-called "blowing agents" within the plastic material with gas expansion, or by release of gases due to the reaction of the solidification process itself, or, finally, by including in the plastic material substances which are subsequently eliminated by dissolution in water or any other appropriate medium.\* Most plastic materials and cellulosic elastomers can thus be transformed into foams, for example, polystyrene, polyethylene, polyvinyl chloride, the polyurethanes, cellulose acetate, the phenol-formaldehyde and urea-formaldehyde resins, and the elastomers of group 344. Merely as an example, the comparative table shows some characteristic properties of the first four of these foams. The other foams have properties which correspond to those of the plastic used. The foams are made while being applied or they are furnished in finished condition.

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\* See table.

(See page 52 for Group 345 table)

## Group 351: Laminates

This group includes stratified insulating materials, that is, materials which are made of superimposed layers bonded one to the other by a thermosetting or, very rarely, a thermoplastic binder. They are generally supplied as sheets, tubing, cylinders, rods, etc., from which the final pieces are obtained by machining. Simply shaped objects can also be fabricated by milling. The sheets are most frequently manufactured by heat-pressing a stack of layers made of paper or fabric (support and reinforcement) previously impregnated with thermosetting synthetic resins. Tubing and cylinders are obtained by heat-forming resin-impregnated paper or fabric around a mandrel, and then by thermosetting the resin in an oven. The insulating materials of

this group are anisotropic, that is, their properties, particularly electrical and mechanical, are not the same in all directions. The tendency of these insulating materials to split along the layers and to absorb moisture depends on the resin content, the degree of impregnation, and the reinforcing material. The elongation at break is much lower than that of metals. Laminates are the materials which, among all plastic materials, possess the highest mechanical strength in a preferential direction. All their properties vary little as a function of temperature. These compounds are, on the other hand, affected by moisture absorption, which is generally very small for laminates with high resin content and which contain an inorganic support or reinforcement.

*(See page 54 for Group 351 table)*

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**Electrical Insulating Materials**  
**Synoptic Table for Group 345**  
**Other Nonlaminated Insulating Materials**

Type of material	General Characteristics													Precautions in use	Price comparisons	Number of the monograph		
	Dielectric Properties				Mechanical Properties		Maximum service temperature, deg C (6)	Combustion resistance	Resistance to Chemical Agents									
	Electric strength	Volume resistivity	Dissipation factor, tan δ, from 50 to 10 <sup>6</sup> cps	Dielectric constant, ε'	Tensile strength	Resistance to compression			Water	Diluted acids	Diluted alkalis	Aliphatic hydrocarbons	Aromatic hydrocarbons				Chlorinated dielectrics	Mineral oil
Hardened casein (with formaldehyde)				6 to 7			70 to 100									The mechanical and electrical properties depend largely on the degree of moisture		
Hardened rubber (less than 25% sulfur)				2.5 to 5			60									May corrode metals		
Untreated wood (including compressed wood) (7)				2 to 9			40 to 60									The properties depend on the type of wood, the direction of the layers, and the humidity		
Wood impregnated with synthetic resin (8)				>5			120											



# Electrical Insulating Materials

## Synoptic Table for Group 351

### Laminates

Constitution		General Characteristics														Precautions in use	Number of the monograph		
		Specific gravity, g/cm <sup>3</sup>	Dielectric Properties				Mechanical Properties			Behavior to Heat		Resistance to Chemical Agents							
Resin	Support		(1)	Volume resistivity	Dissipation factor, tan δ, from 50 to 10 <sup>6</sup> cps	Resistance to tracking	Constancy of the dielectric properties as a function of temperature	Constancy of the dielectric properties as a function of humidity	Tensile and flexural strength	Flexibility	Constancy of the mechanical properties as a function of temperature	Maximum service temperature, deg C	Resistance to combustion	Stability of shape under the influence of humidity, internal stresses or crystallization	Water	Solvents or impregnating varnishes (2)	Hot mineral oils	Chlorinated dielectrics	Comparative price
		Phenol (or cresol formaldehyde)	Paper	1.3 to 1.4									105 to 120						
Cotton	1.2 to 1.4										105 to 120								
Asbestos paper	1.6 to 1.8										130 to 155								
Asbestos cloth	1.5 to 1.8										130 to 155								
Glass	1.4 to 1.8										130 to 155								
Polyamides	1.1 to 1.2										105 to 120								
Wood	1.3										90 to 120								
Paper	1.4 to 1.6										90 to 105								
Cotton	1.3 to 1.5										90 to 105								
Paper	1.4 to 1.6										105 to 120								
Cotton	1.3 to 1.5									105 to 120									
Asbestos	1.7 to 1.8									120 to 130									





## Group 411: Adhesive-Coated Films, Adhering When Cold

The insulating materials of this group comprise the films of group 332, covered on one of the two sides with an adhesive so that, when cold, they adhere to each other or to any other object. The adhesives used are grouped into two distinct classes, namely: (a) *adhesives which rapidly lose adhesion power when warm*, for example, elastomers to which have been added natural or synthetic thermoplastic resins and certain plasticized resins, and (b) *adhesives whose adhesion power can be improved by appropriate heat treatment*, for example, elastomers to which have been added heat-hardening synthetic resins or certain plasticized heat-hardening resins. The adhesives of the second kind are usually applied on films of group 332 which have good heat resistance. After heat treatment, they acquire good resistance to the solvents of the impregnating varnishes. The adhesive covering the films does not noticeably change the characteristics of the uncoated films, as described in the comparative table for group 332. Poor adhesion, however, can lead to displacements between the layers. After being bonded, the films form compact insulations that are only slightly hygroscopic, however, the dielectric properties are in no way pro-

portional to the number of superimposed layers. Submitted to electrical stresses of short duration, the base insulation of the adhesive films shows a generally high electric strength. Since the resistance to corona discharge of insulating materials of this group is below average or poor, electric stress, if applied for a long time, must be maintained below the corona discharge threshold of the air layers surrounding the film. Only if no gas is included in the insulation, i.e., if the interstices are completely filled with a solid or liquid insulating material, is it possible to make full use of the exceptionally high electric strength of the pressure sensitive adhesive films. The electric strength of an insulation of adhesive films therefore depends to a large degree upon their application. This comparative table, therefore, omits indications regarding the electric strength. Insulating materials of this group are primarily used as insulation for objects having a complex form (terminals, flanges, etc.), to tape coils so as to protect them against mechanical stresses and atmospheric influences, and also to identify certain parts of apparatus and machines by the use of various colors.

# Electrical Insulating Materials

## Synoptic Table for Group 411 Adhesive-Coated Films, Adhering when Cold

Type of material	General Characteristics														Price comparison	Precautions in use	Number of the monograph
	Specific weight, g/cm <sup>3</sup>	Dielectric Properties			Mechanical Properties				Maximum service temperature (2)	Resistance to Chemical Agents				Steam permeability			
		Volume resistivity	Constancy of the dielectric properties as a function of temperature	Constancy of the dielectric properties as a function of humidity	Tensile strength	Elongation at rupture	Tearing strength	Constancy of the mechanical properties as a function of temperature		Water	Solvents of the impregnating varnishes	Mineral oils	Chlorinated dielectrics				
Regenerated cellulose	1.4 to 1.5			○	◐	◑	◒	◓	60 to 105	○	●	●	●	◐	◑		danger of electrolytic corrosion in the presence of humidity
Cellulose acetate (primarily diacetate)	1.2 to 1.3	◐	◑	◒	◓	◔	◕	60 to 105	◐	●	●	●	◐	◑			
Cellulose triacetate	1.2 to 1.3	◐	◑	◒	◓	◔	◕	60 to 120	◐	●	●	●	◐	◑			
Polyethylene	0.9	◐	◑	●	◐	◑	◒	60 to 90 <sup>(1)</sup>	●	◐	◑	○	◐	◑		sensitive to sunlight	
Nonplasticized polyvinyl chloride	1.3 to 1.4	●	◐	●	◐	◑	◒	75 to 90	●	●	●	○	◐	◑			
Plasticized polyvinyl chloride	1.2 to 1.7	◐	◑	●	◐	◑	○	75 to 90	◐	◑	◒	○	◐	◑			
Polyvinyl chloride	1.6 to 1.7	◐	◑	●	◐	◑	◒	75 to 90	●	●	●	○	◐	◑			
Polytetrafluorethylene	2.2	◐	◑	●	○	◐	◑	250	●	●	●	●	●	◐			
Polyethylene terephthalate	1.4	●	◐	◑	◐	◑	◒	90 to 130	●	●	●	●	◐	◑			

Numerical values used in the editing of the table (logarithmic scale)  
(should not be used as basis of construction)

Test method and units	ohm-cm	kg/cm <sup>2</sup>	%	ASTM kg/cm <sup>2</sup>	Absorption %	g × mm / m <sup>2</sup> × d × mm Hg	
						>30	>100
○ poor	<10 <sup>9</sup>	<250	<4	<6.3	>25	>30	>100
● excellent	>10 <sup>16</sup>	>6300	>500	>160	<0.2	<0.01	<4
◐ dispersion between inferior and better qualities							

(1) Good elasticity at very low temperature.

(2) Insofar as the adhesive retains its properties at this temperature.

## Group 412: Adhesive Papers and Fabrics

The insulating materials of this group comprise papers and fabrics, mostly straight yarns, covered on one of their surfaces with an adhesive which makes it possible to stick them together or to adhere them to any other object in cold state. They are generally used in the form of tapes. There are two principal groups:

1. The papers and fabrics impregnated with varnish (group 335), to make them less hygroscopic and then coated with an adhesive of the same type as used in the manufacture of adhesive films (see comparative table for group 411). They are used in the same way.

The adhesive does not noticeably change the characteristics of the varnish-impregnated papers and fabrics, such as shown in the comparative table for group 335. Poor-quality adhesives, however, may lead to displacements between the layers and to electrolytic corrosion. The tensile strength and the crush resistance are better than those of adhesive films. However, there is more bulk. Their excellent dielectric properties make it possible to use them at high voltage, taking into consideration the precautions in the following sections.

2. The papers and fabrics where the adhesive serves as impregnation agent. The latter consists either of a sticky coating which is applied by fusion, for example, a mixture of tar, resin, mineral oil, etc. (black tapes), or of an elastomer (rubber, polyisobutylene, etc.), a resin, and a mineral filler (generally white tapes). The filler is used to avoid ex-

cessive penetration of the adhesive into the carrier. Insulating materials of this type have below-average dielectric properties and their use should be restricted to applications at low voltage.

The adhesive papers and fabrics, after being bonded together, give compact insulations with limited sensitivity to moisture, where, however, the dielectric properties are in no way proportional to the number of superimposed layers. Exposed to short-time electric stresses, insulation with an adhesive paper or fabric base, which has first been impregnated with a varnish, shows high electric strength. However, since the resistance to corona discharge of the insulating materials in this group is below average or poor, the electric stress, if maintained for a long time, must be maintained below the corona discharge threshold in the layers next to the papers and fabrics. Only with insulations without any gaseous inclusion, where the interstices are completely filled with a solid or liquid insulation material, is it possible to obtain the benefit of the high electric strength of the appropriately impregnated papers and fabrics.

Like the adhesive films of group 411, the adhesive papers and fabrics have found their main application as insulation for connections of all kinds, as coverings for small low-voltage apparatus, and as insulation for cables.

## Group 413: Adhesive Sheet Laminates

The insulating materials of this group are the flat laminates of group 336, covered on one of the two surfaces with an adhesive, so that they can be bonded together or to any other object in the cold state. The adhesives used may be classified into two groups: (1) the adhesives whose adhesive power deteriorates greatly when warm, for example, the elastomers to which natural or synthetic resins have been added and certain plasticized resins; and (2) the adhesives whose adhesive power can be improved when warm by an appropriate heat treatment, for example, elastomers to which heat-hardening synthetic resins have been added or certain plasticized heat-hardening resins. The adhesives of the second type are generally applied on those of the laminations of group 333 which have good heat resistance. The adhesive covering the laminations does not noticeably change the insulating materials of group 336. Inferior adhesives, however, can lead to displacements between layers. The adhesive laminated insulating materials, after being bonded

together, result in compact insulations little affected by moisture, where, however, the dielectric properties are not all proportional to the number of superimposed layers. Exposed to stresses of short duration, the insulation shows a high electric strength. However, since the resistance of the insulating materials of group 336 to corona discharge is below average or poor, the electrical stress, if of prolonged duration, must be kept under the corona discharge threshold in the adjacent air layers. Only with insulations having no gaseous inclusions, where the interstices are completely filled with a solid or liquid insulating material, is it possible to get the benefit of the high electric strength of the insulating materials of group 333. The electric strength of an insulation made with flat bonded laminations therefore depends to a large degree on its application. Flat bonded laminations are mostly used to insulate objects of simple form, to tape windings and protect them against mechanical stresses and atmospheric differences; they are also used as slot insulation.

## Group 421/422: Heat-Bondable Films, Papers, and Fabrics Bonded With Heat

The insulating materials of this group are films, papers, or fabrics, hereafter called "supports," which have been impregnated or covered on one or both surfaces with a thermoplastic or heat-hardening adhesive, so that under the influence of heat they adhere to each other or to any other object. They are also used to bond objects between which they have been inserted as, for example, insulation or flat conductors. In the latter case, they replace a layer of adhesive and at the same time provide a degree of insulation between the objects which they hold together. The adhesive is applied to the supporting base most often as a liquid at room temperature, by fusion, from solution, or as an emulsion in an appropriate agent. The *films* used as support are the least thermoplastic ones of group 332, especially regenerated cellulose, cellulose ester, polyethylene terephthalate, and the fluorinated ethylenes. The adhesive covering them does not noticeably change the characteristics given in the comparative table for group 332. The films, after being bonded together, provide compact insulation with little hygroscopic effects. However, the dielectric properties are not at all proportional to the number of layers applied. They also make it possible to assemble objects, adding extremely little bulk. The papers and fabrics

used as supports generally are the insulating materials of groups 333 and 334. The adhesive with which they are impregnated, or which covers them, imparts to them the properties described in the table for group 335. By a proper choice of the adhesive (synthetic resin, etc.) and its amount in the support, it is possible to manufacture all the insulating materials of group 351 either by pressing them in flat presses or in molds, or by applying them on a mandrel. The correct choice of the insulating agent and its application are of great importance with regard to the properties of the finished insulation and the adhering quality. A poorly adhered support results in a soft and hygroscopic lamination which easily comes apart. A support thoroughly impregnated with a great amount of adhesive, on the other hand, makes it possible to manufacture a hard and water-resistant lamination. Drying the insulating material before use is helpful, because the volatile substances which it may contain may adversely affect the electrical properties of the insulation. The comparative table for this group omits the dielectric and mechanical properties of adhesive-impregnated or adhesive-coated films and papers because they are of little practical value and they may be deduced from tables 332 and 335.

# Electrical Insulating Materials

## Synoptic Table for Groups 421/422

### Films, Papers, and Fabrics Bonded with Heat

Support	Glue		Application conditions (1)			Adherence			Characteristics after adhering insulating materials together (laminated)	Price comparisons (2)	Precautions in use	Number of the monograph		
	Group	Type	Pressing temperature	Pressure, kg/cm <sup>2</sup>	Duration, min.	On metals	On plastic materials	Stability of the adhesive as a function of temperature (from 20 to 120 C)						
Group 421 Films bonded while warm	Natural resins	Gum-lac	60 to 120	10 to 100	1 to 10				See synoptic table for Group 411					
	Cellulose derivatives and thermoplastic polymers	Cellulose esters	80 to 140	10 to 100	1 to 10									
		Vinyl resins	80 to 160	10 to 100	1 to 10									
Group 422 Papers and fabrics bonded while warm	Natural resins or thermoplastic polymers	Gum-lac	60 to 120	10 to 150	10 to 60				See synoptic table for Group 351					
	Heat hardening synthetic resins	Phenolics	120 to 180	30 to 200	20 to 360									
		Urea melamine	120 to 180	30 to 200	20 to 360									
		Polyesters	60 to 180	10 to 200	20 to 360									
		Epoxy	60 to 180	30 to 200	20 to 360									
		Silicones	120 to 150	30 to 200	20 to 360									
		Fluorinated ethylenes	250 to 350	100 to 300	10 to 60									
		Rubber-phenolics	60 to 180	30 to 200	10 to 120									

- poor
- excellent
- dispersion between inferior and better qualities

(1) Pressure and pressing time are generally shortest for adhering of objects. Pressing time is to be counted from the instant when the object or the lamination attains a uniform temperature.

(2) >100

<4

## Group 423: Laminated Sheets Bonded With Heat (Principally Mica Products)

This group includes all the flat laminated insulations which use a special binder to bond them together, in order to obtain compact insulation. The great majority of these are based upon mica flakes or mica paper, frequently attached to a support. They are supplied in the form of sheets (micafolium, etc.) or in the form of tapes of every size (micaceous tapes). They are ordinarily employed for the insulation of simple or multiple conductors, around which they are wrapped or taped and then heat-pressed.\* The manner of cementing is determined by the nature of the bond rather than by the support used. The only function of the latter is to provide the insulator with enough tensile strength to permit wrapping or taping. Textile materials are more resistant than papers, and must be chosen whenever great tensile strength is required. Inorganic supports are used if the service temperature of the electric machine is elevated.

The general characteristics of the insulators depend upon the binder used for bonding; this is done only with heat for the insulators of the group. Some undergo a lasting transformation of their properties during the heat treatment, and give insulators good geometrical stability. Others, the thermoplastics, especially asphalt, lose their hardness when heated and regain it on cooling.

The final properties of insulation depend greatly

upon the care exerted in cementing the insulators. Occlusion of air, no matter how small, brings about the abrupt increase of dielectric losses as a function of voltage<sup>†</sup> and decreases the thermal conductivity. The dielectric constant (permittivity) at 25 C has a value from 3.5 to 5 for micaceous insulators with organic support. This value may become 6 for the other micaceous insulators. It varies slightly as a function of voltage, but often it varies noticeably as a function of temperature, especially where the dissipation factor reaches a value higher than 0.3. The thermal conductivity between 20 and 100 C of micaceous insulators with organic supports is of the order of 0.2 watt/meter deg C if the manufacturing process includes evacuation of the gases occluded in the insulation. In insulating materials which are swollen or which have an incompletely impregnated mica paper basis, values four times smaller have been measured.

The great variety of available resins and the possibility of combination among themselves and with other agents make possible the manufacture of a great number of binders. For this reason this table is hopelessly incomplete.

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\* Similar insulating forms are obtained by other processes with the insulations of groups 336 and 431.

† For this reason it is impossible to assign comparable values among the insulators of this group.

(See page 64 for Group 423 table)



## Group 431: Sheet Laminates Containing Solvents (Principally Mica Products)

The materials of this group are sheet laminates exactly like those of group 423; however, the binder used to bond the layers still contains a small quantity of solvent which increases the flexibility of the insulating materials, facilitates the adhesion of the layers, and, therefore, improves the dielectric properties of the insulation, as applied. The great majority among these are based on mica flakes or mica paper, bonded to one support or placed between two papers or tissues or films acting as support. They are supplied as tapes of all sizes.

In principle all the insulating materials of group 423 can be fabricated by leaving a certain quantity of solvent in the binder. However, in practice, only the mica insulators having an organic or an inorganic support and an asphaltic binder or an adhesive based on epoxy or epoxy-polyester resins, have been utilized

in appreciable quantities. The presence of the solvent in the insulation imposes two very important limitations upon the use:

1. The tapes should be stored in hermetically closed containers (to prevent evaporation of solvent).

2. The solvent still in the insulation after rolling must be removed from the insulation by heating (at about 150 C) in high vacuum (about 0.1 mm Hg) for a very long time (12 to 15 hours). After elimination of the solvent, voids can be filled either with an asphaltic insulation from group 511, or by direct pressing to compact and standardize the insulation.

The characteristics of the insulation after wrapping, solvent elimination or several compoundings, and bonding of the layers by heat-pressing, are the best among those indicated in the comparative table of group 423.

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## Electrical Insulating Materials

### Synoptic Table for Group 423 Laminated Sheets Bonded with Heat

Nature of support	Cement	Temperature of bonding (1)	Characteristics of the insulation after bonding the layers to each other and pressing								Comparative price (2)	Precautions in use	Number of the monograph
			Dissipation factor, tan $\delta$ , at 50 cps and 25 deg C	Constancy of dissipation factor with temperature	Constancy of dielectric constant with temperature	Stability of form with heat	Resistance to electric discharges	Maximum temperature permitted in service, deg C	Resistance to humidity and water				
Unsupported	Shellac	120 to 140								130			
	Polyester resins	120 to 150								130 to 155			
	Epoxy resins	130 to 160								130 to 155			
	Silicone resins	250 to 300								180			
	Shellac	120 to 140								130		Danger of swelling above 80 deg C	
	Asphalt and analogous products	150 to 180								130		Danger of swelling above 80 deg C, sometimes creeping of the mica	

Micaceous Insulation	Organic support	Polyester resins	120 to 160							130					
		Epoxy resins	130 to 160							130					
		Epoxy-polyester resins	130 to 160							130					
		Asphalt and analogous products	150 to 180							130				Danger of swelling above 80 deg C, sometimes creeping of the mica	
		Polyester resins	120 to 160							130 to 155					
	Inorganic support (glass or asbestos)	Epoxy resins	130 to 160							130 to 155					
		Epoxy-polyester resins	130 to 160							130 to 155					
		Silicone resins	250 to 300							180					
Other Insulation Materials															

Numerical values used in the editing of the table (logarithmic scale)  
(should not be used as basis of construction)

Test method and units	For 80 deg C increase of temperature		Ab-sorption, %
	10x	3x	
	>0.3	3x	>25
	<0.0001	2x	<0.2



excellent

dispersion between inferior and better qualities

(1) This temperature is necessary to obtain complete bond of the layers and to harden the thermosetting binders.  
(2) The cost of the insulator depends on the quality of the mica and on the type of support used. A cost comparison among the products of this group can only be approximate.

## Group 441: Films and Sheets, Bonded by Simple Fusion

This group comprises rigid or soft films and sheets of thermoplastic material which, after being placed on top of each other, may be fused into a compact mass. This operation takes place in a heated state or, as an exception, at an ordinary temperature under sufficient pressure. The sheets are heated by a flame, or by a metal hot plate, a hot air blower, high-frequency inductive heating, or even by infrared rays, and they are kept at the indicated temperature long enough to start the reaction between the contact surfaces. Subsequently applied pressure completes the adhesion without causing extrusion of the film beyond the worked area. High-frequency welding, which is based on the heating due to dielectric losses,

is not applicable to materials having low dielectric losses (polystyrene, etc.). These insulating materials are used to cover electric conductors, connections between wires, cable splicings, coils, and terminals of any kind. They may also be used to provide a protective layer against humidity and against chemicals, both liquid or gaseous. The effectiveness of the protection depends on the quality of the films and sheets and, to a large degree, on the tightness of the adhesion. Analogous films and sheets which undergo a chemical transformation after fusion (vulcanization, etc.) are classified in group 451. Films and sheets having very similar properties, but which cannot be melted into a compact mass, form group 441.

# Electrical Insulating Materials

## Synoptic Table for Group 441 Films and Sheets Bonded by Simple Fusion

Type of Material	General Characteristics														Precautions in use	Number of the monograph			
	Dielectric Properties							Mechanical Properties				Resistance to Chemical Agents							
	Specific weight, g/cm <sup>3</sup>	Volume resistivity	Dissipation factor, tan δ, from 50 to 10 <sup>6</sup> cps	Dielectric constant, ε	Resistance to glow discharge (corona effect)	Constancy of the dielectric properties as a function of temperature	Constancy of the dielectric properties as a function of humidity	Tensile strength	Elongation at rupture	Tearing strength	Constancy of the mechanical properties as a function of temperature	Maximum service temperature, deg C	Water	Solvents of impregnating varnishes			Mineral oils	Chlorinated dielectrics	Steam permeability
Polyethylene	0.9			2.3							60 to 90							110	
Polyisobutylene	0.9			2.3							60 to 90							20	
Polystyrene	1.0 to 1.1			2.2 to 3							60 to 90							130	
Non-plasticized polyvinyl chloride	1.3 to 1.4			3 to 4							75 to 90							150	
Plasticized polyvinyl chloride	1.2 to 1.7			4 to 7							75 to 90							130	
Polyvinylidene chloride	1.4 to 1.7			3 to 5							75 to 90							150	

Numerical values used in the editing of the table (logarithmic scale)  
(should not be used as basis of construction)

Test method and units	ohm-cm	> 10 <sup>6</sup>	< 10 <sup>8</sup>	> 0.3	kg/cm <sup>2</sup>	< 250	> 500	%	< 6.3	ASTM	kg/cm	Ab-sorp-tion, %	> 25	< 0.2	g X mm / m <sup>2</sup> X d X mm Hg	> 30	< 0.01	> 100	< 4
	poor																		
	excellent																		
	dispersion between inferior and better qualities																		

## Group 451: Films and Sheets, Bonded by Fusion and Chemical Reaction

This group comprises insulating materials in the form of films and sheets which, after being placed on top of each other and fused into a compact mass (in group 441), must thereafter undergo a chemical transformation such as heat hardening, vulcanization, etc. The purpose of this transformation is to:

1. Improve the mechanical properties insofar as the adhesion between layers is concerned, as well as the strength of the material itself.
2. Improve the thermal properties by converting the thermoplastic material into a material which is hard when warm, or into a vulcanized elastomer.
3. Increase the resistance to solvents, to liquid dielectrics, and other chemical agents.
4. Improve the dielectric properties.

The fusion, and thereafter the chemical transformation or vulcanization, takes place in a heated state, usually under pressure. In certain cases, the transformation takes place progressively in the insulation while it is in service (autovulcanization).

### Application

The application of the insulation materials of this group is the same as that of the insulating materials of group 441, i.e., covering for electric conductors,

connections, cable splicings, coils, terminals, etc., and as a protective layer against humidity and liquid or gaseous chemical substances.

The films and sheets bonded by fusion and chemical transformation are used in all cases where the fusible films of group 441 do not fulfill the mechanical, thermal, or chemical requirements.

In certain cases, they may be used as adhesives, either between conductors which must be insulated and fastened mechanically, or between conductors and other construction elements.

### Various Types

1. Vulcanizable rubber sheets of natural or synthetic rubber, which are vulcanized on the object which they have to insulate. If the temperatures are high, silicone rubbers are used. The properties of the finished insulation after chemical transformation are as indicated in the comparative table for group 344 (elastomers).

2. Fusible polytetrafluorethylene sheets which reach the properties indicated in the comparative table for group 332 only after heat treatment.

3. Sheets of plastic materials which can be fused and hardened, and which are used as insulation materials, but above all, as adhesives.

## Group 511: Fusible Insulating Materials, Without Filler, Liquefiable by Heating

The insulating materials of this group include solid, heat-fusible, insulating bodies utilized for casting, filling, impregnating, or coating. They generally have excellent dielectric properties and exhibit good resistance to atmospheric agents. Their cost is usually low. On the other hand, they are poor heat conductors (heat conductivity from 0.16 to 0.34 watt/meter deg C); for this reason mineral fillers are often added to them (group 512). They are not resistant to solvents or to mineral oils. Finally, they soften on heating and this fact limits their usefulness.

Many of these substances are sufficiently fluid in the melted state to allow casting without pressure. It is, however, advantageous to apply vacuum to the

molten mass in order to eliminate volatile extraneous matters, especially water, which might be found in a very finely divided state. This operation takes an appreciable amount of time and sometimes results in the increase of the melting point of the substance, such as in the case of asphalts and tars. The volumetric shrinkage is usually large when the mass cools; for this reason several successive castings are necessary. The cast materials may be considered homogeneous and isotropic. This comparative table gives the properties of the main representatives of each group, each of which exists in different forms and degrees of purity. Glasses and quartz, members of this group, are described in the comparative table of group 341, which deals with inorganic insulation.

### Electrical Insulating Materials

Synoptic Table for Group 511  
Fusible Insulating Materials, Without Filler,  
Liquefiable with Heat

Designation	Appearance	General Characteristics												Precautions in use	Number of the monograph		
		Physical Properties						Dielectric Properties								Resistance to Chemical Agents	
		Density, g/cm <sup>3</sup>	Fusion point, Ubbelohde, deg C	Penetration	Viscosity	Volume shrinkage (2)	Electric strength	Volume resistivity	Dissipation factor, tan δ	(3) Dielectric constant, 50 to 10 <sup>6</sup> cps	(3) Constancy of the dielectric properties as a function of temperature	(3) Constancy of the dielectric properties as a function of humidity	Mineral oil at 25 deg C			Chlorinated dielectrics at 25 deg C	Chemical stability in service
Waxes	Paraffin	0.89 to 0.92	50 to 110 <sup>(1)</sup>	●	●	●	●	●	●	2.25 to 2.35	●	●	○	●	flamable		
	Ozokerite	0.90 to 0.95	65 to 80	●	●	●	●	●	2.03 to 2.63	●	●	○	○	flamable			
	Ceresin	0.90 to 0.95	60 to 71	●	●	●	●	●	2.2 to 2.3	●	●	○	○	flamable			
	Vaseline	0.81 to 0.9	35 to 60	●	●	●	●	●	2.16	●	●	○	○	flamable			
Vegetables	Carnauba	1.0	83 to 86	○	●	●	●	●	2.66 to 2.83	●	●	●	●	flamable			
	Beeswax	0.94 to 0.96	62 to 67	●	●	●	●	●	2.65 to 2.87	●	●	○	○	flamable			
Animals	Lanosterol	1.03	141 to 142	●	●	●	●	●	14 <sup>(4)</sup>	●	●	○	○	oxidizable flamable			
	Hydrogenated castor oil	0.98	86 to 88	○	●	●	●	●	13.4 37	●	●	○	○	saponifiable, corrosive, flamable			
Synthetic Products	Cetylacetamide	1.0	140 to 142	○	●	●	●	●	2.6	●	●	○	○	flamable			
	Polyethylene	0.92	60 to 210	●	●	●	●	●	2.25 to 2.3	●	●	○	○	flamable			
	Polyisobutylene	0.93		●	●	●	●	●	2.23	●	●	○	○	flamable			
	Plasticized cellulose derivatives	1.2 to 1.4		●	●	●	●	●	3.5 to 5.3	●	●	○	○				
	Plasticized poly-vinyl resins	1.2 to 1.6		●	●	●	●	●	3.1 to 10.3	●	●	○	○				
	Nonchlorinated																





## Group 512: Fusible Insulating Materials, With Filler, Liquefiable by Heating

The insulating materials of this group comprise the insulating materials of group 511, wherein are dispersed very finely divided solids which are called fillers, in order to modify certain physical and electrical properties and to reduce the price. The fillers consist mostly of inorganic matter, insoluble in the insulating material. The modifications obtained depend on the density, the size and form of the particles, and the proportions in which the fillers are used.

It seems preferable not to place the filled materials in the same group as the nonfilled materials of group 511, because they are a heterogeneous material with different characteristics.

Compared with the corresponding insulating materials of group 511, the insulating materials of group 512 show the following characteristics.

*Density:* Always greater and depends on the density of the filler and the proportions in which it is used.

*Viscosity:* The viscosity increases depending on the type and quantity of the filler. A very finely pulverized filler, where the surface of the grains shows unevenness, increases the viscosity to a higher degree than a filler with heavier but smooth grains which, when the mass is liquid, slide by each other without friction.

*Penetration:* The penetration of a pointed object is less in a filled mass than in an unfilled one.

*Mechanical Properties:* Hardness and compression resistance are higher while flexural and tensile strength are lower.

*Form Stability in Warm and Cold State:* The presence of the filler in the mass improves the dimensional stability, both hot and cold, especially if the particles are porous and have an irregular shape.

*Thermal Conductivity:* Is improved by inorganic fillers.

*Shrinkage, Expansion Coefficient:* Many of the

insulating materials of group 511 show considerable shrinkage at the moment of solidification. The fillers reduce this shrinkage, especially if the particles have an irregular shape and the filler content is high. This characteristic is especially important if the material is to be used to make casings, housings, and tanks for electric equipment for use in tropical climates.

*Dielectric Properties:* The insulating materials of this group have dielectric properties which differ from those of the corresponding insulating materials of group 511. They are derived from the properties of the insulating material and the filler, but cannot be calculated on the basis of these properties because the insulating material of group 512 is a heterogeneous dielectric. The dielectric constant is between that of the base material and that of the filler. It depends on the frequency of measurement and the temperature. The loss index must be determined experimentally. The electric strength depends on the field distribution in the filled insulating material, and sometimes on the ions liberated in the presence of humidity. Factors affecting insulating strength and creep resistance are similar.

*Tendency to Form Sedimentation:* The tendency of the fillers to form sedimentation increases in proportion to the density difference between the filler and the insulating mass, and also with the size of the particles and the smoothness of their surface. It is necessary to stir the filled mass constantly while it is in the molten state, and to cool it rapidly if completely regular distribution of the filler in the mass is desired.

The general properties of the insulating materials of group 512 can be derived from the corresponding materials of group 511, taking into consideration the afore-mentioned particular properties. Group 512 materials are also thermoplastic and should be used only in low-temperature applications.

## Group 513: Nonpigmented Insulating Varnishes, Dried by Evaporation of a Solvent

These insulating varnishes (lacquers) are, as delivered, solutions of natural or synthetic film-forming resins in an appropriate solvent. They dry by evaporation of solvent and reach their final state as the evaporation ends. In contrast to varnishes of groups 531 and 532, the dry residue is not subject to further chemical and physical changes. They are all characterized by the fact that after drying they are softened by heat and are always soluble in certain solvents. Most of them contain plasticizers which increase their flexibility and film adherence, and sometimes they contain resins which augment their hardness and the brilliance of the coating.

By judiciously considering these different factors, it is possible to adapt the resin to one's purpose. The dielectric properties, especially electric strength, are generally good. They become noticeably poorer with increasing temperature or humidity. The varnishes of this group are designed primarily for the treatment of electric apparatus not subject to high temperatures and for the coating of wires and cables. Some of them are utilized to protect electric apparatus against certain chemical agents. Many are used as adhesives. Pigments can be added to them (group 514). They should not be used for impregnating coils.

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**Electrical Insulating Materials**

**Synoptic Table for Group 513**

**Nonpigmented Insulating Varnishes Dried by Evaporation of a Solvent**

Type of varnish (lacquer)	Principal Constituents	General Characteristics of the Dried Lacquers														Comparative price	Precautions in use	Number of the monograph									
		Dielectric Properties					Mechanical Properties			Behavior to Heat		Resistance to Chemical Agents															
		Electric strength	Volume resistivity	Resistance to tracking	Constancy of the dielectric properties with temperature	Constancy of the dielectric properties with humidity	Hardness	Flexibility	Adherence	Resistance to aging	Non-flammability	Water	Aliphatic hydrocarbons (e.g., mineral oils)	Aromatic hydrocarbons	Chlorinated dielectrics	Alcohols	Esters and ketones	Dilute	Dilute alkali								
Cellulose derivatives	Nitrocellulose + plasticizer + possibly resins	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	●					
	Cellulose acetate + plasticizer	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○			
	Cellulose acetate butyrate + plasticizer	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	Cellulose ethers + plasticizer	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		



## Group 514: Pigmented Insulating Lacquers, Dried by Solvent Evaporation

The insulations of this group are made with insulating lacquer of group 513, into which has been dispersed a very finely divided solid which is called the pigment.

It has seemed preferable not to place the pigmented lacquers in the same group as the unpigmented lacquers because these are heterogeneous forms having well-defined peculiarities, which affect their use for certain purposes. The pigments have a tendency to settle. The lacquer should be stirred carefully before use.

The properties of the lacquers of this group depend essentially on the nature of the lacquer base, the quality of the pigment, the proportions adopted, and the care taken in mixing.

Compared with corresponding lacquers of group 513, the lacquers of group 514 are characterized by the following peculiarities:

1. The coatings are opaque, white or colored. This coating

masks the object on which the lacquers are applied.

2. The covering capacity is better. Application with a brush gives a much thicker coating so that fewer layers are needed to obtain a glossy surface.

3. The thick coat affords a better protection against water, provided the layers are not porous.

4. They are appreciably more viscous and do not penetrate as well because the pigments obstruct the pores.

5. They are less flexible than are the lacquers of the corresponding bases.

6. They generally have better heat conductivity.

7. They have better chemical resistance.

The general properties of the lacquers of group 514 can be derived from those of corresponding lacquers in group 513, taking into consideration the afore-mentioned peculiarities. Like group 513, they are thermoplastic and are reserved for treatment of surfaces of electric equipment exposed to little heat. They should not be employed for the impregnation of coils.

## Group 515: Plastisols and Organosols

A *plastisol*, or "PVC paste," is a more or less viscous liquid, consisting of a suspension of polymer (synthetic resin), to which often has been added a filler, coloring agent, stabilizer, etc., in a liquid plasticizer. The suspension is stable in the cold state for a period of time which depends on the plasticizer used. On baking at 150 to 180 C, the solution of the polymer in the plasticizer (gelation) takes place within a few minutes, producing a homogeneous, plasticized polymer.

If the polymer is polyvinyl chloride, which nearly always is the case, a soft plastic mass is obtained with the properties of plasticized polyvinyl chloride as described in the table of group 343. However, it should be remembered that the dielectric properties are poor due to the nature of the polyvinyl chloride and the high plasticizer content.

By incorporating a thickening agent in the plastisol, a substance having the consistency of a mastic is obtained. This is called a *plastigel*.

An *organosol* is a plastisol where the liquid dispersing agent is a plasticizer dissolved in a solvent, either to reduce the viscosity of the suspension or to reduce the plasticizer content, so as to obtain, after gelation, a rather hard plastic material. The solvent must be eliminated at the moment the gelation takes place, which is possible only if the material is present in the form of a thin layer.

Plastisols and organosols lose their identity as time goes on. The plasticizer, which always more or less constitutes a solvent for the polymer, has a slow action which manifests itself by a progressive swelling of the particles and an increase in the viscosity of the whole. The higher the temperature, the faster this process takes place. Plastisols and organosols should be stored at a temperature not in excess of 20 C. Application of a plastisol depends primarily on its flow properties (rheologic properties). All plastisols are characterized by a property which, although not precisely defined, is very important for their practical application, and which is expressed by the words *dilatancy* and *thixotropy*.

Dilatancy is the state of a paste which, although fluid when poured, solidifies when brusquely agitated. This property disappears rapidly when the plastisol is stored.

Thixotropy is the reverse process, i.e., the state of a paste which, at rest, is essentially solid but becomes fluid after more or less violent agitation, and solidifies again progressively after the agitation ceases.

These phenomena depend on the composition of the plastisol, particularly the dimensional uniformity of

the polymer grains and the state of their surface, on the type of plasticizer, and, to a large degree, on the method of preparation.

It follows, therefore, that it is impossible to describe the physical state of a plastisol by a simple viscosity measurement. The results are definitely not comparable, since they depend on the type of viscosimeter used. Thus, it is very necessary to resort to a measuring method which corresponds best to the intended type of application.

### Application

The main applications of plastisols in electrical engineering fall into two categories:

1. Molding of solid and hollow insulations.
2. Covering, which itself can be divided into coating and covering paper, either by dipping or by spraying. (Organosols may also be used for these purposes.)

*Molding* is done by filling a mold with plastisol and gelling by baking at 150 to 180 C. It is desirable to remove bubbles from the plastisol in a vacuum before pouring, and to let the mass settle before baking.

*Coating* is done by applying a layer of plastisol (or organosol) to various objects, for example handles of tools, which are then solidified in the oven. Removal of bubbles is necessary. The thickness of the insulating skin depends on the rheological properties of the plastisol and the initial temperature of the object, which may be preheated. For this purpose, it is preferable to use plastisols which have good fluidity, as well as pronounced thixotropy, even when warm. It is frequently necessary first to apply a primary adhesive layer.

### Properties

The properties of molded polyvinyl chloride plastisol insulation correspond to those given in the table of group 343, under the designation "Plasticized polyvinyl chloride." The minimum values shown should be taken into consideration.

The properties of plastisol- or organosol-coated papers and fabrics are shown in the table of group 335, under "Paper coated with plastic materials" and "Fabric coated with plastic material." The minimum dielectric values shown should be taken into consideration.

The properties of coverings consisting of polyvinyl chloride plastisol or organosol are given in the table of group 343, taking into account that the insulating layer is rather thin.

## Group 516: Adhesives and Mastics, Dried by Evaporation of a Solvent

The insulating materials of this group are applied as liquids or pastes which solidify by evaporation of the solvent. They are similar to the insulating materials of groups 513 or 514, but have a higher viscosity. Furthermore, the compositions of the insulations are designed to provide strong adherence to the objects to which they are applied. They are used to make materials adhere to each other (adhesives), or they are used to fill cavities (mastics). The *adhesives* are composed of one or more materials and, when necessary, of plasticizers, stabilizers, catalysts, or inhibitors, dissolved in appropriate solvents. The *mastics* of this group are compounds to which considerable amounts of fillers have been added in order to improve the viscosity (see comparative table for group 312).

The quality of a bonded junction depends on the nature and form of the objects to be united (sterigma\*), on the adhesive layer, and on the drying conditions, particularly the elimination of the solvent. The quantity of volatile materials at the time of bonding must be strictly controlled, especially for nonporous sterigma and adhesives hardened at low temperature. Pressure must be exerted on the surfaces to be adhered. The durability of the adhesion depends on the stresses to which the bonded objects are subjected, on the resistance of the adhesive to the surrounding conditions, and, if the temperature varies, on the dif-

ference between the thermal expansion coefficients of the adhesive and of the sterigmas. Adhesives having a certain elasticity applied in a thick layer will adjust themselves better to expansion than hard adhesives applied in a thin layer, but the adhesive power will be less. The adhesive strength decreases very rapidly if the temperature is increased. Certain adhesives are friable when cold, which has a bad effect on the adhesion. The mastics of this group, due to the presence of a solvent, are more difficult to apply than those of group 523. Their application is limited to the filling of open cavities. Care should be taken to eliminate the solvent very slowly, first at low temperature, then at increasing temperature, and possibly under a slight vacuum. Only after the volatile materials have been evaporated is it possible to raise the temperature appreciably. This comparative table shows some characteristics of adhesives which have found application in the electrical industry. The mastics derived therefrom have analogous properties which evolve from the indications given in description sheet 312. Generally speaking, it may be said that fillers increase the viscosity, reduce the thermal expansion coefficient, regularize the flow under pressure, and prevent excessive penetration into the material to be bonded. They also decrease the adhesive strength and the softness. But, on the other hand, they increase the thermal conductivity, hardness, and compression resistance. Fillers also have a favorable influence on cost.

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\* See table.



# Electrical Insulating Materials

## Synoptic Table for Group 516

### Adhesives and Mastics Dried by Evaporation of a Solvent

Classification	Principal constituents (the mastics contain also a filler)	Solvents	Hardening temperature, deg C (2)	General Characteristics of the Solid Insulation Material without Fillers								Price comparisons (3)	Principal lines of application	Precautions in use	Number of the monograph	
				Specific weight, g/cm <sup>3</sup>	Coefficient of linear expansion, 10 <sup>-6</sup> /deg C	Dielectric properties	Adherence to non- porous materials	Temperature limits for use	Resistance to Chemical Agents							
									Water	Solvents of the impregnation varnishes	Mineral oils					
Adhesives and mastics which harden by simple evaporation of the solvent	Starches	Water	20 to 80			(4)	○	-30 +110	○	○	●	●	●	Adhering paper to various carriers	Must be kept dry after adhering	
	Dextrin + if necessary, borax, urea and various salts	Water	20 to 80		○	○	○	-30 +110	○	○	●	●	●	Adhering paper to various carriers	Generally contains electrolytes	
	Bitumen and asphalts	Hydrocarbons	20 to 80	0.95 to 1.05		●	●	-15 to 30 +35 to 70	○	○	○	○	○	Adhering of mica and fiber materials	Flows under pressure	
	Natural resins (gum lac, copals, etc.)	Alcohols	20 to 80	1 to 1.1	○	○	○	-30 +50	○	○	○	○	○	Adhering of mica and fiber materials	Flows under pressure	
	Cellulose derivatives (nitrocellulose, etc.)	Esters and ketones	20 to 80	1.3 to 1.4	60 to 120	○	○	-30 +50	○	○	○	○	○	Adhering glass, ceramics, mica, metals, plastics, and textiles	Flows under pressure	
	Vinyl resins (vinyl acetate, acrylic resins, etc.)	Esters and ketones	20 to 60	1.1 to 1.2	80 to 90	○	○	-30 +50	○	○	○	○	○	Adhering glass, ceramics, mica, metals, plastics, and textiles	Flows under pressure	
	Elastomers (natural or synthetic rubbers and their derivatives)	Hydrocarbons and, if necessary, aqueous emulsion	20 to 60	1.3 to 1.7		○	○	-45 +70	○	○	○	○	○	Adhering of rubber and leather	Flows under pressure	

○ poor

● excellent

◐ dispersion between inferior  
and better qualities

(1) Sterigma: generic term designating any material to be held together by gluing. (Not com-  
monly used in English.)

(2) Temperature to be increased very slowly.

(3) ○ > 100

● < 4

(4) In strictly dry condition and if the glue does not contain electrolytes.

(5) The gum lac is transformed under the prolonged effect of a high temperature.

## Group 521: Thermosetting Resins Without Solvent, Nonpigmented, for Casting or Impregnation

The insulating materials of this group are applied in the liquid state and solidify in situ. They represent a mixture of synthetic resins with other compounds, such as hardeners and catalysts, each being supplied separately. These compounds are usually mixed just before application. The process of the material changing from the liquid state to the solid state is done at room temperature or with heat. The change is effected by a chemical action which cross-links the single molecules to macromolecules without splitting off volatile substances and therefore gives solid end-products without applying any pressure. The reaction often takes place with the development of considerable heat. The end-product is infusible, insoluble, and isotropic.

The synthetic resins and the hardening components are available in the solid or liquid state. The working up, i.e., mixing followed by casting, can be effected at room temperature, provided the resin is liquid and the hardening components dissolve in it easily. If the resin is solid or if the hardening agents do not dissolve easily, heat has to be applied.

The viscosity and potential life of the mixture, ready for use, can essentially be varied depending on the resin chosen, the hardening agents, and the working temperature.

The curing takes place at room or elevated temperature, depending on the chosen components. The time of curing can be days, hours, or only minutes; the time being shorter with increasing temperature.

The heat developed on the occasion of curing varies with the resin, and with the same resin, depends on the hardening agent. It results in an increase of temperature in the casting, which is dependent on its specific heat, its thermal conductivity, the dimensions and shape of the casting, the metal pieces embedded in it, and the efficiency of heat transfer to the surroundings.

Shrinkage takes place on curing. According to the type of resin and curing temperature, shrinkage may be as much as 15% by volume. Cured resins usually adhere well to many different kinds of material. Pieces made of cured resins may be bonded to each other, but they cannot be welded.

Liquid resins can be used to impregnate coils and windings, and, being free from solvents, they permit impregnation without pores. They are also used to embed the most varied kinds of electric apparatus and to make insulator castings of all shapes. For the manufacture of big castings the addition of finely divided minerals is recommended. The hardened resins are infusible and insoluble in most solvents.



## Group 522: Thermosetting Resins, Without Solvent, Pigmented, for Casting or Impregnation

The insulations of this group consist of the materials belonging to group 521, containing a dispersion of very finely divided solids, called fillers.

It has been thought preferable not to place the filled formulations in the same group with the unfilled formulations, because the former are heterogeneous materials with well-defined characteristics, requiring certain precautions on the part of the user. For this reason, the materials must be mixed carefully before use.

The fillers consist generally of the inorganic compounds described in the table of group 312, notably powdered quartz, chalk, slate, asbestos, mica, kaolin, talc, etc. Moisture, which is absorbed during storage, is particularly important. Generally, moisture is retained during manufacture of the composition in which the filler is dispersed and, because of this, the resulting mechanical and dielectric properties of the filled product deteriorate appreciably. Therefore, the fillers must be carefully dried before use, sometimes by heating them to red heat.

The quantity of filler to be added depends greatly on the nature, size, and shape of the particles. Up to 300% by volume may be added. The addition of the dry filler can be done with or without heating, preferably in vacuo. The cross-linking agents are added next. In order to obtain nonporous, void-free castings, it is necessary to expel the air bubbles present in the filled resin. This can be done before, during, or after casting.

The effects of powder, flakes, or fibers added to the resins of group 521 are apparent both when the insulations are applied in the liquid state and in the final properties of the solid insulations.

### Influence of Fillers on Insulating Materials of Group 521

#### ON APPLICATION

The fillers increase the *viscosity*. Large, dense, spherical, smooth particles have the least influence, while fine, porous, irregularly surfaced materials and fibers which can intermix show the greatest influence.

The fillers decrease *shrinkage* on solidification, especially if the shape of the particles is irregular and the filler content is elevated. This property is

particularly important in the coating of metallic pieces or ceramics.

The hardening of the resin is always an exothermic reaction. The evolution of heat increases with increasing size of the coatings, with decreasing heat capacity of the filled resin, and with diminishing heat dissipation. *Fillers lower the temperature and facilitate the uniform distribution of heat.*

Fillers also *decrease cost*. In fact the insulating materials of group 312 cost considerably less than those belonging to group 521.

#### IN THE FINAL STATE

Fillers increase the *density*. They also modify the *mechanical properties*. Hardness, resistance to compression, and modulus of elasticity are higher, while elongation, resistance to flexing, and tensile strength are lower. Fillers change the *dielectric properties*, although without uniformity. Flame-resistant fillers which decompose at high temperature without leaving conducting residues improve the arc and surface current resistance.

In general, fillers improve the resistance to *chemical agents* if the time of exposure is short. If the time is long and if the surface of the insulation is attacked, the degradation of the insulation proceeds rather rapidly.

Fillers modify the *thermal properties*. In general, they improve the heat transmission and raise the thermal resistance somewhat. The thermal coefficient of expansion decreases noticeably but not proportionally to the volume of the filler. By using, for example, quartz powder, this coefficient may be reduced about four times. However, it remains higher than that of iron or porcelain.

Fillers change the *appearance* by rendering the insulation opaque. Certain pigments supply coloration.

Fillers may make *machining* difficult when they consist of abrasive material and when they are used in high percentages.

The result of all this, as indicated in the comparative table of group 521, is that only the resins to which fillers have been added are suitable for the casting of very large pieces. However, fillers influence the properties of the material which must be taken into account in service.

## Group 523: Paste Materials, Hardenable, Without Solvent (Mastics and Cements)

Insulating materials of this group are supplied as viscous masses that solidify (1) by action of a hardening agent, or (2) by action of a liquid such as water or sodium silicate. One fundamental characteristic of these materials is their ability to adhere to the bodies to which they are applied. They are used to fill cavities, to assure tight seals, and to fasten materials to each other.

The quality of adhesion depends upon the nature and configuration of the bodies to be bonded together,\* the state of the surfaces, and conditions of hardening. Application of pressure is recommended.

The permanence of the bond depends (1) on stresses to which it is subjected, (2) on the resistance

of the bonded body or bodies to ambient conditions, and (3) in the presence of temperature variations on the difference between its coefficient of expansion and that of the substratum. Insulation materials that possess certain elasticity in masses of thick layers withstand expansion better than hard bodies such as cements. Adhesion decreases with increasing temperature, as do the dielectric properties. These characteristics are important if the insulating material is utilized in thin layers for bonding purposes; they are much less important if the material is used to fill cavities. Since they are solventless, insulating materials of this group can be used more easily than those belonging to group 534. Many among them, however, especially the cements, have rather mediocre dielectric properties.

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\* See table.

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### Electrical Insulating Materials

#### Synoptic Table for Group 523 Paste Materials Hardenable Without Solvent (Mastics and Cements)

Class	Usual Designation	Principal Constituents	approximate quantity	Conditions for Application						Characteristics of the Solid Insulation										Field of Application	Precautions in use	Number of the monograph			
				Temperature of solidification, deg C	Time of congealing, hrs	Time of complete hardening, days	Volume expansion	Volume contraction	Density, g/cm <sup>3</sup>	Linear coefficient of expansion 10 <sup>-6</sup> /deg C	Dielectric properties	Constancy of the dielectric properties as a function of temperature	Constancy of the dielectric properties as a function of humidity	Adherence to nonporous surfaces	Maximum temperature admitted in service, deg C	Resistance to Chemical Agents	Water	Mineral oil	Comparative price						
Substances with a drying oil base	Glasier's putty	Lined oil Calcium carbonate (chalk)	15	20	200 to 300	60 to 100	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	●	Glass-wood or glass-metal joints		Number of the monograph
			85																						
Substances with a synthetic resin base	Epoxy mastics	Cold setting epoxy Mineral fillers (Group 312) Hardeners		20	3	1-1/2 to 2	●	●	1.8 to 2.0	50 to 80	●	●	●	●	●	●	●	●	●	●	●	●	Mastic adherent to almost all supports	Weak physiological reactions	
		Heat setting epoxy Mineral fillers (Group 312)		100 to 150	1/2 to 4	1/8 to 2	●	●	1.8 to 2.0	25 to 40	●	●	●	●	●	●	●	●	●	●	●	●	Mastic adherent to almost all supports		
	Polyester mastics	Unsaturated polyesters Mineral fillers (Group 312) Hardeners for cold setting		20	1/2 to 8	1/6 to 2	●	●	1.75 to 1.78	60 to 80	●	●	●	●	●	●	●	●	●	●	●	●	Mastic perfectly adherent to porous surfaces	Can corrode copper	
		Unsaturated polyesters Mineral fillers (Group 312) Hardeners for heat setting		80 to 100	1/2 to 1	1/10	●	●	1.75 to 1.78	30 to 80	●	●	●	●	●	●	●	●	●	●	●	●	Mastic perfectly adherent to porous surfaces	Has a strong tendency to bubble with heat hardening	

Substances with a mineral base which set in contact with a liquid (cements)	Litharge-glycerine cement	Litharge (PbO) Glycerine	100 20 to 35	20 to 120	1/4	2 to 3		7.8										Cements adherent to ceramics	Toxic	
	Plaster	Gypsum (CaSO <sub>4</sub> ·1/2H <sub>2</sub> O) Water or aqueous solution of glue	100 33 to 40	20 to 120	1/4 to 1/2	4 to 14		2.3	(1) 10									Cements adherent to ceramics		
	Portland cement	Portland cement Water	100 35 to 40	20 to 120	12 to 16	21 to 28		2.7 to 3.0	(1) 6									Cements adherent to ceramics		
	Porcelain cement	Large cement Quartz powder Porcelain powder Water	40 40 20					2.3	9 to 10									Cements adherent to ceramics		
	Magnesia cement	Magnesium oxide (MgO) Solution of magnesium chloride	100 70 to 90	20 to 120	12 to 16	8 to 14		3.2 to 3.4	(1) 12									Cements adherent to ceramics	Corrosive: acid reaction	
	Sodium silicate cements		Aluminum oxide (Al <sub>2</sub> O <sub>3</sub> ) Aluminum oxide hydrate Litharge (PbO) 38% Sodium silicate	50 10 2 to 5 42	150		1		3.6 to 3.8	(1) 10									Cements adherent to ceramics	Corrosive: acid reaction
			Asbestos powder Sodium silicate, 30% Quartz powder	100 100 100	20	1/2	3 to 4		2.6	10									Cements adherent to ceramics	Corrosive: acid reaction
			Quartz powder Barium sulfate Calcium sulfide Sodium silicate, 35%	200 100 6	20	1/10	1		3.4 to 3.8	(1) 10									Cements adherent to ceramics	Corrosive: acid reaction

Numerical values used in the editing of the table (logarithmic scale should not be used as basis of construction)

poor

excellent

dispersion between inferior and better qualities

- (1) Under the action of heat-drying, followed by rehumidification, irreversible changes are obtained which are more important than those resulting from the coefficient of thermal expansion.
- (2) The sign relates to the adhesion to porcelain. These cements oxidize metals, from which they finally detach themselves.
- (3) These temperatures are intended for cements prepared with the greatest of care and with faultless raw materials. Adhesion decreases with increasing temperature, in such a way that above 100 deg C the bonds become extremely fragile.
- (4) The sign relates to cements which, after hardening, are not treated with diluted acids.

Test method and units	Volume expansion, %	Volume shrinkage, %	Cost
	>16	>16	>100
	<0.6	<0.6	<4

## Group 531: Insulating Varnishes for Impregnation of Coils and Protection of Apparatus, Nonpigmented, Dried by Solvent Evaporation and Chemical Reaction

The insulating varnishes of this group are supplied as solutions in suitable solvents of natural or synthetic resins, most often in combination with drying oils or with other plasticizing compounds. The varnishes dry through two distinct phenomena: by *evaporation* of the solvent, which is only present to provide the varnish with a suitable viscosity; followed by a *chemical transformation* of the substances dissolved in the solvent, that is, oxidation in the case of oleo-resinous varnishes, polycondensation, polymerization, or polyaddition for the other varnishes. These transformations occur easily when the varnish forms a thin film, but with difficulty if it appears as a thick layer, as in an impregnated coil. Some varnishes do not dry at all in thick layers. The final properties of an impregnating varnish depend greatly upon the treatment by the user and the equipment used. The main difficulty consists in preventing the surface from drying before the solvent has left the interior of the impregnated coil. No matter what precautions are taken, the properties

of a deep resin-filled section in a coil are not those measured on a varnish film applied in thin layers to a smooth surface. It must also be kept in mind that the solvent, during evaporation, leaves voids in the coil, which may exert an unfavorable influence on the insulation of the machine, especially at high voltages. This disadvantage does not exist for the solventless varnishes of group 521. The dielectric properties of a dry varnish film are generally excellent. They ordinarily deteriorate with increased moisture and temperature. The shelf and impregnation tank life of these varnishes is a very important characteristic. In general, varnishes which dry well in deep sections possess a tendency to thicken unless kept cold during storage and use. The large variety of resins available and the possibility of combining them among themselves, or with film-forming substances, provide the manufacturer with a great number of insulating varnishes. Therefore, classification cannot be complete. This table only accounts for the main groups of insulating varnishes.



See next page for table

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## Electrical Insulating Materials

### Synoptic Table for Group 531

Insulating Varnishes for the Impregnation of Coils and the  
 Protection of Apparatus, Nonpigmented, Dried by Solvent  
 Evaporation and Chemical Processes

Swiss Type of Varnish	Group	Composition of Varnish	General Characteristics of the Dry Varnish												Precautions in use	Number of the monograph	
			Dielectric Properties					Mechanical Properties				Resistance to Chemical Agents					
			Electric strength	Volume resistivity	Resistance to tracking	Constancy of the insulation	Constancy of the insulation with temperature	Constancy of the insulation with humidity	Dryness in the interior of a coil	Resistance to heat aging (2)	Water	Hot mineral oil	Chlorinated dielectrics	Dilute acids	Dilute alkalis	Comparative price	
			20 C	100 C	20 C	100 C	Bond Strength	20 C									
		Natural or synthetic resins, possibly modified with asphalt, dissolved in drying oils							●	●	○	●	●	●	○	●	●
		Phenolic resin	●	●	○	●	●	●	○	●	●	●	○	●	●	●	Strong tendency to crack
		Isocyanates + polyesters "polyurethane varnish"	●	●	○	●	●	●	○	●	●	●	○	●	●	●	Short shelf life; prepare immediately before use
		Epoxy resin + plasticizer	●	●	○	●	●	●	○	●	●	●	○	●	●	●	
		Silicone resin	●	●	○	●	●	●	○	●	●	●	○	●	●	●	Drying of varnish required at 180 C to 250 C
		Reactive phenolic resin + drying oil, "oil modified phenolic varnish"	●	●	○	●	●	●	○	●	●	●	○	●	●	●	
		Alkyl resin, usually + urea (or melamine) formaldehyde with butanol	●	●	○	●	●	●	○	●	●	●	○	●	●	●	
		Alkyd resin + phenolic resin "alkyd-phenolic varnish"	●	●	○	●	●	●	○	●	●	●	○	●	●	●	
		Alkyd silicone resin	●	●	○	●	●	●	○	●	●	●	○	●	●	●	
		Epoxy resin + alkyd either drying oil or fatty acid ester, etc.	●	●	○	●	●	●	○	●	●	●	○	●	●	●	



## Group 532: Pigmented Insulating Varnishes, Dried by Solvent Evaporation and Chemical Processes

The insulating materials of this group consist of the insulating varnishes from group 531 in which are dispersed very finely divided solids, called pigments.

It has been thought preferable not to place the pigmented varnishes in the same group with the nonpigmented varnishes, because the former are heterogeneous bodies having well-defined characteristics that require certain precautions on the part of the user. For instance, the pigments tend to settle out; the varnishes therefore must be stirred carefully before use.

The properties of the varnishes of this group depend essentially upon the nature of the basic varnish, the type of pigment, the proportions employed, and the care exercised in mixing.

As compared with the corresponding varnishes of group 531, the varnishes of group 532 are characterized by the following properties:

1. The varnishes are opaque, either white or colored, thus concealing the objects on which they are applied.
2. Their coating characteristics are better. When applied with a brush, they give a thicker film; consequently, fewer coats are necessary to obtain a smooth surface.
3. Because of the thick film, they offer better protection against water, provided the coats are not porous.
4. They are noticeably more viscous; their power of penetration is small because the pigments obstruct the pores of the substrate.
5. They are less flexible than the corresponding basic varnishes.
6. They generally conduct heat better.
7. They have better resistance to creep.

The general properties of the varnishes of group 532 can be arrived at from those of the corresponding varnishes of group 531, making allowances for the previously cited characteristics. In principle, a pigment can be added to all the varnishes of group 531; in practice, however, only the basic varnishes of great clarity and resistance to light are used. These are, in the case of oven-drying varnishes, certain oleo-resinous varnishes, alkyd, epoxy, polyurethane varnishes; in the case of air-drying varnishes, certain oleo-resinous and alkyd varnishes.

The insulating varnishes of this group are specifically indicated for the treatment of surfaces of electric equipment. They should not be used for the impregnation of coils.

## Group 533: Insulating Varnishes for the Coating of Electrical Conductors

Insulating varnishes (enamels) of this group are, as delivered for use, solutions, in appropriate solvents, of synthetic or modified natural resins, sometimes combined with other substances such as drying oils, and asphalts. Two distinct phenomena cause the drying of the varnish: (1) *solvent* evaporation, the purpose of which is to impart to the varnish a suitable viscosity for application; and (2) a chemical reaction of the substance dissolved in the solvent; oxidation for the oil varnishes, and polymerization, polycondensation, or polyaddition for the other varnishes. In the production of enameled wire these reactions are most usually effected at high temperatures, 250–400 C in a very short time.

The varnish is applied onto the bare wire in a number of layers varying in thickness from 0.02 to 0.2 mil ( $10^{-3}$  inch), depending on the diameter of the wire. The difficulty of drying, described in the table

of group 531, does not arise for the varnishes of this group.

The properties of the dry varnish, notably the mechanical properties, the behavior under heat, and the chemical resistance, depend primarily on the composition. The electric strength and the insulation resistance are generally excellent immediately after the manufacture of the wire. They can decrease markedly under the influence of humidity. Most of the enamels with a synthetic resin base have a tendency to craze, or crack, in the presence of a solvent or under mechanical strain such as rapid elongation; as a result their dielectric properties are considerably diminished. These cracks, which are difficult to see, disappear for the most part if the wire is heated at a temperature above 125 C after winding.

The characteristics indicated in the table are of enamels applied to the wire under optimum conditions.

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### Electrical Insulating Materials

#### Synoptic Table for Group 533

#### Insulating Varnishes for the Coating of Electrical Conductors

Type of varnish (enamel)	Principal Constituents	General Characteristics of Enameled Wires												Precautions in use	Number of the monograph															
		Dielectric Properties				Mechanical Properties			Behavior with Heat				Resistance to Chemical Agents																	
		Electric strength	Volume resistivity	Constancy of the dielectric properties as a function of temperature	Constancy of the dielectric properties as a function of humidity	Hardness	Flexibility	Abrasion resistance	Softening with heat	Heat shock at 170 deg C	Loss in weight after heating 10 hrs. at 170 deg C	Loss in flexibility with thermal aging	Maximum temperature admitted in service (4)			Solvents of impregnating varnishes	Hot mineral oil	Chlorinated dielectrics	Freon 22 (5)	Tendency to crazing by solvent or on rapid winding	Possibility of removing the enamel in a bath of molten solder	Comparative price								
Oleo-resinous varnishes	Drying oils + natural or synthetic resins + possibly asphalt	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●		
	Urea formaldehyde resins and phenol formaldehyde plasticizers	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
	Polyvinyl acetal resin + phenol formaldehyde resin	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
	Polyamide resin + phenol formaldehyde resin	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Synthetic varnishes (enamels)	[Visual indicators: circles with various shading patterns]														[Temperature ranges]						
	Epoxy resin, possibly modified	Polyurethane resin, frequently modified by other resins	Esters of terephthalic acid	Silicone resins, most frequently modified with esters of terephthalic acid	Polytetrafluoroethylene	[...]	[...]	[...]	[...]	[...]	[...]	[...]	[...]	[...]	[...]	120 to 130	120 to 130	130 to 155	155	180	
	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Numerical values used in the editing of the table (logarithmic scale) (should not be used as basis of construction)

Test method and units	kv/cm	ohm-cm (5)	DIN 46453 test by pencil	Diam-eter, mm (1)	NEMA	DIN 46453 deg C	Diam-eter, mm (2)	%	Diam-eter, mm (3)	deg C	many cracks	no cracks
○	<200	<10	<1H	4	<10	140	4	60	15	>500	many cracks	>100
●	>1000	>100000	6H	0.5	>130	300	0.5	5	0.5	350	no cracks	<4

- (1) Diameter on which one can wind a wire of 0.040 in. after 20% elongation.
- (2) Diameter on which one can wind a wire of 0.040 in. without cracking the enamel immediately with heating to 170 C.
- (3) Diameter on which one can wind a wire of 0.040 in. after heating 2 days at 170 C.
- (4) If the winding is suitably impregnated.
- (5) Freon 12 has very little effect.

## Group 534: Adhesives and Mastics, Dried by Evaporation of a Solvent and Chemical Processes

The insulating materials of this group are applied in the form of liquid substances or pastes which solidify by evaporation of the solvent, with or without subsequent chemical transformation. Their main characteristic is that they adhere to objects to which they are applied. They are used to bind materials to each other (adhesives) or to fill cavities (mastics). The adhesives are composed of one or more base materials and possibly plasticizers, stabilizers, catalysts, or inhibitors, dissolved in an appropriate solvent. The mastics are adhesives to which considerable filler has been added in order to increase the viscosity (see comparative table for group 312). The quality of the adhesion depends on the nature and form of the objects to be bonded (sterigmas\*), adhesive applied, condition of the surfaces, thickness of the adhesive layer, and drying conditions, particularly the elimination of the solvent. The quantity of volatile material must be strictly controlled, particularly in the case of nonporous sterigmas and adhesives hardened at low temperature. It is necessary to apply pressure on the surfaces to be adhered. The stability of the adhesive depends on the stresses to which the bonded objects are subjected, the resistance of the adhesive to the surrounding conditions, and, if the temperature varies, the dif-

ference between the thermal expansion coefficients of the adhesive and the sterigmas. Thick layers of adhesives having a certain elasticity will adapt themselves better to expansions than thin layers of hard adhesives but their adhesive power will be less. Generally, the adhesive strength decreases if the temperature rises. Certain adhesives are friable when cold, which has a bad effect on the adhesion.

The mastics of this group, due to the presence of a solvent, are more difficult to apply than those of group 523. Their use should be limited to filling open cavities. Care should be taken that the solvent is eliminated very slowly, first at low temperature, then at a rising temperature, and possibly under a slight vacuum. The baking should not be started until all volatile substances have been evaporated. This table shows some characteristics of adhesives which have found application in the electrical industry. The mastics derived therefrom have analogous properties which evolve from the indications given in description sheet 312. Generally speaking, it may be said that fillers increase the viscosity, reduce the thermal expansion coefficient, regularize the flow under pressure, and prevent excessive penetration into the sterigma. They also reduce the adhesive strength and softness. On the other hand, they increase the thermal conductivity, hardness, and resistance to compression. Fillers also have a favorable influence on the cost.

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\* Sterigma is a generic term designating any material to be held together by gluing. It is not commonly used in English.



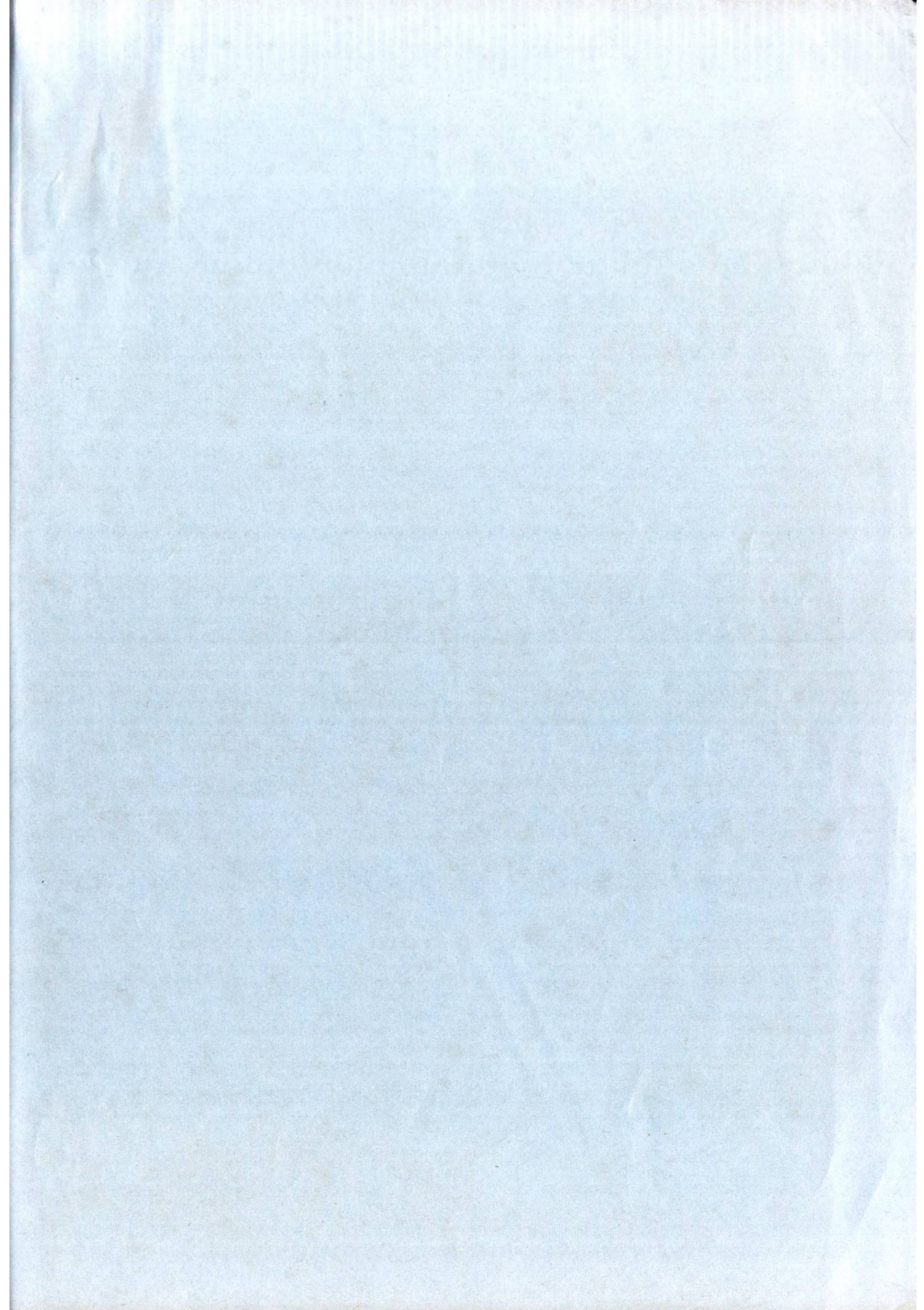
See next page for table



Tearing resistance	ASTM kg/cm	<6.3	6.3 to 10	>10 to 16	>16 to 25	>25 to 40	>40 to 63	>63 to 100	>100 to 160	>160	332, 411, 441
	Elmendorf g	<63	63 to 100	>100 to 160	>160 to 250	>250 to 400	>400 to 630	>630 to 1000	>1000 to 1600	>1600	335
	Elmendorf g	<100	100 to 125	>125 to 160	>160 to 200	>200 to 250	>250 to 315	>315 to 400	>400 to 500	>500	336
Flexural strength	kg/cm <sup>2</sup>	<250	250 to 400	>400 to 630	>630 to 1000	>1000 to 1600	>1600 to 2500	>2500 to 4000	>4000 to 6300	>6300	341
	deg C	<100	100 to 150	>150 to 320	>320 to 400	>400 to 500	>500 to 630	>630 to 800	>800 to 1000	>1000	312
Thermal resistance	kg/cm <sup>2</sup>	<250	250 to 400	>400 to 660	>630 to 1000	>1000 to 1600	>1600 to 2500	>2500 to 4000	>4000 to 6300	>6300	331, 332, 355, 341, 342, 343, 351, 411, 441
	kg/cm <sup>2</sup>	<63	63 to 100	>100 to 160	>160 to 250	>250 to 400	>400 to 630	>630 to 1000	>1000 to 1600	>1600	333, 336
	kg/cm <sup>2</sup>	<40	40 to 50	>50 to 63	>63 to 80	>80 to 100	>100 to 125	>125 to 160	>160 to 200	>200	344, 345
	g/den	<0.63	0.63 to 1.00	>1.0 to 1.6	>1.6 to 2.5	>2.5 to 4.0	>4.0 to 6.3	>6.3 to 10	>10 to 16	>16	321
	ohm-cm	<10 <sup>6</sup>	10 <sup>6</sup> to 10 <sup>10</sup>	>10 <sup>10</sup> to 10 <sup>11</sup>	>10 <sup>11</sup> to 10 <sup>13</sup>	>10 <sup>13</sup> to 10 <sup>14</sup>	>10 <sup>14</sup> to 10 <sup>15</sup>	>10 <sup>15</sup> to 10 <sup>16</sup>	>10 <sup>16</sup> to 10 <sup>18</sup>	>10 <sup>18</sup>	321, 331, 332, 335, 336, 341, 342, 343, 344, 345, 351, 411, 441, 511, 513, 521, 531
Resistivity	ohm-cm	<10	10 to 2500	>2500 to 6100	>6100 to 12500	>12500 to 16400	>16400 to 37300	>37300 to 62000	>62000 to 100000	>100000	533
	%	>16	16 to 10	<10 to 6.3	<6.3 to 4	<4 to 2.5	<2.5 to 1.6	<1.6 to 1	<1 to 0.6	<0.6	511, 521, 523
Volume contraction	kv/cm	<25	25 to 40	>40 to 63	>63 to 100	>100 to 160	>160 to 250	>250 to 400	>400 to 630	>630	331, 335, 336, 341, 342, 343, 344, 345, 351, 511, 513, 521, 531
	kv/cm	<200	200 to 250	>250 to 320	>320 to 400	>400 to 500	>500 to 630	>630 to 800	>800 to 1000	>1000	533
Electric strength		>100	100 to 63	<63 to 40	<40 to 25	<25 to 16	<16 to 10	<10 to 6.3	<6.3 to 4	<4	all except 111, 312 and 511
	Comparative price	>1000	1000 to 300	<300 to 100	<100 to 30	<30 to 10	<10 to 3	<3 to 1	<1 to 0.3	<0.3	111
Variation in viscosity with temperature		>10	10 to 6.3	<6.3 to 4	<4 to 2.5	<2.5 to 1.6	<1.6 to 1	<1 to 0.63	<0.63 to 0.4	<0.4	312, 511
	% deg C	>25	25 to 16	<16 to 10	<10 to 6.3	<6.3 to 4	<4 to 2.5	<2.5 to 1.6	<1.6 to 1	<1	211
Viscosity	cP	<1	1 to 2	>2 to 4	>4 to 8	>8 to 16	>16 to 31.5	>31.5 to 63	>63 to 125	>125	511
Volatility	mm Hg at 100 C	>3	3 to 1	<1 to 0.3	<0.3 to 0.1	<0.1 to 0.03	<0.03 to 0.01	<0.01 to 0.003	<0.003 to 0.001	<0.001	211

## Appendix 2. Alphabetical List of Insulations

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