# DuPont™ Teflon® PFA

## fluoropolymer resins

## Properties Handbook

The miracles of science™

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# General

## Introduction

As with any product, proper understanding of the capabilities and limitations of DuPont™ *Teflon*® PFA fluoropolymer resins is essential for effective design and use of the material. The properties and characteristics of *Teflon*® PFA presented in this handbook are offered to help encourage the proper design of parts made of *Teflon*® PFA, to make *Teflon*® PFA easier to use, and to increase the reliability of finished parts.

It is recommended that an experienced fabricator be involved early in the design stage because the method of fabrication may affect the product cost and properties of the finished article.

## The Product

*Teflon*® PFA is the newest member of the DuPont family of high-performance fluoropolymer resins. It was developed to extend the range of uses of *Teflon*® by providing an easily molded or extruded thermoplastic with outstanding properties. *Teflon*® PFA is especially useful to designers and end-users who require a thermoplastic with excellent chemical stability, electrical properties, and mechanical strength for use in high- and low-temperature environments.

*Teflon*® PFA is available in two grades of resin and as a film.

*Teflon*® 340 fluoropolymer resin, of moderate molecular weight, is a general-purpose resin designed for high-speed extrusion, injection molding, and blow molding. *Teflon*® 340 is successfully used in a variety of applications, such as wire insulation and jacketing, extruded tubing, and intricate molded parts.

*Teflon*® 350 has a higher molecular weight than *Teflon*® 340 and provides outstanding mechanical, chemical, and thermal properties in molded parts that are subjected to extreme mechanical and chemical stress in high-temperature environments. *Teflon*® 350 can be extruded and molded for lining tanks, pipes, valves, pumps, tees, and elbows used in the chemical processing industry.

*Teflon*® PFA film, convenient and easy to use, affords opportunities to design and fabricate parts for a broad range of applications. It can be thermoformed, heat sealed, welded, and heat laminated. It also offers outstanding performance when used as a hot melt adhesive.

## Typical Properties

Typical property data for *Teflon*® 340 and *Teflon*® 350 resins are shown in **Table 1**.

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## Table 1
## Typical Physical and Mechanical Properties of DuPont™ *Teflon*® PFA Resins

| Property | Test Method | Unit | *Teflon*® 340 | *Teflon*® 350 |
|---|---|---|---|---|
| Nominal Melting Point | ASTM D3418 | C° (°F) | 302–310<br>(575–590) | 302–310<br>(575–590) |
| Specific Gravity | ASTM D792 | — | 2.12–2.17 | 2.12–2.17 |
| Melt Flow Rate | ASTM D3307 | g/10 min | 14.0 | 2.0 |
| Continuous Use Temp. | — | C° (°F) | 260 (500) | 260 (500) |
| Tensile Strength | | | | |
| 23°C (73°F) | ASTM D1708 | MPa (psi) | 25 (3,600) | 28 (4,000) |
| 250°C (482°F) | | | 12 (1,800) | 14 (2,000) |
| Ultimate Elongation | | | | |
| 23°C (73°F) | ASTM D1708 | % | 300 | 300 |
| 250°C (482°F) | | | 480 | 500 |
| Flexural Modulus | | | | |
| 23°C (73°F) | ASTM D790 | MPa (psi) | 590 (85,000) | 625 (90,000) |
| 250°C (482°F) | | | 55 (8,000) | 69 (10,000) |
| Creep Resistance* | | | | |
| Tensile Modulus | ASTM D2990 and | | | |
| RT | ASTM D2991 | MPa (psi) | 270 (40,000) | 270 (40,000) |
| 250°C (482°F) | ASTM D695 | | 41 (6,000) | 41 (6,000) |
| Deformation Under Load** | | | | |
| RT | ASTM D621 | % Strain | 2 | 2 |
| 200°C (392°F) | | | 4 | 4 |
| Thermal Conductivity | DuPont | W/(m·k) (Btu·in/ hr·ft$^2$·°F) | 0.19 (1.3) | 0.19 (1.3) |
| Hardness Durometer | ASTM D2240 | D | D55 | D55 |
| MIT Folding Endurance | | | | |
| 0.20 mm (7–8 mil) | ASTM D2176 | Cycles | 15,000 | 500,000 |
| Water Absorption | ASTM D570 | % | <0.03 | <0.03 |
| Coefficient of Linear Thermal Expansion | ASTM D696 | mm/mm/°C (in/in/°F) | | |
| 20–100°C (70–212°F) | | | 14 x $10^{-5}$<br>(7.6 x $10^{-5}$) | 14 x $10^{-5}$<br>(7.8 x $10^{-5}$) |
| 100–150°C (212–300°F) | | | 17 x $10^{-5}$<br>(9.2 x $10^{-5}$) | 18 x $10^{-5}$<br>(9.8 x $10^{-5}$) |
| 150–210°C (300–480°F) | | | 21 x $10^{-5}$<br>(11.5 x $10^{-5}$) | 22 x $10^{-5}$<br>(12.1 x $10^{-5}$) |

**Note:** The data provided in this table are typical for the resins tested and do not represent product specifications.

* 10 hr apparent modulus: stress = 6.9 MPa (1,000 lb/in$^2$) at RT, 0.69 MPa (100 lb/in$^2$) at 250°C (482°F)

** 10 hr compressive stress = 0.69 MPa (100 lb/in$^2$) at RT, 2.1 MPa (300 lb/in$^2$) at 200°C (392°F)

# Mechanical Properties

## *Tensile Strength*

The tensile strength of *Teflon*® PFA fluoropolymer resins vs. temperature is shown in **Figure 1**. As expected, tensile strength decreases with increasing temperatures.

The change with temperature in ultimate elongation or elongation at break of *Teflon*® PFA is shown in **Figure 2**. Typically the elongation of PFA resin increases with increasing temperatures, at least through the rated continuous use temperature.

## *Stiffness*

The stiffness of a plastic material is frequently of importance in determining its use as an engineering material. While fluoropolymer materials are not considered stiff among plastics, their combination of stiffness retention to 200°C (392°F), chemical inertness, and electrical properties has made them an integral part of the chemical process, semiconductor manufacturing, and high-temperature electrical industries.

## *Flexural Modulus*

The change in flexural modulus of *Teflon*® PFA with temperature is shown in **Figure 3**. Two samples of PFA are presented to show the range of properties expected from typical variations in crystallinity. One sample (specific gravity = 2.140) was water quenched to decrease the crystallinity. This resulted in a decrease in stiffness of the material in the temperature ranges studied.

**Figure 1. DuPont™ *Teflon®* PFA Fluoropolymer Resins, Relation of Tensile Strength to Temperature**

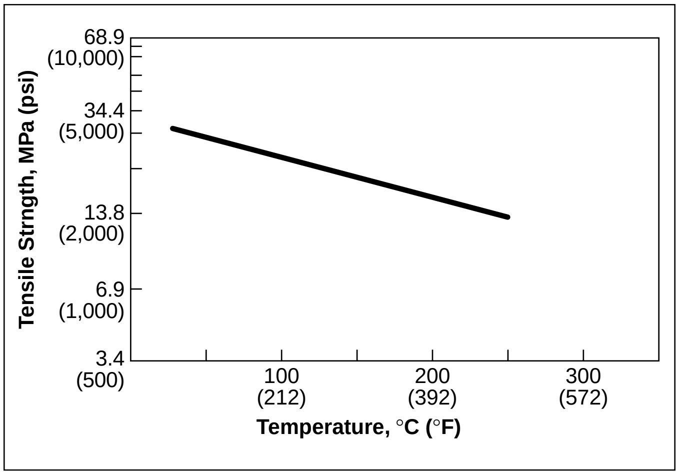


**Figure 2. DuPont™ *Teflon®* PFA Fluoropolymer Resins, Relation of Ultimate Elongation to Temperature**

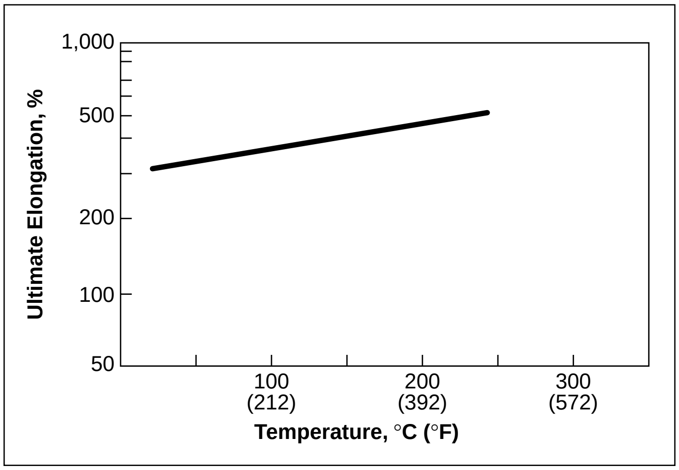


**Figure 3. DuPont™ *Teflon®* PFA Fluoropolymer Resins, Relation of Flexural Modulus to Temperature**

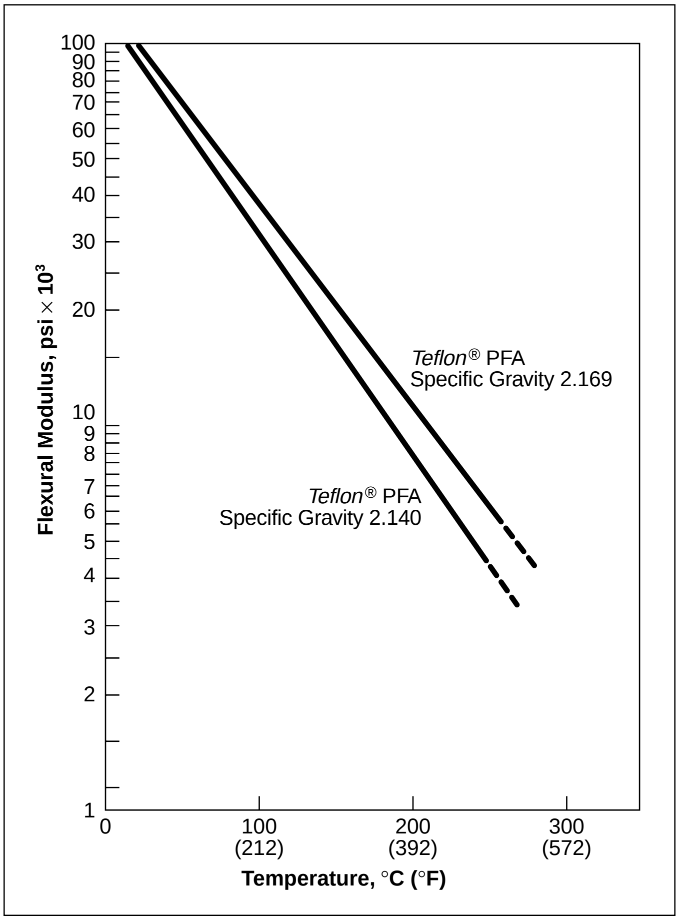


**Figure 4. DuPont™ *Teflon*® PFA, Total Deformation vs. Time Under Load at 23°C (73°F)**

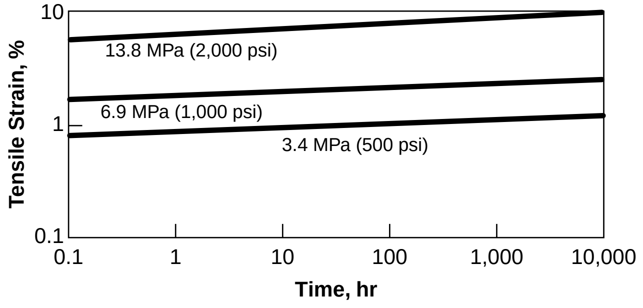


**Figure 5. DuPont™ *Teflon*® PFA, Total Deformation vs. Time Under Load at 100°C (212°F)**

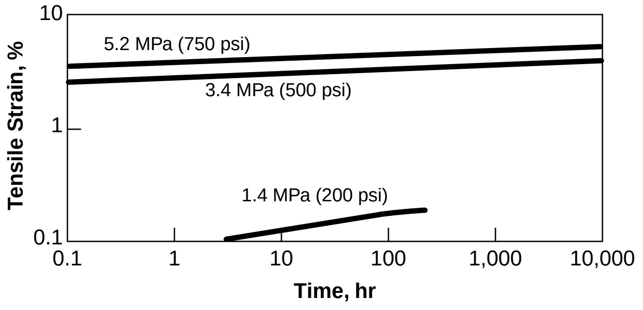
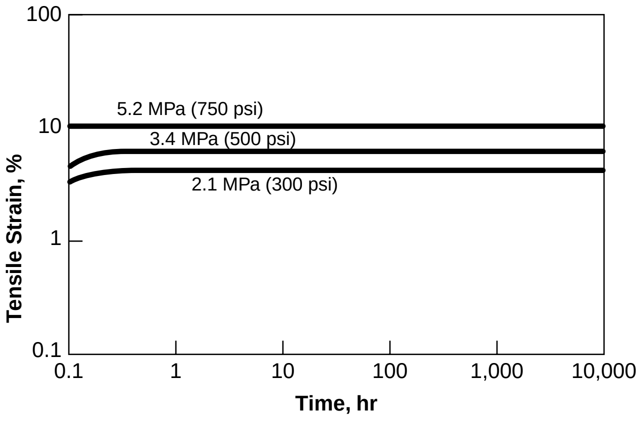


**Figure 6. DuPont™ *Teflon*® PFA, Total Deformation vs. Time Under Load at 200°C (392°F)**



## Cold Flow (Creep)

*Teflon*® PFA fluoropolymer resin, as other plastic materials, experiences deformation when subjected to tensile or compressive stresses. This deformation, or cold flow (creep), occurs well below the yield point of the resin and is especially important when fluoropolymer resins are used in lined pipes, hoses, seals, gaskets, etc.

The resistance to creep in tension is described as the apparent modulus. It describes the sum of the initial response to tensile stress plus a time-dependent response. The numbers shown in **Table 1** are the tensile moduli apparent after 10 hr under varying loads and temperatures.

The creep observed in a compressive situation is usually described as a percent strain under a given load. **Figures 4**, **5**, and **6** show the tensile strain observed under various loads at three temperatures. **Figure 7** shows compressive strain under various loads at one temperature. The figures give a picture of the initial strain under load and the slow increase with time on prolonged exposure.

## Hardness

The hardness of *Teflon*® PFA fluoropolymer resins is 55–57 durometer. This result was obtained in tests run on compression-molded panels according to ASTM D2240.

## Cryogenic Temperature Effects

Tests made at liquid nitrogen temperatures indicate that *Teflon*® PFA performs well in cryogenic applications. The results of standard ASTM tests performed on samples at room and cryogenic temperatures are shown in **Table 2**.

**Figure 7. Cold Flow Properties of DuPont™ *Teflon*® Fluoropolymer Resins, Compressive Creep at 200°C (392°F)**

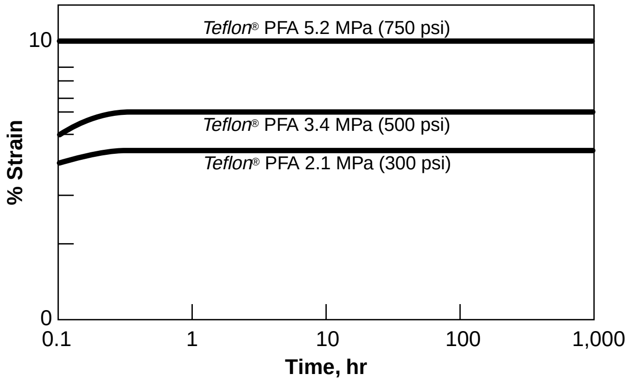


**Table 2**
**Cryogenic Properties of DuPont™ *Teflon*® PFA Fluoropolymer Resins**

| Property | ASTM Method | Unit | Value | |
|---|---|---|---|---|
| | | | Room Temperature, 23°C (73°F) | Cryogenic Temperature, –196°C (–320°F) |
| Yield Strength | D1708[a] | MPa<br>(psi) | 15<br>(2,100) | No Yield |
| Ultimate Tensile Strength | D1780[a] | MPa<br>(psi) | 18<br>(2,600) | 129<br>(18,700) |
| Elongation | D1708[a] | % | 260 | 8 |
| Flexural Modulus | D790-71[b] | MPa<br>(psi) | 558<br>(81,000) | 5,790<br>(840,000) |
| Impact Strength Notched Izod | D256-72a[c] | J/m<br>(ft-lb/in) | No break | 64<br>(1.2) |
| Compressive Strength | D695 | MPa<br>(psi) | 24<br>(3,500) | 414<br>(60,000) |
| Compressive Strain | D695 | % | 20 | 35 |
| Modulus of Elasticity | D695 | MPa<br>(psi) | 69<br>(10,000) | 4,690<br>(680,000) |

[a] Crosshead speed B, 1.3 mm/min (0.05 in/min); used at both temperatures for more direct comparison.
[b] Method 1, Procedure B.
[c] Method A, Head weight is 4.5 kg (10 lb) at 23°C (73°F) and 09 kg (2 lb) at –196°C (–320°F).

## *Thermal Exposure*

*Teflon*® PFA is rated by Underwriters Laboratories for continuous use at temperatures up to 260°C (500°F). However, long-term heat treatment of *Teflon*® PFA plaques, tensile bars, and coated wires at 285°C (545°F) indicates that the resin can be continuously exposed to this temperature without deterioration of its mechanical or electrical properties.

In **Figure 8**, the change in the tensile strength of wire coating, measured at room temperature, is plotted versus hours of thermal treatment in air at 285°C (545°F). The tensile strength of the insulation of *Teflon*® 340 fluoropolymer resin, measured at room temperature, shows a gradual increase with time of about 15% after 20,000 hr at 285°C (545°F). Similar increases were observed when the tensile measurements were made at 200°C (392°F). The room temperature elongation of the tensile specimens increased about 25% with thermal treatment at 285°C (545°F) as shown in **Figure 9**.

The increase in tensile properties is attributed to an increase in molecular weight. This is indicated by a decrease in melt flow, shown in **Figure 10**. Flex life also improves with long-term thermal treatment.

**Figure 8. Tensile Strength of DuPont™ *Teflon*® PFA Wire Coatings After Prolonged Thermal Treatment in Air**

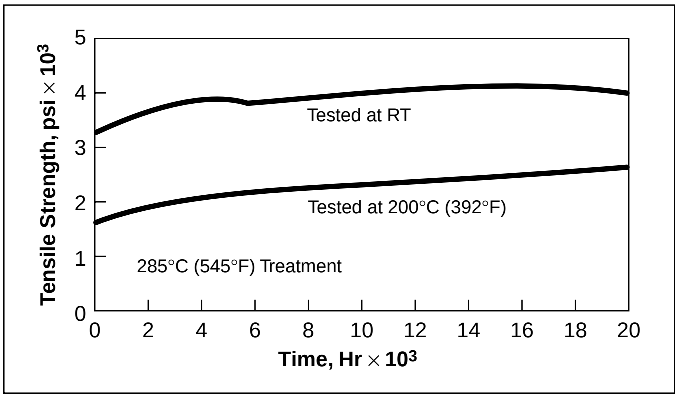


**Figure 9. Tensile Elongation of DuPont™ *Teflon*® PFA Wire Coatings After Prolonged Thermal Treatment in Air**

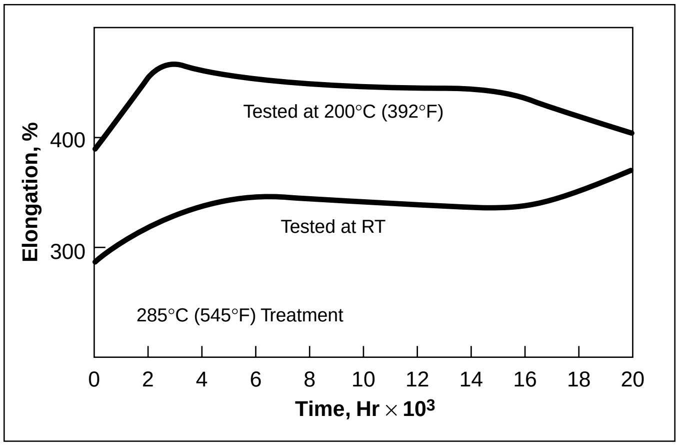
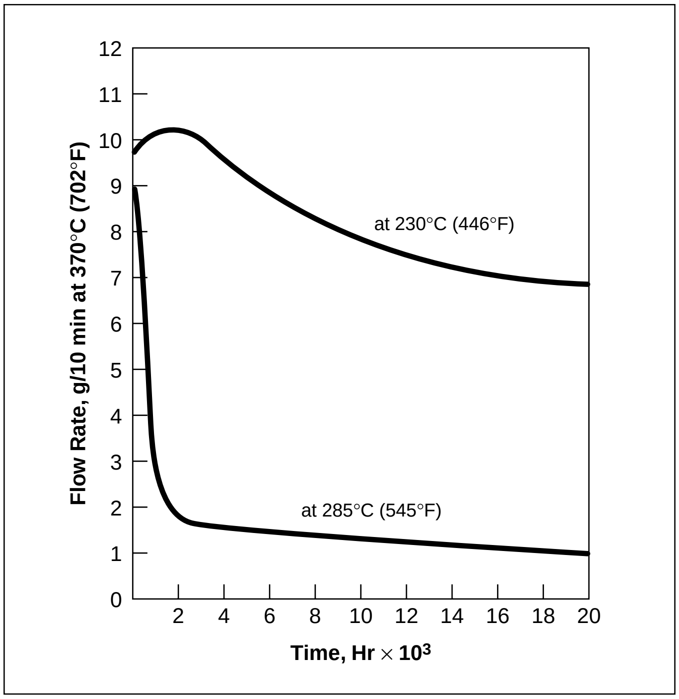


**Figure 10. Change in Melt Flow Rate During Prolonged Thermal Treatment of DuPont™ *Teflon®* PFA Fluoropolymer Resins at 230°C (446°F) and 285°C (545°F)**



## *Wear and Frictional Data*

Frictional and wear tests have been run on *Teflon®* PFA to indicate its level of performance (unfilled) in mechanical applications, such as bearings, and seals. Tests were run on molded thrust bearings at 0.7 MPa (100 psi) against AISI 1018, $R_C$20, 16AA steel; tests were run at ambient conditions in air with no lubrication.

Results, shown in **Table 3**, indicate a limiting PV* value of 5,000, but wear rate, rather than PV, will likely be the critical parameter. At PV = 1,000, for instance, *Teflon®* PFA will wear 5 mm (3/16 in) per 1,000 hr. Wear factors decreased over the PV range 1,000 to 5,000 from $1840 \times 10^{-10}$ to $700 \times 10^{-10}$. Coefficient of friction ran 0.236.

## *Adhesion*

*Teflon®* PFA fluoropolymer resins used as thin-film hot-melt adhesives give strong, highly water-resistant bonds to a variety of thermally resistant substrates. Metals, glass, and other thermally resistant materials have been adhered using this technique. Typical results are shown in **Table 4**.

**Table 3**
**DuPont™ *Teflon®* PFA 340 Fluoropolymer Resin: Wear and Frictional Data Thrust Bearing Wear Test Results**

| Velocity (ft/min) | Wear Factor* (K x $10^{-10}$) | Dynamic Coefficient of Friction | Duration, hr |
|---|---|---|---|
| 3 | 1,591 | 0.210 | 103 |
| 10 | 1,837 | 0.214 | 103 |
| 30 | 983 | 0.229 | 103 |
| 50 | 694 | 0.289 | 103 |

*Units: $in^3$ - min/lb - ft - hr

| | |
|---|---|
| Mating Surface | AISI 1018 steel, $R_c$20, 16AA |
| Contact Pressure: | 100 lb/in² |
| Ambient Temperature: | Room |
| Environment: | Ambient Air |
| Lubricant: | None |

**Table 4**
**Typical Tensile Shear Strengths of Lap Shear Joints Using DuPont™ *Teflon®* PFA as a Melt Adhesive***

| Substrate | Bonding Pressures, MPa (psi) | Tensile Shear, MPa (psi) |
|---|---|---|
| Aluminum Alloy | 0.055 (8) | 10.2 (1,480) |
| Untreated Steel | 0.138 (20) | 16.1 (2,330) |
| Preoxidized Steel | 0.138 (20) | 15.6 (2,260) |

* Bonding conditions: 330°C (626°F) for 30 min, 19 mm (0.75 in) overlap using *Teflon®* PFA with a melt flow number of 12 (ASTM 3304-73).

# Electrical Properties

Applications include extruded coatings for numerous wire constructions, heater cables, heavy wall conduit, cable jacketing, and geophysical cables. *Teflon®* PFA is also injection molded into electrical switch components, connector inserts, insulating bushings, and standoff insulators.

## *Dielectric Constant*

The dielectric constant of *Teflon®* PFA fluoropolymer resins is 2.1 over a wide range of frequencies, temperatures, and densities. The minor changes that occur with changes in these conditions are shown in **Figure 11**. The values for *Teflon®* PFA density vary only slightly, 2.13–2.17, and the dielectric constant varies only about 0.03 units over this range—among the lowest of all solid materials. There is no measurable effect of humidity on the dielectric constant of *Teflon®* PFA.

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*(Pressure) x (Rubbing Velocity)

### Dielectric Strength

The dielectric strength (short-term) of *Teflon*® PFA resins is 80 kV/mm (2,043 volt/mil) when measured on 0.25-mm (10-mil) films by ASTM D149. Thin films of FEP resin give similar results while PTFE films are typically measured at 47 kV/mm (1,200 volt/mil). As with other fluoropolymer resins, *Teflon*® PFA will lose dielectric strength in the presence of corona discharge.

### Dissipation Factor

The dissipation factor of *Teflon*® PFA varies with frequency and temperature. This is shown in **Figure 11**.

The dissipation factor at low frequency ($10^2$–$10^4$ Hz) increases at higher temperatures. Little variation with temperature is seen in dissipation factor with frequencies in the range of $10^4$–$10^7$ Hz. As frequencies increase to $10^{10}$ Hz, there is a steady increase in the dissipation factor. Increases are greatest when measured at room temperature. There is also an indication that a maximum exists at about 3 x $10^9$ Hz. This higher dissipation factor with increasing frequency should be recognized when considering use of this product as an electrical insulation material for use at high frequencies.

### Electrical Resistivity

The volume and surface resitivities of fluoropolymer resins are high and are unaffected by time or temperature. Measurements of the volume resistivity of *Teflon*® PFA fluoropolymer resin by the method outlined in ASTM D257 gave a value greater than $10^{18}$ ohm-cm. The surface resistivity was greater than $10^{18}$ ohm/sq.

### Arc Tracking

When *Teflon*® PFA was tested by the method described in ASTM D495 using stainless steel electrodes, no tracking was observed for the duration of the test (180 sec) indicating that the resin does not form a carbonized conducting path.

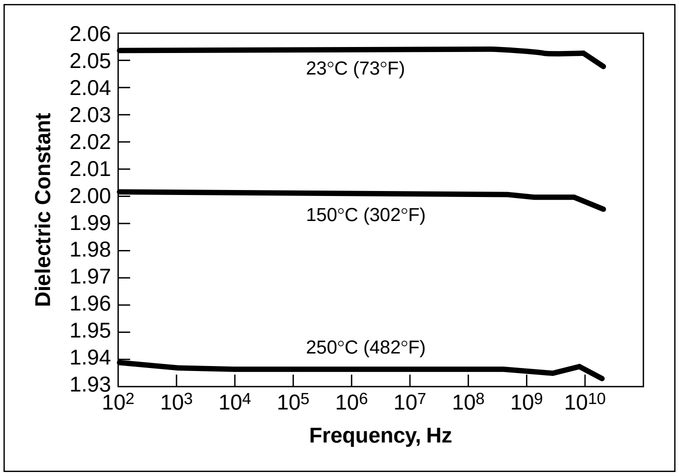
**Figure 11. Dielectric Constant of DuPont™ *Teflon*® PFA Fluoropolymer Resins at Various Frequencies and Temperatures (by ASTM D150)**

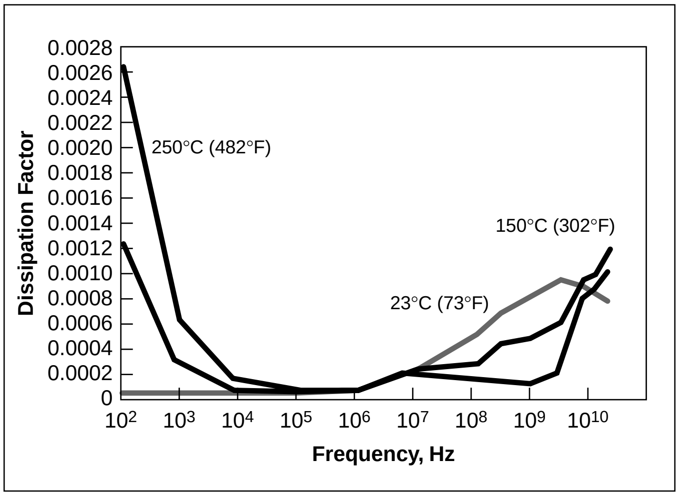
**Figure 12. Dissipation Factor of DuPont™ *Teflon*® PFA Fluoropolymer Resins at Various Frequencies and Temperatures (by ASTM D150)**

## Chemical Properties

The performance of *Teflon*® PFA fluoropolymer resins when exposed to chemicals is typical of completely fluorinated polymers:

- It is not degraded by chemical systems commonly encountered in chemical processes.
- It is inert to:
  - strong mineral acids
  - inorganic bases
  - inorganic oxidizing agents
  - salt solutions
- It is also inert to such organic compounds as:
  - organic acids
  - anhydrides
  - aromatics
  - aliphatic hydrocarbons*
  - alcohols
  - aldehydes
  - ketones
  - ethers
  - esters
  - chlorocarbons
  - fluorocarbons
  - mixtures of the above compounds

As in the case of other completely fluorinated products, *Teflon*® PFA fluoropolymer resins are attacked by certain halogenated complexes containing fluorine. These include chlorine trifluoride, bromine trifluoride, iodine pentafluoride, and fluorine itself. *Teflon*® PFA is also attacked by such metals as sodium or potassium, especially in their

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* Some aliphatic hydrocarbons lower the elongation of samples of *Teflon*® PFA **(See Table 5)**

molten states. Great care should be used when mixing finely divided fluoropolymers with finely divided metals, such as aluminum, magnesium, or barium, because these can react violently if ignited or heated to a high temperature. Certain complexes of these metals with ammonia or naphthalene (in either solvent) also attack the product. Indeed, these complexes are used to provide films or tubes of *Teflon*® PFA with a cementable surface. Certain metal hydrides, such as boranes ($B_2H_6$), aluminum chloride ($AlC1_3$), and certain amines have also been observed to attack fluorocarbon resins at elevated temperatures.

Physical damage resulting from absorption of various chemicals into the walls of fabricated articles (particularly when combined with cycling temperatures), rapid changes in pressure, and mechanical abuse provide the most frequent cause of failure in articles fabricated from *Teflon*® PFA.

**Table 5** shows the performance in tensile testing and the weight gain of fabricated pieces of *Teflon*® PFA after immersion in inorganic chemical media. There is usually no measurable effect of the common inorganic reagents on the tensile properties of the *Teflon*® PFA fluoropolymer resins; however, if there is, a measurable weight gain or loss is observed. Sulfuryl chloride presents a special case in which a “hybrid” compound is absorbed by fabricated forms to give low retention of properties.

In none of the above cases are chemically degradative interactions observed.

**Table 5** also shows the change in tensile properties and the weight gained when fabricated forms of *Teflon*® PFA are subjected to typical organic liquids representing a range of classic compounds.

These data show that liquids which wet the resin will tend to give high weight gains and low retention of tensile strength especially when heated to high temperatures. Therefore, liquids such as trichloroacetic acid, tributyl phosphate, perchloroethylene and carbon tetrachloride produce the largest weight gains.

The test procedure involves exposure of compression-molded micro-tensile specimens, 50-mil thick, in a specific chemical medium at a selected temperature for one week (168 hr). The exposed samples are placed in sealed bottles immediately after removal from chemical exposure. Weight measurements are made within two hours after removal from exposure medium; tensile strength and elongation measurements are made within 8 hr after exposure.

Changes in tensile strength less than 15%, elongation less than 10%, and weight gain less than 0.5% are considered insignificant.

**Table 5**
**Effect of Chemical Immersion (168 hr)**

| Chemical | Test Temperature |  | % Retained Physicals |  | % Weight Gain |
|---|---|---|---|---|---|
|  | °C | °F | Tensile | Elongation |  |
| **Inorganic Chemicals** |  |  |  |  |  |
| **Mineral Acid** |  |  |  |  |  |
| Hydrochloric (Conc) | 120 | 248 | 98 | 100 | 0.0 |
| Sulfuric (Conc) | 120 | 248 | 95 | 98 | 0.0 |
| Hydrofluoric (60%) | 23 | 73 | 99 | 99 | 0.0 |
| Fuming Sulfuric | 23 | 73 | 95 | 96 | 0.0 |
| **Oxidizing Acids** |  |  |  |  |  |
| Aqua Regia | 120 | 248 | 99 | 100 | 0.0 |
| Chromic (50% | 120 | 248 | 93 | 97 | 0.0 |
| Nitric (Conc) | 120 | 248 | 95 | 98 | 0.0 |
| Fuming Nitric | 23 | 73 | 99 | 99 | 0.0 |
| **Inorganic Bases** |  |  |  |  |  |
| Ammonium Hydroxide (Conc) | 66 | 150 | 98 | 100 | 0.0 |
| Sodium Hydroxide (50%) | 120 | 248 | 93 | 99 | 0.4 |
| **Peroxide** |  |  |  |  |  |
| Hydrogen Peroxide (30%) | 23 | 73 | 93 | 95 | 0.0 |
| **Halogens** |  |  |  |  |  |
| Bromine | 23 | 73 | 99 | 100 | 0.5 |
| Bromine | 59* | 138 | 95 | 95 | ** |
| Chlorine | 120 | 248 | 92 | 100 | 0.5 |

*Boiling Point

**No Data

(continued)

## Table 5
## Effect of Chemical Immersion (168 hr) (continued)

| | Test Temperature | | % Retained Physicals | | % Weight |
|---|---|---|---|---|---|
| **Chemical** | **°C** | **°F** | **Tensile** | **Elongation** | **Gain** |
| **Inorganic Chemicals** | | | | | |
| **Metal Salt Solutions** | | | | | |
| Ferric chloride | 100 | 212 | 93 | 98 | 0.0 |
| Zinc Chloride (25%) | 100 | 212 | 96 | 100 | 0.0 |
| **Other Inorganics** | | | | | |
| Sulfuryl Chloride | 69* | 156 | 83 | 100 | 2.7 |
| Chlorosulfonic Acid | 151* | 304 | 91 | 100 | 0.7 |
| Phosphoric Acid (Conc) | 100 | 212 | 93 | 100 | 0.0 |
| **Organic Chemicals** | | | | | |
| **Acids/Anhydrides** | | | | | |
| Glacial Acetic Acid | 118* | 244 | 95 | 100 | 0.4 |
| Acetic Anhydride | 139* | 282 | 91 | 99 | 0.3 |
| Trichloracetic Acid | 196* | 384 | 90 | 100 | 2.2 |
| **Hydrocarbons** | | | | | |
| Isooctane | 99* | 210 | 94 | 100 | 0.7 |
| Naphtha | 100 | 212 | 91 | 100 | 0.5 |
| Mineral Oil | 180 | 356 | 87 | 95 | 0.0 |
| Toluene | 110 | 230 | 88 | 100 | 0.7 |
| **Functional Aromatics** | | | | | |
| O-Cresol | 191* | 376 | 92 | 96 | 0.2 |
| Nitrobenzene | 210* | 410 | 90 | 100 | 0.7 |
| **Alcohol** | | | | | |
| Benzyl Alcohol | 205* | 401* | 93 | 99 | 0.3 |
| **Amines** | | | | | |
| Aniline | 185* | 365 | 94 | 100 | 0.3 |
| nButylamine | 78* | 172 | 86 | 97 | 0.4 |
| Ethylenediamine | 117* | 242 | 96 | 100 | 0.1 |
| **Ether** | | | | | |
| Tetrahydrofuran | 66* | 151 | 88 | 100 | 0.7 |
| **Ketones/Aldehydes** | | | | | |
| Benzaldehyde | 179* | 355 | 90 | 99 | 0.5 |
| Cyclohexanone | 156* | 312 | 92 | 100 | 0.4 |
| Methyl Ethyl Ketone | 80* | 176 | 90 | 100 | 0.4 |
| Acetophenone | 202* | 396 | 90 | 100 | 0.6 |
| **Esters** | | | | | |
| Dimethylphthalate | 220 | 392 | 98 | 100 | 0.3 |
| nButylacetate | 125* | 257 | 93 | 100 | 0.5 |
| Tri-n-Butyl Phosphate | 200 | 392 | 91 | 100 | 2.0 |
| **Chlorinated Solvents** | | | | | |
| Methylene Chloride | 40* | 104 | 94 | 100 | 0.8 |
| Perchloroethylene | 121* | 250 | 86 | 100 | 2.0 |
| Carbon Tetrachloride | 77* | 171 | 87 | 100 | 2.3 |
| **Polymer Solvents** | | | | | |
| Dimethylformamide | 154* | 309 | 96 | 100 | 0.2 |
| Dimethylsulfoxide | 189* | 372 | 95 | 100 | 0.1 |
| Dioxane | 101* | 214 | 92 | 100 | 0.6 |

*Boiling Point

# Other Properties

## *Permeability*

The permeation of gases through thin film (0.08–0.13 mm [3–5 mil]) is dependent on the molecular size, shape, wettability, and soundness of the fabricated membrane.

Attempts have been made to relate permeation rates through thin films to absorption of thicker films, sheets, tubes, pipe, etc. This has been generally unsuccessful. Thicker films and sheets represent an average set of properties obtainable from many thin films produced under a variety of conditions. To produce a thin film representative of this average is impossible from a practical viewpoint. Because permeation in well-fabricated articles is essentially a molecular transport phenomenon through fluorocarbon chains, it is affected by orientation, degree of crystallinity, and temperature.

However, comparative data on identical tests can be used to predict performance in many thin film and coating applications.

**Table 6** shows comparative data as determined by ASTM tests at our DuPont laboratory.

Increased permeability with temperature parallels the decrease in specific gravity with increased temperature in the resin. This corresponds with increased spacing between molecules and increasing molecular activity, which allows easier diffusion of the gas through the specimen.

## *Optical Properties*

In film form, *Teflon*® PFA fluoropolymer resins have excellent optical properties with low haze as measured by ASTM methods. Specific values of percent transmission for given wavelengths are shown in **Table 7**. The refractive index of *Teflon*® PFA film is measured at 546 nanometers wavelength (green light) and room temperature.

An infrared spectrum of *Teflon*® PFA is presented in **Figure 13**. This "fingerprint" is often useful for identifying the resin among other fluorocarbon polymers.

**Table 6**
**Permeability of DuPont™ *Teflon*® PFA Resin to Various Gases**

ASTM D1434 - (cc·mil thickness)/(100 in$^2$·24 hr·atm) at 25°C (77°F)

$CO_2$—2,260(0.00878)*
$N_2$—291(0.00113)
$0_2$—881(0.00342)

*( ) represents (cc·mm)/(m$^2$·24 hr·Pa) at 25°C (77°F)

**Table 7**
**Typical Optical Properties of DuPont™ *Teflon*® PFA Resins**

| | Test Method | Property |
|---|---|---|
| Refractive Index | ASTM D542-50 | 1.350 |
| Haze | ASTM D1003-52 | 4% |
| Light Transmission | | |
| UV (0.25–0.40 µm) | (Cary Model 14) Spectrophotometer, 100-gauge (0.025 mm) film thickness | 77–91% |
| Visible (0.40–0.70 µm) | | 91–96% |
| Infrared (0.70–2.40 µm) | | 96–98% |

## *Glass Transition Temperatures*

The glass transitions of fluoropolymer resins are generally described as relaxations that occur in the amorphous regions of these partially crystalline polymers. These glass transitions are also called second order transitions and are dependent on the frequency at which energy is added to the system.

The glass transition temperatures normally assigned to the resin are shown in **Table 8**.

## *Thermal Conductivity*

Thermal conductivity of *Teflon*® PFA resins has been determined to be 0.19 W/(m·K) (1.32 Btu·in/[hr·ft$^2$·°F]).

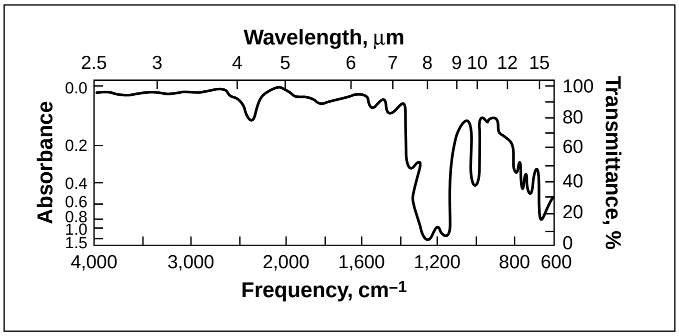
## *Specific Heat*

The heat capacity of *Teflon*® PFA is 1172 J/(kg·K) at 100°C (0.28 Btu/[lb·°F] at 212°F).

## *Liquid Oxygen Impact Sensitivity*

There was no detonation when *Teflon*® PFA samples were subjected to Marshall Space Flight Center Specification 106 B. No detonation was effected when a sample was subjected to a 10-Kg-m drop in an atmosphere of pure oxygen.

**Figure 13. Infrared Absorption Spectrum for DuPont™ *Teflon*® PFA Film, 16 mil (0.0016 in) thick Film, Perkin-Elmer Model 287B Spectrophotometer**



### *Weathering*

Tensile bar specimens of *Teflon*® PFA resins have been weathered out-of-doors in Hialeah, Florida and Troy, Michigan for ten years. There were no significant changes in tensile properties, specific gravity, or melt flow rate after this exposure. Tests are continuing.

### *Response to High-Energy Ionizing Radiation*

The results of preliminary tests using a General Electric transformer to evaluate the radiation resistance of *Teflon*® PFA to high-energy ionizing radiation in air are presented in **Table 9**.

### *Flame Exposure*

When exposed to flame, *Teflon*® PFA fluoropolymer resins burn but do not continue to burn when the flame is removed. The fuel value is approximately 5.14 MJ/kg (2,300 Btu/lb). It passes the UL 83 vertical flame test and is classified 94 V-O according to UL in their burning test classification for polymer materials. The limiting oxygen index by ASTM D2863 is greater than 95% and the smoke density figure (Dm) obtained with the NBS smoke chamber is 4. Based on ASTM D635, it has an average burn length of 10 mm (0.4 in). The numerical flame spread rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.

**Table 8**
**Glass Transition Temperatures of**
**DuPont™ *Teflon*® PFA Fluoropolymer Resins**

| | Glass I | Glass II |
|---|---|---|
| *Teflon*® PFA Resin | 90°C (194°F) | –80°C (–112°F) |

**Table 9**
**DuPont™ *Teflon*® PFA Fluoropolymer**
**Resins:Response to High-Energy Ionizing Radiation**

| Exposure, Mrd | *Teflon*® PFA (ASTM D1708) |
|---|---|
| Control | 4,390 (30)/358 |
| 0.5 | 4,090 (28)/366 |
| 1.0 | 3,620 (25)/333 |
| 2.0 | 3,080 (21)/302 |
| 5.0 | 2,110 (15)/35 |
| 20 | * |
| 50 | * |

**Notes:**

Tensile Strength, MPa (psi)/% Elongation

Samples: 0.25 mm (10 mil) compression molded films of *Teflon*® PFA type 340.

Source: G.E. resonance transformer, 2 MeV capacity, at a current of 1 mA

* Elongation less than 5%

## Properties of Filled Compositions

The addition of fillers to *Teflon*® PFA fluoropolymer resins produces unique properties unattainable with the resins alone. Fillers in general, can do the following:

- increase dimensional stability
- reduce mold shrinkage
- lower coefficient of thermal expansion
- increase thermal conductivity
- reduce static charge

Improvements in strength, stiffness, and creep resistance can be obtained by adding glass fibers. Increases in thermal conductivity can be achieved by adding metallic powders. Increased electrical conductivity can be attained by adding conductive carbon blacks. Radio opaque minerals can be added for X-ray identification.

DuPont has produced, experimentally, representative compositions to illustrate a few of the more commonly used filled systems. Many of these filled compositions are commercially available from custom compounders in the industry.

**Table 10** shows the tensile properties and flexural modulus of several filled compositions indicating the increased tensile strengths, decreased elongation, and increased stiffness associated with the addition of thermally stable fillers.

In a set of experiments designed to show the effects of reinforcing fillers, *Teflon*® PFA fluoropolymer resins were filled with two types of glass fibers as shown in **Table 10**. One sample (glass fiber 497BB as sold by Owens Corning Fiberglas, Inc.) was treated with an amino silane coupling agent. The enhanced tensile strength and flexural modulus observed for the silane-treated fibers indicates chemical interaction between the glass and base resin, which provides enhanced properties over untreated fillers. Tensile bars made from these reinforced compositions have a characteristic “snap” when bent to destruction compared with a gradual breakdown observed in the unreinforced constructions.

The mechanical properties of this composition were measured at elevated temperatures as shown in **Table 11**. The improved tensile strength and flexural modulus are retained to a remarkable degree at temperatures as high as 250°C (482°F). The reinforced composition has about nine times the stiffness of the neat resin at this temperature.

The wear characteristics and the coefficient of friction were examined for a number of compositions, as shown in **Table 12**.

## Table 10
## Mechanical Properties of Glass-Filled and Glass-Reinforced DuPont™ *Teflon®* PFA

| Filler, % by Weight | Tensile Strength, % Elongation, MPa (psi) | Flexural Modulus, MPa (psi) |
|---|---|---|
| Control (Unfilled Resin) | 17.2 (2,500/225) | 552 (80,000) |
| 25% Glass (Filled) | 20.1 (2,920/19) | 1,463 (212,000) |
| 25% Glass (Reinforced) | 34.5 (5,000/4) | 2,634 (382,000) |

**Note:** Base resin–*Teflon®* 340; 127 mm (5 in) tensile bars.

## Table 11
## Effect of Temperature on Mechanical Properties of Glass-Reinforced DuPont™ *Teflon®* PFA (Filler, % by Weight)

| | Unfilled | | 25% Glass Filled | |
|---|---|---|---|---|
| Temperature | Tensile Strength, % Elongation, MPa (psi) | Flexural Modulus, MPa (psi) | Tensile Strength, % Elongation, MPa (psi) | Flexural Modulus, MPa (psi) |
| RT | 17 (2,500/225) | 552 (80,000) | 35 (5,000/4) | 2,634 (382,000) |
| 150°C (302°F) | — | 85 (12,4000) | 17 (2,490/4) | 717 (104,000) |
| 200°C (392°F) | 9 (1,300/260) | 56 (8,100) | 13 (1,810/4) | 593 (86,000) |
| 250°C (482°F) | — | 41 (6,000) | 8 (1,120/4) | 379 (55,000) |

**Note:** Base resin–*Teflon®* 340; 127 mm (5 in) tensile bars.

**Table 12**
**Wear Characteristics and Coefficient of Friction of Filled DuPont™ *Teflon*® PFA**

| | **Wear Factor x $10^{-3}$ (in$^3$–min)/(ft–lb/hr) x $10^{-10}$** | |
|---|---|---|
| | **Measured** | **Coefficient of Friction** |
| Control (Unfilled Resin) | 700 (138)* | 0.236 |
| 5% Glass/5% “$MoS^2$” | 15 (30) | 0.200 |
| 15% Glass Fiber | 16 (32) | 0.160 |
| 25% Glass Fiber | 13 (26) | 0.325 |
| 25% Glass Fiber (Reinforced) | 11 (22) | — |
| 15% Graphite | 147 (290) | 0.200 |

*($m^3$·s)/(kg·m·s)
k **x** $10^{-5}$

## Safety Precautions

**WARNING!**

**VAPORS CAN BE LIBERATED THAT MAY BE HAZARDOUS IF INHALED.**

Before using *Teflon*® PFA, read the Material Safety Data Sheet and the detailed information in the “Guide to the Safe Handling of Fluoropolymer Resins,” latest edition, published by the Fluoropolymers Division of The Society of the Plastics Industry—available from DuPont.

Open and use containers only in well-ventilated areas using local exhaust ventilation (LEV). Vapors and fumes liberated during hot processing, or from smoking tobacco or cigarettes contaminated with *Teflon*® PFA, may cause flu-like symptoms (chills, fever, sore throat) that may not occur until several hours after exposure and pass within about 24 hours. Vapors and fumes liberated during hot processing should be exhausted completely from the work area; contamination of tobacco with polymers should be avoided.

Mixtures with some finely divided metals, such as magnesium or aluminum, can be flammable or explosive under some conditions.

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(2/02) 234398D Printed in U.S.A.
[Replaces E-96679-5]
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