

PLEXIGLAS®

Acrylic Sheet



OPTICAL & TRANSMISSION CHARACTERISTICS

ALTUGLAS
INTERNATIONAL
ARKEMA GROUP



TABLE OF CONTENTS

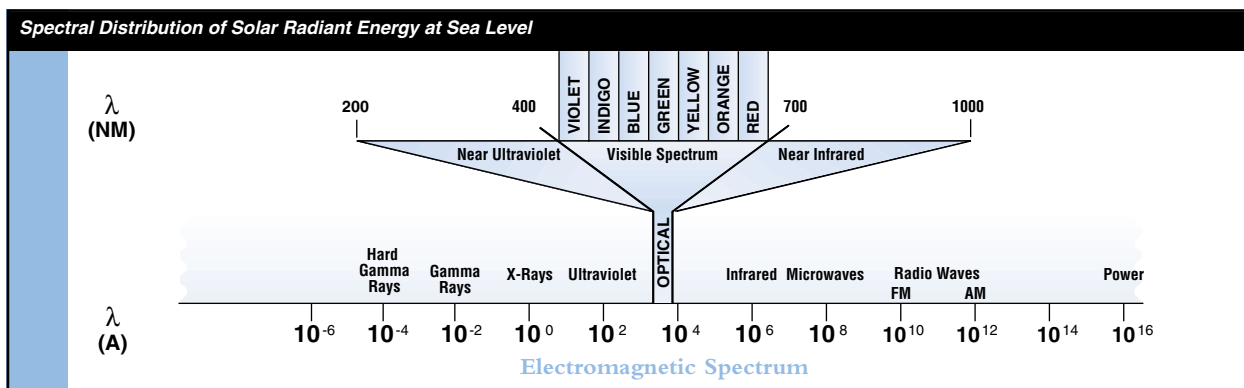
Introduction	Inside Front Cover
Visible Light Transmission	1
Edge Lighting	2
Light Source Technology	3
Ultraviolet Transmittance	3
Plexiglas Ultraviolet-Filtering Formulations	4
Applications for Ultraviolet-Filtering Formulations	5
Other Electromagnetic Energy Responses	5
Infrared Transmittance	5
X-Ray Transmittance	6
Radio Frequency Transmittance	6
Nuclear Radiation Transmittance	6
High-Energy Irradiation of Plexiglas Sheet	6
Fabrication and Maintenance	6
Fabrication	6
Maintenance	7
Health and Safety Information	7
Altuglas International Sales Offices	8

INTRODUCTION

Plexiglas® acrylic plastic sheet in its colorless grade is as clear as the finest optical glass but is lighter in weight, has higher breakage resistance—and can easily be fabricated into shapes limited only by the designer's imagination. The unexcelled versatility of Plexiglas sheet, its optical clarity, ease of fabrication and decoration, its light weight and breakage resistance compared with glass and the variety of sizes, thicknesses, patterns and colors available, allow virtually unlimited use for the unobtrusive protection and display of valuable works of art. In addition, when used as a display, its optics and aesthetics help to make fine merchandise like clothing look its best. It can also open up the intricate interiors of an architectural model or an instructional device. These same properties allow Plexiglas sheet to be used as the optical medium in applications such as lighting lenses or large plotting boards.

This manual provides an array of information including valuable background on the important optical properties of Plexiglas sheet, some guidelines on edge lighting principles, a short technical overview on light sources and their effects on man-made materials, and general information on applications, fabrication, cleaning and safe handling.

The clarity and physical properties of Plexiglas sheet allow it to form a barrier around the exhibit, through which objects can be seen clearly and enjoyed without restraint, yet preventing them from being touched or damaged. Special formulations of Plexiglas sheet protect art and documents from the invisible vandal—ultraviolet radiation. The ability to cut and form Plexiglas sheet into intricate shapes lets the exhibit designer match the display medium with the object and the development of a theme without intruding on that theme. Furthermore, Plexiglas sheet is easy to paint and decorate, and it comes in a variety of colors

FIGURE 1

and patterned surfaces. These attributes make it possible for exhibitors to include Plexiglas sheet containing printed information describing the display or even to use Plexiglas sheet as part of the display.

Thick sections of Plexiglas sheet can be used as pedestals or stands to set off sculpture, making it easier for people to see the object without interference from its surroundings. When Plexiglas sheet is employed in display cases, its toughness and strength help to protect particularly valuable pieces from theft or damage. Regardless of thickness, from 0.236" to 2.0", Plexiglas sheet retains its sparkling optical clarity and brilliance.

Plexiglas sheet can be cut and machined, cemented, and formed into a wide variety of shapes, ranging from cubes, rectangles and simple bends to pyramids, domes and cylinders. This fabrication versatility allows

the design of cases that fit the form, thus setting off the contents for maximum effectiveness.

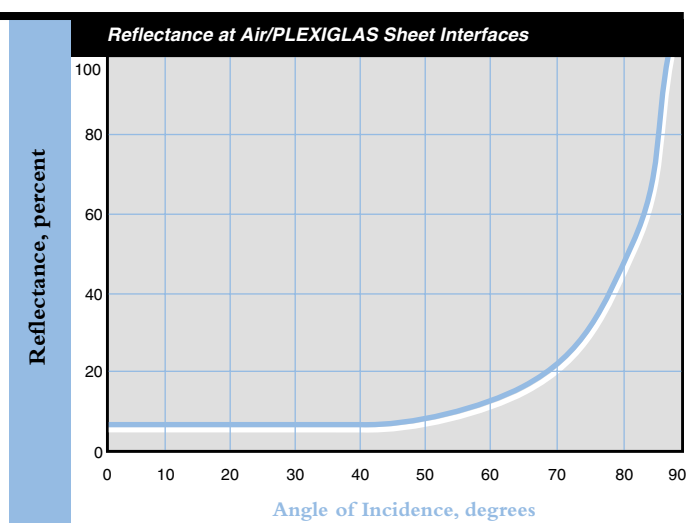
Transparency and many other outstanding properties including toughness, light weight, formability, the control of light ray paths, outdoor weather resistance and good chemical resistance allow Plexiglas sheet to be used where other transparent materials may fail. The ability to have distortion-free vision and protection is important to the exhibit designer as well as to designers of medical devices, industrial safety or chemical shields, enclosures for clean air operations or noise abatement, or hockey rink glazing and simple barriers for wall-mounted displays or tabletops.

VISIBLE LIGHT TRANSMISSION

In colorless form, Plexiglas sheet is as transparent as the finest optical glass. Its total light transmission is 92%, and its measured haze averages only 1%.

The wavelengths of visible light fall within the range of approximately 400 to 700 nanometers in the electromagnetic spectrum. Electromagnetic energy from the sun is rich in these wavelengths, tapering off in the ultraviolet and infrared regions, as shown by the relative energy distribution diagram in Figure 1.

When a light ray strikes colorless Plexiglas sheet perpendicular to its surface (0° angle of incidence), most is transmitted, some is reflected at both the top and bottom surfaces, and a negligible fraction is absorbed (Figure 2).

FIGURE 2

The theoretical maximum transmittance of a non-absorbing optical medium depends on its refractive index. Plexiglas sheet has a refractive index of 1.49 to the sodium D line; the calculated theoretical maximum light transmission for such a medium is 92.5%. Actual measurement shows that colorless Plexiglas sheet in thicknesses of up to 6 mm (0.236") transmits 92% of the light striking it at the perpendicular: this fraction represents virtually all the light that can be transmitted by a perfect optical medium at this refractive index.

Approximately 4% of the incident perpendicular rays are reflected at each air surface interface of colorless Plexiglas sheet, giving a total reflectance loss of approximately 8%. As the incident beam deviates from the perpendicular, the surface reflectance increases.

In all ordinary thicknesses (from 0.060" to 0.236"), the light absorbance of colorless Plexiglas sheet is not significant. Even at a thickness of 1", absorbance is less than 0.5%.

EDGE LIGHTING

The optical properties of Plexiglas sheet make it ideal for edge lighting applications. When refractive index, surface reflectance and absorbance of the sheet are known, the designer can create displays that appear to be self-illuminated. To make the most effective and efficient use of edge-lighted acrylic shapes, fabricators must consider the following basic design factors:

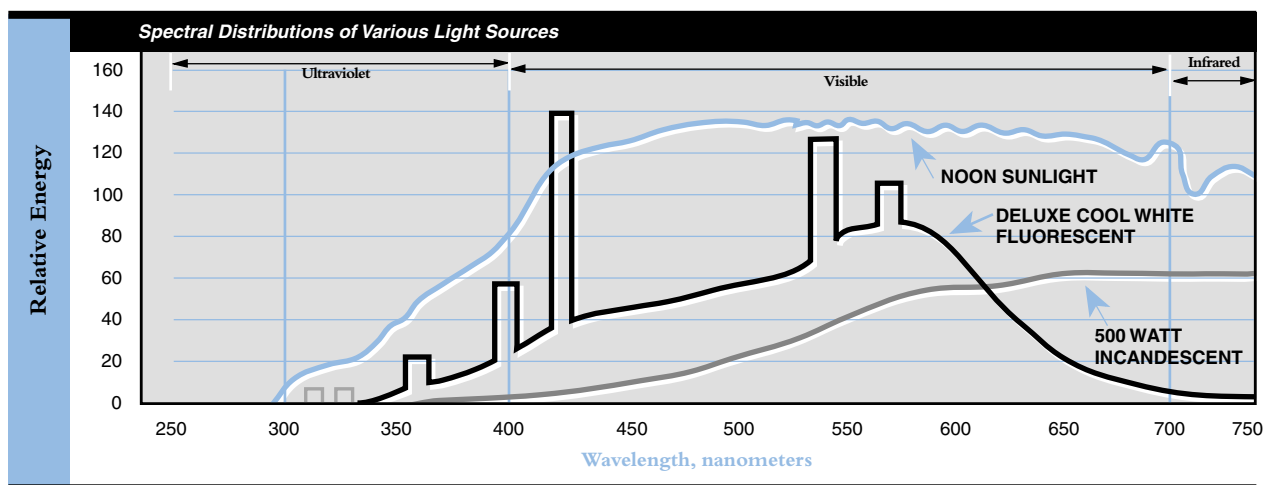
■ **Critical angle**—If any ray of light passing through Plexiglas sheet encounters an air interface at the critical angle (42.2° off the normal) or greater, that ray will not be transmitted, but will be totally reflected back into the sheet at an equal angle opposite to the angle of incidence.

■ **Light entry**—As much light as possible must be directed into the edge of the part, especially for bright environment applications. This means the light source should be as close to the edge as the sheet's heat tolerance permits, and reflectors behind the lamps should be employed to increase the amount of light focused into the edge of the part. The thicker the edge, the more light it will intercept, since light rays radiate from the source.

■ **Control of light within the sheet**—To control the path of light that has entered an edge, to eliminate unwanted glare and stray rays, and to cause designs and markings to glow, designers should be aware of the effects of localized variations in surface contour, surface finish and texture, coatings of light or dark paint, and metallic deposits. In unfinished rectangular acrylic parts, all light rays will be directed internally between the lateral surfaces to emerge at the edge (or end) opposite from the entering edge (or end). Altering any of the four factors mentioned above causes the rays to be redirected in selected zones in which they are absorbed, scattered, diffused, or reflected as an image.

■ **Light escapement**—Local destruction of the as-supplied, reflecting sheet surface by frosting, sand blasting, scratching, or honing will cause light rays to scatter as they strike that zone. A few rays will pass through the frosted zone as a glow; most will scatter diffusely back across the thickness of the acrylic; and

FIGURE 3



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many will emerge from the opposite surface to be viewed as an illuminated marking. Edge-lighted markings, therefore, should be located on the back or second surface of the sheet.

■ **Light piping**—When employing a curved lead section into an edge-lighted panel, it is important to pipe light from the top edge or the sides when the panel is in a vertical plane, and from the bottom edge or sides when the panel is in a horizontal plane. This reduces stray rays escaping in the direction of the viewer's eyes.

LIGHT SOURCE TECHNOLOGY

Visible light is only a part of the electromagnetic energy band. All sources of visible light, whether natural sunlight or artificial light, also emit energy in the ultraviolet and infrared bands. Figure 3 shows the relative spectral distribution of energy of various sources of light. The curves have been drawn so that each source has a peak energy of one.

The amount of energy emitted varies according to the formula:

$$E = \frac{hc}{\lambda}$$

where **h** = Planck's constant; **c** = velocity of light; and **λ** = wavelength.

As the wavelength decreases, the amount of energy increases. Starting at wavelengths of about 500 nanometers, and increasing logarithmically in intensity as the wavelength decreases, this electromagnetic energy

is capable of causing photochemical damage to organic materials. The photochemical damage takes two forms, fading or darkening of colors and structural damage caused by the breakdown of molecular bonds. The damage is not instantaneous; it takes place over long periods of time and is the cumulative effect of exposure.

Irradiation by visible light in the 400 to 500 nanometer range primarily causes fading or darkening of colors, although some minor structural damage may also occur. Irradiation by ultraviolet energy in the 300 to 400 nanometer range causes both structural damage (e.g., embrittlement or loss of tear strength) and color change (fading or darkening). The effect of ultraviolet light increases exponentially as the wavelengths become shorter. The relative damage factors* in Figure 4 show that ultraviolet irradiation at 300 nanometers is potentially 200 times more damaging than visible light irradiation in the blue-green band at 500 nanometers.

Wavelengths shorter than 300 nanometers, such as are found in germicidal lamps, are extremely destructive to organic materials. Most artificial light sources, however, do not emit shortwave ultraviolet energy. The short wavelengths contained in sunlight are absorbed in the atmosphere before they can do any damage.

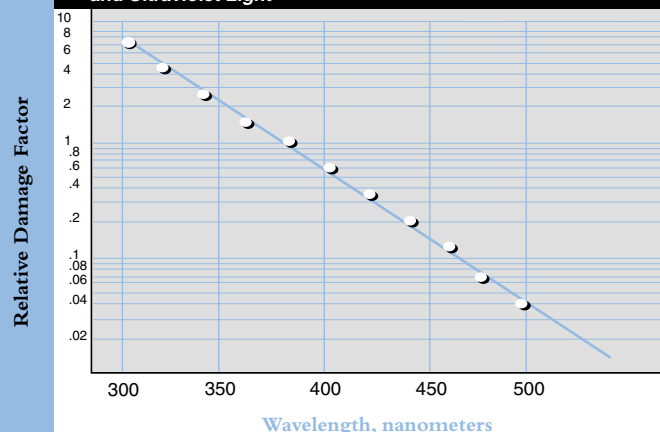
ULTRAVIOLET TRANSMITTANCE

Plexiglas sheet absorbs the shorter wavelengths of ultraviolet (UV) energy, but transmits most of the longer wavelengths (those near the visible region), Figure 5. The UV transmittance, unlike the visible and infrared transmittance, of colorless Plexiglas sheet varies from one formulation to another. Therefore, Plexiglas MC sheet does transmit slightly more of the longer UV wavelengths than does Plexiglas G sheet.

Even after prolonged outdoor or artificial light exposure, the spectrophotometric characteristics of Plexiglas sheet in the UV and visible ranges do not change significantly. Most of the drop in UV transmittance of Plexiglas sheet takes place in the first two years after exposure to sunlight. No measurable change

FIGURE 4

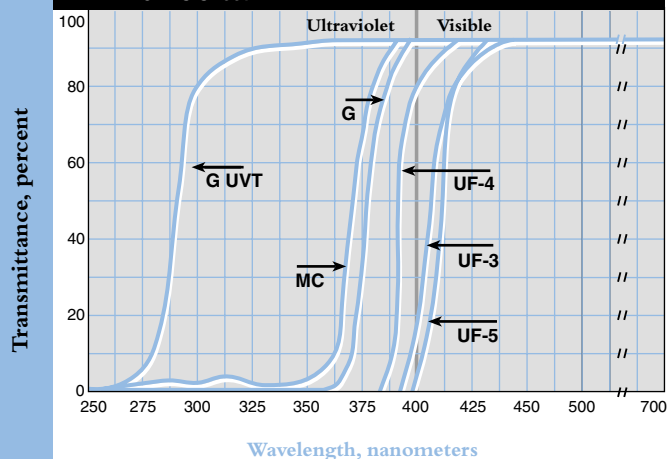
Probable Relative Damage Values for Visible and Ultraviolet Light



*Lawrence S. Harrison, "Report on the Deteriorating Effects of Modern Light Sources," The Metropolitan Museum of Art, New York, 1954.

FIGURE 5

Visible and Ultraviolet Transmittance in Colorless PLEXIGLAS Sheet



occurred in the spectrophotometric curves of these exposed samples between 5 and 10 years outdoors.

Colorless Plexiglas sheet exhibits the same excellent resistance to discoloration when exposed for 20 years or more to constantly lit fluorescent lamps, even when the Plexiglas sheet is only two inches from the lamp.

This unsurpassed UV stability gives Plexiglas sheet superb weatherability and makes it the logical choice among plastic materials for outdoor and artificial lighting applications. Other transparent plastic materials tend to yellow or develop appreciable haze levels when exposed to UV energy.

The spectrophotometric curves in Figure 5 show the light transmission of colorless Plexiglas sheet formulations in the UV bands of the electromagnetic spectrum. Note that regular Plexiglas G and MC sheets block some portions of the UV spectrum, but special grades are needed when virtually all (UF-3/UF-5) or most (UF-4) of the UV wavelengths must be excluded.

PLEXIGLAS ULTRAVIOLET-FILTERING FORMULATIONS

Some special formulations of Plexiglas acrylic plastic have spectrophotometric characteristics that enable them to filter out almost all of the UV energy. These formulations are available in both sheet and molding resins. Plexiglas UV-filtering materials offer protection from structural damage caused by exposure to UV

wavelengths shorter than 400 nanometers. However, since these materials do not appreciably filter visible light in the critical lower violet range from 400 to 500 nanometers, they will not completely prevent colors from fading or darkening.

Limiting exposure to light is only one of the steps that can be taken to slow the deterioration of materials. Factors such as temperature, humidity and atmospheric contamination will also affect this process.

Three Plexiglas sheet formulations that can filter UV light are available. Plexiglas UF-4 sheet absorbs most ultraviolet radiation. Plexiglas UF-3 sheet absorbs virtually all ultraviolet radiation and some of the visible light in the violet wavelength region. Plexiglas UF-5 sheet, a new, special formulation in the MC grade for framing applications, filters the maximum of harmful UV radiation. Figure 5 compares the spectrophotometric curves of these three grades with those of standard colorless Plexiglas G and Plexiglas MC sheets. Note that the spectrophotometric characteristics of the three Plexiglas UF sheet formulations are the same, regardless of the thickness of the sheet. Comparatively, the spectrophotometric characteristics of Plexiglas G and Plexiglas MC sheets change with thickness.

Plexiglas UF-3 and MC UF-5 sheets are the most effective of the ultraviolet-filtering formulations of Plexiglas acrylic. Not only do these materials absorb all ultraviolet radiation (390 nanometers and below), but they also absorb part of the relatively harmful visible light in the critical violet (400-450 nanometers) region. Plexiglas UF-3 sheet does absorb some visible light, therefore it has a very faint yellow edge tint. This tint is not objectionable in most applications.

Plexiglas UF-4 sheet may be used for those applications in which the slight yellow tint of the other materials is objectionable, such as unframed display cases. Plexiglas UF-4 does transmit slightly more UV energy than its counterpart, and, as a result, it is somewhat less effective in retarding fading or darkening of colors caused by visible light in the 400 to 500 nanometer range.

Both cast sheet UF formulations are available in thicknesses of 0.118" (3mm) through 0.472" (12mm),

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and in sheet sizes of 48" x 96", 60" x 96" and 72" x 96". The MC UF-5 formulation is available in the popular framing thicknesses of 0.060", 0.080" and 0.118" and with an optional nonglare finish, as well as the standard high-gloss finish.

Applications for Ultraviolet-Filtering Formulations

The principal applications for the Plexiglas sheet UV-filtering formulations are in fine art framing, in museum lighting and glazing, and for mercury vapor lighting fixture lenses and diffusers. The sheet formulations can be used directly in glazing windows, skylights, exhibit cases, and picture frames. They may also be cut into panels and mounted in front of electric light sources. Sheets may be formed into pans for lighting fixture lenses and diffusers. **Note:** Mercury vapor lamps operate at much higher temperatures than fluorescent light sources. Lenses and diffusers made from Plexiglas sheet must be designed to overcome this high heat by providing adequate ventilation as well as sufficient space between the lamp and the surface of the Plexiglas sheet.

Museums are repositories for valuable objects such as paintings, tapestries, and historical documents. To be seen clearly, these art objects and historical exhibits must be displayed in an environment of balanced white light at a comfortably high level of intensity. Normally, the light necessary for viewing these objects is a mixture of natural daylight and electric light. The sources that provide this light generate UV

as well as visible light. Plexiglas UF-3 sheet is widely used for museum glazing and exhibit cases because its excellent UV-filtering characteristics enable it to protect art objects. For maximum UV protection of fine art, Plexiglas MC UF-5 sheet is suggested as a framing medium. Plexiglas UF-4 sheet may be used when the slight yellow tint of the more effective material is objectionable.

Museums are not the only institutions interested in employing Plexiglas sheet for protective purposes. Plexiglas sheet, in both the UV-filtering formulations and the standard formulations, has long been used by the picture framing industry to protect items, especially old photographs, watercolors, documents and collectibles like trading cards. Plexiglas sheet is not only as transparent as the finest optical glass, but it is also more than 50% lighter than glass, and its impact strength is much greater than glass. These advantages translate into superior protection, easier handling and reduced shipping costs.

OTHER ELECTROMAGNETIC ENERGY RESPONSES

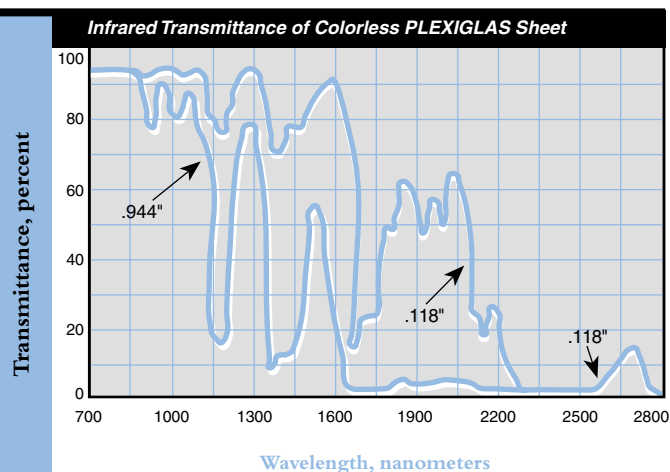
INFRARED TRANSMITTANCE

Colorless Plexiglas sheet transmits most of the invisible near-infrared energy in the 700 to 2800 nanometer wavelength region, but it does absorb certain bands, as shown in Figure 6. The curves for 0.118"- and 0.944"-thick colorless Plexiglas sheet show that near-infrared transmittance depends on thickness, decreasing logarithmically as thickness increases.

Colorless Plexiglas sheet is entirely opaque to infrared wavelengths from 2800 nanometers up to 25,000 nanometers in thicknesses of 0.118" or greater. At thicknesses of less than 0.118", Plexiglas sheet transmits small amounts of certain infrared wavelengths within this portion of the spectrum. All standard formulations of colorless Plexiglas sheet have the same general infrared transmittance characteristics.

Instrumental methods confirm that weathering produces no change in the infrared transmittance characteristics of Plexiglas sheet.

FIGURE 6





Certain devices, such as remote control units or heat sensors, require filters that are opaque to all visible light but transmit selected infrared light wavelengths. Custom-colored made-to-order Plexiglas G 3142 was developed for this purpose.

X-RAY TRANSMITTANCE

All ordinary thicknesses of colorless Plexiglas sheet readily transmit X-rays. Since Plexiglas sheet has essentially the same X-ray absorption coefficient as water, radiographs can be taken of knitting bone fractures without removing the acrylic splints.

RADIO FREQUENCY TRANSMITTANCE

Most formulations of colorless Plexiglas sheet readily transmit standard broadcast, television and most radar waves of the electromagnetic spectrum.

NUCLEAR RADIATION TRANSMITTANCE

Colorless Plexiglas G sheet has the following nuclear transmittance characteristics:

- **Alpha rays**—essentially opaque, exhibiting nearly 100% absorption at all thicknesses.
- **Beta rays**—essentially opaque at thicknesses of 0.334" or more.
- **Gamma rays**—transparent to gamma rays in all ordinary thicknesses. Colorless Plexiglas sheet has about the same gamma ray absorption coefficient as water; however, exposure to high levels of high-intensity gamma radiation, as is common in sterilizing devices, may cause discoloration or even the loss of some physical properties.
- **Neutrons**—opaque to neutrons. Plexiglas sheet serves as a neutron shield with stopping power that varies directly with hydrogen content.

HIGH-ENERGY IRRADIATION OF PLEXIGLAS SHEET

Although Plexiglas sheet possesses unusual resistance to discoloration from exposure to all ordinary light sources, special sources that emit intense, high-energy radiation in addition to visible light may in time discolor and even damage Plexiglas sheet.

Visible light and UV radiation wavelengths as short as 320 nanometers do not affect Plexiglas sheet, but UV radiation between 320 and 280 nanometers, if sufficiently intense or persistent, will cause slight yellowing. Light sources that may cause such yellowing are sunlamps and mercury vapor lamps.

All types of Plexiglas sheet and most other organic materials will be degraded by exposure to the very short UV wavelengths (approximately 260 nanometers) used for germicidal or sterilizing purposes. This short-wavelength ultraviolet radiation has very high energy content capable of physically damaging Plexiglas sheet. For this reason, parts made from Plexiglas sheet should be shielded from the direct exposure to radiation from germicidal lamps such as those used in vending machines.

High-energy ionizing radiation like that which may be encountered in outer space or in nuclear experiments is usually harmful to Plexiglas sheet, causing discoloration, physical deterioration, or both. The reaction of Plexiglas sheet is closely dependent on the nature of the radiation, its intensity and duration.

FABRICATION AND MAINTENANCE

FABRICATION

Plexiglas sheet can be easily fabricated with conventional power saws, routers, drills and other wood-working equipment, provided that the proper blades and bits are employed. Machining and polishing to fine optical finishes are common fabrication techniques. If power equipment is not available, Plexiglas sheet can also be cut along straight lines using simple scribing and breaking procedures.

Plexiglas sheet can be formed to almost any desired three-dimensional shape by thermoforming techniques, once the sheet has been pre-heated between 325°F and 350°F—its optimum forming temperature. Flat sheets of Plexiglas sheet can also be cold-formed (bent while cold to a smooth contour and held to the radius by springing the material into a curved channel support). The optical properties and surface condition of the sheet will vary, depending on the method used to fabricate or form the sheet. Where

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good optical properties are required, parts should be designed so that they can be fabricated by either free-forming (vacuum or positive air-pressure differentials) or drape forming.

The most common method of joining two or more pieces of Plexiglas sheet to produce clear joints involves the use of solvent or polymerizable cements and requires relatively simple tools and techniques. Generally, however, a polymerizable cement provides better joint strength and appearance.

Detailed information regarding fabrication, cementing, forming and decorating can be found in the following brochures available from the Altuglas Division of Arkema Inc.:

Plexiglas Acrylic Sheet Fabrication Manual

Plexiglas Acrylic Sheet Forming Manual

Plexiglas Acrylic Sheet Painting Manual

MAINTENANCE

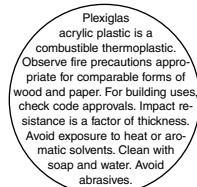
The exercise of reasonable care in cleaning Plexiglas sheet will minimize scratching. Wash Plexiglas sheet with a mild soap or detergent and lukewarm water solution. Use a clean, soft cloth or sponge and as much solution as possible. Rinse well. Dry by blotting with a damp cloth or chamois.

Caution: Abrasives will scratch the surface of uncoated Plexiglas sheet. **Do not use** scouring compounds, gritty cloths, window-cleaning fluids, leaded or ethyl gasolines or solvents such as alcohol, acetone and carbon tetrachloride.

To polish, apply a thin, even coat of a good grade of automobile paste wax (not a cleaner-wax combination) with a soft, clean cloth to protect the surface of the Plexiglas sheet and maintain its luster. Buff lightly with a clean cotton flannel or jersey cloth. After polishing, wipe with a clean, damp cloth to ground any electrostatic charges which may attract dust particles.

HEALTH AND SAFETY INFORMATION

Prior to processing Plexiglas acrylic sheet, it is recommended that you obtain the appropriate Altuglas International technical literature. The processing technical literature gives detailed information for proper handling of Plexiglas sheet and also provides safety and health precautions.





ALTUGLAS INTERNATIONAL SALES OFFICES

Corporate Headquarters

Altuglas International
Arkema Inc.
2000 Market Street
Philadelphia, PA 19103
Ph: 800-523-7500
215-419-7000
Fax: 215-419-5512

Mexico Office

Altuglas International
Arkema Inc.
Quimica Franco Mexicana, SA
Rio San Javier, n°10
Fracc. Viveros del Rio
Tlanepantla, Edo de Mexico
C.P. 54060
Ph: 525-397-69-33
Fax: 525-361-11-54

Brasil Office

Arkema Inc.
Brasil Quimica Ltda.
Av. Ibirapuera, 2033
R. 443 São Paulo - SP
CEP 04029-901
Brasil
Ph: (from USA):
011-55-11-5051-0622
Fax: (from USA):
011-55-11-5051-4780

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ARKEMA GROUP

Altuglas International • Arkema Inc.

2000 Market Street • Philadelphia, PA 19103-3222 • Tel.: (215) 419-7000 Fax: (215) 419-5512 • www.altuglasint.com